Chapter 54

Genetic algorithm applied in the analysis of economic viability of the implantation of biodigesters in dairy cattle

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ABSTRACT
In Brazil, energy consumption is increasing on a large scale, while the number of energy demand grows slowly by small percentages each year. Rural properties intended for raising pigs and cattle for milking have enormous energy potential, since they are the most suitable for the implementation of the biodigester, due to the amount of waste that these animals produce and the ease of collecting them, as long as they are reared in confinement most of the time. Thus, this work presents a linear optimization model to evaluate the feasibility of implementing biodigesters as a source of electrical energy in rural properties intended for dairy cattle. To evaluate the results of the proposed model, simulations of cases applied in three cattle ranching properties are presented, located in the northwest of the state of Sao Paulo, are presented. For the simulations, we used a website (Web application) developed specifically to address the economic feasibility of implementing biodigesters.

Keywords: Biodigesters, Genetic Algorithm, Linear Programming.

1 INTRODUCTION

Electricity consumption has been increasing for a long time in Brazil and in the world on a large scale, while the number of energy sources for supply to demand has been growing at slow pace, despite the various options of energy sources, such as renewable energy sources: photovoltaics, wind and biogas. (TOLMASQUIM, 2007).

Considering the technologies of renewable energy sources for the supply of the demand for electricity and the use of this potential, biotechnology presents itself with a relevant role with regard to the development of new strategies and techniques to provide the development of innovative solutions in the generation of electricity, both from the economic and ecological views.

From the perspective of biotechnology, biogas is seen as a promising method, an alternative technology for the production of electric energy, because it is based on the combustion of methane, which makes this source of resource attractive both from the economic and environmental point of view, because it is a clean energy and has ease of obtaining. In addition, its use can replace other fossil fuels, such as wood for example (COSTA, 2002).

According to the scenario of some countries, with regard to the production of animal waste for biogas production, Brazil is a country that has a large number of livestock breeding, allowing the use of these animals' waste in the production of biogas, used for the production of electricity. In addition, the proper management of these residues constitutes a sanitary, ecological and economic need. Sanitary because waste can harm the health of animals and man, both inside and outside the property. Ecological, because the residues, rich in organic matter and nutrient, cause pollution and imbalance in the natural environment. And finally, economical because waste treatment involves equipment, material and labor resources, which outlast the production system and may even make it impossible (HARDOIM, 2000).

For the implementation of biogas projects and programs, even if it is on a small scale, it is necessary to take into account the economic, political, ecological and cost-benefit conditions from the point of view of the beneficiary and the region of the implementation of these projects. To obtain a good yield, the consideration of these factors becomes necessary (DOTTO, 2012). The biggest obstacle for rural properties to deploy biodigesters is related to ignorance, as many homeowners when analyzing the initial price of the facility are not aware that this investment will return in a short time.

In the literature, there are studies that deal with the problem of the installation of biodigesters as an alternative source for the production of electricity, of which we can mention the work of involved by Guares (2021), which deals with a technical-economic model to evaluate the use of bovine manure in biodigesters for the generation of electric energy and biofertilizers. The work is divided into two phases: technical and economic. In the technical phase, the relevant aspects of the process were investigated, such as raw material (type and quantity), the influence of external temperature, the hydraulic retention time of the system, the amount of energy generated and the reduction of energy costs. In the economic phase, investment projects (IPs) were classified in the Net Present Value (LPV) criterion by applying the Multi-Index Methodology Expanded deterministic (EMIM) in investments projects with positive LPV. Finally, the IPs with high sensitivity were analyzed by Monte Carlo Simulation. The model was valid in a rural property in southeastern Paraná, Brazil. Energy production in the evaluated systems presented economic advantages.

In Oliveira (2021) there is a model to estimate and optimize the energy potential of animal manure and sewage in small and medium-sized properties. For this, a mathematical model was developed capable of estimating and optimizing the allocation of energy potential, from animal waste and sewage. To achieve this goal, a deterministic constructive algorithm coupled with nonlinear model parameters was implemented. The results showed a robust, efficient and adaptable model and that the prospect of investment in renewable energy by a rural producer is dependent on the knowledge he has on the subject and what he consumes on his property. In montoro's (2017) work, a model is used to analyze the economic and financial viability of the use of the biodigester in the confinement of cattle for cutting, which presents a mathematical model to size the biodigester and evaluate the economic viability of its implantation.

Finally, Calza's (2015) work presents a model for evaluating the costs of implementing biodigesters and the energy produced by biogas. To this end, the costs of producing energy from biogas produced by goat, cattle and pig waste for semi-confinement systems were determined. Rural properties with 20 were used; 40; 60; 80 and 100 animals from each of the three groups evaluated. From the volume of waste produced per animal, the biodigesters were sized and the costs for the construction and implementation of each model were calculated, and the total cost of annual energy production according to the number of animals. A practical calculation method was presented for the adequate dimensioning of the biodigester capacity, considering the daily load of organic matter placed in the digester and the retention time. The costs of implementing the biodigesters according to their capacity were evaluated for three models of biodigesters: Indian, Chinese and Canadian.

Unlike the studies mentioned above, this work presents a business model, which evaluates the cost-benefit of the implementation of biodigesters in rural farms of dairy cattle through a *Web Site*, developed specifically for this purpose. The *Website* is named *SocioEnergy*. The mathematical model para evaluate the cost-benefit of the implementation of biodigesters is a linear programming model (PL). To find the proposals of solutions, the model uses as a solution technique a genetic algorithm (GA) (GLOVER, 2003). Each solution proposal is evaluated through a function that considers the difference between the profits and the costs of the implementation of the biodigester system.

To evaluate the proposed model, we present tests of results generated from the *SocioEnergy Web Site*, applied in three cattle farms located in the northwest of the state of São Paulo.

2 MATHEMATICAL MODEL

The proposed mathematical model of linear optimization is represented by equations from (1) to (12). The objective of the model is to analyze the economic feasibility of the implementation of biodigesters in rural properties. In this case, the objective function (equation 1) seeks to maximize net income with the implantation of the biodigester, obeying the restrictions of the problem, from the equations from (8) to (12). In the calculation of costs are considered the following variables, in quantity: cattle heads, confinement hours and necessary employees on the property.

$$Max \quad RL \tag{1}$$

$$RL = RT - CT \tag{2}$$

$$RT = (R_{leite} + R_{biod} + R_{biof}) \cdot x \tag{3}$$

$$R_{leite} = V_{leite} \cdot Q_{leite} \cdot D_{mes} \tag{4}$$

$$R_{biod} = \left(\left(\frac{H_{conf} \cdot Q_{dejet} \cdot D_{mes}}{Q_{dejbio}} \right) \cdot Q_{kwh} \right) \cdot V_{kwh} \tag{5}$$

$$R_{biof} = \left(Q_{dejet} \cdot P_{decomp}\right) \cdot V_{fert} \tag{6}$$

$$CT = G_e + \left(C_f \cdot x\right) + C_{ger} + C_{biod} + C_{lag} \tag{7}$$

$$\left(C_f + C_a + C_{mi} + C_{ger} + C_{biod} + C_{lag}\right) \cdot x \leq O_{manut} \tag{8}$$

$$\left(\left(P_c + C_i + C_b + C_l\right) \cdot x + C_g\right) - \left(P_c \cdot Q_{gad}\right) \leq I_i \tag{9}$$

$$E_p \geq E_g \tag{10}$$

$$\left(\left(\frac{H_{conf} \cdot Q_{dejet} \cdot D_{mes}}{Q_{dejbio}}\right) \cdot Q_{kwh}\right) \cdot x = E_p \tag{11}$$

