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INFLUENCE OF ENVIRONMENTAL TAXES ON THE ECONOMIC ANALYISIS OF A COGENERATION SYSTEM APPLIED TO THE COMMERCIAL AND PUBLIC SERVICES SECTOR: A CASE STUDY

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Abstract. *A cogeneration system based on reciprocating natural gas engine is presented as an alternative to the commercial and public services sector. In this work, the case studied is the current UFSC University Hospital (UH) utility plant. Actual data about electrical energy demand and fuel oil consumption were collected. These and other information collected on site allowed to obtain the daily curves of electrical energy and thermal demands (steam, hot and cold water). An energetic, economic and environmental analysis is performed on the proposed cogeneration system. Several economic scenarios were considered, including taxes due to* CO_2 *emissions (green taxes). This taxes emerged from the necessity to minimise the* CO_2 *emission due to its relation with the greenhouse effect. A sensitivity analysis is performed to investigate the impacts of the variation on electrical energy prices, natural gas prices and green taxes over the Internal Rate of Return (IRR). Despite the trend of strong variation of petroleum prices and its by-products in the international market and the trend of Brazilian currency devaluation, the system conceived is economically feasible in some of the proposed scenarios.*

Keywords. *Cogeneration, Natural Gas, Green Taxes.*

1. Introduction

The increasing necessity to use energetic resources in a rational way has lead several sectors of the society to face the energetic problem within an energy conservation context. This necessity comes from the imminent scarcity of fossil fuels and the negatives effects of the energy conversion activities over the environment. Particularly in Brazil the aspect of energy saving is important in this moment due to the electrical energy supply crisis caused mainly by: (i) lack of a government energetic policy able to attend the high economic growth of the country in the last 10 years; (ii) dry weather, once almost 90% of the electricity produced in Brazil comes from the hydro plants; (iii) low capacity of the integrated power grid.

Among this scenario, cogeneration technology is an effective alternative, since electromechanical and useful thermal energy are obtained simultaneously from the same energy source. Besides cogeneration plants are located close to the consumption sites, generally avoiding transmission lines and, consequently, reliving the load of the power grid.

Furthermore it has been noted an increasing concern about environment pollution, especially CO_2 emissions due to its relation with greenhouse effect. To minimise this problem, several European countries are taxing the CO_2, CO, SO_x and NO_x emissions due to burning of fossil fuels. These taxes are known as “green taxes”. The problem of atmospheric pollution will be greater in plants located in large urban centres, e.g. São Paulo and Rio de Janeiro. Thus, the commercial and public services sector is also responsible for a parcel of atmospheric pollution due to burning of fuel oil in boilers to produce steam and/or hot water, such as observed in hotels and hospitals. For instance, the UFSC University Hospital (UH) utility plant uses fuel oil to produce steam to the hospital processes. In this work a cogeneration system is designed to use natural gas as an alternative to the UH utility plant and an energetic, economic and environmental analysis is performed.

2. The UH environmental problem

Nowadays the atmospheric pollution generated by the burning of fuel oil in the UH utility plant's boiler deeply disturbs the community which lives in the neighbourhood. Figure (1) shows an UH view. On the right side of the street, one can see the UH water tower, where the UH utility plant is located. On the left side one can see the community, consisting of houses, residential and small commercial buildings.

CO_2, CO, SO_x, NO_x and smut result from the fuel oil combustion. The smut is the main aim of the protests generated by the community. The community and the Santa Catarina State Environment Foundation (FATMA) permanently press the UFSC direction in order to solve the problem. Some alternatives were adopted with relative success, such as electrical boilers, despite the high electrical energy costs. However the electrical boiler is only used to start the steam production.

Figure 1. UH and community view.

3. Description of the current utility plant

Fig. 2 shows a sketch of the current UH utility plant. The required products are electrical power, steam, hot and chilled water. An electrical motor driven chiller with nominal capacity of 440 kW (125 TR) provides the chilled water. The electrical power is bought directly from the local power company. A flametube boiler produces saturated steam, which is used in the hospital processes and in a heat exchanger to produce hot water. The boiler burns BPF-01A fuel oil, with a nominal steam generation capacity of 2000 kg/h. The boiler works 12 h/day, from 7:00 to 19:00. The electrical boiler is used to start the system and as backup.

