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RESEARCH and EXPERIMENTATION

Simulation of an alternative energy system for district heating company in the light of changes in regulations of the emission of harmful substances into the atmosphere

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ABSTRACT

In recent years, Poland has been going through many changes, also within energy generation and the legal and regulatory system. According to the EU 2020 Climate and Energy Package, in the nearest future the polish energy industry, will have to significantly modernize most of its power plants. The dynamically changing situation results in higher demand for various analysis (concerning both energy and economic aspect) helping with setting the frames for the future functioning of power engineering companies. One of the Polish power companies, PEC Legionowo, is reshaping its infrastructure to meet the new requirements and from this particular company, authors are using the acquired data for the test case. The first conceptual project related to the development of the PEC Legionowo energy system is currently being realized in terms of increasing its energy efficiency and reducing harmful exhaust emissions. Because PEC Legionowo is obligated to significantly reduce emissions by 2022, they are seriously considering reducing coal-based production. The resulting energy gap is planned to be covered by among others installing high-efficiency combined heat and power (CHP) systems.

This article analyzes and verifies the model of an existing CHP plant and checks the modernization possibilities of the existing installation in terms of reducing emission. The new installation of gas boilers designed to replace coal-fired boilers is being validated, to meet the new emission requirements while still meeting the demand for heat and electricity.

For modelling a test case, the combined techno-economic optimization and analysis software energyPRO is used. The software optimizes the operation of the modeled system according to all input conditions, such as generation and economic data obtained from a functioning CHP plant in the Polish industry.

The results show the quantitative and economic difference related to the introduced changes in the heat and power plant system. The analysis also focuses on the size of the investment outlay and the return time of the project.

Keywords:

District heating;
Energy system analyses;
energyPRO;
Climate and Energy Package;

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1. Introduction

Energy systems around the world are constantly undergoing changes. You can even say it is revolution. This effect is intimately linked to the changing conditions associated, first of all, with energy demands, accessibility of the energy resources and the introduction of EU environmental directives. When the world was overwhelmed by the

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Acknowledgement of value

The Polish energy sector is currently facing many challenges. Like many other energy companies, we are obliged to meet the relevant standards and parameters in energy production. Changes occurring in law, resulting mainly from changes at the European Union level, cause that many energy companies must undergo changes in infrastructure that will allow to meet the required standards for increasing energy efficiency and reducing emissions of harmful substances, and. However, one cannot forget about the economic aspect of these changes. The effects of the work described in this article are very valuable to us and will allow us to develop appropriate strategies for heating companies in the face of changes in legal regulations.

Dariusz Wojtas, Chairman of the Board of Municipal Thermal Energy Company in Ostrowiec Świętokrzyski, Poland.

Abbreviations and Nomenclature

BAT	Best available techniques
BAT-AELs	Emission levels associated with the Best Available Techniques
CB	Coal boiler
CHP	Combined heat and power
DHC	District heating company
EU	European Union
GB	Gas boiler
HCl	Hydrochloric acid
HF	Hydrogen fluoride
RES	Renewable energy sources

industrial revolution, coal became the main energy medium, which remains in many countries of the world to this day. In Poland, coal is the primary fuel and constitutes over 80% of the energy mix. The current state of the energy fuel market is changing rapidly. Constant turbulence of fossil fuel prices can indicate that mankind has started to look for other alternative sources of energy. In Europe, Denmark is the leader of a new approach to energy systems, which in most cases is based on wind energy generation. Despite numerous objections, especially from the coal lobby, the Polish economy is undergoing transformation [1]. Although there are no proper meteorological conditions to effectively increase the share of RES, Poland strives to achieve the level of the most ecologically developed economies in Europe. Numerous economic reforms have bypassed the energy sector, and that left to its own has experienced stagnation. The lack of investment in previous years has led to a sudden need for reform in order to adapt large power plants to the requirements of EU directives [2].

Undoubtedly an important role in the process of energy transformation will be played by scientific entities that have been conducting research on this subject for many years. Numerous scientific papers have been written describing working conditions, simulation, optimization and maintenance of district heating systems. One of the papers describing a wide range of heating (and cooling) systems is a review article by Werner [3] describing the state of heating and cooling systems, with particular emphasis on European countries. Lund et al. [4] take a deeper perspective and examine the state and level of fourth generation district heating, as well as describe the role of new technologies for district heating in future intelligent energy systems. Kontu et al. [5] examine the role and potential of using large scale heat pumps in existing district heating systems as well as try to understand the point of view of district heating companies on the potential of installing heat pumps in the system.

Different strategies for decarbonisation scenario for combined heat and power plants are presented by Popovski et al. [6] The work focus heat and power plants working on coal, and that is of really big importance for Poland to introduce decarbonisation scenarios.

Kazagic et al. [7] with the use of energyPRO perform the optimization of operation of district heating companies based on heat and power production units and renewable sources.

Optimization of a combination of heat and power plants with thermal stores is described by Fragaki et al. [8].

Østergaard et al. [9] point out that also the social and economic aspects of the operation of district heating systems are important. Economic aspect of the operation of district heating plants is discussed by Fragaki et al. [10] on the case of heat and power plants in the UK.

