European Research Studies Journal
Volume XXVIII, Issue 4, 2025

pp. 321-334

Economic and Energy Profitability of Using Geothermal Resources on the Example of a Geothermal Heating Plant

Submitted 14/09/25, 1st revision 6/10/25, 2nd revision 21/10/25, accepted 15/11/25

Zbigniew Matuszak[1], Iwona Żabińska[2], Marcin Matuszak[3], Łukasz Jędraszak[4]

Abstract:

Purpose: *Presentation of the economic and energy benefits of using geothermal water to heat water in a municipal heating plant.*
Design/Methodology/Approach: *Registration of geothermal water parameters used in the urban network. Estimation of the resulting energy and economic benefits of using geothermal water. A comparison of the geothermal energy obtained with the total energy produced by the heating plant. The studies were presented for a 12-month follow-up.*
Findings: *An analysis of the geothermal heating plant's operation revealed that the thermal power obtained from the geothermal source fully met the energy demand only in June, July, and August. During these three months, the amount of geothermal energy exceeded 100 per cent of the total demand, resulting in surplus energy production. Water heating was required in the remaining months.*
Practical Implications: *The presented results can be used to design or prepare the use of geothermal waters in other geothermal heating plants that are under construction or undergoing modernisation.*
Originality/Value: *The advantages and disadvantages of using geothermal water in a geothermal heating plant are presented. The challenges associated with using geothermal waters, particularly saline ones, are emphasised. This research was conducted at an operational technical facility in a small town in the West Pomeranian Voivodeship.*

Keywords: *Geothermal water, geothermal heating plant, municipal heating plant, profitability of using geothermal water.*

JEL codes: *D2, G3, O3.*

Paper type: *Research article.*

[1]*Maritime University of Szczecin Marine Engineering, Poland, z.matuszak@pm.szczecin.pl;*
[2]*Silesian University of Technology, Faculty of Organization and Management, Poland,*
[3]*The same as in 1,*
[4]*The same as in 1,*

1. Introduction

Industrial development towards automation and robotics, climate change, and the need to diversify energy sources and suppliers are forcing dynamic changes in the European energy economy (Huculak and Jarczewski, 2015). In Poland, from 2023, fundamental amendments and regulatory changes are taking place – the Energy Law and the Renewable Energy Sources Act, which implement the provisions of Directive 2019/944 and the RED II Directive (Bujakowski and Zacharski, 2023, http://www.pga.org.pl/geotermia, 2023).

The energy transition aims to accelerate the development of renewable and local energy and to test new solutions in the energy sector. One such solution is systems using geothermal energy. Support for the geothermal sector is particularly visible in the European Green Deal. The directive ensures priority access to geothermal electricity and simplified permitting for large and small heat pumps, and also provides investment incentives, such as premiums or feed-in tariffs (Multi-year Program for the Development, 2022).

Geothermal energy is also included in the Commission's proposal for a law on net zero energy consumption as one of eight strategic technologies. Geothermal energy also plays an important role in Poland's energy transition. The Ministry of Climate and Environment has developed the "Multi-annual Program for the Development of the Use of Geothermal Resources in Poland," which provides a roadmap for geothermal development until 2040, with a 2050 perspective (https://www.mae.com.pl/oferta-mae/baza-wiedzy, 2023).

According to experts (Bujakowski and Zacharski, 2023; Dyrektywa Parlamentu Europejskiego, 2018; Kaczmarczyk and Sowiżdżał, 2024; Sowiżdżał and Kaczmarczyk, 2016; Sowiżdżał, 2016), Poland has significant geothermal energy potential, hence the financial support from the National Fund for Environmental Protection and Water Management (NFOŚiGW) for exploratory drilling and system construction.

Geothermal energy in Poland is ecologically and economically competitive with other energy sources Chomać-Pierzecka and Sobczak, 2022, Huculak and Jarczewski, 2015, Kaczmarczyk and Sowiżdżał, 2025, Kaczmarczyk and Sowiżdżał, 2024, Tomaszewska and Szczepański, 2014, Tomaszewska and Pająk, 2012, Wachowicz-Pyzik and Sowiżdżał, 2022).

According to statistical data, it accounts for approximately 3% of primary energy production from renewable sources. Geothermal energy is the Earth's internal heat, stored in rocks and in the water that fills rock pores and crevices. This is a vast amount of heat accumulated in the Earth's core and crust. In the core, temperatures reach 4000-4200°C, and below the Earth's crust, up to 1000°C.

There is a constant flow of heat from the Earth's interior to the upper layers of the crust and to the Earth's surface (Dyrektywa Parlamentu Europejskiego, 2018).