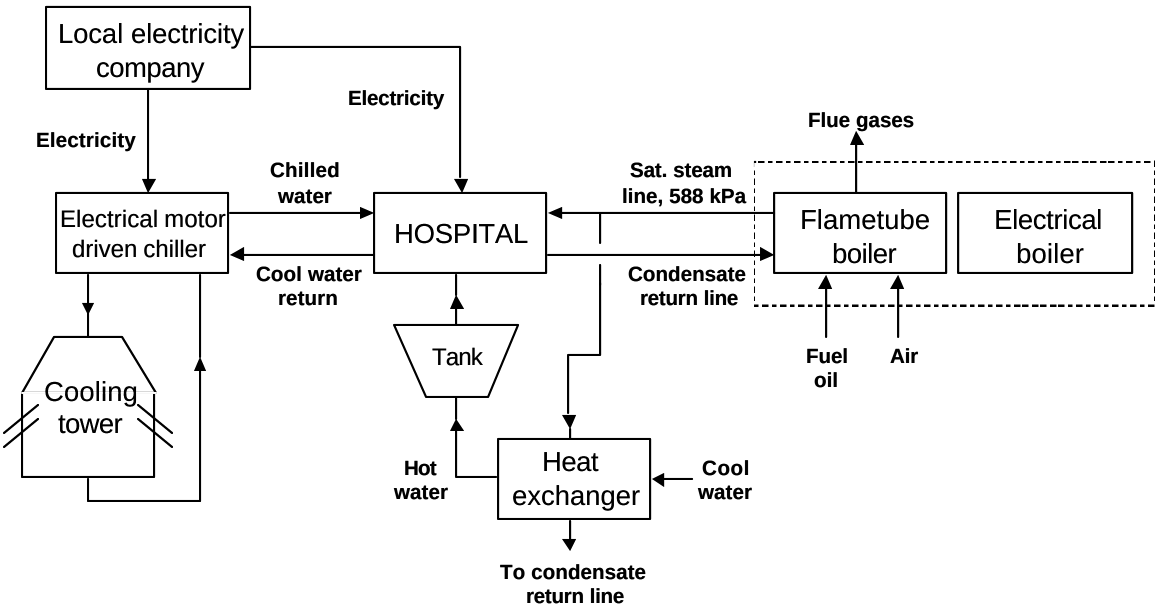

Figure 2. UH current plant sketch.

4. Data Collection

4.1. Electrical energy consumption

The electrical consumption was calculated taking into account the actual UH electrical demand readings, taken every 15 min from 05/25/2000 to 04/25/2001. Figures (3-4) represent the compiled data from the electrical demand readings. Figure (3) represents the daily average demand for June/2000. Figure (4) represents the load duration curve from 05/25/2000 to 04/25/2001. The peak observed in Fig (3) corresponds to the use of the electrical boiler to start the system. It's interesting to note in Fig. (4) that just on 300 hours of the analysed period the demand is greater than 900 kW, which corresponds the use of the electrical boiler.