Decarbonisation or designing future low-carbon [11] energy systems are not the only trends in improving the environmental situation. Ancona et al. [12] presents an approach of reduction in the consumption of fossil fuels and pollutant emissions by converting current heat distribution systems into low-temperature district heating systems.

Returning to modern energy systems, only scientific and technical analyses will allow for a harmonious transformation of the currently operating energy systems based on fossil fuels and will not reveal unnecessary costs incurred by investors and operators of this system. Special software is needed to work with simulation models. The authors' choice of energyPRO as a case study tool in this paper was determined by its worldwide character [13] and the fact that it is designed as a flexible tool for combined technical and economic optimization of different types of energy projects. It is also a widely used tool in research and it is easy to find work written based on EnergyPRO results covering the topic of simulation and optimization of district heating companies.

This article is devoted to the issue of energy transformation in the light of the implementation of EU directives, which Poland has been struggling with for several years. One of the first steps that the energy sector has to take in order to comply with the new regulations is presented. The authors attempted to indicate potential directions of modernization of currently operating energy systems on the example of a heating company operating in Poland (combined heat and power plant).

2. Description of the power sector in Poland

In Poland, approximately 50% of heat demand is covered by district heating. The largest recipients of system heat are housing associations and housing communities as well as public utility buildings. The remaining heat demand is provided from individual sources or small local sources. For historical reasons, district heating systems were built in most Polish cities. As it is presented in Figure 1, Poland is one of the European leaders in the field of district heat.

The majority of heating companies in Poland are controlled by local government units. However, public ownership concerns mainly district heating systems in smaller cities.

District heating has become an important element of the energy sector due to the possibility of developing energy production from cogeneration, which national potential is estimated at 7-10 GW on the electricity side, depending on the technology. The district heating sector is shredded, and the development of cogeneration is possible in large units as well as smaller ones.

The production of district heating in Poland is based primarily on black coal, which comes from the fact that historically was the most accessible and cheapest fuel [14].

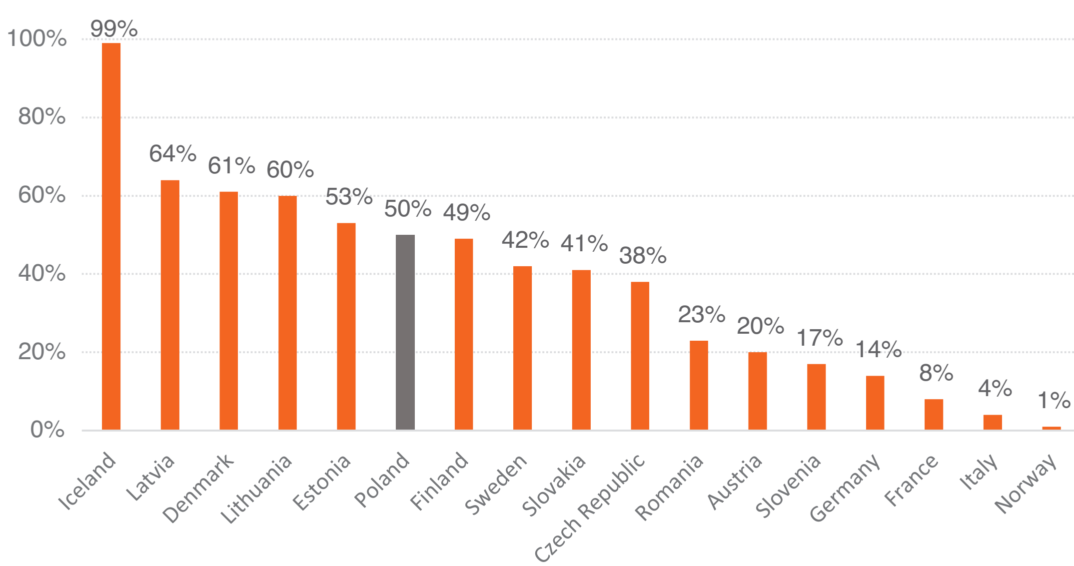


Figure 1: Share of heat covered by district heating in European countries [14]

Despite a slight decrease in the share of coal fuels in heat production - by 6.7 percentage points compared to 2002, in 2016 coal fuels still accounted for 75% of fuels consumed in heat sources. The share of renewable energy sources in 2016 in heat production increased by 4.7% compared to 2002 and amounted to 7.6% [14].

The diversification of fuels used for heat production was slightly higher in companies producing heat in the cogeneration process. In this group of enterprises, already 19% of consumed fuels are fuels other than coal, including 5.6% - heating oil, 7.2% - natural gas [14].

The development of heating systems allows eliminating the problem of low emission in many cities, which brings measurable savings in the field of medical expenses related only to the treatment of civilization diseases of the respiratory system. In 2016, over 71% of expenditures of heating enterprises were spent on investments in heat sources, the remaining part on distribution networks. The licensed heating companies funded those investments with own means.. In 2016, the share of internal funds in the financing of incurred expenditures amounted to over 70% of total spending.

The development of the district heating industry is still inhibited by the lack of legal regulations for linear heat system infrastructure. In 2015, the project of the so-called “corridor act” fell, which was to be replaced by the act on strategic public investment projects, which, however, is not a solution for the legal status of district heating networks. This is not only a problem of new network investments but also for existing systems. Currently, in Poland, almost 80% of the network does not have a regulated legal status. Lack of regulation generates investment problems and maybe the reason for increasing heat prices for recipients (the cost of lawsuits).

