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ECONOMIC AND ECOLOGICAL ANALYSIS OF A LOW-CAPACITY COGENERATION PLANT

MAZĀS KOĢENERĀCIJAS STACIJAS EKONOMISKĀ UN EKOLOĢISKĀ ANALĪZE

Anna Vološčuka, *lecturer, researcher, Dr.Sc.Ing.*
Institution, Department
Address: Kronvalda boulv. 1, LV-1010, Riga, Latvia
Phone: +371 67089923, Fax: +371 67089923
e-mail: anna.voloscuka@rtu.lv

Dagnija Blumberga, *professor, Dr. Hab. Sc. Ing.*
RTU, Institute of Energy Systems and Environment
Address: Kronvalda boulv. 1, LV-1010, Riga, Latvia
Phone: +371 67089908, Fax: +371 67089908
e-mail: dagnija@btv.lv

Ivars Veidenbergs, *professor, Dr. Hab. Sc. Ing.*
RTU, Institute of Energy Systems and Environment
Address: Kronvalda boulv. 1, LV-1010, Riga, Latvia
Phone: +371 67089908, Fax: +371 67089908
e-mail: ivars.veidenbergs@eef.rtu.lv

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Introduction

The issue of power deficit is becoming ever more topical in Latvia. State power supply depends on power stations in neighbouring countries, which operate in basic mode. In order to minimise the gap between power production and power consumption, Latvia has to recruit the state's internal capabilities.

One opportunity is using of cogeneration technology as energy sources, which may be considered most appropriate to Latvia's situation, as indicated by a number of factors. First of all, Latvia has a basic capacity deficit and the deficit may only be negated by predictable power sources; the only type of dispersed power source which may be considered predictable is a cogeneration plant. Secondly, Latvia has a characteristic centralised power supply system, which means inhabited areas have sufficiently high heat loads to accommodate installation an efficient cogeneration facility. Thirdly, the power efficiency of cogeneration is highest compared to separate power and heat production. Fourthly, a cogeneration source is close to the heat load, i.e. the energy consumer, who is consuming power at the same time. This means that cogeneration technology has all the advantages of placing an energy source next to the consumer, such as reduced power management and distribution leakage, and increased power supply stability.

During assembly of a new cogeneration plant, an energy producer faces the basic question of how high a station's installed capacity should be. Due to the fact that cogeneration envisages simultaneous production of heat and power, it becomes crucial for both types of energy to be used appropriately. As concerns power, it may both be used on the spot and transported across great distances; heat, however, may only be used in the vicinity. Thus, the heat energy consumer is considered the determining factor in selecting cogeneration plant capacity. The risks of installed cogeneration capacity are related to two scenarios: if a load is used that exceeds the optimum setting, the station will not be able to operate year-round due to insufficient heat load, while, should the load be installed below optimum, the potential of utilising heat capacity will not be applied to its fullest.

The basis of cogeneration plant operation is a physical process, although process implementation at actual facilities is not free: it is restricted by technical, economic, environmental and legal provisions. In order to achieve widespread adoption of cogeneration in Latvia, research into a new methodology is needed so as to determine preferred cogeneration plant capacity by considering physical processes along with all sorts of restrictions. Heat load parameters should be at the core of such a methodology, which would ensure that selection of optimum capacity considers the most important factor which determines successful operation of a cogeneration plant.

Methodology

The installation of any new cogeneration plant starts with assessment of consumer heat load. The optimal technology and facility capacity for cogeneration are selected based on the amount of heat demanded by consumers.

Heat load values for residential buildings and load prevalence during the year are visualised with a heat duration curve. The optimal cogeneration facility is one that, based on the heat duration curve, will produce the maximum amount of heat year-round while working at full installed capacity. This means that the facility's capacity will be determined by the highest-area rectangle (maximum rectangle) inscribed in the heat duration curve. Division of each hour's load values by the maximum load value yields a normalised, or relative load curve. The relative load duration curve is shown in Figure 1. The Figure also includes the approximation curve for the curve.