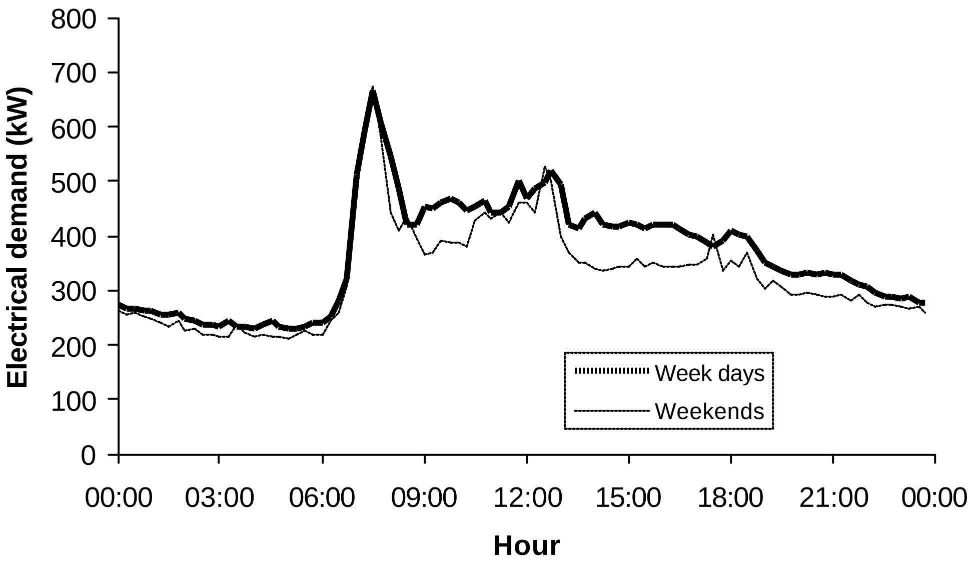

Figure 3. UH electrical demand (daily average: June/2000).

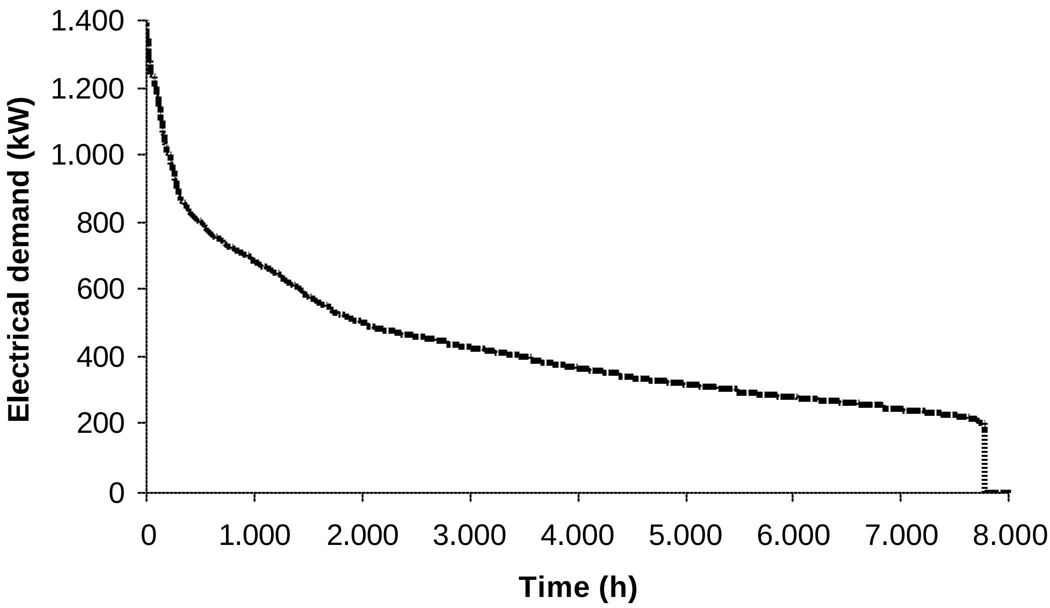

Figure 4. Load duration curve (from June/2000 to April/2001).

4.2. Thermal energy consumption

The UH thermal necessities are steam, hot and chilled water. Table (1) presents the resume of all UH thermal demands. Table (2) shows some data used to calculate the thermal demands. Saturated steam is generated at 588 kPa (6 bar) by a flametube boiler with nominal steam generation capacity of 2000 kg/h. The fuel oil consumption showed in Fig. (5) allowed to estimate the steam production in the boiler and the amount of steam used to produce hot water in the heat exchanger. It was taken into account that the boiler works 12 h/day. The chilled water is provided by an electrical motor driven chiller, with nominal capacity of 440 kW (125 TR).

Table 1. UH thermal energy demands.

