18th Brazilian Congress of Thermal Sciences and Engineering
November 16-20, 2020, Bento Gonçalves, RS, Brazil

PRODUCTION OF SUSTAINABLE ELECTRICITY IN THE CITY OF ANGRA DOS REIS/RJ, BRAZIL.

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Abstract. *The energy crisis and the search for low-cost renewable energy sources are contributing to the appealing of biogas. One of the sources applied in the production of this type of fuel is the use of organic waste, that is, transforming what would be discarded into a product with added value. Due to the importance and feasibility of obtaining this fuel, this study aimed to evaluating the electricity generation capacity via energetic use of biogas produced in a wastewater treatment plant. The wastewater treatment plant used in this study is currently in the phase project (approved by the city of Angra dos Reis). This plant has an average affluent flow of 25 l/s. Concomitantly to the study of this plant, an assessment of the region's power was also carried out in terms of number of inhabitants to establish the potential for a likely standardization in the region's wastewater treatment plant. In the study, the treatment plant had a production capacity of 9.69 m^3/h of biogas, a potential of electricity generation of 125.22MWh/yr, considering the standardization of the sanitation this production could reach 70.67 m^3/h, a potential of electricity generation of 913.48 MWh/yr. The study of economic viability, using tools such as Playback and NPV, demonstrated that the investment with the plant for the use of biogas is quite feasible. The gain from the sale of carbon credits was also assessed. In addition to being economically viable, the environmental gain is beyond measurement.*

Keywords: *Wastewater treatmen, Biogas, Energy production, Renewable energy, Electricity*

1. INTRODUCTION

Due to the intensifications of human activity in the last decades, there has been an exponential increase in the generation of waste; a great concern to public administration. Urban waste deposited in inappropriate locations such as landfill cause soil, air and water pollution promoting the appearance of disease vectors.

According to IBGE 2010, half of the five thousand Brazilian cities have the landfill as the final destination for their urban waste. The absence of collection and treatment of a considerable part of the generated wastewater, for instance, may lead to environmental, health care impacts and, therefore, a detriment to the life quality of the population. It is estimated that 65 % of hospital admissions of children under the age of 10 are caused by the inefficiency or the absence of wastewater treatment and lack of clean and potable water (BEN, 2018).

The recent increase on electricity rates contributes to the appealing of energy generation in Brazil. In addition to rates, the motivation is justified by the low investment in the expansion of large transmission systems and energy distribution, the low environmental impact, the minimization of losses and by the diversification of national energetic matrix (ANEEL, 2015).

According to Karlsson et al., (2014), Brazil has taken slow steps in the implementation of biogas in its energetic matrix in comparison to the international panorama. Despite being a country with a large part of its energy obtained from renewable energy and being one of the leaders in the use of biomass in energy generation, the investments on public policies for biogas are not encouraged enough in Brazil. Even though there are results that show that the country would technologically be able to develop a great program nationwide on biogas.

Thereby, the fundamental goal of this study is to evaluate the potential of electricity production from biogas of wastewater treatment plant (ETE). The study also includes the analysis of economic viability in the implementation of a plant the employs biogas burning generated by an internal combustion engine coupled to a generator. The electricity produced would be distributed in the network which contributed to the diversification of Brazilian electric matrix making it more sustainable with the use of renewable sources.

2. METHODOLOGY

This work is based on a case study to determine the viability of a plant implementation to generate electricity from biogas of wastewater treatment plant using an internal combustion engine in the city of Angra dos Reis. The treatment facility managed by SAAE of Angra dos Reis, is expected to be built in the location known as Praia da Chácara, and it will use an Upflow Anaerobic Sludge Blanket reactor followed by a Biofilter of Organic Matter and Secondary Decanter with an affluent average flow of 25 l/s proposed by the company SANEVIX ENGENHARIA. Although the implementation includes the most suitable reactor for energy use, the company did not present the option of energy reuse from the gas which will be burnt in a Flare.

