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Economic viability of the biogas produced on pig farms in Brazil for electric power generation

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Electric energy generated by clean and renewable sources, such as biogas, is a subject widely discussed and of global importance. Biogas, besides being an alternative to other fuels uses a raw material, which in many cases is considered disposable, worthless and harmful to the environment when not correctly disposed of. Several factors influence the design, operation and collection of the final product. This paper is a technical economic viability report about three biogas projects, which have already been published, and presents the main difficulties and advantages encountered during the whole process involving biogas production, as well as its economic viability when used to generate electrical energy. The analysis show that the use of biogas from wastes of pig farms is economically viable, since all biogas produced is nearly totally used for electrical power generation.

Key words: Carbon credits, biodigester, biomass, methane, biomethane, greenhouse gases.

INTRODUCTION

Biogas was discovered in 1667, however, only 100 years after Alessandro Volta noted the presence of methane in its composition, opening the possibility of its potential to produce heat, and leading to its widespread use in rural installations (Classen et al., 1999). In Brazil, the technology for producing biogas appeared in the 1970's and did not reach any importance initially. Nonetheless, over recent years, mainly due to the escalation in the price of other types of energy sources, such as those derived from oil, biogas regained its place as a viable alternative source of energy.

Different to other renewable energy sources, such as biodiesel and alcohol, biogas does not have the need for the cultivation of any type of culture, such as sugar cane, corn, beetroot etc. The primary material used in the production of biogas is detritus, agricultural waste, materials that in many cases would have no value or use (Barreira, 1993). Noteworthy here is that some countries in Europe use corn plantations as biomass for biogas production. However, Nigatu et al. (2012) conduct their study toward the potential use of the plant Eragrostis *Tef* for the production of biogas, focusing on the care that should be taken in plantations used specifically for the production of biogas, as these areas, when not planned correctly, can lead to a breakdown in food production in that region.

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On the other hand, as shown on Table 1, biogas is composed, in greater part, of methane (CH_4) and carbondioxide (CO_2), although in the composition of biogas there exist other gases but in less significant quantities.

Therefore, the most important component of biogas is methane, which is the main reason for opting for the exploration of this type of energy. According to La Farge (1979) “methane and carbon dioxide represent 60 to 80% and 20 to 40% of the total gas volume, respectively”. This concentration is affected by the type of biomass origins, which, in turn, interferes in the heating potential of the fuel. This represents the maximum energy content of the fuels and in fact this parameter alters with the elementary chemical composition (Barros et al., 2018).

Highlighted also, in agreement with Vanti et al. (2015), is that raw biogas has a strong odor, low heat potential and is highly corrosive, which means that it is not indicated for internal combustion engines, thus there arises the need for purification processes to be applied to the raw product in order to elevate its heat potential and remove components that are responsible for corrosion and the bad odor.

Different to other fuels used as heat sources, such as wood, coal, oils etc., methane when burned does not leave behind residues, and is of low impact environmentally. Table 2 is a list showing the approximate equivalent of other fuels when compared to biogas, where 1 m^3 of biogas is used as a base (Sganzerla, 1983).

In this study, the biomass addressed comes from pig waste. Pig waste is often used for biogas production. One of the reasons for such use can be demonstrated through an experiment performed by Zagorskis et al. (2012). The aim of the experiment by Zagorskis was the analysis of biogas generated through the mixture of chicken excrement with leftover plant material at a ratio of 90:10%, as well as pig excrement and leftover plant material also at a ratio of 90:10%. The conclusion reached from the results of these experiments was that the mixture with pig excrement is better for the production of biogas, as the maximum concentration of methane was around 68%, which was approximately 50% greater than that of the chicken excrement and plant mixture.

Biomass is classified as being all and any biological input that can be decomposed through biological action, and as such “any type of organic material of animal or vegetable origin is considered biomass” (Sganzerla, 1983). Biomass is the most common fuel in nature and for this reason it has greatest ease of access and use, at least until the beginning of the 20^{th} century, when petroleum was finally discovered (Rossilo-Calle, 2000). Currently, due to its use as gas for the production of energy, biomass has started to retake a relevant portion of the market simply because of the biomass digestion process, performed by bacteria, which results in the production of two main inputs, biogas and biofertilizer. Excrement from animals, abattoir waste, sugarcane bagasse, domestic waste and sewage are among the main composts that can be used as biomass.

