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Economic potential of natural gas fired cogeneration plants at malls in Rio de Janeiro

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Abstract

Brazil's power sector reforms are encouraging private investments in the expansion of installed power capacity. Also, natural gas fired thermopower technologies are becoming increasingly important, as they offer faster returns on investment. However, a series of institutional and tariff barriers still block implementation of gas fired cogeneration projects, which are concentrated mainly in the industrial sector. For the commercial sector, despite its relative heterogeneity from the standpoint of both size as well as purpose, cogeneration projects have the advantage of being relatively simple. This article identifies the technical and economic potential of natural gas fired cogeneration systems for malls in Rio de Janeiro through the use of an assessment model. The results are unfavorable within the current regulatory and tariff context in Brazil, indicating the need for combined policies to provide incentives for cogeneration projects in the Brazilian commercial sector. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Gas fired technologies; Commercial sector in Brazil; Cogeneration model

1. Introduction

The expanding participation of natural gas in Brazil's energy grid may be assigned to rising supplies of this energy source due to the start of operations by the Bolivia–Brazil gas pipeline, as

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well as higher domestic output of natural gas and prospects of imports from Argentina. The uptrend in the share held by thermopower in Brazil's power generation sector is intended to minimize the high risks of shortfalls in the Brazilian power system over the short term in addition to ensuring the feasibility of investments in building this gas pipeline and subsequent purchases of imported gas. Furthermore, the gas fired thermopower plants tend to be supported by the recent Brazil's power sector restructuring, which encourages rising private sector participation in the expansion of installed capacity. Private investors in Brazil tend to prefer investments with shorter maturation periods.

As cogeneration is the most efficient alternative for steam and power generation, the prospects for its use should be assessed in terms of expanding Brazil's installed capacity. This assessment naturally focuses on the industrial sector which consumes larger quantities of process steam and power, resulting in larger scale equipment to be installed and higher levels of power required for cogeneration, in addition to high quality steam. Although the commercial sector, covered by this article, is fairly heterogeneous from the standpoint of both size and purpose, ranging from commercial and public buildings to hotels and airports, its cogeneration projects have the advantage of being relatively simple compared to those for the industrial sector [1]. Its consumers need low quality heat, generally for sanitary purposes and cooking food, with power used largely for lighting and air conditioning. These two latter uses together account for over 80% of the power consumed by malls [2].

Among the commercial sector segments, malls post the highest growth rates, reflected in their increased share in Brazil's total retail revenues (excluding the automotive sector), reaching 18% in 1998. Additionally, this segment generates over 277,000 direct jobs and is expected to absorb investments of over US$ 4 billion from 1997 to 2001 [3]. Thus, new malls are expected to proliferate, some of which will be smaller scale ventures specializing in services and recreation.

The most important cogeneration project in this segment is a plant running on a 900 kW gas turbine with two absorption chillers (600 TR each) that can handle a cooling load of 1200 TR [2] in summer, installed at the Ilha Plaza shopping center in Rio de Janeiro. Although efficient from the energy standpoint, the economic ratings for this facility are not very encouraging, failing to top an internal rate of return of 1% p.a. [4].

Faced with this situation, where, despite its technical feasibility, the performance of cogeneration systems is not attractive from the economic point of view, this article assesses possible natural gas fired cogeneration systems for malls in Rio de Janeiro. In order to undertake economic assessments, the COGEN model was used, developed by the authors to assess and select cogeneration systems for the industrial and commercial sectors.

2. COGEN model

The COGEN model has been developed for use in economic feasibility analyses of natural gas fired cogeneration plants, set up by ventures in the commercial and industrial sectors. Through

[2] The cooling load corresponds to the amount of heat that must be removed from the environment in order to reach the level of conditioning required. One ton of refrigeration (TR) corresponds to the removal of 200 BTU/min.

this model, economic assessments are performed from the standpoint of the private investor, pinpointing barriers and incentives for possible future cogeneration ventures.

