

Article

Review of the Low-Enthalpy Lower Cretaceous Geothermal Energy Resources in Poland as an Environmentally Friendly Source of Heat for Urban District Heating Systems

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Received: 2 December 2019; Accepted: 4 March 2020; Published: 11 March 2020



Abstract: The paper presents a review of the geological and hydrogeological data of the Lower Cretaceous aquifer in the Polish Lowlands and discusses the possibilities for the utilisation of geothermal water resources in existing and new district heating systems. Based on experience related to the use of thermal waters in existing geothermal systems, and using data from the literature, assessments have been made of the energy and environmental effects of the application of low-enthalpy geothermal resources from the Lower Cretaceous aquifer as a source of heat for urban district heating systems. The authors concluded that the implementation of such solutions could result in the production of approximately 4 PJ of geothermal energy annually. To date, these resources have only been developed in three locations—Mszczonów, Uniejów and Poddębice—with the total amount of energy generated annually reaching 100 TJ/year. Similar district heating networks in 120 nearby localities have been also identified. Here, specified geological and hydrogeological conditions enable the extraction of heat from the investigated Lower Cretaceous aquifer, with the aim of using this for heating purposes. To achieve this goal, multiple measures are required, including the following: raising public awareness through appropriate education programmes aimed at the youngest school children; systemic, efficient energy management measures at the central, regional and local levels, and providing financial support and ensuring regulations and laws aimed at improving the development of geothermal resources.

Keywords: geothermal water; geothermal energy; earth and environmental sciences; district heating; sustainable development; environmental effect

1. Introduction

The need to reduce the energy shortfall as well as attempts by various countries to become independent from energy imports were significant driving forces behind the global development of geothermal resources in the 20th century. Since the early 1970s, the United Nations (UN) has played an important role in promoting the exploration and exploitation of these resources [1]. Since then, exploratory work has intensified in various parts of the world [2–5], and numerous innovative research and implementation projects have been undertaken, primarily to produce electricity and heat [6–9]. The global utilisation of geothermal potential is increasing, and new statistical data in this respect have been supplied by Bertani [10] and also Lund and Boyd [11], whose papers have been presented during

cyclic global conferences. The degree to which water or geothermal resources can be exploited and developed is closely related to local geological and hydrogeological conditions.

In Poland, geothermal energy use for heating purposes was initiated in the final decade of the 20th century [12,13]. The experimental stage of the first geothermal plant was commissioned by the Polish Academy of Sciences (MEERI PAS) in the Podhale region in 1992. Since that time, five other plants have been launched. Space heating is a key sector for geothermal energy [12]. This manner of utilising geothermal resources has a special role to play in the context of improving air quality in Poland [14,15]. Here, electricity and heat are produced primarily by burning fossil fuels. Approximately 80% of electricity is generated by conventional combined heating and power plants fired with hard coal or lignite [16]. This makes measures aimed at the utilisation of renewable energy resources even more important [17–19].

Geothermal energy resources in Poland exhibit heat flux values ranging from 20 to 90 mW/m², while geothermal gradients vary from 1 to 4 °C/100 m [20,21] and are associated with formations of various ages [3,15,22–26]. Among the most promising are sedimentary formations in the Polish Lowlands (part of the European Lowlands) which dominate the extensive area spanning from the Baltic Sea coast to the central and southern parts of the country (Figure 1). Their thickness is significant, and they include a considerable share of sandstones and carbonates which contain geothermal resources [21]. In 2018, only five geothermal space heating systems operated in those regions: in Pырzyce (since 1996), in Mszczonów (since 2000), in Uniejów (since 2001), in Stargard Szczeciński (since 2012, re-opened after closure in 2008) and in Poddębice (since 2012). In three of those systems (in Mszczonów, Uniejów and Poddębice), geothermal energy is produced using a Lower Cretaceous aquifer (Figure 1).

For this reason, it is extremely important to analyse geological and energetic conditions to assess the possibility of using geothermal resources from the Lower Cretaceous to cover the heat requirements of local cities in a large part of Poland.

In this paper, possibilities for the utilisation of Lower Cretaceous geothermal water resources in the Polish Lowlands in existing district heating systems are discussed. These discussions are based on data from the literature and experience related to the use of thermal waters in existing geothermal systems, including the installation operated by Geotermia Mazowiecka SA (joint stock company) localised in Mszczonów (Poland). The company has exploited geothermal water resources in a single-well arrangement for almost 20 years and has achieved favourable effects in terms of the amount of energy produced [22].

