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TECHNICAL PAPER

INCREASED ENERGY COGENERATION IN THE SUGAR-ENERGY SECTOR WITH THE USE OF SUGARCANE STRAW, ELECTRIFICATION OF DRIVES, AND HIGH-DRAINAGE ROLLERS IN THE EXTRACTION

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KEYWORDS

bioelectricity, biomass, combustion, calorific value, numerical simulation.

ABSTRACT

The sugar-energy sector stands out in the production of electrical energy in the Brazilian energy matrix. The updating of Law 9,427 allowed increasing the limit of power injected in the transmission or distribution systems of existing projects from 30 to 50 MW, encouraging studies of expansion and/or implementation of new cogeneration projects. This study analyzed technologies to enhance energy cogeneration in a plant that sells about 27 MW of surplus power. For this, were studied the use of straw, electrification of drives by steam turbines, and high-drainage rollers (lotus mill roller), which allows reducing bagasse moisture, increasing its lower calorific value (LCV) and, consequently, electrical energy generation. Mass and energy balances in the energy plants of the proposed cases were performed using the software IPSEpro®. Economic analyses were carried out using the conventional techniques of economic engineering (payback period, net present value – NPV, internal rate of return – IRR, and return on invested capital – ROIC). These analyses allowed the technical and economical identification of cases with viability, according to the value of the electrical energy sold.

INTRODUCTION

The bioelectricity produced with the burning of sugarcane biomass plays an essential role in complementing the hydroelectric system, as the harvest period of the sugar-energy sector coincides with the reduction of hydroelectric reservoirs (Macedo et al., 2001; Ensinas et al., 2007; Leal et al., 2013; Moreira et al., 2016; Ahmed & Eldin, 2015).

Also, the market potential with bioelectricity provides mills with financial gains and increase cash flow to face the crisis related to the ethanol price and drop in the sugar value in the international market (Pina et al., 2015; Arshad & Ahmed, 2016; Cervi et al., 2019; Lemos et al., 2014).

However, the sugar-energy sector in Brazil had as an obstacle to investing in new cogeneration projects to expand surplus electrical energy the legislation created for the regulation of discounts on transmission and distribution tariffs for the generated energy, called “encouraged energy,” which was 30 MW. Thus, many mills exported 25 to 27 MW, as exceeding the imposed limit resulted in the loss of granted benefits (Pellegrini & Oliveira Junior, 2011; Dias et al., 2015).

The enactment of Law 13,203 of December 8, 2015, allowed increasing this limit to 300 MW as of January 1, 2016, for projects that resulted from an energy purchase auction or that would be authorized. Old cogeneration projects that did not meet these premises had the export limit increased to 50 MW by Law 13,299, enacted on June 21, 2016, in accordance with the Normative Resolution 745 by ANEEL of November 22, 2016.

This fact allows the resumption of investments in cogeneration projects since most of the mills have an export potential of more than 30 MW, which was the permitted limit in the past. Currently, there is a high biomass availability due to the extinction of sugarcane burning and the implementation of mechanized harvesting, which allows partial use of straw as fuel for boilers (Coelho et al., 2006; Khoodarutha, 2014).

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Improvements in the industrial energy balance and the electrification of equipment drives that use low-efficiency steam turbines, besides the use of high-drainage rollers to reduce bagasse moisture, will enable to increase the production of surplus energy for commercialization (Coelho et al., 2006; Khoodarutha, 2014; Alves et al., 2015; Chantasiriwan, 2016).