The model consists of four integrated modules, running on STELLA software:

- COGEN 1: Gas turbines – commercial sector
- COGEN 2: Gas engines – commercial sector
- COGEN 3: Combined cycle gas turbine – industrial sector
- COGEN 4: Gas turbines – industrial sector

In this study, modules 1 and 2 were used, considering that the commercial sector in Brazil lacks the scale required for combined cycles. For this sector, the following configurations have been defined: open cycle with high performance gas turbine (HPGT) with no additional fuel burned, and open cycle with low-performance gas turbine (LPGT) with additional fuel burned in a heat recovery steam generator – COGEN module 1, and Otto cycle with gas fired alternative engines (GE) burning additional fuel in a heat recovery steam generator – COGEN module 2. The user should compare the results obtained (sizing and economic outcome) between the COGEN 1 and COGEN 2 modules for the commercial sector.

The economic assessment and sizing of a cogeneration system under the COGEN model works on the hypothesis that this system should be sized to meet the user's process heat needs. Thus, the model's user should characterize the heat demands of the venture properly. Depending on variations in heat demand over the period, a cogeneration system may or may not need to burn supplementary fuel in heat recovery steam generators in order to boost the availability of the usable heat of the plant. For the ventures studied in this article, the steam produced by the cogeneration plant is used for cold generation in an absorption refrigeration system (the COGEN 1 includes both a cogeneration plant and an absorption cooling system that uses a lithium–bromide solution in the absorber). The maximum heat removal required by the venture is assumed to occur during the hottest month of the year at the hottest time of a typical day during this month.

When drawing up the economic balance for cogeneration, the COGEN model gives the revenues and costs for each system assessed. Cogeneration revenues consist of: (1) electricity saved, not acquired from the network; (2) the sale of possible surplus generations to the network; (3) the impacts avoided of a possible shortage of power supplies, which is only entered in the accounts should the entrepreneur be averse to risks. In the case of the commercial sector, this involves the fixed and variable costs of a diesel fired generator which runs during power outages. In the case of the industrial sector, this involves a loss in revenues which is avoided after the installation of a cogeneration plant, completely eliminating the risk of any power shortages for the user [5].

The costs consist of: (1) the purchased electricity from a utility to cover system down-time and supplemental electric demand if the cogeneration unit does not supply all the electric demand of the enterprise; (2) investments and maintenance of the cogeneration system [3]; (3) investment in heat recovery steam generators and accessories for the cogeneration system; (4) engineering and installation costs of the cogeneration equipment; (5) balance of expenditures on fuel, taking into consideration the cogeneration plant and the original process.

[3] In some cases, this amount may correspond to an investment balance, meaning that the entrepreneur decides to invest in a cogeneration system instead of acquiring other steam or cold generation equipment [6].

Under the COGEN model, the selection criteria for cogeneration ventures is the internal rate of return, which should exceed a basic figure established by the user of the model.

3. Power consumption for major malls in Rio de Janeiro

Five of the largest malls in Rio de Janeiro were assessed, which have not yet installed cogeneration systems: Rio Sul Shopping Center, Barra Shopping, São Conrado Fashion Mall, Nova América Outlet Shopping and Madureira Shopping (Table 1).

The São Conrado Fashion Mall has the lowest specific consumption among the shopping centers analyzed. This is due to its architecture that makes good use of natural lighting, guaranteeing a comfort level similar to that of other malls but with lower power consumption [3]. The difference of 64.0% in the average specific power consumption between the Fashion Mall and the Madureira Shopping Center reflects the potential scope for power conservation in this segment due to the architectural design of each venture. This is also confirmed by the high specific consumption of the Shopping Nova America, whose single storey building is more exposed to sunlight.

With regard to the power load curve, a power load factor of 0.53 was considered, corresponding to a mall located in Rio de Janeiro with no cold storage system for a weekend day during a summer month (Fig. 1).

Lighting and air conditioning uses represent the largest electric consumption of the malls, varying by the location of the establishment, the intensity of consumer flows, the type of venture and its architectural design (Fig. 2). With regard to the share held by air conditioning in total electric consumption, the figure of 45.5% was taken for the Rio Sul Shopping Center [8], and 34% for the other malls.

