

ENVIRONMENTAL AND FINANCIAL IMPACT ASSESSMENT OF NATURAL GAS COGENERATION PLANTS IN THE INDUSTRIAL SECTOR

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Abstract. *This paper presents a case study on the impact of the use of natural gas cogeneration plants in industrial facilities from food companies established in the State of São Paulo, aiming at the financial and greenhouse gases emissions (GHG) analysis. It is proposed a comparison between two different energy supply models for two manufacturing plants, the first one based on electricity supply from local grid and steam from natural gas fired steam generators, and a second model that considers the industries energy needs being partially supplied through natural gas cogeneration plants which are installed in each one of the companies. This study indicates the differences of the financial results for supplying electricity and steam in both models proposed, describing the main variations and the reasons for those, besides identifying the main current tariff benefits in the legislation for the different classes of power plants and Energy Market. The summarized greenhouse gases inventory is presented for both industries as well, and a later assessment of environmental impact from the studied cogeneration plants in the overall GHG emissions in the two proposed scenarios is done. Finally, it is presented the relation analysis between electricity and steam supplying costs if compared with the greenhouse gases emissions levels for both proposed scenarios, and how public policies can act in order to guide emissions decreasing, since São Paulo State has promulgated a law in which establishes a major GHG emissions reduction to 2020.*

Keywords: *Greenhouse gases emission, Cogeneration, Energy market*

1. INTRODUCTION

The greenhouse effect is a natural phenomenon that occurs in the terrestrial atmosphere, it is responsible for seizing part of the solar energy that enters into the planet as a short wave radiation and reflected back to outer space through the surface of the earth.

In a long term, the Earth has to irradiate energy to outer space at the same proportion it is absorbed from the sun (MCT, 2010a). Such a natural seizure process of part of the solar energy is primordial to keep thermal balance and the basic conditions to the existence of life in our planet.

The gases which are in the atmosphere that present the physical property of absorbing and resending the reflected energy through the Earth's surface are called greenhouse gases (GHG), being either natural or entropic sources. The main greenhouse gases are the steam of water, carbon dioxide, methane and the nitrous oxide, besides the sulphur hexafluoride, hydrofluorocarbons and the perfluorocarbons.

Since the Industrial Revolution, it is being observed a higher elevation in the concentration of the greenhouse gases in the atmosphere, resulting in a great potential of the solar energy detention within the planet. Currently, the most severe case refers to the carbon dioxide (CO₂), which was noticed an elevation of 35% on its concentration in the atmosphere, turning from 280 ppm at the beginning of the Industrial Revolution to 379 ppm in 2005 (IPCC, 2007a). The emission of CO₂, in yearly terms, was amounted from 21 Gt/year to 38 Gt/year between 1970 and 2004, corresponding to a rising of about 80%. The CO₂ emissions represented 77% of the overall emissions of GHG in 2004 (IPCC, 2007a), demonstrating to be the main global warming "villain".

In November 9th, 2009 the State of São Paulo promulgated the State Policy on Climate Change (SPCC) (São Paulo, 2009), which has established the commitment of the State towards the global climate changes, notoriously the global warming. This act establishes, among others, a target of 20% in the reduction of greenhouse gases emissions in São Paulo State until 2020, having as a reference the emissions along 2005. Every economy sectors, including the industrial one, must have their reduction targets established. The SPCC presents the actions and public policies that will have to be developed by São Paulo government in order to stimulate the usage of products or services environmentally cleaner, in spite of stimulating the most pollutant ones. Other governmental actions, such as subsidies, unburdens, financings and taxations must be developed by the State.

The industrial sector will have to adequate itself in order to reach the objectives and targets established by the SPCC, in case of not reaching such further costs is going to be charged to the industries, once the State Policy determines that the doer of the environmental impact will have to be financially responsible towards the expenses on the damage caused in the environment (being a concept of polluter-pays).