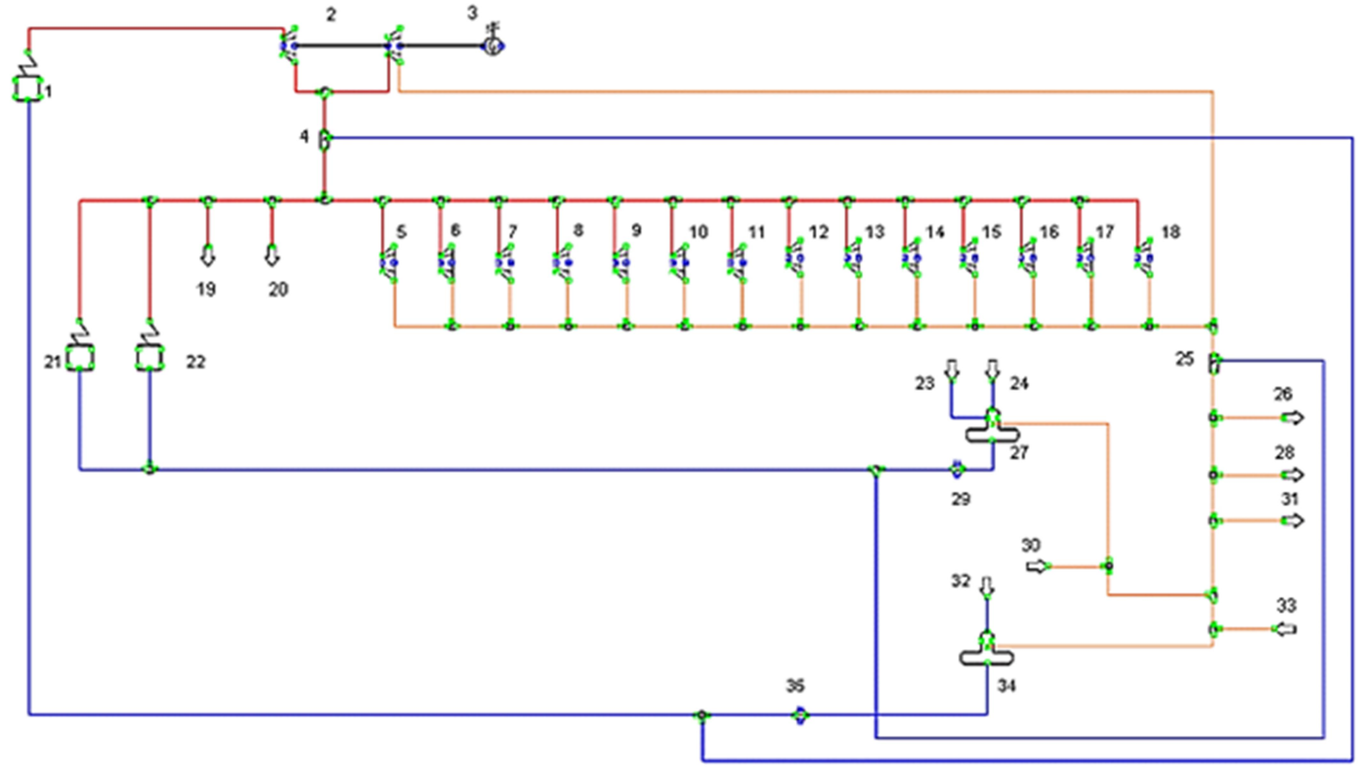
This context motivated to carry out the present study in a sugar-energy plant in the northwest of São Paulo, Brazil, in which modifications are proposed in the industrial plant to enhance energy cogeneration and, consequently, maximize the sale of surplus electrical energy.

MATERIAL AND METHODS

The plant chosen for the study uses 4% of straw per ton of harvested sugarcane (approximately 14.3% of all the straw in the field). This straw is transported to the mill along with the chopped and non-burned sugarcane. The sugarcane is unloaded on the feed table and passes through a dry cleaning system, which generates about 28.33 t/h of straw. A bagasse production of 198.33 t/h after the passage of the sugarcane through the milling machines results in a total biomass (straw + bagasse) of about 226.66 t/h, in which 172.25 t/h for use in boilers, 18.13 t/h for technical reserve (8%), and 36.28 t/h for off-season use.

The current energy plant of the mill taken as a reference and named in this study as Case 1 (Figure 1) consists of two 21 bar/300 °C boilers, with a combined production capacity of 170 t/h. It has another boiler that produces 275 t/h of steam at 67 bar and 515 °C, of which 265 t/h is consumed by an extraction-backpressure turbine coupled to a 50 MW generator, which produces about 39 MW and supplies to the transmission and distribution system approximately 27 MW.

