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Possibilities of using the energy potential of geothermal waters in the case of Poland and Ukraine

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Abstract: The development of energy based on RES is an important element of the policy of sustainable development and maintaining energy security. The difficult situation in the energy sector is turning more and more countries towards alternative energy sources. The feasibility of obtaining energy from renewable sources is linked primarily to the resources that are also economical. The main advantage of geothermal waters is that they can be used to produce heat or electricity, regardless of the time of day or climatic conditions. Data from geological research allows us to conclude that both Ukraine and Poland have favorable conditions for the use of energy from low and medium temperature geothermal waters. Ukraine is also turning to the possibility of using geothermal energy to produce electricity. Examples highlighting the possibility of using the energy potential of geothermal waters in the Lviv region and the Czestochowa poviat were presented.

Keywords: geothermal energy, geothermal water, geothermal installation

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Introduction

Global trends in the development of the energy sector are closely connected to the use of alternative energy sources. Renewable energy sources (RES) complement each other in natural processes, which allows them to be treated as inexhaustible. At the same time, the development of the energy sector towards increasing the share of renewable energy sources is in line with the implementation of the concept

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of sustainable development, where one of the priorities of these activities is to reduce the negative impact of the energy sector on the environment. (Flaksman et al., 2020; Lis, 2020; Østergaard et al., 2022). The share of energy from renewable sources in total primary energy production increased between 2016-2020 from 13.76 to 21.59% (*Energy*; *Renewable*). Supporting and disseminating RES is one of the goals of the energy policy of many countries. Such actions were indicated by the EU Directive on the promotion of the use of energy from renewable sources (Directive of 2018). To meet the challenges related to climate change and environmental degradation, the European Commission has announced the European Green Deal action plan, which aims to achieve climate neutrality in 2050 (Communication, 2019). In order to achieve this goal, it is necessary to increase the share of RES in the integrated energy system to 40%. In response to the disruptions in the global energy market in 2022, the European Commission presented the REPowerEU plan, in which it proposes to raise the EU target for RES for 2030 from the current 40% up to 45% (Communication, 2022). The implementation of the REPowerEU plan is expected to bring the total renewable energy generation capacity to 1,236 GW by 2030, compared to 1,067 GW by 2030 in the "Ready for 55" package (Communication, 2021). In the EU, the share of energy from renewable sources in total primary energy amounted to 32.8% in 2019. The leaders in this respect being Austria, where the share was 82.9%, and Lithuania with a share of 81.1% (*Energy*; *Renewable*).

Geothermal waters are a valuable raw material used in many areas of the economy, and geothermal investments, compared to other RES, are distinguished by the stability of operation and constant production over time, independent of weather conditions. Including them in the structure of the energy sector in a much wider capacity than before would contribute to increasing the amount of heat obtained from RES. According to data presented during the World Geothermal Congress 2020+1 in Reykjavik, as well as data from such institutions as the International Renewable Energy Agency (IRENA) or the International Geothermal Association (IGA) and the European Geothermal Energy Council (EGEC) report, geothermal resources are exploited in 34 countries in Europe, and generally 88 countries around the world. The increase in installed geothermal capacity for direct use in the last 5 years increased by 52% to approximately 108 GWt. The world leaders in the direct use of geothermal energy are China, Turkey, Japan, Iceland and Hungary, which are responsible for 76.5% of global use. The number of countries that generate electricity from geothermal energy has increased to 29 in the world. The production increased to about 95 TWh in 2020 and in Europe to 12.7 TWh. The installed capacity of geothermal power plants at the end of 2019 was approximately 16 GWe. The leader in this respect is the United States, where the installed capacity is about 3.7 GWe. In Europe, electricity from geothermal energy is produced in 11 countries, and the capacity installed in 139 power plants is estimated at around 3.5 GWe (*EGEC*; Hajto, 2021; Lund, Huttrer & Toth, 2022; *Renewable*). A significant share in the production of geothermal energy falls on the use of shallow resources, using heat pumps. The leaders here are European countries: Sweden, Germany, France, Finland and Austria (Bujakowski, 2015; *EGEC*; Hajto, 2021).

1. Purpose and scope of work

The exploitation of individual renewable energy sources in a given country depends on their availability, potential exploitation possibilities and its economic efficiency. Understanding the benefits of individual renewables can help focus efforts on the most promising options. Of all renewable energy sources, geothermal energy has the highest technical potential. The aim of this work was to assess the prospects of using the energy potential of selected geothermal water resources in Ukraine and Poland. Solutions for the case of the Lviv region and the Czestochowa poviat are discussed. Schemes of the use of geothermal water heat with parameters typical for these areas are presented.

2. Potential of geothermal waters in Poland and Ukraine

Almost 80% of Poland's area is within the range of three geothermal provinces: Central European (222,000 km^2), Pre-Carpathian (16,000 km^2) and Carpathian (13,000 km^2). There are natural sedimentary and structural basins filled with underground waters of various temperatures. Lower Jurassic and Cretaceous reservoirs have particularly favorable conditions for the intake of thermal waters (Zimny et al., 2008). The temperature of thermal waters in Poland ranges from 20-130°C (locally 200°C), and the depth of occurrence is from 1 to 10 km. Potential water and energy resources contained in individual geothermal provinces are presented in Table 1.

Table 1. Potential resources of water and energy contained in individual geothermal provinces in Poland (Zimny et al., 2008)

Province	Area	Water resources	Water resources	Water volume	Heat energy
	km^2	km^3	mln toe	m^3/km^2	toe/km^2
Central European	222,000	6,215	32,436	99,401,000	501,000
Pre-Carpathian	16,000	362	1,555	22,600,000	97,000
Carpathian	13,000	100	714	7,700,000	55,000
Total	**251,000**	**6,677**	**34,705**	**129,701,000**	**653,000**

Regions with optimal geothermal conditions in Poland largely overlap with areas of high density of urban and rural agglomerations, highly industrialized areas and regions of intensive agricultural and vegetable cultivation (Bujakowski, 2015; Kępińska, 2021). A map of prospective areas for the exploration and intake of thermal waters is shown in Figure 1. Poland's geothermal resources would be enough to meet the heat needs of 30% of the country (Boguniewicz-Zabłocka, 2019; Kępińska, 2021; Sowizdzal, 2018).

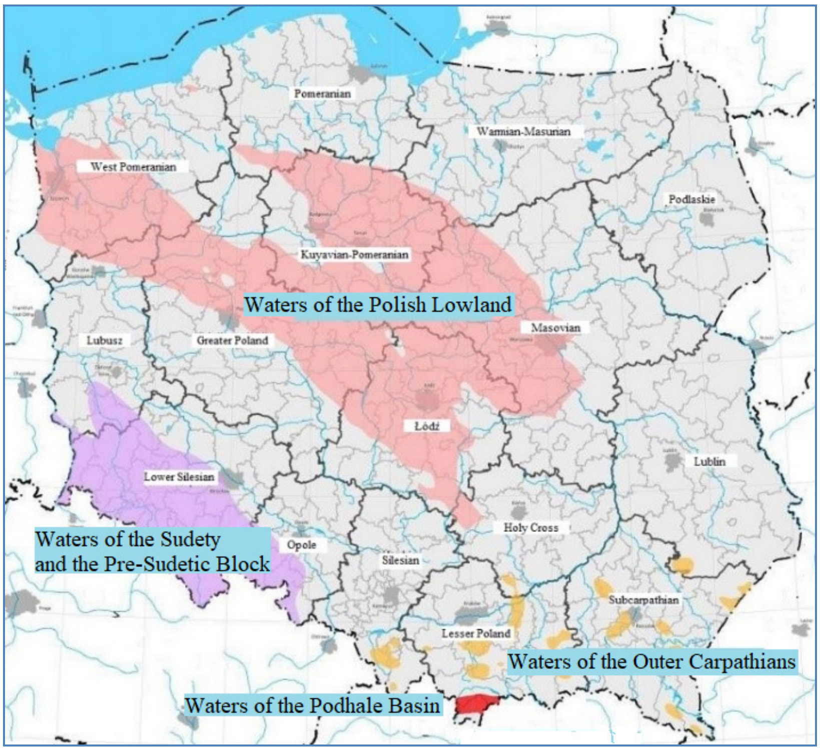


Fig. 1. Prospective areas for exploration of thermal waters (The map was developed by Economic Geology Department of Polish Geological Institute. National Research Institute in 2021)

In order to identify wells suitable for the extraction of thermal waters, the Institute of Engineering Thermophysics of Ukraine of the National Academy of Sciences conducted field studies of geothermal deposits in the Crimea, Transcarpathia and the densely populated region of the Dnieper-Donets Depression where the largest number of wells are located. Ukraine's geothermal potential is shown in Figure 2.

Potential geothermal resources approved by the Ministry of Ecology and Natural Resources of Ukraine are 27.3 million m^3 of thermal water per day, with an average temperature of 70°C. The annual technically achievable energy potential of geothermal energy in Ukraine corresponds to 12 million toe (Dolinskiy & Khalatov, 2016; Morozov & Barylo, 2019). The Institute of Renewable Energy of the National Academy of Sciences of Ukraine has compiled data from over 300 boreholes in which thermal waters with a temperature above 50°C have been identified. Their energy potential was estimated at 1.9 billion MWh/year (Morozov & Barylo, 2019; Shurchkova, 2019).

Ukraine is within the Central European, Eastern, Pre-Carpathian and Carpathian Geothermal Provinces. The most promising use of geothermal resources is in the Carpathian Province (Lymarenko, 2021; Rudakov & Inkin, 2019). Temperature and flow rates of thermal waters in the hydrogeological provinces across Ukraine are presented in Table 2.

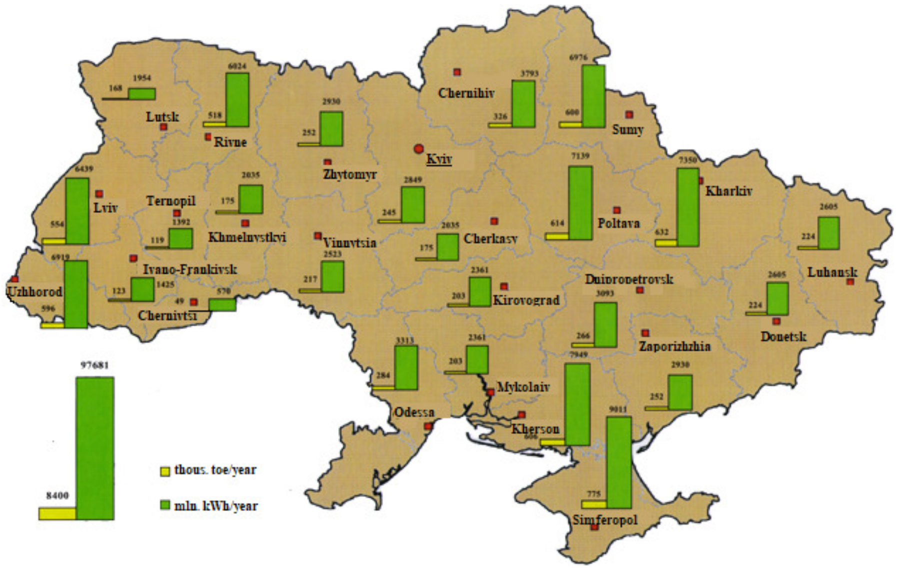


Fig. 2. Potential of geothermal energy in Ukraine (Shurchkova, 2019)

Table 2. Temperature and flow rates of thermal waters in the hydrogeological provinces across Ukraine (Rudakov & Inkin, 2019)

Province	Depth	Water temperature	Flow rate
	km	°C	m^3/day
Carpathian	0.6-0.9	50-75	430-1,200
	1.9-2.3	120-130	5-10
Volyn-Podilsky	0.9-1.1	35-45	20-40
	1.8-2.0	60-70	20-40
Ukrainian Crystalline Shield	0.8-1.0	30-35	300-400
	1.9-2.4	50-55	50-100
Black Sea	1.5	50	500-1,500
	3.0	90	500-1,500
Crimea	1.1	30-35	10-20
	1.9	65-70	10-20
Donets Basin	0.9-1.2	27-40	200-400
	1.8-2.0	70-75	75-150
Dnipro-Donets	1-1.2	35-60	10-250
	1.9-2.3	50-90	80-500

Research in Ukraine also focuses on hot water geothermal resources, which can also be used to produce electricity. According to various estimates, it is about 8.4 million tons of oil equivalent per year (Lymarenko, 2021).

The Energy Strategy of Ukraine provides that from 2025 the consumption of geothermal energy will amount to 1 million tons of oil equivalent, and by 2030 it will increase to 1.5 million tons of oil equivalent and will amount to 1.6% of total energy consumption (Resolution, 2017).

3. Analysis of the use of the potential of geothermal waters in Poland and Ukraine

Depending on the temperature of the geothermal water, different ways of using it are possible. Low and medium-temperature waters (20-35°C, 35-80°C) are a source of geothermal energy that can be used for heating and cooling buildings, in agriculture, in industry, as well as in balneotherapy or recreation. In the case of low temperatures, the use of heat pumps as support devices is required. High-temperature and superheated waters (> 80°C) is used in district heating systems, and at temperatures above 150°C, it is used to produce electricity. Water is pumped to the surface, where its energy potential is used in heat exchangers and discharged into the aquifer (Boguniewicz-Zabłocka, 2019; Kępińska, 2021; Noga, 2022; Romanov & Leiss, 2022). The idea of a closed thermal water circulation was proposed by scientists from the Institute of Engineering Thermophysics of NAS of Ukraine. This method, first used in France, was called the “Ukrainian method of obtaining geothermal energy” (Morozov & Barylo, 2019). Decisions to explore geothermal sources are made after a detailed geological and geophysical analysis, based on the temperature, pressure and chemical composition of reservoir fluids.

There are several institutions dealing with geothermal energy in Poland, e.g.: Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, Polish Geological Institute – National Research Institute or Polska Geotermalna Asocjacja (Polish Geothermal Association). A team of experts from the Polish Geothermal Association has developed, among others, a digital model of the underground structure of Poland and temperatures down to a depth of 6,000 m, allowing the reliable determination of any locations for geoenergetic investments in the country. On this basis, over 300 cities were selected that could switch 100% to geothermal heating energy (Zimny et al., 2008). The Ministry of the Environment supports geothermal energy, e.g. by updating regulations and legal acts related to the exploration of thermal water deposits, their exploitation, as well as providing public aid for such projects under various support programs (Dziadzio, 2021). The Ministry of Climate and Environment has developed a “Long-term Program for the Development of the Use of Geothermal Resources in Poland”. It is a roadmap for the development of geothermal energy until 2040, with a perspective until 2050, which is a coherent concept for the development and use of geothermal energy in Poland (*Multi-year*, 2021). The practical use of geothermal water energy in Poland includes mainly heating, preparation of domestic hot water as well as recreation and balneotherapy (Boguniewicz-Zabłocka, 2019; Bujakowski, 2015; Kępińska, 2021, *The use*). In 2016-2020, the use of geothermal energy in Poland gradually increased, in 2020 its consumption was 15.4% higher than in 2016. Geothermal energy was used mainly in households (75.0% of consumption) and secondly in trade and services (25.0%) (Energy, 2022). However, in Polish geological conditions, it is possible to obtain from a geothermal doublet, i.e. using two boreholes, the heating power of up to 50 MWt and the electric power of up to 10 MWe (*Multi-year*, 2021; Zimny et al., 2008).

There are currently several larger geothermal heating plants operating in Poland with the use of geothermal energy (Fig. 3).

Fig. 3. Geothermal installations in Poland: 1 – district heating systems, 2 – individual heating systems, 3 – health resorts (Kępińska, 2021)

The oldest plant, Geotermia Podhalańska, was commissioned in 1993. It has 3 production openings and 2 absorption openings. Geothermal waters with mineralization of 2.5 g, temperature at the outflows of 82-86°C and yields of up to 120-550 m^3/h are extracted from a depth of 2.5-3 km. The thermal power of the geothermal installation is 40.7 MW. Parameters of subsequent plants are presented in Table 3.

At the end of 2021, the total installed geothermal thermal capacity of the systems was approximately 138 MW. The share of geothermal heat in the production and sale of heat in individual heating plants was 30-100% (Kępińska, 2021). The latest plant, opened in October 2022, is a geothermal heating plant in Toruń. Estimated production of heat energy amounts to 81.5 GWh, the capacity of the injection well is 320 m^3/h and the temperature of the water in the deposit reaches 64°C. Efficiency parameters of the bed of 500-1000 m^3/h are the highest in Europe. In Poland, there are also single individual geothermal heating systems in Cudzynowice Kleszczów, Karpniki, Czarnków, Słomniki and Klikuszowa. On a European scale, Poland ranked fourteenth in 2020 in terms of the number of geothermal central heating systems. however, in terms of installed geothermal heat pumps, it was ranked 8th and 5th in terms of their sales dynamics (*EGEC*, 2022; Hajto, 2021; Kępińska, 2021).

Table 3. Geothermal district heating plants in Poland (Bujakowski, 2015; Kępińska, 2021)

Geothermal plant	Depth	Mass flow	Inflow temp.	Minera-lization	Installed power	Heat production
	km	m^3/h	°C	g/dm^3	MW	TJ
Stargard	2.67	180	84	150	12	57.85
Pyrzyce	1.64	200	64	121	12,8	21.15
Uniejów	1.7-2.25	120	68-70	6-8	3.2	212.5
Poddębice	2.1	252	68	0.4	10	17.38
Mazowiecka	1.7	60	42	0.5	3.7	4.49
Podhalańska	2.5	1,070	82-86	2.5	40.7	152.58

The Institute of Geophysics of the National Academy of the Sciences of Ukraine has developed the Geothermal Atlas of Ukraine, which estimates the territory's geothermal resources at depths of 3, 4.5 and 6 km. Presented, among others are results of calculations of the distribution of geoenergetic resources in Ukraine. (Morozov & Barylo, 2019; Shurchkova, 2019). In Ukraine, there are many legal regulations regarding the development of alternative and renewable energy sources, including geothermal waters, e.g. Act on Alternative Energy Sources. Regulations on the adaptation of geothermal deposits for commercial exploitation and the procedure for conducting geological exploration of geothermal fields were also approved. The following national standards were adopted: "Geothermal energy. Concepts and definitions", "Geothermal energy. Geothermal heating plants" and "Geothermal energy. Geothermal power plants". In 2018, thanks to government support, the Institute of Renewable Energy of the National Academy of Sciences of Ukraine created an experimental installation to study the storage of heat from renewable energy sources in the underground aquifer thermal energy system (Morozov & Barylo, 2019).

The first geothermal circulation system in Ukraine was built in Illinka, Autonomous Republic of Crimea. Following the development of the "Ecologically Clean Geothermal Energy of Ukraine" Program, nine geothermal power plants with a total capacity of approximately 11 MW were installed. The energy was used to heat public buildings. Some of the objects were dismantled. Currently, there are two geothermal systems: in the village of Medvedivka in the Autonomous Republic of Crimea (0.7 MW) and in the village of Kosino in the Zakarpattia Oblast (0.2 MW) (Morozov & Barylo, 2019).

Priority sites are determined based on the analysis of hydrogeological indicators of the prospecting data and an assessment of their performance. Table 4 presents the most frequently studied geothermal objects.

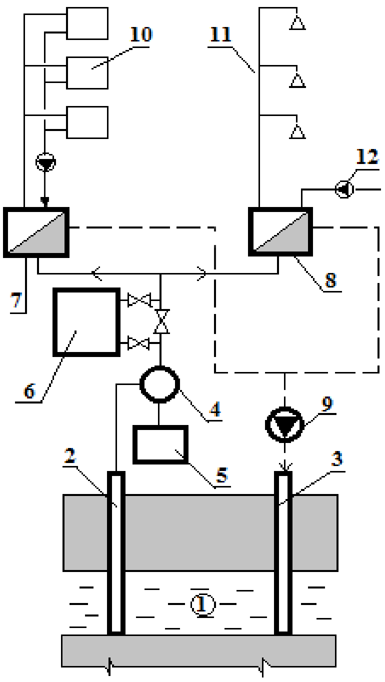
Currently, Ukraine has signed memoranda with foreign countries, in particular with China and Iceland, on cooperation in the field of geothermal energy and research into the geothermal potential of Ukraine, and the development of geothermal energy takes place only at the research and industrial stage (Yurkevych et al., 2022).

Table 4. Priority geothermal objects in Ukraine (Morozov & Barylo, 2019)

Geothermal object	Placement by region	Bed temperature	Depth of productive horizon
		°C	m
Russkie Komarovtsy	Zakarpattia	89	1350
Henichesk	Kherson	89	2620-2651
Monastyryshche	Chernigiv	96-98	3374-3384
Spivakovskaya	Kharkiv	98	2780
Gadyach	Poltava	119-120	4950
Mostyska	Lviv	90-95	3160
Hlinsko-Rozbyshevskoe	Poltava	127	5060

4. An example of the possibility of using geothermal waters in the Lviv region

The geothermal waters of the Lviv region are characterized by a temperature of 90-95°C, a mineralization of more than 30 g/dm^3, and a high content of hydrogen sulphide (Ivanov et al., 2022; Yurkevych et al., 2022). It is advisable to consider the possibility of using these waters to generate heat, in particular for heat supply systems in housing estates. The optimal solution for the use of geothermal waters in the Lviv region would be a "doublet" system (Fig. 4).



DOUBLET SYSTEM

1 – flow of geothermal waters
2 – receiving well
3 – injection well
4 – gas sludge cleaner
5 – system for utilizing gases and sludge
6 – peak boiler room
7 – heat exchanger of the heating system
8 – heat exchanger of hot water supply system
9 – discharge pump
10 – heating system
11 – hot water supply system
12 – booster pump of cold water supply system

Fig. 4. Geothermal heat supply scheme (Yurkevych et al., 2022)

In this scheme, geothermal water from deep aquifers is transported to the ground surface through a receiving (production) well and fed to the peak boiler room for heating, and then to the heat exchangers of heating and hot water systems for heating their coolants. After giving up the heat, the geothermal water is pumped back into the aquifers through an injection well. Two wells can provide from 0.4 to 4.5 MW of heat energy. The peak boiler room in this scheme is turned on when the outside air temperature drops and the heat energy potential of geothermal water is insufficient to cover the heat load of consumers. Using the peak boiler room, geothermal water is heated to the required temperature and supplied to indirect heat exchangers of heat consumers. When the outside air temperature increases, the peak boiler room is turned off and the geothermal water is delivered directly to the recipients' indirect heat exchangers.

