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# ANALYSIS OF VIABILITY OF COGENERATION IN THE ENERGY GENERATION PLANT IN A HOTEL AND A SHOPPING LOCATED IN CARUARU

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***Resumo:*** *The objective of this work was to perform an ex-economic analysis in the distributed generation plant located at the Hotel Caruaru Park and Shopping for the implementation of a cogeneration system. The hotel and shopping has electric generators that are powered by internal combustion engines, which operate on the second Diesel Cycle and produce a maximum output power of 3960 KVA. An exergetic analysis of the available energy in exhaust gases at the exit of the motors was carried out, being directed to the drive of a cogeneration system using a vapor absorption refrigeration machine and a water heating system. The generators are activated at peak times when electricity has its highest cost, the cogeneration system would allow in addition to the reduction of the cost of electricity in the peak hours also benefit from the decrease of the electric consumption in the conventional refrigeration system of the Hotel and Shopping. The modeling of the system and the simulation in the EES (Engineer Equation Solver) were performed, the results showed that it is possible to implement a cogeneration system for water heating with little return time.*
***Key-words****: Cogeneration, Economic analysis, Absorption refrigeration.*

## 1. INTRODUCTION

### 1.1. Current scenario

Currently, the growth of electric energy consumption in Brazil is greater than economic growth (GDP), a large portion still originating from non-renewable matrices, bringing to the fore the need for theoretical and practical policies and studies, about potential energy generation systems, especially those of distributed generation: diesel / gas generators, photovoltaic and wind power generators.

Currently, energy production is still under the pillar of non-renewable energies, data from ANEEL (2016) point out that production in that same year was due to a 27% non-renewable matrix, mainly from thermoelectric plants. And because of the frequent droughts in the hydroelectric basins, thermoelectric plants have been constantly being activated, which reflects in the increase of energy costs (given through tariffs and readjustments) for the consumer and environmental impacts.

According to ANEEL (2015), in 2014 the consumption of electricity by industrial and commercial means was approximately 61% of the total produced this year. In shopping malls the electric consumption is mainly due to the air conditioning systems by electric chillers, which represent 50% of the total consumption. It is also accepted that in peak times where the flow of people also increases and energy reaches its highest price by the concessionaire, there is an increase in the need for thermal load of refrigeration, resulting in higher costs for the sector. These undertakings, however, have a high feasibility of having in their generation plants, cogeneration systems of energy that reduce the amount of electric energy consumed by the concessionaire.

### 1.2. Cogeneration in Brazil

Cogeneration is defined as the combined generation of more than one form of energy as product in the same system. That is, in a cogeneration system it is possible, in addition to the production of electric energy, the production of thermal energy for heating water or for the production of ice water in absorption chillers. It is therefore sought in these systems to increase the efficiency of the process. Cogeneration takes advantage of some of this energy, which would inevitably be lost in the form of heat and thus increase the efficiency of the thermal cycle (Costa e Silva, 2000).

In the 1960s, RB Evans, YM El-Sayed, RA Gaggioli and M. Tribus, among others, began to work on the analysis, optimization and design of thermal systems using concepts of thermodynamics associated with economics to increase efficiency and reduce costs (Tsatsaronis and Pisa, 1994). But it was only in the 1990s that cogeneration became popular in Brazil, when the national energy scenario went into great difficulties, with uncertainties in energy supply. Initially the cogeneration systems were implanted in the sugar and alcohol industry, with the objective of producing energy from the burning of sugarcane bagasse.

ANEEL created several incentive policies starting in 2003. Among the policies for cogeneration is the program for qualified cogeneration launched in 2006 for energy producers that meet the various requirements established in Normative Resolution No. 235/2006.

In Table 1, we can see the reflection of this measure in the Brazilian energy matrix in 2017, qualified and unskilled cogeneration (UTE), accounting for 24.82% of energy production in that year. Cogeneration plants using biomass as fuel need not necessarily meet these requirements to participate in the incentive program.

**Table 1. Summary of the Brazilian energy matrix and participation of cogeneration.**

| Code | Type | Nº of power plants | Granted power (KW) | % |
|---|---|---|---|---|
| **UHE, PCH, CGH** | Hydroelectric plant | 1262 | 98.080.942 | 67,01 |
| **UTE** | A qualified cogeneration | 98 | 4.234.310 | 2,74 |
| | Separate generation and cogeneration not qualified | - | 39.599.531 | 22,08 |
| **UTN** | Nuclear | 2 | 1.990.000 | 1,31 |
| **EOL** | Wind power | 424 | 10.393.742 | 6,86 |
| **Total** | | | 154.298.525 | 100 |

Source: adapted from ANEEL, 2017.

