MODELO MATEMÁTICO PARA O PLANEJAMENTO DA PRODUÇÃO E COLETA DE BIOMASSA PARA COGERAÇÃO EM USINAS SUCROENERGÉTICAS

DANIEL FERNANDO GARCIA[1], EDILAINE MARTINS SOLER[2], ANTONIO ROBERTO BALBO[3]

[1] Mestre Curso de Engenharia Elétrica, Faculdade de Engenharia, Universidade Estadual Paulista – UNESP, Campus de Bauru/SP, e-mail: daniel.garcia@unesp.br
[2] Profa. Doutora, Departamento de Matemática, Faculdade de Ciências, Universidade Estadual Paulista – UNESP, Campus de Bauru/SP, Av. Engenheiro Luiz Edmundo Carrijo Coube, 14-01, Vargem Limpa, 17033-360, Bauru, São Paulo, Brasil, edilaine.soler@unesp.br
[3] Prof. Doutor, Departamento de Matemática, Faculdade de Ciências, Universidade Estadual Paulista – UNESP, Campus de Bauru/SP, Av. Engenheiro Luiz Edmundo Carrijo Coube, 14-01, Vargem Limpa, 17033-360, Bauru, São Paulo, Brasil, antonio.balbo@unesp.br

RESUMO: A produção de energia a partir da biomassa de cana-de-açúcar tem se tornado cada vez mais comum nas usinas que produzem açúcar e álcool. Além de ser uma alternativa renovável para a produção de energia, a venda da eletricidade excedente pode aumentar significantemente o lucro das usinas sucroenergéticas. A otimização dos processos reduz consideravelmente os custos envolvidos em todo o processo produtivo. Considerando a utilização da biomassa da cana para a produção de energia, as usinas se deparam com o problema de alocação dos recursos para a produção de açúcar, álcool e energia, e de planejamento da coleta da biomassa remanescente da colheita mecanizada. Assim, este trabalho propõe um modelo matemático de programação linear inteira mista para o planejamento da produção e coleta da biomassa remanescente da colheita mecanizada, com o objetivo de realizar o balanceamento econômico através da cogeração de energia, e produção de açúcar e etanol. Propõe-se resolver o modelo proposto pelo *solver* CPLEX. Foram realizados testes numéricos com o modelo proposto aplicado à um cenário base. O *solver* CPLEX mostrou-se eficiente nos testes numéricos realizados e os resultados obtidos demonstram um equilíbrio do *mix* de produção.

Palavras-chaves: otimização linear inteira mista, cana-de-açúcar, bioenergia, balanço econômico, alocação ótima.

MATHEMATICAL MODEL FOR PLANNING THE PRODUCTION AND COLLECTION OF BIOMASS FOR COGENERATION IN SUGAR ENERGY PLANTS

ABSTRACT: The production of energy from sugarcane biomass has become increasingly common in mills that produce sugar and alcohol. In addition to being a renewable alternative for energy production, the sale of excess electricity can significantly increase the profits of sugarcane plants. Process optimization considerably reduces the costs involved in the entire production process. Considering the use of sugarcane biomass for energy production, the mills are faced with the problem of allocating resources for the production of sugar, alcohol, and energy, and planning the collection of biomass remaining from mechanized harvesting. Thus, this work proposes a mixed-integer linear programming mathematical model for planning the production and collection of biomass remaining from mechanized harvesting, in order to achieve economic balance through energy cogeneration, and sugar and ethanol production. It is proposed to solve the model proposed by the CPLEX solver. Numerical tests were performed with the proposed model applied to a base scenario. The CPLEX solver proved to be efficient in the numerical tests performed and the results obtained demonstrate a balance of the production mix.

Keywords: mixed integer linear optimization, sugarcane, bioenergy, economic balance, optimal allocation.

1 INTRODUCTION

The historical production and milling of sugarcane in Brazil in the 2018/19 and 2019/20 harvests, according to the Sugarcane Observatory (2021), were approximately 621 and 643 million tons, respectively. In relation to the same harvests, sugar production was approximately 30 million tons in both harvests, and ethanol production was approximately 34 and 36 thousand cubic meters. According to the Energy Research Company (2021), the use of sugarcane biomass for energy production since 2019 has constituted 8.4% of the Brazilian electricity matrix, occupying the fourth position behind hydroelectricity, natural gas, and wind power.