Several Brazilian industries use natural gas cogeneration plants inside its facilities in order to supply partially, or totally, the electricity and steam needs. However, it is necessary to do a careful environmental impact assessment of

these power plants, mainly regarding greenhouse gases emission, since the companies will have to reach reduction targets defined by the government.

It is proposed a comparison between two different energy supply models for two manufacturing plants, the first one based on electricity supply from local grid and steam from natural gas fired steam generators, and a second model that considers the industries energy needs being partially supplied through natural gas cogeneration plants which are installed in each one of the companies.

This study presents the financial result and the greenhouse gases emissions impact in each one of the models.

2. GREENHOUSE GASES INVENTORY

The State Policy on Climate Change, promulgated by Act n.º 13.798/2009, clearly defined the São Paulo State objective in the reduction of greenhouse gases emissions until 2020. Before starting the natural gas cogeneration plants impact assessment in the GHG emissions for both factories, it is presented the 2010 summarized greenhouse gases inventory, not considering the use of cogeneration plants to supply factories energy needs.

The emissions levels presented in this paper were calculated following the Intergovernmental Panel on Climate Change (IPCC) guidelines, in accordance with IPCC (2006).

The focus of this work is not on the inventory preparation itself, but in the environmental and financial analysis of cogeneration plants, so it will not be presented details on inventory preparation, only the results will be showed.

Tables 1, 2 and 3 present the summarized greenhouse gases emissions inventory of factory 1, considering only key categories in 2010 (model with no cogeneration plant in operation). Intergovernmental Panel on Climate Change defines key category as “one that is prioritized within the inventory because its estimate has a significant influence on a total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals” (IPCC, 2006).

Table 1. GHG yearly emissions of factory 1 due to grid purchased electricity (no cogeneration plant in operation).

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	TOTAL
Grid purchased electricity (MWh)	7.612	6.947	7.216	7.113	7.075	5.887	6.682	6.962	6.875	7.723	7.503	8.317	85.912
Emission factor (t CO ₂ /MWh) ⁽¹⁾	0,0211	0,0280	0,0243	0,0238	0,0341	0,0506	0,0435	0,0774	0,0907	0,0817	0,0869	0,0511	0,0512
GHG emissions (t CO ₂ eq)	161	195	175	169	241	298	291	539	624	631	652	425	4.400

⁽¹⁾ Source: MCT (2010b), except Month 12 (last eleven months average)

Table 2. GHG yearly emissions of factory 1 due to natural gas consumption (no cogeneration plant in operation).

	Consumption	Conversion factor ⁽¹⁾	Consumption	CO ₂ Emission factor ⁽²⁾	CO ₂ Emissions	CH ₄ Emission factor ⁽²⁾	CH ₄ Emissions	N ₂ O Emission factor ⁽²⁾	N ₂ O Emissions
	(unit)	(GJ/un)	(GJ)	(kg CO ₂ /TJ)	(t CO ₂)	(kg CH ₄ /TJ)	(t CH ₄)	(kg N ₂ O /TJ)	(t N ₂ O)
Natural gas									
Steam generators (m3)	21.600.000	0,0367	792.390	56.100	44.453	1	0,792	1	0,792
Cogeneration plant (m3)	0	0,0367	0	56.100	0	1	0,000	3	0,000
				Total	44.453	Total	0,792	Total	0,792

⁽¹⁾ Source: Comgas (2008)

⁽²⁾ Source: IPCC (2006)

Table 3. Total greenhouse gases yearly emissions of factory 1 (no cogeneration plant in operation).

	Emissions (t)	GWP ⁽¹⁾	Emissions (t CO ₂ eq)
Natural gas			
CO ₂	44.453	1	44.453
CH ₄	0,792	25	20
N ₂ O	0,792	298	236
Grid purchased electricity			
CO ₂ eq	4.400	1	4.400
Total emissions Factory 1			49.109

⁽¹⁾ Source: IPCC (2007b)

Tables 4, 5 and 6 present the summarized greenhouse gases emissions inventory of factory 2, considering only key categories in 2010 (model with no cogeneration plant in operation).