Figure 5 shows the dependence of the amount of thermal energy that can be obtained per year from 1 km^2 of the surface depending on the deposit temperature. For the parameters of the well, such as: reservoir diameter equal to 500 mm, energy recovery factor 10% and the well's exploitation period of 50 years, it was determined that for a 1 MW installation, the area should be approximately 2 km^2 during year-round operation.

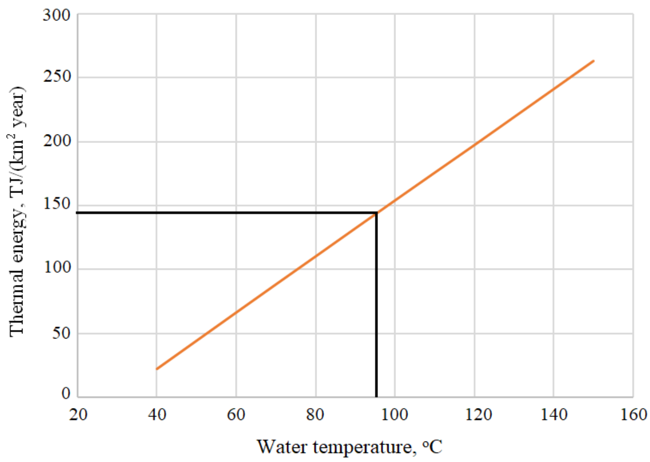


Fig. 5. Dependence of the amount of thermal energy that can be obtained from 1 km^2 of surface depending on the formation temperature (Yurkevych et al., 2022)

When developing geothermal heat supply systems of the Lviv region, the maximum value of the coefficient of efficiency of thermal water intake should be ensured. The value of the coefficient depends on the type of heat energy consumer and amounts to: for the heating system – 0.05-0.34; for the ventilation system 0.15-0.45; for a hot water supply system – 0.7-0.92. In order to obtain high efficiency values for the use of thermal water, it is advisable to use combined geothermal heating systems, in which heating systems are combined with recipients using geothermal heat throughout the year.

5. An example of the possibility of using geothermal waters in the Czestochowa poviat

The example of the potential for utilizing low-temperature geothermal water for heat-generating purposes is a bore-hole in Poczesna (Silesian province, Czestochowa poviat). Biochemical and physical parameters of the water enable this well to be used as the lower heat source for heat pumps to heat selected local utility buildings. At the spontaneous outflow (24 m^3/h) water temperature was about 20°C. The achievable heating and cooling powers as a function of the bottom heat source temperature and the possible electricity consumption for two assumed volume fluxes, min. 24 m^3/h and max. 80 m^3/h, of geothermal water are shown in Figure 6.

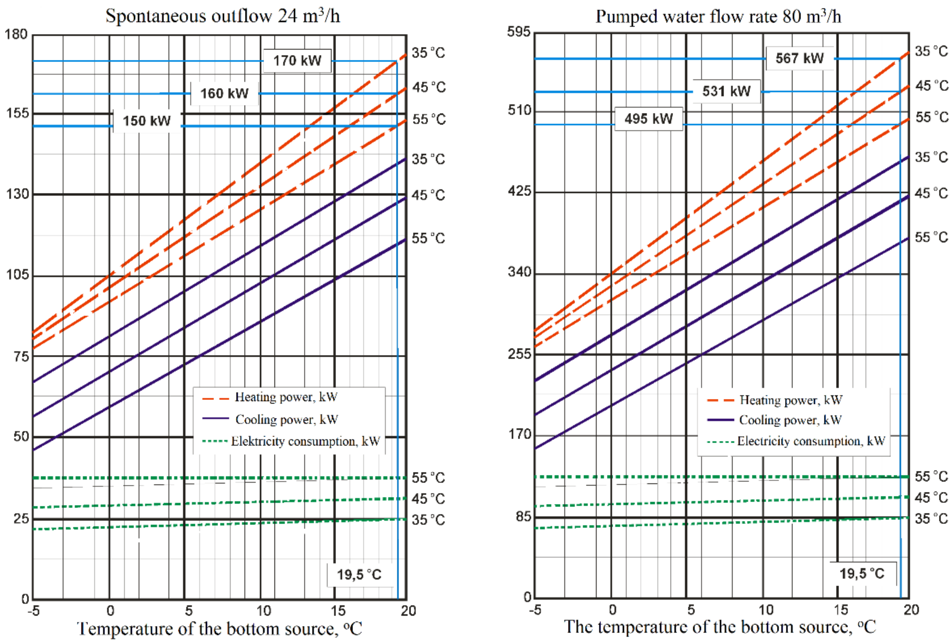


Fig. 6. The technical potential of the geothermal source at the flow capacity of 24 and 80 m^3/h (Sekret & Pidzik, 2008)