Geothermal energy is used as the earth's thermal energy to produce heat. It is obtained by drilling into naturally hot underground water. Low-temperature geothermal resources are used to reduce energy demand by using them for direct heating of homes, factories, and greenhouses, or can be used in heat pumps, devices that extract heat from the earth at shallow depths and release it indoors for heating purposes. High-temperature sources are used in specialized installations to produce electricity and heat (Chomać-Pierzecka and Sobczak, 2022).

Poland has relatively large geothermal energy resources that can be used for heating purposes. In Poland, waters in porous rocks generally occur at depths ranging from 700 to 3000 m and have temperatures ranging from 20 to 100ºC (Bujakowski and Barbacki, 2013; Bujakowski and Tomaszewska, 2014; Górecki and Sowiżdżał, 2013; Sowiżdżał and Kaczmarczyk, 2016; Sowiżdżał, 2016; Sowiżdżał and Semyrka, 2016).

In the case of geothermal installations utilizing deep aquifer resources, high investment costs and the risk of failure that still accompany exploration work are barriers to their widespread adoption. Information on thermal waters in Poland comes primarily from hydrogeological observations conducted in deep boreholes drilled over the past several decades, primarily for the exploration of crude oil and natural gas. Hydrogeological information played a secondary role in these studies (Chomać-Pierzecka and Sobczak, 2022).

2. Characterization of the Geothermal Heating Plant in Pyrzyce

The town of Pyrzyce is located in the southwestern part of the West Pomeranian Voivodeship, 46 km from Szczecin and 30 km from Stargard Szczeciński. The town covers an area of approximately 39 km² and has a population of approximately 13,000. Until the beginning of this century, the town lacked a unified heating system. Buildings were heated by small coal-fired boilers, which consumed approximately 30,000 tons of fuel annually, resulting in significant pollutant emissions.

The geothermal heating plant in Pyrzyce is located approximately 1.5 km from the center of Pyrzyce. It provides centralized heating and domestic hot water to end users, replacing the previous heating system based on local boilers. It operates largely automatically.

A heating network with a total length of approximately 15 km transports hot water from the geothermal heating plant to the heating substations of individual customers in the town. Dual-function heat exchanger substations, located in former coal-fired boiler rooms, utilize existing installations in the buildings they serve. All substations

are constructed using energy-efficient technology, enabling settlement between the heat producer and its users. A computer-aided remote monitoring and control system ensures constant monitoring of the system's operation, adjusting the network's heating water parameters to the heat demand of the users at any given time, and ensuring its proper distribution and utilization in accordance with the principles of rational energy management.

The design and construction of the Pyrzyce geothermal heating system utilized state-of-the-art, cost-effective solutions and equipment to ensure the efficient use of the abundant geothermal water resources. The geothermal heating plant is currently one of the most modern in Europe.

The heat obtained from Pyrzyce's geothermal sources is used, among other things, to heat municipal buildings, prepare domestic hot water, and compensate for losses in the transmission network. The geothermal system in Pyrzyce consists of a geothermal heating plant, a pre-insulated heating network, and 65 heat exchanger substations. Selected geothermal heating plant equipment is shown in Figure 1.

Figure 1. *Selected equipment at the geothermal power plant in Pyrzyce: a – high-temperature and low-temperature gas boilers, b – extraction well installation, c – submersible pump, d – absorption heat pump*

a) *b)*

c) *d)*

3. Research Methodology

3.1 Geothermal Water and District Heating Water Circulation

The heating plant has two production wells, each with submersible pumps. Each pump is designed for a production capacity of 170 m³/h and a head of 160 m. Both pumps are equipped with infinitely variable speed (capacity) control via a frequency converter.

After entering the heating plant, the geothermal water flows through filters with a nominal filtration degree of 1 μm. The water extracted from the geothermal deposits is highly saline.

The heat from the geothermal water is collected in double-plate heat exchangers (arranged in series). Both exchangers are made of titanium plates and EPDM gaskets. The titanium plates are used to protect the exchangers against corrosion. Because the geothermal water in Pyrzyce is highly saline, it is highly corrosive.

In the first-stage geothermal exchanger, the geothermal water transfers heat to the return district water. In the second heat exchanger, the water also transfers heat to the return district heating water, which has been previously cooled in the heat pump's absorption evaporators to a temperature of 25 degrees Celsius.

Table 1 presents the operating parameters of the first- and second-stage heat exchangers. Both heat exchangers are designed for pressures up to 16 bar and temperatures up to 110ºC.

