Evaluation of the environmental impact of a cogeneration plant for an urban area

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Abstract: - The paper presents a methodology for evaluation of the environmental impact of a cogeneration plant. The authors have analysed different types of energy generating facilities, including cogeneration plants and separate energy production plants. There have been calculated different environmental impact indictors for all analysed solutions. For cogeneration plants with gas turbines and internal combustion engines there has been calculated the impact of the eco-tax on the economic feasibility of the plant. All the analyses lead to that fact that the environmental “externalities” can substantially diminish the feasibility of the plant. The optimal solution from all points of view, for the analysed case, is a cogeneration plant with gas turbines.

Key-Words: - Cogeneration, environmental impact, eco-tax, environmental impact indicators, economic analysis

1 Introduction
Cogeneration, as a technology for combined production of power and heat, through its energetic, economic and environmental advantages, is one the technologies for energy generation that can be called “clean”. Compared to separate energy production, cogeneration leads to fuel economy and thus to lower costs, and at the end to diminishing environmental impact [1].

Therefore, cogeneration is considered as being one of the most economic solutions for reducing the environmental impact, a fact recognised officially at the EU level. At the Kyoto Conference cogeneration has been identified as a main measure that can lead reduction of green house gasses emissions, the potential being estimated at about 180 million tons per year [2].

2 Technical characteristics of small and medium scale cogeneration plants
The type of the cogeneration equipment sets the level of thermodynamic performance (efficiency of power generation), the level of technical performances (the maximum weight of heat recovery) and also sets different limits (maximum temperature, pressure of recovered heat).

Small and medium scale cogeneration plants use as prime movers gas turbine (GT) and internal combustion engine (ICE). For both technologies heat can be recovered from the flue gasses (flue gasses temperature for GT is between 450 °C and 600 °C and for ICE is between 300 °C and 450 °C). For the ICE the heat can be also recovered from the engine chilling circuits [3].

3 Economic characteristics of small and medium scale cogeneration plants
Economic efficiency of a cogeneration plant is influenced by two types of factors: factors that characterize the cogeneration plant and factors that characterize the economic environment where cogeneration plant operates.

Factors that characterize the cogeneration plant are the following:
• Investment cost of the plant;
• Lifetime of the plant;
• Duration of utilisation of power and heat capacities;
• Fixed costs;
Maintenance costs. Factors that characterize the economic environment are the following:
- Fuel price;
- Purchasing price of electricity;
- Selling price of electricity.
The life time of the plant and the fixed and maintenance costs are influenced by the number of start/stop of the plant. Comparing the GT and ICE, there can be mentioned that the maintenance costs for GT are 2-3 times lower than for ICE. Changing the fuel influences significantly the lifetime of the plant.

4 Environmental impact evaluation of a cogeneration plant – case study
There has been performed a case study for heat supply for an urban area for the environmental impact evaluation of small and medium scale cogeneration plants. The main characteristics of the urban area are:
- Maximum heat demand for heating: 36.25 MWt;
- Maximum heat demand for hot water preparation: 25.82 MWt;
- Average heat demand for hot water preparation: 12.91 MWt;
- Structural coefficient of heat demand: 0.36;
- Heat demand: 49.16 MWt.

Net Present Value (NPV) has been used for the technical-economic evaluation.

4.1 Aspects regarding the methodology used for the environmental impact evaluation
The objective of the study is to provide different elements necessary for a complex analysis of different cogeneration solutions in order to be able to choose the optimal one. The methodology includes the following steps:
- Setting up the hypotheses;
- Establishing a data base including specific pollutant emissions for different types of equipment;
- Determining the pollutant emissions for heat and power generation;
- Establishing and calculating the environmental impact indicators;
- Analysing of the environmental impact indicators;
- Comparing the environmental impact indicators with existing norms and standards;
- Economic quantification of the environmental impact within the heat and power production costs for different technologies, including cogeneration and separate energy production.

4.2 Environmental impact analysis of the different heat supply solutions
The environmental impact of the heat and power generation is depending on the following aspects:
- Type of the energy generation facility;
- Type of the primary energy source used for heat and power generation within the energy facility;
- Stages of the life cycle considered in the study.
The environmental impact analysis has been performed only taking into account that the fuel conversion is made the energy generating facility. The main hypotheses taken into account for the analysis are the following:
- The same type of fuel is used for all types of cogeneration technologies;
- There have not been taken into account all the aspects regarding the environmental impact of the manufacturing of all equipment within the cogeneration plant, since this impact is much lower compared with energy generation;
- All the efficiencies of the main equipment (turbines, engines, electric generators, heat recovery generators, etc.) are considered included in the global efficiency of the cogeneration plant.
The calculation of the environmental impact indicators and economic indices has been performed for the following types of cogeneration plants:
- Cogeneration plant with gas turbine;
- Cogeneration plant with internal combustion engine.
The environmental impact analysis has been performed for each type of cogeneration plant. There has also been performed a comparative analysis between the different types of cogeneration plants [4]. There has been performed the following analyses for the given urban area:
- Environmental impact analysis of different technical solutions for heat and power supply of an urban area, using different types of indicators;
- Economic quantification of the environmental impact of different cogeneration technologies. Using the established hypotheses there have been calculated the values for the pollutant emissions after the combustion process into the atmosphere. For this calculations it has been used the following data:
Fuel type used at each energy generating facility and its characteristics;
- Fuel consumption for each energy generating facility;
- The values for the specific pollutant emissions into the atmosphere;
- Technical aspects of each analysed solution, such as global efficiency, etc.;
- Heat and power production;
- Different specific indicators for each analysed cogeneration solution.