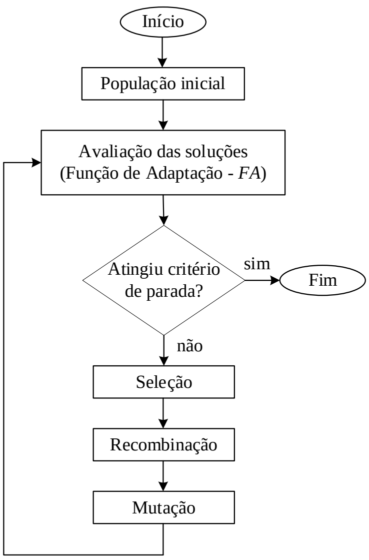
$$x \geq 0, \qquad \forall\, x \in N \tag{12}$$

in which: it is net income; is the total income; is the total cost; represents the number of head of cattle; is the income from the sale of milk; the income generated by the biodigester; income from biofertilizer; the value of the sale of the litre of milk; the quantity of milk produced per head of cattle; $\boldsymbol{RLRTCTxR_{leite}R_{biod}R_{biof}V_{leite}Q_{leite}D_{mes}}$ the number of days in the month; $\boldsymbol{H_{conf}}$ the amount of hours that cattle are left in confinement; the amount of waste produced per month; the amount of waste required to produce 1m3$\boldsymbol{Q_{dejet}Q_{dejbio}}^{\text{of}}$ biogas; the amount of kWh that each m3$\boldsymbol{Q_{kWh}}$ of bovine biogas can generate; the amount charged by the operator per kWh; is the remaining percentage of matter; : biofertilizer value; energy expenditure; employee spending; the cost of maintaining the generator; is the cost of maintaining the biodigester; it is cost of maintaining the pond; are the expenses with the feeding of cattle; are the costs of maintaining the facilities of confined cattle; is the budget available for maintenance; is the price of the head of cattle; is the cost of installing the confinement; is the cost per m$\boldsymbol{V_{kWh}P_{decomp}V_{fert}G_eC_fC_{ger}C_{biod}C_{lag}C_aC_{mi}O_{manut}P_cC_iC_b}^{3\text{ of}}$ the biodigester; is the cost of the pond; is the cost of the generator per kW; is the amount of cattle already existing on the property; is initial investment; is the energy produced; is the energy expended by the property.$\boldsymbol{C_lC_gQ_{gad}I_iE_pE_g}$

3 SOLUTION TECHNIQUE

The proposed linear optimization model to solve the problem and find possible solutions uses as a solution technique a genetic algorithm (GA) dedicated to the problem. The basic principles of GA can be studied in Glover (2003). Figure 1 illustrates the operation of the MA. The particularities of the GA, adapted to the problem to evaluate the feasibility of the implementation of biodigesters as an electric power source in rural properties, are described below.

Figure 1. Operation of the AG.



Source: The Author.
Translation:
Start
Initial Population
Evaluation of solutions
Did you reach the stopping criterion? yes, END
Selection
recombination
Mutation

3.1 CODING SYSTEM AND INITIAL POPULATION

The vector that represents each individual (chromosome) of the population is formed by three plots, which considers:

- Amount of cattle (P1): the amount of cattle considers a 50% variation for more and for less of the reported value.
- Number of confinement hours (P2): The amount of confinement hours considers a 10% change for more and less than the reported value.
- Number of employees (P3): The number of employees considers a 50% change for more and less than the reported value.

Each individual *i* of the population is then randomly generated, considering the variation in % of the data provided by the owner of the place where the biodigester will be installed, thus forming the initial population. Figure 2 illustrates the example of a *population with n* vectors representing the individuals of the population, with the following data provided by the owner:

- Cattle quantity (P1): 30
- Number of hours (P2): 10
- Number of employees (P3): 2

Figure 2. Representation of the coding system and initial population.

P1	P2	P3	
25	9	2	*i*=1
41	10	1	*i*=2
33	11	3	*i*=3
	. . .		
30	10	1	*i*=*n*

Source: The Author.

3.2 ADAPTATION FUNCTION

Each individual of the population is evaluated through an adaptation function (FA) (equation 13 and 14) that considers the objective function plus the penalty of violated restrictions, represented by equations from (15) to (17).