Biofertilizers, produced by means of anaerobic digestion in biodigesters, are organic fertilizers rich in nutrients that can be used as substitutes for chemical fertilizers. As these are the result of the decomposition of organic animal or vegetable material, biofertilizer possesses in its composition live cells and several microorganisms. This type of fertilizer possesses a more liquid nature than solid, which therefore facilitates its use in the field (Medeiros and Lopes, 2006). In the study by Kocyigit et al. (2017), the authors reached the conclusion that the biofertilizer that results from anaerobic digestion of biomass has a lower rate of mineralization than other organic fertilizers. Mineralization in biology is the conversion of organic matter into inorganic matter.

The biodigester is a chamber into which the biomass is deposited, maintaining the appropriate proportions between solid and liquid mass, in order that the digestion process occurs as expected, liberating in this way the biogas and the biofertilizer as its final products. Currently, there exist various models of biodigester, depending on the type of biomass, final product, available materials, among other factors (Tiago Filho and Ferreira, 2004). According to these authors, the biodigester can act in continuous mode, where the installation possesses a collection mode, in which biogas is continuously collected with no interruption, and batch mode, when the process is maintained inside the biodigester for a given period until it is concluded and the biogas is removed at the end. The two most common models of biodigester are the Indian and Chinese models, where both are continuous biodigesters, as illustrated in the schematic drawing shown in Figure 1. The Indian model of biodigester is built with a bellflower design gasometer, and in this way the pressure inside the gasometer remains constant during the whole process. In Figure 1, a two-dimensional plan of the biodigester, in which the input and output entrances can be seen, thus allowing for a constant supply without the need to interrupt the process (Cervi et al., 2010). The Chinese model also possesses an uninterrupted mode of working. The differences are that, in the Chinese model, the biodigester is constructed in brick and is fixed, and, in this way the pressure inside the chamber is not constant as happens in the Indian model. In both models, the structures are supplied with biomass in solid concentration of around 8%, in such a way to avoid the occurrence of possible blockages in the input pipes (Deganutti et al., 2002).

In recent years, the world market has seen high price rises on fossil fuels and their derivatives, where both petroleum and natural gas are highlighted. These constant price changes, among other market factors, occur due to increases in demand and the absence of

Table 1. Biogas composition.

Type of gas	Biogas composition (%)
Methane (CH_4)	60 to 80
Carbon dioxide (CO_2)	20 to 40
Hydrogen sulfide (H_2S)	until 1.5
Nitrogen (N)	Trace
Hydrogen (H)	Trace

Source: Obtained from La Farge (1979).

Table 2. Comparison of biogas with other fuels.

Fuel	Corresponding value at 1 m³ of biogas
Alcohol	0.790 L
Gasoline	0.610 L
Diesel	0.550 L
Kerosene	0.570 L
Liquid gas	0.450 kg
Wood	1.538 kg
Electric energy	1.428 KWh

Source: Originally from Sganzerla (1983).

conditions for increasing the production of these fuels in a way that meets such demands, even though there has been growth in fossil fuel production over time. Petroleum started to be exploited around 1845, and its production went on to surpass 86 million barrels per day" according to the International Energy Agency (IEA) (2010), leading to a number of problems. The most important problem concerning the use of this type of fuel is based on the fact that it is not renewable, thus at some moment in the future, the production of petroleum will fall and the price, in virtue of increased demand, will rise even more, making it impractical. To avoid this problem in the future, investments on renewable energies are necessary, and according to Song et al. (2014), the anaerobic fermentation of agricultural wastes for production of biogas is a good alternative than the use of fossil fuels.

Faced with this, several countries see as alternatives the search for new sources of renewable energy, such as energy from hydroelectric, wind turbines, solar systems, biodiesel and biogas, which are all excellent alternative sources to the use of petroleum. The importance of these renewable energy sources is increasing, not only to substitute fossil fuels but also to protect the environment.

