High efficient cogeneration potential

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ABSTRACT

The development of the industrial sector requires increased energy efficiency as to improve competitiveness and restrict the use of fossil fuels, with co-objective reducing the emission of greenhouse gases. Achieving this objective can only by implementing energy efficient solutions that are economically attractive and viable for different industries so that they will be implemented quickly, efficiently and with high impact. The work described in this paper has the objective to evaluate the potential of cogeneration in the industrial sector of Ecuador, using data published by the INEC in 2011.

Keywords: Cogeneration, efficient use of energy, industry.

RESUMEN

El desarrollo del sector industrial requiere una mayor eficiencia energética, tanto para mejorar la competitividad como para reducir el uso de combustibles fósiles y colaborar en la reducción de las emisiones de gases de efecto invernadero. Esto solo puede ser posible implementando soluciones de eficiencia energética que sean económicamente atractivas y viables para las diferentes industrias, de forma que se implementen de forma rápida, eficiente y con un gran impacto. El trabajo realizado tiene como objetivo evaluar el potencial de cogeneración en el sector industrial del Ecuador, para lo cual se utilizó una base de datos publicada por el INEC en 2011.

Palabras clave: Cogeneración, uso eficiente de la energía, la industria.

1. INTRODUCTION

Thermal energy in industry is generally generated local from fossil fuels, while electricity is obtained from the electric power grid. However, a significant part of electric energy is generated in thermal power plants wasting a large part of the input energy through the exhaust of gases and cooling systems. This problem can among others be solved by turning waste heat from combustion engine exhaust gas into electricity. Doing so will raise the global efficiency of the system, reduce the overall cost, pollution and other problems. Figure 1 shows the energetic benefit produced by applying this concept, called *cogeneration*. As shown in this figure, the concept of cogeneration results in a saving of the primary energy of 20% as compared with the traditional system.

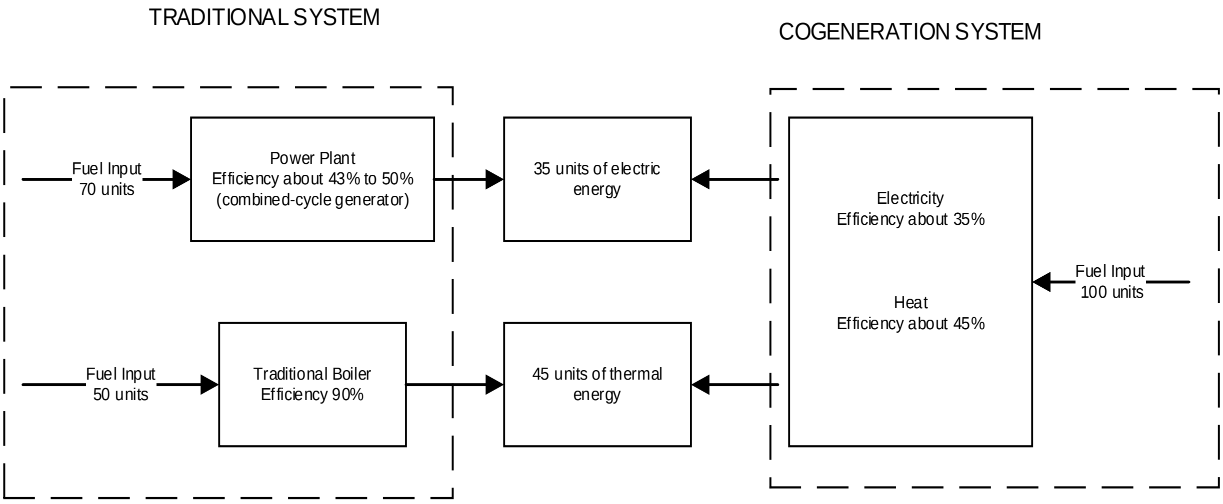

Figure 1. Comparison of energy flow in a traditional system versus a cogeneration system.

Cogeneration or CHP (Combined Heat and Power) is defined as the sequential use of a primary energy stream to produce two useful energy forms, e.g., thermal energy and electric power (Orlando, 1991, p. 4). Although used in a few industries since a long time, the oil crisis of the 1970s and 1980s led to a generalized promotion of this process in several countries in North America and Europe, with the objective to increase the primary energy use efficiency, and in this way to reduce the dependency on oil as primary source. The main targets have been industries with a significant use of heat in the industrial process as well as the production of heat for acclimatization of buildings (Bluestein & Lihn, 1999). The energy saving resulting from cogeneration, when compared to the separate production of electric power and heat, results mainly from the thermoelectric power generation process and the possibility of recovering what otherwise is considered waste energy.

In the conversion process of heat to mechanical energy, not all thermal energy can be converted, and according to the second thermodynamic law, the best theoretical performance implies circa 50% of losses through heat exhausted and absorbed in engine cooling systems. However, exhausted gases possess a considerable thermal energy content which is not difficult to recover when using appropriate heat exchangers. The same applies to an eventual cooling circuit. The extracted heat can be supplied to an appropriate thermal load, frequently in the form of steam, then composing a cogeneration system by simultaneously producing heat and mechanical energy, eventually converted into electricity. In other cases, cogeneration occurs by local production of electric energy from recovered thermal outputs of others industrial processes. Cogeneration is classified according to the sequence in which heat and mechanical power are generated, which of course strongly depends on the industrial process. Two types of cogeneration cycles are defined, respectively topping cycle and bottoming cycle (see Fig. 2).

The use of cogeneration increases the global efficiency of the industrial processes either by reducing the primary energy consumption or by the local production of electricity from recovered thermal outputs. To stimulate the use of cogeneration, given its beneficial effects, some countries introduced in their legislation laws or directives to regulate cogeneration (European Union Directive 2012/12/EU, 2012), simultaneously targeting an overall increase in energy efficiency (Gambini & Vellini, 2014). In Latin America is Mexico an example where a specific program to promote cogeneration was implemented. In the case of the European Union, the directive pushes member states to assess periodically the potential for cogeneration. In line herewith, is the work presented in this paper an attempt to assess the cogeneration potential of Ecuador, using data belonging to the public domain.

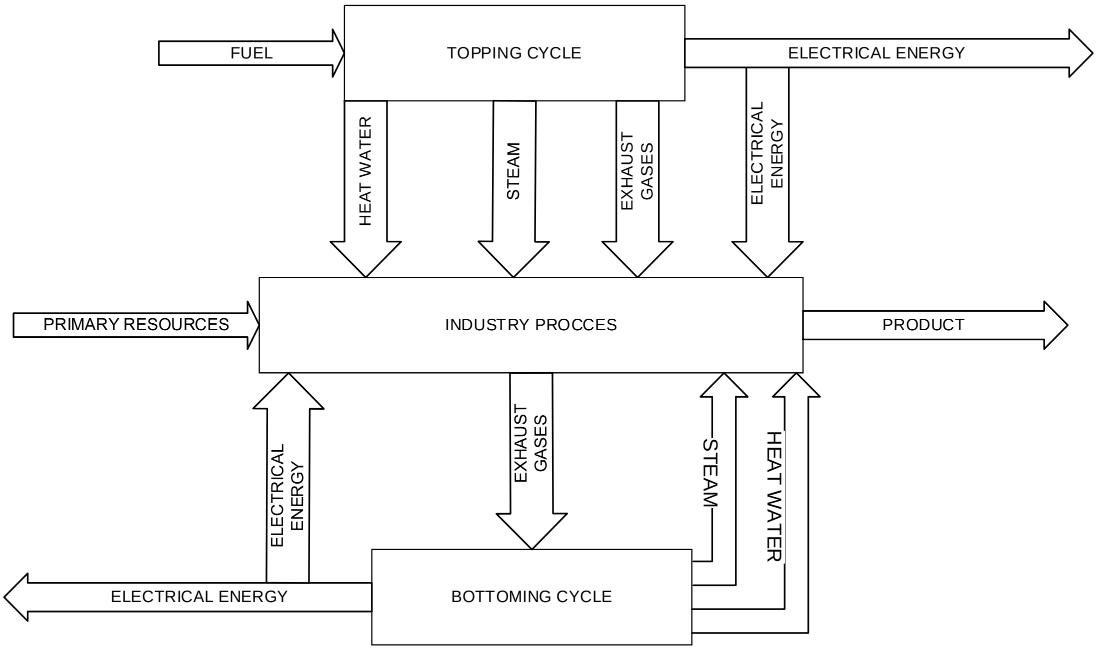

Figure 2. Classification of cogeneration systems according to sequence production of electricity and heat.

2. METHODOLOGY

To evaluate the potential of cogeneration, the following steps were considered in this work. In a first step, the data published in 2011 by the "National Institute of Statistics and Census" (INEC) were selected. This data was structured according to the classification developed by the International Standard Industrial Classification of all Economic Activities" (ISIC) (Revision 4) (UN Department of Economic and Social Affairs, 2008). This standard divides the economic activities into twenty-one sections, based on the range of economic activities. INEC limited the classification in its database to only nine divisions (see Fig. 3), representing Ecuador's main industrial sectors.

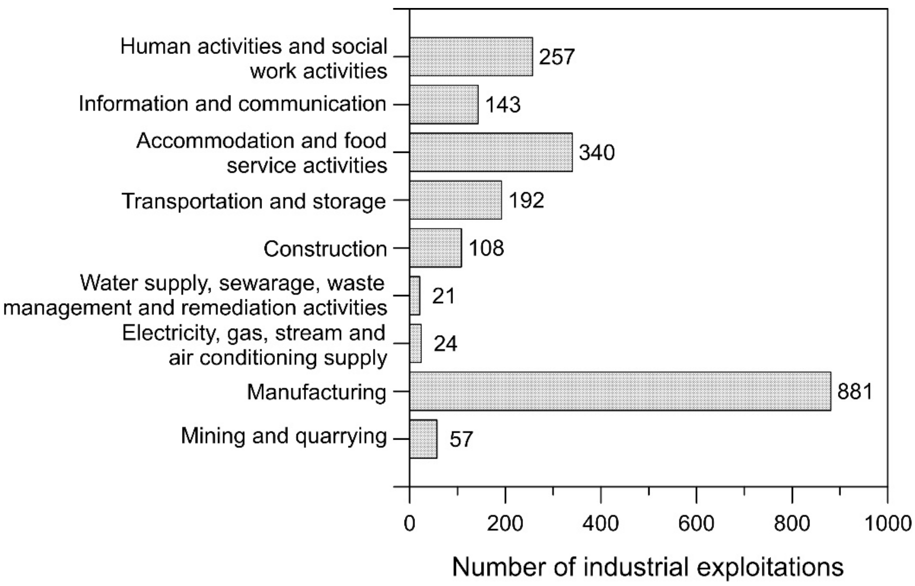

Figure 3. Division of businesses according to their principal activity.

In the second step, based on the classification performed in previous step, only the industries that have potential to cogeneration were chosen. The sectors “Manufacturing” and “Mining and Quarrying”, representing 938 industries, were retained and further considered in the analysis. Although the sectors “Accommodation and food service activities”, “Human Health and Social Work Activities” have high potential of cogeneration, in this study those sectors were not considered due to lack of information and the specific characteristics of Ecuador’s climate. For example, needs of heating for climatization do not exist in most part of the country because the relative good conditions for human life. However, heat in this sector is used for sterilization of medical instruments, washing, drying among many other activities. Notwithstanding, the sector “Human Health and Social Work Activities” was not further considered in the analysis by lack of information.

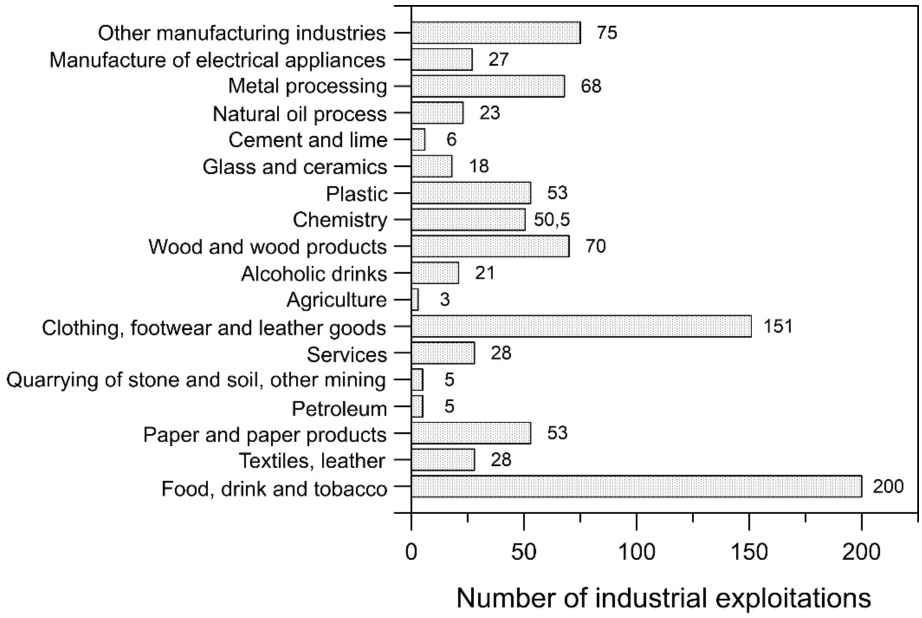

Figure 4. Division of the subsectors of manufacturing business.

In step 3, based on the information obtained before, the different industries are divided into eighteen subsectors, as depicted in Figure 4. The following hypothesis were considered:

- Hypothesis 1. It is supposed that industries according to their size are daily operative 8, 16 or 24 hours (small, medium or big).
- Hypothesis 2. For the case of electric energy and LPG gas, only the monthly consumption is available. The annual consumption was estimated using this data combined with annual hours worked.

Based on these hypotheses, the total quantity of fuel and electric energy consumed for each industry and subsector was calculated.

In the fourth step, considering the fuel information obtained previously, and the Lower Heating Value (LHV) for each fuel, it was feasible to determine the thermal energy consumed by each subsector, as shown in Figures 5 and 6. For the fifth step, due to the lack of information about cogeneration in Ecuador, information obtained from studies realized in 2014 for Germany and in 2016 for Portugal, were considered to estimate the share of thermal energy consumption that can technically be supplied by cogeneration (Klotz *et al*., 2014; ISR-UC & INESC, 2016). Obviously, this estimate is clearly imperfect due to differences in weather, altitude, technology, etc. Nevertheless, the authors considered the followed approach acceptable as a first approximation.

Additionally, a process to obtain the cogenerated electricity was applied using the following equation:

$$R = \frac{H_{CHP}}{E_{CHP}}$$

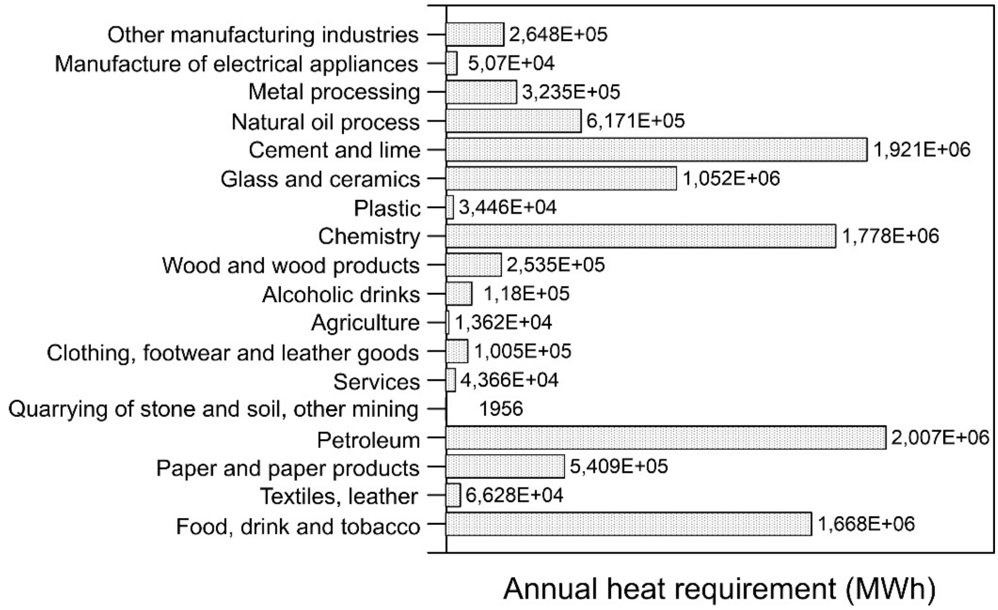

Figure 5. Annual heat requirement (MWh) per subsector.