Two systems are used for cold generation in Rio de Janeiro's malls: (1) Compression refrigeration systems using centrifugal compressors; (2) Absorption refrigeration systems using a

Table 1
Indicators for malls studied

Mall	GLA[a] (m^2)	Power consumption		
		(kW h/ m^2 month)	Monthly (MW h)	Annual[b] (MW h)
Barra Shopping	74,600	36.2	2700.5	32,406.2
Nova América Outlet Shopping[c]	21,000	44.8	941.5	11,881.0
Rio Sul Shopping Center	48,107	39.2	1887.6	23,284.8
São Conrado Fashion Mall	12,500	32.0	400.0	4,800.0
Madureira Shopping Rio	25,000	52.2	1306.0	19,418.4

Source: Schaeffer et al. [7].
[a] Gross Leasable Area.
[b] Estimated figures for 1998.
[c] Mall with cold-storage system.

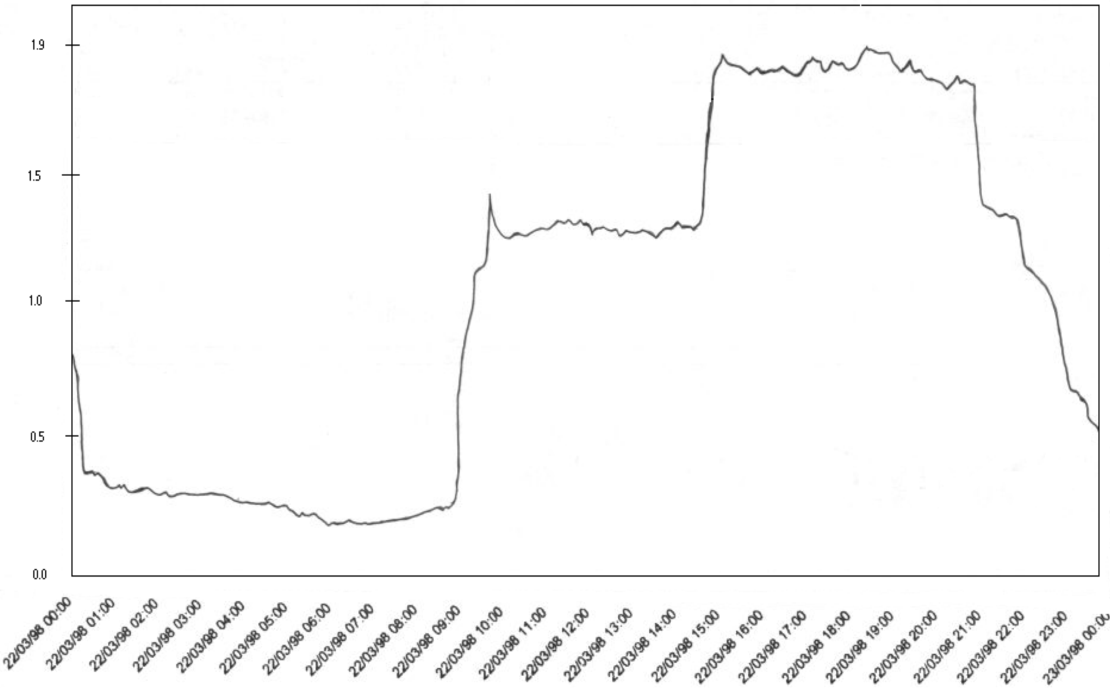

Fig. 1. Power load curve for a mall in Rio de Janeiro – March 1998 (weekend day).