In addition, the extraction-backpressure turbine allows extraction of 80 t/h of steam at 21 bar, which is added to the steam produced in the two 21 bar boilers to activate the equipment by the steam turbine, yeast factory, and cleaning of conveyors. The remaining steam continues to expand up to a pressure of 2.5 bar to meet the manufacturing process.



1. 67 bar/515 °C boiler
2. Extraction-backpressure turbine
3. Generator
4. Desuperheater
5. Turbopump
6. Exhaust fan turbine
7. Shredder turbine
8. Defibrator
9. 1st and 2nd mill turbine
10. 3rd and 4th mill turbine
11. 5th and 6th mill turbine
12. Shredder turbine
13. Defibrator turbine
14. 1st mill turbine
15. 2nd mill turbine
16. 3rd and 4th mill turbine
17. 5th mill turbine
18. 6th mill turbine
19. Conveyor washing
20. Yeast factory
21. 21 bar/300 °C boiler
22. 21 bar/300 °C boiler
23. Water replenishment
24. Condensate from the process
25. Desuperheater
26. Steam losses
27. Deaerator
28. Evaporation
29. Turbopump
30. Purge steam
31. Miscellaneous
32. Condensate from the process
33. Purge steam
34. Deaerator
35. Turbopump

FIGURE 1. Energy plant of the mill considered as reference (Case 1).

The simulations proposed in this study considered the use of lotus rollers in the last mill of the train at the upper roll position (Figure 2) in order to reduce moisture and POL (percentage in mass of sucrose in the bagasse) to increase biomass LCV (lower calorific value), given the high juice drainage capacity in this configuration.

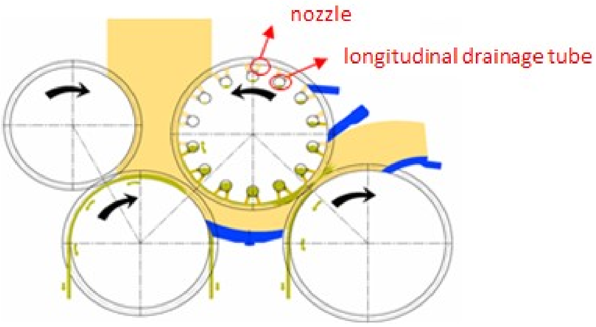


FIGURE 2. Lotus roller at the top. Source: Delfini (2015).

The average values of moisture and POL, analyzed at the industrial laboratory in the last two harvests, were obtained at the end of each harvest, and the respective values of bagasse LCV, used as fuel in the boilers, were calculated and are shown in Table 1.

TABLE 1. Moisture, POL and LCV values for bagasse in the 2014/15 and 2015/16 harvests.

Harvest	Moisture (%)	POL (%)	LCV (kJ/kg)
2014/15	51.06	2.27	7,311.62
2015/16	51.23	2.12	7,284.63
Average of two harvests	51.15	2.20	7,298.13

Four other cases using the lotus rollers (Figure 2) were considered from the average values of moisture, POL, and LCV of bagasse in the last two harvests, with an additional reduction of 1% for each one and are shown in Table 2.

TABLE 2. Cases studied with the use of high-drainage rollers (lotus rollers).

Case	Moisture (%)	POL (%)	LCV (kJ/kg)
2.1	51.15	2.20	7,296.86
2.2	50.15	2.05	7,507.46
2.3	49.15	1.90	7,718.05
2.4	48.15	1.75	7,928.65
2.5	47.15	1.60	8,139.24

The electrification of equipment drives for preparation, milling, motor pumps, and boiler fans, previously drove by steam turbines, was performed for the proposed cogeneration configurations. Shredder sets were removed from the sugarcane preparation because the mill processes only chopped sugarcane, remaining only the shredder set that maintained a good preparation index.

Pistore (2004) proposed the use of three-phase induction motors for the drives, adopting medium voltage motors (MV – 4.16 kV) with direct power for constant speed drives, and low voltage motors (LV – 690 V) for variable speed drives, powered by frequency inverters. Table 3 shows the main parameters of the equipment considered in the electrification.

TABLE 3. Equipment parameters considered in the electrification.