***Table 1**. Operating characteristics of the first and second-stage heat exchangers*

	First-stage heat exchanger	**Second-stage heat exchanger**
Thermal efficiency	7.7 MW	5.8 MW
Geothermal water, inlet temp.	62.0ºC	42.0ºC
Geothermal water, outlet temp.	42.0ºC	27.0ºC
Network water, inlet temp.	40.0ºC	25.0ºC
Network water, outlet temp.	60.0ºC	40.0ºC

***Source:** Authors.*

After flowing through additional filters, the cooled geothermal water is directed to injection wells located approximately 2 km from the heating plant. This injection is performed to renew the thermal properties of the depleted water. The geothermal water pressure in the pipeline before entering the injection wells is maintained at a minimum of 5 bar. The purpose of this procedure is to prevent the formation of gas bubbles in the geothermal water. Bubbles escaping from the geothermal water can cause flaking of the pipeline's internal surface. The geothermal water then flows into

the injection well. The assumed return temperature of the district water is approximately 45°C in summer and 40°C in winter.

After flowing to the heating plant, the return district heating water is divided into the following parallel streams: one flowing to the first-stage geothermal exchanger, one flowing to two absorption heat pumps (the absorption heat pumps are integrated with the second-stage geothermal exchanger), and then to four economizers. After these streams are mixed again, the water reaches a temperature that can be regulated, to some extent, by the flow rates through the heat pumps.

The water streams directed to the heat pumps are integrated with the second-stage heat exchanger, and the water is first cooled in the heat pump evaporators. It is then reheated in the second-stage geothermal exchanger and the heat pump absorbers, and finally reheated in the heat pump condensers. The system is also equipped with a bypass, allowing part of the district heating water to be directed directly to the absorbers without passing through the heat pump evaporators and the second-stage geothermal exchanger.

The required supply temperature to consumers is determined based on the outside temperature. If the required supply temperature cannot be achieved using heat pumps alone, a high-temperature heat exchanger and/or low-temperature boilers are activated.

The supply pipeline is equipped with three pumps operating in parallel. Each has a capacity of 475 m^3/h. Two of the pumps have stepless speed control via frequency converters. Both water circuits – the geothermal and the district heating circuit – are supplied with treated water.

The geothermal circuit is supplied with water softened in a water softening station, while the district heating circuit is supplied with demineralized water in a demineralization station. The geothermal heating water treatment process prevents scaling of the district heating network and boilers.

3.2 High-Temperature and Low-Temperature Boilers

The heating plant is equipped with two high-temperature gas boilers, each with a thermal output of 8 MW and a design pressure of 14.5 bar/160ºC. Each boiler is equipped with an exhaust gas cooler (economizer) to recover heat from the boiler exhaust gases. These cool the exhaust gases to approximately 50ºC, providing an additional 1 MW of thermal power.

The boilers' primary function is to prepare high-temperature water to drive absorption heat pumps. Under normal load conditions, to extract 1 MW of thermal power from the pump's lower source (evaporator), approximately 1.5 MW of thermal power in hot water must be supplied to the pump's desorber.

If the desired supply temperature cannot be achieved using the heat pumps alone (as described above), the district heating water is supplemented in a high-temperature heat exchanger. The heat exchanger is designed for 160ºC and 16 bar. Table 2 presents the operating parameters of the high-temperature heat exchanger.

Table 2. *Operating parameters of the high-temperature exchanger*

	Thermal power	**Temperature at the inlet**	**Temperature at the outlet**
At the hot water side	16 MW	155ºC	130ºC
At the network water side	16 MW	70ºC	84ºC

Source: *Authors.*

The heating plant also has two low-temperature gas boilers. Each has a capacity of 10 MW and is rated at 120ºC and 10 bar. Additionally, approximately 1.2 MW is generated by the economizers of each boiler. The boilers are only activated during peak loads, when the previously described equipment is unable to meet the thermal power or supply temperature requirements.

3.3 Absorption Heat Pumps

Each of the two heat pumps consists of four main components (absorber, desorber, condenser, and evaporator). The desorber is connected to the condenser and operates at the highest pressure, but below atmospheric pressure. The absorber and evaporator are also connected (practically located in the same tank) and operate at very low pressure.

Treated water and its vapor circulate in the condenser and evaporator. The absorber and desorber contain a lithium bromide solution (typically 60% LiBr), water, and vapor. Passing water at temperatures up to 160ºC through the desorber tubes causes the solution to boil, creating superheated vapor. This vapor exits the desorber and "migrates" to the condenser.

In the condenser, the vapor condenses (at a maximum temperature of 80ºC) upon contact with the tubes through which the district heating water flows. Heat exchange between the steam and district heating water increases the district heating water temperature.

Condensate flows through the steam trap to the evaporator. A 1.5 kW circulation pump maintains constant circulation of the working fluid (treated water) in the evaporator, which contains tubes. Return district heating water flows through the tubes. The very low pressure in the evaporator causes the working fluid to evaporate, thereby extracting heat from the return district heating water. Geothermal water, being highly corrosive, cannot come into direct contact with heat pumps.

The saturated steam generated in the evaporator is absorbed by the LiBr in the absorber. This is possible because the temperature in the absorber is much lower than that in the desorber. Cooling the absorber also involves adding heat to the district heating water. An additional pump (7.5 kW) feeds the LiBr solution to the desorber.

The LiBr solution, with the same LiBr content but a lower water content, returns to the absorber. Lithium bromide flows from the absorber to the desorber and vice versa, from the desorber to the absorber, through a heat exchanger. The thermal efficiency of the absorber and condenser is typically approximately 2.5 times greater than the energy absorbed in the evaporator. Therefore, a temperature reduction in the evaporator always corresponds to a 40% temperature increase in the absorber and condenser.

Directing a portion of the district heating water directly to the absorber allows for the district heating water to be cooled to a lower temperature without increasing the temperature in the condenser or exceeding the permissible operating parameters. Table 3 presents the parameters demonstrating the highest heat pump operating efficiency.

***Table 3**. Characteristics of the operation of an absorption heat pump at a given load*

	Evaporator	**Absorber + Condenser**	**Desorber**
Temperature at the inlet [ºC]	52.0	52.0	160.0
Temperature at the outlet [ºC]	30.2	78.0	150.0
Efficiency [MW]	-4.1	+10.7	-6.9

***Source:** Authors.*

Both pumps are equipped with rupture discs, as standard safety valves allow small amounts of air to enter the pump. Even small amounts of air in the pump would reduce its efficiency and cause extensive corrosion. The Pyrzyce geothermal heating plant utilizes absorption heat pumps from the Japanese company SANYO.

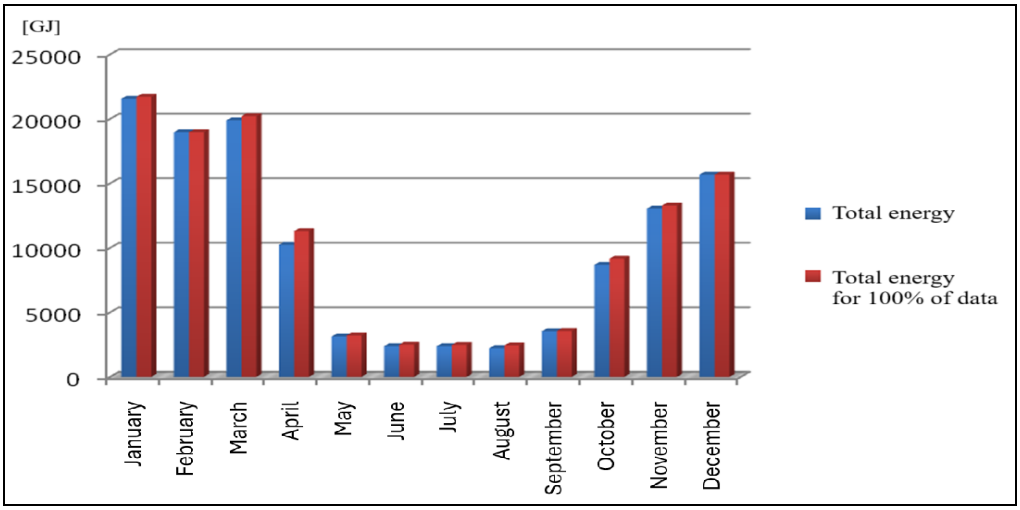
4. Research Results and Discussion

4.1 Energy Characterization of the Geothermal Heating Plant in Pyrzyce

Figure 2 compares the system's total energy production data, recorded by the geothermal heating plant's control system, with statistical data filling in the gaps in the system's recording. The operational data recording system, in terms of total energy production, recorded the largest outages in April (only 90.69% data completeness). Total energy produced by geothermal energy includes geothermal energy and energy obtained from supplementing the geothermal circuit with gas

boilers. Analyzing the total energy production by the geothermal heating plant, it can be seen that the highest levels of operation occurred from October to April (over 5,000 GJ of energy produced).

