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Production of Biogas and Electric Energy in the Rural Environment

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Abstract: Data from the Ministry of Energy and Water indicate that in Angola only 70% of the population has access to electricity, with rural areas being the least covered. The rural environment, however, has local energy resources that, once harnessed, can contribute to solving the problem of electricity production, as an essential asset for the production of goods and an increase in the population's standard of living. The fact that large amounts of cattle, goats, pigs and others are found in rural Angola, particularly in the various agricultural farms, biogas can be an alternative for generating energy in rural areas. The objective of this work is to show the possibility of producing biogas through animal manure to use it as fuel for heat production and for engines and consequently the generation of electricity. Finally, encourage the country to obtain energy through this route. The methodology used was the bibliographic review carried out within the scope of the project “Construction and experimentation of biogas energy installations for rural territories. Case study: Bairro Caimama located in Plantações da Ganda, municipality of Ganda, province of Benguela, Angola”, which served as support for the discussion and even the necessary understanding of the biodigester being a fundamental part for the production of biogas, as well as the elaboration of the final project for the Mechanical Engineering Degree. In the project, necessary calculations are made for the production of biogas from cow manure to later be used to operate the motor-generator, with the possibility of burning the biogas for cooking food. The motor-generator produces electrical energy that would be sent to the local grid for consumption. The operation of the engine-generator with biogas replaces the use of fossil fuels, which in fact represents a very high cost center for the localities. In addition to the high costs of fossil fuels that are reduced to zero with the production of biogas, the production of biofertilizer in this process is also highlighted, which can be used for crops on farms, thus providing greater productivity in the fields and constituting another gain. Thus, the rural environment will solve the problem of waste management using the biodigester and gaining with lower fuel, energy and biofertilizer costs.

Keywords: Cow Manure, Biodigester, Biogas Prodution, Electricity Generation

1. Introduction

The exponential growth of the world population and the increase in energy demand, make oil still the main source of energy in the world; Climate change is one of the most serious problems today. Fossil fuels have been identified as the main responsible for these changes through the intensification of the greenhouse effect, related to the emission of gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The constant crises caused by the fluctuation in the price of a barrel of oil in the international market, the high costs of exploration and purchase of its derivatives, have led the world to an energy transition, which aims to replace oil and, in general, fossil energy sources for renewable energies.

Alternative and renewable energy sources aimed at sustainable development have been developed and used as fuel in the production of heat and electricity, such as wind, solar, biomass and Hydroelectric Power Plants - PCHs [18]. However, renewable energy sources make it less dependent on non-renewable and more polluting sources.

One of the energies that has been taking up more and more space in the context of renewable, clean and viable energies is biomass energy. Biomass is a renewable resource derived from organic materials (animal and plant) that can be decomposed by biological effects by the action of anaerobic bacteria [14].

Anaerobic digestion technology facilitates the decomposition of renewable resources of biomass, inside a closed chamber and in the absence of oxygen, called a biodigester.

In this context, anaerobic digestion can play a key role in order to produce renewable energy in the form of a biogas, which can be used on-site to generate process heat and electricity, as well as to replace conventional fuels. In addition, it allows a controlled stabilization of organic material, reduces greenhouse gas emissions and contributes to the closing of nutrient cycles. Several studies have been developed regarding the production of biogas from industrial waste from slaughterhouses [5, 17, 20], dairy industries [7] and potato processing industries [4].

In the case of Angola, the country has an enviable biodiversity and rich agricultural production in the different provinces, but the modern use of biomass for energy purposes is still incipient. This use can originate a distributed generation of electric energy and supply the energy deficiencies of rural communities and agricultural properties. Distributed electricity generation is decentralized and small-scale production [8].

Organic residues from agricultural and livestock activities are treated inside the biodigester, producing a high quality organic fertilizer and a gas called biogas that can be used for energy production, thus contributing to the generation of income, the reduction of environmental damage and the improvement of the population's quality of life [23].

In this way, the objective of this work is to show the possibility of producing biogas through animal manure and agricultural residues to use it as fuel for heat production and for engines and consequently the generation of electric energy. Also, encourage the country to obtain energy through this route.

This research can assist organizations in the creation and implementation of renewable energy projects according to the amount of waste generated in a locality, particularly in rural areas, which may have a positive impact on the contribution to the mitigation of environmental impacts, if animal waste is not managed, leveraging competitiveness in the electricity production market, thus contributing to an increase in economic production in rural areas, consequently increasing income generation and improving the quality of life of rural populations.

2. Materials and Methods

The proposed study was carried out through a literature review on the topic of Electricity Generation from animal manure and the analysis of the case study of a project developed in the locality of Plantações da Ganda, Caimama district, Ganda municipality, province of Benguela, Angola.

2.1. Biomass

Biomass is any organic matter (animal and plant) that, through its decomposition, can be transformed into mechanical, thermal or electrical energy [24]. Also according to the same authors, biomass energy is renewable and does not increase the emission of CO_2 into the atmosphere, and can be converted into electricity, heat and fuels.

However, biomass is defined as organic matter of animal and plant origin, which, through thermochemical, biochemical and extraction routes, can be converted into heat, electricity and fuels.

The use of biomass as an energy source is not a recent event. The burning of firewood for heating and cooking food was widely used by many societies and, in a more restricted way, can be observed until the present day. However, this practice has always been associated with deforestation, as the extraction of wood for burning was not supported by sustainable production. This picture began to change after the oil crisis in 1970, as biomass came to be seen as a raw material for energy production [12].

Electric energy produced from biomass is an interesting alternative from an environmental point of view compared to energy obtained from conventional processes. Therefore, biomass is one of the sources of energy production with the greatest potential for growth in the coming years, consequently reducing the dependence on fossil fuels.

To be used as energy, it is necessary that the biomass undergoes a conversion process. The main methods used to convert biomass into energy are [9]:

Gasification: conversion of solid biomass sources into gaseous ones through thermochemical reactions. The process is applied to urban and industrial organic waste and wood. The resulting gas can still be filtered to remove the chemical components.

Pyrolysis: also known as carbonization, this process is carried out under high temperatures and without the presence of oxygen. It is commonly applied to firewood and organic residues of agricultural origin. As a product, gases, liquids and solids can be obtained, such as charcoal.

Combustion: in this process the biomass is burned at high temperatures and with the abundant presence of oxygen. In this way, high pressure steam is generated, which is used in boilers or to drive turbines.

Transesterification: transformation of biomass from vegetable oils into intermediate products, such as glycerin and biodiesel.

Anaerobic digestion: occurs in the absence of oxygen. In this process, organic residues undergo decomposition by the action of anaerobic bacteria in biodigesters. As a product, biogas is obtained.

Fermentation: conversion of sugars present in some sources of biomass (sugarcane, corn, beet, among others) into alcohol.

Figure 1 below shows the flowchart of the biomass energy conversion routes.