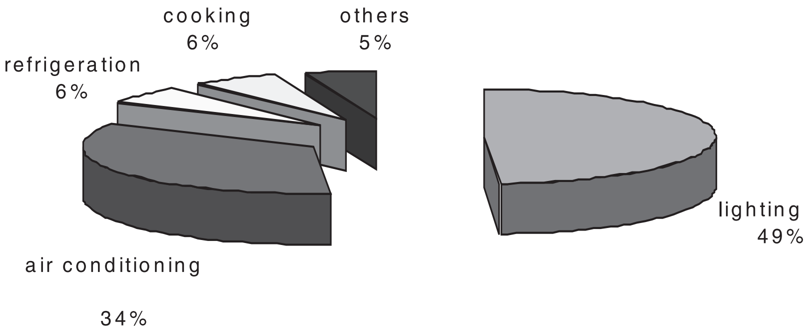

Fig. 2. Estimated participation of end uses in power consumption by malls in Brazil (source: Schaeffer et al. 1998. [7]).

mixture of lithium bromide and water in the absorption unit. This latter system is associated with steam generation equipment, which could be either a boiler or a cogeneration plant. The performance of these two systems is determined on the basis of the conditions given in Table 2. The heat load curve in Fig. 3 gives the demand profile for refrigeration adopted in this study.

Table 2
Sizing conditions for refrigeration systems

Hot source temperature for absorption cooling system	120°C
Minimum temperature of cooling system	5°C
Room temperature[a]	40°C
Efficiency of compression and absorption cooling systems[b]	60%

[a] Estimated maximum daily temperature for hottest month of the year in Rio de Janeiro.
[b] Source: Silva [9].

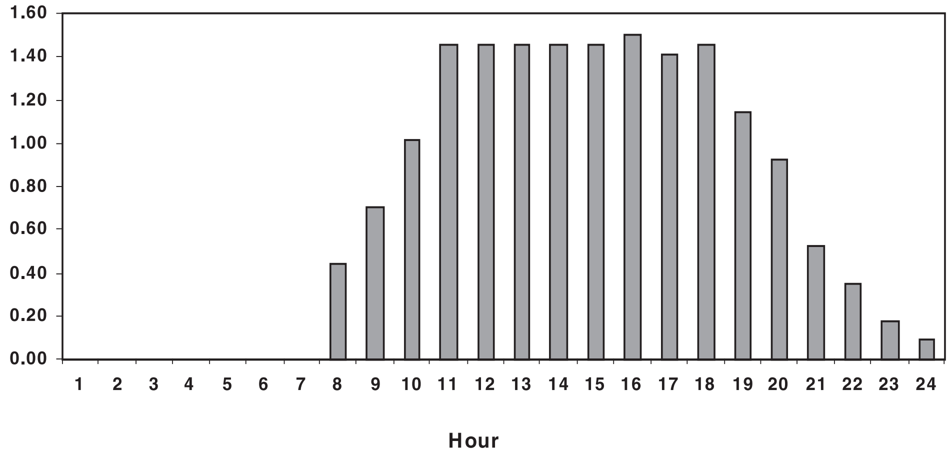

Fig. 3. Heat load profile for a mall on a typical summer's day in Rio de Janeiro (average TR = 1.0). Source: Andreyevich and Pinto [10].

4. Technical and economic potential of gas fired cogeneration at malls in Rio de Janeiro – base case

The selection criteria for the cogeneration systems assessed consisted of the internal rates of return on investment. In the assessment undertaken, in order for a specific system to be considered as economically feasible, its internal rate of return had to top the highest rate of return found on the Brazilian market for investments that did not involve appreciable risks, or for fixed income investments. The upper limit for these investments rates is 25.0%. This figure represents the minimum remuneration that a private investor would expect to obtain on invested capital in the current economic context. This is a relatively high rate compared to the figure of 15.0% p.a. traditionally used by Eletrobrás [4] in its planning [11]. However, although this figure may drop over the next few years, it is also expected that private investors will use a certain amount of prudence for short term investments, particularly with regard to activities other than their core businesses, such as power generation at malls.

[4] Eletrobrás is the federally owned holding company that controlled, till 1995, 90% of electricity generation activities in Brazil.