In the current EU financial perspective for the years 2014–2020, the heating sector has limited possibilities of using public aid under regional aid. In this perspective only horizontal aid is possible, and for network investments, network upgrades, public aid is implemented only for systems that meet the condition of an effective heating system.

According to the definition in the Energy Efficiency Directive, an efficient heating and cooling system is one in which at least half of the energy comes from RES or waste heat, at least 75% of heat comes from cogeneration or 50% of heat coming from heat or cold production from the mix of the above-mentioned sources.

In Poland, about 10% of the largest heating companies meet these requirements, which means that the rest, that needs investment just as much, have no chance of obtaining any funds, even for the modernization of old networks not to mention the development of new ones. In Figure 2, heating companies with inefficient heating

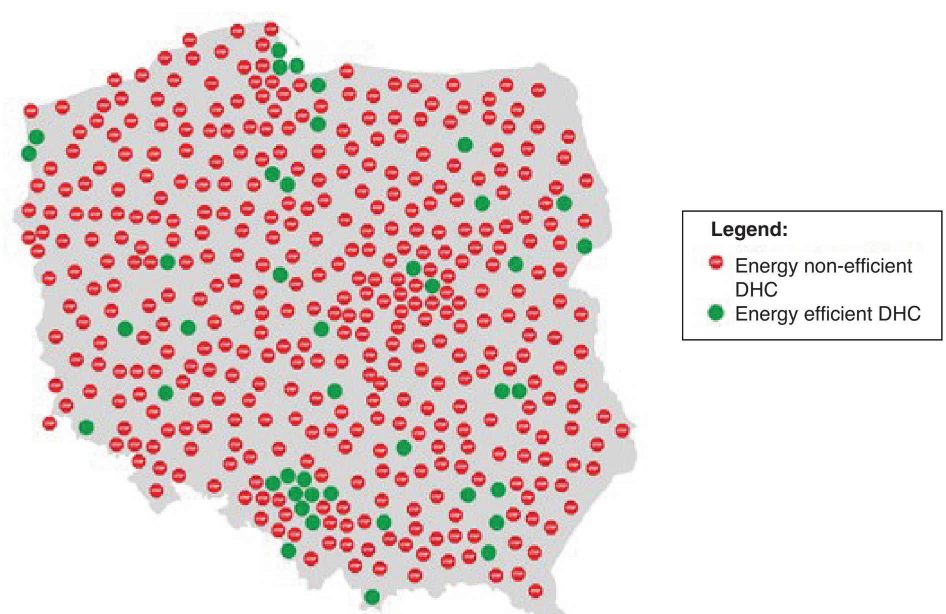


Figure 2: Energy-efficient DHCs in Poland [14]

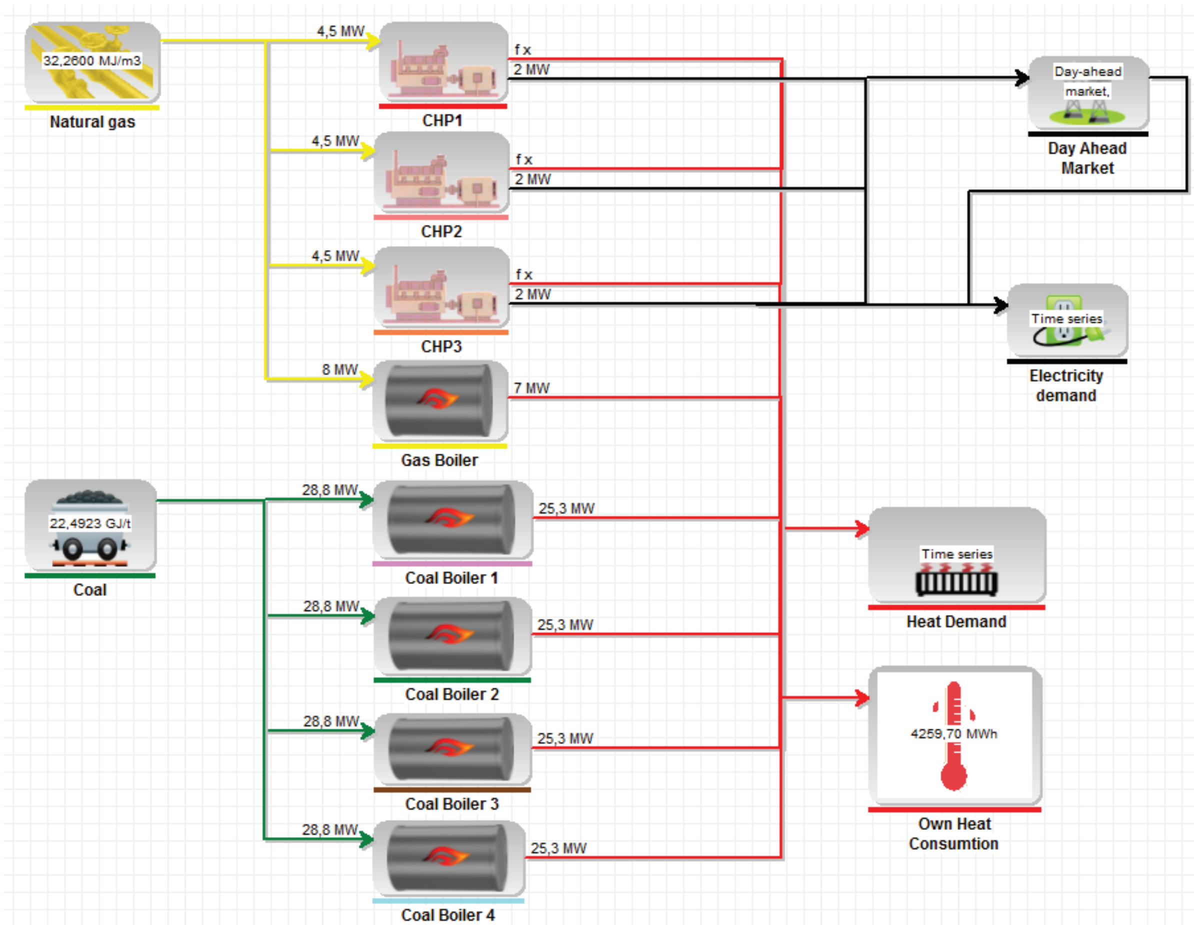
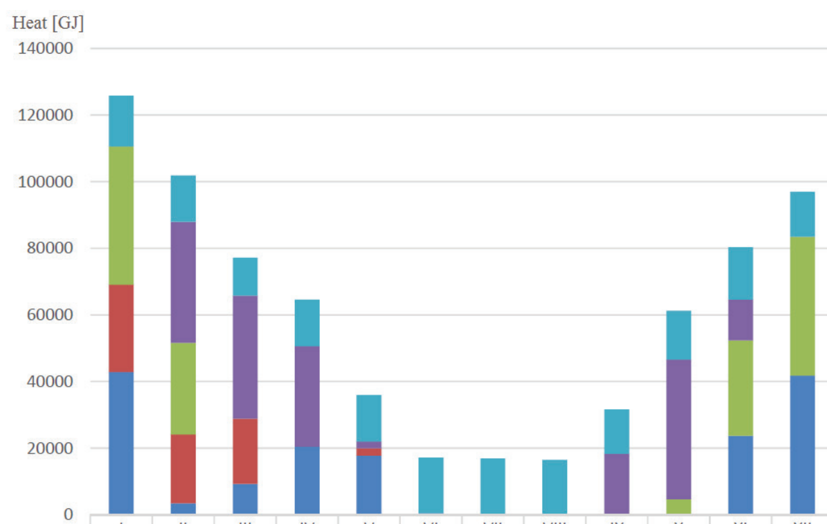


Figure 3: Structure of the DHC model consisting of three CHP engines, gas-fired boiler



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Other sources	15343	13961	11424	14015	14026	16626	16923	16479	13278	14624	15674	13511
Coal Boiler 4	0	36303	36914	30133	2021	0	0		18360	41942	12314	0
Coal Boiler 3	41396	27453	0	0	0		0	0	0	4674	28585	41643
Coal Boiler 2	26295	20683	19550	0	2251	0	0		0	0	0	0
Coal Boiler 1	42826	3479	9289	20465	17705	520	0	0	0	0	23706	41813

Figure 4: Overall heat production [GJ] during one year.

systems are marked in red, whereas the ones with efficient heating systems are marked in green.

3. Challenges for the energy sector and enterprises

The implementation of environmental regulations regarding the energy sector in the European Union member states indirectly affects the domestic heat engineering sector, as 75% of fuels used in Polish heating enterprises is black coal. In 2007, the European Union climate and energy package (so-called "3×20" package) was presented at the EU forum:

- a 20% reduction of greenhouse gas emissions,
- increase in the share of renewable energy sources (RES) in energy production by 20%,
- increasing energy efficiency by 20%.

Filling of commitments resulting from the climate and energy package was undertaken by the whole community of member countries and individual obligations were assigned to individual countries.

By the Directive of the European Parliament and the Council 2009/28/EC, Poland was obliged to achieve a minimum of 15% share of energy from renewable sources in final gross energy consumption, whereas according to the National Action Plan for renewable energy from 2010, Poland assumes that this share will increase to 15.85% by the end of 2020.

The perspective of further extension of these regulations is undoubtedly a significant threat to the domestic black and lignite mining sector, and thus to the heating sector. The new objectives of the European Union's climate and energy policy for 2021-2030 are:

- reduction of greenhouse gas emissions in 2030, compared to 1990, by at least 40%,
- improvement of energy efficiency by 27%
- achieving at least a 27% share of renewable sources in total energy consumption.

In order to provide appropriate mechanisms to help achieve the objectives of the climate and energy package by 2020, a number of regulations have been introduced to implement the premises of the "3x20" package. The action aimed at meeting the greenhouse gas emission reduction target was the introduction of new regulations for the CO2 emission allowance trading scheme (EU ETS). The current phase III of the system has introduced the need to reduce greenhouse gas emissions by 21% (by 2020) in relation to 2005.

A very important element in the context of the "new" EU rules are the so-called BATs which set for the standards for Best Available Techniques for large combustion plants in accordance with European Parliament and Council Directive 2010/75/EU, which have been published on 31 July 2017, The BAT conclusions refer to the combustion of fuels in installations with a total nominal thermal power of 50 MW or more, only if such activity takes place in combustion plants with a total nominal thermal power of 50 MW or more.

