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ARTICLE

Cogeneration Potential in the Industrial Sector and Gas Emission Reduction: A Case Study

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ABSTRACT

The aim of the current paper is to discuss the replacement of diesel oil (DO) consumption by natural gas (NG) in a cogeneration system. A specific industrial consumption case study was chosen to be the method used to accomplish a robust analysis. The results have shown the advantages in reducing CO_2, CH_4, N_2O and particulate matter emissions, as well as the need to keep the NOx emission rates. After proceeding with theoretical studies concerning our case, we concluded that the diesel oil replacement by natural gas is beneficial for gas emission reduction. Public policies should consider local development based on the use of different fuels, such natural gas, to achieve the integration between decentralized energy generation and energy-efficient initiatives.

1. Introduction

The use of different fuels has become an important concern when it comes to Climate Change debate, to pollution impacts from local to global levels, as well as to lifestyle changes within modern society. Therefore, the use of low carbon alternative fuels began to gain more space in politics and public planning. Thus, many researches have been focused on diesel replacement to lesser pollutant fossil fuels, such natural gas [1, 2].

Society is now living a time when its demands regarding amenities provided by different forms of fuels are clear. Thus, it is mandatory to think, create and build practices that meet community demands in order to help solving the emerging environmental problems.

The aim of the current paper is to discuss local development based on replacement of fuels (natural gas instead of diesel) in order to achieve the integration between decentralized energy generation and energy-efficient initiatives. Our study is based on a specific industrial consumption case study to accomplish a robust analysis, specifically the cogeneration potential in the industrial sector of Novo Hamburgo City.

Thus, in order to achieve our goal, section 2 exposes the literature review. Section 3 includes our methods. Section 4 shows our results. Finally, section 6 presents our conclusions.

2. Literature Review

2.1 Combined Heat and Power (CHP)

CHP or cogeneration consists of a way to produce heat

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and power within the same system. Such technology provides two ways of using energy from the same fuel, minimizing wastes. There is a vast literature on CHP. It demands lower costs and causes lesser GHG emissions than other electricity and heat production mechanisms [3].

Conventional electricity generation systems are usually centralized, and in Brazil it is mainly based on thermal and hydroelectric powerplants. Within such concept, it is necessary to invest in long electricity transmission and distribution lines in order to connect the centralized generation to the customers, in other words, to a distributed demand [4].

On the other hand, it is possible to produce energy in a decentralized pattern way. This method is called distributed generation and its main feature is that electricity generation is close to the consumer point [5, 6, 7].

The benefits of adopting CHP as a distributed generation source are: elimination of technical losses in transmission and distribution [8]; diversification of the energy matrix [9, 10]; decreased energy intensity [9]; improved energy efficiency [11]; fulfillment of GHG reduction targets [12]; and CO_2 emission reduction [11].

Ouellette et al. [12] found that the implementation of a CHP system in Alberta may result in the approximately 15–24% CO_2 reduction expected by the 2008 Alberta Climate Strategy. Thus, CHP implementation could bring up significant contributions to the achievement of the Kyoto Protocol's emission reduction targets [11].

Cogeneration also presents negative points such as the need to invest in CHP equipment, a more complex and demanding operation and the lack of technical training, as it was already stressed by Andreos [5] and Baer et al. [13]. Also, Baer et al. [13] have pointed out that CHP installations have high upfront costs and long payback periods, when they are compared to traditional equipment.

CHP has been mainly used by industries and for district heating worldwide [14, 15, 16]. It has been analyzed as part of a system involving the eco-industrial park concept (EIP) [17]. According to some authors, local heating systems distribute the centralized-generated heat in a residential and sometimes commercial location, managed at low costs [18, 19].

Chung et al. [20] analyzed a CHP plant case study applied to a set of buildings such as residential buildings, offices, hospitals, stores, and schools in Korea. They found that the payback period might be of approximately two years in buildings investing in a generator with the capacity to hold 50% of their electricity peak demand.

Nowadays, several countries are developing their own policies to promote small-scale cogeneration in the residential sector. Small-scale residential cogeneration systems are widely recognized as efficient systems and they have an important potential for energy and economic saving [21, 22]. They are often used in industries that use their on waste as a fuel such as the sugarcane, chemical, petrochemical and pulp and paper industries.

Brazil had only 550 working cogeneration units up to 2000. However, this scenario began to change in 2010 when this indicator went up to 851 units. Today, the country has approximately 943 working cogeneration units [23]. In addition to such fact, the recent discovery of the pre-salt layer in the Santos basin doubled the Brazilian oil and gas reserves, leading the country's gas market to a favorable scenario [5].

The installed cogeneration capacity in Brazil will reach its peak (14,056.0 MW) in 2015, time when it is going to have the same production as Itaipu hydroelectric powerplant, which has an installed capacity of 14,000 MW [5].

Hwang [24] pointed out many studies that evaluate the efficiency of this process in industries. Hwang [24] looked for ways to improve existing technologies or even for possible innovative cogeneration uses in different industrial processes.

The present research aims to determine the cogeneration potential in the industrial sector of Novo Hamburgo City, by considering the importance of implementing integrated decentralized energy generation and energy-efficient initiatives. The analysis was made through the replacement of diesel oil (DO) consumption by natural gas (NG) in a CHP system in the industrial sector of the abovementioned city.

Natural gas has been pointed out as a transition fuel that will facilitate the insertion of renewable fuels [4, 1, 2]. There is a lot of research studying the use of renewables such as biogas in the cogeneration process [25, 26]. Additionally, Celma et al. [27] and Andersen and Lund [28] have pointed out that CHP systems, along with the renewable energies (solar, wind, biomass etc.), are key elements for future cleaner energy policies.

Usually, the heat and power production in a cogeneration system releases considerable amounts of GHG into the atmosphere. Accordingly, the study by Aldrich et al. [29], is an attempt to expose and evaluate different allocation methods, to apply them to a combined heat and power plant integrated to a paper mill, and to propose an alternative method to better calculate the efficiency of the process.

Finally, the present research is an attempt to show that there are alternative fuels ready to be consumed in the study area, such natural gas (a fossil fuel lesser pollutant than diesel). However, investors lack information on the feasibility of the project [30]. Therefore, we also show the

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possibility of reducing local environmental impacts, and the feasibility of using already established technology in the electricity production market at lower costs.

It is worth minimizing the emission of pollutants resulting from the decentralized CHP conversion process, since it is often located close to urban perimeters. Thus, it is important to present the results by Fahlén and Ahlgren [31], who account for the social and environmental costs of the local heating process when the option for using CHP technologies is made. Fahlén and Ahlgren [31] pointed out that the use of district heating processes is just justified when natural gas is used as fuel.

3. Material and Methods

The methods used in the current study consist of a case study, considering quantitative and qualitative approaches.

The case study concerns a Decentralized Energy Plan (DEP) in Novo Hamburgo City, which is located in the metropolitan region of Porto Alegre, Rio Grande do Sul State, Brazil. This case study focuses on the Novo Hamburgo industrial sector and is divided in 4 parts:

a. Industrial sector evaluation;

b. Fuel replacement evaluation, from DO to NG;

c. CO_2 emissions reduction evaluation.

The DEP of Novo Hamburgo is part of a data acquisition system initiated in 2011 during the research project: “The data survey, the analysis of energy diagnosis, and the evaluation of potential renewable sources in Novo Hamburgo County” [32] . The study was conducted in State University of Rio Grande do Sul under the supervision of Professor Elton Gimenez Rossini.

However, in 2015, the study faced changes and updates in order to evaluate the replacement of DO by NG in a CHP system.

Thus, the present research aim to contribute to integrate an environmental analysis towards an eco-industrial park (EIP) program in Novo Hamburgo’s industrial park when it comes to the industrial ecology (IE) field. As Korhonen [33] (p. 509) have stated, the IE concept draws “from the metaphor that a natural ecosystem is a vision for industrial environmental management and environment policy.”

3.1 Assumptions

The following assumptions were made in order to compare the use of DO and its replacement by NG in a cogeneration system at the municipal industrial sector:

A. The DO generator specific fuel consumption considered was 0.26 l/kWh. Based on an efficiency of the generator of 38%, a typical calorific value of 10,500 Kcal/kg, and a capacity factor rated 70% of nominal capacity;

B. The NG generator specific fuel consumption considered was 0.3m³/kWh. Based on an efficiency of the generator of 35%, a typical calorific value of 8,560 Kcal/m³, and a capacity factor rated 80% of nominal capacity;

C. The cogeneration system considered the same temperature in all systems presenting 85% efficiency, and 80% of capacity factor; so, the total system efficiency is 68%;

D. An ICE (Internal Combustion Energy) fueled by NG and with power capacity of 100kW per consumer, operated for 12 hours a day, 22 days a month, which is equivalent to 3168 hours a year;

E. Only the following industries were considered likely to substitute DO generation by NG in a cogeneration system: the metallurgical, mechanical, chemical, textile, food and beverage industries.

3.2 Calculation

3.2.1 NG Evaluation for DO Replacement

Equations 1, 2 and 3 summarize the calculations to evaluate the amount of necessary NG in a CHP system to replace the DO consumed in the industrial sector in one year.

$$EEj = \sum_{j=1}^{n} DOtj \times SFCdo \tag{1}$$

$$NGj = \sum_{j=1}^{n} \frac{EEj}{SFCng} \tag{2}$$

$$NGcoj = \sum_{(j=1)}^{n} NGj \times Efng \tag{3}$$

Where: DOt = total diesel oil consumption by the industrial sector, in liters, l; SFCdo = specific fuel consumption of diesel generator, l/kWh; NG = natural gas consumption to generate the same amount of energy generated by diesel oil, m³; EE = electric energy generated by diesel oil, kWh; SFCng = specific fuel consumption of natural gas generator, m³/kWh; NGco = natural gas necessary to substitute diesel oil in a cogeneration process, m³; Efng = efficiency of natural gas generator; j = time considered, one year, 2013.

3.2.2 CO_2 Emission Estimation

We estimated the CO_2 emissions of the DO electric generation using a top-down approach designated by IPCC [34] against the emissions of the cogeneration system fueled by NG. Six (6) steps were used to evaluate CO_2 emissions the flowchart shows in summary all the steps.

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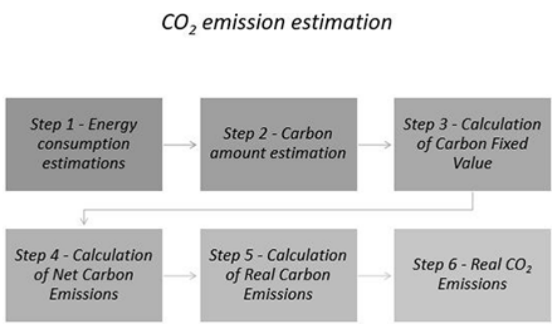

Figure 1. CO_2 emission estimation flowchart

Step 1: energy consumption estimations

It is necessary to multiply the fuel consumption by the following factors, namely: conversion factor (toe/fuel unit), correction factor[1] (dimensionless) from Higher Heating Value (HHV) to Lower Heating Value (LHV), and 45.2x10^{-3} TJ (equivalent to one Brazilian toe, in order to convert the energetic content from toe to TJ) in order to find the energy consumption in joules, as shown in Eq. (4). The parameters are shown in Table 1.

Table 1. Conversion factors for medium toe (toe/fuel unity)

	Diesel Oil	Natural Gas (cogeneration)
ConvF	0,848	0,857

Source: ELETROBRAS [35]; Ribeiro [36].

$$EC = FC \times ConvF \times CorrF \times 45.2 \times 10^{-3} \quad (4)$$

Where: EC = Energy Consumption (TJ); FC = Fuel Consumption (fuel unit); ConvF = Conversion Factor (toe/fuel unit); CorrF = Correction Factor[2] (dimensionless) of Higher Heating Value (HHV) to Lower Heating Value (LHV); 45.2x10^{-3} TJ = 1 Brazilian toe (to convert the energetic content from toe to TJ).

Step 2: Carbon amount estimation (GgC[3])

It applies the following equation, Eq. (5):

$$CA = EC \times EmissF \times 10^{-3} \quad (5)$$

Where: CA = Carbon Amount (GgC); EC = Energy Consumption (TJ); EmissF = Emission Factor (tC/TJ).

Considering data in Table 2.

Table 2. Carbon emission factors (GgC/TJ)

	Diesel Oil	Natural Gas
EmissF	20,2	15,3

Source: Ribeiro [36].

Step 3: Calculation of Carbon Fixed Value (GgC)

In this case, the carbon fixed value (CFV) equals zero, because there is no carbon energy consumption, since all the fuel is burned to generate electricity [35]. Thus, Eq. (6) equals zero.

$$FCA = 0 \quad (6)$$

Step 4: Calculation of Net Carbon Emissions (GgC)

Since the CFV is equal to zero, net carbon emissions (NCE) is equal to CA, as exemplified in Eq. (7).

$$NCE = CA - FCA \quad (7)$$

Step 5: Calculation of Real Carbon Emissions (GgC)

The RCE (GgC), Eq. (8), is the multiplication of the NCE (GgC) found in Eq. (7) by the OCF (dimensionless). The factors used for each type of fuel are shown in Table 3.

Table 3. Carbon Oxidized Fraction (dimensionless)

	Diesel Oil	Natural Gas
OFC	0,99	0,995

Source: Ribeiro [36].

$$RCE = NCE \times OCF \quad (8)$$

Where: RCE = Real Carbon Emissions (Gg C); NCE = Net Carbon Emissions; OCF = Oxidized carbon fraction (dimensionless).

Step 6: Real CO_2 ($GgCO_2$)Emissions

The real CO_2 emissions are obtained by Eq. (9).

$$RECO2 = RCE \times {}^{44}/_{12} \quad (9)$$

Where: $RECO_2$ = Real Carbon Dioxide Emissions (Gg CO_2); RCE = Real Carbon Emissions (Gg C); ${}^{44}/_{12}$ = Ratio between CO_2 and C molecular weights.

1 *The used correction factor (Fcorr) to turn HHV into LHV are 0.95, for solid and liquid fuels, and 0.90, for the gaseous fuels [35, 36].*

2 *The correction factor (Fcorr) to transform the HHV in LHV, used are 0.95 for solid and liquid fuels and 0.90 for the gaseous fuels [35, 36].*

3 *GgC is a unit used to measure the mass of emitted CO_2 and it means Giga grams of CO_2, it is also common to be used tons of CO_2, or tCO_2.*

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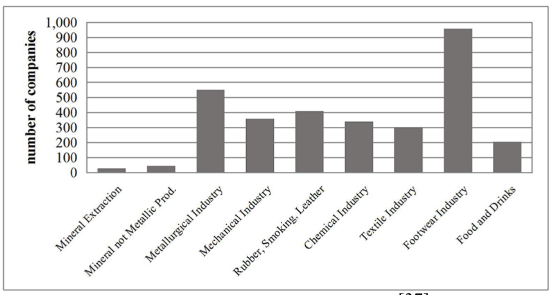
4. Results and Discussions

Results are presented as follows.

4.1 Industrial sector evaluation

According to the Commerce, Industry and Services Association of Novo Hamburgo, Campo Bom and Estância Velha [37] the main industrial activities in Novo Hamburgo are: footwear, metallurgical, textile, and chemical industries. The city also stands out as a hub of trade and services [38]. Fig. 2 shows the number of industrial business registered at ACI-NH/CB/EV [37], in 2014, a total of 3,202 industrial companies are registered. The footwear sector accounts for 30% of this total, and it is followed by the metal sector, which represents 17% of the companies in this sector. It is worth noticing that only 1,293 of these companies have their industrial activities located in Novo Hamburgo County.



Source: ACI-NH/CB/EV, 2015 adapted by authors [37]

Figure 2. Industrial business types in Novo Hamburgo

The industrial sector aggregates energy consumption data from all industrial plants, in this case: 1,293 industrial plants. Energy consumption in this sector was characterized in 2013, and shown in Fig. 3. It is important to notice, that this sector is the only one presenting energy consumption reduction of approximately 12% between 2005 and 2013, probably because of the reduction in exports of footwear industry [32].

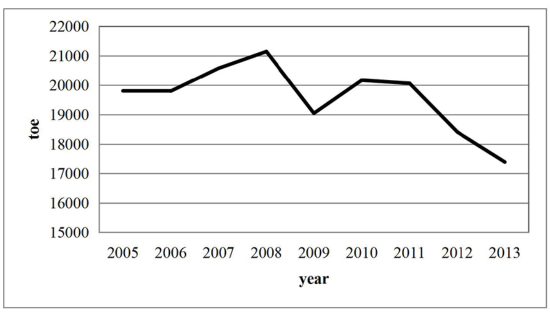


Figure 3. Total energy consumption in Novo Hamburgo's industrial sector (2005 – 2013)

Next, Fig. 4 shows the percentage of energy sources consumed by Novo Hamburgo's industrial sector; Diesel oil is the most consumed energy, thus accounting for 55% of all the energy consumed by the sector in 2013.

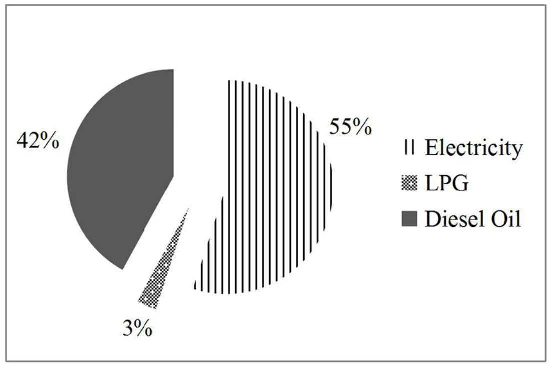
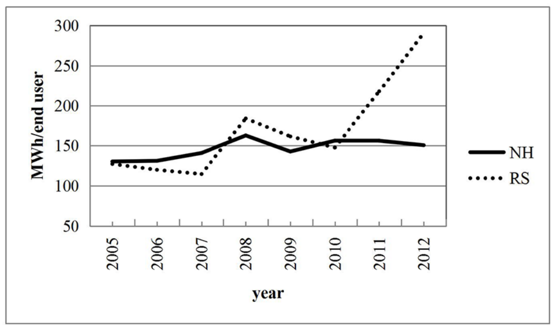


Figure 4. Energy consumption by source in the industrial sector of Novo Hamburgo in 2013

Energy consumption behavior can be analyzed through the final energy consumption related to the number of consumers within the main economic sectors. The final electricity consumption per consumer in Novo Hamburgo's industrial sector was similar to that of Rio Grande do Sul State up to 2010, approximately 147.6 MWh/end user, as shown in Fig. 5. In 2013, the electricity consumption per end user in Novo Hamburgo was 149.3 MWh/end user, growing at low rates.



Source: Capeletto; Moura, 2014; Weber, 2014 adapted by authors, 2016[39]

Figure 5. Final electricity consumption according to the number of consumers in the industrial sector of Novo Hamburgo County and in Rio Grande do Sul State from 2005 to 2012 - MWh/end user

4.2 Fuel replacement evaluation, from DO to NG

According to Sulgás [40], companies subject to cogeneration use, in other words, those simultaneously demand electricity production and heat, i.e: engineering, food, beverage, chemical, automotive, textile, paper, non-ferrous and white ceramic industries, among others.

Therefore, considering such industries at Novo Hamburgo and also their energy consumption it was possible estimate the cogeneration potential. The estimated total

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number of industries able to use cogeneration systems in industrial production system was 213. The estimated mean consumption, according to the proposed methods, was 149.3 MWh/year, and 19,450 liters of DO per year. Values of NG use in a CHP system to replace DO are shown in Table 4, and they were based on the aforementioned data and on the assumptions originated from the herein proposed methods.

Table 4. Results on the necessary amount of NG in a CHP process to replace the DO consumed in Novo Hamburgo's industrial sector

	2013	Base unit
DO consumed	4.142.637	l (liters)
Electricity generated by DO	1.077.086	kWh
NG needed to generate the same amount of electricity	3.590.285	m³
NG in a cogeneration process needed to generate the same amount of electricity	2.333.686	m³

4.3 CO_2 emissions reduction evaluation

According to the method used it was possible to measure DO emission in 2013: 11,061 $GgCO_2$. So, if we replaced the fuel used in the industrial sector for NG, the total annual NG emission would be: 4,541 $GgCO_2$. Fig. 6 shows the total emission of each fuel type by considering the time estimated for the project (10 years).

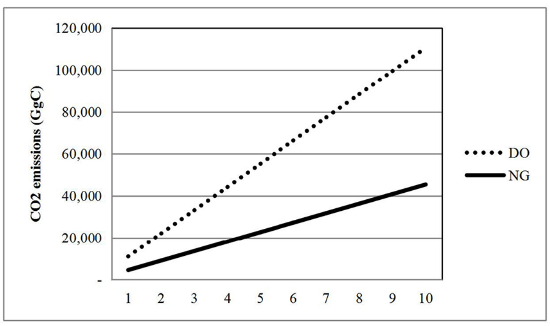

Figure 6. Total CO_2 emission by fuel type

We found that at the end of the project (considering a 10 year period) we estimate 65,196 $GgCO_2$ or 6,520 $GgCO_2$/year (6.52 $MtCO_2$/year) on emissions savings. So, the difference of using a NG CHP system presents approximately 60% lesser GHG emission than that using DO.

5. Conclusion

Diesel replacement to natural gas can be a powerful instrument to achieve integration between decentralized energy generation and energy-efficient initiatives. Thus, CHP is a potential technical solution to be explored in the integration of energy generation initiatives in the industrial sector of Brazilian cities.

A comparative analysis of the DO use and replacement by NG in a CHP system at the municipal industrial sector was performed due to such opportunity. It was estimated that the mechanical, chemical, textile, metallurgical, food and beverage industries in Novo Hamburgo consume a lot of power and heat in their industrial processes; therefore, they are suitable for the use of cogeneration systems.

In addition, it was estimated that if NG replaces the current electricity generation by DO in cogeneration systems in Novo Hamburgo's industrial sector, NG consumption in 2013 would have been almost half of the DO consumption.

An evaluation of CO_2 emissions and the difference in using a NG cogeneration system on GHG emissions is approximately 60% lower than the emissions of CO_2 from DO, representing a reduction of 6.52 $MtCO_2$/year.

Such difference in the industrial activities will benefit the environment as a whole and the people who live in Novo Hamburgo since it will be good to their health, due to the decrease in the emission of hazardous gases.

Therefore, the results showed that the replacement by cogeneration plants fueled by NG in the studied industries, it is a suitable solution from an energetic, economic and environmental point of view. Public policies should play an important role in promoting investments in order to increase NG consumption in Novo Hamburgo's the industrial sector. In addition, we recommend studies that compare those systems combined with renewable resources (solar, wind, biomass, hydro-electric power) in order to improve the cleaner energy practices in this city.

Acronyms

C	Carbono	IP	installed power
CA	carbon amount	J	Joule
CH4	Methane	J	time considered in years
CHP	combined heat and power	LHV	lower heating value
CO2	carbon dioxide	N2O	nitrous oxide
ConvF	conversion factor	NCE	net carbon emissions
CorrF	correction fator	NG	natural gas
DO	diesel oil	NGc	natural gas consumption
DOt	total diesel oil consumption	NGco	natural gas in a cogeneration system necessary to substitute diesel oil
EC	energy consumption	OFC	oxidized carbon fraction
EE	electric energy generated per year	PM	particulate matter
EmissF	emission fator	RCE	real carbon emissions
FCA	fixed carbon amount	RECO2	real carbon dioxide emissions
G	Giga	T	Terá
GHG	greenhouse gases	T	Tons
HHV	higher heating value	toe	tonne of oil equivalente
ICE	internal combustion engine		

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References

[1] Brito, T. L. F.; Galbieri, R.; Mouette, D.; Costa, H. K. M; Moutinho Dos Santos, E.; Faga, M. T. W. (2017), Bus fleet emissions: new strategies for mitigation by adopting natural gas. Mitigation and Adaptation Strategies for Global Change, v. 23, p. 147-160.

[2] Brito, T. L. F.; Moutinho dos Santos, E.; Galbieri, R.; Costa, H. K. M. (2016), Qualitative Comparative Analysis of cities that introduced compressed natural gas to their urban bus fleet. Renewable & Sustainable Energy Reviews, p. 502-508.

[3] Lovins, A. (2011), Reinventing Fire: Bold Business Solutions for the New Energy Era. Rock Mountain Institute. Chelsea Green Publishing, USA.

[4] Collaço, F.M.A., Weber, N.A.B., Costa, H.K.M., Santos, E.M., Bermann, C. (2016), How decentralized energy planning can contribute to cleaner production initiatives, p. 209-228. In: Biagio, F., Giannetti, C.M.V.B., Almeida, F.A., Sevegnani, F. Advances in Cleaner Production, NY, Nova Publisher, v. 2.

[5] Andreos, R. (2013), Estudo de viabilidade técnico-econ**ô**mica de pequenas centrais de cogera**ção** a gás natural no setor terciário do estado de S**ão** Paulo. Dissertação de Mestrado. Programa de Pós Graduação em Energia (EP/FEA/IEE/IF). São Paulo.

[6] Driesen, J., Katiraei, F. (2008), Design for Distributed Energy Resources. IEEE power & energy magazine, v. 6, p. 1540-7977.

[7] Ren, H., Gao, W. A. Milp (2010), model for integrated plan and evaluation of distributed energy systems. Applied Energy, v. 87, p. 1001–1014.

[8] Doluweera, G.H., Jordaan, S.M., Moore, M.C., Keith, D.W., Bergerson, J.A. (2011), Evaluating the role of cogeneration for carbon management in Alberta G.H. Energy Policy, v. 39, p. 7963–7974.

[9] Moya, J. A. (2013), Impact of support schemes and barriers in Europe on the evolution of cogeneration. Energy Policy, v. 60, p. 345–355.

[10] Siler-Evans, K., Morgan, M. G., Azevedo, I.L. (2012), Distributed cogeneration for commercial buildings: Can we make the economics work? Energy Policy, v. 42, p. 580–590.

[11] Korhonen, J. (2002), A material and energy flow model for co-production of heat and power. Journal of Cleaner Production, v. 10, p.537-544.

[12] Ouellette, A., Rowe, A., Sopinka, A., Wild, P. (2014), Achieving emissions reduction through oil sands cogeneration in Alberta's deregulated electricity market. Energy Policy, v. 71, p. 13–21.

[13] Baer, P., Brown, M.A., Kimb, G. (2015), The job generation impacts of expanding industrial cogeneration. Ecological Economics, v. 110, p. 141–153.

[14] Andrews, D., Riekkola, A.K., Tzimas, E. (2012), Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion. Luxem- bourg.

[15] Chittum, A., Østergaard, P.A. (2014), How Danish communal heat planning empowers municipalities and benefits individual consumers. Energy Policy, v. 74, p. 465–474.

[16] Connolly, D., Lund, H., Mathiesen, B.V., Werner, S., Möller, B., Persson, U., Boermans, T., Trier, D., Østergaard, P.A., Nielsen S. (2014), Heat roadmap Europe: combining district heating with heat savings to decarbonise the EU energy system. Energy Policy, v. 65, p. 475–489.

[17] Tian, J., Liu, W., Lai, B., Li X., Chen, L. (2014), Study of the performance of eco-industrial park development in China. Journal of Cleaner Production, v. 64, p. 486-494.

[18] Iacobescu, F., Badesc, V. (2011), Metamorphoses of cogeneration-based district heating in Romania: A case study. Energy Policy, v. 39, p. 269–280.

[19] Rutter, P., Keirstead, J. (2012), A brief history and the possible future of urban energy systems. Energy Policy, v. 50, p. 72–80.

[20] Chung, M., Park, C., Lee, S., Park, H.C., Hoonim, Y., Chang, Y. (2012), A decision support assessment of cogeneration plant for a community energy system in Korea. Energy Policy, v. 47, p. 365–383.

[21] Celador, C., Erkoreka, A., Escudero K., Sala, J.M. (2011), Feasibility of small-scale gas engine-based residential cogeneration in Spain. Energy Policy, v. 39, p. 3813–3821.

[22] Palomino, R.G., Nebra, S.A. (2012), The potential of natural gas use including cogeneration in large-sized industry and commercial sector in Peru. Energy Policy, v. 50, p. 192–206.

[23] COGEN. Associa**ção** da Indústria de Cogera**ção** de Energia. 2015. Available at: http://www.cogen.com.br/ (Accessed 15.10.2015).

[24] Hwang, J. J. (2012), Thermal regenerative design of a fuel cell cogeneration system. Journal of Power Sources, v. 219, p. 317 and 324.

  DOI: https://doi.org/10.30564/jasr.v2i1.419

[25] Karschin, I.; Geldermann, J. (2015), Efficient cogeneration and district heating systems in bioenergy villages: an optimization approach. Journal of Cleaner Production, v. 104, p. 305- 314.

[26] Ravina, M.; Genon, G. (2015), Global and local emissions of a biogas plant considering the production of biomethane as an alternative end-use solution. Journal of Cleaner Production, v. 102, p.115- 126.

[27] Celma, A. R., Blázquez, F. C., Rodríguez, F.L. (2013), Feasibility analysis of CHP in an olive processing industry. Journal of Cleaner Production, v. 42, p. 52-57.

[28] Andersen, A.N., Lund, H. (2007), New CHP partnerships offering balancing of fluctuating renewable electricity productions. Journal of Cleaner Production, v. 15, p. 288-293.

[29] Aldrich, R., Xavier, F., Puig, J., Mutjé, P., Pèlach, M. (2011), Allocation of GHG emissions in combined heat and power systems: a new proposal for considering inefficiencies of the system. Journal of Cleaner Production, v. 19, p.1072-1079.

[30] Moloney, S., Horne, R. E., & Fien, J. (2010). Transitioning to low carbon communities—from behaviour change to systemic change: Lessons from Australia. Energy policy, 38(12), 7614-7623.

[31] Fahlén, E.; Ahlgren, E. (2012), Accounting for external environmental costs in a study of a Swedish district-heating system e an assessment of simplified approaches. Journal of Cleaner Production, v. 27, p. 165- 176.

[32] Weber, N. (2014), Levantamento e análise de dados para diagnóstico energético do município de Novo Hamburgo. Trabalho de conclusão de curso. Engenharia em Energia. Universidade Estadual do Rio Grande do Sul (UERGS), Novo Hamburgo.

[33] Korhonen, J. (2001), Co-production of heat and power: an anchor tenant of a regional industrial ecosystem. Journal of Cleaner Production, v. 9, p. 509-517.

[34] IPCC. Revised 1996 IPCC Guidelines for National Green House Gas Inventories. 1996. Available at: http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html (Accessed 10.10.2015).

[35] ELETROBRAS. Inventário de Emissões de Gases de Efeito Estufa provenientes de Usinas Termelétricas (fontes fixas): 2003 a 2008. 2009. Available at: http://www.eletrosul.gov.br/files/files/sustentabilidade/gestao-ambiental/INVENT%C3%81RIO_DE_EMISS%C3%95ES_DE_GEE_UTES_2003_2008%5B1%5D.pdf (Accessed 15.10.2015).

[36] Ribeiro, L. S. O Impacto do Gás Natural nas Emissões de Gases de Efeito Estufa: o Caso do Município do Rio de Janeiro. 2003. Available at: http://www.ppe.ufrj.br/ppe/production/tesis/lsribeiro.pdf [Accessed 15.10.2015].

[37] Associação Comercial, Industrial E De Serviços De Novo Hamburgo, Campo Bom E Estância Velha, Aci-Novo Hamburgo/Cb/Ev, 2015. Data sent by e-mail (18.09.2015).

[38] Martins, C. M. R., 2013. Caracterização da Região Metropolitana de Porto Alegre. 2013. Available at: http://cdn.FUNDAÇÃO DE ECONOMIA E ESTATÍSTICA.tche.br/tds/112.pdf (Accessed 28.09.2014).

[39] Capeletto, G., 2014. Balanço Energético do Rio Grande do Sul 2014: ano base 2013.http://www.ceee.com.br/pportal/ceee/archives/BERS2013/Balanco_Energetico_RS_2014_base_2013.pdf (Accessed 21.10.2015).

[40] SULGÁS. Com a cogeração, você pode obter maior aproveitamento energético. 2015. Available at: www.sulgas.rs.gov.br/sulgas/index.php/cogeracao (Accessed 20.10.2015).

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