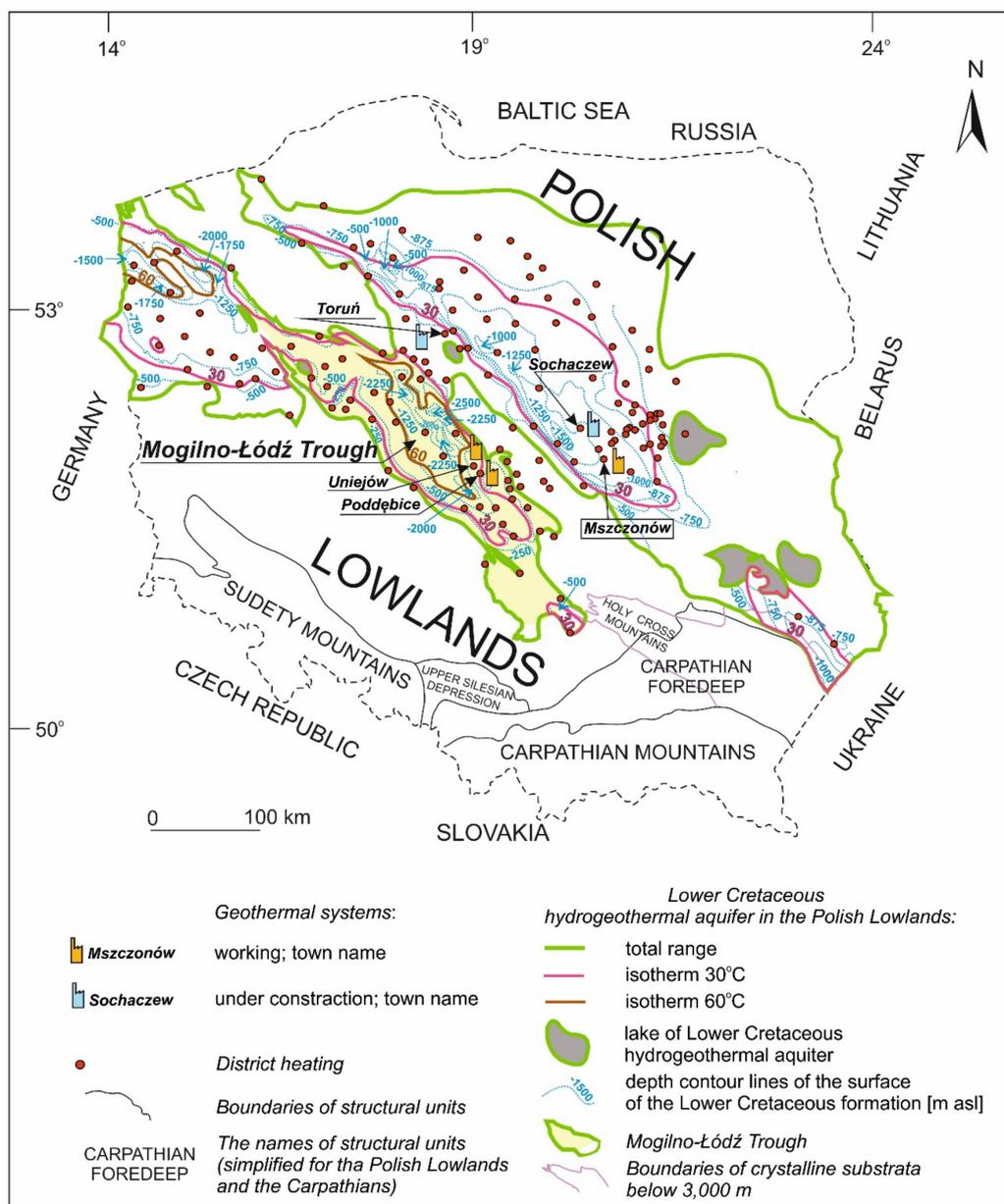


Figure 1. Locations with district heating systems being operated against the background of the boundaries of the Lower Cretaceous hydrogeothermal aquifer in the Polish Lowlands (based on [20,21]).

