Potential of Renewable Energies to Power a Natural Gas Driven Trigeneration System

Szymon Wojciech Głuszkiewicz
szymon.gluszkiewicz@gmail.com

Instituto Superior Tecnico, Universidade de Lisboa, Portugal

May 2018

Abstract

In this dissertation, the potential of incorporation of Renewable Energy Sources (RES) in trigeneration systems is analysed. The case study considered is the Climaespaço plant located in Lisbon. Conclusion from literature review is that there is a lack of appropriate regulations regarding support of trigeneration plants in European Union combined with immaturity of technology. Assessment of suitable RES solutions for this plant is carried out and the RES potential in the region is estimated. The baseline scenario is modelled, different scenarios are proposed with corresponding technical analysis and economic assessment. The software tool EnergyPLAN is used to simulate each scenario and obtain the technical results. The net present value, the internal rate of return and the simple payback time are calculated. The results are checked and compared with baseline scenario to decide if they are both technically and economically feasible. Two of the considered scenarios are selected and recommended to implement, showing biomass potential to power the trigeneration systems. Further investigation needs to be done in the topic with more accurate data and other tools selected through the process to ensure better reliability of the analysis and obtained results.

Keywords:

Fossil fuel replacement, Renewable energy sources, Trigeneration, EnergyPLAN

1. Introduction

1.1 Framing and motivation

Climate change, security of energy supply and fossil fuels depletion are well-known issues that determine the need of finding pathways for sustainable energy production. These pathways include energy efficiency and renewable energy production. However, the worldwide current energy infrastructure was designed for conventional technologies, based on fossil fuels that have provided large and cheap energy storage. This flexibility of fossil fuels enables the production of energy whenever it is required. On the other hand, fluctuating Renewable Energy Sources (RES) as wind and solar are not flexible. Their intermittent nature introduces barriers to their high penetration into the electricity supply system, like the struggle to match the demand with the supply. In addition, the current energy systems consist of very segregated energy divisions, where the supply chains for mobility, electricity, heating and cooling have very little interaction with each other, disabling the use of possible synergies, what decreases efficiency.

1.2 Problem statement

One of the problems faced nowadays by the polygeneration plants is the lack of appropriate regulations, specifying the amount of money earned by selling different types of energy at the same time [1]. Apart from the regulations missing at EU level, there is a strong need for clear national regulation, namely regarding financial support. Currently, the dominant tools of trade at energy market, used both in EU and the rest of the world, are the Feed-in-Tariffs (FIT). There is a strong need for a change in current system of support.

1.3 Objectives

The main objective of this work is to assess the technical and financial feasibility of using RES in a trigeneration plant which input is, currently, natural gas. Different scenarios are assessed and compared with the baseline scenario. To reach this global objective, several specific objectives need to be accomplished:

- Analysis of the operation of the trigeneration plant;
- Assessment of suitable RES technologies for the trigeneration plant;
- Assessment of RES potential in the region of the trigeneration plant;
- Modelling of the baseline scenario and of the proposed scenarios;
- Technical and economic assessment of the different scenarios.

2. LITERATURE REVIEW

2.1 Trigeneration systems

Trigeneration technology is improved version of Combined Heat and Power (CHP) approach. This system combines not only the electricity and heat generation but also provides another useful product, namely cooling, likewise from one fuel source. Trigeneration systems are also called in the literature Combined Cooling, Heating and Power (CCHP) systems. When it comes to the technology used, the main idea is to combine a cogeneration unit with an absorption/adsorption or a compression chiller. The chillers convert the leftover steam (after cogeneration system) to chilled water by the process of absorption/adsorption or by compression using electricity. As the heating yield is higher than the electric one, electricity is more expensive source of energy than heat, the major effort is made to use the absorption/adsorption chillers (instead of compression ones) as the main technology to generate cooling. The chillers using the 'waste heat' after cogeneration unit do not need the compressor as part of the system. These chillers use desiccant liquid and the circulating pump which delivers the drying agent to their internal heat exchangers. The trigeneration systems offer the further optimization of the efficiencies, introducing more flexible distribution of heat used for heating or rather cooling allocation (Figure 2.1) [2].