According to the above directive , the definition of a combustion plants reads: *"Any technical device in which fuels are oxidised in order to use the heat generated in this way. For the purpose of BAT conclusions, a combination of two or more separate combustion plants in the case where the exhaust gases are discharged through a common stack (…) is considered as one combustion plant. For the purpose of calculating the total rated thermal input of fuel of such a combination, the power of all individual combustion objects considered shall be added whose nominal thermal power in the fuel is at least 15 MW. "*

Classification of combustion plants/units depending on their total nominal thermal power delivered in the fuel:

- *"Where a part of a combustion plant discharging fumes with one or more separate pipes in a common chimney is used for less than 1500 hours/year, that part of the facility may be considered separately for the purposes of BAT conclusions. BAT-AELs (Emission levels associated with the best available techniques) apply to all parts of the structure in relation to the total rated thermal input applied to the fuel of this facility. In such cases, emissions from each of these wires are monitored separately. "*

The above-mentioned regulations are currently introducing a very big confusion on the heat and power plant heating market in Poland. Namely, they make the enterprises significantly reduce emission from solid fuels or switch to another type of fuel (eg. gas) by the end of 2022, in order to meet the goals indicated by the EU.

This article examines several variants of the statistical transition of a CHP plant in Poland to another type of energy system that meets the BAT conclusions.

4. Methods and Data

4.1. Simulation environment

For the modeling of a DHC test case the combined techno-economic optimization and analysis software energyPRO was used. The software, developed by EMD International A/S, optimizes the operation of the modeled system in accordance to all input conditions such as generation and economic data, obtained from PEC Legionowo, a functioning heat and power plant in Polish industry. The optimization has been implemented by analyzing yearly data profiles on an hourly resolution.

4.2. DHC reference model

The simulation model was based upon an existing DHC power plant and consists of heat generation technology and electrical energy generation technology widely used across Poland. Figure 1 visualizes the entire system setup as it was implemented. The same structure was used for the simulation with values which are explained in the following subsections in detail. In the figure, black arrows represent electricity flows, whereas red arrows represent heat flow. Following generation units were implemented as a basic DHC system:

- Four stoker fired boilers type WR-25 with a total nominal capacity of 124 MWt. Two 32 MWt boilers based on RAFAKO units and two 30 MWt based on SEFAKO units, the average efficiency of 87% each,
- Three CHP engines based on Caterpillar type G3516H with 1.9 MW thermal capacity and 2.0 MW electric power and average efficiency of average 85% each [15],
- High temperature gas-oil boiler with thermal power of 8.0 MWt and efficiency 92.35%/ 92.66%. Working as a peak-reserve source for cogeneration engines. Based on HOVAL THW-I HT E unit [16].

Stoker fired boilers are supplied with fuel in the form of fine coal and 22.4923 GJ/t heat value. CHP engines and high-temperature gas-oil boiler are supplied with natural gas with a heat value of 32.26 MJ/m^3.

4.3. Load profiles

Heat load profile, with an hourly resolution, was provided by an existing DHC power plant on which the model was based upon. The facility is responsible for meeting a heat demand of 198782.1 MWh/year including 4259.7 MWh own use. It should be noted that DHC is an energy engineering enterprise operating in the field of electricity trading and distribution.

For Poland, it is common to use “Standardowe profile zużycia energii” […] (standard load profiles), which are provided by Main Distribution System Operators for electricity load forecasting for municipal utilities or energy suppliers. Nevertheless, on behalf of this simulation external software and algorithm were used to generate electricity load profile.

The demand profile for electricity was prepared using the Artificial Load Profile Generator [17]. Based on the algorithm this tool calculates, the electric energy demand profile for a given number and types of households. In this algorithm, many variables are taken into account, including the number of people living in a given household, hours spent at home, working hours, number of appliances consuming electricity, etc. The number of households has an impact on the sum of energy demand, while the type of household affects the distribution. The received data is refreshed every minute, while for the purposes of this article, data was aggregated to refresh every hour. The authors, for the purpose of the analysis, assumed that the total demand is 22295 MWh, and 50% is generated by households run by families, 30% - two working people, and 20% - older people. The above methods of obtaining heat load profiles are only design methods using many variables. The best input data for implementation would be the one as comparable to real life data as possible, generated e.g. by using graph theory [18].

4.4. The economy of DHC reference model

Meeting EU standards is a necessary condition for the optimization issue, while the comparative aspect of the variance of the model is the economics of a given system, the size of investments and the company’s revenue during the first year of the new system’s operation. It is very important to point out that all economic data was obtained through cooperation with the heating energy enterprise. The values used in the model are as close as possible to the actual costs and profits per unit.

