Mathematical model for an energy mixed system as technological alternative in the electric power supply in not interconnected areas

Case study, use of electrical generators from the production of biogas originated from porcine garbage in San Antonio of Tequendama Cundinamarca, during 2016/2017.

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Abstract

This article final product is a mathematical model from an Energy Mixed System (EMS) using Biogas – Electrical Energy (B-EE) from residual biomass from porcine garbage is developed through a Case Study conducted in San Antonio del Tequendama, Cundinamarca, Colombia. This research reports the relations among carbon – nitrogen (C; N), temperature and PH levels in regards to the total or partial capacity of charging in an organic way; and the relations between the nominal potency and the consumption of residential electric power regarding the generator as variables for the ideal operation of the biodigester. The study standardizes a 2.84 "Chorizo" biodigester for six (6) hogs with a charge of 1:30 relation C: N, a temperature between 18 and 24 °C; implementing a 6.8 and 7.2 intermission of PH. In order to give a potency of 2 KW to a generator that works with this biogas, for a consumption of 0. 55 m ^ 3 h, to be able to guarantee 2kwh in a farm sustainable and auto sufficient.

keywords: Bio digester, Biogas, Mixed energy system, Electric generator.

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Introduction

Colombia is divided in departments; the department of Cundinamarca is divided in provinces and those in lanes. For the development of this project, the study was carried out in the province of Tequendama, in the municipally of San Antonio del Tequendama, located to 56 km by the South Este of Bogotá D.C. at an altitude of 1600 masl; with an average temperature of 26 °C, a relative moisture of 64% and a few agricultural porcine systems. In this area, a large number of farms cope with the lack of electrical energy supply and belong to the low percentage which are not supplied by the SIN (National Immediate Service in English); electrical energy serves as a basis for the production and settlement of human needs, for that reason it requires solutions. The project works with an only case study in the municipally described already where the rate for families dedicated to performing is high, the implementation and use of bio digesters had been developed as an energy solution taking advantage of porcine garbage in different farms. Considering this context, the article provides a sustainable solution based on a mixed model to produce electrical energy.

The research conducted is a descriptive and interpretative Case Study. It was carried out in the farm Villaletty. Letty Rodríguez, the owner, explains the sequential process developed. It included a situational diagnosis, an in-depth explanation about the use and exploitation of biogas in this technological alternative; this mathematical model determines the manure and gas production based on the amount of pigs available in the farm and the autonomy of a conventional generator that works properly by the appliance of the biogas.

Problem statement

The development of a project based on a EMS with B-EE, that works using porcine organic matter, is framed by an electrical technological initiative through the supplement of Biogas into a biodigester. Having in mind that some rural sectors are not interconnected areas, but the productivity, sustainability and development level requirements for this communities should be motivated under certain ideal conditions of the current resources.

Therefore, the core problem for this project aims to mold mathematically a EMS with B-EE, as an energy alternative for the farm in mention, which later the results can be generalized. The variables for this model, the referential framework and the algorithmic equations allows the research to stablish the relationships between two main concepts about generation; both of biogas and electrical energy for independent farms with porcine organic matter or charge; it should contain the ability to supply biogas to an electrical energy generator during a determined period of time depending on any residence power charge in general.

Objectives

General objective

The main objective of this article is to mold mathematically the functioning of an EMS as proper technology for not interconnected rural areas; including productive porcine systems that work with B-EE production. This research is a one-case study.

Specific objectives

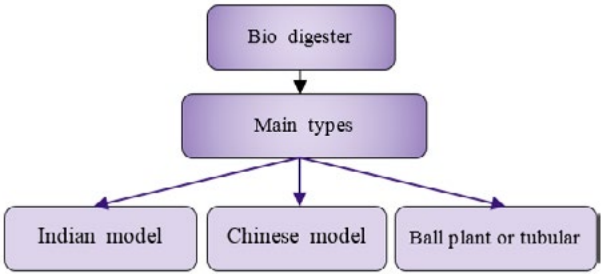
- To describe the proper operation of a biodigester from the production system of biogas characterizing the variables of the model.
- To typify the current electrical energy generator allowing the use of porcine biogas as fuel defining the variables of the model.
- To build up the suitable setting between the theoretical and experimental variables affording the definition of an optimization model in the production of biogas and electrical energy with the ideal standards for generalizing this case study.