Access to clean and nonpolluting energy is currently defined as a sustainable development goal. Within this new context, many countries are developing and promoting incentive policies for the implementation of new energy projects using renewable sources, also known as nonconventional energy sources. A more prominent alternative is related to the use of residual biomass left by agribusiness production chains, such as sugarcane biomass. For the cogeneration sector, the search for alternatives that provide evidence of sustainability is fundamental, as its environmental role has been discussed more intensely in recent years. According to Rivera-Cadavid, Velásquez, and Duque (2019), energy generation through the use of agricultural waste leads to an agribusiness concept based on environmental preservation and the conscious and efficient use of available resources, thus increasing reducing CO_2 emissions $_{into}$ the atmosphere through the burning of fossil fuels.

Mathematical models and solution methodologies for optimizing agro-industrial processes related to sugarcane have been proposed in the literature in recent years. Costa, Potrich, Cruz (2016), Ba, Prins, and Prodhon (2016), and Carpio and Souza (2017) presented mathematical models for the allocation of sugarcane in industrial production. Models applied to the planning of sugarcane planting and harvesting were addressed by Isler, Florentino, and Martins (2012); Leda, Gonçalvez, and Lima (2019); and Junqueira

and Morabito (2018). Ramos and Florentino (2012) proposed a model focused on determining the energy production costs in sugarcane cultivation. The works of Sartori and Florentino (2002) and Oliveira, Braga and Santos (2014) presented models that address the feasibility of using sugarcane biomass. Carvalho Junior (2016) proposed a mathematical linear optimization model to determine the plant production configuration that maximizes the mill's profit. Rivera-Cadavid, Velásques and Duque (2019) proposed a model that determines the selection of plots for collecting and transporting the remaining biomass from mechanized harvesting for energy production.

Most models proposed in the literature for optimizing sugarcane agro-industrial processes focus on specific moments in agro-industrial production and fail to consider internal energy demands or the demands of *commodities* (sugars and alcohol). There are also models that assist in planning sugarcane planting and models that demonstrate the benefits of biomass utilization without considering industrial production. There are also more comprehensive models, but owing to their formulation, they require significant computational effort for their resolution when applied to large-scale instances.

Thus, with the aim of obtaining a model that assists in the production planning of a sugarcane-based power plant, as well as the collection and use of biomass in the direct production of sugarcane-derived products, this article proposes a mixed integer linear programming mathematical model for optimizing the economic balance of energy cogeneration and sugar and ethanol production in sugarcane-based power plants and for determining the selection of plots where the remaining biomass from mechanized harvesting should be collected.

To validate the proposed model, numerical tests with a baseline scenario, which were performed via the CPLEX solver implemented in the IBM ILOG CPLEX *Optimization Studio software, are presented*.

The model proposed in this work is a tool that can assist in the decision-making of entrepreneurs in the sugarcane and energy

sector, providing information regarding the selection of plots and the best allocation of resources destined for the manufacture of *commodities* and meeting the energy demands involved in sugarcane production. The contribution of this work comes from a detailed analysis of production planning, the supply chain, and resource allocation in relation to price variations that influence decision-making.

This work is organized as follows: Section 2 describes the mathematical model proposed in this work, Section 3 presents the results obtained and the relevant discussions on the basis of the tests performed, and Section 4 presents the conclusions of this work.

2 MATERIALS AND METHODS

The mathematical model proposed in this work is based on the models of Carvalho Junior (2016) and Rivera-Cadavid, Velásques and Duque (2019). The objective function and the constraints of the proposed mathematical model are the result of the objective functions and constraints of the models presented in these two works, which are aggregated into a single mixed integer linear programming mathematical model.