In the simulation model sale of electricity has been divided into two streams (Table 1). The first of them “Sale of el.en.” is the fulfillment of the energy demand that is provided to end-users. The second profit “Surplus electricity” refers to the profits resulting from the sale of

Table 1: Operation income revenues/expenditures pre-unit

	Value	Unit		Value	Unit
Revenues			**Emissions**		
Sale of heat	110	PLN/MWh	**Emissions from coal**		
Sale of el. en.		DAM	CO_coal	0.11	PLN/kg
Surplus electricity		DAM	SO_2_coal	0.53	PLN/kg
CHP propotion	40	PLN/MWh	NO_x_coal	0.53	PLN/kg
			Dust_coal	0.35	PLN/kg
Opeating Expenditures			Soot_coal	1.47	PLN/kg
Purchase of gas	1.20	PLN/m^3	BaP_coal	381.36	PLN/kg
GB maintenance cost	12000	PLN/unit/year	**Emissions from gas**		
Purchase of coal	330	PLN/t	CO_gas	0.11	PLN/kg
CHPs maintenance	137721	PLN/unit/year	SO_2_gas	0.53	PLN/kg
CBs maintenance	222063	PLN/unit/year	NO_x_gas	0.53	PLN/kg
Grid Tariff	200	PLN/MWh	Dust_gas	0.35	PLN/kg

excess produced electricity. For the sake of simplicity, both profits are calculated based on the Day-Ahead Market, however, they were separated to observe the ratio of profits.

Day-Ahead Market (DAM) is operating since June 30, 2000. It is a spot market for electricity in Poland. From the beginning of trading, prices on the Day-Ahead Market (DAM) are a reference for energy prices in bilateral contracts in Poland. DAM is intended for those companies that want to close their purchase/sale energy portfolios in an active and safe manner on a daily basis.

Within the electricity DAM, hourly and block contracts (base, peak and off-peak) are available. The changes on the DAM are currently presented by 6 price indices referring to the day and time of the delivery day. The latest electricity market index - TGe24 is the base instrument for contracts on the Financial Instruments Market (futures). It is determined by exchange transactions concluded on hourly products in the single-price auction system at the first auction on the DAM for electricity. Trading on the DAM is done for one and two days before the delivery period.

Until the end of 2018 In Poland, there was support for cogeneration plant operators. The Energy Regulatory Office in succession in 2016, 2017 and 2018 set out substitution charges referred in art. 9a paragraph 10 of the Energy Law Act, and in subsequent years amounted to 125 PLN/MWh in 2016, 120 PLN/MWh in 2017 and 115 PLN/MWh in 2018. At the beginning of 2019 funding for CHP technology ceased to apply. The current plans of the Ministry of Energy provide support for cogeneration at the level of 40 PLN/MWh. This is an important factor that the authors used when designing one of the variants of the alternative system.

5. Heating enterprises adaptation

District heating companies fulfill an important role in the social and economic map of Poland, ensuring reliable and ecological delivery of heat and more often also electricity. Because of the needs of growing recipients and the local heating and energy market becoming more competitive, the main goal is a successive development of the companies and a further increase of their value. Simultaneously, district heating companies have to achieve commitments resulting from the climate and energy package and Best Available Techniques for large combustion plants. In the following, the analyzed system variants are presented.

5.1. Variant 1: Harmful substances reduction system

The first option assumes that all standards of BAT conclusions will be met by all four, based on fine coal heat sources. A considered variant would consist of construction works including dismantling current harmful substances reduction system (excluding the chimney) and building-up new devices in its place. The following variant would consist of disassembly of four current dust extraction systems, which do not meet the requirements, construction of four individual exhaust gas dedusting systems (including complete pre-separators (MOS type), complete pulsing bag filters) and construction of four individual reduction systems: NOx, SO2, HCl, HF. In addition, each coal boiler would be equipped with reagent injection installation. The cogeneration system would be operated as before along with the gas boiler. Heat sources would work under the following regime shown in Figure 5: cogeneration engines operated throughout one year with an average use of 8500 h each. In the post-heating season as a peak source, a gas boiler would be used in a maximum level of 3000 h. However, during the heating season, along with the cogeneration system, the currently WR25 sources would be used. It should be borne in mind that simulated models are aimed at proposing possible solutions to meet EU directives while taking into account the need to reorganize the main elements of the current DHC system.

BAT standards for existing WR25 boilers after implementation of standards are presented in Table 2. Emission standards for existing cogeneration sources and an existing gas boiler with a dual-burner are presented in Table 3.

The dust extraction system uses electricity and compressed air at a rate of 170 kWh per hour of work per boiler. Assuming that in this variant total annual consumption would be 9500 h x 0.17 MW = 1615 MWh x 200 PLN/MWh = 323 000 PLN per operating year of the installation. Obviously assuming full boiler operation power and the full amount of exhaust. On average, it gives 34 PLN per hour of work. The flue gas desulfurization installation uses reagent and electricity. Reagent costs 0.95 PLN/l (including transport), and consumption (for SOX <200 mg / m2u) is about 17 dm^3t of coal, which gives 16.15 PLN/t. Electricity consumption by pumps and auxiliary installations at the level of 15 kWh per hour of work, i.e. 0.015 MW x 9500 h x 200 PLN/MWh = 28 500 PLN. Coal-fired boilers in 2017 consumed 28 288 tons of coal, this means an annual cost of: 28 288 tons x 17 l/t x 0.95 PLN/l = 456 851 PLN/year plus 28 500 PLN of consumed electricity. On average, it gives 51.09 PLN per hour of work. In cooperation with DHC, it was established that the installation of a full harmful substances reduction system would cost about 7 million PLN.

5.2. Variant 2: Additional gas fired boiler

The option assumes achieving emission standards specified in the BAT conclusions by grouping and optimizing the working times of sources and the installation of a new generation unit. The new unit would be a 15 MWt boiler fired with natural gas. The Hoval boiler was used as the reference unit for the device model. The discussed variant does not assume discontinuation of any source of WR25 from operation. In a previous variant, coal-fired boilers were supposed to work with a regular timetable as shown in Figure 5. This variant assumes that coal-fired boilers will be peak sources, i.e. they will not be able to be operated for more than 1500 h per year. Due

Table 2: BAT standards for existing WR25 boilers

No.	Standard type	The annual average level in BAT for an existing source at power >100 MW & <300 MW	The daily average level in BAT for an existing source with a power of >100 MW & <300 MW
1	Increase overall environmental efficiency	None	None
2	NO_x, N_2O and CO emission reduction	NO_x 100-180 (mg/Nm^3)	NO_X 155-210 (mg/Nm^3)
3	SO_x, HCl and HF emission reduction	SO_2 95-200 (mg/Nm^3) HCL 1-5 (mg/Nm^3) HF 1-3 (mg/Nm^3)	SO_2 135-250 (mg/Nm^3)
4	Reduction of emission of dust and metals contained in dust to the air	Dust 2-14 (mg/Nm^3)	Dust 4-25 (mg/Nm^3)
5	Reduction of mercury emission (Hg) to air	Hg 1-9 $\mu g/Nm^3$)	None

Table 3: Emission standards for existing cogeneration sources and an existing gas boiler with a dual-burner

No.	Natural gas fired cogeneration	Natural gas fired boiler
1	NO_x 190 (mg/Nm^3) with 15% of oxygen (since 2030)	NO_x 150 (mg/Nm^3) with 15% of oxygen
2	None	SO_2 35 (mg/Nm^3) with 3% of oxygen
3	None	Dust 5 (mg/Nm^3) with 3% of oxygen

Table 4: BAT standards for existing WR25, cogeneration and gas boiler peak sources

No.	Solid fuels for units >100 MW & <300 MW, existing, peak sources	Natural gas fired cogeneration	Natural gas fired boiler
1	NO_x 450 (mg/Nm^3) with 15% of oxygen (since 2030)	NO_x 190 (mg/Nm^3) with 15% of oxygen	NO_x 150 (mg/Nm^3) with 15% of oxygen
2	SO_2 800 (mg/Nm^3) with 6% of oxygen	None	SO_2 35 (mg/Nm^3) with 3% of oxygen
3	Dust 25 (mg/Nm^3) with 6% of oxygen	None	Dust 5 (mg/Nm^3) with 3% of oxygen

to the use below 1500 h on an annual basis, do not have to meet the BAT requirements. However, these sources must comply with the ordinance of the Minister of the Environment of 6 April [19]. The following Table 4 contains standards for existing WR25, cogeneration and gas boiler peak sources. The above work regime will involve the need to build four additional dust extraction systems for these sources to achieve dust levels of 25 mg/Nm^3. In cooperation with DHC, it was established that expenditure capital related to the installation of a new generative unit would amount to 8 million PLN. Similarly to the first variant, the dust extraction system uses electricity and compressed air. This results in 170 kW per hour of work for one unit per boiler and on average, 34 PLN per hour for the coal boiler.

5.3. Variant 3: Additional gas-fired boiler and CHP engine

The last variant of the system is near identical to variant No. 2. It is based on the reference model, the coal boilers have been operated in a regime of <1500 h per year each, whilst the 15 MW gas boiler (mentioned in the previous paragraph) works in the system. The additional production unit is a CHP engine with a capacity of 1.9 MWt / 2 MWe, identical to the units already operating in the system. A new CHP unit was added to analysis if guaranteed bonuses supporting cogeneration planned by polish Government would improve the economic situation of DHC. In cooperation with DHC, it was established that the installation of a full harmful substances reduction system would cost about 3.5 million PLN and a new CHP unit investment would be 6.8 million PLN.

6. Results and discussion

In the following, the results of the system simulations are presented regarding financial outcomes. The results for three different variants are shown in Table 5.

It should be noted that both Variants 1 and 2 have identical revenues of 32 364 476 PLN, while Variant's 3 revenue is 3 088 371 PLN higher, which is caused by profits from the export of surplus electricity and additional profits from CHP funding. Variants of coal-fired boilers working in a regime of the reduced number of hours, the need for production from natural gas-based units increases, which entails higher consumption of this fuel. Together with the decreasing number of working hours, coal boilers costs related to the emission of harmful substances into the atmosphere generated from coal boilers fall by more than 58% in option 1 and over 60% in option 2. At the same time, increased pressure on the operation of gas and CHP boilers results in an increase in emission costs by over 75%. 0n the other hand general outcome of emissions variances results in almost 45% decrease in emissions expenditures. The costs of purchasing a larger amount of natural gas are so high that they generate negative revenue per year. The co-financing of cogeneration, which at the level of 40 PLN is not able to improve the economic situation of the enterprise, despite obtaining 619 520 PLN subsidy. Assuming the same amount of electricity generation from a new engine, the value of CHP funding would have to exceed 60 PLN/MWh to improve outcome.