2.1 Affluent wastewater flow

The amount of wastewater that will feed the treatment plant in the project is 25 l/s, a flow from small size plant that will serve a small territory. According to Chernicharo et al., (2006), the affluent wastewater flow can be also estimated by the population served as shown in equation 1. Thus, both scenarios are analyzed. One is the real flow, 25 l/s, and the other is the relative flow considering that all the population is being served by a regional hypothetical wastewater treatment plant.

$$Q = \frac{Q_{Hab} \times C_r \times Pop}{1000} \quad (1)$$

In which:
Q – Affluent wastewater flow in the wastewater treatment plant (m^3/d).
Q_{Hab} – Per capita contribution flow (l/inhab.d).
C_r – Coefficient of recycle of wastewater/water per capita.
Pop - Population (Hab).

2.2 Volume of biogas produced in UASB reactors

According to Von Sperling (2005), it is acceptable to use 300mg/l and 600mg/l of BOD and COD respectively, due to the physical chemistry characteristics of sanitary wastewater. These values of BOD and COD are the same as the ones proposed in the project.

Chernicharo et al (1999) stated that the biogas production is directly proportional to the total removal of organic load in the reactor. The COD from the effluent depends on the efficiency of the reactor as shown in equation 2.

$$E_{COD} = 1 - 0{,}68 \times HRT^{-0.35} \quad (2)$$

In which:
E_{COD} – Efficiency of COD removal in the UASB reactor (%).
HRT – Hydraulic retention time (h).

Pecora (2006) recommended hydraulic retention time (HRT) of 6 to 10 hours. The hydraulic retention time adopted in this study is 8 hours.

According to Chernicharo et al. (1999), the removed organic load in the reactor can be obtained by equation 3.

$$COD_{util} = [Q \times (S_0 - S)] - (Y_{obs} \times S_0 \times Q) \quad (3)$$

Where:
COD_{util} - Organic load converted to methane (kgCOD/d).
Q - Affluent flow (m^3/d).
S_0 - affluent COD to UASB (kgCOD/d).
S - effluent COD to UASB reactor (kgCOD/d).
Y_{obs} - Coefficient of Total Suspended Solids production (kgCODsludge/kgCODapplied).

The methane flow produced in m^3/d is the ratio between the organic load converted to CODutil by the correction factor to an operational temperature $K_{(T)}$, as shown in equation 5.

$$Q_{CH4} = \frac{COD_{util}}{K_{(T)}} \quad (5)$$

The biogas from domestic wastewater has a concentration of 60 to 70% of methane depending on the organic load. The value used in this calculation was 60% of methane in its composition. Another estimate is referring to the losses of methane to the theoretical production around 40%. Thus, all unfavorable conditions such as leaks or a diluted gas on the effluent have been considered (PEROVANO & FORMIGONE, 2011).

2.3 Potential of biogas generation in UASB reactors

The electricity produced from biogas can be estimated by equation 7.

$$P_{generation\ EE} = \frac{(Q_{biogas} \times 365)}{1000} \times \frac{LCV \times \eta_{engine} \times \eta_{generator} \times C_s}{C_{kw}} \quad (6)$$

In which:
$P_{generation\ EE}$ – Potential of electricity generation (MWh/yr).
LCV – Lower calorific value of biogas (5167.46 kcal/m^3).
η_{engine}– Engine efficiency (%).
$\eta_{gerador}$ – Generator efficiency (%).
C_s – Coefficient that adjusts the plant operation throughout the year (considering an operation of 8000 hours during a year) (91%).
C_{kw} – Conversion of kcal to kWh (860.42 kcal/kWh).

The yield of motors of Otto cycle vary between 30 to 34% according to Pecora (2006). The electric generator has an efficiency between 90 to 97%; to be on the safe side, the lowest values will be used for both cases.

2.4 Economic Viability

The economic viability will be assessed by an extensive analysis of all costs involved in the implementation of the plant as well as the annual revenue. Tools such as investment recovery, Payback and Net Present Value - NPV will be studied.

Any investment project has an initial period of expenses that is followed by a net revenue period. Payback is the period in which all expenses are covered up by the revenues. This period can be considered with or without an updated cash flow.

2.4.1 Cost with implementation of the unit

We will evaluate the cost of implementation of the unit that attends the demands of the project and size of the Treatment Plant. According to the studies by Pecora (2006), the cost/benefit with a generator group (Otto cycle) is higher than microturbine, another common equipment in units of biogas usage.