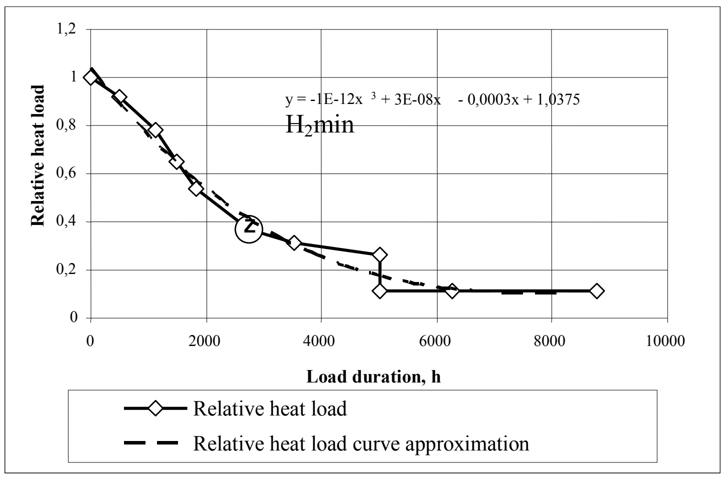

Figure 1. Relative heat duration curve and approximation

Curve approximation is done in order to produce an equation that describes it as a continuous function, which can be used for calculations. The equation for this is specified in the Fig.1. Point "z" seen on the curve denotes facility selection where facility capacity is y_z and duration of work x_z hours per year. The facility will produce y_z. x_z heat energy. This means that the optimisation assignment $y_z * x_z \rightarrow \max$ (maximal solution) must be resolved, where "z" coordinates are linked by the equation

$$y_z = -10^{-12} x_z^3 + 3 \cdot 10^{-8} x_z^2 - 0{,}0003\, x_z + 1{,}03 \qquad (1)$$

The y_z. x_z values calculated depending on relative load for the real and the approximated load curve, are given in Figure 2. The parameter in the graph denotes the aforementioned y_z. x_z product, which describes the amount of heat produced.
The Fig. 2. shows that both the real and the approximated load duration curves have maximum energy production when relative load equals 0,3. This means that selection of cogeneration facility heat load at 0,3 of maximum consumer demand allows full-capacity operation for about 5000 h in a year. Selection of a lower-capacity solution raises the number of hours in operation but lowers energy production. Increase of installed capacity above optimum reduces potential operation time and, despite increased capacity, lowers energy output as well.

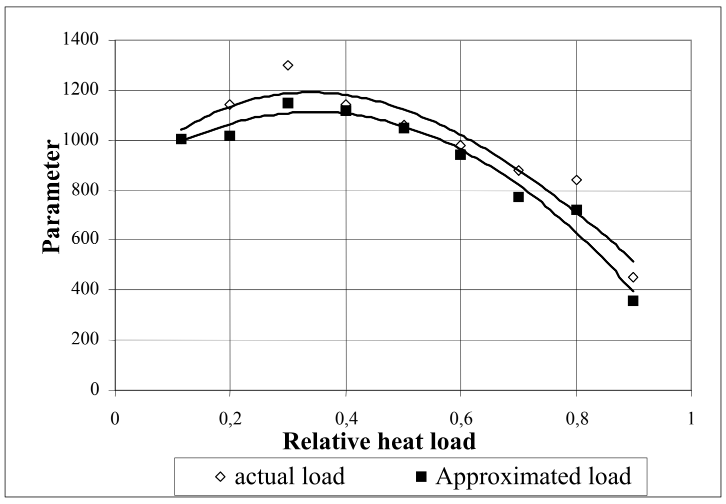

Figure 2. Heat production depending on relative facility load

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Methodology approbation algorythm

No technological solution stands on its own. Selection of a certain engineering/technical alternative is only possible once its economic and ecological parameters are assessed and optimisation is sought.
The carbon strategy model consists of four modules:

- Raw data module, which includes an analysis of the state of affairs at the energy source (emissions trade participant);
- Engineering/technical solutions module, which includes a description and analysis of at least three alternative technological measures;
- Climate module, which assesses the CO_2 emissions of each alternative;
- Economic foundation module, which includes an assessment of the capital investment, calculation of income from savings and emissions trade, profit and optimisation of each alternative.