$$Max \quad FA \tag{13}$$

$$FA = RL - \left(P_{cm} \cdot F_1 + P_{in} \cdot F_2 + P_{energ} \cdot F_3\right) \tag{14}$$

$$P_{cm} \begin{cases} se\ C_{manut} \leq O_{manut} \rightarrow P_{cm} = 0 \\ se\ C_{manut} > O_{manut} \rightarrow P_{cm} = C_{manut} - O_{manut} \end{cases} \tag{15}$$

$$P_{in} \begin{cases} se\ C_{inv} \leq I_I \rightarrow P_{in} = 0 \\ se\ C_{inv} > I_I \rightarrow P_{in} = C_{inv} - I_I \end{cases} \tag{16}$$

$$P_{energ} \begin{cases} se\ E_p \geq E_g \rightarrow P_{energ} = 0 \\ se\ E_P < E_g \rightarrow P_{energ} = E_g - E_P \end{cases} \tag{17}$$

where: P_{cm} is the penalty of the maintenance cost; P_{in} is the penalty of the cost of investment; P_{energ} is the penalization of energy; C_{manut} is the cost of maintenance; C_{inv} is the cost of investment.

According to equations from (15) to (17), if any restriction is violated, the function FA is penalized and its value is decreased. Otherwise, $FA = RL$. The variables F_1, F_2 and F_3, are penalty factors, whose values are defined according to the problem and through simulations.

3.3 SELECTION

The selection of individuals who will participate in the recombination process is made through the tournament technique, as follows:

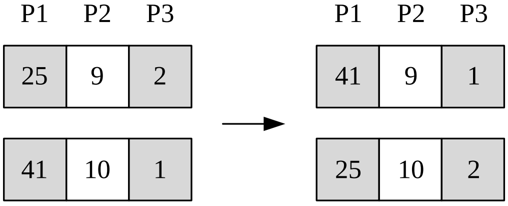
1. Games are *not held* , being *not the size* of the population.
2. andm each game are randomly selected *k different settings* of the current population, being *k* equal to 3.
3. andm then generate a random number (FS) between 0 and 1.
   - if $FS \leq 0{,}75$, one chooses the best of the three individuals who will make up the pair of individuals who will recombine.
   - sand $FS > 0{,}75$, one chooses the worst of the three individuals who will make up the pair that will recombine. Isto means that the chance of getting the most adapted individual is over 75%."
4. You generate the pairs. In this case, the same individual can recombine several times, which cannot be choose an individual to recombine with himself.

3.4 RECOMBINATION

In the recombination process, the pairs of individuals (chromosomes) chosen in the selection process may recombine. In this case, to have the recombination the chromosomes are submitted to the recombination operator (). The recombination consists of the exchange between the portions of these individuals, thus generating two new descendants that will make up the new population. Figure 3 illustrates an example of how the recombination process occurs. The recombination process works as follows:$f_r P$

1. for each portion of the chromosome, Pa random number () is generated between 0 and 1.TR
   - if $\rightarrow$ recombine$TR \leq f_r$
   - if $\rightarrow$ keep$TR > f_r$

Figure 3. Recombination process.



Source: The Author.

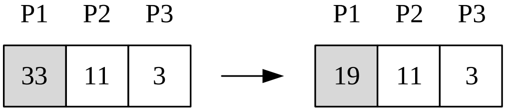
According to Figure 3, plots P1 and P2 were t rotated between chromosome pairs, thus generating two new chromosomes that will form the new population and will go through the mutation process.

3.5 MUTATION

After recombination, the chromosomes of the population are subject to mutation. For the mutation to occur the chromosomes are subjected to mutation rate (). The mutation process consists of changing the information of each portion of the chromosome at random and respecting the established limits, as described in subsection 3.1. Figure 4 illustrates an example of the mutation process. The mutation process works as follows:$f_m P$

1. for each portion of the chromosome,Pa random number () between 0 and 1 is generated.TM
   - if $\rightarrow$ mutation$TM \leq f_m$
   - if $\rightarrow$ keep$TM > f_m$

Figure 4. Mutation process.



Source: The Author.

According to Figure 4, plot P1 mutated, generating a change in the chromosome. After the mutation process, you can have a modified population that will be evaluated again.

3.6 STOP CRITERION

The adopted stop criterion is to evaluate the improvement of the solution during a certain *number of n* iterations. Thus, if during a certain number *of iteration n* the solution does not improve, the process is considered converged.