The model proposed in this work considers sugarcane industrial operation where the manufacturing of goods, such as the *commodities* sugar and ethanol, as well as the generation of *surplus* electricity from the same resource, i.e., sugarcane, occurs simultaneously. For industrial operations, the production of thermal, mechanical, and electrical energy to meet the internal needs of the plant is also considered, and for this purpose, the use of resources derived from sugarcane, such as biomass remaining from mechanized harvesting (BRCM), bagasse, juice, and residual molasses from the juice, is considered.

Additionally, the proposed mathematical model determines which plots BRCM (broken sugarcane mill) should be collected to supplement energy generation. Part of the BRCM from each plot is transported along with the sugarcane and then used for energy generation. Owing to the energy generation capacities of the mills and the profit

resulting from the sale of surplus energy, there may be a need to collect more BRCM in plots where sugarcane has already been harvested. The proposed model also aims to determine the plots where this additional BRCM collection will be carried out. BRCM collection should occur after sugarcane harvesting in the plots and should be performed 7 to 10 days after harvesting. Thus, in aggregate, the proposed model seeks to overcome the difficulties encountered in both production planning and supply chain planning.

The objective of the model is to achieve maximum benefit between the revenues and costs of a sugarcane processing plant, the latter being linked to the market prices of each *commodity*. The approach considered the production of derivatives from sugarcane byproducts, along with their market prices, production costs, and logistical costs of collecting and transporting these byproducts from the fields to the plant.

The objective function and constraints that make up the model proposed in this work are detailed below. In the notation adopted, the model's decision variables are denoted by lowercase letters, and the parameters are denoted by uppercase letters and Greek letters.

Indices

i: *commodities*, i = 1, 2, 3 (VHP sugar, anhydrous ethanol, hydrated ethanol);

j: resources, j = 1, 2, 3, 4 (BRCM, bagasse, broth, molasses);

h: energies, h = 1, 2, 3 (thermal, mechanical, electrical);

k: plots, k = 1..., K.

Decision variables

x^e: *quantity* of surplus electricity produced (in MW);

x_i^c: quantity of *commodity* i produced (in tons or m³);

x_{ij}^{cr}:   quantity of *commodity* i produced from resource j (in tons/ton or m³/ton);

x_{hj}^{er}:   quantity of energy h for internal demand produced from resource j (in MW/ton);

x_{ji}^{rc} :   quantity of resource j needed to produce *commodity* i (in tons);

x_{jh}^{re} :   quantity of resource j needed to produce energy h to meet domestic demand (in tons);

x_k :   quantity of BRCM collected in plot k (in tons);

d_h :   internal energy demand h required for sugarcane production (in MW);

y_k :   binary variable that takes a value of 1 if there is BRCM collection from plot k and 0 otherwise.

Parameters

C_{ij}^C :   cost of producing *commodity* i from resource j (in R\$/ton);

C_{hj}^E :   cost of producing energy h to meet domestic demand, produced from resource j (in R\$/ton);

C_k^F :   fixed cost of collecting d from the BRCM of plot k (in R\$);

C_k^T :   cost of transporting BRCM from plot k to the plant (in R\$/(ton/km))

D_k :   distance between the plot and the plant (in km);

D_i^C :   demand for *commodity* i to be met by the plant (in tons or m³);

D_{aux}^E :   electrical demand consumed at the power plant (in MW);

E_k^D :   number of teams available for BRCM collection in plot k;

P_i^C :   unit price of *commodities* produced (in R\$/ton or R\$/m³);

P^e :   unit price of surplus electricity *commodity* (in R\$/MW);

P^Q :   BRCM processing capacity of the plant (in tons);

Q_{moa}^C Grinding capacity (in tons   );

Q_{ij}^E :   amount of electrical energy needed to produce *commodity* i from resource j (in MW/ton);

Q_{moa}^E :   amount of electrical energy consumed in the   sugarcane milling stage (in MW/ton);

Q_{rec}^E :   amount of electrical energy consumed in the   sugarcane reception stage (in MW/ton);

Q_{moa}^M :   amount of mechanical energy consumed to grind one ton of sugarcane (in MW);

Q_k^P :   The quantity of BRCM available in plot k for collection (in tons) is considered to be that the quantity of BRCM available in each plot for collection is already reduced by the amount that must remain in the soil to generate fertilizer for the next planting;

Q_j^R :   quantity of resource j, available for each ton of processed sugarcane (in tons);

Q_{ij}^T :   amount of thermal energy (process steam) required to produce *commodity* i from resource j (in MW/ton);

η_{jh}^R :   transformation coefficient of resource j into energy h (in tons/MW).