Algorithm is shown in Fig. 3. The coal strategy model consists of four modules:

- Raw data module, which includes an analysis of the state of affairs at the energy source (emissions trade participant);
- Engineering/technical solutions module, which includes a description and analysis of at least three alternative technological measures;
- Climate module, which assesses the CO_2 emissions of each alternative;
- Economical foundation module, which includes an assessment of the capital investment, calculation of income from savings and emissions trade, profit and optimisation of each alternative.

The raw data module utilises survey, statistical data collection and processing, as well as creation of a measurement scheme, data processing and uncertainty assessment.
The engineering/technical module utilises technical parameters determined during the empirical research.
The climate module calculates SEG emissions increase due to assembly of new cogeneration facilities.

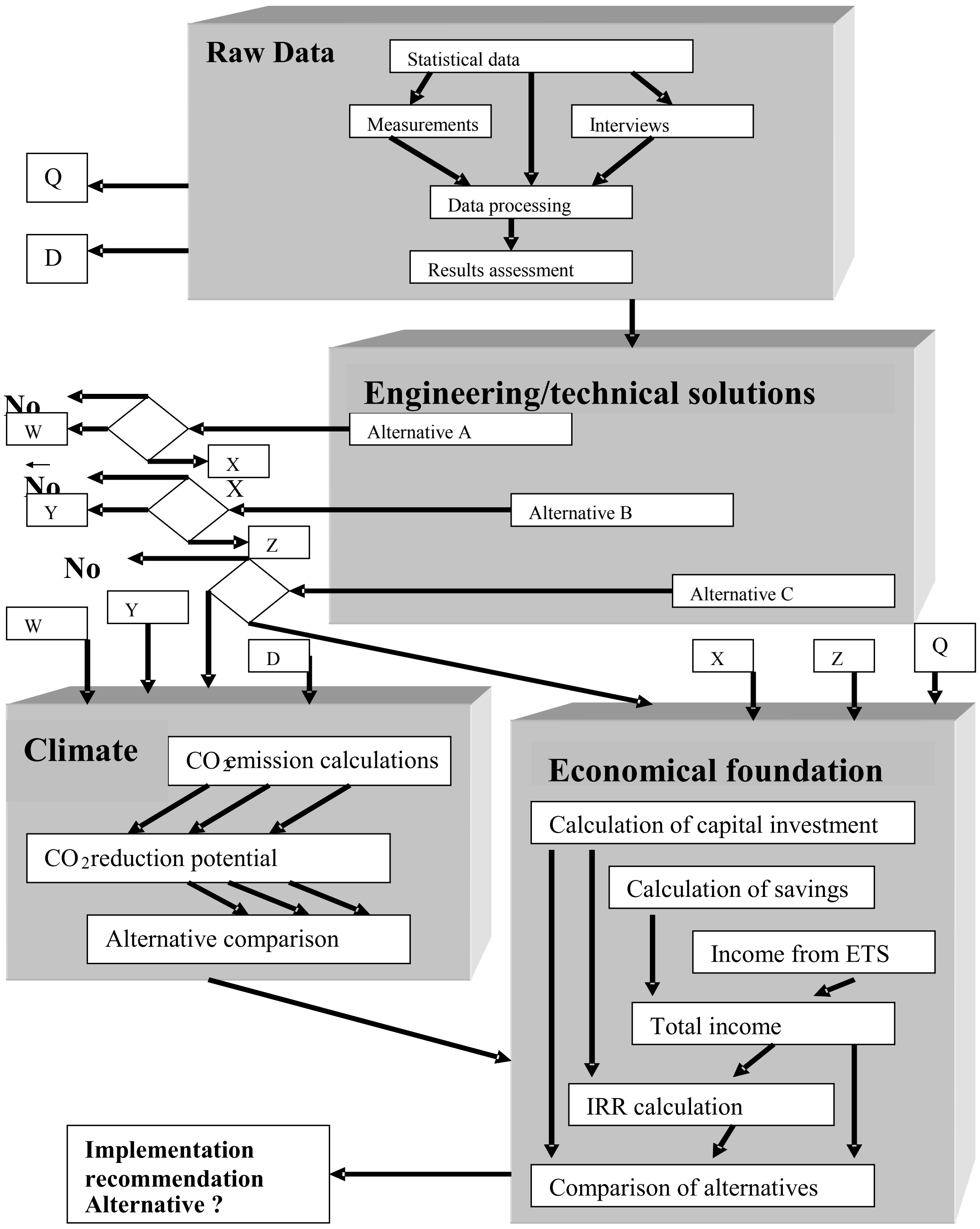

Figure 3. Carbon strategy algorithm

The necessary emissions quota during installation of new cogeneration plants are calculated using the following equation:

$$EQ_{ko\dot{g}} = \frac{\left[\left(\frac{Q_{ko\dot{g}}\cdot 100}{(100-q_{sz})}\right)+E\right]\cdot R\cdot O\cdot 0{,}0036\cdot 100}{\eta_{ko\dot{g}}} \text{ ,tCO}_2\text{/year} \qquad (2)$$

where

$Q_{ko\dot{g}}$ - heat consumption forecast, MWh/year;

q_{sz} - heat loss in the heating networks (given no data, assumed no more than 10%;

E - amt of power produced, MWh/year;

$\eta_{ko\dot{g}}$ - cogeneration plant efficiency, % (given no data, assumed at 80% for coal or peat, 85% for natural gas or diesel).

Validation of the Methodology

In order to illustrate the application of the methodology provided and not only test it, but also establish the range of its application, an actual situation is analysed where a boiler house is connected to a new heat consumer and heat load is increased. The owner of the boiler house has to decide on subsequent measures, i.e. whether to assemble a new boiler or a cogeneration installation. If the owner decides in favour of a cogeneration plant on location at the current boiler house, an important consideration is capacity of the cogeneration facility: avoidance of pointless spending of funds on purchase and operation of the equipment.

3 various alternatives are provided and described; they differ in installed capacity and nominal operation time, as well as other technical parameters. All the parameters relate to technologies used on the market. The technical parameters of each alternative are summarised in Table 1.

Table 1.

Technical Parameters of Alternative Facilities

Parameter	Alternative A	Alternative B	Alternative C
Nominal operation time , h	4300	3400	2600
Power capacity, kW	514	835	1050
Heat capacity, kW	645	997	1387
α ratio, kW/kW	0,8	0,84	0,76

Fuel supply, kW	1354	2090	2757
Power production efficiency, %	38,0	39,9	38,1
Heat production efficiency, %	47,6	47,7	50,3
Total efficiency, %	85,6	87,6	88,4

The object's heat duration curve for the centralised heat supply system was created according to the methodology for optimising cogeneration heat load. Heat production has been calculated for several heat load selections. The changes in heat produced depending on cogeneration heat capacity are provided in Fig. 4.