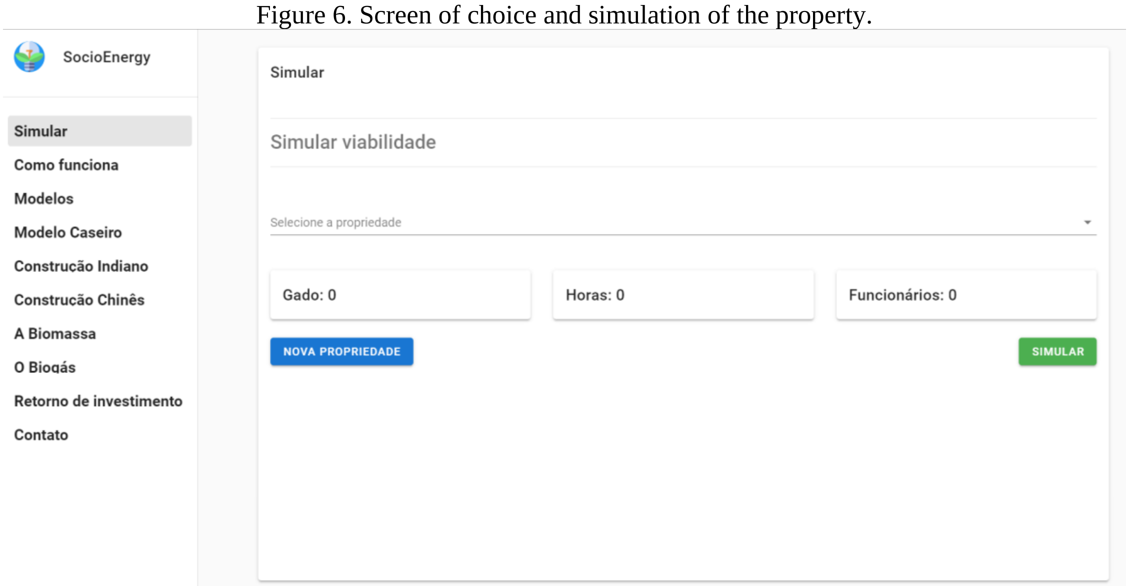
4 WEB APPLICATION TO EVALUATE THE FEASIBILITY OF IMPLEMENTING BIODIGESTERS

To promote the evaluation of the feasibility of the implementation of biodigesters in rural farms of dairy cattle, the model was implemented as a website named *SocioEnergy*. The *SocioEnergy* website was developed using the hp *p programming language* (NIEDERAUER, 2011; CONVERSE, 2033) with *laravel framework* (STAUFFER, 2017; BEAN, 2015) and *Javascript* (FLANAGAN, 2013) with *Vue framework* (INCAU, 2017). It is an interface of easy application, containing the following interfaces: 1) registration of properties; 2) choose the propertyto be simulata and perform dthe simulation; 3) presentation of the results. Figures 5 to 7 illustrates the interfaces of registration of properties, choice and simulation of the property and results generated, respectively. It should be pointed out that *the SocioEnergy Web Site* is not yet available on the Internet.

Figure 5. Properties registration screen.

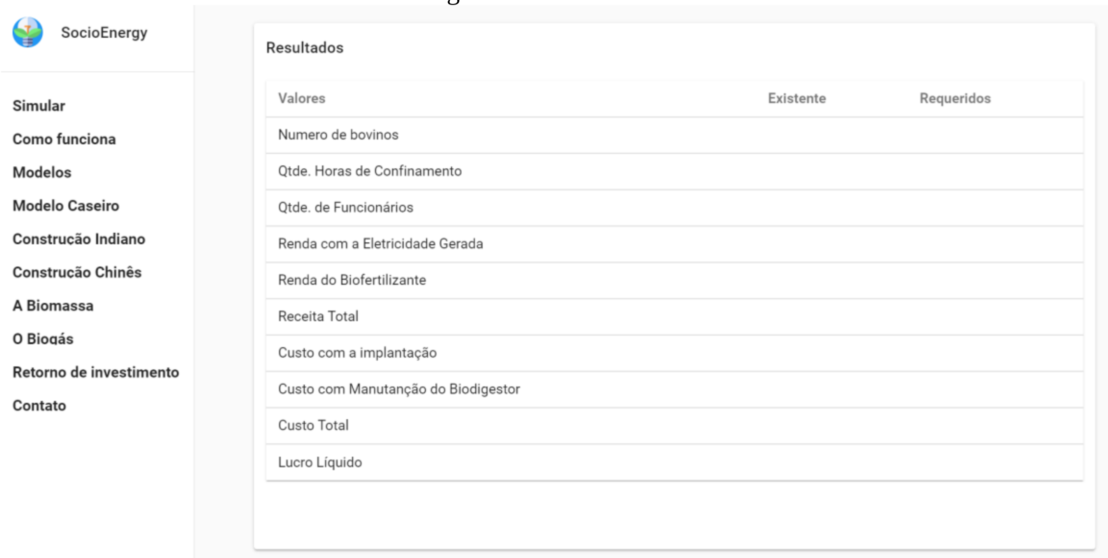
Source: The Author.