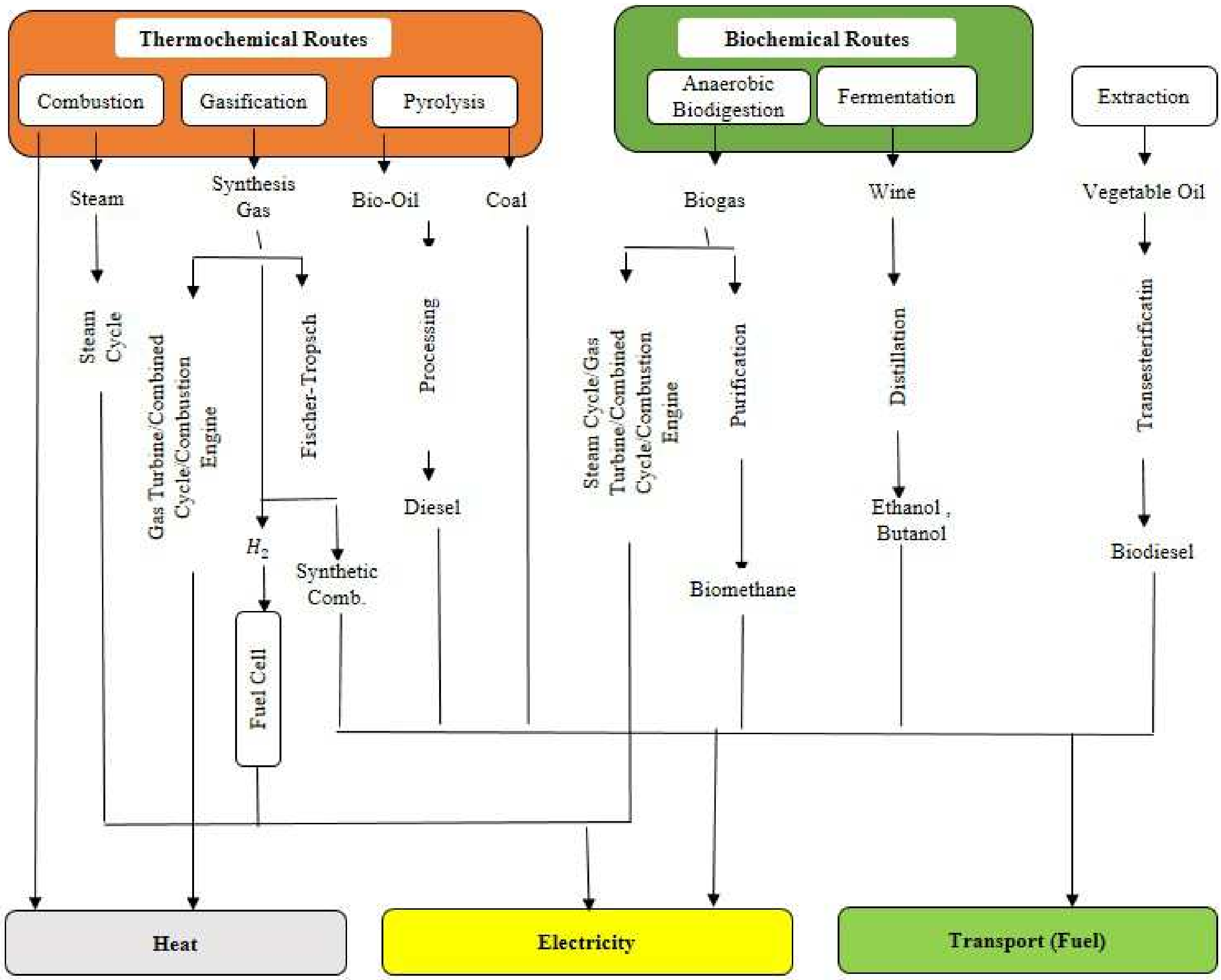

Figure 1. *Simplified representation of biomass energy conversion routes [26].*

The conversion of chemical energy contained in biomass to obtain electricity occurs mainly through technologies that use thermodynamic cycles. Sometimes the biomass source requires pre-treatments, such as evaporation or biodigestion, to be converted into an energy source more suitable for storage or electricity generation" [26].

Electrical energy, also known as electricity, is the most popular form of energy in the world. It is produced through the difference of electric potential between two points of a conductor, which allows the generation of electric currents.

2.2. Biogas

The authors agree in saying that biogas is a gaseous fuel resulting from the anaerobic digestion of organic matter, carried out by a group of microorganisms, and consists of methane (CH_4) and smaller amounts of other gases, such as carbon dioxide (CO_2), hydrogen sulfide (H_2S), water vapor (H_2O), to a lesser extent traces of Nitrogen (N_2) and Hydrogen (H_2), in addition to volatile hydrocarbons [6-22].

Others conceptualize biogas as a combustible gas resulting from the action of anaerobic bacteria on biomass composed mostly of methane that can be used in lamps, stoves, water heaters, absorption system refrigerators and internal combustion engines [11-14].

As it can be analyzed, the authors converge in saying that biogas is a biofuel mainly made up of methane resulting from the anaerobic degradation of organic matter (animal or plant) in a biodigester.

2.3. Biodigester

Biodigester is a closed chamber with its interior protected from contact with atmospheric air, so that all the biomass contained in its interior undergoes the fermentation process through the activity of anaerobic bacteria [11-13].

Others claim that a biodigester is a structure designed so that the degradation of biomass is carried out without contact with the air, providing a reduction in environmental impact and the generation of low-cost fuel [3-8].

The referred authors agree to say that the biodigester is a closed chamber where the biomass is inserted and controlled in order to prevent any entry of air inside for subsequent fermentation and production of biogas.

The biodigester is an equipment that has several functionalities, among them the minimization of environmental impacts caused by the incorrect destination of organic waste, and reuse of waste that would be discarded without adding value.

The biodigester is a viable alternative, since it is an equipment designed according to the amount of waste existing or generated in a locality. Thus, organic residues from agricultural activities are treated inside the biodigester, producing a high quality organic fertilizer and a gas that can be used for energy production, thus contributing to the generation of income, the reduction of environmental damages and the improvement of the population's quality of life [23].

Biodigesters use all kinds of materials that decompose under the action of anaerobic bacteria, but animal waste is considered the best food for them, as they are naturally loaded with anaerobic bacteria [1]. To a certain extent, it motivated the use of animal manure, in the case of pigs, in the biogas production project in a locality.

2.4. Anaerobic Digestion

Anaerobic digestion can be understood as the direct conversion of biomass into a biogas consisting essentially of methane, hydrogen, carbon dioxide and residual amounts of other gases [12].

Most authors describe anaerobic digestion as a process of biological degradation of biomass by bacteria, in the absence of oxygen, producing biogas and biofertilizers. These same authors continue to say that anaerobic digestion is particularly suitable for the use of raw materials with a high moisture content, such as animal waste, sludge from the treatment of sanitary sewage, wet agricultural residues, and organic fraction of municipal solid residues.

Anaerobic digestion also occurs naturally within landfills, which may contain biogas capture and transport systems for the desired purposes.

In reality, it is a dynamic process and there is the interaction of several different microorganisms. Simply put, the process can be divided into four phases [23]:

Hydrolysis: where complex organic residues such as carbohydrates, proteins and lipids are broken down into smaller and simpler particles by hydrolytic bacteria, whose released enzymes break down the material through biochemical reactions.

Acidogenesis: the soluble products of hydrolysis are fermented and acidified, forming organic acids, CO_2, alcohols, etc.

Acetogenesis: Acetogenic bacteria converts the products of acidogenesis into hydrogen, carbon dioxide and acetate. The pH value in the aqueous medium decreases.

Methanogenesis: is the final step, in which methane and carbon dioxide are produced. Such products are generated through methanogenic archaea, which uses organic compounds from the acetogenic phase.

Figure 2 below presents the stages of the anaerobic digestion process.

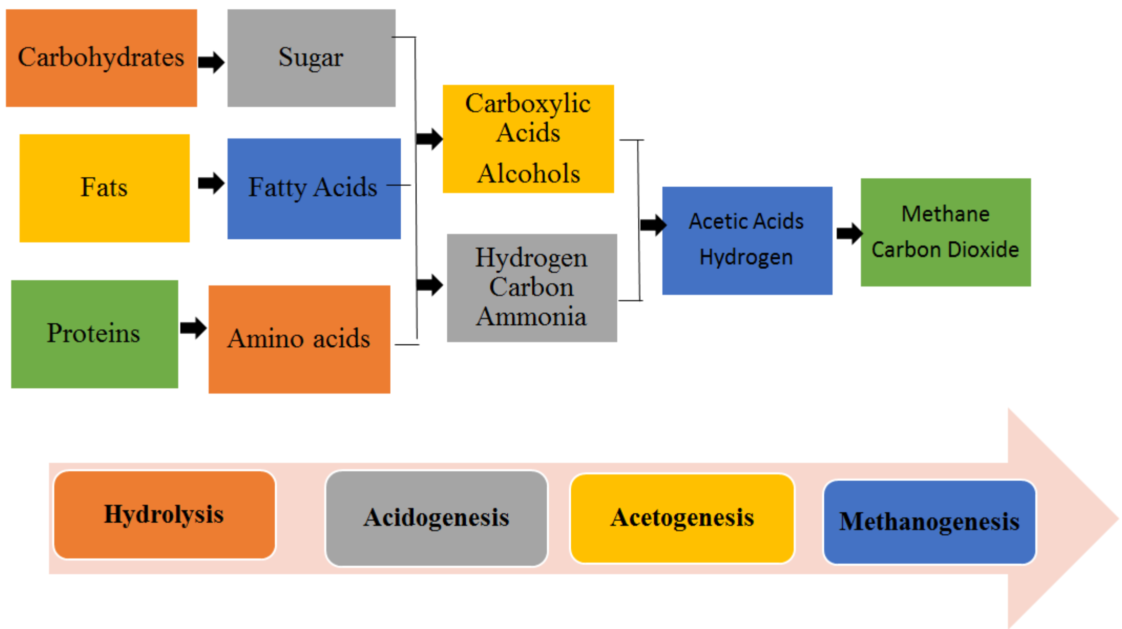

Figure 2. *Flowchart of the anaerobic digestion process.*

Actually most part of the authors converge talking about three stages of anaerobic digestion, that is, hydrolysis, acetogenesis and methanogenesis. However, this difference does not detract from the essence of the anaerobic digestion process, as acidogenesis, not highlighted by several authors, occurs as a sub-process of acetogenesis.

