Software That Assists the Analysis of the Economic Viability of the Installation of Biodigesters in Rural Properties Destined for Milking

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Abstract: The economic development and disorderly population growth, coupled with the modern society’s lifestyle, are complex processes that share a common denominator: the availability of an adequate and reliable supply of energy. An alternative is sustainable development through alternative sources of energy, such as solar energy, wind energy and biomass. In both the international and domestic markets, biomass is considered one of the main alternatives for the diversification of the energy matrix and the consequent reduction of dependence on fossil fuels. The objective of this work is to develop a linear programming model that helps in the decision making as to the feasibility of the implantation of biodigesters for the production of biogas in rural properties destined for milking. In order to solve the proposed model, the classic simplex method was implemented, in the Java programming language with the aim of obtaining results that can be used to support decision making.

Key words: Renewable energy, biogas, bioenergy.

1. Introduction

In Brazil, in recent years, there has been an increase in the consumption of electric energy. This increase is due to the industrial development and the increase of the purchasing power of the population. In contrast there were no significant investments in electricity generation. About 80% of the electricity consumed in Brazil comes from hydroelectric plants, whose potential in the more developed regions of the country is practically depleted. The great hydroelectric potential of Brazil is concentrated in the North, where the predominant relief is lowland and the ecosystem is fragile. With this, there is great difficulty in using this potential [1].

Faced with this energy problem the research on alternative sources of energy has been taking up increasing space in the scientific community. As for example, wind, solar and biogas energy, derived from biomass biodigestion that is defined as any material that has the property of decomposing by biological effect, i.e. by the action of different types of bacteria.

It should be noted that biomass is one of the sources for energy production with the greatest potential for growth in the coming years. Both internationally and domestically, it is considered one of the main alternatives for the diversification of the energy matrix and the consequent reduction of dependence on fossil fuels. From it, it is possible to obtain electricity and biofuel, such as biodiesel and ethanol, whose consumption is increasing in substitution of petroleum derivatives such as diesel and gasoline [2].

In order to exploit the biomass, biodigesters are used, basically consisting of a closed chamber in which the biomass is fermented anaerobically. The process of
anaerobic biodigestion is one of the alternatives used for the treatment of residues, because it reduces the potential of contamination, produces biogas and allows the use of the waste as biofertilizers. Its use in rural properties for biogas production is in increasing expansion, because its construction is relatively simple.

Biogas can be used both as a fuel for generating thermal energy in boilers and stoves, and for generating electricity, which represents an increase in income for the rural producer, who can invest in other parts of his property [3].

It is important to point out that an energy source exerts influence in several aspects. The most latent is the economic aspect, but the political, social and environmental aspects must be taken into account.

However, the process of implantation of the biodigesters must result from the analysis obtained through the comparison of the economic variables, natural and social observed on the property and therefore we must carry out a careful investigation of the potentialities and limitations within each rural setting and must carry out, therefore a careful work of investigation of the potentialities and limitations within each rural setting.

Due to the great advancement of technologies in the programming areas, the implementation of mathematical models to represent or interpret reality in a simplified way has become increasingly feasible. The model has its reliability by means of its validation in the representation of the real system; which it is representing. The difference between the real solution and the solution proposed by the model depends directly on the accuracy of the model in describing the original behavior of the system, considering the maximum number of variables that influence the analysis.

In the last years, the research in mathematical models seeks to relate the variables that influence the biogas production in different types of biodigesters using pork manure as raw material [4-6].

Until then, the great majority of the authors propose models for the implantation of biodigesters without using the tool of the operational research for economic viability analysis [7-10].

The greatest obstacle for such properties to implant the biodigester is related to knowledge. There are not always qualified people, or even financial resources on the part of the owners to do this analysis. By analyzing the initial price of the deployment, they may end up creating a barrier without being aware that this investment will return in a short time.

With this in mind, we propose to develop a mathematical model using the tool of the operational research that can be used in several rural properties destined to cattle and, together, a software that facilitates and makes accessible the economic viability analysis of the installation of a biodigester.

The use of manure from dairy cattle as a raw material for biodigesters is an interesting option because the cattle before being milked remain in an area that usually has its surface covered with cement. This area has to be constantly washed, so one of the components necessary for biodigestion is included in the process which is the water used to clean the stable. In this way the waste is sent to the interior of the biodigester through channels for the processing of the anaerobic biodigestion. After fermentation of organic matter in the biodigester, we have the biogas and biofertilizer. To transform the produced biogas into electrical energy, a generator-motor set is used, coupled to an electric power generator. Thus, through the combustion of biogas by the engine, the generator turns the biogas into electric energy [11].

2. Mathematical Model

The model proposed in the paper can be described as a standard linear programming problem:

\[ \text{MAX } RL = RT - CT \]

On what:

\[ RT = (R_{\text{lote}} + R_{\text{biod}} + R_{\text{bio}l}) \cdot x \]

\[ R_{\text{lote}} = V_{\text{lote}} \cdot Q_{\text{lote}} \]
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\[
R_{\text{biod}} = \left( \left( H_{\text{conf}} \cdot Q_{\text{dejet}} \cdot D_{\text{mes}} \right) / Q_{\text{dejobio}} \right) \cdot Q_{\text{kwh}}
\]
\[
R_{\text{biof}} = \left( Q_{\text{dejet}} \cdot P_{\text{decomp}} \right) \cdot V_{\text{fert}}
\]
\[
CT = G_e + (C_f \cdot x) + C_{ger} + C_{\text{biod}} + C_{lag}
\]
subject to:
\[
\left( C_f + C_a + C_{mi} + C_{ger} + C_{\text{biod}} + C_{lag} \right) \cdot x \leq O_{\text{manut}}
\]
\[
\left( P_c + C_i + C_b + C_f \right) \cdot x + C_g \leq I_i
\]
\[
E_p \geq E_g
\]
\[
\left( \left( Q_{\text{dejet}} \cdot H_{\text{conf}} \cdot D_{\text{mes}} \right) / Q_{\text{dejobio}} \right) \cdot Q_{\text{kwh}} \cdot x = E_p
\]
\[
x \geq 0, x \in N
\]

Being: RL: liquid income; RT: total income; CT: total cost; x: number of heads of livestock; \(R_{\text{leite}}\): income from the sale of milk; \(R_{\text{biod}}\): income generated by the biodigester; \(R_{\text{biof}}\): income from the biofertilizer; \(V_{\text{leite}}\): value of the sale of the liter of milk; \(Q_{\text{leite}}\): quantity of liters of milk produced per head of cattle; \(H_{\text{conf}}\): number of hours that cattle are kept in confinement; \(Q_{\text{dejet}}\): amount of waste produced per month, second the amount of waste produced per hour is on average 1,046 kg [12]; \(Q_{\text{kwh}}\): amount of kWh that each m³ of bovine biogas can generate, which is equivalent to 6.5 kWh according to Ref. [1]; \(V_{\text{kwh}}\): value charged by the operator per kWh; \(P_{\text{decomp}}\): remaining percentage of matter, this percentage is between 10% and 20% of loss of matter [13], the fixed value of 0.85 was used; \(V_{\text{fert}}\): value of the biofertilizer, can vary greatly from region to region, in partnership with Ref. [14], estimated the value of $0.065 per liter of biofertilizer; \(G_e\): spent with energy; \(C_f\): employee expenses; \(C_{ger}\): cost of generator maintenance, according to the company [14], the annual expenses represent 8% of the value of the generator. The annual expenses \(C_{\text{biod}}\), \(C_{\text{lag}}\) and \(C_{\text{mi}}\), together represent the equivalent of 2% of the value of the installation; \(C_{\text{lag}}\): biodigester maintenance cost; \(C_{\text{mi}}\): maintenance cost of the pond; \(C_z\): costs of feeding cattle; \(C_{\text{mi}}\): expenditure on the maintenance of the premises of the confined cattle; \(O_{\text{manut}}\): budget available for maintenance; \(P_c\): cattle head price; \(C_i\): cost of the installation of the confinement per head of livestock, $168.80 [15]; \(C_{\text{lag}}\): cost per m³ of the biodigester per head of cattle, $109.40 [1]; \(C_{\text{mi}}\): cost of the pond per head of cattle, $23.17 [14]; \(C_g\): generator cost per kW, $203.90 [1]; \(Q_{\text{gad}}\): amount of livestock already in the property; \(I_i\): initial investment, considering a margin of error of 10%; \(E_p\): produced energy; \(E_g\): energy spent by the property; \(D_{\text{dejobio}}\): necessary quantity of waste to produce 1 m³ of biogas, according to Ref. [1] it is equivalent to 25 kg.

After solving the system that is represented by the constraints of the model, the computational program will obtain the optimal value of head of cattle and will calculate the total income, total costs, net income and expenses with the implantation and maintenance. If the amount of livestock on the property is greater than or equal to the calculated optimum quantity, then the implantation of the biodigester on the property is already viable, and it is not necessary to buy more livestock.

3. Materials and Methods

The proposed solution to solve the problem of the feasibility of implantation of biodigesters in rural properties intended for milking is approached through the simplex method and implemented in the Java programming language. Fig. 1 presents the initial screen of the software and Fig. 2 presents dates entry.

3.1 Simplex Method

The simplex method was developed in 1947 by George B. Dantzig. It is an algorithm that makes use of a tool based on linear algebra to determine, by an iterative method, the optimal solution of a linear programming problem. The optimal solution of the model is a basic solution of the system, that is, an extreme point the polygon generated by the constraints.

To be started it is necessary to know a basic compatible solution (initial solution) of the system, that is, one of the points of the generated polygon. The
simplex method verifies that the present solution is optimal. If it is, the process is closed. If it is not optimal, it is because one of the adjacent points provides a better value for the objective function than the current one. In this case, the simplex method then changes the point by another that best optimizes the value of the objective function and verifies if this new point is optimal. The process ends when you get an endpoint where all other endpoints provide worse values for the objective function [16, 17].

3.2 Java Programming Language

When it was created by Sun Microsystems, the main goal of this was to be a language for consumer electronics, which means that it should be compact and architecture neutral. Although it has not been very
The computational program presented the following result: the amount of cattle needed to maximize the profitability with the implantation of the biodigester in the property would be 148 cattle, thus generating an implantation cost of $34,304.36; a maintenance cost of $1,909.60; a profit of $2,599.80 in generated electric energy and $361.26 with biofertilizer produced. Even with the costs it is observed that the net income of the property will be $15,855.86. With the amount of existing cattle, which is 170, the owner will have a deployment cost of $39,435.60; a maintenance cost of $2,195.24; a profit of R $2,988.66 in electricity generated and $415.30 with biofertilizer produced. In this case, it is observed that the net income of the property will be $18,577.93, as can be seen in Fig. 3.

Test 2: Using the data from Farm X, mentioned in Table 1.

The results obtained from Fazenda X data showed that the property will need to buy 4 heads of cattle to maximize its income with the implantation of the biodigester, that is, it needs to have 74 heads of cattle, thus generating a cost of implantation of $72,350.65; a maintenance cost of $960.58; a profit of $1,307.77 in electric energy generated and $181,72 with biofertilizer produced. The net income of the property will be $7,113.80. The results with the amount of cattle existing, that is of 70, showed that, the property will have a

### Table 1  Property data.

<table>
<thead>
<tr>
<th>Data</th>
<th>Farm São Joaquim</th>
<th>Farm X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount hours of confinement</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Amount of livestock</td>
<td>170</td>
<td>70</td>
</tr>
<tr>
<td>Food expenditure ($)</td>
<td>10,067.65</td>
<td>4,145.50</td>
</tr>
<tr>
<td>Price of cattle head ($)</td>
<td>1,158.48</td>
<td>1,158.48</td>
</tr>
<tr>
<td>Liter of milk per head of cattle (L)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Price of the liter ($)</td>
<td>0.37</td>
<td>0.37</td>
</tr>
<tr>
<td>Amount of employees</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total expenditure on employees ($)</td>
<td>1,390.18</td>
<td>1,390.18</td>
</tr>
<tr>
<td>Energy expenditures ($)</td>
<td>2,329.37</td>
<td>2,329.37</td>
</tr>
<tr>
<td>Value of Kwh ($)</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Budget for maintenance ($)</td>
<td>16,218.72</td>
<td>9,267.84</td>
</tr>
<tr>
<td>Power installed in kW</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Source: author.
cost of implantation of $68,082.91; a maintenance cost of $903.92; a profit of R $1,230.63 in electric energy generated and $171.00 with biofertilizer produced. In this case, it can be observed that the net income of the property is $6,625.10, as can be seen in Fig. 4.

5. Conclusion

Based on the simulations, the validation of the proposed mathematical model can be verified, since the cost with the implementation compared to the net income shows the viability of the project under the economic-financial approach. However, when considering the environmental benefit provided by the project the favorable decision of the enterprise is reinforced.

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References