Table 5 does not include investment expenditures of the proposed solutions, but only costs related to the operation of the district heating company. In order to realize such large investments, DHC would have to take appropriate steps to obtain loans and additional co-financing. However, already at this level is visible that if the company does not bring profits, it would not be able to repay any loan installments. The key aspect is the price of natural gas, which at the level of 1.2 PLN/m^3 generates no profits. However, a decrease by 0.1 PLN/m^3 would cause a drop in the cost of natural gas purchase by 2 397 361 PLN in Variant 2 and it would lead into a positive annual profit of the company. This would be possible, for example, by negotiating the price with the supplier, caused by a significant increase in the demand for fuel

Table 5: Simulation results summary

Revenues	Unit	Price PLN/unit	Variant 1 Amount	Variant 1 Value [M PLN]	Variant 2 Amount	Variant 2 Value [M PLN]	Variant 3 Amount	Variant 3 Value [M PLN]
Sale of heat	MWh	110	198782.10	21.87	198782.10	21.87	198782.10	21.87
Sale of el.en.	MWh	DAM	22295.33	3.76	22295.33	3.76	22295.33	3.76
Surplus electricity	MWh	DAM	30204.10	4.64	30204.10	4.64	45692.10	7.11
CHP promotion								
CHP1	MWh	40	17515.60	0.70	17515.60	0.70	17515.60	0.70
CHP2	MWh	40	17508.70	0.70	17508.70	0.70	17508.70	0.70
CHP3	MWh	40	17457.10	0.70	17457.10	0.70	17457.10	0.70
CHP4	MWh	40					15488.00	0.62
CHP promotion Total				2.10		2.10		2.72
Total Revenues				34.46		34.46		37.55
Expenditures								
Purchase of gas	1000 m^3	1.20	13554.87	16.27	23973.6	28.772	27172.26	32.61
GB maintenance cost				0.012		0.020		0.012
Purchase of coal	t	330	28142.70	9.29	12456.20	4.11	10825.80	3.57
CHPs maintenance cost				0.41		0.41		0.41
CB maintenance cost				0.89		0.89		0.89
Grid Tariff	MWh	200	5.80	~ 0	5.80	~ 0	5.80	~ 0
Dust extraction system	h	34	9349.00	0.32	5487,00	0.19	5.76	~ 0
Flue gas desulfurization installation	h	51.09	9349.00	0.48				
Emisson CO_coal	t	110	10.62	0.001	4.70	517	4.08	~ 0
Emisson SO2_coal	t	530	147.80	0.078	65.42	0.035	56.86	0.03
Emisson NOx_coal	t	530	55.05	0.029	24.37	0.013	21.18	0.011
Emisson Dust_coal	t	350	33.55	0.0117	14.85	0.0052	12.90	0.0045
Emisson Soot_coal	t	147	0.63	~ 0	0.28	~ 0	0.24	~ 0
Emissons from coal Total				0.124		0.056		0.048
Emisson CO_gas	t	110	3.25	~ 0	5.75	~ 0	6.52	~ 0
Emisson NOx_gas	t	530	23.72	0.012	41.95	0.022	47.55	0.025
Emissons from gas Total				0.013		0.02		0.03
Emissions Total				0.14		0.07		0.07
Total Operating Expenditures				27.8		34.47		37.57
Operation income				6.66		–0.0028		–0.016

7. Conclusions

Regulations regarding the introduction of BATs after 2022 significantly complicate the technical and economic situation of heat plants / CHP plants located in Poland. As can be seen from the results presented in the previous parts of this article, the two most-considered scenarios of adaptation to BAT implemented in DHCs are not optimal in terms of both economic and energy efficiency, not to mention the resignation from using fossil fuels. This state of affairs is caused by the lack of specific decisions at the European and national level regarding financial support allowing for energy transformation in countries where coal is the main energy carrier. In this article, the authors analyzed the most frequently considered energy transformation scenarios of a DHC type company.

In the beginning, it should be noted that all calculations made in this article are qualitative and not quantitative.

In the analyzed cases, the most popular option is the one installing appropriate filtration to existing coal installations, which meet the BAT guidelines,. This is currently the safest option when it comes to operating costs of the installation, which currently provides the largest profits but also brings the perspective of no vision for a change in the heating plants energy systems currently operating in Poland. It is highly probable that in a few years, the now installed filtering installations will not meet the next climate requirements. Summarizing variant no. 1: it is currently the most-considered option in Poland.

Another analyzed approach to solving the BAT problem, is the limitation of the operating times of coal boilers to up to 1500h/per annum, and producing the shortage of heat using natural gas. This is an option that is now gaining more and more sympathizers. Unfortunately, this is an option that, based on the assumptions made by the authors, does not allow to generate profit, however, it allows to feel safe in the context of future possible changes regarding the regulation tightening on climate change. The authors note that the reduction of the price of gas (with the assumptions for the energyPRO model) by 0.1 PLN (0.1 PLN=0.024 EUR) results in savings of 3.5 million PLN.

To sum up, for Poland and the countries of Eastern Europe, there is still a lot of work to be done on the subject of energy transformation. This article was designed to show the initial paths chosen by companies that can directly relate to this topic. The authors hope, that it will allow readers to see a larger perspective on the current problems of the energy sector in Eastern European countries with Poland being an example.

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