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Biogas, friendly and sustainable energy for small producers: Cost analysis for a rural farm

Telly Yarita Macías Zambrano[1], Tanya Beatriz Bravo Mero[2], Teresa Viviana Moreira Vera[3]
Jorge Velepucha Sánchez[4], Antonio Vázquez Pérez[,5,6]

[1] Instituto Superior Tecnológico Paulo Emilio Macías, Portoviejo, Manabí, Ecuador
[234]Universidad Técnica de Manabí, Portoviejo, Manabí, Ecuador
[56]Universidad de Alicante, Alicante, España

[1]itspem.tmacias@gmail.com, [2]tanya. bravo@utm.edu.ec, [3]teresa.moreira@utm.edu.ec
[4]jorge.velepucha@utm.edu.ec, [5]antonio.vazquez@utm.edu.ec

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Abstract

The study refers to biogas as a form of sustainable energy production for small agricultural producers, having as its central objective the design and budget of a biogas generation system for a rural property, through a practical methodology on the farm With the biomass produced by guinea pig farming and peanut cultivation, applying a cost analysis of implementing a biodigester, it was possible to determine the volume, temperature, pressure and calorific value of the biogas obtained from the biodigestion process, and consequently for the generation of electrical energy for lighting a chicken coop; The unit costs of the biogas generation system were analyzed and the total costs were determined, having an advantage for the small producer in terms of system costs compared to those offered in the market, managing to be in the short-term bankable range, considering the quality materials of the system.

Introduction

Although renewable energies have been used for several decades, especially in rural areas where the lack of electrical energy for its various uses has been felt, which has meant that to meet this need the peasant must use fuels such as Diesel to light your home, to run irrigation motors and pumps used daily in agriculture (Alexander & Boyle, 2014), climate change, peak (or zenith) oil and energy security are global trends that are beginning to set the pace of the energy transition required to supply the growing world energy demand while abandoning that which has been the main source of energy to date: fossil fuels (Castro, 2011). Faced with this challenge, renewable energy source technologies are receiving strong incentives and development stimuli at a global level (Kammen, 2014). This has allowed several of them to become competitive against traditional energy generation alternatives and begin to have a commercial deployment and use (WEC, 2010).

In Ecuador, the last 25 years of investment in renewable energy sources have constituted a practical and environmentally friendly alternative, especially in the current times when the planet is going through severe climatic changes that particularly affect agricultural fields and ecosystems in general, allowing cost reductions in values of 40% in technologies related to biomass, 70% in geothermal energy and 90% in wind, solar photovoltaic and solar thermal energy. It is considered that for these technologies to have the potential to be used in Ecuador, they are in the deployment and commercialization phase (Peláez & Espinoza, 2015).

In the country, so much biomass is potentially produced in the agricultural sector, a great technical potential for the production of biogas in rural areas, being an opportunity for the diversification of the energy matrix, which depends on the hydrothermal system (Soria & Carvajal, 2016), as contemplated in the Ecuadorian mother legislation, art. 43 that promotes the search for alternatives to diversify renewable energy sources to reduce the consumption of fossil fuels (Constituent Assembly, 2008).

Some projects at the country level have been reported, especially as an investigation by official bodies, thus the project conceived by the public company of the municipality of Quito with the private company works to use 2000 tons of garbage from the sanitary landfill in a generation plant of electrical energy from the biogas captured in the landfill and connected to the national energy network, which consists of 3 generators with a production of 40 MW / day that benefit 20,000 families in suburban neighborhoods (Metropolitan Public Company of Comprehensive Management Solid Waste EMGIRS - EP, 2016).

For their part, institutions such as CTCN-CIMNE-IIGE-INIAP promote the National Biodigester Program, as part of the public policy of energy sustainability (Martí, et al., 2018), which encouraged the use of all types of biomass and waste, whether urban such as household and industrial, or rural such as agricultural, livestock and agro-industrial, providing technical assistance to the beneficiaries, based on the sustainable assurance of a nascent technological sector of biodigesters that take advantage of the biomass potential generated by the agricultural production in Ecuador (Beegroup, 2017).

The study of (Martí, 2019) at the level of experiences in Latin America with the use of biodigesters for the generation of biogas as a source of primary energy from renewable sources, sustainable and focused as a contribution to the Ecuadorian energy reality (Vera, et al. , 2017), emphasizes the resilience of small agricultural production systems to climate change based on minimizing dependence on supplies that the farm cannot produce, but is based on what it can produce, giving added value to its agricultural production.