Referential framework

¿What is a Biodigester?

A biodigester is a deposit or tank utterly seal (hermetic) where the organic substances (animal, vegetable and even human wastes) are fermented without air exposure to obtain three sub products: biogas, organic compost, and irrigation water. [1]. The main types of biodigester [2], are mentioned next. (See Figure 1).

Figura 1. *Main types of bio digesters.*



Fuente. Elaboración propia

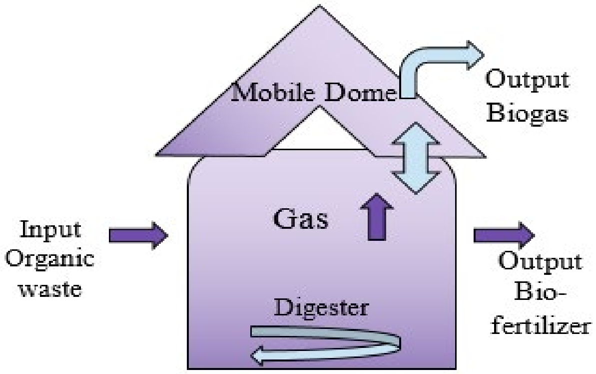
The Indian biodigester (See Figure 2) is made out of a digester constructed out of masonry; or a concrete structure and a bell shape mobile gas tank where it floats directly in the fermentation mass or a water ring, depending on the production of biogas. [2]. In Table 1 it is presented the advantages and disadvantages of the floating bell shape biodigester.

Tabla 1. *Advantages and disadvantages of the Indian model*

Advantages	Disadvantages
Long-Life Masonry	Expensive bell
--	Building materials susceptible to corrosion
--	Periodic maintenance

Fuente. Elaboración propia

Figura 2. *Indian model schemes*



Fuente. Elaboración propia

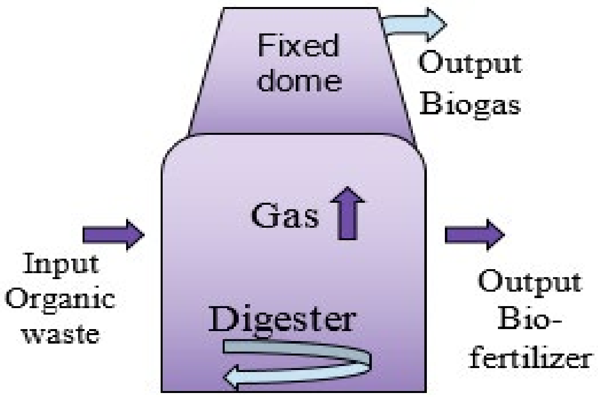
On the other hand, the Chinese biodigester (See Figure 3) consist of a digester buildup of masonry too and, in this case, a permanent dome completely seal where the biogas is store. The gas has to be constantly evacuated to release the pressure generated inside the digester. During the interactions presented in the biodigester, it is observable that the fermentation mass is displaced towards the filler/buffer tank. Once you extract the gas the liquid mass comes back to the biodigester. [2]. In Table 2, the advantages and disadvantages of a fixed bell shape digester are presented.

Table 2. *Advantages and disadvantages of the Chinese model [2].*

Advantages	Disadvantages
Long-life masonary (approximately 20 years old)	Gas pressure is not constant
No metal parts that can be oxidized	--
Low costs because your bell is not made of metal	--

Fuente. Elaboración propia

Figura. 3. *Chinese model scheme.*

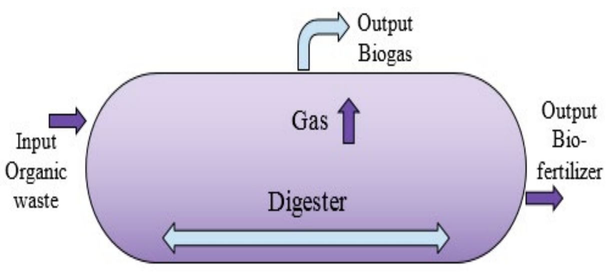


Fuente. Elaboración propia

Finally, the ball or Tubular biodigester (known also as "Chorizo" biodigester) is formed by a plastic tubular (polyethylene, PVC, plastic canvas, etc.) that should be completely sealed; also, the entrance and exit must be grabbed to the plant. This biodigester is suggested for areas with constant temperatures. When The biodigester is in its maximum capacity the tubular's lower fraction contains a 75% from the corresponding volume of the fermentation mass, and its upper fraction contains the remaining 25 % where the biogas is stored (See Figure 4) [2].