### 1.3. Goals

This work aims to perform an energy, exergética and financial analysis in the plant of generation of a mall and of a hotel located in the Agreste of Pernambuco, in the city of Caruaru. The general objective is to verify the financial viability of the implementation of two cogeneration systems, which have as products, besides electricity, cold and hot water, having as primary drive Diesel Cycle combustion engines with a total electric power of 3960 KVA.

## 2. PROPOSAL COGENERATION PLANT

At the site there are nine motor-generator groups used for the generation of distributed electric power and that, due to its capacity the system, fits in the mini generation classification. STEMAC Generator Sets provide the generator sets. The engine used is the SCÂNIA model DSC 11. The generator is from the WEG model GTA.

**Figure 1. Hotel generator group.**

In figure one it is possible to see the two motor-generators group used for the energy production of the hotel. The other seven generator sets are located in the nearby area, which would make piping connections viable.

The objective of the proposed system is to realize the heat of combustion of the motors for the production of hot and cold water, through absorption chillers and a heat regenerator, respectively. The excess of cold water will be stored in the thermal reservoir already in the mall, which stores cold water through the operation of compression chillers. This way, it is foreseen a saving of energy coming from the smaller activation of the compression chillers.

The heated water will be stored in an industrial tank that will be purchased together with the system. His quotation was made at a company in the area, which provided the exact value of its construction and on-site installation.

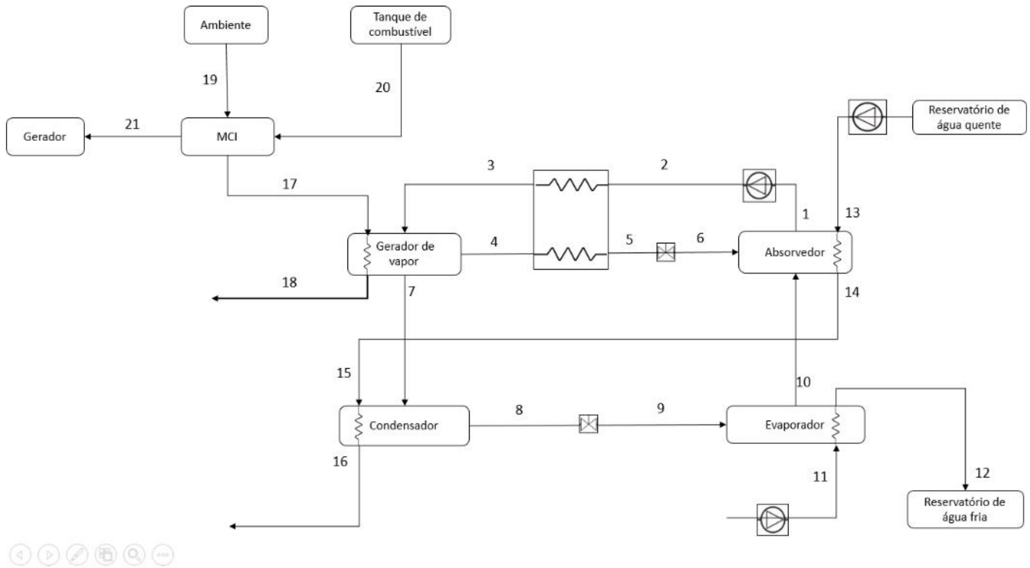


**Figure 2. Co-generation system proposed for the hotel and the shopping center.**

The system has two recirculation pumps for cold water and hot water. And a pump for pumping the working pair Water - Lithium bromide cooling system.

For the modeling and design of the vapor absorption refrigeration system, the methodology available in Herold (1996) was used for a simple effect system, as shown in figure 2. The system solution was implemented in the EES and had some of its parameters analyzed and optimized for the case.

## 3. METHODOLOGY

### 3.1. Measurement of variables in loco

For the initial point of this work, measurements were made of some important variables in loco, the objective was to verify the temperature of the exhaust gases and the electric energy generated by the system. The measured data of the exhaust gas temperature can be seen in figure 3.

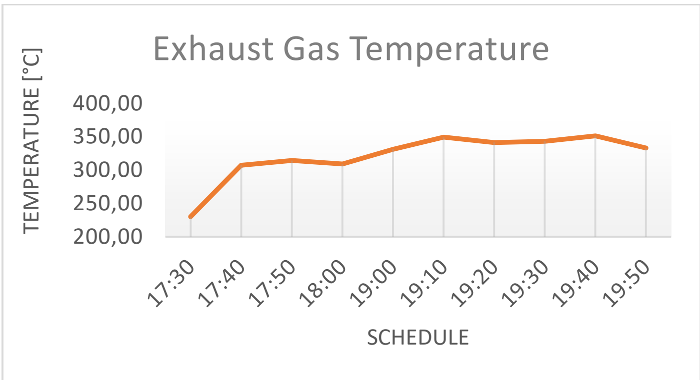


**Figure 3. Average exhaust gas temperature of the generators.**

However, these measured data did not show consistency with the data declared by the generator manufacturer (WEG) and the engine (SCANIA). It was therefore preferred to use the data provided in the datasheets by SCANIA.

### 3.2. Energy analysis

The energy balance in the system components was performed through the following mathematical inequality applied to the control volumes:

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_s * (h_s + u_s + V_s) - \sum \dot{m}_e * (h_e + u_e + V_e) \quad (1)$$

Neglecting all potential and kinetic energy and considering the system in permanent regime, we have:

$$0 = \dot{Q} - \dot{W} + \sum \dot{m}_s * h_s - \sum \dot{m}_e * h_e \quad (2)$$

### 3.3. Exergy analysis

The exergy balance in the components of the system can be realized through the following mathematical inequality applied to the control volumes:

$$\frac{dE}{dt} = \Sigma\left(1 - \frac{T_0}{T_f}\right)\dot{Q} - \left[\dot{W} - p_0.\frac{dV}{dt}\right] + \sum \dot{m}_e.e_e - \sum \dot{m}_s.e_s - \dot{I} \quad (3)$$

Considering a system running on a permanent basis, we have:

$$0 = \Sigma\left(1 - \frac{T_0}{T_f}\right)\dot{Q} - [\dot{W}] + \sum \dot{m}_e.e_e - \sum \dot{m}_s.e_s - \dot{I} \quad (4)$$

The exergetic analysis of the exhaust gases represented the first plane a problem, due to its division between its chemical exergetic and physical component. Therefore, it was considered that exergy of the exhaust gases is only physical, since in the process of exhaustion the chemical reactions are irrelevant. The Cp of the exhaust gases was obtained through a weighted average between the chemical components present ($CO_2$, $H_2O$, $O_2$ and $N_2$). To reduce the Cp error due to temperature variation, an empirical correlation was adopted to calculate the error, providing a final error lower than 0.95%.

$$\overline{C_P} = a + b * T + C * T^2 + d * T^3 \quad (5)$$

**Table 2. Constant of the equation 5 exhaust components.**

| Constant/component | a | b | c | d |
|---|---|---|---|---|
| CO2 | 22,26 | 5,981e-2 | -3,501e-5 | 7,469e-9 |
| H2O | 32,24 | 0,1923e-2 | 1,055e-5 | -3,595e-9 |
| N2 | 28,90 | -0,1571e-2 | 0,8081e-5 | -2,873e-9 |
| O2 | 25,48 | 1,520e-2 | -0,7155e-5 | 1,312e-9 |

Source: Çengel (2013).

### 3.4. Financial analysis

In the financial analysis, it was vitally important to take into account all costs that encompass the plant, even if approximate. Important costs such as operation and maintenance can alter the design or even make it unfeasible. This requires the use of appropriate financial analysis methods. It is also important to correct the values by rates that are representative of their respective sectors.

For the case in question, the methods used to provide answers such as the correction of maintenance and operation expenses (O&M), investment recovery time and financial viability were respectively: Net Present Value (NPV), Payback of Return) and the IRR (Internal Rate of Return).

### 3.5. Estimates of the costs of the plant

The energy and exergetic analysis was used for two things: Sizing of the system, optimizing variables according to the exergetic power of the exhaust gases and Calculation of the thermal load of heating and cooling of water. The thermal load is used to carry out the quotation of the absorption chillers used in the cogeneration plant and also for the O & M costs.