2.5. Biofertilizer

Biofertilizer is one of the products resulting from the fermentation process of organic matter, carried out through biodigesters, which main function is to meet the needs related to rural sanitation [23]. On average, they have 1.5 to 2.0% nitrogen, 1.0 to 1.5% phosphorus and 0.5 to 1.0% potassium.

However, these values are quite variable, as the quality of the biofertilizer will depend on the substrates used and the management of the biodigester.

The biofertilizer is popularly known as residue from the biodigester; this residue is very well used in agriculture, that is, it is produced after the anaerobic process in parallel with the production of biogas and is an organic fertilizer [13].

It is an organic fertilizer, free from agents that cause diseases and pests to plants, and it contributes, in an extraordinary way, to the restoration of the humus content of the soil, working as an improver of its chemical and physical properties and improves the microbial activity of the soil, which plays an important role in its structuring [16].

The biofertilizer provides the multiplication of bacteria, generating more life and health to the soil and causing a significant increase in agricultural production [3]. The same author goes on to say that the manure at this stage (biofertilizer) is practically "cured" (in the expression of the field), as there is no possibility of further fermentation; thus, it has no odor and is not polluting and, therefore, does not attract any type of insect.

In this way, the biofertilizer originated in the biodigestion process provides the maximum use of organic waste, optimizing the process of adding value to communities and rural properties.

2.6. Sizing of the Biodigester for Electricity Supply

In the present work, a case study is carried out in the locality of Plantações da Ganda, Caimama neighborhood, municipality of Ganda, province of Benguela. The municipality of Ganda is located to the east of Benguela, 210 km from the province capital municipality, with an area of 4817 km^2, limited to the north by the municipality of Balombo, to the east by the municipality of Tchindjendje (Huambo province), to the south by the municipalities of Caluquembe and Caconda (both in the province of Huíla) and to the west by the municipality of Cubal.

The Ganda Plantation area is located on the east of the main commune of the municipality, at a distance of 25 km from the city centre. The locality has 8 districts, namely: Bairro 18, Fazenda, Banda, Kamupa, Dois, Caimama, Tira Chapéu and Kalunhe, with approximately 281 families or houses with an average of 5 (five) people per house. It has a strong biomass potential, as its vegetation consists of open forests, savannah with shrubs and dense and dry forest formations and its main economic activity is agriculture and animal husbandry.

The region has 7 cattle corrals, and each corral holds an average of 24 animals. Based on these facts, these wastes were used to produce biogas and with it the generation of electricity, to satisfy the demand of the Caimama neighborhood, in a first phase, which involves 15 houses and approximately 75 people.

2.6.1. Energy Demand of the Caimama Neighborhood

The daily, monthly and annual electrical demand of a house in rural areas is determined by calculating the consumption of the electrical equipments of the houses for the hours that they work in a period of 24 hours, thus adding the total of Wh or kWh [15]. Next, the author presents the quantity and typical equipment for a house in rural areas.

Table 1. *Typical domestic equipment for a house in the countryside.*

Equipment	Power (W)	The Amount
Refrigerator	100	1
Television	30	1
Radio	2,5	1
Fan	40	2
Lamp	8	4
Total	244,5	

For one residence, a daily demand of approximately 3.5kWh was obtained, making a total of 52.5kWh for the 15 existing residences in the Caimama neighborhood.

The equipments built with the purpose of generating electrical current need a very strong support with regard to its construction, sustainability so that over time they do not cause damage that can compromise the production of the same.

Biodigesters are no exception to the international standard, that is, in terms of safety because they are infrastructures that will support small or large components to generate electrical current.

Generally, the digesters are constituted by: substrate inlet box, fermentation chamber, gasometer, biogas outlet and biofertilizer discharge box.