Table 4. GHG yearly emissions of factory 2 due to grid purchased electricity (no cogeneration plant in operation).

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	TOTAL
Grid purchased electricity (MWh)	7.148	6.456	6.763	6.390	6.298	5.714	5.634	6.208	6.300	6.918	7.126	7.709	78.663
Emission factor (t CO ₂ /MWh) ⁽¹⁾	0,0211	0,0280	0,0243	0,0238	0,0341	0,0506	0,0435	0,0774	0,0907	0,0817	0,0869	0,0511	0,0512
GHG emissions (t CO ₂ eq)	151	181	164	152	215	289	245	480	571	565	619	394	4.027

⁽¹⁾ Source: MCT (2010b), except Month 12 (last eleven months average)

Table 5. GHG yearly emissions of factory 2 due to natural gas consumption (no cogeneration plant in operation).

	Consumption (unit)	Conversion factor ⁽¹⁾ (GJ/un)	Consumption (GJ)	CO ₂ Emission factor ⁽²⁾ (kg CO ₂ /TJ)	CO ₂ Emissions (t CO ₂)	CH ₄ Emission factor ⁽²⁾ (kg CH ₄ /TJ)	CH ₄ Emissions (t CH ₄)	N ₂ O Emission factor ⁽²⁾ (kg N ₂ O/TJ)	N ₂ O Emissions (t N ₂ O)
Natural gas									
Steam generators (m3)	19.200.000	0,0368	706.568	56.100	39.638	1	0,707	1	0,707
Cogeneration plant (m3)	0	0,0368	0	56.100	0	1	0,000	3	0,000
				Total	39.638	Total	0,707	Total	0,707

⁽¹⁾ Source: Comgas (2008)

⁽²⁾ Source: IPCC (2006)

Table 6. Total greenhouse gases yearly emissions of factory 2 (no cogeneration plant in operation).

	Emissions (t)	GWP ⁽¹⁾	Emissions (t CO ₂ eq)
Natural gas			
CO ₂	39.638	1	39.638
CH ₄	0,707	25	18
N ₂ O	0,707	298	211
Grid purchased electricity			
CO ₂ eq	4.027	1	4.027
Total emissions Factory 2			43.894

3. COGENERATION POWER PLANTS CHARACTERISTICS AND INDUSTRIES ENERGY NEEDS

Table 7 shows the cogeneration power plants characteristics, besides the energy consumption needs of the industrial facilities studied.

Table 7. Cogeneration power plants characteristics and energy consumption needs of the industrial facilities (monthly average).

	Factory 1	Factory 2
Factories monthly consumption		
Electricity (MWh)	7.159	6.555
Process steam (t)	22.500	20.000
Cogeneration plant		
Utilization factor (%)	90%	90%
Installed capacity (MW)	8,4	6,0
Monthly electricity generation (MWh)	5.519	3.942
Specific natural gas consumption (m ³ /h)	3.400	2.300
Natural gas monthly consumption (m ³)	2.233.800	1.511.100
Monthly steam generation (t)	17.506	10.555

As from data listed in Tab. 7, the environmental and financial impacts will be evaluated for both energy supply models proposed.

3.1. Model 1

This model considers all electricity supply from local grid and steam from natural gas fired steam generators in each one of the factories.

3.2. Model 2

This model considers the industries energy needs being partially supplied through natural gas cogeneration plants which are installed in each one of the companies. The remaining energy needs are supplied with electricity from local grid and steam from natural gas fired steam generators.

Table 8 presents energy supply sources to factories 1 and 2 for each proposed model.

Table 8. Energy supply sources for each proposed model.

	Model 1	Model 2
Factory 1		
Grid purchased electricity (MWh)	7.159	1.641
Electricity from cogeneration plant (MWh)	0	5.519
Steam from steam generators - boilers (t)	22.500	4.994
Steam from cogeneration plant (MWh)	0	17.506
Factory 2		
Grid purchased electricity (MWh)	6.555	2.613
Electricity from cogeneration plant (MWh)	0	3.942
Steam from steam generators - boilers (t)	20.000	2.494
Steam from cogeneration plant (MWh)	0	17.506

4. FINANCIAL ASSESSMENT

Brazilian legislation establishes benefits to some classes of electricity generators sources, including cogeneration power plants. These benefits may be applied either in electricity tariffs or in natural gas tariffs, or in both ones.

4.1. Benefits on electricity charges

The National Electricity Agency (ANEEL), in order to stimulate the electricity renewable sources use in the energy matrix, has established in the legislation some criteria for power plants (or electricity end consumers) take advantages in electricity tariffs.

4.1.1. Discounts in the Charges for use of the system

The Resolution 77/2004 stipulates the requirements to take the discount in the Distribution charge for use of the system (TUSD) and in the Transmission charge for use of the system (TUST). This resolution establishes 50% discount on distribution and transmission charges, reflecting in the generation and consumption of the following electricity sources:

- Hydroelectric power plants with installed capacity less or equal 1MW;
- Small hydroelectric plants;
- Solar photovoltaic energy;
- Wind energy;
- Biomass;
- Qualified cogeneration.

Furthermore, it is defined 100% discount on TUSD and TUST charges for power plants burning at least 50% of biomass from municipal solid wastes, animal and vegetable waste digesters, landfill gas and sludge from wastewater treatment plants.

4.1.2. Concept of Qualified cogeneration

The Resolution 235/2006 stipulates the qualification criteria for cogeneration ventures. This resolution defines Qualified cogeneration as “attribute granted to cogenerators which meet the minimum requirements for rational energy use, as described in legislation, in order to participate in the cogeneration incentive policies”.

According to this resolution, cogeneration plants should comply with the following energy efficiency minimum requirements to take advantage in the incentives described in the previous topic:

$$\frac{E_t}{E_f} \geq 15\% \quad (1)$$

$$\left(\frac{E_t}{E_f} \right) \div X + \frac{E_e}{E_f} \geq Fc\% \quad (2)$$

Being as ANEEL (2006) definition:

- E_f (Source energy): input energy in the cogeneration plant, in its average operative system, in kWh/h, based on the specific energy content, which in the case of fuels is the net calorific value (NCV);
- E_e (Electrical-mechanical energy): electrical-mechanical energy resulting from cogeneration power plant, in its average operative system, in kWh/h, in net basis, discounting from generated gross energy the consumption due to plant auxiliary services;
- E_t (Thermo energy): thermo energy provided by cogeneration power plant, in its average operative system, in kWh/h, in net basis, discounting from gross energy provided to the process the low potential heat coming back to the plant;
- $Fc\%$ (Cogeneration factor): parameter defined due to the installed capacity and cogeneration plant source, bringing closer to Exergetic Efficiency concept; and
- X (Weighting factor): dimensionless parameter defined due to the installed capacity and cogeneration plant source, derived from the relation between thermo and electrical-mechanical reference efficiency, in conversion processes to obtain these energy types separately.

Table 9 shows values for Cogeneration factor ($Fc\%$) and Weighting factor (X) (ANEEL, 2006).

Table 9. Cogeneration factor ($Fc\%$) and Weighting factor (X) of cogeneration power plants.

Source/installed capacity	X	Fc%
Petroleum-derived, Natural gas and Coal		
Up to 5 MW	2,14	41
Between 5 MW and 20 MW	2,13	44
Over 20 MW	2,00	50
Other fuels		
Up to 5 MW	2,50	32
Between 5 MW and 20 MW	2,14	37
Over 20 MW	1,88	42
Process heat recovery		
Up to 5 MW	2,60	25
Between 5 MW and 20 MW	2,17	30
Over 20 MW	1,86	35

As from Eq. (1) and Eq. (2), it was evaluated if the power plants installed at factories 1 and 2 can be classified as Qualified cogeneration. Both power plants meet requirements established in the legislation, as shown in Tab. 10.