Besides equipment costs, the cost of operation and maintenance must be estimated as well. According to Souza et al. (2004), the expenses with operation and maintenance present annually, about 4% of the total investment of the unit. The estimate cost with operation and maintenance is calculated in equation 8.

$$C_{o\&m} = \left(C_d + C_p + C_{gas} + C_{gg} + \alpha\right) \times 0.04 \quad (7)$$

In which:
$C_{o\&m}$ – Cost with operation and maintenance.
C_d – Cost of investment with dehumidifier.
C_p – Cost of investment with purifier.

C_{gas} – Cost of investment with gasometer.
C_{gg} – Cost of investment with generator group.
α – Diverse cost with flowmeter, pipelines, valves and connections, peripherical and structure.

2.4.2 Cost of electricity generation

According to the methodology of Silveira, et al. (2012), applied by Xavier (2016), the cost is calculated by equation 10. In this method, the cost is estimated by the ratio between the initial investment of the project and the potential of electricity generation amortized according to a rate of interests added to the cost of operation and maintenance.

$$C_{el} = \frac{(Inv_{plant}) \times f + C_{o\&m}}{P_{generation\ EE} \times 1000} \quad (8)$$

In which:
C_{el} – Cost with electricity production (R$/kWh).
Inv_{plant} – Total investment with the unity (R$).
$P_{generationEE}$ – Potential of electricity generation (MWh/yr).
f – Annuity factor (1/year).
$C_{o\&m}$ – Cost with operation and maintenance (R$/kWh).
k – Useful life of the unit.
i – Interest rates.

2.4.3 Revenue from electricity added to the distribution network

According to ANEEL (2018), a compensation system is carried out in which a loan consisting on the energy produced by consumption unit is covered by the energetic consumption of this unit. The quantity added to the network is deducted from the consumption.

The revenue is given by equation 9.

$$Revenue = P_{generation\ EE} \times (R_{final} - C_{el}) \times 1000 \quad (9)$$

Onde:
R_{final} – Weighted average rate (R$/kWh).
R_{Ep} – High demand energy consumption rate (R$/MWh).
R_{USDP} – Distribution system use rate – peak hours (R$/MWh).
H_{FP} – Volume of hours outside the peak (hours).
Revenue – Annual profit generated by electricity added to the distribution network (R$/yr).
C_{el} – Cost with electricity production (R$/kWh).
$P_{generation\ EE}$ – Potential of electricity generation (MWh/yr).

3. RESULTS AND DISCUSSION

3.1 Affluent flow

The project proposed the implementation of a unit with capacity of 25 l/s of affluent sewage, that corresponds to 2,160 m^3/d. As equation 1 is applied, the production of wastewater in relation to the quantity of inhabitants in the region can be estimated.

According to IBGE (2018), the current population of Angra dos Reis is around 200,000 inhabitants, 84.9% of them have “adequate sanitary sewage” thereby, 169,800 inhabitants receive adequate sewage treatment. To evaluate the potential of the region in terms of biogas production, 84.9% of the sewage will be considered as the volume of wastewater converted to biogas. The contribution flow per capita in Brazil in 2018 was 116 l/hab.d, and in developed countries this value is approximately 200 l/hab.d. The return coefficient is a standardized value and sewage companies adopt a value of 0.8 (SABESP, 2018).

Considering the population size of the region and applying equation 1, the affluent sewage flow is 15,757.44 m^3/d. It is worth noting that this value is higher than the proposed project to the city of Angra dos Reis. The value obtained from equation is the real capacity of the region and it will used concomitantly with the project unit calculations (lower capacity) to compare the potential of the region in the usage of biogas if all sewage was treated.

3.2 Volume of biogas

From equations 3, 4, 5 and 6 and using 0.2 as the Coefficient of Total Suspended Solids Production the volume of biogas is predicted to be 387.48 m^3/d in the region. As for the real capacity of the region, in case the sanitation quality reached an expressive value of inhabitants, the volume of biogas would be higher than 2826.72 m^3/d. These values are taken into consideration a biogas with a composition of 60% methane.

Considering the pertinent operational losses, around 40%, the approved WWTP would have a biogas production of 232.49 m^3/d (9.69m^3/h) and the biogas production related to quantity of all inhabitants from the region would be 1,696.03 m^3/d (70.67m^3/h).

3.3 Energetic potential of biogas generation

From equation 7, applying the proper considerations (efficiency of engine of 30% and generator 90%), the energetic potential is 125.22 MWh/yr. When the whole region capacity is taken into consideration, that is, the production of sewage per inhabitant, the energetic potential is 913.48 MWh/yr. Table 5 compares results from other authors in terms of daily biogas and electricity production.

Table 1 – Comparison of other authors, in different cases, in relation to the usage of biogas in the electricity production.

AUTHOR	BIOGAS(m³/d)	ELECTRICITY(MWh/yr)	OBSERVATION
BRITTO & ANDREO (2017)	1349.88	956.66	*MCI145 kW
COSTA (2006)	240	150	MCI 30 kW
PECORA (2006)	216	96.78	MCI 14 kW
LITTIG (2011)	6.63	2.36	MCI 3.6 kW

*ICE- Internal Combustion Engine

3.4 Cost with implementation of the unit

The unit budget approved by the City Hall (plant using a biogas flow of 9.69 m^3/h) has a list of all equipment required to convert biogas into electricity according to the calculation done by the Chinese company Shandong Tiger Machinery Technology Co., ltd. The values are presented in table 2 are already converted to Reais.

Table 2 – Budget of project unit (9.69 m^3/h of biogas).

EQUIPMENT	COST
Generator Group 25kW and accessories*	31,459.00
Purifier	5,790.00
Gasometer (20m³)	1,621.20
Shipping	1,910.70
Federal and State Taxes**	20,428.71
Other Expenses	877.68
TOTAL	**62,087.29**

* Accessories are comprised of a system of frequency automated control, silencer and control panel.

** Custom charges were obtained by the table of calculations of Plus Brasil Logística LTDA.

3.5 Cost of electricity generated

The cost with electricity generation is calculated by equations 10, 11 and 12, in which the cash flow is amortized throughout its useful life by the annuity factor that will be obtained by interests of 15%, 12% and 8%, shown in Figure 1 below.

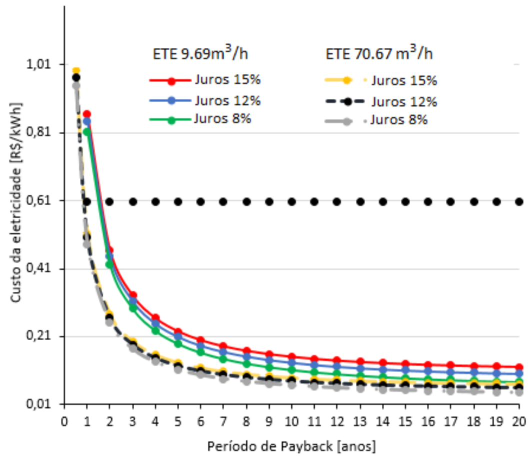

Figure 1 – Cost of electricity generated throughout the useful life of units.

The cost with electricity production decreases with time for different amortized rates (15%, 12% and 8%). Thus, in 1 year and 6 months the unit with production of 9.69 m^3/h of biogas presents a cost of electricity lower than the rate charged by the local distributor. In the case of the unit with biogas production of 70.67 m^3/h, the energy production cost is lower than the rate charged after about 1 year of operation.

3.6 Economic viability

3.6.1 Payback

The Payback was obtained from an analysis of cash flow year by year, in terms of revenue obtained from the usage of biogas to produce electricity and it was calculated by equation 14.

The revenue consists of the difference between the local energy rates, this is calculated from the weighted electricity rate applied by Enel in 2018 (table 4, calculated by equation 13) and by the cost with electricity production throughout useful life of the unit (20 years).

Table 4 – Distribution rates of Enel - RJ.

	PEAK HOUR RATES		NON-PEAK HOUR RATES		
DISTRIBUTOR	TUSD	TE	TUSD	TE	**FINAL RATE**
Enel – RJ	R$ 865.85	R$ 396.03	R$ 266.45	R$ 248.02	R$ 607.89

The assessment of the annual revenue from the electricity produced by the 9.69 m^3/h unit revealed an investment return (Payback) of 1 year and 6 months. As for the unit with biogas production capacity of 70.67 m^3/h, the investment return was between 9 months to 1 year of operation. The analysis of Payback shows that the usage of biogas in the production of electricity is a profitable option and it has a fast return. As this biogas is a by-product that would generally be burnt in a flare, its usage, in an efficient way, provides a more noble destination of this residual producing a low-cost fuel that activates the generator group.

Another factor that affects the investment return time is the equipment value. All the equipment of the lower capacity unit is imported; the price is highly competitive to national equipment. Maybe the lack of investment in this area explains the lack of technology and prices that are less attractive nationally. .

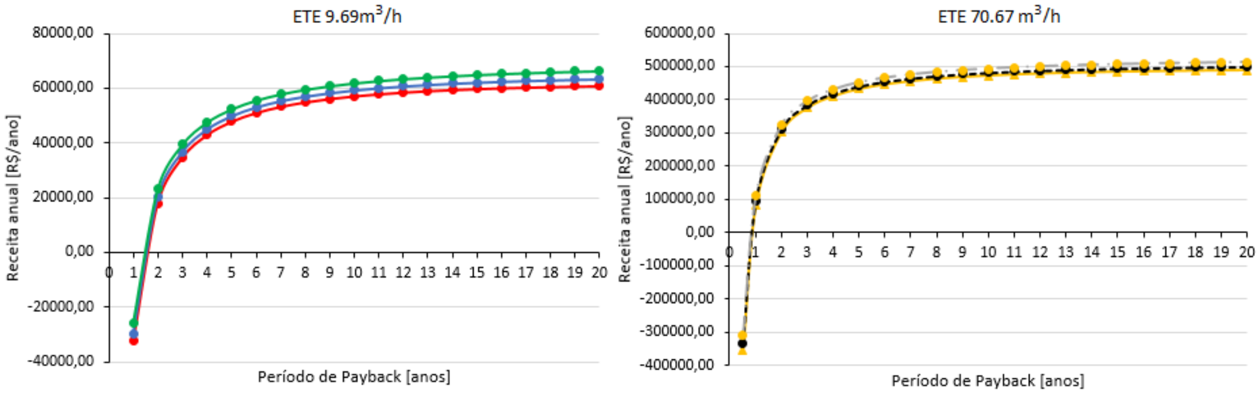

Figure 2 – Annual revenue with electricity produced to both units

A similar study done by other authors such as Pecora (2006), evaluated the usage of biogas generated by the wastewater treated from the Residential Complex of USP (CRUSP) in reactors UASB, continuous operation with capacity of production of 9 m^3/h showed that the economic analysis had an investment return, a Payback, of 10 months and 22 days.

According to Xavier (2016) who assessed the efficiency of a cogeneration system from different types of fuel (synthesis of gas, biogas and natural gas), in a plant with an internal combustion generator with production capacity of around 200 kW, the biogas was the one that showed more efficiency in comparison to other fuels. The investment return of the plant fed with biogas was around 2 years, while the natural gas was between 3 and 4 years and the synthesis gas was not feasible.

Britto & Andreo (2017), evaluated the biogas usage produced by a unit of wastewater treatment with capacity to serve 100,000 inhabitants with an internal combustion engine generating a power of 180kVA/145kW. The investment return (Payback) was approximately 4 months and 21 days (not considering the electricity cost of the unit itself).

The results obtained by other authors demonstrate the importance of research towards renewable alternatives of energy production giving emphasis in the usage of biogas. A process residual 21 times more harmful to the greenhouse effect than carbon dioxide with guarantees of investment return in a short time as shown in the different related studies.

4. CONCLUSIONS

The biogas generated from Wastewater Treatment Plants that use anaerobic digestion presents an energetic potential that is very little exploited. This may be due to the high investment on equipment or the lack of national technology that hinder its wide application.

The economic viability assessment showed that the usage of biogas from the wastewater treatment plant approved by the city of Angra dos Reis, other than burning the biogas, results on a very promising economic energetic capacity with a production of 125.22 MWh/yr.

The Payback analysis of three different interest scenarios resulted in an investment return of around 1 year and 6 months; the lower the interest rate, the faster the return. The analysis of NPV was positive after 7 years of the plant operation to the attractiveness interest rate of 15% and 12%, while 8% of interest resulted in a positive NPV after 6 years of operation.

The unit, already approved by the city, is a small size plant with reduced capacity. However, the if the total potential of the region was used in its full capacity, the energy production would be 913.48 MWh/yr, and the investment return (Payback) would be lower, around 9 months. The study of NPV to a higher capacity unit resulted positive in only 4 years of operation to an attractiveness rate considered independent of the interest rate applied.

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