### 3.5.1. Initial investment

The system was quoted through GASBRASILIANO DISTRIBUIDORA SA, a company of the Petrobrás system, which operates the distribution of Natural Gas piped in the Northwest region of the State of São Paulo, covering 375 municipalities. According to GASBRASILIANO, the average cost per TR and / or KW for cogeneration systems can be given in table 3. These costs are related to the thermal load of refrigeration. The costs for the recovery of heat (water heating) are already included and accounted for in these values.

**Table 3. Average cost of investment for cogeneration systems.**

| Type of system | Cost | Description |
|---|---|---|
| Absorption chiller (Stove or Direct Burning) | 1.500 USD / TR | Recovery from hot gases or hot water |
| Multi-Energy Absorption chiller | 1.815 USD / kW | Direct burning and heat recovery in the same equipment |

Source: adapted from Guide to cogeneration and electricity generation-GasBrasiliano, 2015.

### 3.5.2. O&M costs

One of the great challenges present throughout this work was the estimation of the operation and maintenance (O & M) costs of the system. As these systems are formed by rotating equipment, they need periodic maintenance. In addition, they have operating costs (fuel, operators etc.)

O & M costs can be approximated according to table 4. These costs were formed for systems in operation in the United States, in Brazil, we have the advent of high fuel costs and this factor was taken into account to define O & M costs.

Maintenance and operating costs increase year by year, considering these increases in the analysis of the financial viability of the system, O & M costs have been corrected according to the standard established by the Energy Saver - Cogeneration Feasibility Guide (2014). According to them, this representative increase is around 5 to 10% per annum. The value chosen for correction was 7% / a.

Table 5 shows the summary of costs and investments of the cogeneration plant.

**Table 4. Specific costs of maintenance and operation of cogeneration technology.**

| Cogeneration technology with | Maintenance, $ USS/kWhe produced | Comments |
|---|---|---|
| Alternative engines | \$0.018–\$0.05 | The high cost of maintenance is due to the high number of moving parts. 85% average availability. |

Source: adapted from Energy Saver-Cogeneration Feasibility Guide, 2014.

**Table 5. Investment Costs of the System, Industrial Tank and O&M.**

| Reference values for investment | | |
|---|---|---|
| Type | | Valor |
| A3 - Absorption chiller (conventional) | | USS/kW 426,14 |
| A4 - Multi-Energy Absorption chiller | | USS/kW 1850 |
| A5 - Maintenance – Cogeneration with alternate Engine | | USS/Kwhe 0,018-0,05 |
| T1 - Industrial tank (70 m³) | | R$ 120.000,00 |
| Values for O&M | Multi-Energy | USS/Kwhe 0,035 |
| | Conventional | USS/Kwhe 0,04 |

## 4. RESULTS

In this section the results of the energy and exergetic analysis of the plant are discussed, although only partially using the heat of the exhaust gases, the plant proved to be technically feasible. Providing large amounts of heat load, both for heating and cooling. Initially, code validation is performed in comparison with Santos (2005).

Subsequently the parametric analysis is done with the purpose of analyzing the condition of greater reduction of the electric consumption of the concessionaire. In the end, financial viability is discussed for two absorption systems, one conventional and one Multi – Energy

### 4.1. The validation code in the EES

To validate the code the points were compared with those of Santos (2005). It also performs the analysis of the system of simple effect comparing it to the work of Herold et al (1996). It is possible to observe the agreement with the reference work, since the same correlations were used for the calculation of the high and low pressure and the entropy of the cooling system, as well as the same library available in the EES for the water - lithium bromid.