Equipment	Steam consumption (t/h)	Yield (%)	Required power (kW)	Speed characteristic
Defibrator A	9.70	46.4	531.97	Constant
1st/2nd mills MA	13.12	46.1	716.72	Variable
3rd/4th mills MA	13.12	43.1	670.31	Variable
5th/6th mills MA	13.12	45.2	702.87	Variable
Defibrator B	12.46	48.2	711.69	Constant
1st mill MB	8.50	47.5	478.54	Variable
2nd mill MB	8.50	40.5	408.00	Variable
3rd/4th mills MB	14.35	40.5	688.67	Variable
5th mill MB	11.87	44.2	621.86	Variable
6th mill MB	11.87	45.0	683.11	Variable
Turbopumps	2.80	45.0	149.32	Variable
Exhaust fan	5.70	45.0	303.96	Variable

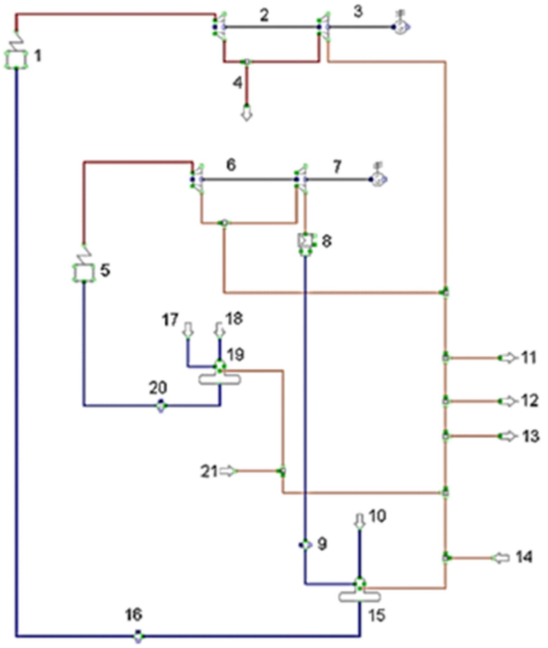
According to Pistore (2004), the amount of additional electrical power P_a for the drives to replace the mechanical work performed by steam turbines W_t is given by [eq. (1)], taking into account the weighted correction factor of electrification F_c:

$$P_a = W_t \; F_c \tag{1}$$

The weighted correction factor (F_c) is determined according to the consumption of medium (C_M) and low voltage (C_L) and efficiencies of medium (η_M) and low voltage (η_L) drives to be applied to the total value of mechanical work produced by steam turbines in the drives of existing equipment (disregarding shredders) through the following equation (Pistore, 2004):

$$F_c = \frac{1}{[(\eta_M . C_M) + (\eta_L . C_L)]} \tag{2}$$

Figure 3 shows the power plant of the mill, modified for simulations of Case 2, considering the removal of turbines from the drives and their replacement by electric motors.



1. 67 bar/515 °C boiler
2. Extraction-backpressure turbine
3. Generator
4. Conveyor washing
5. 67 bar/515 °C boiler
6. Extraction- condensation turbine
7. Generator
8. Condenser
9. Pump
10. Condensate from the process
11. Steam losses
12. Evaporation
13. Miscellaneous
14. Purge steam
15. Deaerator
16. Pump
17. Water replenishment
18. Condensate from the process
19. Deaerator
20. Pump
21. Purge steam

FIGURE 3. Thermal plant of the modified sugar-energy mill (Case 2).

Mass and energy balance

Mass and energy balance was based on the principles of conservation of mass (Continuity Equation) and energy (First Law), in which the volume of control in each isolated equipment or a set could be considered and its performance verified separately or as a whole.

The solution to the system of equations resulting from the mass and energy balance of the cases was obtained using the software IPSEpro® (Benedikt et al., 2018; Bösch et al., 2012).

Economic analysis

The economic analysis was based on estimations for future cash flow, obtained from forecasts for several variables, and the initial cash flow analysis was carried out using representative values for the considered variables, allowing the calculation of deterministic financial indicators (Dias et al., 2010). The techniques of capital investment analysis consider the time factor in the value of money and involve the concepts of cash flows supposedly known throughout the project, which was defined as 20 years in this study.