Thus, cogeneration plants from factories 1 and 2 can take discounts in the charge for use of the system.

There are two options relative to power plants classification at National Electricity Agency (ANEEL), depending on the manner in which power is retailed. In order to obtain the benefit in the tariff for use of the system, cogeneration plant must be classified as Independent Power Producer (IPP), which is defined as “a corporate legal entity or companies grouped together in consortia that are awarded concessions or authorizations to produce electricity and sell it, total or partially, at their own account and risk” (ANEEL, 1996). In this case study, in order to take the discount, the industries would sell the produced electricity to themselves.

Table 10. Qualification requirements assessment for cogeneration plants installed at factories 1 and 2.

Requirements defined in the legislation						Calculated value
Factory 1						Factory 1
$\frac{Et}{Ef} \geq 15\%$	Et	Ef	Ee	X	Fc%	
	21.722	34.647	-	-	-	63%
$\left(\frac{Et}{Ef}\right) \div X + \frac{Ee}{Ef} \geq Fc\%$	21.722	34.647	7.560	2,13	44%	51%
Factory 2						Factory 2
$\frac{Et}{Ef} \geq 15\%$	Et	Ef	Ee	X	Fc%	
	13.097	23.437	-	-	-	56%
$\left(\frac{Et}{Ef}\right) \div X + \frac{Ee}{Ef} \geq Fc\%$	13.097	23.437	5.400	2,13	44%	49%

Other option would be classify the cogeneration plants as Self-producer, which is defined as “an individual or corporate legal entity, or companies grouped into a consortium, that are awarded a concession or authorization to produce electricity for their own use” (ANEEL, 1996). In this situation, there is not any electricity trade.

4.2. Benefits on natural gas charges

The natural gas incentives to cogeneration plants vary widely, depending on the geographical location of the plant, since depends on the natural gas grid.

The Decree CSPE-1/1999 defines the different tariff levels and the natural gas consumption unit classification for consumption units located at concession area of the grid responsible to supply natural gas to the factories. This decree presents the “Cogeneration class”, so that all natural gas billed for cogenerators has differentiated tariffs if compared to consumption units receiving the regular “Industrial class” natural gas.

Tariffs benefits offered to the cogeneration plants depends on natural gas contracted volume with the grid. In this case study, the discount is around 26%. In other words, the natural gas burned in the cogeneration plants studied is subsidized.

Table 11 shows the financial assessment result of factory 1 for the proposed models, considering the electricity and natural gas charges benefits. Model 2 was divided into Model 2_{IPP} (power plant classified as Independent Power Producer) and Model 2_{SP} (power plant classified as Self-producer).

Table 11. Financial assessment result of factory 1 cogeneration plant (monthly values).

	Model 1	Model 2 _{IPP}	Model 2 _{SP}
Local grid cost			
Contracted demand [R\$]	256.336	256.336	134.257
Electricity consumption [R\$]	227.881	52.217	227.881
Energy trader cost [R\$]	1.031.083	243.354	267.198
Natural gas cost			
Industrial tariff natural gas [R\$]	1.404.000	311.636	311.636
Cogeneration tariff natural gas [R\$]	0	1.295.604	1.295.604
Operation and maintenance average cost [R\$]	0	360.000	360.000
Total monthly cost [R\$]	2.919.300	2.519.147	2.596.576

Model 2, with the plant classified as Independent Power Producer, is the best option for factory 1. The yearly saving is R\$ 2.969.628 if compared to Model 1.

Table 12 presents the financial assessment result of factory 2 for the proposed models.

Table 12. Financial assessment result of factory 2 cogeneration plant (monthly values).