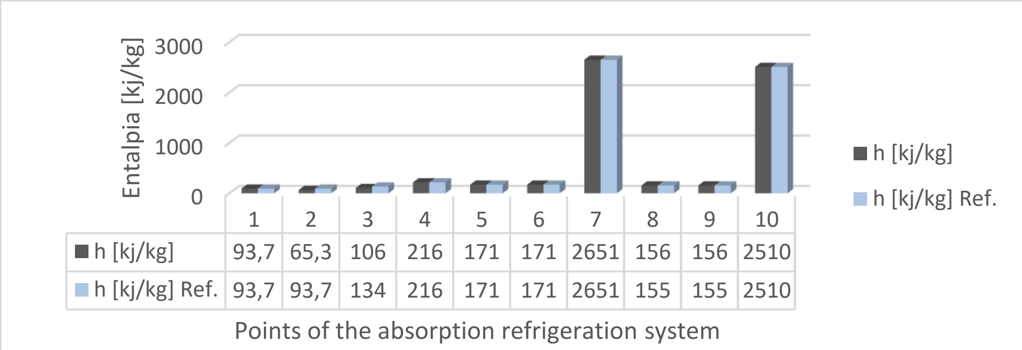


**Figure 4. Energy comparison of the system of the present work with the work of Santos (2005).**

### 4.2. Parametric analysis

The objective of parametric analysis is to evaluate and optimize certain variables so that the system presents the best operating conditions. In this way 3 variables were studied: the evaporation temperature, condensation and the temperature difference between points 17 and 18 of the plant.

#### 4.2.1. Analysis of the temperature variation of evaporation

One of the analyzes carried out was in relation to the evaporation temperature. It was observed that by reducing it, the COP had its added value, due to the influence of the less necessary power of the pump between points 1 and 2 of figure 2.

The evaporation temperature was chosen based on this analysis, where its temperature can not be less than 5 degrees, to avoid water freezing in the ducts, and so that the 5 [°C] provides the highest possible COP.

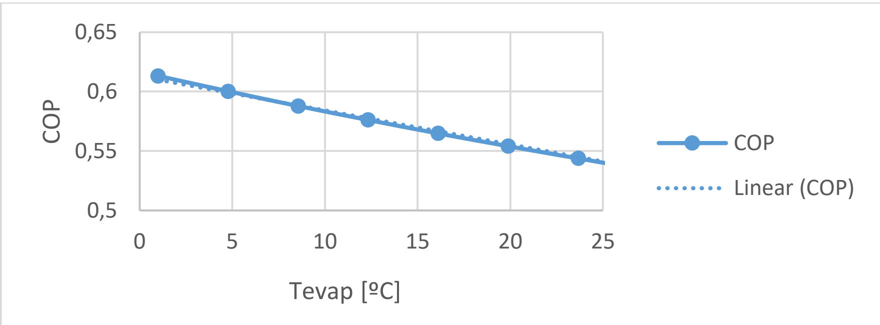


**Figure 5. Analysis of the COP to the variation of the evaporating temperature.**

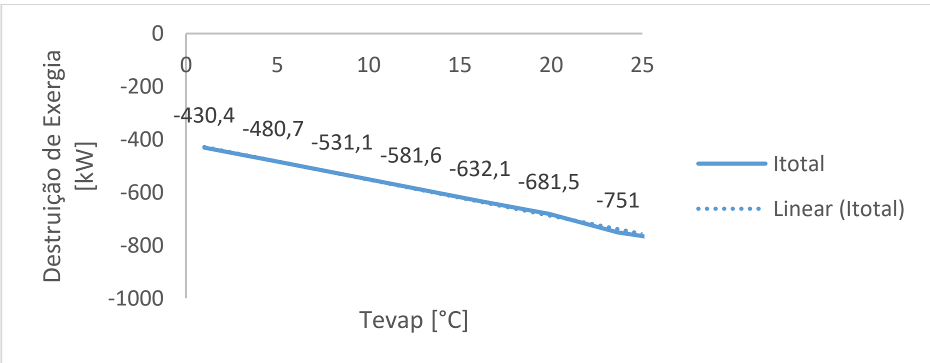


**Figure 6. Analysis of exergy destruction by evaporating temperature variation.**

The analysis of the irreversibility has showed that the system destroys more exergy as the evaporation temperature increases, as seen in Figure 6. This justifies the reduction of the POP.

### 4.2.2. Analysis of the temperature variation of condensation

Many authors and designers such as Santos (2005) and Herold et al. (1996) "set" the condensation temperature at 37 ° C, temperature also adopted in this work. This temperature is commonly adopted due to the high cost of heat exchangers which, in order to give more heat to the environment and consequently reduce the temperature of condensation, need or be greater or have more technology employed or even a larger ventilation system. In Figure 7, we can see the decrease of the COP with the increase of the condensation temperature. The "ideal" would be to keep it at the lowest possible value, however, it is not economically and technically feasible.