The payback period allows determining the period when the updated and cumulative cash flow cancels the initial investment. An investment is more interesting when its annual cash inflows allow it to recover more quickly the initially invested capital within the project life, which was 20 years in this study.

The net present value (*NPV*) is based on cash flow, used to describe the interaction between the invested capital (*C*) and the net annual capital inflow (*In*) and the adopted discount rate (*j*) for the period of the project (*n*).

$$NPV = \sum_{k}^{n} \frac{I_n}{(1+j)^k} - C \tag{3}$$

Thus, the project should be accepted when $NPV \geq 0$, as there will be a return equal to or higher than the cost of the invested capital, and the project will conserve or increase its equity; otherwise, the project should be rejected if $NPV < 0$.

The internal rate of return (*IRR*) for an investment is the j^* rate that returns the present value of the net cash inflows associated with the project equal to the initial investment or, similarly, the j^* rate that makes the project's *NPV* equal to zero. It is a more objective criterion, in which the decision to evaluate the project is based on the cost of capital: if *IRR* is equal to or greater than the cost of capital or adopted discount rate, which was the SELIC rate in this study, the project is accepted; otherwise, it should be rejected. *IRR* is determined iteratively by:

$$IRR = \sum_{k}^{n} \frac{I_n}{(1+j)^k} - C = 0 \tag{4}$$

The return on invested capital (*ROIC*) is the ratio between the operating net income minus adjusted taxes (*L*) and the invested capital (*C*), allowing measuring the return of capital invested in the company, regardless of how the investment is financed (Jennergren, 2006). It is determined by:

$$ROIC = \frac{L}{C} \tag{5}$$

Investments

The investments for the project of electrification of drives, considering as acquired equipment the planetary motors and reducers for milling A and B, defibrators of millings A and B, turbopumps, and exhaust fans, were R$ 64,004,885.00.

The investments in the energy cogeneration systems considered the purchase of the following equipment: 67 bar/515 °C water-tube boiler, the extraction-condensing turbine, energy generator, and condenser. Table 4 shows the investment values for each of the analyzed cases.

TABLE 4. Investments for energy cogeneration projects.

Case	Investment (R$)
2.1	141,856,478.00
2.2	149,641,436.00
2.3	157,241,523.00
2.4	163,490,556.00
2.5	171,090,644.00

The performed analysis showed the possibility of selling obsolete equipment (steam turbines, shredders, speed reducers, couplings, impellers, 22 bar boilers, among others) from the electrification of drives, resulting in additional revenue for the sugar-energy mill of R$ 53,166,875.00.

According to the historical values practiced in mills, the costs of operation and maintenance of energy cogeneration plants were considered to be R$ 1.00 per ton of sugarcane, while the costs of transporting straw for an average radius of 33 km was considered to be R$ 29.00 per ton.

RESULTS AND DISCUSSION

According to the data presented for the reference mill in Case 1, the technical reserve of biomass was 8% (18.13 t/h), with surplus biomass stored for use in the off-season or during periods of rain. However, it was proposed to reduce the technical reserve to 5% (11.33 t/h) in Case 2, which would safely meet the mill's needs. In addition, the previously surplus biomass could be used by incorporating a new cogeneration system with another 67 bar/515 °C boiler (same standard as the high-pressure boiler in Case 1), an extraction-condensing turbine with steam extraction at 2.5 bar to meet the process, generator, condenser, and condensate motor pump for feeding the new boiler, with capacities defined according to the amount of biomass available.

In addition, the harvesting period was extended from 225 to 275 days because the mill has had a history of sugarcane surplus of around 200,000 t at the end of the harvest period, besides being close to other plants of the same group that also have a history of sugarcane without harvesting. Thus, there would be the possibility of milling an additional amount of around 700,000 t.

Considering η_M = 0.94, η_B = 0.91, C_M = 0.18, and C_B = 0.82 (Pistore, 2004), an F_c = 1.092 was obtained through Equation (2). This value was used in Equation (1) considering W_t = 4,652.71 kW to obtain an additional power of 5,080.76 kW due to the use of electric motors to electrify the drives with steam turbines.

The increased surplus electrical energy of the proposed cases was simulated with the use of high-drainage rollers, allowing varying moisture, POL, and thus LCV of the bagasse, as shown in Table 5.

TABLE 5. Analysis of cogeneration cases.

Case	Electrical energy generation (MWh)	Electrical energy consumption (MWh)	Surplus electrical energy (MWh)	Increase in surplus (MWh)
1	39.10	12.10	27.00	0
2.1	87.46	17.20	70.26	43.26
2.2	91.29	17.20	74.09	47.09
2.3	95.11	17.20	77.91	50.91
2.4	98.93	17.20	81.73	54.73
2.5	102.76	17.20	85.56	58.56

The variation in the production of surplus electrical energy using high-drainage rollers between Case 2.1 (43.26 MW) and Case 2.5 (58.56 MW) was 15.3 MW, technically proving the effectiveness of this equipment in the production of quality fuel for boilers, as it enabled an increase of 35% in the electrical energy generation.

Cash flows showed that the revenue was composed of the annual sale of energy, and expenses were composed of taxes, industrial cost, and depreciation, thus obtaining the gross (before taxes) and net income (after taxes).

The minimum acceptable rate of return considered here was the Selic rate for the last 12 months, which reached 14.22% in 2016.

The economic results of Case 2.1 showed economic viability for situations in which electrical energy is sold from R$ 210.00/MWh (Table 6).

TABLE 6. Economic results for Case 2.1.

Energy price (R$/MWh)	Payback (year; month)	*NPV* (R$)	*IRR* (% p.a.)	*ROIC* (% p.a.)
150.00	Above 20 years	-37,037,240.00	9.71	4.44
180.00	Above 20 years	-10,928,387.00	12.94	6.09
210.00	13; 7	15,180,467.00	15.95	7.75
240.00	9; 7	41,289,321.00	18.83	9.41
270.00	7; 8	67,398,175.00	21.62	11.06

The economic results of Case 2.2 are shown in Table 7 and also presented economic viability for situations in which electrical energy is sold from R$ 210.00/MWh.

TABLE 7. Economic results for Case 2.2.

Energy price (R$/MWh)	Payback (year; month)	*NPV* (R$)	*IRR* (% p.a.)	*ROIC* (% p.a.)
150.00	Above 20 years	-32,336,888.00	10.51	4.84
180.00	Above 20 years	-3,916,502.00	13.79	6.55
210.00	11; 10	24,503,885.00	16.86	8.27
240.00	8; 10	52,924,272.00	19.81	9.98
270.00	7; 1	81,344,658.00	22.67	11.70

The economic results of Case 2.3 showed better results than Cases 2.1 and 2.2 (Table 8), with economic viability for situations in which electrical energy is sold from R$ 180.00/MWh. In this case, the reduction in moisture and POL reduction of bagasse allowed a significant increase in the electrical energy generation, which can be sold with a lower value and still be economically viable.

TABLE 8. Economic results for Case 2.3.

Energy price (R$/MWh)	Payback (year; month)	*NPV* (R$)	*IRR* (% p.a.)	*ROIC* (% p.a.)
150.00	Above 20 years	-27,503,872.00	11.23	5.20
180.00	18; 1	3,222,013.00	14.56	6.97
210.00	10; 9	33,947,897.00	17.69	8.74
240.00	8; 2	64,673,781.00	20.70	10.51
270.00	6; 8	95,399,665.00	23.63	12.28

The economic results of Case 2.4 showed economic viability for situations in which electrical energy is sold from R$ 180.00/MWh (Table 9).

TABLE 9. Economic results for Case 2.4.

Energy price (R$/MWh)	Payback (year; month)	*NPV* (R$)	*IRR* (% p.a.)	*ROIC* (% p.a.)
150.00	Above 20 years	-21,480,789.93	11.99	5.59
180.00	15; 0	11,550,591.70	15.38	7.43
210.00	9; 10	44,581,973.34	18.59	9.26
240.00	7; 7	77,613,354.97	21.68	11.10
270.00	6; 3	110,644,736.61	24.69	12.93

The economic results of Case 2.5 are shown in Table 10 and presented economic viability with the sale of electrical energy from R$ 180.00/MWh.

TABLE 10. Economic results for Case 2.5.