Process steam	370 kg/h
Steam for hot water production	450 kg/h
Hot water*	2,5 m^3/h
Chilled water	120 TR

*Considering 80% heat exchanger efficiency

Table 2. Data to calculate the thermal demands.

Boiler efficiency	84%
Heat exchanger efficiency	80%
Condensate returning	~100%
Cool water temperature	17,5 °C

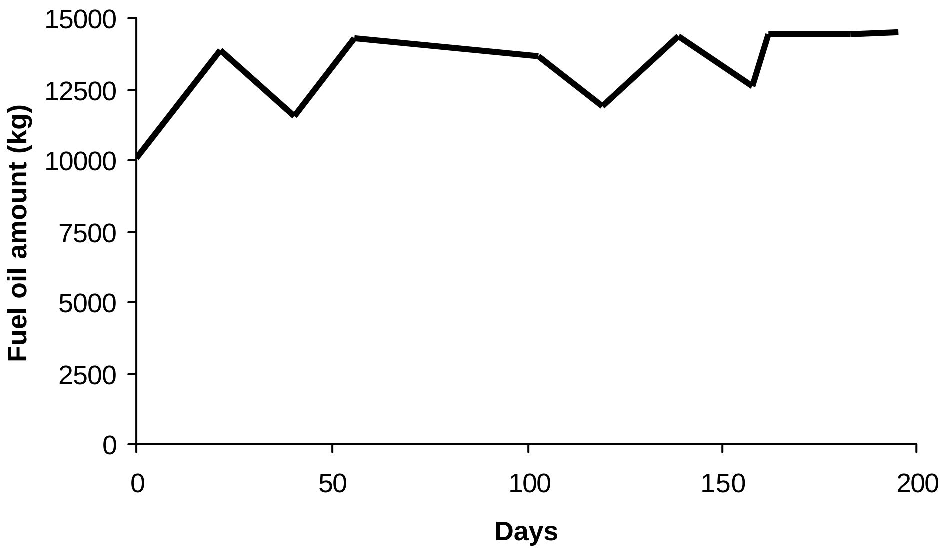

Figure 5. Fuel oil consumption

5. Proposed cogeneration system description

The proposed cogeneration system is based on two 450 kW_{el} natural gas reciprocating engine (NGRE), totalising 900 kW_{el} of electric generation capacity. The option of two NGRE gives more flexibility to the system and is sufficient to attend the electrical demand, as one can see in Fig. (4). According this figure the probability of the electrical demand be greater than 900 kW is around 3,75 % yet considering the demand associated to the electrical boiler. Once the cogeneration system would dispense the electrical boiler, the probability of the electrical demand be greater than 900 kW is practically zero. Thus the value of 900 kW is conservative. The option of the NGRE as prime mover is a good alternative due to its high electromechanical production compared with its thermal production capacity. This fact becomes the engine compatible with the typical electrical and thermal demand profiles of a hospital (Orlando, 1996).