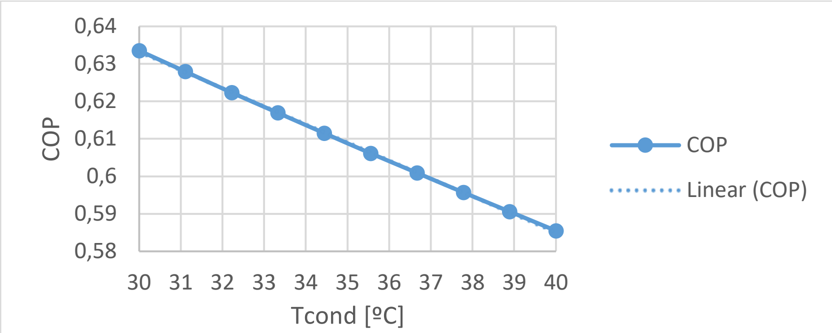


**Figure 7. Analysis of the COP for temperature variation of condensation.**

### 4.2.3. Analysis of the variation of the temperature difference of the exhaust gases

The thermal load of the steam generator is given by the difference in temperature between the outlet and the inlet of the exhaust gases, the smaller this difference is the less the amount of heat received and consequently the lower the heat load used. As the cooling load is directly proportional to the load of the generator, or to the harnessed heat, it is reduced proportionally in a linear way, as can be seen in figure 8.

The COP remains unchanged with the variation of the temperature difference of the exhaust gases.

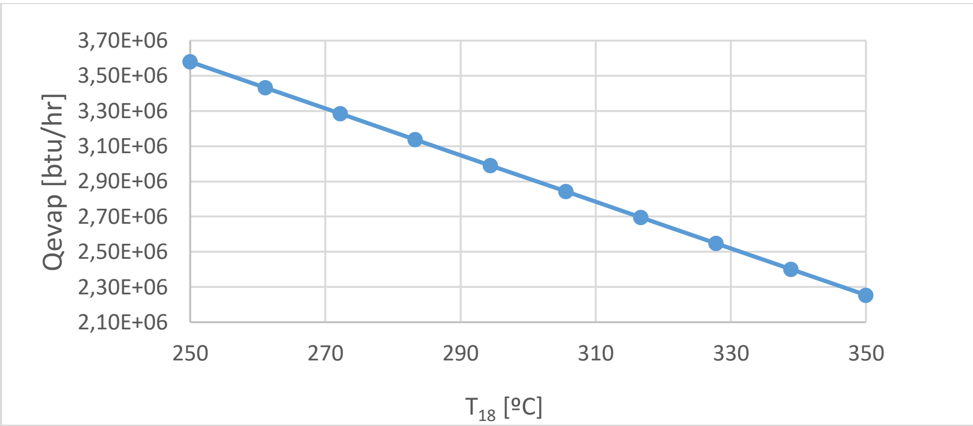


**Figure 8. Analysis of thermal load for cooling exhaust temperature variation (point 18).**

### 4.3. Reduction of power consumption

In order to evaluate the economy with heating and cooling of water, all the costs related to the electrical expenses of the operation of the refrigeration system and the recirculation pumps were taken into account. The energy rate used for the calculations was a weighted average between the peak and off-peak rates according to the consumption of water heated at these times. The amounts are updated according to CELPE for the year 2018.

Initially, a parametric analysis of the evaporation, condensation and exhaust gas temperature was carried out, in order to verify the behavior of the cost curve.

In Figure 9 it is possible to verify the behavior of the curves by the variation of exhaust gases, curves of greater importance in this analysis. This, because, the system has been sized according to the required amount of heated water.

The reason, it is simple, is that due to the greater economy provided by this, shown in figure 9, the system is more likely to have sufficient viability. Values are driven by the rate of energy increase observed in the last 6 years.

