Journal of Engineering and Applied Sciences 12 (Special Issue 10): 8774-8779, 2017
ISSN: 1816-949X

Reducing Environmental Impact Through Trigeneration: A Case Study

[1]Eduard Minciuc, [2]Ioana Diaconescu and [1]Roxana Patrascu
[1]Department of Energy Generation and Use, University Politehnica of Bucharest, Bucharest, Romania
[2]Department of SIM, Facultatea de Inginerie SI Agronomie din Braila (FIAB),
University "Dunarea de Jos", Galati, Romania

Abstract: The study presents an analysis of environmental impact assessment of different trigeneration plants compared to separate energy generation. The researchers have analysed different trigeneration plant sizing methodology. There have been used as cogeneration equipment gas turbines and internal combustion engine and for cold generation absorption and compression chilling machines. The comparison of all analysed solutions with separate energy generation show that combined energy generation leads to lower environmental pollution and trigeneration leads to lower CO_2 emissions compared to cogeneration. There should be always performed alongside with technical and economic analysis also an environmental impact assessment in order to identify the best solution from all three points of view.

Key words: Trigeneration, cogeneration, environmental pollution reduction, energy efficiency, CO_2, solution

INTRODUCTION

Combined energy generation is known to have multiple advantages compared to separate energy generation. The concept of combined energy generation can be used for cogeneration and trigeneration. Cogeneration is a combined and simultaneous power and heat generation using the same equipment and same primary energy source. Trigeneration can be defined as combined and/or simultaneous (not always necessarily) production of power, heat and cold using a cogeneration equipment and a chilling machine and using the same primary energy source. The main advantages of combined energy generation, respectively of cogeneration and trigeneration are the following:

- Higher global efficiency of energy generation compared to separate energy production
- Energy savings, usually savings of fossil fuels
- Lower pollutant emissions (including Green House Gasses, GHG) corresponding to fossil fuel savings, compared to separate energy generation
- Cogeneration/trigeneration can lead to lower energy generation costs and thus, leading to either decreasing of energy prices or increasing profits of energy generating facility, profits that can be used for further investments
- Contribution to reduction of energy losses in transportation and distribution networks which is due to the fact that cogeneration/trigeneration plants are usually placed near consumers or even at consumer's site

There should be said that trigeneration can lead to even higher energy efficiency and fuel savings and respectively lower pollutant emissions compared with cogeneration. There should be mentioned that both, cogeneration and trigeneration have their advantages and limitations but they are quite a few and with a limited negative impact compared to all above-mentioned advantages.

Today's energy policies of European Union (EU) and other countries worldwide are stressing a very special attention to environmental pollution and climate change issues. There can be even said that all these policies are driven by these issues. Cogeneration/trigeneration technologies can lead to reducing environmental pollution including GHG emissions. Thus, these technologies have great support and are being promoted at different levels (worldwide, EU, EU member states), since, they can greatly contribute to achieving common goals of limiting climate changes. Due to this fact there has been and still is a lot of research in the field of cogeneration and trigeneration. Taking just the trigeneration concept there are numerous scientific papers that analyse the reduction of environmental impact of this technology compared to separate energy generation.

Goyal *et al*. (2015) have presented a performance and pollutant emissions analysis of a trigeneration plant equipped with an internal combustion engine compared with separate energy generation. The obtained results show clearly that combined energy generation lead to fossil fuel savings, respectively to reduction of pollutant emissions. Shukla (2015) has presented a new concept in Indian building sector which addresses the energy

Corresponding Author: Eduard Minciuc, Department of Energy Generation and Use, University Politehnica of Bucharest, Bucharest, Romania