According to the Mines and Energy Ministry (2017), which pointed out in its newsletter "World Ranking of Energy and Socioeconomics", Brazil is one of the highest producers of renewable energy, although the exploitation of some sources is still very much in their initial stages. Nevertheless, with adequate investment, the power generation of the country in this area will be much higher than that currently presented. Unexplored sources, or those that are in their initial stages of exploration, represent a great potential in energy generation.

One of the biggest concerns that lead to the search of renewable sources is associated with the increase in the greenhouse effect, which is caused by the emission of polluting gases denominated GHG (Greenhouse gases). This group includes gases such as methane (CH_4) and carbon dioxide (CO_2), which are among the main aggravating components for this type of problem. If we take into consideration agricultural and livestock production, there exist other aggravating gases, such as carbon monoxide and nitrous oxide. According to the Intergovernmental Panel on Climate Change (IPCC) (1996), the agricultural sector is responsible for an increase of around 20% of global radiative forcing, which is an index used for analyzing possible impacts of greenhouse gases on the climate by means of studies related to its radiative forcing characteristics. According to Pertl et al. (2014), the greenhouse gas from digestion of organic wastes is less prejudicial to the climate than the use of renewable agricultural resources to the production of energy.

The use of biogas is not only an alternative to the use of natural gas or any other fuel in the generation of electric energy, but it also provides a reduction in pollution loads. In addition, organic material deposited in the biodigester, after being digested, ends up being used

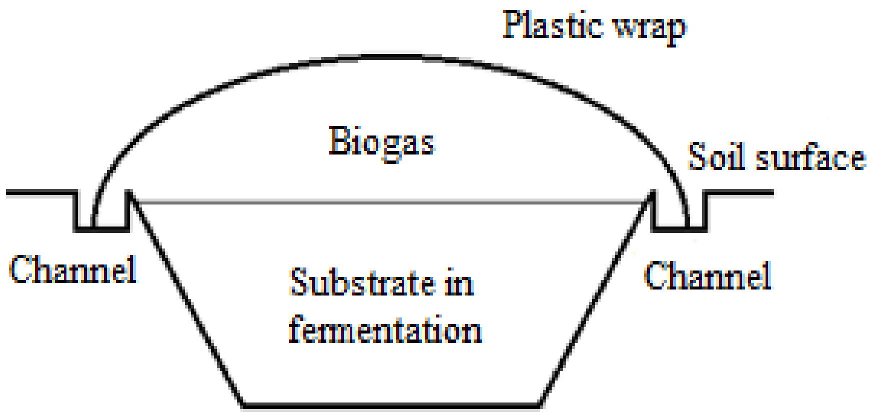

Figure 1. Cross-section of the tubular biodigester model.
Source: Originally from Cervi et al (2010).

Table 3. Yield of conversion technologies from chemical energy to electric.

Yield		
Gas turbine	**Steam turbine**	**Internal combustion engines**
25 to 40%	14 to 35%	Diesel Cycle: 35 to 45%

Source: Adapted from Antônio (2016).

as compost. This means the reuse of something that would be simply discarded can now be used for the generation of energy and fertilizer. This is very attractive for investment, in terms of the financial point of view (Pereira, 2005).

Currently, China is one of the fastest growing countries in terms of economy in the world, and the fact that it is the country that possesses the largest quantity of biodigesters is an indication that the generation system can, in the future, become responsible for a considerable percentage of electric energy production. In Brazil, the production of electricity using biodigesters has transformed rural properties into self-sustaining units, producing in this manner new incomes and jobs. It is in this way that "the use of these biodigesters collaborates with the maintenance of labor in the field and as way to reduce rural migration" (Sganzerla, 1983). In addition, the dependence on external networks of electric energy is no longer a difficulty in this sector.

In line with these prospects, this study proposes the investigation of the subject of electric energy generation using biogas as a primary source, with the aim of presenting basic concepts employing the main models of biodigester currently in use. The proposal here analyze if the electric generation units supplied with biogas are in fact an economically viable alternative, by presenting cases in which projects were developed for the installation and operation of this type of plant.