η_{ji}^R :   transformation coefficient of resource j into *commodity* i (in tons/ton or tons/m³);

In (1), we have the objective function of the proposed model, which is formed by the sum of the revenue obtained from the sale of *commodities* plus the revenue from the sale of surplus electricity, lower production costs of *commodities*, production costs for internal energy demands, and transportation costs, thereby maximizing the economic balance of the power plant.

$$\max\left(\sum_{i=1}^{3}\left(P_i^C x_i^c\right)\right)+\left(P^E x^e\right)-\left(\sum_{i=1}^{3}\sum_{j=3}^{4}\left(C_{ij}^C x_{ij}^{cr}\right)+\sum_{h=1}^{3}\sum_{j=1}^{2}\left(C_{hj}^E x_{hj}^{cr}\right)+\sum_{k=1}^{K}\left(y_k C_k^F\right)+\sum_{k=1}^{K}\left(x_k D_k C_k^V\right)\right) \qquad (1)$$

2.1 Restriction in meeting the demands of *Commodities*

In (2), the quantities of the *commodities* VHP sugar, anhydrous ethanol and hydrated ethanol (i=1, 2, 3) produced from the resource juice (j = 3) and molasses (j = 4) must be greater than or equal to the demands of these to be met by the plant.

$$\sum_{j=3}^{4} x_{ij}^{cr} \geq D_i^C, i = 1, 2, 3 \qquad (2)$$

2.2 Restrictions on meeting energy demands

In (3), the amount of thermal, mechanical and electrical energy (h=1,2,3) to meet the internal demands produced from the resources BRCM (j = 1) and bagasse (j = 2) must be greater than or equal to the internal energy demands required for sugarcane production (in MW).

$$\sum_{j=1}^{2} x_{hj}^{cr} \geq d_h, h = 1, 2, 3 \qquad (3)$$

In constraints (4) – (6), the values of internal energy demands are calculated, separated by type, to meet the demands of *commodity production*.

It follows from (4) that the thermal energy demand required at the plant must be equal to the product of the amount of thermal energy required to produce *commodity* i by the amount of *commodity* i produced from the resource juice (j = 3) and molasses (j = 4).

$$d_1 = \sum_{i=1}^{3} \sum_{j=3}^{4} \left(Q_{ij}^T x_{ij}^{cr} \right) \qquad (4)$$

In (5), the mechanical energy demand required in the plant must be equal to the product of the amount of mechanical energy consumed to grind one ton of sugarcane by the amount of sugarcane available for grinding.

$$d_2 = Q_{moa}^M Q_{moa}^C \qquad (5)$$

In (6), the electrical energy demand required in the plant is equal to the sum of the amount of electrical energy consumed in the reception stage plus the amount of electrical energy consumed in the milling stage multiplied by the amount of sugarcane available for milling; this term is added to the product of the amount of electrical energy required to produce commodity *i* by the amount of *commodity* i produced from the juice (j = 3) and molasses (j = 4) resources plus the auxiliary electrical demand consumed in the plant.

$$d_3 = \left(Q_{rec}^E + Q_{moa}^E \right) Q_{moa}^C + \sum_{i=1}^{3} \sum_{j=3}^{4} \left(Q_{ij}^E x_{ij}^{cr} \right) + D_{aux}^E \qquad (6)$$

2.3 Resource constraints

In the restrictions (7), the quantity of *commodity* i produced from resource j must be equal to the product of the quantity of resource j needed to produce *commodity* i by the transformation coefficient of resource j into *commodity* i (in tons/tons or tons/m³).

$$x_{ij}^{cr} = x_{ji}^{rc} \eta_{ji}^R, i = 1, 2, 3; j = 3, 4 \qquad (7)$$

In (8), the amount of energy h needed to meet the internal demand produced from resource j must be equal to the product given by the amount of resource j needed to produce energy h by the transformation coefficient of resource j to internal energy h (in tons/MW).