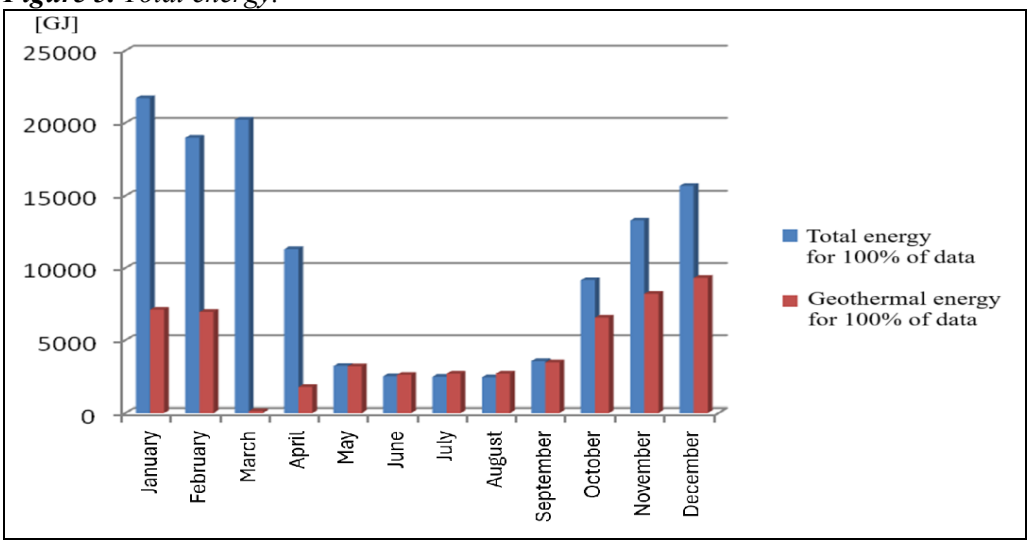
***Figure 2**. Total system energy production data.*



***Source:** Authors.*

Figure 3 shows a comparison of the total amount of energy produced by geothermal energy and the amount of geothermal energy obtained solely from the ground source.

***Figure 3.** Total energy.*

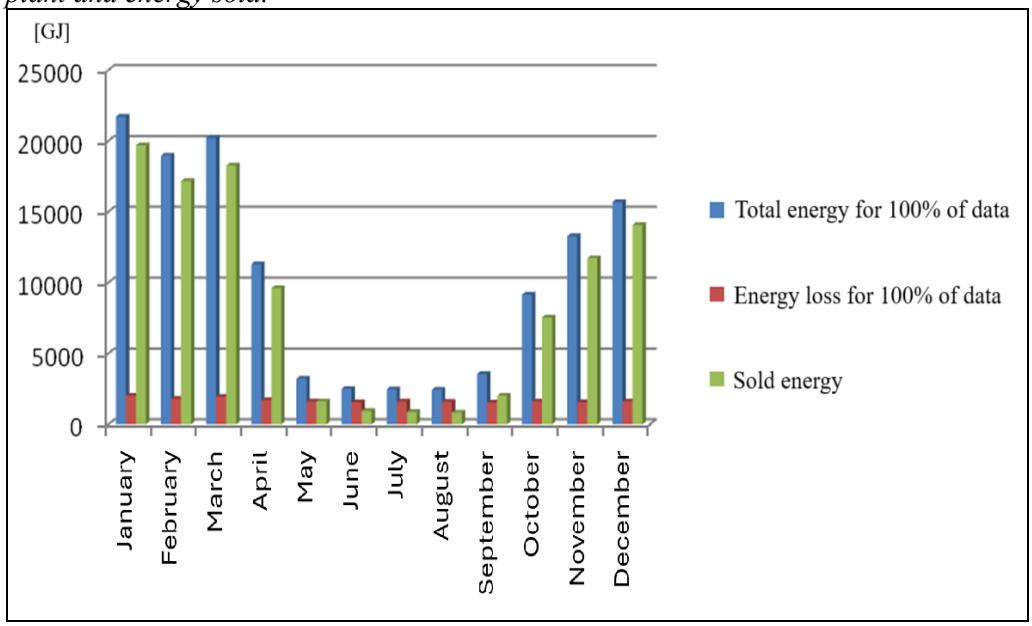


***Source:** Authors.*

It can be noted that the power generated from the geothermal source fully covers energy demand only during the months of June, July, and August. During these three months, the amount of geothermal energy exceeded 100% of the total demand, thus exceeding total energy production.

Figure 4 shows the difference between the total energy generated by the heating plants and the energy delivered to the user. It was noted that energy losses occurring in the municipal network reduce the final energy efficiency by an average of approximately 1.678 GJ.