	Model 1	Model 2 _{PP}	Model 2 _{SP}
Local grid cost			
Contracted demand [R\$]	269.880	269.880	135.420
Electricity consumption [R\$]	206.359	82.265	206.359
Energy trader cost [R\$]			
	944.086	387.650	404.682
Natural gas cost			
Industrial tariff natural gas [R\$]	1.248.000	589.342	589.342
Cogeneration tariff natural gas [R\$]	0	876.438	876.438
Operation and maintenance average cost [R\$]			
	0	160.000	160.000
Total monthly cost [R\$]	2.668.325	2.365.575	2.372.240

Model 2, with the plant classified as Independent Power Producer, is the best option for factory 2. The yearly saving is R\$ 2.596.728 if compared to Model 1.

5. ENVIRONMENTAL ASSESSMENT

Natural gas is the fuel burned at studied power plants. This type of technology interferes in the industries greenhouse gases emissions levels, so it is recommended to perform an impact assessment of GHG emissions reduction due to cogeneration plants.

According to ANEEL (2010), renewable sources represents 74,3% of installed capacity from brazilian electricity matrix, so that greenhouse gases emissions due to electricity generation are significantly small. Table 13 presents the average greenhouse gases emissions to different energy generation sources, as adapted from Sovacool (2008).

Table 13. Greenhouse gases emissions for different sources of electricity.

Technology	Emissions (kg CO ₂ eq / MWh)
Wind	9
Hydroelectric	10
Biogas	11
Solar thermal	13
Biomass	28
Solar PV	32
Geothermal	38
Nuclear	66
Natural gas	443
Fuel cell	664
Diesel	778
Heavy oil	778
Coal	1.005

Clearly, the use of electricity from fossil sources (like in the cogeneration plants studied) it is not advantageous on greenhouse gases emissions viewpoint if compared to renewable sources. Table 14 presents the equivalent greenhouse gases emissions result of factory 1 for the Models 1 and 2.

Table 15 presents the equivalent greenhouse gases emissions result of factory 2 for the Models 1 and 2.

Table 14. Greenhouse gases yearly emissions of factory 1 in the Models 1 and 2.

Emissions (t CO ₂ eq)	Model 1	Model 2
Natural gas		
CO ₂	44.453	65.033
CH ₄	20	29
N ₂ O	236	932
Grid purchased electricity		
CO ₂ eq	4.400	1.016
Total emissions factory 1	49.109	67.010

Table 15. Greenhouse gases yearly emissions of factory 2 in the Models 1 and 2.

Emissions (t CO ₂ eq)	Model 1	Model 2
Natural gas		
CO ₂	39.638	55.978
CH ₄	18	25
N ₂ O	211	694
Grid purchased electricity		
CO ₂ eq	4.027	1.610
Total emissions factory 2	43.894	58.307

It's easy to observe a major increase in the GHG emissions levels when the cogeneration power plants are operating (Model 2).

Greenhouse gases emissions quantifying due to grid electricity consumption in both models was done using the average emission factors proposed by Brazilian Science and Technology Ministry (MCT) for inventory preparation (MCT, 2010b). According to Tabs. 1 and 4 previously presented, the average emission factors of factories 1 and 2 are:

- 0,0281 t CO₂eq/MWh for factory 1 (yearly average)
- 0,0277 t CO₂eq/MWh for factory 2 (yearly average)

The values showed above are substantially low. Nonetheless, according to Esparta studies (2008), the fact that Brazil presents an electrical energy generation matrix relatively clean, it does not mean necessarily that the “avoided emissions in the operation margin” of the Brazilian Interconnected National System (SIN) are going to be small. In such a case, if the cogeneration plants do not operate, the GHG emissions at SIN to compensate the increase in energy consumption along the Brazilian electrical system (due to factories 1 and 2) could come from power plants with higher emission factors, as in the case of thermal coal, residual fuel oil, diesel oil and natural gas power plants.

Therefore, it is necessary to evaluate the real impact of greenhouse gases emissions due to cogeneration plants very carefully, since electricity generated inside the industries reduces the electricity supply through power plants running on operation margin of SIN, which usually are plants that burn fossil fuels, and presents emission factors higher than the proposed by MCT for inventory preparation (2010b).