The use of biogas in the generation of electric energy

Burning biogas in combustion engines or boilers is one of the ways to produce electric energy. To decide the best technological option when selecting equipment for electric energy generation, one needs to consider the following: The power that will be generated, the fuel employed, the yield and the type of motor or turbine used. Another point that needs to be considered relates to global yield. Some conversion technologies are more efficient when thermal energy is used for cogeneration of electric energy. However, such technology will be economically viable when one needs to use the heat generated from burning biogas.

In order to demonstrate the yield from generators, the conversion efficiency of some technologies is emphasized in Table 3 for those most commonly used.

Legislation and free trade of energy

In Brazil, one option for increasing the attraction of this type of installation is the trade of electric energy within the free energy market. It allows the energy of small electric sources to be sold as stated by the decree number 5.163 of July 30th, 2004. In this decree, it is determined that there exist two types of trade: (1) The Regulated Contracting Environment (RCE), which is the segment of the market, in which one performs the buying and selling operations of electric energy among selling and distribution agents, prior to bidding, except for those cases covered by law, as in specific rules and commercial procedures, and (2) The Free Contracting Environment (FCE), which is the segment of the market in which one realizes the buying and selling operations of electric energy, as the object of freely negotiated bilateral contracts, as set out in rules and procedures of specific trade.

The RCE is based on the regulated market, to which most consumers are associated. Within this setting, tariffs and distribution are regulated by the Brazilian government. However, FCE allows for direct negotiation with the energy producer, in a way that enables the consumer to decide to buy energy according to their needs. According to the Energy Trading Chamber (2016), the participation in the Free Energy Market in the buying and selling scenario in Brazil was approximately of 27% in 2016, and the tendency is for increased growth over the coming years.

Carbon market

Over recent decades, the carbon credit trading model has become viable in the carbon market. Carbon credits are a type of exchange currency for the emission of greenhouse gases. Following the commitment made under the Kyoto Protocol, goals were set to which developed and developing countries would adhere, in relation to the emission of greenhouse gases. However, as some countries are unable to adapt over the short term and as such forfeit the targets set out, there exists the possibility of buying these credits as a compensation for the emission of these gases.

Each equivalent ton of CO_2, which a country no longer emits into the atmosphere, is equal to 1 carbon credit. In Brazil, this can be negotiated by means of auctions organized by BM&FBOVESPA. In such events, brokers associated with the organization representing their clients can participate, including market traders from REC (Reduced Emissions Certificate) and from the European permissions market, financial multilateral organizations, global carbon market accredited by BM&FBOVESPA, carbon funds and government entities (Brazil, 2012).

Mitigating factors in the production of biogas

Biogas can be obtained from many types of raw materials. Some of them are more commonly used than others, due to efficiency in the production of gas, handling facility and availability. Some sources are brewery waste, abattoir waste, farm waste, animal excrement and grass. Highly fibrous materials, such as sugar cane, have a less efficient digestion, resulting in a lower biogas production when compared to other materials rich in starches, as is the case of grains and proteins, waste and blood from abattoirs. They present an elevated efficiency when it comes to biogas production (Prati, 2010).

Considering the two basic continuous models, in which the biodigester is continually receive biomass, without the need to terminate the digestion process, and the batch type biodigester, where the biogas is only removed at the end of the digestion process, the following systematization occurs. In the first case, in order to maximize the production of biogas, it is necessary that the concentration of dry mass is of 7 to 9%, which is a concentration considerably lower when compared with the second model, in which the concentration can reach 25% without incurring problems (Mazzuchi, 1980). The digestion process is also affected by the pH present in the biomass, where its ideal level is of pH 6.0 to 8.0. In cases where the pH reaches values below 6.0, the process starts to wane, to the point where it may even stop. If this occurs, it becomes necessary to perform a pH correction; also it is important to monitor these acidity levels (Comastri Filho, 1981).