The application of the COGEN model to the base case corresponding to the current regulatory and tariff context in Brazil [5] showed that cogeneration plants to be installed in malls in Rio de Janeiro have an internal rate of return virtually nil (Table 3). In other words, there is no economic potential for cogeneration units in malls in Rio de Janeiro within the current regulatory and tariff context. With regard to the technical potential for cogeneration in large commercial centers, a technical potential of 23.5 MW was noted for the HPGT system; 10.2 MW for the LPGT system; and 15.6 MW for the GE system. [6]

As the power generation equipment available on the market has specific net heat rates, [7] in some situations, particularly in larger malls, surplus power may be generated that can be sold, if a buyback rate has been properly established and the power utility is interested in acquiring this surplus. In Brazil, utilities are not obliged to acquire surplus power from cogeneration ventures. In this case, cogeneration systems having supply level above one are oversized for electric generation. Nevertheless, even for systems that operate at a supply level near to 1, [8] the results do not change. To check possible cogeneration incentive policies for the commercial sector in Rio de Janeiro, sensitivity analyses were performed.

5. Changes in electric tariffs

Changes in the purchase rates for power charged by the utility, maintaining the buyback rate and the back-up rate of the base case unchanged, did not ensure the feasibility of gas fired cogeneration systems for the malls assessed (Table 4).

Another simulation was also performed to assess the influence of a limit tariff context over the medium term on the feasibility of cogeneration systems for malls. This limit situation is quite improbable over the medium term, corresponding to increases of up to 100% in the power purchase rates and tying these rates to the others. [9] In this simulation the HPGT system performed better than the LPGT system due to its higher supply levels, guaranteeing better revenues through the sale of surplus power (the sale of surplus power is a key factor underpinning the feasibility of cogeneration systems, particularly in larger malls). Nevertheless, the internal rates of return obtained were still below the established threshold of 25.0%. Under current economic conditions in Brazil, with high capital opportunity costs, this suggests that there is no possibility of ensuring the feasibility of gas fired cogeneration plants in these businesses through higher rates with a favorable context for selling off surplus power and purchase of back-up power. This means that other measures should be taken jointly with higher power rates in order to ensure the feasibility of cogeneration plants based on high performance turbines.

[5] Electricity rate: US$ 52.1/MW h; buyback rate: US$ 0/MW h; back-up purchase rate: US$ 109.4/MW h; and natural gas rate: US$ 3.9/MMBTU. Within the current regulatory context in Brazil, utilities are not obliged to purchase surplus power produced through cogeneration.

[6] These technical potentials are not added together, as the systems are mutually exclusive.

[7] Amount of fuel energy required to generate one unit of electric power.

[8] Gas engines for the Nova América, Fashion Mall and Barra Shopping Centers, and low performance turbines for the Rio Sul Shopping Center.

[9] Corresponds to the BSRC in Table 4.

Table 3
Results for the base case

	HPGT	LPGT	GE
Shopping Nova América Mall			
Internal rate of return (% p.a.)	≈0.0	≈0.0	≈0.0
Capital cost of system (US$/kW)	1124	739	550
Maximum cool load – refrigeration (TR)[a]	1161	1161	1161
Rated power (MW)	0.50	0.26	1.76
Supply level[b]	0.50	0.26	1.1
Natural gas consumption (10^6 m^3/year)	1.4	0.6	3.5
Madureira Shopping Center			
Internal rate of return (% p.a.)	≈0.0	≈0.0	≈0.0
Capital cost of system (US$/kW)	511	588	640
Maximum heat load – refrigeration (TR)	2080	2080	2080
Rated power (MW)	5.20	2.40	3.30
Supply level	1.7	0.7	1.3
Natural gas consumption (10^6 m^3/year)	8.5	5.1	6.4
Rio Sul Shopping Center			
Internal rate of return (% p.a.)	≈0.0	≈0.0	≈0.0
Capital cost of system (US$/kW)	487	514	640
Maximum heat load – refrigeration (TR)	2992	2992	2992
Rated power (MW)	8.20	3.40	4.80
Supply level	2.5	1.0	1.7
Natural gas consumption (10^6 m^3/year)	12.8	7.4	9.3
São Conrado Fashion Mall			
Internal rate of return (% p.a.)	≈0.0	≈0.0	≈0.0
Capital cost of system (US$/kW)	777	733	550
Maximum heat load – refrigeration (TR)	483	483	483
Rated power (MW)	1.04	0.55	0.63
Supply level	1.3	0.7	0.99
Natural gas consumption (10^6 m^3/year)	2.4	1.2	1.7
Barra Shopping Center			
Internal rate of return (% p.a.)	≈0.0	≈0.0	≈0.0
Capital cost of system (US$/kW)	485	507	640
Maximum heat load – refrigeration (TR)	3173	3173	3173
Rated power (MW)	8.60	3.60	5.10
Supply level	1.7	0.7	1.2
Natural gas consumption (10^6 m^3/year)	13.6	7.8	9.8