through trigeneration technology. The proposed trigeneration plant includes an internal combustion engine and an absorption chilling machine. The result of implementation of this technology can lead to up to 85% of increasing energy efficiency and respectively decreasing environmental impact compared to separate energy generation. Basrawi *et al*. (2014) have analysed a hybrid photovoltaic-microgas turbine trigeneration system. The study investigates the economic and environmental performance of trigeneration plant for various operation strategies and the results show the best operation strategy from the environmental impact point of view. Lozano *et al*. (2014) have analysed environmental impact of simple trigeneration systems operating under variable conditions. The results show different operation modes of trigeneration plant for maximising economic criteria and minimising environmental impact. Borg *et al*. (2014) compared the performance of a residential micro-trigeneration system to a hybrid micro-trigeneration/SWH system. The results obtained were then used to quantify the energetic and environmental performance of both systems. Maraver *et al*. (2013) have performed an environmental assessment of CCHP (Combined Cooling Heating and Power) systems based on biomass combustion in comparison to conventional generation. The obtained data show different results with an impact on using trigeneration technology. Freschi *et al*. (2013) have studied the application of a trigeneration system to fruit conservation food-industry. The economic and environmental benefits of the trigeneration are analyzed by means of multi-objective optimization which takes into account operational costs of the system and greenhouse gas emissions. Ahmadi *et al*. (2011) have performed a greenhouse gas emission and exergo-environmental analyses of a trigeneration energy system. Parise *et al*. (2011) have presented a study of the thermodynamic performance and CO_2 emissions of a vapour compression bio-trigeneration system. A comparative analysis between the biofuel trigeneration and conventional fossil fuel with no waste heat recovery was carried out, showing that, depending on the relative values of energy demands and on component characteristics, significant reduction on primary energy consumption (up to 50%) and on CO_2 emissions (up to 5% of the original emissions) can be attained with the biofuel-trigeneration combination. Fumo *et al*. (2009) have proposed emission operational strategy for combined cooling, heating and power systems targeting to reduce emissions of pollutants. Mago and Chamra (2009) have performed an analysis and optimization of trigeneration systems based on energy, economical and environmental considerations. Sugiartha *et al*. (2009) have presented results on the evaluation of energy utilisation efficiency and economic and environmental performance of a Micro-Gas Turbine (MGT) based trigeneration system for supermarket applications. The results showed that energy and environmental benefits can be obtained from the application of trigeneration systems to supermarkets compared to conventional systems. Chicco and Mancarella (2008) present a novel approach based upon an original indicator to assess the emission reduction of CO_2 and other GHGs from cogeneration and trigeneration systems with respect to the separate production. Mancarella and Chicco (2008) use the approach presented by Chicco and Mancarella (2008) for validating it on different application cases. The numerical outcomes indicate that cogeneration and trigeneration solutions could bring significant benefits in countries with prevailing electricity production from fossil fuels, quantified by the use of the proposed indicators.

Description of the case study: The analysed case study has been performed for a consumer from tertiary sector. First, there have been performed technical and economic analysis for different solutions and the results have been presented by Minciuc and Patrascu, Minciuc and Bitir-Istrate and further on the researchers have performed an environmental impact assessment of all analysed solutions. The energy demands of the consumer from tertiary sector are covered as follows:

- Electricity is supplied from the power grid
- Heat for heating during the winter period is supplied by a local district heating company
- The cooling is ensured only at few places using local air conditioning equipment

Table 1 shows energy demands for all three types of energy. For covering all energy demands of the consumer from tertiary sector there have been analysed several solutions for installing a trigeneration plant based on different technologies. These technologies include different cogeneration technology and also different types of chilling machines.

Table 1: Energy demands of consumer from tertiary sector

Energy demands	Values (MW)
Maximum power demand	3.5
Average power demand	0.742
Minimum power demand	0.2
Maximum heat demand	17.5
Average heat demand	8.4
Minimum heat demand	4
Maximum cold demand	3.5
Average cold demand	1.68
Minimum cold demand	0.8

Assumptions and limitations: For the technical and economic analysis of different technical solutions there have been considered the following assumptions:

- The power supply is all year round (8760 h)
- The period for heat supply for heating is in accordance with Romanian standards and it is 188 days (4512 h)
- The period for air conditioning has been considered as being 75 days with an average of 6 h per day and with a coefficient of sunny days of 0.7 (315 h)
- The surplus of electricity produced can be sold to the grid
- If the plant does not cover all electricity demand, the difference can be bought from the grid
- The cold produced by peak equipment is generated using compression chilling machine
- The fuel price (natural gas) has been considered as being 25/MWh
- The electricity price bought from the grid and sold to consumer has been considered as being 105/MWh
- The electricity price sold to the grid has been considered as being 77/MWh
- The heat price has been considered as being 43/MWh
- The cold price has been considered as being 43/MWh
- The maintenance costs for all equipment have been considered as being 20% from all costs
- The actualisation rate for the economic analysis has been considered as being 10%

The results of this technical and economic analysis have been presented by researchers. For the environmental impact assessment there have been considered the following assumptions:

- The lower calorific value of natural gas has been considered as being 36 MJ/Nm^3
- The emission factor for CO_2 for natural gas has been considered as being 1.92 kg CO_2/Nm^3

Description of the analysed solutions: The researchers have analysed 6 different technical solutions for the trigeneration plant. All 6 solutions use a cogeneration technology for power and heat generation and chilling machines for cold production. There have been adopted three approaches for designing and sizing the plant:

- Sizing the trigeneration plant based on average power demand
- Sizing the trigeneration plant based on maximum power demand
- Sizing the plant on maximum cold demand

For these approaches there has been considered that for cogeneration equipment there would be used gas turbine and internal combustion engine technologies. For cold generation there would be used absorption chilling machine that uses waste heat from cogeneration equipment. The compression chilling machine can also be used for cold production as peak equipment, it can use electricity generated by cogeneration equipment or electricity bought from the power grid.

Figure 1 presents a general scheme of a trigeneration plant. A trigeneration plant usually consists of cogeneration equipment that generates power and heat and a chilling machine for cold production. There are presented 6 technical solutions that have been analysed:

- The solution design and sizing has been based on average power demand using gas turbine
- The solution design and sizing has been based on average power demand using an internal combustion engine

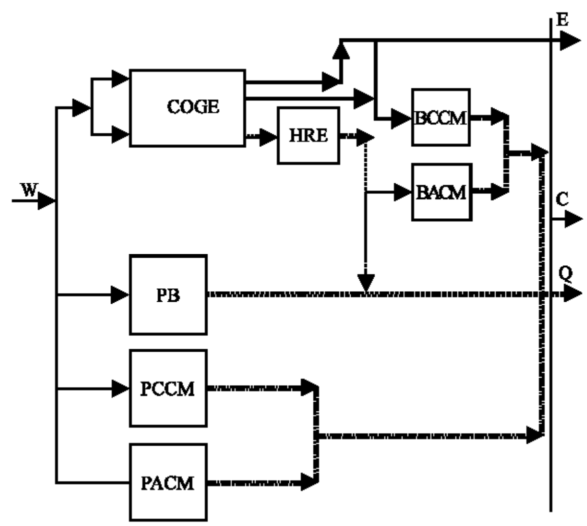

Fig. 1: General scheme of trigeneration plant; COGE-Cogeneration Equipment; HRE-Heat Recovery Exchanger; BCCM-Base load Compression Chilling Machine; BACM-Base load Absorption Chilling Machine; PB-Peak Boiler; PCCM-Peak load Compression Chilling Machine; PACM-Peak load Absorption Chilling Machine

- The solution design and sizing has been based on maximum power demand using gas turbine
- The solution design and sizing has been based on maximum power demand using an internal combustion engine
- The solution design and sizing has been based on maximum cold demand during the summer time using gas turbine
- The solution design and sizing has been based on maximum cold demand during the summer time using an internal combustion engine

MATERIALS AND METHODS

The researcher have performed an environmental impact assessment of all 6 proposed solutions and separate energy generation for covering all energy demands of the consumer from tertiary sector. The used methodology for assessing environmental impact has included the following steps:

- Determining the annual fuel consumption used for covering strictly only the energy demands of the analysed consumer
- Determining the annual CO_2 emissions

The annual CO_2 emissions have been determined strictly for each annual energy demand of the consumer from tertiary sector for the following energy generation cases:

- Trigeneration plant for all 6 chosen solutions for analysis configuration
- Cogeneration plant for all 6 chosen solutions for analysis configuration plus a compression chilling machine for cold demand
- Separate energy generation of power, heat and cold

This approach and methodology gives the possibility to analyse the following aspects:

- To compare trigeneration with cogeneration plus compression chilling machine and with separate energy generation (power, heat and cold)
- To evaluate the greatest potential of reducing CO_2 emissions for each energy demand (power, heat and cold) when switching from separate energy generation to cogeneration and further on to trigeneration for this specific energy consumer from tertiary sector

RESULTS AND DISCUSSION

The study had the aim at analysing CO_2 emissions from different trigeneration plant configurations for supplying energy to a consumer from a tertiary sector and also to compare these emissions with separate energy generation.

Table 2: Economic criteria for the analysed solutions

Solutions	1	2	3	4	5	6
Investment (mln. €)	2.7	2.5	4.1	4.4	2.7	7.3
PBP (years)	8.9	7.9	5.5	3.6	6.5	4.0
NPV (mln. €)	<0	<0	2.3	5.0	0.84	6.3
IRR (%)	9	10	18	26	14	23

There should be mentioned that in order to perform a more complex analysis of the environmental impact, there should be presented also the results of the technical and economic analysis. Thus, Table 2 shows the results of economic analysis of the 6 proposed solutions for a trigeneration plant.

The results of the environmental impact assessment are presented in Table 3. The CO_2 emissions are presented as a total value corresponding to ensure total energy demands of the consumer and also as split values corresponding to covering each type of energy demand (power E, heat Q and cold F). Analysing Table 2 and 3, there can be drawn the following conclusions.

All trigeneration solutions and cogeneration solutions plus a compression chilling machine lead to lower CO_2 emissions compared to separate energy generation. The best solution from economic point of view, respectively solution 6 is also the solution with the lowest environmental pollutant emissions.

The worst economic solution, respectively solutions 1 and 2 are also the worst solutions from the environmental point of view having the highest pollutant emissions among all analysed solutions. However, there should be mentioned that pollutant emissions of these two solutions are lower compared to separate energy generation.

From the economic point of view the second best solution is solution 4 but from the environmental impact point of view the second best solution is solution 3, since, it leads to lower pollutant emissions compared to solution 4. This fact can be transposed into the following: not always the best economic solution is also the best from the environmental point of view. Thus, it can be concluded that it is important to perform alongside with technical and economic analysis also the environmental impact assessment in order to choose the best solution from all three points of view.

Upgrading from a cogeneration plant plus a compression chilling machine to a trigeneration plant always leads to reduction of CO_2 emissions. Even though, for this specific case the CO_2 emissions reduction is not so, great but this fact can be explained that this specific consumer from tertiary sector has a very short period when air conditioning is needed. Thus, for other consumers with greater periods for air conditioning the

Table 3: Results of the environmental impact assessment

	CO_2 emissions (t/year)			
Solutions	Total	E	Q	F
Solution 1	11094	5258	5824	11
Solution 1 divided in cogeneration+compression chilling machine	11151	5258	5824	68
Solution 2	11378	4001	7334	44
Solution 2 divided in cogeneration+compression chilling machine	11403	4001	7334	68
Solution 3	6344	4383	1962	0
Solution 3 divided in cogeneration+compression chilling machine	6413	4383	1962	68
Solution 4	8024	3160	4853	11
Solution 4 divided in cogeneration+compression chilling machine	8081	3160	4853	68
Solution 5	9292	5448	3844	0
Solution 5 divided in cogeneration+compression chilling machine	9360	5448	3844	68
Solution 6	4587	3235	1352	0
Solution 6 divided in cogeneration+compression chilling machine	4655	3235	1352	68
Separate energy generation	12847	4529	8249	68

advantage of trigeneration compared to cogeneration plus compression chilling machine should increase due to the increase of annual cold demand.

The greatest decrease of CO_2 emissions for trigeneration/cogeneration compared to separate energy production is due to combined production of heat, since, usually cogenerated heat is generated through recovery from flue gasses.

For some analysed solutions of trigeneration/cogeneration plants CO_2 emissions corresponding to annual Electricity production (E) is greater compared to separate energy generation. This can be explained by the fact that power efficiency of cogeneration equipment used for this study has been lower compared to average power efficiency of the national power grid. The conclusion that can be drawn from this statement is that it is better to use equipment with higher power efficiency compared to average efficiency of National Power Grid. This issue is especially, important for small size equipment, since in that case power efficiency is usually lower compared to great size equipment.

CONCLUSION

Analysing the results presented in the study there can be concluded the following: combined energy production, either it is cogeneration or trigeneration, leads to lower CO_2 emissions compared to separate energy generation. The case study showed that the best solution from economic point of view is also the best solution from the environmental point of view. The worst analysed solutions from economic point of view lead, however to lower emissions compared to separate energy production. The case study revealed that not always the best economic solution can lead to the lowest emissions, thus, it is important to perform a complex analysis from technical, economic and environmental points of view in order to establish the best solution. Emissions from a trigeneration plant are lower compared to cogeneration plus a chilling machine. To increase the overall efficiency of trigeneration plant it is important to use equipment with higher power efficiency compared to average efficiency of national power grid.

REFERENCES

Ahmadi, P., M.A. Rosen and I. Dincer, 2011. Greenhouse gas emission and exergo-environmental analyses of a trigeneration energy system. Int. J. Greenhouse Gas Control, 5: 1540-1549.

Basrawi, F., T. Yamada and S.Y. Obara, 2014. Economic and environmental based operation strategies of a hybrid photovoltaic-microgas turbine trigeneration system. Appl. Energy, 121: 174-183.

Borg, S.P., N.J. Kelly and V. Buhagiar, 2014. Energetic, environmental and economic modeling of a solar-assisted residential micro-trigeneration system in a mediterranean climate. ASHRAE. Trans., 120: 1-8.

Chicco, G. and P. Mancarella, 2008. Assessment of the greenhouse gas emissions from cogeneration and trigeneration systems: Part I; Models indicators. Energy, 33: 410-417.

Freschi, F., L. Giaccone, P. Lazzeroni and M. Repetto, 2013. Economic and environmental analysis of a trigeneration system for food-industry: A case study. Appl. Energy, 107: 157-172.

Fumo, N., P.J. Mago and L.M. Chamra, 2009. Emission operational strategy for combined cooling, heating and power systems. Applied Energy, 86: 2344-2350.

Goyal, R., D. Sharma, S.L. Soni, P.K. Gupta and D. Johar *et al.*, 2015. Performance and emission analysis of CI engine operated micro-trigeneration system for power, heating and space cooling. Appl. Therm. Eng., 75: 817-825.

Lozano, M.A., M. Carvalho and L.M. Serra, 2014. Tackling environmental impacts in simple trigeneration systems operating under variable conditions. Int. J. Life Cycle Assess., 19: 1087-1098.

Mago, P.J. and L.M. Chamra, 2009. Analysis and optimization of CCHP systems based on energy, economical and environmental considerations. Energy Build., 41: 1099-1106.

Mancarella, P. and G. Chicco, 2008. Assessment of the greenhouse gas emissions from cogeneration and trigeneration systems: Part II; Analysis techniques and application cases. Energy, 33: 418-430.

Maraver, D., A. Sin, F. Sebastian and J. Royo, 2013. Environmental assessment of CCHP (combined cooling heating and power) systems based on biomass combustion in comparison to conventional generation. Energy, 57: 17-23.

Parise, J.A., L.C.C. Martinez, R.P. Marques, J.B. Mena and J.V. Vargas, 2011. A study of the thermodynamic performance and CO 2 emissions of a vapour compression bio-trigeneration system. Appl. Therm. Eng., 31: 1411-1420.

Shukla, A., 2015. Combined Cooling, Heating and Power or Trigeneration Technology: An Approach Toward Higher Energy Efficiency, Emission Reduction Potential and Policy. In: Energy Sustainability Through Green Energy, Atul, S. and K.K. Sanjay (Eds.). Springer, India, South Asia, ISBN:978-81-322-2336-8, pp: 493-506.

Sugiartha, N., S.A. Tassou, I. Chaer and D. Marriott, 2009. Trigeneration in food retail: An energetic, economic and environmental evaluation for a supermarket application. Appl. Therm. Eng., 29: 2624-2632.