Figure 4. *Summary of the volume of energy production in the geothermal heating plant and energy sold.*

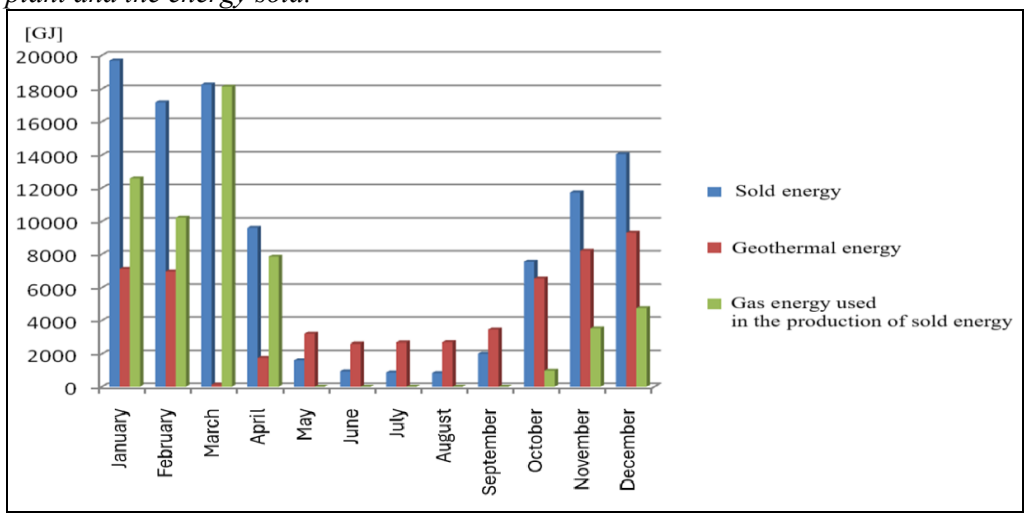


Source: *Authors.*

Figure 5 shows the ratio of energy produced by heating plants to energy sold to end customers. From October to December, geothermal energy exceeded gas consumption in the heating process by more than half. In the winter months of January and February, heat obtained from gas supplementation exceeded heat obtained from geothermal sources. In the summer, geothermal energy exceeded the demand for sold energy, and gas use during this period was due to minimal system failures.

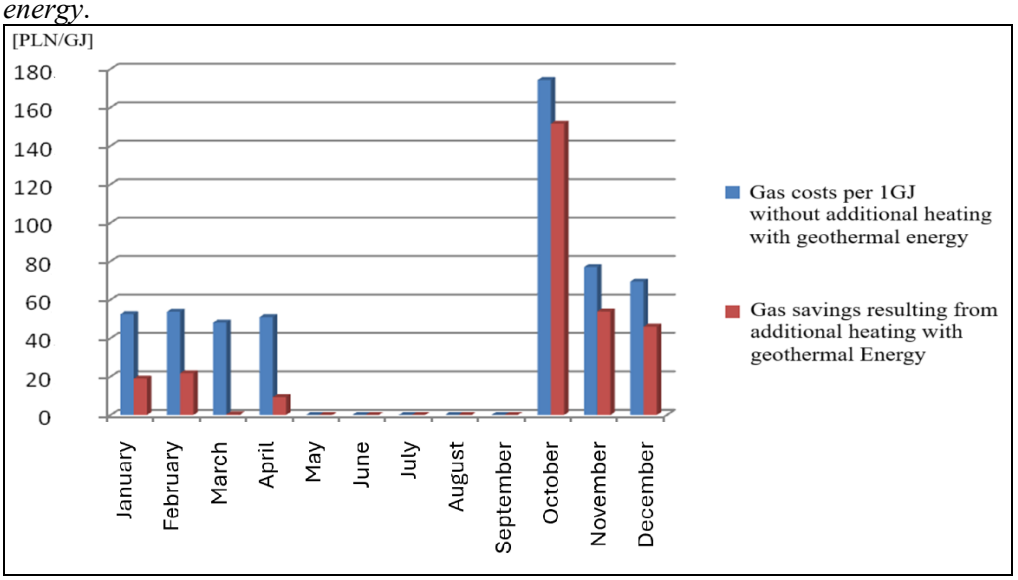
The summary in Figure 6 clearly shows the savings trend resulting from the use of geothermal energy in heat production. The largest savings resulting from this use were recorded from October to December.

Figure 5. *Summary of the amount of energy produced in the geothermal heating plant and the energy sold.*



Source: *Authors.*

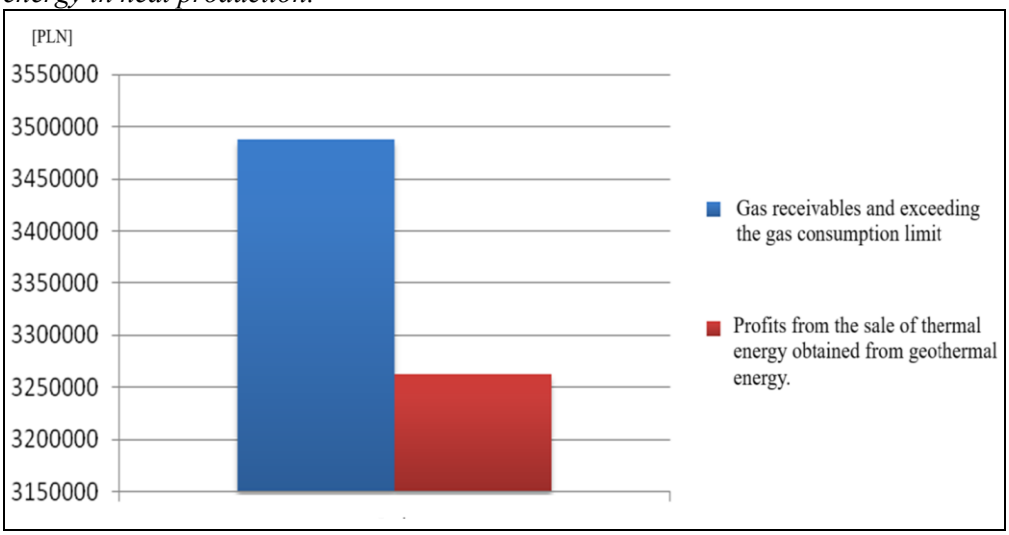
Figure 6. *Comparison of gas costs per 1GJ without additional heating with geothermal energy, with savings resulting from additional heating with geothermal energy.*



Source: *Authors.*

The cost breakdown in Figure 7 shows the financial savings associated with year-round thermal energy production using geothermal energy. It can be seen that the annual energy gains from geothermal heat production are approximately 94%.

Figure 7. *Summary of gas costs and profits resulting from the share of geothermal energy in heat production.*



Source: *Authors.*

5. Conclusions

Geotermia Pyrzyce is a company specializing in the utilization of geothermal energy. As a modern facility, the Geotermia facility meets European and ecological standards for energy production, transmission, and delivery. The use of new technology, integrating soft acidification and super-soft acidification, allows for increased efficiency of the geothermal energy source. These methods allow for maintaining constant geothermal water parameters.

Geotermia Pyrzyce, like most geothermal heating plants, struggles with maintaining high thermal water extraction efficiency. The main problems with injection wells include a progressive decline in injection efficiency and effectiveness, rapid corrosion, and imperfect materials used in the transmission lines. The lack of adequate insulation in rooms heated by the geothermal heating plant is also a significant factor.

Thermal losses at the end customer site are prevented by thermal insulation of heated buildings. Another aspect that increases the efficiency of geothermal energy is lowering the domestic hot water temperature at night, combined with the use of a variable-displacement circulation pump. The energy and financial analysis of Geotermia Pyrzyce is presented in Figures 4-6.

The thermal power obtained from the geothermal source fully covers energy demand only during the months of June, July, and August. During these three months, the amount of geothermal energy exceeded 100% of the total demand, thus exceeding

total energy production. Energy losses occurring in the municipal network reduce final energy efficiency by an average of approximately 1.678 GJ.

The cost breakdown shown in Figure 7 indicates that the financial savings associated with year-round thermal energy production using geothermal energy are approximately 94%.

Among the geothermal heating plants operating in Poland using high-enthalpy water, some struggle to ensure adequate performance to ensure smooth operation. Decreased efficiency and injection efficiency, as well as rapid corrosion, are related to problems with injection wells. Problems with reinjecting cooled thermal waters back into their parent aquifers via infiltration wells are not unique to Polish geothermal heating plants.

These problems occur in all European and worldwide heating plants that inject cooled thermal water back into their parent aquifers, particularly into pore collectors. The super-soft acidification method is currently being used and continually refined at Pyrzyce Geothermal Plant. It has displaced the company's plans to construct two new wells, which were intended to prevent injection problems in the first phase of the project.

References:

Bujakowski, W., Barbacki, A., Skrzypczak, R. 2013. Nowe kierunki badań polskiej części Sudetów w aspekcie technologii HDR i EGS. Przegląd Geol., nr 61(11), 706-711.

Bujakowski, W., Tomaszewska, B. (red.). 2014. Atlas możliwości wykorzystania wód geotermalnych do skojarzonej produkcji energii elektrycznej i ciepła w systemie binarnym w Polsce. IMGiES PAN, Kraków.

Bujakowski, W., Zacharski, P., Bielec, B., Tyszer, M., Pierzchała, K., Tomaszewska, B., Pająk, L., Pińska, B., Szczepański, K. 2023. Verification of the geothermal conditions in the Polish Lowlands based on data from new drilling performed in the years 2000-2022. Mineral Resources Management, vol. 39 Issue 1, pp. 193-216. DOI: 10.24425/gsm.2023.144636.

Chomać-Pierzecka, E., Sobczak, A., Soboń, D. 2022. The Potential and Development of the Geothermal Energy Market in Poland and the Baltic States: Selected Aspects. Energies, 15, 4142. https://doi.org/10.3390 /en15114142.

Dyrektywa Parlamentu Europejskiego i Rady (UE) 2018/2001 z dnia 11 grudnia 2018 r. w sprawie promowania stosowania energii ze źródeł odnawialnych Dz.U.UE.L.2018.328.82.

Dziadzio, P., Maj, J., et al. 2021. Geothermal development support programs in Poland and their effects. Przegląd Geologiczny vol. 69, nr 9, pp. 549-558.

Energy. 2024. Statistics Poland, Rzeszów 2024, file:///C:/Users/ROZ1-/Downloads/energia_2024.pdf.

Górecki, W., Sowiżdżał, A., Hajto, M., Jasnos, J. 2013. The latest results of geothermal projects in Poland. In: Proceedings, European Geothermal Congress, Pisa, Italy, 3-7, June 2013, pp. 8-9.

Huculak, M., Jarczewski, W., Dej, M. 2015. Economic aspects of the use of deep geothermal heat in district heating in Poland. Renewable and Sustainable Energy, Rev, 49, pp. 29-40.

Kaczmarczyk, M., Sowiżdżał, A., Tomaszewska, B. 2025. Environmental Evaluation of Geothermal Heating Plant in Poland. Proceedings, 50th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 10-12, SGP-TR-229.

Kaczmarczyk, M., Sowiżdżał, A., Tomaszewska, B. 2024. Life Cycle and Water Footprint Assessment in the Geothermal Energy Sector. Energies, 17, 6050. https://doi.org/10.3390/en17236050.

Kępińska, B., Kasztelewicz, A., Miecznik, M., Petursson, B. and Gudmundsson, J.R. 2023. Current challenges and opportunities for the development of geothermal heating in Poland and Iceland in the light of the Key Geothermal project (EEA FM, 2014-2021). Proceedings World Geothermal Congress 2023, Beijing, China, April 17-21.

Multi-year Program for the Development of the Use of Geothermal Resources in Poland. 2022. Raport Krajowy Prezesa Urzędu Regulacji Energetyki. Urząd Regulacji Energetyki. 2024.

REPowerEU Plan (COM(2022) 230 final). 2022.

Sowiżdżał, A. 2018. Geothermal energy resources in Poland – Overview of the current state of knowledge. Renewable and Sustainable Energy Reviews, Elsevier, vol. 82(P3), pp. 4020-4027.

Sowiżdżał, A., Kaczmarczyk, M. 2016. Analysis of thermal parameters of Triassic, Permian, and Carboniferous sedimentary rocks in central Poland. Geological Journal, 51(1), s.65-76.

Sowiżdżał, A. 2016. Petrogeothermal energy resources in Poland. Appl. Ecol. Environ Res. 14(2), pp. 555-574.

Sowiżdżał, A., Górecki, W., Hajto, M. 2020. Geological conditions of geothermal resource occurrences in Poland. Geological Quarterly, 64(1), 185-196.

Sowiżdżał, A., Semyrka, R. 2016. Analyses of permeability and porosity of sedimentary rocks in terms of unconventional geothermal resource explorations in Poland. Geologos, 22(2), pp. 149-163.

The European Green Deal (COM(2019) 640 final). 2019.

Tomaszewska, B., Szczepański, A. 2014. Possibilities for the efficient utilisation of spent geothermal waters. Environ Sci Pollute Res (Springer Verlag). 21(19), pp. 11409-11417.

Tomaszewska, B., Pająk, L. 2012. Geothermal water resources management - economic aspects of their treatment. Gospodarka Surowcami Mineralnymi – Mineral Resources Management, 28(4), pp. 59-70.

Wachowicz-Pyzik, A., Sowiżdżał, A., Pająk, L. 2022. Environmental benefits from geothermal energy use with a well doublet located in the Szczecin Trough (NW Poland), Environ. Geochem. Health, vol. 44, no. 7, pp. 2325-2339.