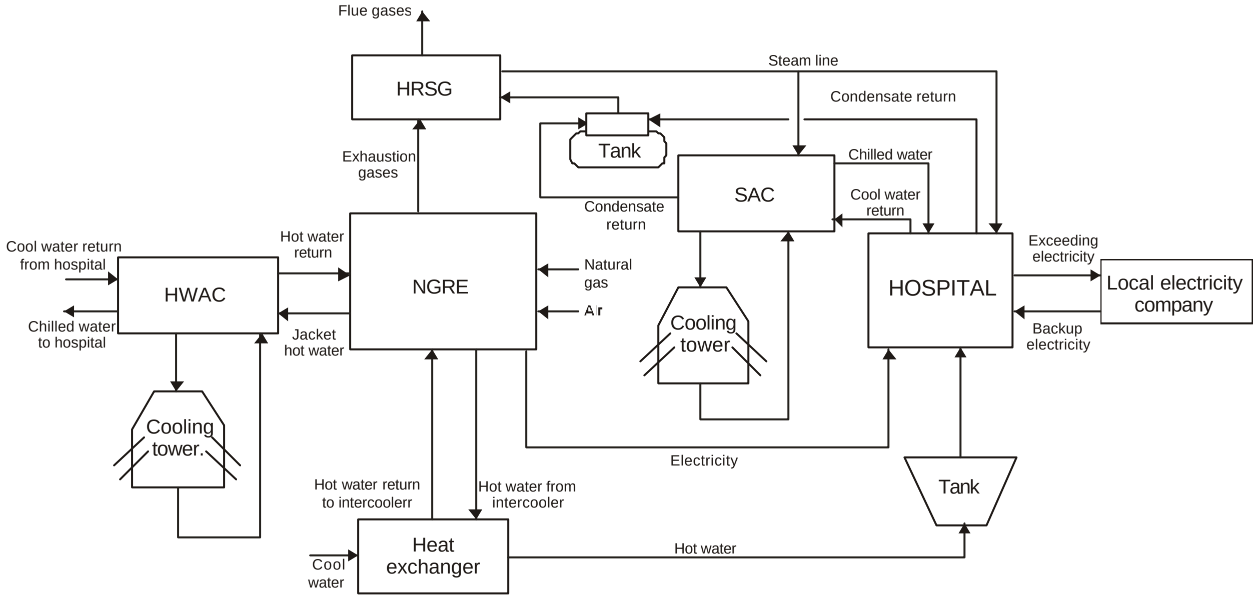

Figure 6. Sketch of proposed cogeneration system.

Figure (6) shows a sketch of the proposed cogeneration system. The heat associated to the exhaust gases is recuperated in a heat recovery steam generator (HRSG) in order to produce saturated steam at 588 kPa (6 bar). Once the steam generated in the HRSG exceeds the UH steam necessity the exceeding steam is taken to a steam absorption chiller (SAC). The heat associated to the jacket water is recuperated in a hot water absorption chiller (HWAC). The heat associated to the water coming from the intercooler is recuperated through a heat exchanger which generates the hot water to the UH. During the day, from 6:00 to 18:00, both the NGRE work and the exceeding power is sent to the power grid. During the night, from 18:00 to 6:00, or during low power demand periods and low steam consumption, only one NGRE must be kept working.

6. System simulation

6.1. Energetic analysis

An equation system with “n” equations and “n” variables is obtained from the application of the 1st Law, Eq. (1), and Mass Conservation, Eq. (2), on each component of the proposed cogeneration system. Thus, for each system and considering steady-state:

$$\dot{Q} + \dot{W} + \sum \dot{m}_i h_i + \sum \dot{m}_o h_o = 0 \quad (1)$$

$$\sum \dot{m}_i - \sum \dot{m}_o = 0 \quad (2)$$

The component’s characteristics and the UH energy demands were considered as input. The Engineering Equation Solver Software v. 6.181 (Klein and Alvarado, 2001), was used to solve the equation system.

6.2. Environmental analysis

The pollutant gases emmited by the current UH utility plant and the proposed cogeneration system were calculated. The amount of CO_2 and SO_2 were evaluated based on the stoichiometric combustion reactions, Eqs (5-8) of the natural gas and fuel oil. For the sake of simplicity the Eqs (5-8) present O_2 as the carburant. However, air were considered as carburant indeed.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (5)$$

$$C_2H_6 + \tfrac{7}{2}O_2 \rightarrow 2CO_2 + 3H_2O \quad (6)$$

$$C + O_2 \rightarrow CO_2 \quad (7)$$

$$S + O_2 \rightarrow SO_2 \tag{8}$$

The amount of CO and NO_x were evaluated considering the equilibrium constants at atmospheric pressure, Eq. (9-10) of the most relevant dissociation reactions occurring during the natural gas and fuel oil combustion, Eqs (11-13), which chemical composition are shown in Table (3).

$$\ln K = -\frac{\Delta G^0}{RT} \tag{9}$$

$$K = \frac{\prod_i Y_{P_i}^{n_i}}{\prod_i Y_{R_i}^{n_i}} \tag{10}$$

$$2CO_2 \leftrightarrow 2CO + O_2 \tag{11}$$

$$N_2 + O_2 \leftrightarrow 2NO \tag{12}$$

$$N_2 + 2O_2 \leftrightarrow 2NO_2 \tag{13}$$

Table 3. Chemical composition (Bazzo, 1995).