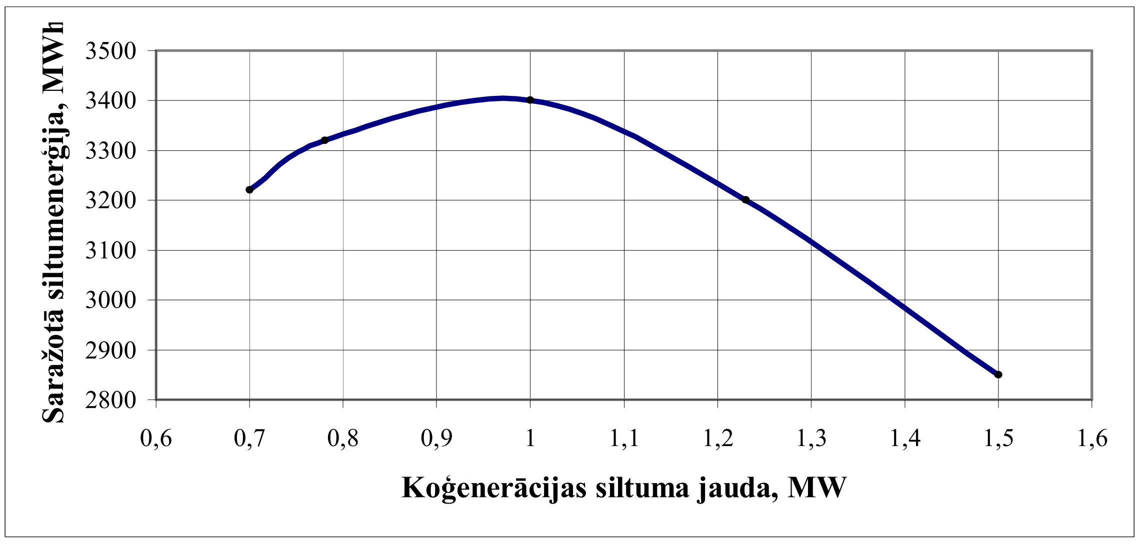

Figure 4. Cogeneration heat production depending on installed heat capacity

The optimal heat capacity for the object's heat load scenario is observed at around 1 MW_{th}. If an internal combustion engine facility is used, the corresponding power capacity would be around 0,8 MW_e.
Verification of results is performed using profitability analysis, which is based on raw data obtained from equipment manufacturers and processed in accordance with the applicable state legislation and methodological requirements.

The alternative funding plans and profitability parameters are reflected in Table 2.

Table 2.

Alternative funding plan and profitability parameters

Alternative	Alternative A	Alternative B	Alternative C
Simple payout time	7 years	6,1 years	6,9 years
Net present value (NPV)	131 961 Ls	316 924 Ls	253 442 Ls
Internal revenue rate (IRR)	11,0 %	14,5 %	12,2 %

Economic optimisation is performed by seeking extremes for the value which best describes economic profitability.
In this case, it is related to determining maximum internal revenue depending on installed power capacity.
The internal revenue change depending on power capacity is shown in Figure 5.
As seen in the results graph, the IRR optimum is observed at a power capacity of 0,83 MW_e, which corresponds to the cogeneration facility's heat capacity at 1000 MW_{th}.

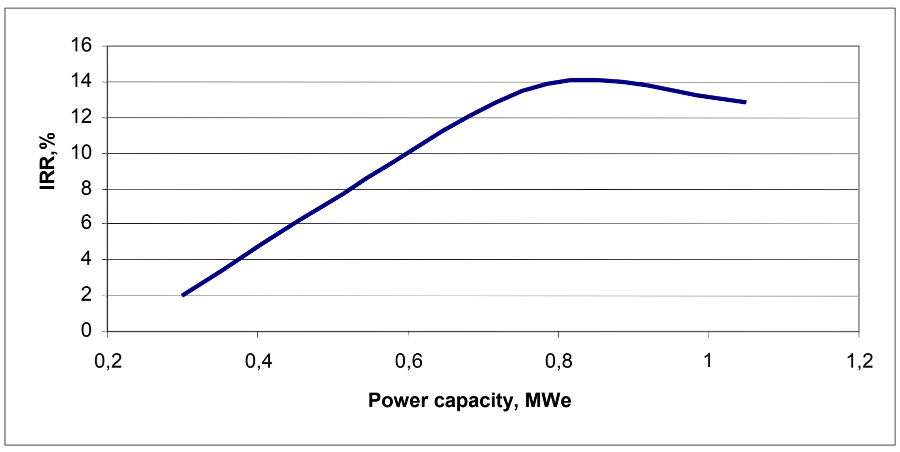

Figure 5. Internal revenue change depending on power capacity

The engineering/technical optimisation has established that the methodology optimum coincides with the optimum obtained through economic testing of the results. This confirms that the cogeneration load optimisation methodology described above is applicable for future projects and development of state-level energy strategies.

Conclusions

A Methodology for determining optimal cogeneration plant capacity, which uses annual heat production at full capacity as the optimality factor was provided. Selection of the optimality factor is based on the heat consumer's load duration curve. Validation of the methodology based on an actual heat load curve and its approximation has indicated that the optimality factor reaches its peak at 0,3 relative load and annual operation time of around 5000 h.