Figure 6. Screen of choice and simulation of the property.



Source: The Author.

Figure 7. Results screen.



Source: The Author.

5 RESULTS AND DISCUSSIONS

For the evaluation of the proposed model, simulations were made in three rural properties located in the northwest of the state of São Paulo: the São Joaquim farm, in the municipality of Araçatuba, which sells Milk Honey Type A and Type A Light milk and also the butter class A Milk Mel, the São Sebastião farm, located in the municipality of Santo Antônio do Aracanguá, which markets Type B milk and the Vendrame Site, located in the municipality of Piacatú.

In order to perform the calculation of the analysis of the implementation of the biodigester, it is necessary that the owner informs some data about the property. Table 1 illustrates the property data and Table 2 shows the cost data used in the simulations.

Table 1 - Property data.

Data	São Joaquim Farm	São Sebastião Farm	Place Vendrame
Quant. of confinement hours	15	15	15
Quant. of cattle heads	170	70	45
Food expenditure (R$)	21726	8946	5751
Price of cattle head	2500	2500	2500
Liter of milk per head of cattle	12	12	12
Price of the liter	3,9	3,9	3,9
Quant. of employees	4	4	3
Total employee spend	6103,32	6103,32	4577,49
Energy expenditures	5026,77	2500	6632
Kwh value	0,41	0,41	0,41
Maintenance budget	35000	20000	20000
Installed power in Kw	20	20	20
Quant. liters of milk per head of cattle (month)	360	360	360

Source: The Author.

Table 2. Cost data.

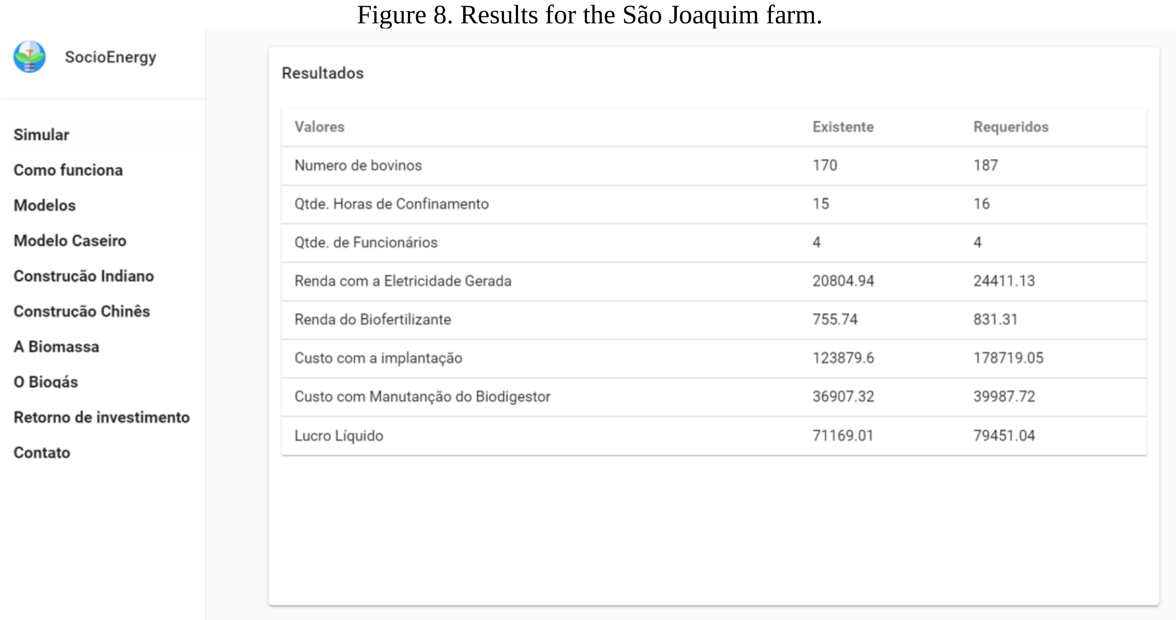
Description	Costs (R$)
Price of a liter of milk	3,90
Price of liter of biofertilizer	0,017
Cost of installation of feedlot per head of cattle	410,50
Cost of biodigester per head of cattle, per m³	260,20
Cost of pond per head of cattle, per m³	55,15
Generator cost, per kW	485,10
Cost of maintaining the generator	8% of generator value
Cost of maintenance of biodigester, pond and confined cattle facilities	2% of the value of the installation