6. RESULTS ANALYSIS

Table 16 shows the financial and environmental analysis result for factories 1 and 2 in both proposed models.

Table 16. Environmental and financial assessment result (yearly values).

	Model 1	Model 2	Diference (%)
Factory 1			
Electricity and steam cost (R\$)	35.031.599	30.229.763	-14%
Greenhouse gases emissions (t CO ₂ eq)	49.109	67.010	36%
Factory 2			
Electricity and steam cost (R\$)	32.019.897	28.386.894	-11%
Greenhouse gases emissions (t CO ₂ eq)	43.894	58.307	33%

As mentioned, figures presented in Tab. 16 uses emission factors of grid electricity consumption proposed by Brazilian Science and Technology Ministry for inventory preparation (MCT, 2010b), resulting in increases of 41% and 37% in the greenhouse gases emissions levels at factories 1 and 2 respectively.

Nevertheless, the use of cogeneration plants to supply electrical energy demands of both industries replaces the use of power plants that operate in the operation margin of SIN, which are able to present average emission factors higher than those suggested by the MCT in the elaboration of corporate inventories, causing thus distortions in the analysis of the real environmental impact of the power plants. In this case, the emission factor of the cogeneration plants must be compared with the average emission factor of the plants that operate on SIN operation margin, that is, the emission factor proposed by MCT to elaborate inventories would not be used, but the emission factor of operation margin should be used.

Science and Technology Ministry has defined the average emission factors for power plants running on operation margin (MCT, 2010c). Table 17 shows the values proposed between 2006 and 2010.

Table 17. Emission factors for power plants running on operation margin.

Year	2006	2007	2008	2009	2010
Margin Emission Factor	0,2023	0,1842	0,3112	0,1635	0,2835

National Plan on Climate change (NPCC, 2008) adopts 0,29 t CO₂eq/MWh as emission factor in order to estimate the greenhouse gases emissions reduction potential resulting from future initiatives which may lead to grid electricity use decreasing.

Studies from Reis (2009) point to an increase trend of emission factor from electricity consumed in operation margin. According to Reis calculation, margin emission factor will be 0,37 t CO₂eq/MWh by 2017.

Table 18 presents the values of the average emission factors of the power plants that operate on SIN operation margin that would make the Models 1 and 2 to have the same final value of greenhouse gases equivalent emissions, that is, it is shown as from the emission factor value (break even) of the plants working within the operation margin that the cogeneration plants would be favorable if compared to the Model 1 (which does not consider the use of the plants).

Table 18. Average emission factor break even of power plants running on SIN operation margin in order to match greenhouse gases equivalent emissions in Models 1 and 2 for both factories.

Break even	Average emission factor from SIN plants (t CO ₂ eq/MWh)	Emissions (t CO ₂ eq)
Factory 1	0,3215	67.010
Factory 2	0,3559	58.307

7. CONCLUSIONS

It is concluded that the cogeneration power plants studied in this work propitiate a huge financial advantage to the companies, mainly due to benefits in legislation applied to electricity and natural gas charges.

From the greenhouse gases equivalent emissions point of view, the cogeneration plants studied have shown to be very harmful when the emission factors suggested by MCT are used in the preparation of the inventories (MCT, 2010b), which is the official source for inventories elaboration. The use of those emission factors leads to a substantial addition in the emission levels, once it uses the average emission factor of Brazilian electrical system. Yet, it is necessary to evaluate and compare the impact of those cogeneration plants using the emission factors of the power plants running on operation margin, which generally burn fossil fuels and present higher emission factors.

Still in relation to the greenhouse gases emissions, the studied cogeneration plants are able to proportionate an effective reduction in the GHG emissions in the case the emission factors of the power plants running on operation margin of Brazilian electrical system are superior to 0,3221 and 0,3590 t CO₂eq/MWh, for the factories 1 and 2 respectively.

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