Another item that should be assessed is temperature. In this case, the main precaution to be taken is with sharp variations, as some microorganisms responsible for the process are sensitive to these variations. Higher temperatures also produce better results. For temperatures around 35 to 37°C, the digestion process occurs at an accelerated rate, and in the other extreme, for temperatures below 15°C the process can arrive at a stop (Barreira, 1993). There should also be a level of attention paid to the presence of unwanted substances in the biodigester. In other words, care should be taken with substances that can, not only damage the digestion process but also present a risk to the installation itself. Excessive quantities of nutrients, strong disinfectants, and oil derivatives can all cause the loss, in greater part, of the bacteria involved in the process. For this reason, according to Comastri Filho (1981), the water used in the cleaning of equipment and installations is not adequate for use in biodigesters.

MATERIALS AND METHODS

Here, the objects of study dealt with herein are presented; these involve economic aspects and case studies.

Economic viability

The economic viability concerning the use of biogas to produce electric energy is directly linked to several different factors. Some of such factors can be the type of biomass to be used, the demand and/or selling of electric energy/fertilizer produced, active operation time of the electric generator, the initial investment, the costs with future maintenance, depreciation and labor. Therefore, one notes that the installation of an energy generator via biogas is not always economically viable.

In order to assess whether a project is economically viable, it is common to use mathematical indicators, such as NPV (net present value), IRR (internal rate of return), BCR (benefit-cost ratio), SPB (simple payback), EPB (economic payback), as well as the use of MARR (minimum attractive rate of return), which is the minimum rate desired for the investment to become economically viable. When applied in a correct fashion, these calculations aid in the execution or rejection of a project, as well as for applying corrections along its course. In a simplified manner, NPV as determined through Equation 1, is the sum of all the revenues presently assigned to the project, subtracting the costs and taking into consideration interest rates and the duration of the undertaking.

$$NPV = -In + \Sigma_{j=0}^{n} R_j (1+i)^{-j} - \Sigma_{j=0}^{n} C_j (1+i)^{-j} \quad (1)$$

Where variable In is the initial investment, R_j is the current value of the revenue, C_j is the current value of costs, *I* is the interest rate, *j* is the period in which the costs or revenues occur and *n* is the duration of the project. A positive NPV means that the project presents a good result. However, negative values make the project impossible to execute. When positive, "the higher the obtained NPV value, the better will be the project performance" (Dossa, 2000). The IRR is a more complex technique than NPV; nevertheless it is still widely used. According to Gitman (2002), by using the same parameters, it is the same as the NPV calculation when it presents a null value, which is: NPV = 0, as calculated using Equation 2.

$$0 = -In + \Sigma_{j=0}^{n} \frac{R_j - C_j}{(1+IRR)^j} \quad (2)$$

To know whether a project will be accepted, or not, the following analysis can be used: if IRR is higher than the cost of capital, consider the project as viable and attractive. It should be discarded, if the opposite condition occurs. In Equation 3, the cost benefit, is the ratio of the current values of expected benefits and the current value of expected costs and for a project to be considered financially interesting, this value should be greater than 1 (Dossa, 2000).

$$BCR = \Sigma_{j=0}^{n} \frac{B_j (1+r)^j}{C_j (1+r)^j} \quad (3)$$

In Equation 3, B_i is the benefit of the project in monetary units in year *i*, C_i is the cost of the project in monetary units in year *i*, *I* is the time counter in years, *j* is the discount rate as a percentage, and *n* is the period representing the useful life of the investment in years. Finally, one has the capital recovery period, also known as *SimplePayback* (SPB), which represents, in years, the time necessary for the cash flow to equal itself to the initial investment and the economic payback (EPB), which considers a minimum attractive rate for calculating the recuperation period according to Casarotto Filho and Kopittke (2007).

Case study A

In Cervi et al. (2010), a project developed at a rural property with a diversified production, including poultry, coffee as well as pig, cattle and sheep farming, was presented. In this investigation, the decision was reached for the use of pig excrement, due to the fact that it holds great potential for generating biomass by means of this type of culture in that place. To carry out the project, the choice of a continuous operation biodigester was made, with a working capacity of 496 m³.

The floor where the biomass is deposited is made of bricks. And the top part is made of a plastic sheet covering, as illustrated in the schematic drawing of Figure 1.

Case study B

In the study developed by Lindemeyer (2008), emphasis is given to the economic viability analysis, based on the use of biogas as a source of electric energy at a pig farm in Santa Catarina, Brazil. The study was developed around the breeding of 2,500 animals. By means of the digestion of waste in the biodigester, an average of 158 m³ of biogas was produced per day. In the plant, there is a generator of 50 kVA that remains on 4 h per day, which consumes 80 m³ of biogas as fuel.

Case study C

The objective of the study presented by Antônio (2016) is found in the economic viability of the generation of electric energy through the use of the biogas produced at a pig farm in Minas Gerais, Brazil. According to the author, the goal of the study was to analyze the production capacity and use of biogas from pig farming, as a fuel for generating electric energy. In this project, information from 22 farms was collected, registering data such as the number of animals and the maximum consumption of electric energy. In this manner, the quantity of biogas produced by each farm, as well as the quantity of biogas necessary to supply the consumption of electric energy of the establishment was estimated.

In order to calculate the economic indicators (NPV, IRR, BCR, SPB, EPB and MARR), the cash flow for ten years was calculated by Antônio (2016), where the output values considered were the installation of the biodigester, generation equipment, connection to the electric network, labor, availability of electric energy, depreciation of the generation equipment, maintenance of the biodigester and the generator. The cash flow input corresponds to the savings generated by the autonomy ascertained by the electric energy. Also there is an important increase in the tenth year due to the residual value of the generation equipment, and the tariff used was US$ 0.0975 per KWh and a MARR (minimum attractive rate of return) of 8.75% per year.

Case selection

Considering that Brazil is a great producer of pigs, it was selected for the analysis of the use pig farms to produce biogas. Another reason for the choice is that pig manure is a good material to produce biogas with high methane concentration.

The Table 4 shows some differences and similarities, about the biodigester and biogas, of the three cases.

RESULTS

The results shown refer to the three case studies covered herein listing the collected and simulated values.

Case study A

The estimated production of biogas obtained at the end of the Project reached 670,760.5 m³/year. In the same study, 72.072 m³ of biogas/year were also estimated,

Table 4. Differences and similarities among the three cases.

Cases	Substrate type	Biodigester type	Biodigester working capacity (m³)	Biogas consume per day (m³)
Case A	Pig manure	Tubular model	496	197
Case B	Pig manure	Canadian model	900	158
Case C	Pig manure	Indian model	1,479 ~ 8,074	168 ~ 6,058

Source: Cervi at al. (2010), Lindemeyer (2008), and Antônio (2016).

Table 5. Simulation for the consumption of electric energy for use at 10.5 h/day.

Energy consumption (KWh)	Working period (h/day)	Benefit (US$/year)	Cost* (US$/year)	NPV (US$)	IRR (%)	BCR (index)	SBP (years)	EPB (years)
20	10.5	5,925.34	5,737.84	(-27,878.62)	-	0.05	-	-
25	10.5	7,406.67	5,737.84	(-16,787.47)	-9.10	0.43	-	-
30	10.5	8,888,01	5,737.84	(-5,696.32)	1.35	0.81	10.30	-
35	10.5	10,369.34	5,737.84	5,394.83	9.34	1.18	7.32	9.04
40	10.5	11,850.68	5,737.84	16,485.98	16.24	1.56	5.79	6.75

*In this cost the interest over the capital is not included. Source: Originally from Cervi at al. (2010).

considering the consumption of 72.072 m³ of biogas/year and a working period of 3,276 h/year for the generators.

For a per day consumption of 17.1 KWh, adopted at the property, there was an annual financial return of US$ 5,066.16. This was calculated considering the electric energy tariff applied during 2008, the year in which the Project was developed. In that year, the tariff was US$ 0.0937 per KWh in the dry season (7 months) and of US$ 0.0858 per KWh in the wet season (5 months), both at off-peak h. As one notes from Table 5, the annual cost of the Project was calculated at US$ 5,737.84. That means, for this scenario, that the production and use of biogas only produces desirable results for higher end consumers than those addressed herein. Finally, a new study was performed that considered the employment of the generator for a greater working period. It was 10.5 h outside of the peak and 3 h at peak, resulting in 4,212 h of energy generation per year. In this second case, one notes that for the same consumption of 17.1 KWh, adopted by the property, as well as possible increases in consumption up to 40 KWh, the project becomes viable as noted from Table 6.

Case study B

The project made possible an annual production of 58,400 KWh of electric energy. As the consumption on the farm was 58,400 KWh and the KWh tariff at US$ 0.092, this led to a generated economy of approximately US$ 5,400. In the farm place, Lindemeyer (2008) performed an economic analysis and calculated for a 15 years period the items for the working life of the generator, NPV, IRR, and payback. After he recalculated the economic parameters for an alternative scenario, by considering that the generator would remain on 8 h per day, a use of 158 m³ of biogas generated per day was calculated. To achieve this, he considered that the surplus KWh would be sold to the energy utility for US$ 0.076. This was the price paid by COPEL (The Energy Company of Parana), where it was possible to sell the surplus electric energy produced at that time. In both conditions, the income generated by the selling of carbon credits was also considered in the calculation of economic indicators. Table 7 provides the results for the economic viability of the two calculated conditions, involving 4 h in the first condition and 8 h in the second condition. Note that, operating 8 h per day, the result presented herein is higher than that for the operation occurring for only 4 h.

Case study C

By analyzing Table 8, which contains the economic indicators for some farms, one notes the best and worst results. This is in addition to allowing for possible motivation of some farms not producing a positive result.

As shown on Table 8, Farms 4, 5, 13 and 19 obtained a good performance in the analysis, and this is seen mainly due to the fact that they possess a positive NPV and high value. Another point is that the IRR presents a much higher value than MARR, which was only 8.75%. Taking into consideration the average working life of around 15

Table 6. Simulation for the average energy consumption for use at 13.5 h/day.

Energy consumption (KWh)	Working period (h/day)	Benefit (US$/year)	Cost* (US$/year)	NPV (US$)	IRR (%)	BCR (index)	SBP (years)	EPB (years)
17.1	13.5	11,290.31	6,567.74	6,076.64	9.79	1.21	7.20	8.85
20	13.5	13,205.05	6,567.74	20,412.75	18.52	1.70	5.41	6.22
25	13.5	16,506.3	6,567.74	45,130.17	31.79	2.54	3.95	4.32
30	13.5	19,807.57	6,567.74	69,847.59	44.04	3.39	3.21	3.44
35	13.5	23,108.83	6,567.74	94,565.01	55.82	4.23	2.77	2.92
40	13.5	26,410.09	6,567.74	119,282.43	67.37	5.07	2.48	2.59

Source: Originally from (Cervi et al., 2010).

Table 7. Comparison of economic indicator.

Parameter	1st condition - 4 h	2nd condition - 8 h
Initial investment	US$ 68,306.01	US$ 88,797.81
Payback	5.56 years	3.33 years
IRR	14%	24.71%
NPV	US$ 76,956.19	US$ 169,097.60
Generator operating	4 h per day	8 h per day

Source: Adapted from Lindemeyer (2008).

Table 8. Economic indicators for investment in the use of biogas for generating electric energy.

Farm	NPV (US$)	IRR (%)	SPB (years)	EPB (years)
4	264,852.23	21	4.3	5.62
5	33,156.24	11,99	6.49	9.27
13	791,893.14	25.11	3.72	4.7
16	(-106,318.76)	4.28	9.15	-
17	(-119,938.48)	-15.64	-	-
19	430,347.72	25.47	3.69	4.66

Source: Adapted from (Antônio, 2016).

Table 9. Comparison of the number of animals and electric energy consumption for farms 5 and 17.

Farm	Number of animals	Maximum consumption of electric energy (KWh/month)
5	9.604	42.120
17	9.800	6.226

Source: adapted from Antônio (2016).

years for the generation equipment, an EPB of less than six years is attractive for this type of investment. By the analysis of farms 5 and 17, and considering the data in Antônio (2016), some inferences are listed at Table 9.

As shown on Table 9, the number of animals is almost the same; however, the consumption of energy of farms 5 is almost 7 times higher than that of 17. This meant that the economic viability study for the use of biogas on farm

Table 10. Data for farm 16.

Farm	Number of animals	Maximum consumption of electric energy (kWh/month)	Estimation of biogas produced (m^3/day)	Estimation of biogas necessary (m^3/day)
16	52,430	79,102	9,437.40	1,618.00

Source: Adapted from Antônio (2016

Table 11. Economic viability comparison between the cases.

Case	Worst situation			Best situation		
	NPV (US$)	IRR (%)	SPB (years)	NPV (US$)	IRR (%)	SPB (years)
Case A	(-27,878.62)	-	-	119,282.43	67.37	2.48
Case B	76,956.19	14	5.56	169,097.60	24.71	3.33
Case C	(-119,938.48)	(-15.64)	-	430,347.72	25.47	3.69

Source: Cervi at al. (2010), Lindemeyer (2008) and Antônio (2016).

5 was positive, while for farm 17 presented a dire performance. The electric economy generated on farm 17 is very low in terms of the viability of using biogas for the generation of electricity only for supplying local demand. Should the case arise where the selling of excess electric energy is permitted, farm 17 would also become a viable option. Farm 16 demonstrated a low performance, as shown on Table 8, in the investment study for the use of biogas for the generation of electricity, which is due to the negative value of NPV and IRR that had a value below MARR. This occurred due to the high cost in the construction and maintenance of the biodigester, because as shown on Table 10, the biogas production estimate is much higher than the estimate necessary for farm 16 to become self-sufficient in electric energy. In this way, the savings will be lower than the cost. However, if the possibility to sell the excess electric energy arises, this farm will obtain a large financial return, as it has a high estimative to produce biogas.

Comparison

Observing Table 11, it is possible to see that in each case there is a situation in which the project has a worst and a good performance. This depends on the amount of biogas converted to electricity. The worst situations are when it uses low amount of biogas for electricity production while the best situations used practically all biogas produced.

DISCUSSION

The authors performed an analysis of distinct projects with the aim of investigating if in fact the use of biogas for generating electricity is a good investment. To gain a better understanding into the study, concepts were introduced as to how biogas is produced and how the calculation is performed for its economic indicators, which allows the knowledge if an investment is lucrative. Three cases A, B and C was also presented allowing the realization of the study and the reaching of its conclusions.

Case study A

An explanation for the result obtained in the first study can be reached if one takes into consideration the low use of the potential for biogas production, where only 10.74% of the total biogas produced is in fact being converted into electric energy. In this way, emphasis is also given to the point that to produce 17.1 KWh, only 43% of its nominal power output is being used. Noteworthy also is that, in the second case, the project becomes viable even for the partial use of the nominal power offered by the generator, as can be shown on Table 6, even when the annual cost increase is considered, due to higher utilization, which results in a new cost estimated at US$ 6,567.74.

Case study B

Based on observable data, the second condition, where it was considered that the generator would remain on for 8 h, thus consuming the total generated biogas, one would establish the condition in which near total financial return would be achieved. However, this would only be possible if the energy utility were to buy the surplus energy produced.

Case study C

The analysis of the third case showed that some laws should be in place to induce the power distribution company to buy the surplus energy would be welcome. Farm 16 is an example of this, as it possesses a high potential for energy production. However, this cannot be fully exploited until it is possible to sell the surplus production to the energy utility.

Conclusion

In situations where the consumption of energy in the form of electricity is considerably less than the capacity of biogas production, as is the situation on small rural properties, the installation of a biogas plant becomes invaluable due to high costs of its installation and maintenance.

However, under balanced conditions, when faced with other alternative sources of energy, biogas is economically viable, as it represents a great investment potential with a guaranteed return, in those cases of high efficiency. In other words, the almost complete conversion of the biogas produced in the installation into electric energy can be achieved. In those cases the surplus should be sold. Nevertheless, there is still the use and/or selling of the biofertilizer generated, and finally the participation in the carbon credits market when such credits are sold through the appropriate entities. All three cases analyzed show that the use of biogas from wastes of pig farm is economically viable, since the biogas is nearly totally used for electrical power generation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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