[a] COP – coefficient of performance for the refrigeration system is defined as the ratio between the removal of the heat obtained – usually measured in tons of refrigeration (TR) and the work required for this purpose. $COP_{compression}$ is equal to 4.77 and $COP_{absorption}$ is equal to 0.99.

[b] Supply level is the ratio between the electricity generated by the cogeneration system and the electricity demand of the mall after installing the cogeneration plant.

In the case of the gas engines, it was noted that this equipment is generally more appropriate for medium sized commercial establishments with higher rates of return in situations where the sale of surplus power does not take place at such favorable levels as those simulated in the limit case.

Table 4
Internal rates of return (% p.a.) for sensitivity analyses

	Rio Sul	Madureira Shopping	Barra Shopping	Fashion Mall	Nova América
100% increase in power purchase rates[a]					
HPGT	0.0	0.0	0.0	0.0	0.0
LPGT	0.0	0.0	0.0	0.0	0.0
GE	0.0	5.7	8.1	7.1	0.0
Best simulated rates context (BSRC)[b]					
HPGT	23.5	19.7	23.0	0.0	0.0
LPGT	6.4	0.0	0.0	0.0	0.0
GE	17.8	19.5	17.7	7.1	0.0
Reduction in gas rates[c] *– gas engines*					
Situation 1	4.0	7.1	5.4	6.0	0.0
Situation 2	30.5	29.5	34.0	22.5	0.0

[a] Power purchase rate equals = US$ 104.3/MW h; Buyback rate = nil; Back-up power purchase rate = 2.10 times power purchase rates.
[b] Power purchase rate = US$ 104.3/MW h, equal to the surplus power sell and back-up power purchase rates.
[c] Situation 1: Base Case Conditions and Gas Tariff = US$ 1/MMBTU; situation 2: Power Rate = US$ 104.3/MW h and Gas Tariff = US$ 2/MMBTU.

Finally, in the case of the Nova America Mall, the existence of a cold storage system reduces its power purchase rates and the cold demand to be met by the absorption refrigeration system installed jointly with the cogeneration plant. This undermines the feasibility of the systems assessed within any power rates context. Thus, no further sensitivity analyses were performed for the Shopping Nova America Mall, the results obtained being relatively elucidative. In order to ensure the feasibility of cogeneration for the Brazilian commercial sector with relatively small plants, the average power rates paid by the entrepreneur should be high. By shifting the power load curve, the cold storage system reduces these rates. The average power load factor for the Nova America Mall was 0.74 in 1998, 40% higher than that used for the other establishments [12].

6. Changes in natural gas tariff

As shown in Table 4, even with the gas tariff at US$ 1/MMBTU, a figure which is not feasible in practice, the results are also not satisfactory for the gas fired cogeneration systems assessed.

A second analysis based on the best simulated power rate context analyzed the effect of reducing the gas rate to US$ 2.0/MMBTU, a figure which could be used at the conventional thermopower plants planned for expansion of the Brazilian power system. As the results show, the joint effects on factors influencing the economic performance of the cogeneration facility improve its performance. For the gas fired engines, the internal rate of return achieved could underpin the feasibility of these ventures. However, these results depend on a gas tariff of US$ 2.0/MMBTU, with a power rate 100% higher than that currently charged, in addition to a rate context which encourages the sale of surplus power and the purchase of back-up power. This is a somewhat idealized situation from the cogeneration standpoint. It was also noted that the smaller the cogeneration plants, particularly in the case of the Fashion Mall, the greater is the effect of the gas tariff variation on the economic performance of the cogeneration system (GE, in this case).