2. State of the Art of Lower Cretaceous Geothermal Water Use in Poland

2.1. Geological and Hydrological Characteristics of the Lower Cretaceous Aquifer

Lower Cretaceous aquifers in the Polish Lowlands are reservoir sandstones of the lower Valanginian and/or Aptian and Albian [20]. These form a complex of discontinuous, interspersed sandy, sandy-marly and sandy-mudstone layers with varying permeabilities and with hydraulic contact locally. The aquifer is hydraulically connected both to the underlying Jurassic aquifers and mainly to the underlying carbonate formations of the Upper Cretaceous [23]. The upper boundaries of the Lower Cretaceous formations lie at variable depths, ranging from approximately 250 m a.s.l. in their southern and northern parts to more than -2500 m a.s.l. in their central part [20,23]. Górecki et al. [23] determined that the greatest quantities of geothermal waters are held in the central part of the reservoir, within the so-called Mogilno-Łódź Trough, where the upper boundary of the Lower Cretaceous formations

usually lies at depths ranging from 400 to 1600 m. The thickness of aquiferous sandstones ranges from 10 to 100 m, but locally—mainly in the aforementioned central part of the aquifer—their thickness may exceed 100 or even 200 m, reaching up to 300 m in the area of Toruń. The effective porosity of Lower Cretaceous sandstones ranges from 3% to 45%, and most typical values are from 15% to 25%. Their permeability coefficient range is estimated at 11–4265 mD. Szczepański [24] states that the average value of the hydraulic conductivity for Lower Cretaceous deposits, determined on the basis of pumping tests, amounts to 5.41×10^{-5} m/s. In around half of the central part of the Mogilno-Łódź Trough, the hydraulic conductivity is the highest in relative terms and ranges from 4×10^{-4} to 1×10^{-3} m/s [20]. According to Górecki [20,23], in peripheral areas of the aquifer, low geothermal well flow rates of around $25 \text{ m}^3/\text{h}$ should be expected. High potential well flow rates of above $100 \text{ m}^3/\text{h}$ can be expected within the boundaries of the thickest central parts of the structure (the Kujawy-Pomeranian anticlinorium), reaching up to $200 \text{ m}^3/\text{h}$, and even $300 \text{ m}^3/\text{h}$ locally.

The temperature distribution in the upper layer of the Lower Cretaceous formations indicates that the dominant temperature range is from 20 to 40 °C [18]. In the Mogilno-Łódź Trough, water temperatures in the Lower Cretaceous range from just a few degrees above the freezing point (near outcrops) to over 80 °C.

The groundwater mineral content of the upper layers of the investigated aquifer differs between its lateral and central parts. In outcrop zones, the water mineral content drops below 2 g/L and increases with the direction of water flow and also with depth, reaching 20 g/L and even beyond 50 g/L locally. The less mineralised Lower Cretaceous groundwaters occur in the most promising areas of the geothermal aquifer, with mineral contents ranging from 1 to 10 g/L. The Mogilno-Łódź unit includes very thick rock formations within which freshwater flows were detected [27]. Based on geological drilling data, no mineralised water circulation in the axial zone of the synclinorium was detected down to a depth of about 1000–6000 m. In this part, fresh water locally occurred at the upper and lower layers of the Cretaceous aquifer, as well as saline water in the intermediate ones. Moreover, the Lower Cretaceous formation falls in a very extensive zone, where an intense water exchange takes place. This has been revealed to be important for the long-term exploitability of geothermal resources, especially in the case of geothermal water exploitation on the basis of a single production well.

2.1.1. Characteristics of Hydrogeothermal Conditions in the Mszczonów Area

Within the Warsaw Trough, fresh geothermal waters (of drinkable water quality) occur in Lower and Middle Albian glauconite sandstones and sands within the Lower Cretaceous aquifer complex; their mineral content is around 0.5–0.6 g/L [28,29]. The thickness of Lower Cretaceous formations in this area ranges from around 200 to 300 m, and in the well named Mszczonów IG-1, it amounts to 132.5 m [22]. The water-bearing strata exhibit porosities of around 18%; the values measured in the Mszczonów IG-1 well ranged from 7.28 to 33.09% [28,30]. Geothermal water is extracted from a depth interval of 1600 to 1700 m [22], based on a single productive well without the reinjection of cooled geothermal water to the reservoir. The temperature at the wellhead is around 42 °C [20,25]. The nominal geothermal water flux extracted from the Mszczonów IG-1 well averages $45 \text{ m}^3/\text{h}$ [22], with approved exploitable resources amounting to $60 \text{ m}^3/\text{h}$ [29,30].

2.1.2. Characteristics of Hydrogeothermal Conditions in the Uniejów Area

The reservoir rocks which contain geothermal waters in the area of Uniejów are Lower Cretaceous sandstones situated at depths ranging from 1982 to 2084 m b.g.l.; these waters are extracted using three wells: the Uniejów PIG/AGH-2 productive well, and two wells for reinjection, Uniejów PIG/AGH-1 and Uniejów IGH-1. Approved exploitable resources for the Uniejów PIG/AGH-2 well amount to $120 \text{ m}^3/\text{h}$, the water temperature at the wellhead reaches 69.2 °C and the static pressure under artesian conditions amounts to 2.6 bar [31]. The water exhibits an elevated mineral content ranging from 6.8 to 8.6 g/L [32]. The total thickness of the sandstone series from which water is extracted in Uniejów is around 120–150 m. The effective porosity of the sandstone ranges from 12% to 20%. The parallel

permeability in the uppermost layer ranges from several dozen to 2000 mD, sometimes reaching 3000 mD and in isolated cases up to 3600 mD [33,34].

2.1.3. Characteristics of Hydrogeothermal Conditions in the Poddębice Area

Poddębice is located around 15 km from Uniejów. Geothermal waters are extracted from depths ranging from 1950 to 2060 m b.g.l. using the single Poddębice GT-2 production well with a depth of 2101 m. The upper boundary of the Lower Cretaceous formation was reached at the depth of 1962 m b.g.l., while its lower boundary was reached at 2063 m b.g.l. The well capacity is 252 m³/h at the operating water level of 85.3 m b.g.l. [35,36], and the water temperature at the wellhead is 68.4 °C. As in Mszczonów, fresh water of the HCO₃-Na-Ca type is extracted in Poddębice (0.4 g/L), which clearly distinguishes this area from the central part of the Trough, where Na-Cl type waters prevail (e.g., in Uniejów). The Lower Cretaceous aquifer complex in Poddębice is built of grey, fine and medium-grained sandstones which formed on land during the Albian, Aptian and Barremian stages. The upper part of the aquifer exhibits better reservoir parameters with an effective porosity of around 17%. In the lower part of the profile, below 2027 m b.g.l., within Lower Cretaceous formations, lens inserts are present, quartz grains become smaller and the porosity drops to 14%. The permeability of the reservoir zone ranges from 87.98 to 1021 mD [36]. The thickness of the sandstone aquifer is 98 m.

2.2. Operating Geothermal Heating Installations Using Lower Cretaceous Waters

Within the Polish Lowlands, geothermal energy resources are only produced from the Lower Cretaceous aquifer in three locations (Mszczonów, Uniejów and Poddębice).

2.2.1. Characteristics of the Mszczonów Geothermal Installation

The diagram in Figure 2 shows the geothermal installation in Mszczonów. Within the District Heating (DH) system, two parts with different operating temperatures have been distinguished. The first DH system is the main one, and it operates temperatures ranging from 80/60 °C (supply/return temperature at outdoor temperature -20 °C). The second one is the smallest, and it operates between 70/50 °C (at outdoor temperature -20 °C). In both DH systems, heat pumps are used: in the main zone, an absorption heat pump with a thermal power of 2.7 MW (driven by 1.9 MW high-temperature natural gas boilers) operates, and a compression heat pump with a thermal power of 1 MW is used in the small circuit.

In addition to heat pumps, the geothermal system uses two boilers driven by high methane content natural gas from the grid with a capacity of 2.3 MW each. The total installed capacity of the heating system in Mszczonów is 8.5 MW, and the peak capacity actually used is the same as that in 2017, at 5.8 MW. The amount of energy sold to customers annually is around 40 TJ of which 15 TJ is geothermal energy. Once the energy accumulated in geothermal water has been used, its temperature decreases to 17 °C, leading to effective water cooling within the cascade system assisted by heat pumps. The difference in temperature between the extracted and cooled water (ΔT) here is ca. 25 °C. The effective geothermal power generated is around 1.3 MW. After treatment, around 40,000 m³ of cooled geothermal water is used annually as drinking water and for other household purposes. However, the largest recipient of geothermal water is the “Termy Mszczonowskie” recreational pool complex, for which 100,000 m³ of geothermal water is extracted annually, and it utilises both the water directly and the energy accumulated therein. The geothermal installation has covered building energy needs since 2000 [37]. During this operation period of slightly less than 20 years, no significant downtime was recorded. Geothermal heat is used in all apartment buildings managed by the housing cooperative in Mszczonów as well as in most public buildings, including the primary school, kindergarten, cultural centre, sports hall and clinic.

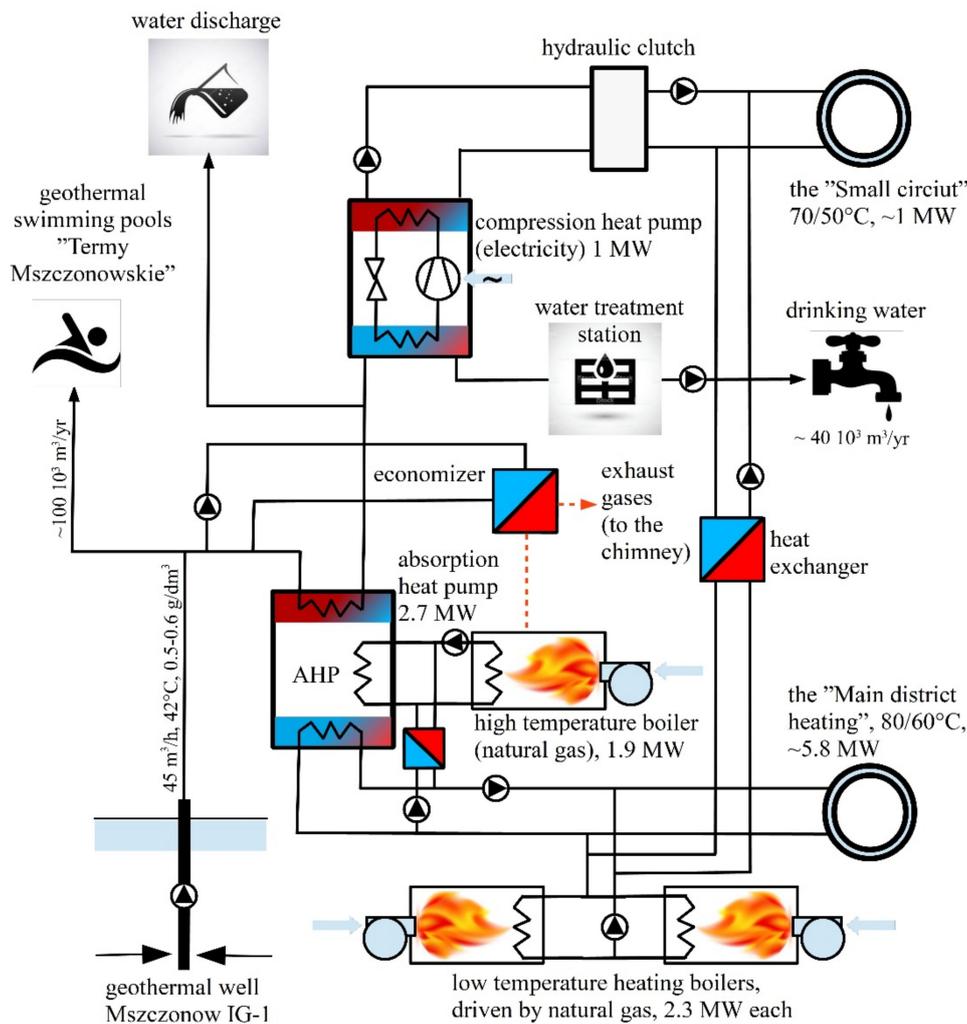


Figure 2. Diagram of the geothermal installation in Mszczonów.

2.2.2. Characteristics of the Uniejów Geothermal Installation

The total thermal capacity installed in Uniejów amounts to 7.4 MW, including 3.2 MW of geothermal capacity [38], 1.8 MW from the biomass-fired peak load boiler and 2.4 MW from oil-fired peak load boilers, which currently serve as a reserve. The district heating installation supplies heat to around 80% of buildings in Uniejów. The district heating network in Uniejów is 13 km long [39]. It is made of pre-insulated pipes suitable for 70/35 °C heating water parameters. The production of domestic hot water for both residential and public facilities is centralised. Two two-stage heat exchangers are responsible for supplying hot water [39]. Heat exchangers may also be located in the recipient's compact nodes. The district heating system covers public buildings, tourist and sport facilities (e.g., the football pitch complex), companies, residential buildings (around 70% of all residents within town limits), the thermal and swimming pool complex, hotels, conference centre and restaurants. The water within the system is supplied to customers by means of circulation pumps. These pumps operate under a continuous control system and have a combined capacity of 360 m³/h. The entire heating system is controlled and monitored by an integrated computer system which facilitates operation and reduces energy losses [39]. Annual geothermal energy sales are estimated at 40 TJ. Apart from the use of the water for district heating purposes, it is also utilised for balneological and recreational purposes in the "Termy Uniejów" pool complex.

2.2.3. Characteristics of the Poddębice Geothermal Installation

The capacity of the Poddębice geothermal heating system is about 5.4 MW [36]. The installation is operated by Geotermia Poddębice Sp. z o.o. (limited liability company). The extraction of geothermal water is conducted in a single-well arrangement without reinjection (cooled water is dumped in the Ner River). Geothermal water has a low mineral content and could be used as drinking water. To date, however, only heat has been extracted, with only a very small amount of water used as drinking water. The operating parameters observed are ~80/~55 °C [36]. The amount of heat sold to the users is estimated at 48 TJ/year.

3. Geothermics as Environmentally Friendly Heating Systems

3.1. Available Geothermal Resources

It should be noted that the extraction of geothermal water is based on the approved amount of exploitable resources under defined geological, hydrogeological, and structural conditions, which have been confirmed by hydrodynamic tests. This amount allows geothermal energy resources to be estimated, because water is the carrier of this energy. These values are variable, but—as has been indicated—the real capacities of Lower Cretaceous geothermal wells in Poland range from 25 m³/h in peripheral zones to as much as over 300 m³/h locally in the central parts of the aquifer. These capacities differ between the investigated DH networks (60 m³/h in Mszczonow, 120 m³/h in Uniejov, 252 m³/h in Poddębice), confirming a significant source of geothermal waters with wellhead temperatures of 42 °C, 69.2 °C and 68.4 °C, respectively.

The Lower Cretaceous aquifer covers an area of 127,872.60 km². The first scientists in Poland who estimated static and exploitable resources in Poland for the considered Lower Cretaceous were Górecki et al. [20]; the estimation of considered geothermal energy resources was based upon the EU standards [40,41].

Static resources are defined as the amount of thermal energy stored in rocks and within the free (gravitational) geothermal water which is present in pores, fissures or caverns of the hydrogeothermal level in question. The following formula was adopted for the calculation [20]:

$$E_{SR} = A \cdot m_p \cdot [(1 - p_e) \cdot p_s \cdot c_s + p_s + p_e \cdot p_w \cdot c_w] \cdot (T_s - T_o) \quad [J]$$

where

- m_p —cumulative thickness of groundwater horizons in the reservoir [m];
- p_e —effective porosity [-];
- T_s —temperature at the top surface of the groundwater reservoir [°C];
- T_o —mean annual temperature at the Earth's surface [°C];
- p_s and p_w —mean density of the rock framework and water, respectively [kg/m³];
- c_s and c_w —mean specific heat of the rock framework and water, respectively [J/kg °C];
- A —area of the calculation block [m²].

The estimated static resources accumulated in the Lower Cretaceous waters and rocks are 4.23·10²⁰ J.

The exploitable resources (safe yield) are understood as the amount of free (gravitational) geothermal water within the hydrogeothermal level, but without indicating the detailed locations and technical and economic parameters of water extraction. The exploitable resources are expressed in m³/h at relevant drawdown, and afterwards they are recalculated to J/year. The exploitable resources are assessed based upon the results of all hydrogeothermal studies and tests made in exploration and production wells mentioned in Section 2 and are determined for a single production well or for a cluster of wells. Exploitable resources (safe yield), which amount to 3.95·10¹⁷ J per year, are found

within the area of 24,235.84 km²; i.e., 18.95% of the total area of the Lower Cretaceous aquifer within the Polish Lowlands [42].

3.2. Conditions for Geothermal Installations

To date, only three geothermal installations have been commissioned which produce heat from Lower Cretaceous geothermal waters; one such installation, in Sochaczew, is under construction (Figure 1). However, as indicated in Figure 1, there are about 120 towns and cities within the boundaries of the geothermal aquifer in question, in which district heating network systems were constructed in the past to supply residents with heat and hot water. These systems use heat generated from conventional energy sources. Slightly less than 100 towns and cities are located within the boundaries of the identified geothermal water resources, where the temperatures of the uppermost layer of the Lower Cretaceous reservoir are around 30 °C. Moreover, about a dozen of these are located where waters have the same values of Poddębice and Uniejów reservoirs. This demonstrates the huge potential of low-enthalpy geothermal energy resources as an alternative and environmentally friendly source of heat which will improve air quality and the residents' living conditions.

In case of the Lower Cretaceous geothermal resources considered, it was recognised that the temperature at the wellhead (documented as 71–41 °C) is 50 °C on average and cools to 20 °C. The water flow (documented at 295–60 m³/h) is 150 m³/h on average. The average installed capacity utilization factor is 0.3 (for heating and domestic water). Thus, one installation from 100 potential locations is able to generate about 40 TJ/year of energy. Assuming theoretically the use of this energy in the 100 mentioned locations, the potential geothermal energy resources generated can be estimated at 4 PJ/year. That is why the implementation of geothermal heating solutions in the locations is so important.

Typical operating temperatures for district heating systems, used for heating of residential buildings in Poland can be summarized as follows:

- 130/65 °C (where the first temperature corresponds to the supply temperature, while the second to the return temperature) for large district heating systems;
- 90/70 °C for small local systems.

The authors' experience has shown that the above parameters are often excessive; examples of operating geothermal installations in Mszczonów (DH network temperatures between 50 and 70 °C), in Uniejów (70/35 °C network parameters) or in Poddębice (80/55 °C network parameters) demonstrate that they could be operated at lower temperatures, allowing for greater efficiency. In many cases, this requires a thermal efficiency improvement of some buildings, aimed at obtaining the requested energy needs. In the summer period, temperature parameters of the district heating network are usually around 65/30 °C. The temperature of the supplied hot water must range from 55 to 60 °C according to the Journal of Laws [43]. Since the temperatures of the Lower Cretaceous horizon range from 20 to 80 °C, the use of heat pumps and peak load boilers in installations could be more profitable in many cases. Regarding peak load boilers, an environmentally friendly solution is the construction of a system integrated with biomass-fired boilers, since a significant amount of the available biomass resources in Poland—integrated systems consisting of biomass-fired boilers—represents an environmentally friendly solution [44]. Such a solution was implemented at Geotermia Uniejów.

3.3. Important Environmental Aspects

The use of geothermal energy in the installations described in this paper contributes to improving air quality locally and enables the consumption of conventional energy carriers to be reduced. In the case of Mszczonów, reductions in pollutant emissions into the atmosphere due to the use of geothermal energy are estimated as follows [22]:

- A total of 48 kg/year SO₂ for natural gas as a reference fuel and 23.8 × 10³ kg/year for hard coal;

- In the case of CO₂, emissions of 1200×10^3 kg/year for natural gas and 3027×10^3 kg/year for hard coal are avoided.

The reduction in emissions in the case of Poddębice is estimated as follows:

- In total, 35×10^3 kg/year SO₂ for coal as a reference fuel;
- In total, 5000×10^3 kg/year CO₂ for coal as a reference fuel, and 2900×10^3 kg/year CO₂ for natural gas as a reference fuel.

The reduction of pollutants estimated above was calculated based on factors suitable for selected fuels and types of energy sources. The values are provided by the National Centre for Emissions Management (KOBiZE). The values of emission factors are summarised in Table 1.

Table 1. Emission factors for selected fuels and types of energy sources [45].

Pollutant Name	Hard Coal, Heating Power P in the Range $500 \text{ kW} < P \leq 5 \text{ MW}$, Natural Chimney Draft [g/10 ³ kg]	Natural Gas, Heating Power P in the Range of $500 \text{ kW} < P \leq 5 \text{ MW}$ [g/m ³]
SO _x /SO ₂	16,000 s_{hc}	0.002 s_{ng}
NO _x /NO ₂	1000	1.75
CO	45,000	0.24
CO ₂	2106	2000
Total suspended particulates (TSP)	1500 A_{hc}	0.0005
B(A)P	14	0

where s_{hc} is the hard coal sulfur content [%] (the typical value for Polish coal is assumed to be 1%), s_{ng} is the natural gas total sulfur content [mg/m³] (the typical value for Polish network natural gas is assumed to be 40 mg/m³), and A_{hc} is the hard coal ash content [%] (the typical value for Polish good quality hard coal is assumed to be 10%). Assumed common values of the gross caloric values of fuels are as follows: hard coal, 27 MJ/kg; natural gas (high methane content—the E-type natural gas according to the national nomenclature), 35.5 MJ/m³.

The reduction of pollutant emissions in Poddębice is greater than that achieved in Mszczonów despite the similar amounts of energy produced by the installations. This is due to the higher temperature of the geothermal water extracted in Poddębice and to the operational phase without the use of heat pumps, as well as to the very short operating time of peak load boilers.

In the case of Uniejów, reductions in emissions are estimated (based on Table 1) at ca. 28 Mg/year SO₂ and 4188 Mg/year CO₂ for coal as a reference fuel, and 2418 Mg/year CO₂ for natural gas as a reference fuel.