$$x_{hj}^{er} = x_{jh}^{re} \eta_{jh}^R, h = 1, 2, 3; j = 1, 2 \qquad (8)$$

In the restrictions (9), the quantity of *commodity* i produced must be equal to the sum of the quantities of *commodity* i produced from the resource juice (j = 3) and molasses (j = 4).

$$x_i^c = \sum_{j=3}^{4} x_{ij}^{cr}, i = 1, 2, 3 \qquad (9)$$

In (10), the amount of surplus *electricity* produced is equal to the sum of the amount of electricity produced from the BRCM (j = 1) and bagasse (j = 2) resources decreased by the

demand for electricity (h = 3) required for sugarcane production.

$$x^e = \sum_{j=1}^{2}\left(x_{3j}^{er}\right) - d_3 \qquad (10)$$

In (11), the sum between the quantities of resource j needed to produce *commodity* i and the quantities of resource j needed to produce energy h must be less than or equal to the quantity of resource j available.

$$\sum_{i=1}^{3} x_{ji}^{rc} + \sum_{h=1}^{3} x_{jh}^{re} \le Q_j^R Q_{moa}^C, \ j = 2, 3, 4 \qquad (11)$$

With respect to restrictions (12), in addition to the total amount of BRCM available per ton of processed cane, we add to this value the amount of BRCM collected in the plots available for the production of *commodities* and surplus electricity.

$$\sum_{i=1}^{3} x_{ji}^{rc} + \sum_{h=1}^{3} x_{jh}^{re} \le \left(Q_j^R Q_{moa}^C\right) + \sum_{k=1}^{K} x_k, \ para \ j = 1 \ (12)$$

According to (13), the amount of BRCM in the processed sugarcane added to the amount of BRCM harvested from the stalks must be less than or equal to the BRCM processing capacity of the mill.

$$\left(Q_j^R Q_{moa}^C\right) + \sum_{k=1}^{K} x_k \le P^Q \qquad (13)$$

2.4 Plot selection restrictions for BRCM collection

In (14), the number of plots in which the BRCM must be collected is limited by the number of teams available for collection. In (15), the amount of BRCM collected in each plot was limited by the amount of BRCM available from the plot for collection.

$$\sum_{k=1}^{K} y_k \le E_k^D \qquad (14)$$

$$x_k \le Q_k^P y_k; \ k = 1,...,K \qquad (15)$$

BRCM collection should occur after sugarcane harvesting in the plots and is essentially performed 7 to 10 days after harvesting. According to Rivera-Cadavid, Velásques and Duque (2019), the total amount of BRCM generated in each plot k depends on its area, the variety of sugarcane cultivated, and the harvesting tools used. Notably, the amount of BRCM available in each plot for collection is Q_k^P considered to be reduced by the amount that must remain in the soil to generate fertilizer for the next planting.

2.5 Nonnegativity constraints

In (16), we have the domain of definition of the model variables.

$$\begin{aligned} &x_i^c \ge 0, \ i = 1, 2, 3 \\ &x^e \ge 0 \\ &x_{ij}^{cr} \ge 0, \ i = 1, 2, 3; j = 1, 2, 3, 4 \\ &x_{hj}^{cr} \ge 0, \ h = 1, 2, 3; j = 1, 2, 3, 4 \\ &x_{ji}^{rc} \ge 0, \ j = 1, 2, 3, 4; i = 1, 2, 3 \qquad (16) \\ &x_{jh}^{re} \ge 0, \ j = 1, 2, 3, 4; h = 1, 2, 3 \\ &x_k \ge 0, \ k = 1, 2, 3, ..., K \\ &d_h \ge 0, \ h = 1, 2, 3 \\ &y_k \in \{0,1\}, \ k = 1, 2, 3, ..., K \end{aligned}$$

The proposed models (1) - (16) were implemented in IBM ILOG CPLEX *Optimization Studio software* and solved via the CPLEX *solver (IBM, 2021). For model validation, a hypothetical plant with a milling capacity of 20 thousand* tons/day is considered; according to the National Supply Company (CONAB, 2013), plants with this milling capacity are considered large-scale agro-industrial plants. A planning horizon of 1 day of production is considered. The parameters adopted in the tests were adopted according to the literature. The *commodity* selling prices were considered on the basis of the April 2021 quotation according to the Chamber of Electric Energy Commercialization (2021) and the Center for Advanced Studies in Applied Economics (2021a, 2021b) and are as follows:

R$ 2,083.00/ton of VHP sugar, R$ 3,012.40/m³ of anhydrous ethanol, R$ 2,674.70/m³ of hydrated ethanol and R$ 226.73/MWh of surplus electricity.

Twenty plots with the Brazilian Sugarcane Mill (BRCM) available for collection are considered; these plots are of different sizes and are located at different distances from the mill. It was assumed that the mill has a total of 10 teams available daily to collect BRCM from the plots. With a milling capacity of 20,000 tons/day, the demand for VHP sugar is considered to be 1,700 tons/day, and the demands for anhydrous and hydrated ethanol are 400 m³ and 240 m³, respectively. Demands may vary, as they depend on preestablished contracts with the mill but always respect the milling capacity. The mill's BRCM processing capacity is 3,000 tons/day.

For the implementation and testing, a computer with an Intel(R) Core (TM) i5-7200U processor and 4.00 GB of installed RAM was used. The results obtained are presented in the next section.

3 RESULTS AND DISCUSSION

Models (1) - (16) were solved in 1 second and 85 milliseconds, respectively, for the instance tested.

Table 1 shows the quantities produced by each *commodity* in the obtained solution and the value of the objective function. The production *mix* (calculated by the ratio between the total volume of juice processed by the plant and the quantity destined for the production of both sugar and ethanol) assumes a ratio of 69.45% (sugar production) to 30.55% (ethanol production). These percentages show an expected productive balance in a plant with aggregate production of sugar and ethanol. High productivity in the production of surplus electricity can also be observed; that is, in addition to meeting internal electricity demands, the plant is also able to produce a large amount of surplus electricity, which is sold to the market, thus directly impacting the increase in the plant's profit.

Table 1 Production quantities of **each** *commodity*.

Results	Unit
Economic Balance Sheet (Objective Function)	R$ 6,433,726.27/day
Quantity of VHP sugar *commodity produced*	1700.00 tons/day
Quantity of anhydrous ethanol *commodity* produced	410.60 m³/day
Quantity of hydrated ethanol *commodity* produced	240.00 m³/day
Quantity of the *commodity* electricity produced	17,511.00 MW/day
Production *mix*	69.45%/30.55%

Source: Authors (2021)

Table 2 presents the quantities of each *commodity produced* from the juice and molasses. This table shows that sugar and anhydrous ethanol production is based entirely on the use of juice. Hydrated ethanol production, on the other hand, uses both juice and molasses.

Table 2 Quantities of each **commodity** *i* produced from juice or molasses.

Results	Unit
Amount of VHP sugar produced from the juice	1,700.00 tons/day
Amount of VHP sugar produced from molasses	0 tons/day
Amount of anhydrous ethanol produced from the broth	410.60 m³/day
Amount of anhydrous ethanol produced from molasses	0 m³/day
Amount of hydrated ethanol produced from the broth	73.40 m³/day
Amount of hydrated ethanol produced from molasses	166.60 m³/day

Source: Authors (2021)

Table 3 shows the quantities of each type of energy produced in the resulting solution. An analysis of the data in this table revealed that bagasse was used entirely in the production of electrical energy, whereas the BRCM was divided among the three energy sources used for production.

Table 3source to meet domestic demand from BRCM and bagasse.

Results	Unit
Amount of thermal energy produced from BRCM	7,189.30 MW/day
Amount of thermal energy produced from bagasse	0 MW/day
Amount of mechanical energy produced from BRCM	220.00 MW/day
Amount of mechanical energy produced from bagasse.	0 MW/day
Amount of electrical energy produced from BRCM	4,350.70 MW/day
Amount of electrical energy produced from bagasse	13,608.00 MW/day

Source: Authors (2021)

Table 4 presents the energy production for meeting internal demand. In descending order, the internal energy demand with the lowest production requirement is mechanical energy, followed by electrical energy, and finally, the highest generation requirement is thermal energy.