Fuel oil (% in mass)	Natural gas (% in volume)
Carbon – 83%	Methane – 90%
Hydrogen – 10%	Ethane – 6%
Sulphur – 6%	Nitrogen – 3%
Others – 1%	Carbon dioxide – 1%

7. Economic analysis

Three economic scenarios are considered to evaluate the Internal Rate of Return, as described in Tab. (4).

Table 4. Economic scenarios.

Scenario 1	- No government subsides*; - No exceeding power sale; - No green taxes.
Scenario 2	- 25% government subsides; - Exceeding power sale; - No green taxes.
Scenario 3	- 25% government subsides; - Exceeding power sale; - Green taxes.

* To purchase the cogeneration system components.

Basically scenario 1 is the most unfavourable situation, scenario 2 is the provable actual situation in the short term and scenario 3 is the most favourable, although reasonable, situation.

Green taxes are already applied in some European countries, such as Sweden. In the Swedish case just the CO_2 emitted due to the thermal energy production is taxed. However, Sweden is studying new climate policy scenarios up to 2010 (Silveira et al., 2001). In USA studies conducted by Hoerner & Mutl (2000) point out to 50,00USD/tonCO_2. In this work a value of 50,00R$/ton$CO_2$ is considered over thermal energy production. Tables (5) and (6) presents the parameters considered on the economic analysis. The IRR (Eq. 14) (Bejan et al, 1996) and the pay-back period (Eq. 15) (Matelli, 2000) are the methods chosen to evaluate the cogeneration investment feasibility.

$$\sum_{z=0}^{BL} Y_z (1 + IRR)^{-z} = 0 \tag{14}$$

$$n_{pb} = \ln\left(\frac{R}{R - iC_0}\right) \cdot \frac{1}{\ln(1+i)} \qquad (15)$$

Table 5. Economic analysis parameters.

Total Investment	R$2.440.000,00*
Exceeding power	R$60,00/MWh
Natural gas price	R$0,4473/$m^3$
Fuel oil price	R$0,46/kg
Current O&M costs	R$22.000,00/year
Cogen. O&M costs**	R$20,92/MWh
Current power costs	R$840.000,00
Green taxes	R$50,00/ton$CO_2$
Interest rate	15%

* R$ 1,00 = USD 0,42 (01/24/2002)

** NGRE Manufacturer estimative

Table 6. Total investment description

Electrical equipments	
Description	Cost Estimative (R$)
2 Generator sets Waukesha/2900GSI	805.000
1 Transformer 750 kVA	15.000
1 Switch Gear 380 V	80.000
Circuit braker 13,8 kV	10.000
Ancillary service panel	8.000
Thermal equipments	
Description	Cost Estimative (R$)
2 Absorption chillers	500.000
1 Heat exchanger	25.000
2 Radiators	60.000
1 Equilibrium Tank	2.000
1 Hot water tank	5.000
1 Heat recovery steam generator	50.000
2 Cooling tower	80.000
8 Pumps	40.000
1 Separator tank	10.000
Others	
Description	Cost Estimative (R$)
Pipes and wires	200.000
Assembly (labour cost)	200.000
Engineering	250.000
Control system	100.000
TOTAL	2.440.000

8. RESULTS

8.1. Energetic Analysis

Tables (7-9) show the results obtained from the energetic analysis.

Table 7. Cogeneration system efficiencies.

Electrical			30 %
Thermal	Hot Water	2 %	38 %
	Steam	15 %	
	Chilled water	21 %	
Global			68 %

Table 8. Cogeneration system daily production.