For this group of producers, the current conception of a productive and sustainable farm that tends to the use of alternative energy sources that contribute to the integrality of the farm, making better use of the organic waste generated by agricultural production for the benefit of the farm as such (Macías T., et al., 2021) may be far from reality, since traditional agricultural farms dedicated to the production of varied crops, raising cattle and pigs, and poultry, generate daily a certain volume of organic waste such as litter, stems, fallen, dry and wet fruits, manure from cattle, pigs, poultry, etc. that constitute an obstacle for the farmer in terms of time and money, since the way in which residues have been managed within the farm is with stacking and burning (Carreño, Rodríguez, Macías, Ormaza, & Lozano, 2020).

In this sense, the scarce use of the natural resources that are possessed, which implies endemic flora (shrubs, herbs, etc.) and production waste (litter, various vegetable fibers, livestock manure, poultry manure, etc.), which are stacked to be subsequently burned, consequently causing contamination to the environment, constitutes one of the most frequent limitations that occurs at the level of rural farms, (Macías, Bravo, Palma, & Giler, 2020). The participation of families in the daily activities of the farm is essential to maximize the productivity of the farm and minimize production costs, since the payment of day laborers represents a large percentage of the income that can be obtained from the sale of agricultural products, limiting the fact of moving towards a more sustainable farm from the social, economic and environmental point of view; tending also to affect the well-being and productive capacity of the land of the farm (Macías, Rodríguez, Moreira, Mera, & Bravo, 2020).

Therefore, to take advantage of all the waste that is generated within the farm, it is necessary to use renewable energy sources, such as the generation of biogas from all the biomass collected. Thus, the present work aims to design and budget a self-sustaining biogas generation system for small farmers producing agricultural properties in rural areas, taking as a reference a beekeeping and agricultural farm, with which a sustainable alternative is provided to farmers. farmers and farmers, as a way of using renewable energies that promote a more environmentally friendly conscience, as well as contributing to the reduction of costs for the use of electrical energy.

Materials and methods

An experimental research was carried out, based on bibliographic reviews and desk research, the qualitative and quantitative method was used for the analysis of the information; It was based on the use of the local resource obtained from the residuals of domestic productions, the materials used for construction were plastics, pipes, among others.

Analysis and discussion of the results

The study was carried out at the Mis 2 Principitos farm, located in the El Limón Commune, Portoviejo canton, Manabí province, Ecuador, with a rainfall of 800 mm, 90% relative humidity, temperature between 20-32 ^{or}C depending on the winter or summer season

The farm studied is dedicated to beekeeping and agroculture, it has an apiary made up of 40 bee hives of the species (*apis melífera*), a small meliponiary of melipon bees (*meliponini*), long cycle crops such as coconut palm (*Cocos nucifera*), banana (*musa paradiasiaca*), lemon (*citrus limon*), stick beans (*Cajanus cajan*), fruit trees such as mango (*mangifera indica*), currant (*Phyllanthus acidus*), guava (*Psidium guajava L.*), custard apple (Annona squamosa;L.,), pomegranate (*Punica granatum; L.*), passion fruit (*Passiflora edulis*), a family garden of vegetables and legumes, raising poultry such as chickens, ducks and pigeons, pigs and guinea pigs. In figure 1, its geographical location is observed.

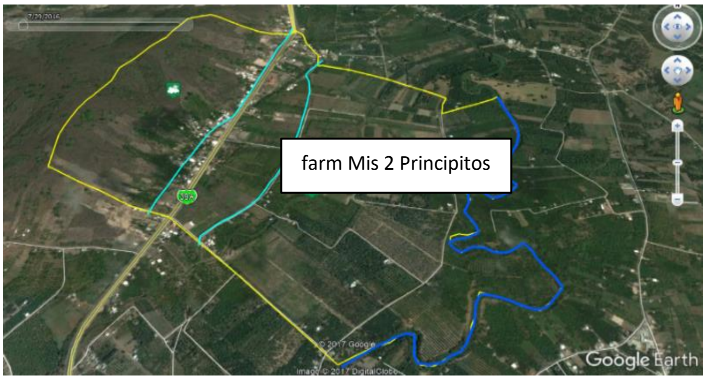

Figure 1. Location of the farm

Source: Google Earth

To take advantage of the residuals from agricultural productions, a biodigester was designed, this will help to improve the living conditions of the owners of the farm, in addition to introducing a utility energy for support energy sustainability.

Installation of the system

The assembly of the system was carried out by means of PVC pipe connections, which go from the biodigester tank to the gasometer, a pressure gauge is placed in the biodigester that indicates the pressure generated in the tank and a valve to discharge the biogas towards the gasometer when required, that is when the pressure of 1.01972 Kg f / cm^2 is reached; in the same way, a manometer and a second valve are placed on the gasometer to release the biogas to the generator set that will supply electrical energy to the farm's hen house.

Biodigester

To feed the biodigester, the selected biomass of peanut husk and guinea pig manure was used, in the proportions of 12.64 Kg of excreta, 19 Kg of vegetable fiber and 0.1 m^3 of water, considering that the biodigester is fed with this biomass approximately up to 50% of its capacity, this is 0.1 m^3, table 1 shows in detail the proportions of biomass used in the biodigester:

Table 1. Biomass used

Biomass	Quantity	Unit
Guinea pig manure	19.00	Kg
Peanut	shell 12.64	Kg
Water	0.1	m^3

A daily monitoring of the production of the system was carried out, on day two the reading of the data such as temperature and pressure begins, these are entered into the Excel spreadsheet that automatically shows the daily biogas volume when the biodigester has been discharged to the gasometer. Table 2 shows the details of the data entered.

Table 2. Data entered into the spreadsheet

Data	Value	SI unit
Diameter 1 = D1	0.57	m
Diameter 2 = D2	0	m
Gauge pressure 1 = Pman1	0.421842	Kg f / cm^2
Gauge pressure 2 = Pman2	0	Kg f / cm^2
Length 1 = L1	0.89	M
Length 2 = L2	0	M
Temperature 1 = T1	30	° C
Temperature 2 = T2	30	° C
Gas(constant)	flow16.043	Methane
Molar mass 1 = m1	0.20659	Kg m
Molar mass 2 = m2	0.146697	Kg m
Volume 1 = V1	0.227425	m^3
Volume 2 = V2	0.227425	m^3
Pressure = P = ρ	0.717	Kg /m^3
volume1	Biogas0.288131	m^3

Calculation of the volume of biogas generated by the system

To calculate the volume of biogas that is generated daily in the biodigester, the universal gas equation (1) is used, clearing the mass to be able to calculate it (2).

$$PV = mRT \qquad (1)$$

$$m = \frac{PV}{RT} \qquad (2)$$

To apply this formula, you must know the values of the absolute pressure, the volume, the absolute temperature and the constant of the methane gas in order to know the value of the mass, from In such a way that the absolute pressure expressed in Kgf / cm^2 is calculated by adding the gauge pressure and the atmospheric pressure, according to equation (3).

$$Pabs = Pman + Patm \qquad (3)$$

When the temperature reading is taken in the biodigester with the thermometer, it must be transformed from ° C to ° K, to be able to replace it in the mass formula, using equation (4).

$$T = {}^\circ C + 273.15 = {}^\circ K \qquad (4)$$

For the calculation of the biodigester volume, equation (5) is used.

$$V = \frac{\pi D^2}{2} L \qquad (5)$$

The gas constant R is calculated by dividing between the universal gas constant R_u and the molar mass of the methane gas, which is expressed in Kgf m / Kg ºK, shown in equation 6.

$$R = \frac{Ru}{m} \qquad (6)$$

With the calculated gas volume, pressure, temperature and constant values, we proceed to apply equation (7) cleared of the molar mass.

$$m = \frac{PV}{RT} \qquad (7)$$

$$m = 0.20659\ Kg\ m$$

Finally, the volume of biogas generated within the biodigester is calculated using equation (8).

$$V = \frac{m}{\rho} \qquad (8)$$

The values used are reflected in table 3.

Table 3. Calculation of biogas generated

Data	Value	Unit (SI)
Molar mass = m	0.20659	Kg m
Pressure = ρ	0.717	Kg / m^3
Biogas volume = V	0, 288131	m^3

During the subsequent days, the daily temperature and pressure readings generated by the biodigester continued to be read in order to enter these data into the spreadsheet and obtain the daily gas volume. When the pressure reached 1.01972 Kg f / cm^2 in the biodigester, the valve was opened to release the biogas to the gasometer, this procedure was repeated every day until the pressure gauge no longer showed pressure, which means that all the gas was It is stored inside the gasometer.

Biogas test

In a plate of 10 saving bulbs of 9 Watts, they were connected to know the energy consumption, being able to determine that 0.25 m^3 of biogas were used to ignite the 10 saving bulbs, reaching a total ignition time of 1.02 minutes.

Use of biogas on the farm

To use the gas that is stored in the gasometer, the valve located at the gas outlet is opened, this is led through a pipe to the generator set connected to the electrical system of the farm's hen house that It has two 60 Watt saving bulbs.

As a result of the implementation of a biogas generation system on the farm, the volume of total biogas generated and the economic analysis are graphically available.

Volume of biogas generated by the system

In table 4 you can see the measurements of variables such as temperature, pressure and volume in a time of 32 days of the biogas generation system in which a mixture of 19 Kg of manure of guinea pig, 12.64 kg of peanut husk and 0.0001 m^3 of water in a 2.5 m^3 capacity biodigester tank. It can be seen that the generation of biogas began on day two and from then on until day 32, a total of 5.95 m^3 of biogas was generated, observing the days with the highest production.

Table 4. Total volume of biogas generated by the system

Day	Temperature (ºC)	Pressure (Kg /m^3)	Volume (m^3)
2	28	5.5	0.28303697
4	51	11.1	0.35216312
7	29	1.9	0.23181495
8	59	4	0.23756097
14	59	4.3	0.24137293
16	58	4.5	0.2446508
17	58	4.3	0.2704998
18	44	6.9	0.28871919
20	46	15.1	0.39402511
21	46	8.2	0.3014564
23	72	12	0.32643677
25	31	10.5	0.34962664
31	38	20	0.47062004
		V biogas	**5.95420129**

As can be seen in the table, the days that a greater volume of biogas was generated were on day 4 with a volume of 0.35m^3, on day 20 with a volume of 0.39 m^3, on day 23 with a volume of 0.33 m^3, on day 25 with a volume of 0.35 m^3 and on day 31 with a volume of 0.47 m^3.

In the graph of figure 2, the curve obtained from the calculation of the daily volume of biogas generated by the system is observed, in which the maximum points reached in terms of the volume generated daily by the system can be clearly appreciated.

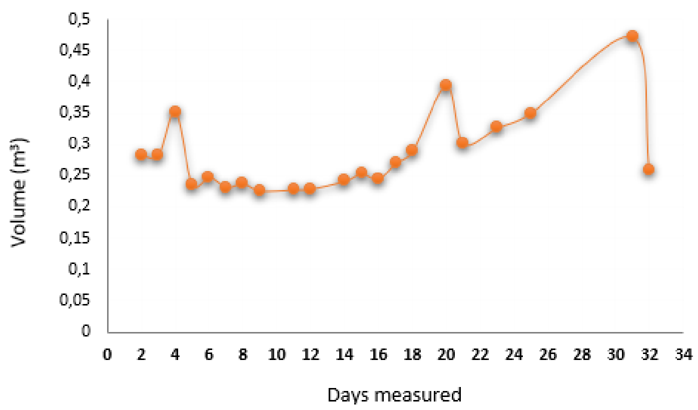

Figure 2. Curve of the volume of biogas generated by the system

The peak volume of biogas production on day 31 can be seen, obtaining an average of 0.19m^3 / day, which reflects a small-scale system that supplies needs such as lighting, cooking, etc., which agrees with what was referred by (Carreño, Rodríguez, Macías, Ormaza, & Lozano, 2020), who indicate that crops such as rice are producers of biomass in Manabí that can be used to become biofuels and biogas to generate heat, electricity and even to cook food. In addition, biomass energy systems are generators of sources of employment and income, helping to improve the living conditions of the people who live in the area and promote rural development (Rodríguez, Macías, Velepucha, Mera, & Cantos, 2020). This is a good consideration to be able to adopt biogas generation systems with low cost in money and in the short term that are more environmentally friendly.

Analysis of unit prices of the system

Table 5 details the unit prices for materials, equipment and labor to carry out the mixing and filling of biomass in the biodigester.