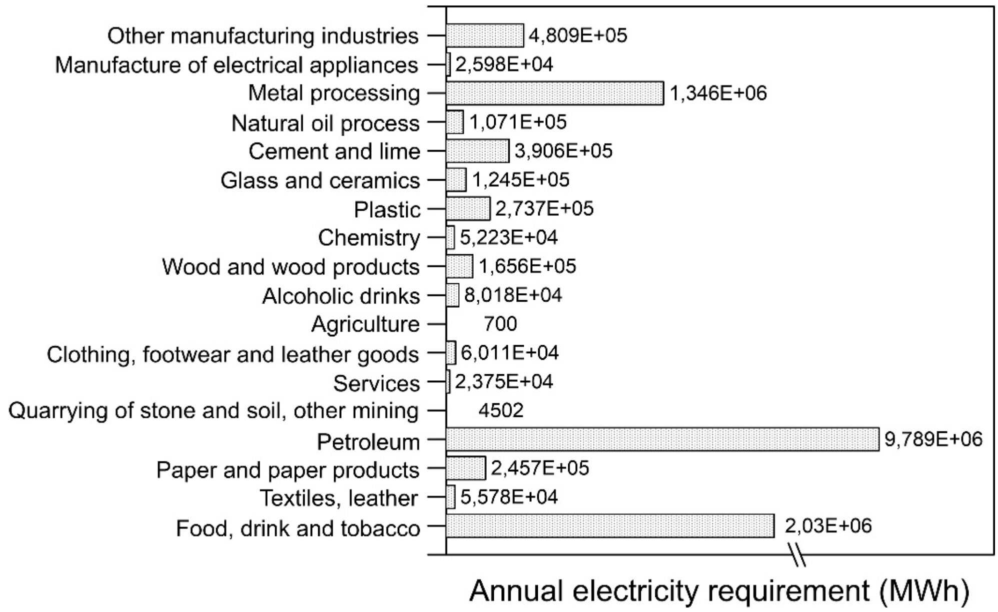

Figure 6. Annual electricity requirement (MWh) per subsector.

The thermal to electricity efficiency ratio R was derived and checked to typical values published in a similar study carried out in the USA in 2016 (Hampson, Tidball, Fucci, & Weston, 2016). For some subsectors approximations were taken and the final values chosen are represented in Table 1.

In the sixth and final step, two cases were considered to define the technical potential. In the first case, 100% of the diesel oil consumption was assumed to be used for industrial heat generation. In the second case, only 50% of the diesel consumption was considered, assuming the remaining 50% was used for non-replaceable end-uses, e.g. engines. For both cases, cogeneration was assumed to be used for auto consumption given the lack in Ecuador of clear laws or rules for the sale of electricity to the grid. Ultimately, to cope with the availability of data and time, the analysis was limited to applications where the demand is equal or higher than 50kW electric and 60kW thermal energy.

Table 1. Percentage of heat used for cogeneration (Klotz *et al*., 2014, p. 92).

#	Subsector	<300°C[1]	Ratio Heat/Power[2]
1	Food, drink and tobacco	100%	2.00
2	Textiles, leather	40%	1.50
3	Paper, paper products	100%	3.50
4	Petroleum	40%	3.93
5	Quarrying of stone and soil, other mining activities	98%	2.00
6	Services	0%	0.00
7	Clothing, footwear, leather goods	40%	2.50
8	Agriculture	4.66%	1.51
9	Alcoholic drinks	40%	2.50
10	Wood, wood products	40%	1.88
11	Chemistry	40%	1.88
12	Plastic	100%	1.88
13	Glass and ceramics	7%	1.74
14	Cement and lime	90%	2.50
15	Natural oil process	40%	1.51
16	Metal processing	17%	2.50
17	Manufacture of various electrical appliances	66%	2.50
18	Other manufacturing industries	50%	2.50

Table 1 presents the potential share of heat subsectors can supply by cogeneration according to the used reference. However, a few adaptations were considered to better reflect the characteristics of Ecuador's industrial sector, as in the case of subsector 18, "Other Manufacturing Industries", where only 50% of the heat was considered replaceable due to the difference in industrial development between Ecuador and Germany. The same strategy was used to estimate for the different sectors the thermal-to-electricity ratios used in cogeneration facilities.

3. RESULT AND DISCUSSION

The results obtained after applying the proposed methodology are presented in Table 2. The 2nd and 4th columns present the estimation for the potential thermal power, which technically could be installed in each industrial sector given respectively 50 and 100% of diesel is used for heat production, and the 3rd and 5th columns represents for both conditions the equivalent electric power potential. Interpreting the results in Table 2, one ought to be aware that the uncertainly regarding the use of diesel various around 19%. As presented in this table, the principal subsectors with cogeneration potential are "Food, drink and tobacco", "Paper and paper products", "Petroleum" and "Natural oil process", representing a good match with the main industrial activities in the country. For the cases of "Textile, leathers", "Cement and lime" and other important subsectors, the potential is low mainly due to the assumption of electricity self-consumption, not considering the possibility of selling surplus generation. For the subsector "Quarrying of stone and soil, other mining" is the potential low because the mining sector in Ecuador is poorly developed.

Furthermore, it is possible to observe in the Figures 5 and 6 that the thermal energy needs are high when compared with the electric needs. Considering this, and the lack of a law to sell electricity, are important limitations for the development of the country's cogeneration potential.

[1] Potential heat per subsectors
[2] Ratio thermal/electrical energy per subsector

Table 2. Technical potential of cogeneration considering respectively 50 and 100% of diesel is used for heat production.

Sector	50% diesel cogenerated		100% diesel cogenerated	
	MWter	MWelect	MWter	MWelect
Food, drink and tobacco	69.813	34.907	94.724	47.362
Textiles, leather	3.396	2.264	4.764	3.176
Paper, paper products	65.948	18.842	68.041	19.440
Petroleum	72.139	18.356	95.252	24.237
Quarrying of stone and soil, other mining activities	0.388	0.194	0.775	0.388
Services	-	-	-	-
Clothing, footwear, leather goods	3.065	1.226	4.936	1.974
Agriculture	-	-	-	-
Alcoholic drinks	5.168	2.067	9.691	3.876
Wood, wood products	-	-	-	-
Chemistry	4.029	2.143	5.258	2.797
Plastic	2.921	1.554	4.352	2.315
Glass and ceramics	14.209	8.166	16.011	9.202
Cement and lime	0.239	0.096	0.478	0.191
Natural oil process	33.388	22.111	34.878	23.098
Metal processing	1.979	0.792	2.606	1.042
Manufacture of various electrical appliances	-	-	-	-
Other manufacturing industries	2.800	1.120	3.432	1.373
Total	279.483	113.837	345.197	140.471

4. CONCLUSIONS

The sectors were cogeneration may be an interesting option are the petroleum, paper, and food-drink-tobacco industries. Attention should be payed to the food-drink-tobacco sector, since this presents a considerable potential, but have less self-stimuli to consider cogeneration as an option. With the implementation of a law or normative to regulate cogeneration and generation of the possibility to sell energy to the electricity grid, the potential of cogeneration can be increased. This can be derived by analyzing the Figures 5 and 6, because those figures depict that the difference between thermal and electrical energy needs are considerable. Even without this change, the technical electrical power potential is around 2.93% of the power generation installed in 2011.

Although not a large number, the amount of cogeneration potential may represent an important way to reduce fossil fuel consumption and to help the global effort to reduce emissions of greenhouse gases. Cogeneration produces new challenges to the electrical grid of the country, implying new rules in the legal and technical framework, but may lead to additional benefits by improving the quality of service and reducing electric power transmission losses. The creation of incentives to industrial cogeneration is a good form to introduce this technology in existing and new industrial plants.

Problems caused by altitude in the Andean region are an important topic to be considered in future studies, because of power losses presented in equipment possibly due to the typical Andean conditions. In this regard, the introduction of new technologies, such as the Stirling Engine, can be an interesting option for cogeneration applications.

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