The main calculation stages of the analysis are presented in Fig. 1.

In order to be able to compare different solutions for energy supply of an urban area, they should be equivalent from the energetic point of view. The main environmental impact indicators that have been considered are:
- Global warming potential;
- Acidification;
- Photo oxidant emissions.

There have been calculated the environmental impact indicators for the analysed solutions, presented in Table 2. Table 2 shows the type of the environmental impact, substances that cause this impact and formulas for calculations [5, 6].

The results of the calculations of the environmental impact indicators are presented in Table 3.

4.3 Economic quantification of the environmental impact
There has been analysed the effect of eco-tax on the production costs of heat and power for all solutions for energy supply. There has been considered that the eco-tax is 10 $/t CO₂.

The economic quantification of the environmental effects of different energy generation facilities shall appear in the production costs of the two types of, respectively heat and power.

The annual variable costs with fuel have a high weight from the total annual costs, for both cogeneration and separate production. This cost is considered to be the only affected by the environmental “externalities”, the effect being as well direct as indirect.
The direct effect is quantified through increasing the pollutant emissions and economically it is quantified through increasing the taxes for pollutant emissions (the carbon tax).

The indirect effect is quantified through the impact indicator “fuel consumption” and economically it is quantified through increasing the tax for the energy (fuel consumption).

There have been analysed two technical solutions, respectively a cogeneration plant with gas turbines and a cogeneration plant with internal combustion engines. The technical-economic analysis revealed that the optimal solution is the cogeneration plant with gas turbine. Table 4 shows the results of this analysis, respectively the values for NPV for the analysed solutions.

Table 4. Results of the economic analysis.

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<th>Cog. with ICE</th>
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<tbody>
<tr>
<td>NPV without eco-tax, $</td>
<td>5,566,332</td>
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<tr>
<td>Cog. with GT</td>
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<tr>
<td>NPV without eco-tax, $</td>
<td>12,648,319</td>
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Table 5 shows the economic quantification of the environmental impact indicators.

Table 5. Economic quantification of the environmental impact indicators.

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<th>ICE</th>
<th>GT</th>
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<tbody>
<tr>
<td>t CO₂/year</td>
<td>82,667</td>
<td>59,616</td>
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<tr>
<td>$/year</td>
<td>826,668</td>
<td>596,162</td>
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After the economic quantification of the environmental impact, the analysed solutions for energy supply of an urban area suffer modifications, i.e. the value of NPV changes. Table 6 presents the impact of this modification.

Table 6. Economic indicators with eco-tax.

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<td>NPV with eco-tax, $</td>
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<td>NPV with eco-tax, $</td>
<td>8,200,951</td>
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5 Conclusion

The effect of eco-tax, with conditions that the necessary legislation exists, influences directly the production costs of heat and electricity.

It also influences the economic efficiency of all analysed solutions. For the case of a cogeneration plant with internal combustion engine, it leads to that fact that this solution can become unfeasible from the economic point of view. For the case of a cogeneration plant with gas turbine it leads to decreasing the NPV with approximately 30 %.

An important stage in the environmental impact analysis of the cogeneration systems is the evaluation of the different calculated indicators. The cogeneration systems can be evaluated, from the environmental point of view, as follows:

- "Impact to impact" evaluation, taking into account only one calculated indicator;
- A global evaluation of all possible environmental impact categories.

There has been performed an “impact to impact” evaluation for the cogeneration solutions and separate energy production solutions. The conclusions of this evaluation are as follows:

- The cogeneration plant with gas turbines is the optimal one from the point of view of environmental impact, if analysed based on the Global Warming Potential indicator;
- The cogeneration plant with gas turbines is the optimal one from the point of view of environmental impact, if analysed based on the Photo oxidant emissions indicator;
- The cogeneration plant with gas turbines is the optimal one from the point of view of environmental impact, if analysed based on the Acidification indicator.

The optimal solution for supplying with energy of an urban area is a cogeneration plant with gas turbines.

The effect of eco-tax is considered to be quite high, since it leads to disqualifying the cogeneration plant with internal combustion engine as being feasible and in the case of a cogeneration plant it leads to diminishing the NPV value with about 30 %.

References: