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ENVIRONMENTAL AND FINANCIAL ASSESSMENT FOR A CCHP DISTRICT PLANT IN A CITY IN ROMANIA

BY

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Abstract. The benefits of cogeneration that is highlighted also by the European Union through different directives along with the energy legislation in Romania has started to raise some question on what it will be the cost to improve and expand this system and how to make it even more energy efficient. Of course, one of the solution is to transform a cogeneration system into a tri-generation system and upgrading or changing the equipment inside them to newer ones but there will be still another issue. What will it happen with the new neighborhoods that have appeared during the economic boom between 2008 and 2013 and with the residential buildings that are still being constructed somehow chaotic? The purpose of this paper is to demonstrate that small district CCHP, for only 4 or 5 residential buildings is viable and with many benefits for the investors and for the environment. We concluded that for a small number of residential buildings in one of the largest cities of Romania, the optimal solution is by using mature technologies along with a fuel that has a pipe network very well structured and allows future development.

Key words: district heating and cooling; combined cooling heating and power (CCHP); gas turbine; internal combustion engine.

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1. Introduction

Improvement and the increase of heat and power production through cogeneration represents one of the steps made to fulfill the objectives of the European Union to improve energy efficiency until 2020 expressed in the 2012/27/Eu Directive. Also, the European Union issued several amendments and guidelines for establishing and improving methodology that EU member states can rely on when creating their own legislation (Decision 2011/877/EU; Decision 2008/952/EC). The intense campaign of cogeneration led to a rise of CHP (combined heat and power) and all the sectors but mainly in the industrial part. Taking into consideration that 26.2% of the final energy consumption was made only by residential sector and only 25.6% was attributed to the industrial sector (http://ec.europa.eu/energy/sites ...), we can safely draw the conclusion that there is still room for improvement. Energy efficiency of CHP plants can be increase by producing cold during the summer and thus turning the CHP into a CCHP plant or a tri-generation plant. The tri-generation principle is not new and it is the next step of improving the old CHP plants that have been build few decades ago. Also, at the moment, new CCHP small application are installed but are concentrated mainly on commercial or service sector (office buildings, airports, hospitals, etc.) (Mago & Hueffed, 2010; Denilson Boschiero do Espirito, 2014).

CHP and CCHP can be applied in two different way to buildings. Both can be used in distributed generation systems or in district heating (and cooling) systems and both have advantages and disadvantages. However, the district heating approach has increased benefits and the best example is represented by Denmark (http://dbdh.dk/district-heating-history/). While in Scandinavian countries, district heating is based on CHP plants, which have different sizes and some of them are using renewable resources (mostly geothermal energy), the district heating with CHP plants in Eastern Europe countries rely mostly on fossil fuels such as coal and natural gas and, in fewer cases, oil. In Western Europe, district heating has started to gain terrain and more and more studies have been conducted so that a national plan can be established. The studies show a decrease in global emissions of carbon dioxide and the feasibility of the systems, however the cost analysis is influenced by the prices of fuel, taxes, type of technology and so on (Torchio, 2015; Klaassen & Patel, 2013; Truongle & Gustavsson, 2014).

The evolution of cogeneration in Romania can be divided into two periods that are totally different regarding investments and future planning. The first period is the one before the 1990’s, when all the current thermoelectric and district heating plants. Both of them use cogeneration, but had lower efficiency.