Energy price (R$/MWh)	Payback (year; month)	*NPV* (R$)	*IRR* (% p.a.)	*ROIC* (% p.a.)
150.00	Above 20 years	-16.617.596.65	12.58	5.90
180.00	13; 5	18.725.317.81	16.01	7.78
210.00	9; 3	54.068.232.27	19.27	9.67
240.00	7; 3	89.411.146.74	22.42	11.55
270.00	6; 0	124.754.061.20	25.50	13.43

Regarding the economic analysis technique of return on invested capital (*ROIC*), which guides investors on the assertiveness in making new investments, the investor would have the highest return in Case 2.5 (13.43%), with an energy sale value of R$ 270.00/MWh. This case also presented the lowest payback period, i.e., the investment made in the electrification and cogeneration systems would return after six years, thus allowing an *NPV* of R$ 124,754,061.20 over the 20 years, with an *IRR* of 25.50%. These results can be a motivation to make investments in new energy cogeneration projects.

CONCLUSIONS

The transportation of straw along with sugarcane in the same truck is operationally easier, but it presents a high and significant cost in the economic analysis, as it reduces the density of load on the truck and requires an efficient dry cleaning system in the industrial area.

Investments made in the electrification of drives are essential when the intention is to produce surplus electrical energy. Also, the removal of shredders from the preparation of chopped sugarcane showed no reduction in the preparation rate historically practiced by the mill but requiring changing the hammer set in the defibrators in a shorter time than that commonly performed.

The use of high-drainage rollers reduced bagasse moisture, enabling boilers to burn fuel with high calorific value. Moreover, Case 2.5 had an increase of 11.5% in steam production relative to the reference case, increasing electrical energy cogeneration and, therefore, tripling the power injected into the electrical energy transmission and distribution system.

The economic analysis techniques (Payback, *NPV*, *IRR*, and *ROIC*) showed that Cases 2.1, 2.2, 2.3, 2.4, and 2.5 might be economically viable if prices of the energy to be sold are at least R$ 180.00 per MWh. However, Case 2.5 presented the highest economic viability, as it had better preparation of the sugarcane biomass for use in boilers.

It is worth mentioning that if any of the cogeneration alternatives to export surplus electrical energy proposed in this study are implemented, the data must be reviewed to ensure that the decision on project execution is made based on updated information.

Moreover, we suggest that future studies carry out a technical and economic viability analysis with higher use of straw, such as 6, 8, 10, 12, and 14%, to reduce project impact on costs and present better values for economic viability indicators.

REFERENCES

Ahmed AE, Eldin AOMA (2015) An assessment of mechanical vs manual harvesting of the sugarcane in Sudan – The case of Sennar Sugar Factory. Journal of the Saudi Society of Agricultural Sciences 14(2):160-166. DOI: http://dx.doi.org/10.1016/j.jssas.2013.10.005

Alves M, Ponce GHSF, Silva MA, Ensinas AV (2015) Surplus electricity production in sugarcane mills using residual bagasse and straw as fuel. Energy 91:751-757. DOI: http://dx.doi.org/10.1016/j.energy.2015.08.101

Arshad M, Ahmed S (2016) Cogeneration through bagasse: A renewable strategy to meet the future energy needs. Renewable and Sustainable Energy Reviews 54:732-737. DOI: http://dx.doi.org/10.1016/j.rser.2015.10.145

Benedikt F, Schmid JC, Fuchs J, Mauerhofer AM, Müller S, Hofbauer H (2018) Fuel flexible gasification with an advanced 100 kW dual fluidized bed steam gasification pilot plant. Energy 164:329-343. DOI: https://doi.org/10.1016/j.energy.2018.08.146

Bösch P, Modarresi A, Friedl A (2012) Comparison of combined ethanol and biogas polygeneration facilities using exergy analysis. Applied Thermal Engineering 37:19-29. DOI: https://doi.org/10.1016/j.applthermaleng.2011.12.048

Cervi WR, Lamparelli RAC, Seabra JEA, Junginger M, Hilst F (2019) Bioelectricity potential from ecologically available sugarcane straw in Brazil: A spatially explicit assessment. Biomass and Bioenergy 122:391-399. DOI: https://doi.org/10.1016/j.biombioe.2019.02.001