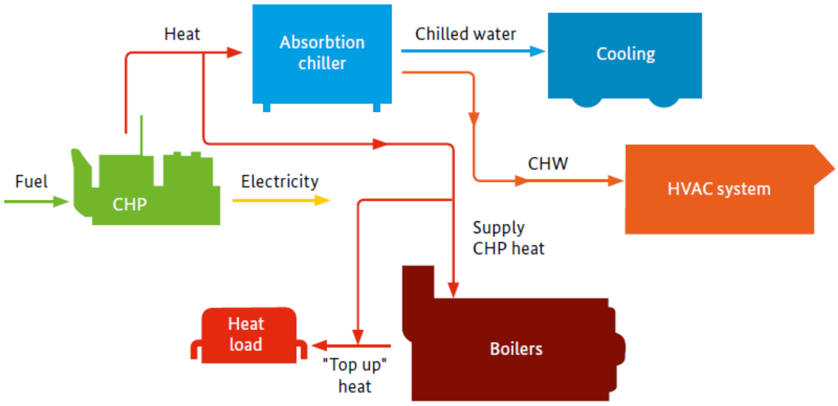

Figure 2.1 Elements of a trigeneration system (using absorption technology) [2]

2.2 RES technologies in context of trigeneration

The wide range of outputs from polygeneration systems based on RES can be achieved and the energy sources to provide these outputs can be found in different fields of the nature. This mix of options, from solar to hydro system, enables the right combination with regards to the climate zone and its conditions, in the country that polygeneration operates – Figure 2.2.

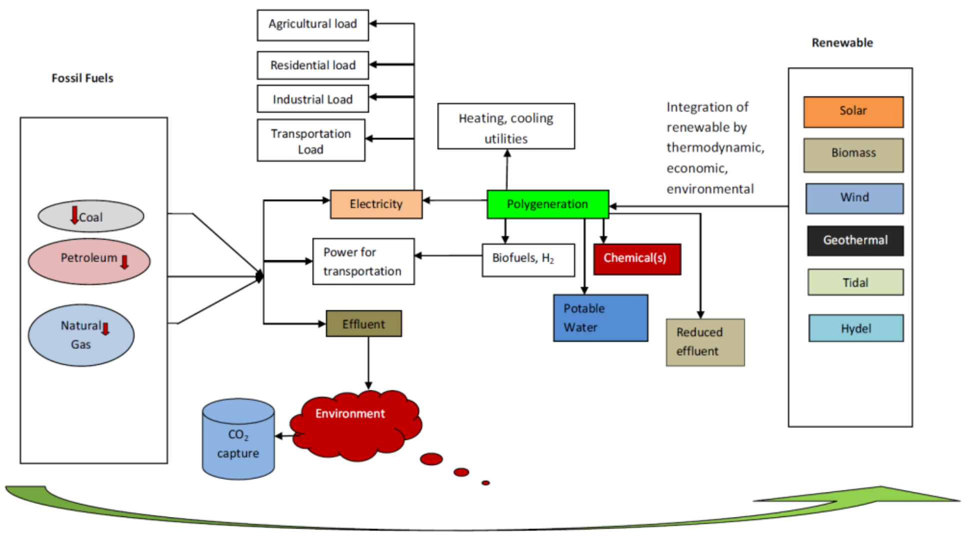

Figure 2.2 Transition from fossil fuel based energy systems to renewable based polygeneration [3]

2.3 RES in Portugal

In recent years, in Portugal, the electricity market underwent essential transformation. The reason of such changes is the process of unbundling of power transmission network, followed by liberalization in the context of generation and supply of energy. Nowadays, national electricity market is highly-deregulated with big emphasis on promotion of RES. In 2006 Portuguese customers were allowed to choose the electricity supplier and from January 2013 there are no longer regulated tariffs for final customers. That was the last step for the electricity market, when it comes to already mentioned liberalization process. Portugal is a world leader using RES, being currently, on the 3rd place, regarding the percentage of incorporation of RES inside the EU-28 group. Majority of this energy is from wind and hydro power. Looking ahead, Portugal has great potential for the use of RES, mainly solar and wind [4].

3. CASE STUDY

The case study assessed in the present thesis is a trigeneration system (Climaespaço) located in Parque das Nações, Lisbon. It is the only DHC system in Portugal. An entire district was built from the scratch, so the solution used in this plant is relatively modern and efficient, using natural gas as a fuel source to power the trigeneration system.

3.1 Climaespaço Plant

The plant is part of the Engie group. The installation cooling capacity is 35 MW, heating capacity is 29 MW and electrical capacity around 5 MW. Trigeneration system enables to achieve high efficiencies, namely 30% for production of electricity and 55% of thermal energy production, which gives in sum the overall efficiency at level of 85% [5].

3.2 Data treatment and analysis

To carry out the analysis of the trigeneration system used in Climaespaço, answering questions regarding production of the plant was necessary. Through the good offices of headquarters of the company in charge of Climaespaço, part of the requested data was provided, namely typical daily profiles (Figures 3.4 and 3.5) [5]. The rest was taken from [6].

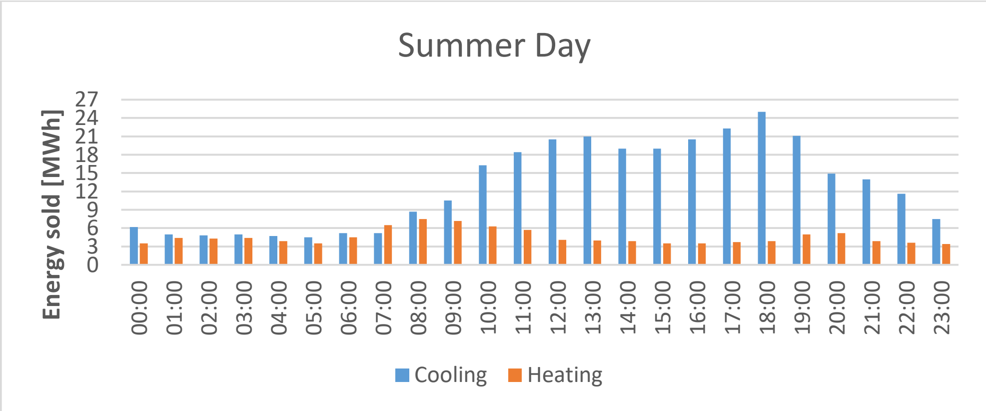

Figure 3.1 Typical daily profile of the heating and cooling distributed for a summer day in Climaespaço plant [5]

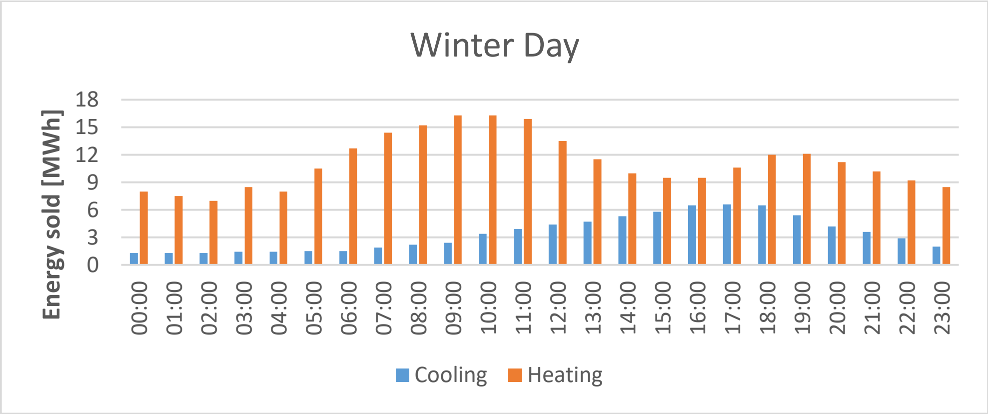

Figure 3.2 Typical daily profile of the heating and cooling distributed for a winter day in Climaespaço plant [5]

3.3 Scenarios

The main purpose of this thesis is to analyse Climaespaço plant and suggest future solutions which could be used to replace or improve the current system. In order to evaluate different configurations, the following scenarios were considered:

- **Baseline scenario**

This scenario represents the system as it is now. The system was modelled and validated based on the data provided, giving data that will be used also in the next scenarios.

- **Scenario 1**

In this scenario, the assumption regarding Climaespaço plant cooperation with Valorsul Project installations is made [7]. The main idea of this cooperation is to import the leftover steam from Waste to Energy (WtE) plant of Valorsul, which is currently wasted energy. In this scenario, the delivery of steam and the construction of a new 5.5 km pipeline are considered. Nevertheless, the demand of Climaespaço plant to be covered is relatively small, comparing to the entire amount of the steam produced by the WtE plant. Because of that, the price of this steam which would enable the system to be profitable and the cost of construction the pipeline must be considered in the economic analysis. This scenario is divided into two parts due to the different approaches in the utilization and the amount of steam imported from WtE plant.

- **Scenario 2**

In this scenario, the system based on the gas turbine is completely removed and replaced by a biomass boiler system. Back-up boiler remains in the system but it is also supplied by biomass. This scenario is the first one with the assumption of 100% RES energy production. Scenario 2 is divided in two parts also.

- **Scenario 3**

The last scenario is the combination of the scenario 1b with scenario 2b. The solution proposed is 100% RES and is based on the use of steam from WtE plant, the installation of an auxiliary 15 MW boiler based on biomass and of PV and wind power systems in the plant.

4. METHODOLOGY

4.1 Technical analysis

The software used in this work is called EnergyPLAN. The program itself is a deterministic tool, using hourly data such as electricity, cooling, heating distributions and much more, to simulate a one year operation of a given energy system. The range of inputs is wide, from energy demand and power capacities with separate RES section, to detailed costs. From outputs energy balance, RES participation, CO_2 emissions and fuel consumption are the fundamental ones. The model existing in the EnergyPLAN software is the example of applying manual heuristics to find optimal configurations of energy systems. Different regulation strategies can be chosen, depending on user's needs: technical analysis with balancing heat or/and electricity demands as well as separate market economic simulation. The software is able to model high-RES systems and helps to find optimal utilization, for example of otherwise limited RES-based power production, in different energy sectors [8] [9] [10]. Due to the reasons mentioned above and the fact that EnergyPLAN provides detailed results (crucial to obtain in this dissertation) as well as it is widely used by other researchers, this tool has been chosen for technical analysis.

4.2 Economic assessment

4.2.1 EnergyPLAN results

Apart from calculating economic indicators externally, there is also a way to use internal cost database of the EnergyPLAN [8]. By using the software and putting the prices in cost section, it is possible to achieve some results regarding economic analysis: such as CO_2 emission cost, fuel cost, fixed O&M cost or RES participation in energy production. The appropriate results from tool will be also used in the economic assessment process.

4.2.2 NPV

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o \qquad (1)$$

where: C_t – Net cash inflow during the period t, C_o – Total initial investment costs, r - Discount rate, t – Number of time periods

$$NPV = R_d - C_d = P_V \times E_a \times k_a - (I_t + C_{O\&M} \times k_a) \qquad (2)$$

where: R_d – Discounted revenues [M€], C_d - Discounted cost [M€], P_V – Price of the energy sold to the grid [M€/GWh], E_a – Energy produced [GWh], k_a – Discount factor [–], I_t – Total investment cost [–], $C_{O\&M}$ – Other annual fixed cost [M€]

$$k_a = \sum_{j=1}^{n} \frac{1}{(1+a)^j} = \frac{(1+a)^n - 1}{a \times (1+a)^n} \qquad (3)$$

where: a - Discount rate/effective interest rate, j – Year of analysis, n – Whole period in years

4.2.3 IRR

$$R_N \times \frac{(1+IRR)^n - 1}{IRR \times (1+IRR)^n} = I_t \qquad (4)$$

where: R_N - Financial balance between revenues and operational and maintenance cost [M€]

$$R_N = R - C_{O\&M} \quad (5)$$

where: R – Revenues [M€]

4.2.4 SPBT

$$SPBT = \frac{I}{Z_i} \quad (6)$$

where: I – Amount of financial outlays incurred [M€], Z_i - Annual gross benefits [M€]

$$SBPT = \frac{I}{\Delta Z} \quad (7)$$

where: ΔZ - Reduced costs of energy use [M€]

5. Results and Discussion

5.1 Simulation

The procedure for calculating the basic technical parameters of Climaespaço plant has undergone double verification process. Table 1 reveals the needed inputs to run the simulation in EnergyPLAN for one year.

Table 1 Inputs requested to run simulation in EnergyPLAN

Input	Value
Electricity demand without cooling [GWh]	8.98
Electricity demand for cooling purposes [GWh]	13.01
Total electricity demand [GWh]	21.99
Consumption of heat by absorption chillers [GWh]	6.67
Consumption of heat to produce steam [GWh]	53.60
Total heat demand [GWh]	60.28
Coefficient of Performance for electricity for cooling [-]	4.98
Coefficient of Performance for district heating for cooling [-]	1.67
Electric efficiency [%]	29
Thermal efficiency [%]	40
Estimated CHP electric capacity [kW]	5,000
Estimated CHP thermal capacity [kW]	7,800

The system modelled in the tool was validated by the data provided and treated previously.

5.2 Comparison

Table 16 provides a summary of the results of all scenarios. In the line, 'RES share of PES', where 'PES' means primary energy source, for the case of the scenarios where steam is from WtE it is assumed that PES of the whole process is waste incinerated in the WtE plant. RES electricity generation in this case is the sum of production of electricity from CHP based on biomass, PV and wind. It is important to mention that EnergyPLAN does not take into account the imported electricity to RES share of PES.

Table 2 Comparison of the results of all scenarios

	Baseline scenario	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b	Scenario 3
NPV [€]		-9,843,603	- 9,328,481	26,902,409	27,339,809	- 6,287,373
IRR [%]				25.78	25.62	
SPBT [years]				3.87	3.89	
RES share of PES [%]	0	30.1	83.2	100	100	100
Ratio of RES electricity production to overall electricity demand [%]	0	0	0	116.8	118.6	1.8
RES electricity production [GWh]	0	0	0	25.69	26.09	0.4

6. Conclusions

In this dissertation, the main effort has been done to check if trigeneration systems could operate with the utilization of RES, using Climaespaço plant in Portugal as a case study. Technical analysis and economic assessment have been done to compare the suggested scenarios.

It was verified in the literature review that trigeneration technology is not clearly supported in Portugal. With the future perspective ahead, regulations are going to change but there is no certainty. Portugal is the country with high RES potential especially wind, hydro and solar and with one of the highest indicators regarding RES participation in EU. Natural from this point of view is the approach to exchange already existing installations with renewable sources. However, the idea might seem simple but the realization still faces some boundaries such as not well defined FIT or other forms of supporting RES sector combined with immaturity of technology. Energy sector has not found yet fuel able to compete with natural gas in trigeneration system, mainly because of the easiness of maintenance of this fuel. Nevertheless, analysis carried out in this work shows that, even now RES gives satisfactory results.

Both technical and economic analysis enabled to have a deep insight in the topic discussed. Technical part gave the author opportunity to clearly realize how such systems work and what are expected demands and products needed. EnergyPLAN was the main tool used for creating the simulations. As the same demand values were used, basing on the current plant, the main challenge was to project solutions with appropriate initial parameters. At the technical stage every scenario described is equal to each other with no sure leader as all of them are able to supply the system. The key point was to implement RES and present an economically feasible scenario. Due to that, actually all scenarios are somehow replacing the current system, only scenario 1a partly-using gas turbine is considered. As there was no need to remove the auxiliary boiler due to its back-up function it remained in the system during simulation stage (in scenarios 1a and 1b powered by natural gas, in scenarios 2a, 2b and 3 by biomass). There were issues not covered in this thesis regarding technical analysis. In the scenarios with the steam delivered from the WtE plant, as it is not clear how the cooperation of Climaespaço and Valorsul Project would look like and who would pay the cost of the interconnection, only hypothesis were considered. The assumptions made in scenario 2a and 3 regarding wind and PV plants in Climaespaço area are also questionable, as it is hard to forecast such plants. The big issue, occurred during simulation of baseline scenario and the demand section, crucial for further analysis. As EnergyPLAN is a tool which needs hourly data for the calculation process, it was crucial to find out if there are such to run the simulation. In this dissertation, creating the baseline was possible because of the combination of existing data followed by the approximations, which resulted in some degree of uncertainty (as the data are not always direct or from the same time). The software despite its advantages such as the simulation of whole year production in plant with hourly time step, forced the user to support with different external data. EnergyPLAN is mainly the software for national energy systems and is suited for this scale simulation but not for so specified installation. Technical analysis, in overall, enabled to analyse how the scenarios should work but it was the economic assessment that verified the actual feasibility of those scenarios. From the economic part it can be seen that only two scenarios out of assumed five, were actually feasible and significantly satisfactory at the same time. The scenarios which can be recommended are Scenario 2a and 2b, so the scenarios with the CHP biomass-based unit. Values of these scenarios are interesting, although it is important to mention that the cost of delivery and storage of the biomass was not included in the analysis. All scenarios were analysed with the timeframe of 25 years, with the help of EnergyPLAN cost database and its functions to simulate the fixed O&M and investment costs. The investment cost in scenarios was planned as the initial cost to be paid at the process of building the projected installation. The data regarding the cost and profit sections is also assumed with the degree of uncertainty, as only average data were available.

Summing up the whole analysis section in the dissertation, RES-based trigeneration systems are feasible ones but more accurate data is needed regarding such plants, with some pilot installations which will lower the uncertainty degree. PV and wind plants are not appropriate RES to power the trigeneration systems, as they are producing only electricity, while type of source producing heat is necessary. Such RES technologies are appropriate as the addition but not as the main component of the system. The main renewable source to power the trigeneration should be a fuel from which both electricity and heat could be generated and natural candidate from this position is biomass such as in scenario 2a and 2b.

An issue that should be considered in the future is incorporating the decision-making techniques combined with sensitivity analysis. Consultation with the person from the management of Climaespaço is needed in more advance way. It is important to set the appropriate criteria in order to evaluate the performances in different aspects of operation of the plant. Not only economic impact is important but there are environmental and society ones to examine.

REFERENCES

[1] progRESsHEAT Report: Barriers and Drivers, pages 91-92 2016. [Online]. Available: http://www.irees.de/irees-wAssets/docs/publications/projektbericht-report/17-05_progressheat_d3.2__barriers_drivers_local_level.pdf (last attempt 23.01.2018).

[2] DFIC - Dr. Fromme International Consulting, Cogeneration & Trigeneration – How to Produce Energy Efficiently, pages 18-26: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2016.

[3] Y. Jiang, J. Xu, Y. Sun, C. Wei, J. Wang, S. Liao, D. Ke, X. Li, J. Yang and X. Peng, "Coordinated operation of gas-electricity integrated distribution system with multi-CCHP and distributed renewable energy sources," *Applied Energy,* no. 211, pp. 237-248, 2018.

[4] export.gov Helping U.S. Companies Export, [Online]. Available: https://www.export.gov/article?id=Portugal-Renewable-Energy (last attempt 15.02.2018).

[5] Climaespaço Engie, *data gathered from the company,* 2017.

[6] D. M. Q. Correia, Technoeconomic analysis of a trigeneration system based on biomass gasification, 2017.

[7] Blomeyer & Sanz, Guadalajara in partnership with CSIL, Centre for Industrial Studies, Milan, Integrated Solid Waste Management in Northern Lisbon, Milan, 2012.

[8] EnergyPLAN, [Online]. Available: http://www.energyplan.eu/ (last attempt 09.03.2018).

[9] D. Connolly, H. Lund, B. Mathiesen and M. Leahy, "A review of computer tools for analysing the integration of renewable energy into various energy systems," *Applied Energy,* no. 87, p. 1059–1082, 2010.

[10] P. A. Østergaard, „Reviewing EnergyPLAN simulations and performance indicatorapplications in EnergyPLAN simulations," *Applied Energy,* nr 154, pp. 921-933, 2015.