Power production	16200 kWh/day
Exceeding power	6422 kWh/day
Process steam	28231 MJ/day
Hot water	4007 MJ/day
Chilled water	34945 MJ/day
Natural gas consumption	5137 m^3/day

Table 9. Cogeneration system capacity.

Power production	900 kW
Process steam production	370 kg/h
Hot water production (49 °C)	2,53 m^3/h
Chilled water production	457 kW

8.2. Environmental analysis

Table 11 shows the results obtained from the environmental analysis for the current UH utility plant and for the proposed cogeneration system.

Table 11. Pollutant gases emissions.

Gases	Current Plant (peak)	Cogeneration Plant
CO_2 (ton/h)	0,1802	1,1820
CO (ppm)	187,8	278,2*
SO_2 (ppm)	8812	~0
NO_x (ppm)	923,6	417,4*

* Data supplied by the NGRE manufacturer

The results presented in Tab. (11) refer to local values. However it's important to take into account the global emission, which reflects the real situation of the problem. The CO_2 global emission is defined as the amount of CO_2 emitted by a thermal plant due to the production of the power to be used by a given system plus the amount of CO_2 generated by the system itself. In this work, it's considered that the power is supplied by Jorge Lacerda Power Plant, a 847 MW coal thermal plant installed in the South of Santa Catarina State. Table 11 shows the CO_2 peak global emission of the current UH utility plant and the proposed cogeneration system.

Table 12. CO_2 peak global emission.

Plant	Emission (tonCO_2/h)
Current	1,6511
Cogeneration	0,5902

9. Economic analysis results

Table (13) shows the results obtained for the three considered scenarios.

Table 13. Results from economic analysis.

Scenario	IRR (%)	Pay-back (years)
1	$-\infty$	∞
2	7	∞
3	23	7,6

A sensitivity analysis which takes into account variations in the natural gas and power prices is performed for scenarios 2 and 3, as shown in Figs. (8-9). For scenario 3 is also conducted another sensitivity analysis taking into account variations in the natural gas price and green taxes value, as shown in Fig. (10).

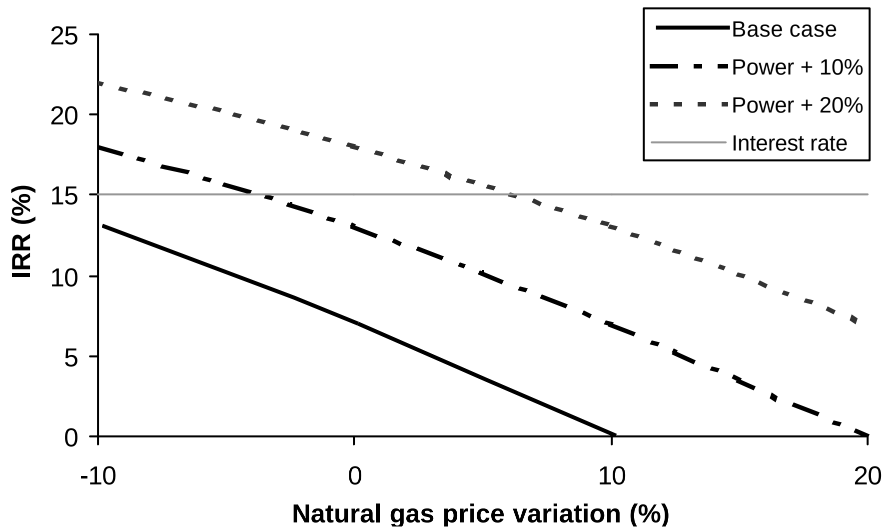

Figure 8. Sensitivity analysis (Scenario 2)