Table 5. Analysis of unit prices of the biogas generation system

Materials	Unit	Quantity A	Unit B	Unit Cost C = A * B	%
Minor tools (% MO)	Global			$ 4.20	0.46
Adapters, elbows, unions, pipes, and various	Global			$ 260.00	28.71
			Partial N	**$ 264.20**	**29.18**
Equipment	Unit	Quantity A	Unit B	Unit Cost C = A * B	
Vacuum pump 8.5 to 9 CFM 3/4 HP	U	1	350	$ 350.00	38.65
Generator 110V - 60HZ 950W AC	U	1	170	$ 170.00	18.77
55 Galmetal drum	U	3	12	$ 36.00	3.98
2500 L PE bottle tank w / kit	U	1	2.6	$ 2.60	0.29
Pressure gauge 0-30 Psi	U	4	11	$ 44.00	4.86
			Partial O	**$ 602.60**	**6.55**
Labor	Quantity A Day	/ Hour B	Cost per hour C = A * B	Unit Cost D = C / R	
Day laborer	1	1.98	$ 1.98	$ 12.38	1.37
			Partial P	**$ 12.38**	**1.37**
Direct costs	Q = (N + O + P)			**$ 879.18Contingencies**	97.09
:	(Q) x	3.00%	$ 26.37		2.91
Total Unit Price				**$ 905.55**	**100.00**

Budget for the implementation of the biogas generation system

The installation and assembly of the biogas generation system is calculated based on the 10% reference that a technician charges to start up an electromechanical system, shown in the table 6.

Table 6. Budget for the implementation of the biogas generation system

	Description	Value	%	Cost
1	Installation and assembly of biodigester, pressure gauge, connection pipes, feeder tank, vacuum pump, generator.	$ 602.60	10	$ 60.26

Sub Total		$ 60,26
VAT	12	7,23
Discount		7.23
Total		$ 60.26

From the sum of the costs of materials, equipment, labor, installation and assembly, the total investment to implement the biogas generation system on the farm was calculated, which reached $ 965.81, as can see in table 7.

Table 7. Total investment budget in the biogas generation system

Description	Value ($)	%
Cost of investment in materials, equipment and labor	905.55	93.76
Cost of installation and assembly of the system	60.26	6.24
Total system costs	965.81	100.00

However, in the study carried out by the national biodigester program (PNB) sponsored by the CTCN-CIMNE-IIGE-INIAP, the assembly and installation prices of biodigestion systems are high for a small agricultural producer, which depending on the material and volume of biogas production are around $ 1500 the most economical, of plastic material with a capacity of 20 m^3 (Martí, et al., 2018). In this regard, it is necessary to highlight biodigester installation options such as this one, in a personalized way, based on the particular needs of the small producer.

Biogas requirement for lighting the hen house

Table (8) shows the requirement for the lighting of the hen house of the farm that has an area of 30 m^2 and two saving light bulbs of 60 W, for 0.17 hours per day, it needs 1.5 m^3 of biogas in a month or its equivalent to 0.025 m^3 of biogas per day.

Table 8. Energy consumption in the farm poultry house

Quantity	Artifact	Power (W)	Ignition time (hrs)	Daily volume of biogas required (m^3)
2	Saving lights	60	0.17	0.025

The results obtained show that the volume of biogas obtained, is used for lighting the farm's hen house that has 2 energy-saving light bulbs and a motion sensor, in accordance with what is expressed in the manual of the (FAO, 2011), which states that in those places where fuels are scarce, small biogas systems can also be used for lighting. Likewise, the manual of the (OLADE, 2014), establishes that in the southern countries of America work is being done on obtaining biogas with plant residues, which were part of the biomass (rice and peanuts) used in this study mixed with manure. of animals (guinea pig) to accelerate the fermentation process of the biomass in the biodigester and the generation of biogas.

Attending to the energy needs of an agricultural farm such as the farm model studied, and in order to help minimize the problems encountered in the management of organic waste from the planting and harvesting of banana and coconut, a renewable energy system was designed and budgeted in the farm understood as the production of biogas from guinea pig manure biomass and peanut husks, using a 2.5 m^3 gasometer and a 0.0002 m^3 capacity biodigester, whose total cost of the system amounted to USD $ 657, 54. The volume of biogas obtained was 6m^3 in the test. To carry out the installation of this system on the farm with the exclusive purpose of lighting a 30 m^2 chicken coop that has 2 energy-saving lights and a motion sensor; a generation of 3.75 m^3 of biogas per day is required; In addition, the maintenance of the system is simple, once the small producer has been trained in its use and proper handling.

Conclusions

The biogas generation system is one of the most suitable to implement on a farm as a source of renewable energy, due to considerations such as: the disposal of organic waste to feed the biodigester, the ease of execution of the feeding tasks of the system, the savings in labor payment, the savings in the purchase of chemical inputs to eliminate weeds, the low investment amount for the implementation of the system.

The small producer is able to handle the feeding of the biodigester tank, not having to handle safety mechanisms to extract the biogas from the gasometer and lead it to the generator set that will feed bioenergy to the chicken coop's electrical system, since this installation is part of the system to produce energy.

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