Except from the temperature of the bottom source of the heat pump, a very important quantity that influences the energy effect of well utilization is the upper source temperature, i.e., the central heating system supply temperature. Generally, the following rule applies: the lower the upper heat source temperature, the higher heat pump efficiency index COP, and consequently the lower the operational costs. In order to increase the heat pump efficiency, a surface heat flow system should be chosen. Low-temperature floor heating and wall heating systems (e.g. with a max. supply temperature of 35°C) are perfectly suitable for this. In the case of radiator heating, the central heating system should be designed for the supply temperature equal to 55°C (Sekret et al., 2009). The list of possible operating parameters of the heat pump or pumps for the considered test well is presented in Table 5.

Table 5. List of achievable operating parameters of the pump or pumps (Sekret & Pidzik, 2008)

Water flow rate	Central heating system supply water temperature					
	35°C		45°C		50°C	
	Heat power	COP	Heat power	COP	Heat power	COP
m^3/h	kW		kW		kW	
24	170	6.8	160	5.0	150	4.0
40	265	6.8	250	5.0	235	4.0
50	335	6.8	313	5.0	290	4.0
80	567	6.8	531	5.0	495	4.0

The heat pump is able to meet the average and peak thermal loads in the case of those buildings being heated with a low-temperature central heating system. In the event that more power of the central heating system would be needed, a bivalent system supplied by two different sources could be used. In the bivalent system with a heat pump as a basic system, an additional heat source could be provided for example a gas or oil-fired boiler. Three solutions can be proposed in bivalent systems: the separated system, a parallel system, and a mixed system. In the separated system, the heat sources do not operate at the same time. At a limiting external temperature, the heat pump will be shut off, and the heat demand will be met by the other heat source. In a parallel system in the period of increased heat demand, an additional heat sources is started. The heat demand met by the heat pump is about 80%. In the mixed system the heat pump is incorporated into the return circuit of the heating system. The heat pump supplies all heat needed for heating up to the bivalent point. Below the bivalent point, the pump increases the return temperature of the heating circuit, and the other heat source reheats the water to attain the necessary temperature level at the supply. If the system's return temperature is higher than the maximum temperature that can be provided by the heat pump, the other heat source takes over entirely the job of meeting the heat demand. The degree of heat demand met by the heat pump is about 75%.

Conclusions

Currently, Ukraine and Poland attach great importance to the problem of energy savings and efficiency, as well as to the development of the sector of alternative energy sources. Both countries have promising geothermal water potential. However, the Supreme Audit Office report shows that significant financial support for geothermal energy in 2015-2021 did not translate into a significant increase in the production of geothermal heat. The reasons for this were the long-term process of obtaining funds, as well as the implementation of geothermal projects, resulting, among others, from the the dual nature of geothermal heating plants, which are also mining plants. In order to stimulate the development of geothermal energy in Ukraine, it is necessary to amend the current regulations, which provide for the double taxation of such systems. For the use of groundwater for geothermal purposes, it is necessary to obtain permits resulting from both water and land law.

Analyzing the possibilities of using the thermal potential of geothermal waters of the Lviv region, it was found that:

1. In the initial phase, it is recommended to use a closed heating system with an independent connection to the heating system with "doublet" installations, which will allow the supply of thermal energy to the heating and hot water systems.
2. Due to the high mineralization and high corrosive activity of geothermal waters, it is necessary to solve the issue of their pre-treatment before using them in heat supply systems.
3. In order to increase the efficiency of thermal water intake, it is advisable to use combined geothermal systems in which heating systems are combined with recipients using geothermal heat throughout the year.

For an exemplary concept of heating public utility buildings in Poczesna, the following was proposed:

1. Monovalent solution with a heat pump – for a maximum pumping capacity of 80 m^3/h, the thermal power of the source is in the range of 495 to 576 kW, in this case it is required to use low-temperature heating (central heating system supply temperature max. 55°C). For the central heating supply water temperature 35°C a COP value of 6.8 can be obtained, while at 55°C the COP value would be 4.0.
2. If more power of the heating system is needed, a bivalent system with a conventional fuel boiler should be used.
3. An interesting solution may also be a dual-source heat pump, which has two evaporators in its circuit placed in parallel to each other. This solution enables the use of two independent lower heat sources.

Bibliography

Boguniewicz-Zabłocka, J. (2019) Analysis of the sustainable use of geothermal waters and future development possibilities. A case study from the Opole Region, Poland. *Sustainability*, 11, 6730.

Bujakowski, W. (2015) *Geological, environmental and technical factors affecting the design and operation of geothermal plants in Poland*. Cracow, Mineral and Energy Economy Research Institute of the Polish Academy of Sciences.

Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. *The European Green Deal* (2019) Brussels, European Commission.

Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. *Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality* (2021). Brussels, European Commission.

Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. *REPowerEU Plan* (2022). Brussels, European Commission.

Directive 2018/2001/EU of the European Parliament and of the Council of 11 December 2018 *on the promotion of the use of energy from renewable sources*. OJ L 328, 21.12.2018, p. 82.

Dolinskiy, A.A. & Khalatov, A.A. (2016) Geothermal energy: the electricity and thermal energy production. *Visnyk of the National Academy of Sciences of Ukraine*, 11, 76-86.

Dziadzio, P. (2021) Geothermal development support programs in Poland and their effects. *Przegląd Geologiczny*, 69(9), 549-558.

EGEC Geothermal Market Report 2021 (2022) Bruxelles, European Geothermal Energy Council.

Energy from renewable sources in 2020 (2022) Warsaw, Statistics Poland.

Flaksman, A.S. et al. (2020) Prospects for the development of alternative energy sources in the world energy. *IOP Conference Series: Earth and Environmental Science*, 723, 052040.

Hajto, M. (2021) The state of geothermal energy utilization in Europe and the world as of 2020. *Przegląd Geologiczny*, 69(9), 566-577.

Ivanov, Ye.A. et al. (2022) The geographical location, current state and forecasting of development of renewable energy facilities within Lviv region. *Journal of Geology, Geography and Geoecology*, 31, 59-70.

Kępińska, B. (2021) Geothermal energy applications in Poland in 2019-2021. *Przegląd Geologiczny*, 69(9), 559-565.

Lis, A. (2020) Renewable energy sources and rationalization of energy consumption in buildings as a way to reduce environmental pollution. *Heating, Ventilation and Sanitation*, 29(6), 264-271.

Lund, J.W., Huttrer, G.W. & Toth, A.N. (2022). Characteristics and trends in geothermal development and use, 1995 to 2020. *Geothermics*, 105, 102522.

Lymarenko, O. (2021) Effect of geothermal energy production on ecological Environment in Ukraine. *Journal of New Technologies in Environmental Science*, 5(1), 46-50.

Morozov, Y. & Barylo, A. (2019) Geothermal Energy Use. Country Update for Ukraine. In: *European Geothermal Congress*. Den Haag, EGEC.

Multi-year Program for the Development of the use of Geothermal Resources in Poland (2021) Warsaw, Ministry of Climate and Environment.

Noga, B. (2022) *How to use the potential of geothermal energy?* Warsaw, Multiconsult Polska.

Østergaard, P.A. et al. (2022) Renewable energy for sustainable development. *Renewable Energy*, 199, 1145-1152.

Renewable energy statistics 2022 (2022) Abu Dhabi, International Renewable Energy Agency.

Resolution of the Cabinet of Ministers of Ukraine of 18th August 2017 *Energy Strategy of Ukraine up to 2035. Security, energy efficiency, competitiveness*. OJ 2017 No. 605-r.

Romanov, D. & Leiss, B. (2022) Geothermal energy at different depths for district heating and cooling of existing and future building stock. *Renewable and Sustainable Energy Reviews*, 167, 112727.

Rudakov, D. & Inkin, O. (2019) An assessment of technical and economic feasibility to install geothermal well systems across Ukraine. *Geothermal Energy*, 7, 17.

Sekret, R., Lis, P. & Lis, A. (2009) Application of the low temerature geothermal energey sources to the heating of buldings. In: *Scientific Conference Building and Energ*y. Košice, Technical University of Košice, 69-72.

Sekret, R. & Pidzik, E. (2008) *Analysis of the possibility of using the 17-BN borehole for heating purposes of public utility buildings in Poczesna*. Czestochowa, Czestochowa University of Technology.

Shurchkova, Yu.A. (2019) Resource base for the development of geothermal energy in Ukraine. *The Problems of General Energy*, 3(58), 24-29.

Sowizdzal, A. (2018) Geothermal energy resources in Poland. Overview of the current state of knowledge. *Renewable and Sustainable Energy Reviews*, 82(3), 4020-4027.

The use of thermal water energy for the purposes of heat generation. Information on the inspection results (2022) Warsaw, Supreme Audit Office.

Yurkevych, Y., Savchenko, O. & Savchenko, Z. (2022) Prospects for development of geothermal energy in Lviv Region. *Energy Engineering and Control Systems*, 8(1), 1-6.

Zimny, J., Karch, M. & Szczotka, K. (2008) *Geothermal provinces and districts of Poland and potential water and energy resources contained therein according to Professor J. Sokołowski and others*. Kraków, Polish Geothermal Association.