Figure 5 correspond to a ball or Tubular biodigester settled in the municipally of San Antonio de Tequendama in VILLA-ALICIA farm. In Table 3 the advantages and disadvantages of a ball or Tubular biodigester are showed.

Figura 4. *Tubular bio digester scheme.*



Fuente. Elaboración propia

Figura 5. *Tubular bio digester built in VILLA-ALICIA (San Antonio del Tequendama).*

Fuente. Elaboración propia

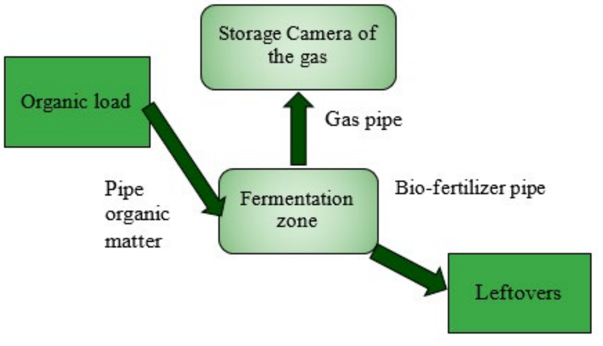
Table 3. *Advantages and disadvantages of the Tubular bio digester [2].*

Advantages	Disadvantages
Easy to transport materials	Gas pressure is low
Simple intallation	Short life
Optimum in areas of the tropics	Materials susceptible to damage
Lower construction and operation costs	--

Fuente. Elaboración propia

The common structure of a biodigester (Figure 6) consist of charge battery where the process starts and the organic wastes are deposited, therefore, through a piping the wastes are putted in a fermentation chamber where the organic decomposition process starts because of the anaerobic bacterium. This structure has two ways out by ducts; one of the ducts leads to the uncharged battery where the bio compost is produced, the other gets to the gas storage chamber (known as reservoir in the case of the Tubular biodigester). [1].

Figura. 6. *General structure of a bio digester.*



Fuente. Elaboración propia

To obtain an ideal operation of the biodigester, it must meet certain conditions related to environmental factors and biodigester structure criteria. In Table 4, the basic ideal conditions to be meet according to the environmental factors are presented.

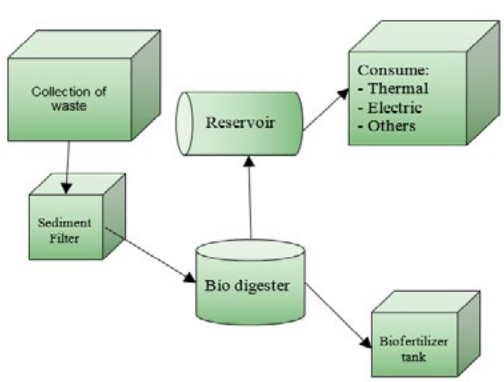
Table 4. *Optimal values that environmental factors must present [2].*

Enviromental factor	Optical Values
PH	Between 6.5 and 7.5
Temperature	0-20 °C ➔ For psychophilic enviroment 0-20 °C ➔ For psychophilic enviroment 0-20 °C ➔ For psychophilic enviroment
Holding time	Retention time depends on temperature
Carbon and nitrogen ratio (C:N)	Ratio of 20:1-30:1
Ammonia	Below the 2000 mg/1

Fuente. Elaboración propia

Talking about the construction of the biodigester, it is necessary to have in mind the amount of organic wastes as well as the biogas production capacity and the physical layout of each one of the biodigester elements. For tropical areas in which Colombia is located, where Cundinamarca is one of the thirty-two departments of the country, the construction of Tubular or ball digesters is a fact. Figure 7 shows the correct layout the Tubular biodigester parts must have to take advantage of the gravitational pull for the organic matter and wastes fluxes; and to leverage the gas pressure produced avoiding the atmospheric pressure affectation.