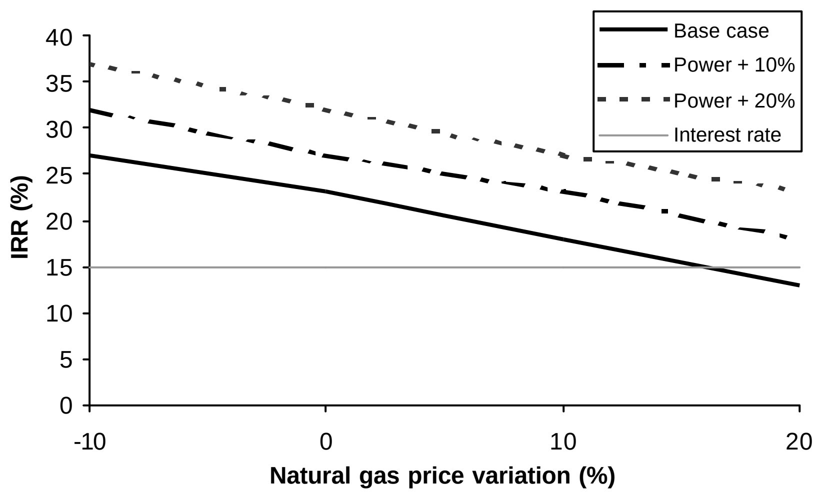

Figure 9. Sensivity analysis (Scenario 3)

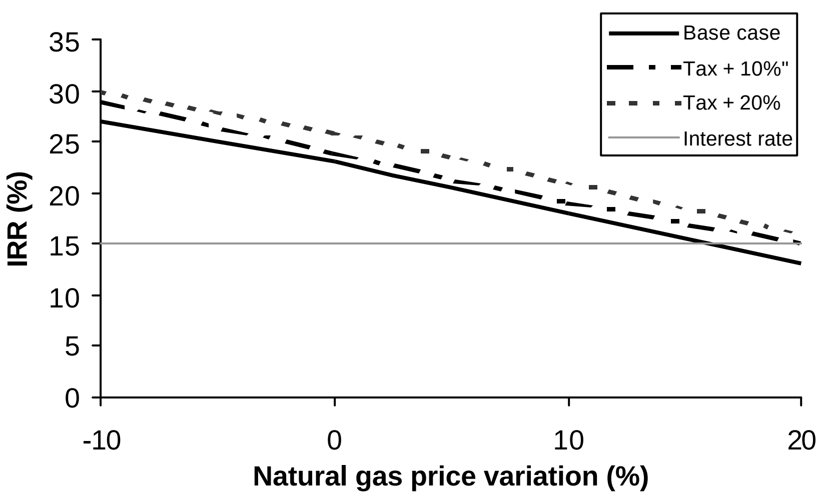

Figure 10. Sensitivity analysis (Scenario 3): green taxes variation

9. Conclusions

The proposed cogeneration system attends all the UH energetic necessities, presenting a reasonable global efficiency of 68%. The environmental analysis indicates that the proposed cogeneration system (and generally on-site plants) are an effective alternative to minimise the greenhouse effect because the CO_2 global emission significantly diminished. In the UH case, the CO_2 global emission is almost three times lower than the current plant. The problem of the smut is solved, once the natural gas combustion is free of ashes and particles. Furthermore, the SO_2 emissions is practically zero and NO_x emission is around half of the current plant.

Several criteria can be adopted related to economic feasibility of an investment. In a pragmatic way one can argue that an investment is feasible if the IRR is greater than a reference interest rate. Under this point of view, the sensitivity analysis show that only if the power prices increases more than 10% or if green taxes are applied, the investment becomes feasible. However there are real cases in Brazil which present very low IRR (almost zero indeed) as the cogeneration system built to attend the Rio Sul Shopping Centre (Szklo and Tomalquim, 2001). Some government strategic issues related to the natural gas market and changes on the energetic matrix also must be taken into account. In this way, the proposed cogeneration system can be feasible under more unfavourable conditions. It must be taken into account some advantages of cogeneration systems which can be crucial in hospitals, as reliability and power quality. The sensitivity analysis shows that the natural gas and electrical energy are very important to make the investment feasible. Green taxes can also contribute to the feasibility of the system, besides be a good way to stimulate new cogeneration plants.

The results presented here can be used as references for further studies related to other commercial and public services plants located at large urban centres, where problems related with air quality and environment in general are quite significant.

10. Acknowledgments

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