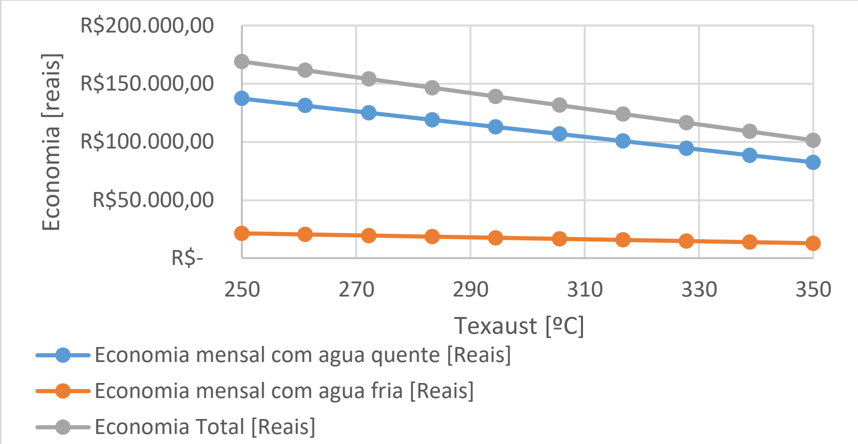


**Figure 9. Analysis of monetary economics by the exhaust temperature variation (point 18).**

## 4.4. Financial viability

### 4.4.1. Investments and O&M costs

The initial capital invested in the A4 system is perceptible, as being the highest. Although its technical feasibility is greater (lower O & M costs, higher aggregate technology and the possibility of burning other gases), investment costs will end up making it unviable under certain conditions, as will be seen in the next section.

Already the capital invested in the A3 system is much smaller, even though its O & M costs are higher, the system may become viable since its initial capital is much smaller than the A4 system.

Start-up capital is a determining factor on the viability of the investment, since it will accrue interest from the outset, in this preliminary analysis it is possible to observe that the financial viability of the A4 system is compromised.

**Table 6. Final investments for the cogeneration system of type A3 and A4.**

| Type conj. | Description | Total (With import costs) | |
|---|---|---|---|
| A3 e T1 | Conventional system | R$ | 1.275.695,45 |
| A4 e T1 | Syst. Multi - Energy | R$ | 5.072.017,80 |

**Table 7. O&M fixed system costs year after year by the rate of adjustments.**

| O&M costs | Maintenance A3 | | Maintenance A4 | |
|---|---|---|---|---|
| Descrição | O&M of higher cost | | Lowest-cost O&M | |
| Total per year | | | | |
| Year 1 | R$ | 638.668,80 | R$ | 558.835,20 |
| Year 2 | R$ | 683.375,62 | R$ | 597.953,66 |
| Year 3 | R$ | 731.211,91 | R$ | 639.810,42 |
| Year 4 | R$ | 782.396,74 | R$ | 684.597,15 |
| Year 5 | R$ | 837.164,51 | R$ | 732.518,95 |
| Year 6 | R$ | 895.766,03 | R$ | 783.795,28 |
| Year 7 | R$ | 958.469,65 | R$ | 838.660,95 |
| Year 8 | R$ | 1.025.562,53 | R$ | 897.367,21 |
| Year 9 | R$ | 1.097.351,91 | R$ | 960.182,92 |
| Year 10 | R$ | 1.174.166,54 | R$ | 1.027.395,72 |
| Year 11 | R$ | 1.256.358,20 | R$ | 1.099.313,42 |
| Year 12 | R$ | 1.344.303,27 | R$ | 1.176.265,36 |
| Year 13 | R$ | 1.438.404,50 | R$ | 1.258.603,94 |
| Year 14 | R$ | 1.539.092,81 | R$ | 1.346.706,21 |
| Year 15 | R$ | 1.646.829,31 | R$ | 1.440.975,65 |
| TOTAL | R$ | 16.049.122,33 | R$ | 14.042.982,04 |

### 4.4.2. TIR

The Internal Rate of Return is obtained through attempts between the initial value and the net final value of the investment, which is corrected by an interest rate which represents its attractiveness.

For the investment in the A3 system in a 15-year operating time, having already performed all the calculations referring to O & M expenses, the IRR resulted in a value of 11.365% / year. While the investment in the A4 system resulted in a negative rate of -0.619% / year.

The system A4 rate represents a depreciation of the investment made in the cogeneration system. The opposite of what happens with the A3 system, which generates interest at a very attractive rate.

**Table 8. The main investments yield in 2017.**

| Main investments | |
|---|---|
| Name | Interest |
| Letters of credit (LCI/LCA) | 8,55% |
| SELIC treasure (maturing in 2021) | 10,21% |
| CDB (certificate of deposit) | 10,55% |
| Cogeneration System investment A3 | 11,365% |
| Treasure IPCA (due in 2035) | 17,97% |
| MGLU3 (Magazine Luiza) | 450% |
| ABEV3 (Ambev) | 33% |
| SAAG11 (Santander) | 17% |

Available at: https://jurosbaixos.com.br. (Accessed 03 April 2018).