Source: The Author.

The simulations were made using the site developed to evaluate the feasibility of the implementation of biodigesters. Figures 8 and 9 illustrate the results for the São Joaquim and São Sebastião farms, respectively, and Figure 10 illustrates the results for the Vendrame Site.

For the São Joaquim farm, as can be seen in Figure 8, to maximize the net income of the property, it will be necessary to increase the amount of cattle, from 170 to 187 and also increase 1 hour of confinement, from 15 to 16 hours and maintain the amount of 4 employees, thus increasing the net income from R$ 71169.01 to R$ 79451.04.

Figure 8. Results for the São Joaquim farm.



Source: The Author.

For the São Sebastião farm, as can be seen in Figure 9, to maximize the net income of the property, it will also be necessary to increase the amount of cattle, from 70 to 77 and also increase 1 hour of confinement, from 15 to 16 hours and decrease 1 employee, from 4 to 3 employees. Thus, net income will go from R$ 25415.03 to R$ 30593.64.

Figure 9. Results for the São Sebastião farm.

Valores	Existente	Requeridos
Numero de bovinos	70	77
Qtde. Horas de Confinamento	15	16
Qtde. de Funcionários	4	4
Renda com a Eletricidade Gerada	8566.74	10051.64
Renda do Biofertilizante	311.19	342.3
Custo com a implantação	51294.6	73875.55
Custo com Manutanção do Biodigestor	18787.32	20055.72
Lucro Líquido	25415.03	30593.64

Source: The Author.

For the Vendrame site, as can be seen in Figure 10, to maximize the net income of the property, it will also be necessary to increase the amount of cattle heads, from 45 to 49 and also increase 1 hour of confinement, from 15 to 16 hours and maintain the amount of 3 employees. Thus, net income goes from R$ 8509.62 to R$ 10797.88.

Figure 10. Results for vendrame.

Valores	Existente	Requeridos
Numero de bovinos	45	49
Qtde. Horas de Confinamento	15	16
Qtde. de Funcionários	3	3
Renda com a Eletricidade Gerada	5507.19	6396.5
Renda do Biofertilizante	200.05	217.83
Custo com a implantação	33148.35	46051.75
Custo com Manutanção do Biodigestor	12731.49	13456.29
Lucro Líquido	8509.62	10797.88

Source: The author.

6 CONCLUSIONS

The work presents a linear programming model (PL) to evaluate the feasibility of the implantation of biodigesters in rural farms of dairy cattle. To solve the problem and find viable solutions, a genetic algorithm (GA) adapted to the problem is used as a solution technique.

According to the results, the model implemented as a *Web Site* using as a solution technique the AG, proved to be efficient in the search for solutions, indicating the best data / parameters so that the implementation of biodigesters in properties is feasible.

We also highlight the contribution of the proposed model in relation to the importance of the use of biodigesters in rural properties for energy generation and consequently collaboration in the reduction of polluting gases in the environment.

Finally, it is emphasized that the model proposed and implemented as a *Web Site is useful*, easy to apply in the analysis of the implementation of biodigesters in rural dairy farms, and can also be extended to beef cattle and other animals.

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