Table 2 below indicates the starting data:

Table 2. *Departure data.*

Description	Symbol	Value	Unit
Number of animals	$N_{a.i}$	168	-
Swine manure mass par day	$m_{a.i}$	10	kg/day
Mixing factor with water for Swine	K_{water}	1	-
Mix Density	ρ	1000	kg/m^3
Retention time for Swine manure	T_{rh}	30	days
Ratio of gas production (varies from 0,45 to 0,65)	K_R	0,62	m^{3}gás/m^{3}fermen. volume*day
Lower calorific value of biogas (cwith 65% de methane)	PCI_{biogas}	23	MJ/m^3
Engine-generator Efficiency	$\eta_{engine-generator}$	0,30	-
Availability	-	24	h/day

The data from table 2 processed through the equations described below generates the results of table 4.

2.6.2. Calculation of the Volume of Biogas to Be Produced

The calculation of the volume of biogas starts with the dimensioning of the biodigester for the use of animal manure in a rural location; firstly, the amount of manure produced by these animals per day is determined, with the help of equation 1, proposed by [21]:

$$m_{r,i} = N_{a,i} \times m_{a,i} \quad (1)$$

Where:
$N_{a,i}$ Number of animals.
$m_{a,i}$ Animal manure mass per day.

After knowing the amount of manure that is produced daily on the farm, it is necessary to know the amount of water needed to dilute these manures, since, for the production of biogas to occur correctly, the biodigester must be fed with manure diluted in water. For each type of manure, there is a certain amount of water. Table 3 below shows the proportion of water for the different types of biomass.

Table 3. *Proportion of water for some types of biomass [14].*

Types of biomass	kg of biomass	Water Volume (l)
Cattle droppings	100	100
Equine droppings	100	193
Sheep droppings	100	317
Goat droppings	100	321
Swine droppings	100	200
Human waste	100	118
Crop remnants	100	846
Poultry manure	100	880

The total mass entering the fermenter, that is, the daily load, is obtained through equation 2 [19-21].

$$m_{tot,f} = \sum mtots, i = (1 + K_{water}). m_{r,i} \quad (2)$$

Where:
$m_{tot,i}$ Total supply of manure (kg/day).
$m_{tot,f}$ Total mass entering the Fermenter or daily load (kg/day).
K_{water} Mixing Factor with water.

With the information obtained, it is already possible to calculate the daily substrate feed volume in the fermenter (V_{subs}), using equation 3, the volume contained in the fermenter (V_R) with the aid of equation 4, [21]:

$$V_{subs} = \frac{m_{tot,f}}{\rho} \quad (3)$$

$$V_R = V_{subs} \times T_{rh} \quad (4)$$

Where:
ρ mix density (kg/m^3).
T_{rh} Retention time.

The amount of biogas produced per day is related to the daily substrate feed volume in the fermenter (RV), previously calculated in equation 4. To calculate the biogas volume, equation 5 below was used, [15-21]:

$$V_{biogas} = K_R \times V_R \quad (5)$$

Where:
K_R gas production ratio, varies from 0,45 to 0,65 (m^3 gas/m^3 fermentation volume*day).

The volume of biogas produced is an available energy source, either for heat or for generating electrical energy through mechanical energy. The heat is the biogas to be used for cooking food or even for heating any product. However, in the specific study, we proceed to determine the power from this volume of biogas, since the purpose of the study is the generation of electrical energy.

2.6.3. Calculation of Power and Energy

The calculation of electrical power takes into account the volume of biogas per day, efficiency of the motor-generator set and the lower calorific value of biogas (PCI). Equation 6, [15-25], determines the electrical power that can be produced daily in kW

$$P_{elect} = \frac{V_{bg}}{24 \times 3600} \times PCI_{bg} \times \eta_{mg} \quad (6)$$

Where:
PCI_{bg} Lower calorific value of biogas with 65% methane (MJ/m^3).
η_{mg} engine-generator efficiency.

In order to analyze the amount of electrical energy that the designed biodigester can produce per day, the daily produced power calculated in equation 7 is taken into account. Equation 7 [15-25] estimates the amount of electrical energy produced daily by the biodigester:

$$E_{elect} = P_{elect} \times D \quad (7)$$

Where:
$D\ Availability$ - Hours worked during the day (h).

The calculations made, using the methodology described above, resulted in the following results shown in table 4 below:

Table 4. *Results obtained.*

Description	Symbol	Value	Unit
Total mass of manure produced per day	$m_{r,i}$	1680	kg/day
Total supply of Swie manure	$m_{tot,i}$	3360	kg/day
Total mass enteringthe fermenter or daily load	$m_{tot,f}$	3360	kg/day
Daily Substrate feed volume in the fermenter	V_{subs}	3,36	m^3/day
Volume contained in the fermenter	V_R	100,8	m^3/day
Biogas volume	V_{bg}	62,5	m^3/day
Electric Power	P_{elect}	4,99	kW/day
Electric Energy	E_{elect}	119,78	kWh/day

3. Analysis and Discussion of Results

The production of biogas using biodigesters and the consequent production of electrical energy involves several processes, which can be seen in the flowchart below.

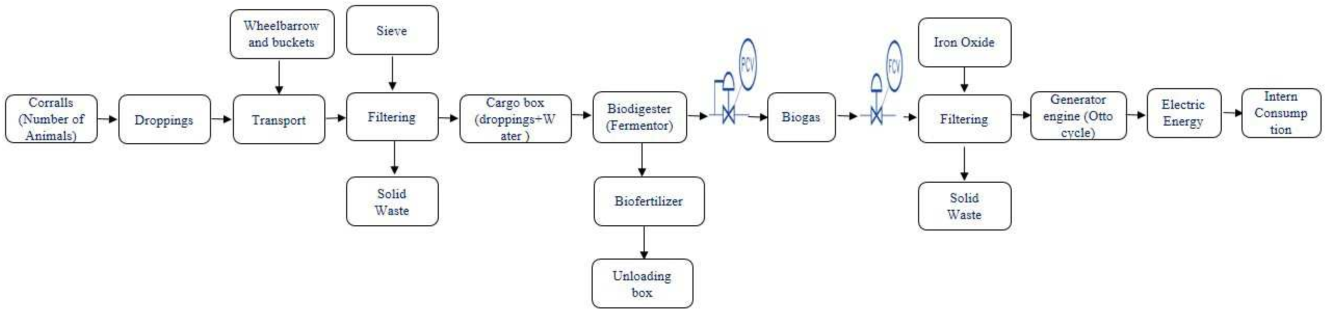

Figure 3. *Flowchart of the project's complete energy production process at the location.*

For the reality of the locality of the plantations of Ganda, the bidigestor chosen was the continuous one, since the manure in its entirety is available daily, as the animals are in corrals [1].

The construction of biodigesters in rural areas is presented as potentially viable for the production of biogas and consequently the generation of electricity, due to the fact that large amounts of cattle, goats, pigs and others are found in rural Angola, particularly in the various agricultural farms. Biogas is an alternative for energy generation in rural areas, it can contribute to solving the problem of electricity production in a country where 70% of the population has access to electricity [2], with the rural environment being the least covered, as an essential asset for the production of goods and increasing the quality of life of populations, even if they are low-income, at the same time that the environment is favored with the collection and use of waste, which in another way is a factor of contamination of the environment.

The results presented attest that for the 168 cattle, the locality of the Ganda plantations will have an installed power of 4.99 kW and daily electrical energy of 119.78 kWh, which would be satisfactory to meet the energy demand of the Caimama neighborhood in a first phase.

As the number of animals increases in the locality, as a result of local reproduction, the quantity of manure will increase and consequently the data on the biodigester's capacity, power and electricity production will be increased.

Table 5. *Forecast of increased power and electrical energy with an increase in the number of animals.*

$N_{a,i}$	$m_{tot,f}$ (kg/day)	V_{subs} (m^3/day)	V_R (m^3)	V_{biogas} (m^3/day)	P_{elect} (kW)	E_{elect} (MWh/year)
5	100	0,1	3	1,86	0,148	1,301
15	300	0,3	9	5,58	0,445	3,904
30	600	0,6	18	11,16	0,891	7,807
45	900	0,9	27	16,74	1,337	11,71
60	1200	1,2	36	22,32	1,783	15,61
75	1500	1,5	45	27,9	2,228	19,52
90	1800	1,8	54	33,48	2,674	23,42
105	2100	2,1	63	39,06	3,119	27,33
120	2400	2,4	72	44,64	3,565	31,23
135	2700	2,7	81	50,22	4,011	35,13
150	3000	3	90	55,8	4,456	39,04
168	3360	3,36	100,8	62,5	4,991	43,72
180	3600	3,6	108	66,96	5,348	46,84
200	4000	4	120	74,4	5,942	52,06

From table 5 above, it can be seen that when 200 confined cattle are reached, the locality will have an installed power of 5.94 kW and a daily energy production of 0.14 MWh/day, sufficient to supply electricity to approximately 39 rural houses. It is possible for each of the families to opt for an isolated home system, if the construction of a centralized biogas production system to supply electricity to the neighborhood is not possible. For this, it is necessary to have 5 heads of cattle and obtain a daily power and electrical energy of 0.14kW and 3.56kWh respectively, sufficient to meet the demand of a residence in rural areas.

The power, as well as the electrical energy produced during a day from the biogas generated in the biodigester is a function of the number of animals. In Figure 4 and Figure 5, the graphs Number of animals vs Electric power and Number of animals vs Electric energy are shown.

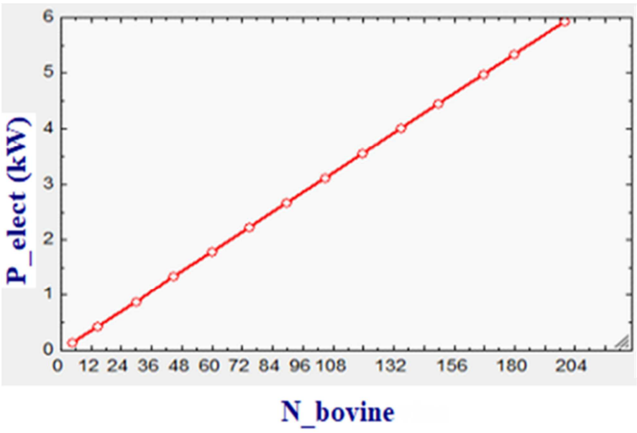

Figure 41. *Relation number of animals vs electrical power.*

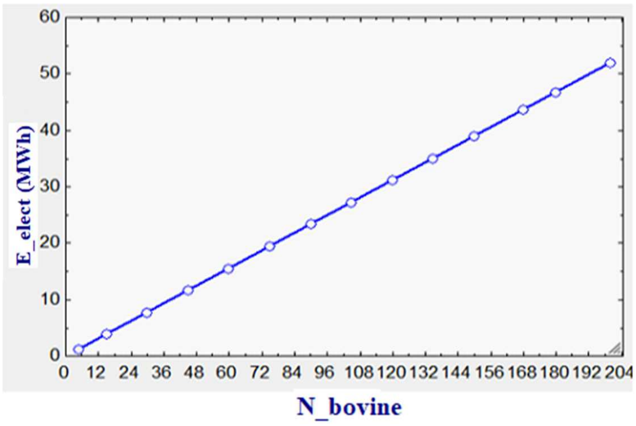

Figure 5. *Relation number of animals vs electrical energy that can be generated in a year.*

4. Conclusions

This article shows the importance of biodigesters in the production of electricity, in addition to providing an overview of the methods of calculation and production of gas and consequently energy from animal waste.

The power, as well as the electrical energy produced during a day from the biogas produced in the biodigester is a function of the number of animals, which in the case of the locality under study can reach 14.26 MWh/day with 200 cattle. There is still the possibility for each resident to build an isolated home system, if difficulties are encountered in building the centralized system, requiring 5 heads of cattle for this purpose.

Thus, the energy obtained is renewable and clean and mitigates the environmental impacts that the waste would generate. At the same time, GHG emissions are avoided if fossil fuel were used to start the engine-generator. The commitment and investment in biodigesters will help in the growth of distributed electricity generation, contributing to the improvement of energy security and sustainable development.

Research on the topic of producing electricity from biogas highlights its importance in the economic, social and environmental areas. Research work carried out in recent years points to the significant energy potential that animal waste and agricultural and other residues can have in the energy matrix of countries. For many countries like Angola, investment is needed in this area to allow the use of this energy potential and ensure that this energy production can contribute to solving the electrical problem in rural areas.

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