In terms of fuel, the vast majority are adaptable to two or three fossil fuels such as coal, natural gas, oil but this fact wasn't a problem because Romania had an intensive mining industry and the soil reserves were plenty. The district cogeneration plants served a whole city or town and all of the buildings, regardless of the sector that there were involved, were linked to the urban heating system and at the national electric system. After the 1990's it can been easily observed a period of severe decline of district heating produced by cogeneration mainly because of mismanagement and the because of a huge wave of new technologies that were unknown to Romanian people. The most important benefit that the people saw in them was the ability to be control by the owner and that made a huge impact, district heating systems was old and because no investments were made to increase the efficiency, everybody had heating agent 24 hours a day and they would all pay the same. Because of no investment were made during made during a period of 10,…,15 years many people switch to gas fired boilers to heat up their homes and this process continues even now. After the Romania acceptance in the European Union in 2007, things started to change but at a very low speed (Vaida, 2014). As a comparison, in 2008, the production of energy from cogeneration plants 47755 GWh and in 2013 the production reached 38,641, a 19.08% drop (http://www.anpm.ro...; http://www.insse.ro/cms...). In terms of heating, the production of heat from district heating in 1993 was 35,977,306 Gcal but in 2010 the production barely reached 12,781,399 a drop of 64 %. Between 2007 - 2011 a number of 243,991 apartments requested to leave to district heating and a number of only 28,544 wanted to come back to the district heating system (http://www.fonduri-ue.ro...).

2. Case Study Data

2.1. Background Information

Our assessment is made for a number of four residential buildings that are situated in the city of Iasi, Romania, in the north-east region of the country, the largest urban settlement in the area. The city of Iasi has an important history in producing heat and power through cogeneration, its first cogeneration plant, being built in 1966, which could produce 50 MWe from two steam turbine units of 25 MWe each, that were fueled with hydrocarbons. Between 1972 and 1973, two additional units were installed, each producing 50 MWe that were fueled with coal as a response to the oil crisis. After the 1980's when the industrial sector was rising very quickly, the need of electricity grew and, therefore, another cogeneration plant was built, outside the city, that could supply 150

MWe from three steam turbine units of 50 MWe each, all of them fueled with coal. At the moment, due to several investments made between 1990 and present day, the first cogeneration plant can produce 125 MWe with 1 unit of 25 MWe and two units with 50 MWe, all of them using condensing steam turbines and fueled with natural gas or oil. The second cogeneration plant can produce 100 MWe and is equipped with two 50 MWe steam turbines, one of them running in condensing and the other in counter pressure (Vaida, 2014; http://www.cet-iasi.ro/My_Homepage_Files caiet%...). Both units are link with each other and through a series of pipelines, the heating agent, which is hot water with temperatures above 110^{o}C, travels to different points in the city, substations, which supply one or more buildings with heating agent and domestic hot water. Between 2004-2008 investment in improving the thermal efficiency of the substations and pipelines, totaling approximately 12,000,000 euro(http://www.cet-iasi.ro/My_Homepage_Files/investitii%...).

In Iaşi, according to the statistics there are a number of 100,000 apartments (http://www.recensamantromania.ro...) from which, in 2012, only 45,000 (http://www.veolia.com/en/veolia-group...) where connected to the district heating systems, but this number is accurate, because there were many people that disconnected themselves from the district heating without notifying the company that operate the system. It is said that only 30 % of the apartments are still connected to the urban heating system.

2.2. Hypothesis and Data

After the year 2008, all around Romania the residential sector has flourished, many apartment buildings and dwellings were built, many on the outskirt of the cities. In Iasi, the phenomenon was the same and thus creating a metropolitan area that implied several issues, one of them being that the pipe network for the main utilities and the electrical network had to be redesign.

All of the apartments and dwellings are heated using gas-fired boilers. The objective of the paper is to determine if this solution is the most suited one or if there is another solution, using small district heating, and we propose also cooling, using a tri-generation system that runs on several stable technologies: gas turbines (case B) and internal combustion engine, that runs on diesel (case C) or natural gas (case D). Case A is the current situation with cooling being done with split units, for each apartment. For the analysis we used Retscreen Software.

The buildings proposed for the analysis are not new, being built around the 1990's. They consist of a frame structured made from prefabricated components with the *U* value detailed in Table 1.

Table 1
U Values for the Structure of the Residential Buildings

	Envelope component	*U* value, [W/m^{2}K]
1	Walls	0.80
2	Floor wall	0.46
3	Roof wall	1.09
4	Windows	1.81

The heated and cooled surfaces area is 13,353 square meters in five apartment building totaling 856 kWth heating power, 1,206 kWth cooling power and the peak electric power needed is 1,835 kWe. The gas fired boilers have an energy efficiency of 80% and the COP for a split unit is 3. The fuel rate for those considered in the paper are shown in Table 2.

Table 2
Fuel Rate Average for Year 2015

	Natural gas	Grid electric power	Diesel fuel
Rate	0.352 €/m^3	0.101 €/kW	1.23 €/l

In order to lower the energy consumption, the buildings will suffer thermal insulation works, the costs of this works being taking into consideration in the analysis. After the thermal insulation of the buildings, the system design (in all three proposed cases) will take into consideration the new needs of power, heating and cooling. In case B it will be used a tri-generation system that is equipped with a small scale gas turbine that can produce 1,550 kWe electric power, in case C we will considered an internal combustion engine that is fueled with diesel that produces 1,294 kWe and in case D the power produced with internal combustion engine that runs on natural gas is 1,622 kWe. The electrical powers can cover the consumption all around the day excepting the peak loads when electricity from the grid will be used.

In all three proposed cases, the cooling agent will be produced using an absorption chiller, with a capacity of 989 kWth and a COP of 1.32. Peak heating loads will be covered with a gas fired boiler with a capacity of 234 kW and an efficiency of 97%.

Financial parameters will be the same for all three proposed cases, with fuel escalation prices valued at 5%, inflation rate at 2.5% (http://www.bnr.ro/Proiectii-BNR-6152.aspx), effective income tax rate at 16% and the life of the project will be considered 20 years. No incentives or grants has been taking into consideration.

The emission factors for carbon dioxide, CH_4 and N_2O can be observed in Table 3, according to the fuel considered.

Table 3
Emission Rate

Fuel	Emission factor CO_2 kg/kJ	Emission factor CH_4 kg/kJ	Emission factor N_2O kg/kJ
Natural gas	49.4	0.0036	0.0009
Electric energy grid	121	0.0089	0.0022
Diesel	69.3	0.0019	0.0019

3. Results and discussions

Economic analysis has a great importance to investors in determining whether an investment in district heating and cooling is feasible. First of all, the total cost of fuel has a great impact because the price of it can influence the return of the investment. As it can be seen in Fig. 1, the lowest fuel cost is in case D with internal combustion engine running with natural gas. This can be easily explain because of the low heat rate of the combustion engine in comparison to the gas turbine. Case C has a higher fuel cost because diesel fuel is more expensive than the natural gas, although they have approximately the same heat rate. Although in the initial case natural gas it is also used, the fuel cost is higher because the share of grid power is much higher than the natural gas, grid power being used in cooling also.

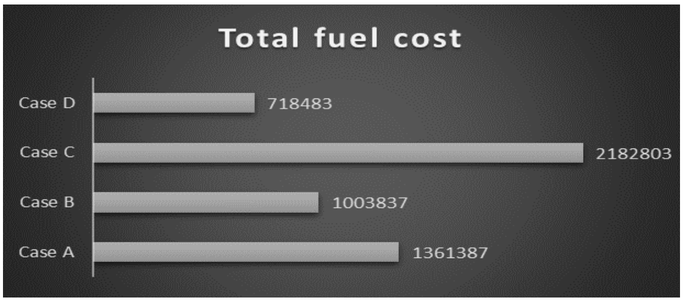

Fig. 1 – Total fuel cost.

The cost of the equipment used in all three proposed cases have the largest impact in the global cost of the investment, this being showed in Fig. 2. The difference between case C and case D occurs because we choose the best engine with the lowest heat rate for every case and this translated in the fact that the engine in case D can produce 400 kWe more power than the one in case C. If the same engine with the same power were elected the cost of the equipment will be the same, because the costs for other equipment were the same (peak gas fired boiler, absorption chiller, etc.). The final cost is influenced by the documentation and design costs that were considered 2% of the equipment costs and the costs for operation and maintenance (labor work, spare parts, training and commissioning, etc.).

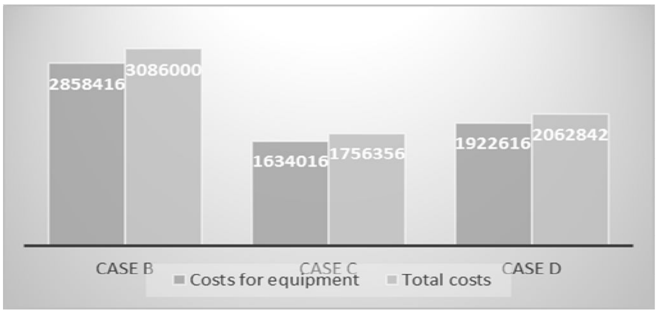

Fig. 2 – Total cost and the cost for equipment.

The financial parameters are illustrated in Table 4. As it can be easily seen, case D has the best financial parameters, followed by case B. Case C is not financially suited for investment, because there is no return date in the 20 years project life that we estimated it will be. However case B and case D both use the same fuel but case D has a payback period of half of case B.

Table 4:
Financial Parameters

Case	Net present value, [€]	Benefit cost ratio	Payback, [years]
Case B	6,550,000	3.14	10
Case C	Negative	Negative	> 20
Case D	16,000,000	8.80	4

In Fig. 3 are illustrated the emissions for three most important GHG: carbon dioxide, methane and nitrous oxide. As it can be seen case D has the lowest GHG emissions along with case C that is in second place. Compared to

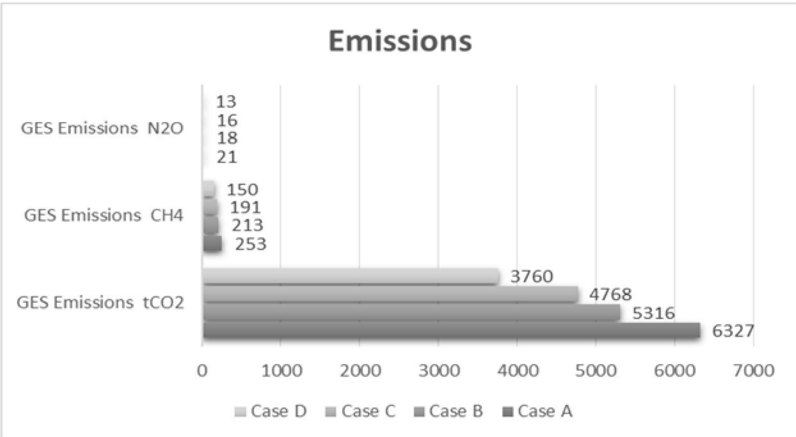

Fig. 3 – Emission rate.

case A, the initial situation, case D has reduce the emissions of carbon dioxide with almost 40%. Even the small scale gas turbine in case B has lower emissions than case A. It also can be noticed that although case C and D both use internal combustion engines case D has lower emissions and if we compare case D with case B that run on the same fuel, case D is still the best.

4. Conclusions

The intent of this paper is to point out that there are small scale solution for district CCHP plants that can sustain the need of the population without increasing the current old network. From the results mentioned above there can be highlighted the following aspects:

1º Internal combustion engine are still cheaper than using small scale gas turbines, because the last is still being improved while the first are a stable technology and mature one, with low equipment costs that makes it more appealing to investors.

2º Diesel fuel in Romania is much more expensive than the natural gas at this point, but in future years, when the price of natural gas is predicted to increase, a new analysis should be made. Also, diesel fuel requires tanks to storage it and logistic to fed the fuel to the plant. The network of natural gas is very large and can cope with the demand, investments being made every year to develop even further.

3º The financial and environmental analysis place the case D as the best scenario for a small district CCHP plant, but in the future further more studies should be made on comparing small scale gas turbine with internal combustion engines that run also on natural gas, because the development of the first has a lot of potential. It can easily be noticed that although the payback period of small scale gas turbines is double there is money to be made there also and the impact on the environment it is noticeable. Further studies are still to be made in this domain and in Romania regarding small district CCHP plants or urban CCHP plants.

REFERENCES

Denilson Boschiero do Espirito Santo, *An Energy and Exergy Analysis of a High-Efficiency Engine Trigeneration System for a Hospital: A Case Study Methodology Based on Annual Energy Demand Profiles.* Energy and Buildings, **76**, 185-198 (2014).

Klaassen R.E., Patel M.K., *District Heating in the Netherlands today: A Techno-Economic Assessment for NGCC-CHP* (Natural Gas Combined Cycle combined heat and power). Energy, **54**, 63-73 (2013).

Mago P.J., Hueffed A.K., *Evaluation of a Turbine Driven CCHP System for Large Office Buildings Under Different Operating Strategies*. Energy and Building, **42**, 1628-1636 (2010).

Torchio M.F., *Comparison of District Heating CHP and Distributed Generation CHP with Energy, Environmental and Economic Criteria for Northern Italy*. Energy Conversion and Management, **92**, 114-128 (2015).

Truong le N., Gustavsson L., *Cost and Primary Energy Efficiency of Small-Scale District Heating Systems*. Applied Energy, **130**, 419-427 (2014).

Vaida V., *Centralele termoelectrice şi de termoficare în Romania*. 2014, http://tineret.sier.ro/istorie/Documente/termo.pdf

* * * European Commission, "EU energy in figures – statistical pocketbook 2014". http://ec.europa.eu/energy/sites/ener/files/documents/2014_pocketbook.pdf

* * * European Parliament and Council, Decision 2008/952/EC "establishing detailed guidelines for the implementation and application of Annex II to Directive 2004/8/EC of the European Parliament and of the Council", November 2008.

* * * European Parliament and Council, Decision 2011/877/EU "establishing harmonized efficiency reference values for separate production of electricity and heat in application of Directive 2004/8/EC of the European Parliament and of the Council and repealing Commission Decision 2007/74/EC", December 2011.

* * * European Parliament and Council, Directive 2012/27/EU "on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, October 2012.

* * * http://dbdh.dk/district-heating-history/

* * * http://www.bnr.ro/Proiectii-BNR-6152.aspx

* * * http://www.cet-iasi.ro/My_Homepage_Files/caiet%20procesare%20gaz.pdf

* * * http://www.cet-iasi.ro/My_Homepage_Files/investitii%20realizate%20in%20sistemul%20de%20termoficare.pdf

* * * http://www.recensamantromania.ro/wp-content/uploads/2012/08/TS2.pdf

* * * http://www.veolia.com/en/veolia-group/media/press-releases/dalkia-operate-district-heating-network-iasi-romania-s-second-city

* * * Romanian Government, Documentation Analysis report on energy sector and efficiency, 2013, http://www.fonduri-ue.ro/res/filepicker_users/cd25a597fd-62/2014-2020/Dezbateri%20parteneriale/Rezultatele%20analizei%20documentare/03.06.2013/3.Energy_22%20mai.pdf

* * * Romanian National Institute of Statistics, Balanta energetica si structura utilajului energetic in anul 2009, http://www.anpm.ro/anpm_resources/migrated_content/uploads/63141_Annex%204.2%20%20Romanian%20Energy%20Balance%20 2009,%202008%20revised%20and%202007%20revised.pdf

* * * Romanian National Institute of Statistics, Balanta energetica si structura utilajului energetic in anul 2013, http://www.insse.ro/cms/files/publicatii/balanta%20energetica%202013.pdf

ANALIZA FINANCIARĂ ŞI DE MEDIU PENTRU UN ANSAMBLU REZIDENŢIAL AL UNUI ORAŞ DIN ROMÂNIA DOTAT CU CENTRALĂ DE TRIGENERARE

(Rezumat)

Îmbunătăţirea şi creşterea producţiei de energie termică şi electrică prin cogenerare reprezintă unul din paşii realizaţi pentru a îndeplini obiectivele Uniunii Europene de a îmbunătăţi eficienţa energetică până în 2020, obiectiv exprimat în Directiva din 2012/27/Eu. Campania intensă de promovare a cogenerării a condus la o creştere a numărului acestor sisteme în toate sectoarele, în special în cel industrial. Având în vedere că 26,2% din consumul european final de energie a fost realizat de către sectorul rezidenţial şi doar 25,6% a fost atribuită sectorului industrial, se poate concluziona că există încă loc de îmbunătăţire în ceea ce priveşte răspândirea cogenerării.

În timp ce în ţările scandinave, încălzirea districtuală se bazează pe centralele de cogenerare, iar unele dintre ele se folosesc resurse regenerabile (în cea mai mare parte energie geotermală), centralele de cogenerare din Europa de Est se bazează în mare parte pe combustibili fosili, precum cărbune şi gaze naturale. În Europa de Vest, încălzirea districtuală a început să câştige teren fiind stabilite planuri naţionale de dezvoltare şi promovare a unor astfel de sisteme.

Analiza realizată în prezenta lucrare îşi propune să evidenţieze, pentru un grup compus dintr-un număr de cinci clădiri de locuit de tip bloc situate în localitatea Iaşi. Fiecare clădire are regimul de înălţime parte şi 4 etaje. Pentru analiză s-au propus patru cazuri: primul caz, de referinţă, este cel regăsit preponderent în oraşul Iaşi, în care energia electrică este achiziţionată din sistemul electric naţional, încălzirea este realizată cu centrale murale pe gaz natural, iar răcirea este realizată cu aparate de aer condiţionat de tip split. Se mai propun încă trei cazuri, toate producând energie în sistem de trigenerare, fiecare având un alt sistem de producere a energie electrice, precum turbina pe gaz natural, motorul cu ardere internă cu funcţionare pe gaz natural sau pe motorină.

S-au analizat parametrii financiari şi de mediu. Cele două categorii de parametrii sunt corelaţi, deoarece prin anumite subvenţii acordate pentru scăderea nivelului de poluare se pot obţine subvenţii. În analiza realizată, aceste subvenţii nu au fost luate în considerare.

Ca şi concluzii care se pot extrage din analiza realizată s-a putut deduce faptul că motorul cu ardere internă este o soluţie mai puţin costisitoare decât utilizarea turbinelor cu gaz, deoarece motorul cu ardere internă reprezintă o tehnologie stabilă şi ajunsă la maturitate.

Datorită faptului că, în România, motorina este mult mai scumpă decât gazele naturale în acest moment, utilizarea echipamentelor care au la bază acest combustibil nu sunt fezabile din punct de vedere economic. De asemenea, motorină necesită rezervoare pentru stocare şi logistică pentru a asigura o alimentare continuă. Reţeaua de gaze naturale din România este foarte dezvoltată şi poate face faţă cererilor de pe piaţă energetică.

Analiza financiară şi de mediu plasează cazul trigenerării cu motor cu ardere internă pe gaz natural ca fiind cel mai bun scenariu pentru instalaţii de cogenerare de dimensiuni reduse, dar asta nu înseamnă abandonarea sistemelor cu turbine, acestea fiind într-o continuă dezvoltare. Deşi perioada de amortizare pentru sistemele cu turbine cu gaz este mult mai mare, se poate observa că acestea sunt fezabile şi generează profit.