Table 4 Energy production to meet internal demand**.**

Results	Unit
Thermal energy demand required at the power plant.	7,189.30 MW/day
Mechanical energy demand required at the plant.	220.00 MW/day
Electrical energy demand required at the power plant.	447.34 MW/day

Source: Authors (2021)

Tables 5 and 6 show how each resource is allocated for the production of *commodities*. Table 5 shows that the juice was used to produce all three *commodities*; however, the molasses resource is used entirely in the production of hydrated *ethanol*.

Table 5 Required quantities of broth and molasses needed to produce each *commodity* **i**.

Results	Unit
Amount of juice needed to produce VHP sugar.	10,000 tons
Amount of broth needed to produce anhydrous ethanol.	3,732.70 tons
Amount of molasses needed to produce VHP sugar	0 tons
Amount of molasses needed to produce anhydrous ethanol.	0 tons
Amount of broth needed to produce hydrated ethanol.	667.27 tons
Amount of molasses needed to produce hydrated ethanol.	340.00 tons

Source: Authors (2021)

Table 6 confirms that the use of BRCM is divided among the production of the three energy sources, whereas the use of bagasse is restricted to the production of electricity.

Table 6 Required quantities of BRCM and bagasse needed to produce each h of energy.

Results	Unit

Amount of BRCM needed to produce thermal energy	1,732.40 tons
Amount of BRCM needed to produce mechanical energy	72,368 tons
Amount of BRCM needed to produce electricity	1,195.30 tons
Amount of bagasse needed to produce thermal energy	0 tons
Amount of bagasse needed to produce mechanical energy	0 tons
Amount of bagasse needed to produce electricity.	5,600.00 tons

Source: Authors (2021)

Finally, Table 7 presents the quantities of BRCM that should be collected in each plot. The solution obtained from the 20 plots available for BRCM collection included samples collected from 7 plots.

Table 7 Choice of plot and the amount collected in each plot.

Plot	1	2	3	4	5	6	7	8	9	10
Quantity of BRCM collected in the *plot* (in tons)	0	30	0	25	26	35	0	0	21	0
Plot	11	12	13	14	15	16	17	18	19	20
Quantity of BRCM collected in the *plot* (in tons)	0	0	27	0	0	36	0	0	0	0

Source: Authors (2021)

The results showed that the BRCM is used in the combined production of the three energy sources involved in the sugarcane energy process. Thus, the BRCM is used in the process of meeting internal thermal energy demands and is also allocated to the production of surplus electricity to be sold, which maximizes the economic balance.

Tables (1) – (6) show how sugarcane-derived inputs should be allocated in the industrial process of sugar and ethanol production and energy generation to maximize the mill's profit. Table 7 shows the plots in which the BRCM should be collected and how much should be collected from each plot, also assisting the mill's transport logistics.

The model proposed in this work is a decision-making tool that can assist entrepreneurs in the sugar-energy sector in making decisions regarding resource allocation and *commodity production* to obtain the most advantageous economic balance for the mill.

4 CONCLUSIONS

This article addresses a production planning problem in the sugar and ethanol industry, focusing on the production of sugarcane byproducts and biomass collection in the field, aiming at energy generation and thus maximizing the industry's economic balance.

The results obtained through the implementation of the model are promising, as they show an allocation of sugarcane resources in a way that prioritizes the production of *commodities* that will benefit the industry's economic balance. Furthermore, regarding resources, the model proves efficient in determining the plots where BRCM (biochemical oxygen demand) data should be collected.

It can be concluded from the results obtained that the proposed model is an important tool that can be used in decision-making by sugarcane mill owners, as it demonstrates its efficiency in the optimal allocation of the resources involved, redirecting the Brazilian Sugarcane Mill Management (BRCM) in energy production in a way that benefits the mill's production *mix and thus maximizes its economic balance.*

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