### 4.4.3. Payback

In order to perform the calculation and obtain the time of return of the investments, two graphs were drawn, as seen in figures 10 and 11, where the blue curves represent the expenses and investments with the system and the orange represents the economy of the electric consumption. The point at which they intersect represents the moment when the investment has been fully recovered. From then on the cogeneration plant will start to make a profit. At the end of the 15 years the profit is given by the difference between the two curves.

The payback of the A3 system occurs with approximately 9 years, the investment at the end of the 15 years of operation generates a total interest of R $ 6,411,684.54.

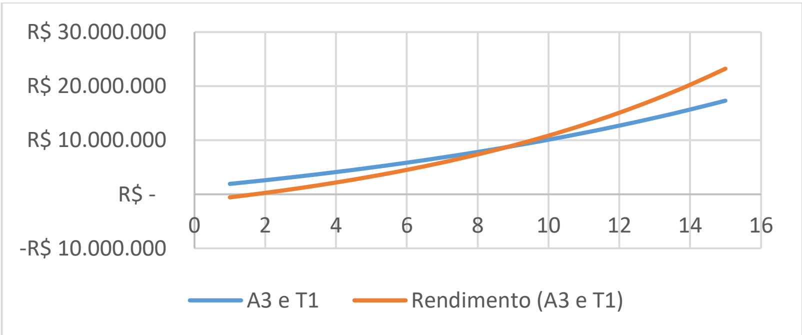


**Figure 10. Recovery time of the investment in the system A3.**

In the case of the A4 system, its viability was totally unsatisfactory from a financial point of view. The system has Payback over 15 years, which makes the system impracticable, as its useful life is 15 years. Added to this is also the depreciation of the investment, as seen in the previous section, represented by a negative interest rate.

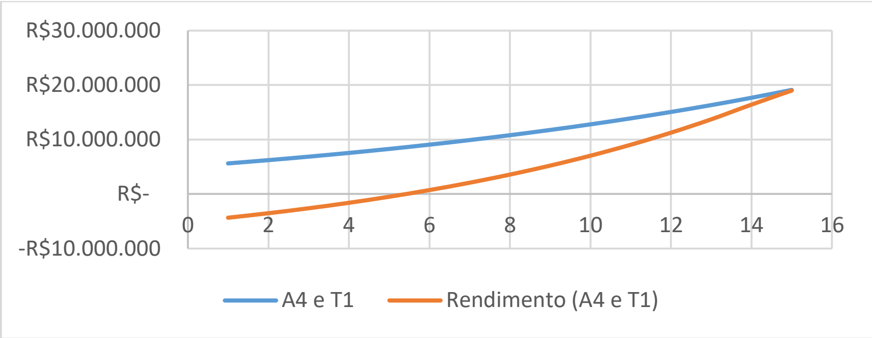


**Figure 11. Recovery time of the investment in the system A4.**

## 5. CONCLUSIONS

This work aimed to evaluate the financial viability of two trigeneration systems to operate with thermal rejects from an existing mini-generation system that operates at peak times in a Shopping and hotel in the city of Caruaru-PE.

Of the two systems chosen for the analysis, only one showed concrete financial viability, which was due to the low investment of operation, even though O & M cost higher. The A3 system showed high TIR and medium Payback, its feasibility is shown by its interest rate, placed among the largest in the market for bank bonds, that is, those with lower risks.

Relevant fact in this application, the lifetime of the system could make the A4 investment feasible. O & M costs are lower in this type of system and with a relatively high lifetime, around 30 years, the system would recover its initial contribution and would have a TIR greater than that of the A3 system. To do so, it is necessary to consider that such systems depreciate, and in reasonable possibility, would have their maintenance costs high from 15 years of operation, making the analysis of this application more complex.

One of the great difficulties encountered was related to the availability, in literature or specialized websites, of rates that represent the increase of costs with electric energy. It was necessary to develop a parallel study of the price of the last 23 years of electric energy for the industrial sector.

As suggestions and objectives for future work are the ex-environmental analysis of the trigeration plant so that, in addition to financial viability, it provides clearer results of its viability by reducing impacts to the environment.

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## 7. RESPONSABILIDADE AUTORAL

The authors H. A. Marinho Moreira and M. C. Lima Cordeiro is are the only responsible for the printed material included in this paper.