7. Installation of a cold storage system

For the best power rate context simulated, a situation was assessed where the mall installs an ice bank jointly with a cogeneration plant. This allows the load curve to be shifted from peak periods, reducing the average power rates as well as the maximum cool load imposed on the air conditioning system during the day [13]. Also, this results in lower investments in the cold generation system and, consequently, in the cogeneration plant.

The internal rates of return for all the malls assessed for the best power rate context simulated dropped to nil after the installation of the ice bank. This shows that some measures that allow gains in energy efficiency, particularly measures related to demand side management, which shift the load curve, result in lower power rates and lower revenues for the cogeneration system as well. In this case, it is interesting to assess whether it is more advantageous to reduce peak period demands or install cogeneration plants that reduce the risk of power outages during peak consumption periods.

8. Inclusion of the avoidance of power outage risks

The installation of a cogeneration plant reduces the impacts of power outages. In the case of the commercial sector, these correspond to the variable costs of a diesel generator operating during power outages. In this study, the expected figure of 9.0% is used for the loss of load probability of the Brazilian electric system [11].

Even when the avoided impacts of power outage were considered in the cogeneration economic balance, the results were not favorable for the systems assessed, not ensuring its economic feasibility. This is an interesting result, as another study has shown that gas fired cogeneration has become feasible in Brazilian industrial plants due to the high risk of blackouts in Brazil's power system [14]. This fact was not repeated for malls in Rio de Janeiro, meaning that a possible power outage has larger impacts in the industrial sector.

9. Conclusions

Although cogeneration is technically feasible in major malls, with two cases in Rio de Janeiro of combined power and cold generation plants (Ilha Plaza and Norte Shopping Malls), the economic potential of cogeneration for the base case analyzed (current regulatory and tariff context) is nil. This result reflects both the difficulty of the entrepreneur in recovering investments in the cogeneration plant and the greater economic feasibility of investments in other energy alternatives in major malls at Rio de Janeiro. For example, demand side measures such as cold storage systems have proven more feasible in economic terms than cogeneration. The cold storage system shifts the power load curve away from peak hours, generating and storing cold during off peak hours of the day.

Cogeneration plants in malls were feasible only within a rates context that is favorable for them, supported by combined incentive policies for this energy alternative. Not only are higher power rates required, but gas tariffs must drop as well. Incentives for equipment purchases, are other measures that underpin the feasibility of the units analyzed here for some malls, particularly larger ventures with higher power consumption, such as Rio Sul, Barra Shopping and Madureira Shopping Centers. It should be noted that the possibility of selling off surplus power and the easy purchase of back-up power had an appreciable effect on the results, with alternatives generating reasonable power surpluses being more feasible within a tariff context favorable to the self-producer.

Smaller malls or those that are not major power consumers, as their architectural designs make good use of natural lighting and ventilation, are not attractive for cogeneration, as is the case of the fashion mall in the study undertaken. Thus, it is more interesting to make better use of natural ventilation, lighting and space, with no loss of comfort for the consumer, than install a cogeneration system in malls at Rio de Janeiro.

These unfavorable results for cogeneration in malls in Rio de Janeiro may seem surprising, in view of the progress made by this technological option in some of the industrialized countries, particularly the USA. However, even in the USA, where the PURPA Act (1978) and the Energy Policy Act (1992) upped cogeneration incentives, the feasibility of small cogeneration plants generating cold and electricity is still uncertain and depends on high power rates and possible supply problems. Additionally, heat demands are higher in US shopping centers, as heating is required at some months of the year. This is not the case in Brazil where there is no demand for heating except in a few places, and cold demands can be reduced through making better use of natural ventilation.

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