Based on the engineering/technical, economic and environmental modules, a validation algorithm has been developed for testing the optimal load selection methodology, which is used to test the methodology in a real environment. The methodology helps assess an actual situation when a new heat consumer is connected to a boiler house, increasing the heat load. Based on outside air temperatures and the current heat consumption by heat consumers connected to the boiler house as of 2006, a heat duration curve was plotted. Considering that the centralised heating network at the analysed object is to be connected to a new office centre, a heat duration curve forecast was also plotted. The methodology is applied in order to compare three alternative cogeneration plants (with respective installed heat capacities of 780/1000/1230 kW_{th}), establishing that the optimal heat capacity for the cogeneration facility is 1000 kW_{th} and the corresponding power capacity given an internal-combustion installation is 830 kW_e. Testing of the results was performed using profitability analysis based on raw data obtained from equipment manufacturers, processed in accordance with the applicable state legislation and methodological requirements. The highest internal revenue rate (14,5%) is seen in the project with 1000 kW_{th} and 830 kW_e installed heat and power capacities, respectively. This means that the methodology optimum coincides with the optimum obtained through economic testing of the results, confirming that the methodology described above is applicable for future projects and development of state-level energy strategies.

Acknowledgement

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Vološčuka A., Blumberga D., Veidenbergs. I. Mazās koģenerācijas stacijas ekonomiskā un ekoloģiskā analīze
Rakstā ir piedāvāta un praktiski aprobēta koģenerācijas stacijas optimālas jaudas noteikšanas metodika, kur par optimalitātes kritēriju ir izvēlēts siltuma daudzums, kas saražots koģenerācijas stacijā gada laikā, ja stacija strādā ar pilnu slodzi. Optimalitātes kritērija noteikšanas pamatā ir siltuma patērētāja slodzes ilguma grafiks. Balstoties uz inženiertehnisko, ekonomisko un vides moduli, ir izstrādāts optimālās jaudas noteikšanas metodikas rezultātu aprobācijas algoritms, kas izmantots, pārbaudot metodiku reālajos apstākļos. Ar metodikas palīdzību tiek novērtēta reālā situācija, kad katlu mājai pieslēdzas jauns siltumenerģijas patērētājs un pieaug siltuma slodze. Metodika tiek piemērota, lai salīdzinātu trīs alternatīvas koģenerācijas stacijas (ar uzstādīto siltuma jaudu 780/1000/1230 kW_{th}). Rezultāti tiek pārbaudīti ar ienesīguma analīzi, balstoties uz izejas datiem, kas iegūti no iekārtu ražotājiem un aprēķināti saskaņā ar valstī spēkā esošo normatīvo tiesību aktu un metodiku nosacījumiem. Izstrādātā metodika ir izmantojama nākotnes energoprojektos.

Vološčuka A., Blumberga D., Veidenbergs I. Economic and Ecological Analysis of a Low-Capacity Cogeneration plant
The paper provides and empirically validates a methodology for determining optimal cogeneration plant capacity, which uses annual heat production at full capacity as the optimality factor. The selection of the optimality factor is based on the heat consumer's load duration curve. Validation of the methodology based on an actual heat load. Based on the engineering/technical, economic and environmental modules, a validation algorithm is developed for testing the optimal load selection methodology, which is used to test the methodology in a real environment. The methodology is applied in order to compare three alternative cogeneration plants (with respective installed heat capacities of 780/1000/1230 kW_{th}). The results were tested using profitability analysis based on raw data obtained from equipment manufacturers, processed in accordance with the applicable national legislation and methodological requirements. The methodology developed in the paper is applicable for the development of future energy projects.

Волощук А., Блумберга Д., Вейденбергс И. Экономический и экологический анализ малых когенерационных станций
В статье предложена и практически апробирована методика определения оптимальной мощности когенерационной станции, где критерием оптимальности выбрано объем тепловой энергии, произведенной на когенерационной станции в течении года, принимая, что станция постоянно работает с полной нагрузкой. В основе определения критерия оптимальности график длительности тепловой нагрузки потребителя. Основываясь на инженерно-технический, экономический и экологический модуль разработан алгоритм апробации результатов применения методики определения оптимальной мощности. Алгоритм применен в реальных обстоятельствах. С помощью методики оценена реальная ситуация, когда к котельной присоединяется новый потребитель тепловой энергии и возрастает тепловая нагрузка. Методика применяется, чтобы сравнить три альтернативных когенерационных станции (с установленной тепловой мощностью 780/1000/1230 $кВт_{th}$). Результаты были проверены с помощью анализа доходности, основываясь на исходные данные, которые были получены от производителей оборудования и рассчитаны, согласно условиям имеющего силу законодательства и методик. Разработанная методика может быть использована в будущих энергопроектах.