Figura. 7. *Optimal construction of the tubular biodigester.*



Fuente. Elaboración propia

The resultant gas quality from the anaerobic decomposition phases, given that it comes from different organic wastes sources, has multiple chemical components that are toxic; for that reason, it is necessary to incorporate an output filter to obtain a better and free toxic wastes biogas.

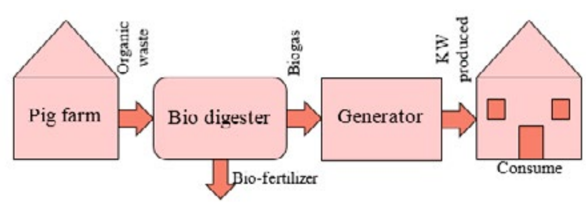
Generators theory

Once the biogas productions have been defined, for the EMS of B-EE model, it is necessary to stablish how the energy production is carried out through the biogas made out of the organic matter.

In power systems, the electrical energy production is carried out through the exploitation of any renewable or nonrenewable source which produces a significantly high difference in the potential while various processes achieve the movement of a synchronous generator; "synchronous machines use to convert mechanical power into electric power AC". [8].

The EMS of B-EE model aimed to develop (See Figure 8) focuses on a rural area in the department of Cundinamarca out of the NIS (National Immediate Service) or without electrical energy supply where the consume of KWh in any residence in the area is inside the average consumed by a residence in general.

Figura. 8. *Scheme of an MES of B-EP.*



Fuente. Elaboración propia

As the generator is feed by the biogas stemming from the biodigester whose charge will come from the known number of pigs wastes and the system is design to provide energy to the residence, the power supplied by the generator could be not very high nominal power as the ones given by conventional commercial generators.

Contextual framework

To develop the EMS of B-EE that works with porcine dregs, three case studies are conducted where the necessary variables are observed during the processes accomplished to transformed the porcine wastes into biomass; from these processes, the data collected stablishes the biogas production, and then, it provides the electrical energy through the range installed charge assumed in any common residence. For this reason, Data from three farms that work as pig farming homestead in the municipally of San Antonio del Tequendama; considering that they have already implemented the "Chorizo" biodigester technology.

Case 1. Farm VILLA-LETTY

The first place where the measuring in regards to the use of "Chorizo" biodigester in pig farming is implemented is the VILLA-LETTY farm (See Figure 9), indicating the collected data on Table 5:

Table 5. *Values obtained on the farm VILLA-LETTY*

Factor	Value
Number of pigs (adult females)	6 units
Average production of animal biomass	13.5 Kg
Temperature	20°C
Reservoir capacity	3m^3 (aprox)
Bio digester capacity	2000 Lts
Pipe diameter (biogas output)	2,4 cm
Biogas combustion time (used for cooking)	3 hours

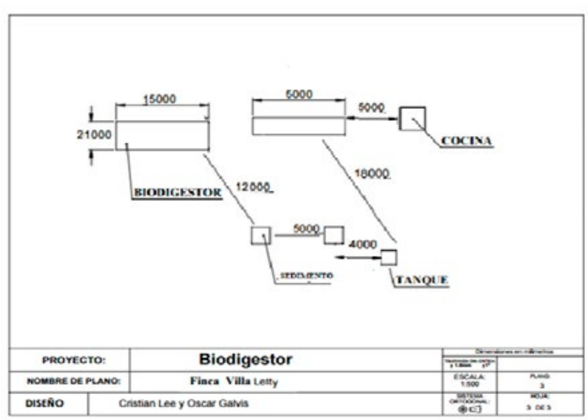
Fuente. Elaboración propia

Figura. 9. *Tubular bio digester implemented in VILLA-LETTY farm.*

Fuente. Elaboración propia

The general disposition of the constitutive elements of the biodigester, as well as the measurement in the mentioned farm, are appreciated in the Figure 10.

Figura. 10. *Location and sizing of the bio digester implemented in the VILLA-LETTY farm.*



Fuente. Elaboración propia

Case 2. Farm EL RECUERDO

The second place where the measuring is conducted is EL RECUERDO farm (See Figure 11), pointing out the values obtained in Table 6:

Table 6. *Values obtained on the farm RECUERDO I.*

Factor	Valor
Number of pigs (adult females)	2 units
Average production of animal biomass	5 Kg
Temperature	20°C
Reservoir capacity	3m^3 (aprox)
Bio digester capacity	2000 Lts
Pipe diameter (biogas output)	0,7 cm
Biogas combustion time (used for cooking)	10 hours

Fuente. Elaboración propia

Figura. 11. *Tubular bio digester implemented in EL RECUERDO farm.*

Fuente. Elaboración propia

Case 3. VILLA-ALICIA. Farm

The las place where the measuring is carried out is VILLA-ALICIA, denoting the data collected in Table 7:

Table 7. *Values obtained on the farm Villa Alicia.*

Factor	Valor
Number of pigs (adult females)	3 units
Average production of animal biomass	7,5 Kg
Temperature	20°C
Reservoir capacity	3m^3 (aprox)
Bio digester capacity	2000 Lts
Pipe diameter (biogas output)	2,2 cm
Biogas combustion time (used for cooking)	2 hours

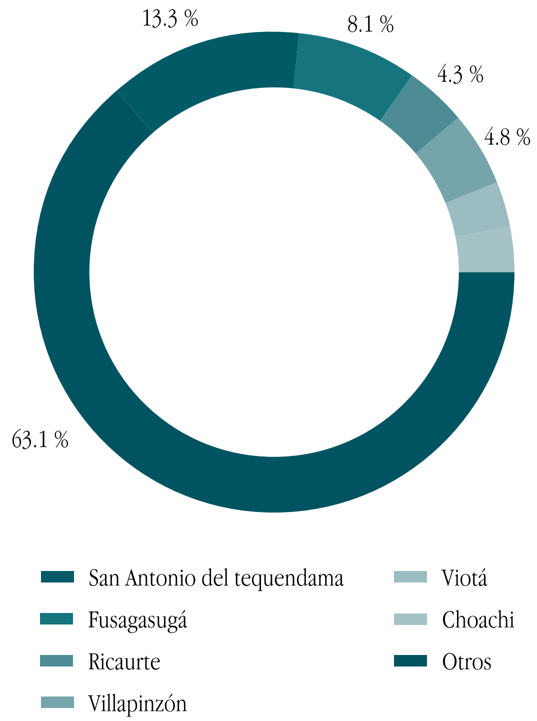
Fuente. Elaboración propia

Cundinamarca and the National Immediate Service (SIN)

In the department of Cundinamarca, the 99,16% out of the territory is constituted by rural areas. [5]. Those areas have renewables resources with a energetical power owing to the agricultural and cattle carried out in the territory, activities that are important to conduct the development of the EMS of B-EE model.

Considering that the rural areas of the are most of the department territory, it is significant the diversity of farming and cattle activities presented in the area. For the development of the model, the organic matter to produce the biogas is produced of organic wastes resulting from the pig farming. In 2012, the department was provided with a porcine population of 784.192 animals where the most of the porcine production had place in the municipalities of "San Antonio del Tequendama (13,3%), Fusagasugá (8,1%), Ricaurte (5,8%), Villa pinzón (4,8%), Viotá (3,6%) y Choachí (3%), respectively (See Figure 12)". [6].

Figura. 12. *Production of pigs by municip alities in Cundinamarca year 2012.*



Fuente. Elaboración propia

The information source considered by the government of Cundinamarca regarding to the subscriptions and the electrical energy consumption are the Empresas de Energía de Cundinamarca S. A. E.S.P. and Codensa S. A. [7]

Even though most of Cundinamarca areas are part of the NIS, there are small percentages from the head of the municipally have electrical service. The previously mentioned areas have pig farming activities, which is a renewable source that can be used for electrical energy production purposes.

Restrictions

The restrictions that the EMS of B-EE presents are determined by technical specifications and environmental conditions of the biodigester and the generator.

Biodigester restrictions:

Environmental Restrictions (See Table 8):

Table 8. *Ranges for requirements in the biogas production. [2]*

Requirements for biogas production	Minimun range	Optimal	Maximun range
Height above sea level	1500	1600	1800
Room temperature	21	32	38
Ratio (C:N)	11	13	25
PH	6.8	7	7.2

Fuente. Elaboración propia

Organic Matter restrictions (porcine wastes) (See Table 9):

Table 9. *Pigs farms, digester size and biogas production.*

Number of pigs	kilograms pigs waste	Digester size [m3]	biogas production [m3/Day]
15	33,75	5	2,2
24	54	9	4
25	56,25	10	4,25
39	87,75	15	7
40	90	16	7,31
83	186,75	29	14,9
85	191,25	30	15
200	450	50	36

Fuente. Elaboración propia

Table 10. *Pig's farms size of the digester and biogas production of farms case study.*

Number of pigs	kilograms pigs waste	Digester size [m3]	biogas production [m3/Day]
2	5	1,43	0,52
23	7,5	2,5	0,65
6	13,5	2,84	1,07

Fuente. Elaboración propia

Building restrictions:

- Elements correct location
- Biodigester and its component suitable sizing
- Biodigester popper working necessary elements

Economical Restrictions:

- Generator installation costs
- Biogas production costs

Generator restrictions:

Technical factors restrictions:

- efficiency
- power
- fuel type
- fuel quantity
- supply time
- frequency
- rated voltage

Results

Mathematical Models

To bring out the mathematical model, the EMS of B-EE considered the equation (1) which corresponds to the annual gas productions from the parameters stablished next. [9]

$$Pb = 365 * n\_s * d\_s * V\_bs \qquad (1)$$

Where:

Pb: Annual biogas production. [m3/year]

n_s: Total amount of pig in the farm [dimensionless]

d_s: Daily waste production per pig [Kg]

V_bs: Biogas volume per kilogram pig waste [m3/Kg]

The equation (2) is used for the daily biogas production.

$$Pb = n\_s * d\_s * V\_bs \qquad (2)$$

Solving the equation (2), the biogas volume per kilogram pig waste corresponding to the equation (3) is obtained.

$$V\_bs = Pb / (n\_s * d\_s) \qquad (3)$$

From Table 9 and 10, a daily biogas production estimation is gathered. Replacing these biogas volume values in equation (3) the volume of biogas per Kg manure (See Table 11) from the information obtained from the bibliography [3] and the case studies presented.

Table 11. *Volume of biogas per Kg pig waste.*

Number of pigs	kilograms pigs waste	Digester size [m3]	Volume of biogas per kilo [m3/Kg]
1	2,25	0,28*	5,19E-03
2	5	0,52	2,16667E-03
3	7,5	0,65	1,20370E-03
6	13,5	1,07	5,50412E-04
15	33,75	2,2	1,81070E-04
24	54	4	1,28601E-04
25	56,25	4,25	1,25926E-04
39	87,75	7	8,52266E-05
40	90	7,31	8,46065E-05
83	186,75	14,9	4,00531E-05
85	191,25	15	3,84468E-05
200	450	36	1,66667E-05

*This value corresponds to [3], page 35.

Once the data has been collected, the EMS of B-EE mathematical model is developed establishing as an input variable the amount of pigs in the farm (), keeping in mind that they are the main source for the biogas production.

Considering Table 9 and 10, through the implementation of the mathematic software MATLAB, an equation for the estimation of porcine manure collected from these values related to equation (4) is found; likewise, equation

(5), which is related to the biogas production depending on the input variable, was obtained

MATLAB software equation for the amount of manure obtained:

$$C_E = (31{,}19 * E - 9)x^4 + (11{,}1 * E - 6)x^3$$
$$-(0.0011x^2 + 2.2124x$$
$$+0.4093 \quad (4)$$

Where:

$\boldsymbol{C_E}$**:** Amount of Manure [Kg]

$\boldsymbol{x}$**:** Number of pigs [dimensionless]

MATLAB software equation for the biogas production:

$$P_B = (134{,}99 * E - 9)x^4 + (43{,}62 * E - 6)x^3$$
$$+(3{,}8 * E - 3)X^2 + 0.0832x$$
$$-0.3525 \quad (5)$$

Where:

$\boldsymbol{P_B}$**:** Biogas production [m3/day]

$\boldsymbol{x}$**:** Number of pigs [dimensionless]

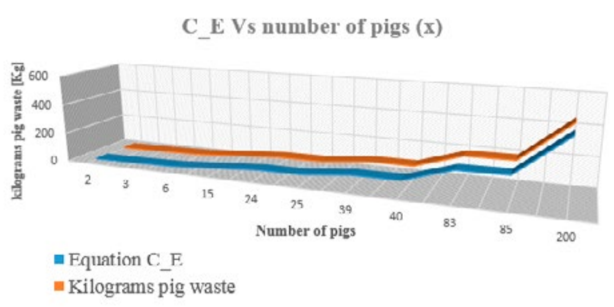
Along with the information gathered from bibliography [3] and the case study farms presented, a comparison test between this information and the data from the equation (4) is made, where the error between these two values is observable.

Table 12. *Test of Equation obtained for the Mathematical Model of Pig Manure Production.*

Number of pigs	kilograms pig waste	Equation C_E with the MATLAB program [Kg]	% Error [%]
1	2,25	2,622788931	0,16
2	5	4,838411699	3,23
3	7,5	7,056102827	5,92
6	13,5	13,72094283	1,64
15	33,75	33,8069167	0,17
24	54	53,99740302	0,00
25	56,25	56,24554766	0,01
39	87,75	87,77972458	0,03
40	90	90,03475664	0,04
83	186,75	186,7499792	0,01
85	191,25	191,2223588	0,01
200	450	447,9997	0,44

Based on the data obtained in Table 12 a graphic comparing the values of the research and the values from the equation (4) of the mathematical model, where it is observable the difference is low; it should be pointed out that the equation is adapted to the research gathered data.

Figura. 13. *Comparison between research data and mathematical equation (4).*

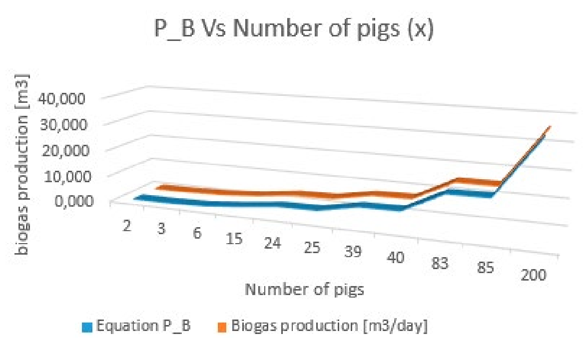


For the biogas production, the amount of pigs and the data from the different farms where the biogas is used is considered [3]. During the analysis, the values in the mathematical equation are replaced in order to guarantee that the calculated mathematical model correspond with the research data. In Table 13, it is presented the error hosted among the research data and the values in equation (5).

Table 13. *Test of the Equation obtained for the Mathematical Model of Biogas Production.*

Number of pigs	Biogas production [m3/day]	Equation P_B with the MATLAB program [m3/day]	% Error [%]
1	0,28	0,439	0,56
2	0,52	0,534	2,64
3	0,65	0,635	2,29
6	1,07	0,979	8,48
15	2,2	2,315	5,23
24	4	3,980	0,50
25	4,25	4,179	1,68
39	7	7,102	1,46
40	7,31	7,314	0,06
83	14,9	14,901	0,01
85	15	15,138	0,92
200	36	36,017	0,05

Figura. *14. Comparison between research data and mathematical equation (5).*



From Table 13, it is developed of the graphic that compares the biogas production data in the different farms with the equation (5) from the mathematical model. In this graphic appears that the equation seems to provide values similar to the ones presented in the information given by the research.

For the exploitation of the biogas, it is necessary to look for conventional generators that could work with this type of fuel, with a nominal power and the known biogas consumption for its operation. Below are the conventional generators selected in which the data is presented.

In Table 14, the minimum of biogas consumption needed to guarantee the nominal power is showed. The EMS of B-EE attempts to give an equation that provides as a result a generators time autonomy, depending on its technical characteristics, regarding the minimum volume of biogas for its functioning and the amount of pigs.

Table 14. *Electric generators operating with biogas as fuel [10].*

Generators	Power [KW]	Biogas consumption [m3 per Kwh]
Generator 1	1,2	0,55-0,65
Generator 2	2	0,55-0,65
Generator 3	2	0,35
Generator 4	1,5	1,03
Generator 5	3,5	2,1
Generator 6	5	3,75
Generator 7	20	0,36

The EMS of B-EE mathematical model in regards to the generator production autonomy is established below:

$$P_E = \frac{P_B}{C_{M_B}} \quad \text{Hours per day} \qquad (6)$$

Where:

P_E: Generator Autonomy [h]

P_B: Daily Biogas Production [m3/day]

C_{MB}: Minimum of Biogas consumption [m3/h]

For example, in the case of VILLA-LETTY farm, it is possible to determine which could be the production of electrical energy in this way:

In VILLA-LETTY farm are an amount () of pigs, equal to six pigs.

Finding the value in equation (5) it is obtained the gas production in the farm:

$$P_B = (134{,}99 * E-9)x^4 + (43{,}62 * E-6)x^3 + (3{,}8 * E-3)X^2 + 0.0832x - 0.3525 \qquad (5)$$

$$P_B = 0.979 \ \frac{m3}{day}$$

Then, the previous value is taken and replaced in the equation (6) in this form, considering that the is determined depending on the generator type (it is selected arbitrarily a value of 0,55 m3):

$$P_E = \frac{Pb}{C_{M_B}} = \frac{0.979}{0.55} = 1.78[\text{Hours per day}] \qquad (10)$$

The conversion (11) is realized to observe how much time the data gather is equal to.

$$P_{ER} = P_E * 60[\text{minutes}] \qquad (11)$$

$$P_{ER} = 1.78 * 60[\text{minutes}] \qquad (12)$$

$$P_{ER} = 106[\text{minutes}] \qquad (12)$$

VILLA-LETTY farm and its amount of pigs cover the generator nominal power for approximately two hours per day.

The EMS of B-EE developed for minimal pig quantities farms do not achieve a considerable autonomy value of the generator; for this reason, to stablish an autonomy of 24 hours (1440 minutes) it is solved the pig quantity needed.

$$P_E = 24[\text{Hours per day}] \qquad (13)$$

$$P_B = P_E * C_{M_B}[\text{Hours per day}] \qquad (14)$$

$$P_B = 24 * 0{,}55[\text{Hours per day}] \qquad (15)$$

$$P_B = 13{,}2[\text{Hours per day}] \qquad (16)$$

Finding (16) in (5) it is given the estimated pig amount value needed in the farm to reach a 24 hours generator autonomy

Conclusions

An alternative for renewable resources production is the biodigester. It reduces the environmental effects which are consequences of fossil fuels use and non-renewable resources exploitation.

In somural areas located in Cundinamarca exist livestock activity in regards to pig farming cattle raising. This fact stimulates the implementation of the biodigester technology having in mind it works through organic porcine wastes selected by its energy potential properties.

Considering that in Cundinamarca many zones practice pig farming, the electrical energy product through biogas as fuel is and viable alternative for electricity issues in those areas.

To provide more efficiency in power generation and optimum use of equipment, it is necessary to stablish rightly the biodigester parameters (dimensioning, load capacity, organic substance, environmental conditions, system distribution, biogas production, among others) as the generator standards (rated power, voltage and rated voltages, fuel type, among others).

The model gathered from the equations can estimate approximately the amount of organic biomass needed to supply a farm during some hours per day, depending on the number of pigs available in the farm and knowing the power to be connected to the generator, having in mind the required parameters by the biodigester to complete its fermentation process, thus, it can deliver the enough biogas so the generator supplies power in regular conditions avoiding an oversizing as in the biodigester as in the biogas stoking tank and, mainly, preventing the generator to work without the biodigester condition.

During the implementation of this paper, the EMS of B-EE flexes to the reality according to the parameters considered in this research.

One consequence of the lack of appropriation of knowledge and wisdoms from communities is that that information could serve as a bridge to the academy to design, develop and implement alternative energies using the organic matter that's is not exploited efficiently.

Analyzing the gathered model through the data from the case studies, an approximately estimation gave the number of pigs needs to offer the wanted autonomy during a period of time to a generator; to achieve it, 6 pigs will be necessary for two hours of generation, 32 for 12 hours and 71 for an all-day supply.

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