Chantasiriwan S (2016) Optimum imbibition for cogeneration in sugar factories. Applied Thermal Engineering 103:1031-1038. DOI: http://dx.doi.org/10.1016/j.applthermaleng.2015.08.113

Coelho ST, Goldemberg J, Lucon O, Guardabassi P (2006) Brazilian sugarcane ethanol: lessons learned. Energy for Sustainable Development 10(2):26-39. DOI: https://doi.org/10.1016/S0973-0826(08)60529-3

Delfini PT (2015) Eficiência e custos na extração de caldo. Available: http://sucroenergetico.revistaopinioes.com.br/revista/detalhes/10-eficiencia-e-custos-na-extracao-de-caldo/. Accessed: Apr 10, 2016.

Dias MOS, Cunha MP, Jesus CDF, Scandiffio MIG, Rossell CEV, Filho RM, Bonomi A (2010) Simulation of ethanol production from sugarcane in Brazil: economic study of an autonomous distillery. Computer Aided Chemical Engineering 28:733-738. DOI: https://doi.org/10.1016/S1570-7946(10)28123-3

Dias MOS, Filho RM, Mantellato PE, Cavalett O, Rossell CEV, Bonomi A, Leal MRLV (2015) Sugarcane processing for etanol and sugar in Brazil. Environmental Development 15(2015):35-51. DOI: http://dx.doi.org/10.1016/j.envdev.2015.03.004

Ensinas AV, Nebra SA, Lozano MA, Serra LM (2007) Analysis of process steam demand reduction and electricity generation in sugar and ethanol production from sugarcane. Energy Conversion and Management 48(11):2978-2987. DOI: http://dx.doi.org/10.1016/j.enconman.2007.06.038

Jennergren LP (2006) Continuing value in firm valuation by the discounted cash flow model. European Journal of Operational Research 185(3):1548-1563. DOI: https://doi.org/10.1016/j.ejor.2006.08.012

Khoodarutha A (2014) Optimisation of a cogenerat Continuing value in firm valuation by the discounted cash flow model d energy systems: the cane biomass flexi-factory case study. Energy Procedia 62:656-665. DOI: http://dx.doi.org/ 10.1016/j.egypro.2014.12.429

Leal MRLV, Galdos MV, Scarpare FV, Seabra JEA, Walter A, Oliveira COF (2013) Biomass and Bioenergy 53(2013):11-19. DOI: https://doi.org/10.1016/j.biombioe.2013.03.007

Lemos SV, Denadai MS, Guerra SPS, Esperancini MST, Bueno OC, Takitane IC (2014) Industrial crops and products 55:97-101. DOI: https://doi.org/10.1016/j.indcrop.2014.02.010

Macedo IC, Leal MRLV, Hassuani SJ (2001) Sugar cane residues for power generation in the sugar/ethanol mills in Brazil. Energy for Sustainable Development 5(1):77-82. DOI: https://doi.org/10.1016/S0973-0826(09)60022-3

Moreira JR, Romeiro V, Fuss S, Kraxner F, Pacca SA (2016) BECCS potential in Brazil: Achieving negative emissions in ethanol and electricity production based on sugar cane bagasse and other residues. Applied Energy 179:55-63. DOI: http://dx.doi.org/10.1016/j.apenergy.2016.06.044

Pellegrini LF, Oliveira Junior S (2011) Combined production of sugar, ethanol and electricity: Thermoeconomic and environmental analysis and optimization. Energy 36(6):3704-3715. DOI: http://dx.doi.org/10.1016/j.energy.2010.08.011

Pina EA, Bereche RP, Rodriguez MFC, Ensinas AV, Modesto M, Nebra S (2015) Reduction of process steam demand and water-usage through heat integration in sugar and ethanol production from sugarcane - Evaluation of different plant configurations. Energy 138:1263-1280. DOI: http://dx.doi.org/10.1016/j.energy.2015.06.054

Pistore TT (2004) Avaliação técnico-econômica e ambiental da eletrificação das moendas na indústria sucroalcooleira. Dissertação Mestrado, Itajubá, Universidade Federal de Itajubá.