Given the fact that around 80% of thermal energy in Poland is produced by burning hard coal [16] and the energy obtained from natural gas accounts for less than 8% [16], the reductions resulting from the use of geothermal energy should be calculated in comparison to the emission values typical of hard coal.

Improving air quality and fighting smog are possible through systemic, efficient energy management measures at the central, regional and local levels. According to [46], these measures must also be supported by appropriate financial support as well as relevant regulations and laws. Examples of good practice in this area may be found in the experience of France and Germany [47].

After Bulgaria, Poland is one of the top ten countries in Europe with the most polluted air [48,49]. During air quality monitoring conducted at 123 urban and suburban measurement stations in Poland with measurement series covering at least 85% of days in the year, air quality standards were exceeded more than 75 times at 77% of measurement stations (Central Inspectorate of Environmental Protection

2016). Poor air quality is mostly caused by the burning of fossil fuels, which mainly comprises coal in small district boilers or at the users' homes.

3.4. Important Economic Aspects

Geothermal energy in the economic sphere (the costs of energy production) is often compared with coal in Poland. The costs of energy production based on coal are usually lower than the costs of energy from geothermal energy. Current trends are aimed at the gradual elimination of coal-based energy sources; their transformation into other energy carriers seems to be assured in Poland, at least in terms of small and medium heat sources (up to several MW). Geothermal energy represents a good alternative in this area; however, the high level of investment expenditure affects the cost of energy production. Other energy carriers require higher operating costs. Reservoir conditions and district heating demand allow us to determine the total cost of energy production without heat pumps based on geothermal energy, which can be compared with natural gas and even coal [50].

4. Prospectives for Geothermal Energy in Poland

Promoting the use of renewable energy sources is among the key mechanisms which can be used to disseminate environmentally friendly energy solutions. Another important factor is raising public awareness through appropriate education programmes aimed at the youngest school children [51], as well as through projects whose stakeholders are adults [46,49]. Such measures have been taken at all of the locations analysed. In Mszczonów, Uniejów and Poddebice, the entrepreneurs who operate geothermal installations focus not only on providing environmentally friendly energy and on the local environment, but also on educating both residents and tourists who visit these towns. Geothermal plants can be visited on guided tours, during which the main elements of the geothermal system are presented and the value of investing in geothermal energy is discussed. Companies participate also in numerous international and local scientific projects, promoting the use of geothermal energy in Poland. In Uniejów, a series of comic books (“Welcome to the Thermal Town of Uniejów” and “Uniejów Spa—in Harmony with Nature”) devoted to geothermal energy are offered to the youngest visitors; i.e., primary school students. Additionally, to raise the environmental awareness of inhabitants of the Łódź Province, Geotermia Uniejów runs an educational project entitled “Geothermal Energy with Class”. Using a grant from the Provincial Fund for Environmental Protection and Water Management in Łódź, it publishes educational and promotional materials (e.g., the “Geothermal Wealth” brochure) and holds a series of lectures for school students entitled “the utilisation of geothermal waters in Uniejów Spa” [39]. These lectures are given at 45 schools in the city of Łódź and in all districts within the province. The effects of this educational campaign can be assessed during the school competition “Why and how to save water?”, in which the reward for winners is a trip to Uniejów [39].

5. Conclusions

The amount of available energy resources globally varies depending on multiple geological and hydrogeological parameters. Given the current level of technological development and global experience, it is obvious that the use of low-temperature resources may be of significant economic and environmental importance. To date, these resources have only been developed in three locations, with the total amount of energy generated annually reaching 100 TJ/year. Similar infrastructure conditions as those in existing district heating networks have been identified in around 120 towns and cities whose location enables the extraction of heat from the aquifer in question for space heating purposes. The implementation of such solutions could result in the production of 4 PJ of geothermal energy annually. In order to achieve this goal, multiple measures are required, including the following:

- Raising public awareness through appropriate education programmes aimed at the youngest school children;
- Systemic, efficient energy management measures at the central, regional and local levels;

- Providing financial support and ensuring that regulations and laws are conducive to the development of geothermal resources.

The environmental impact in Poddębice is slightly better than that achieved in Mszczonów despite the similar amounts of energy produced by the installations in Mszczonów and in Poddębice. This is due to the higher temperature of the geothermal water extracted in Poddębice and the fact that the installation there operates without the use of heat pumps; furthermore, the operating time of the peak load boilers is also very short.

We hope that our considerations regarding the development of geothermal heating systems based on the use of Lower Cretaceous water potential in Poland will be reflected in investment projects. This solution would undoubtedly help to improve air quality in many parts of the country.

Author Contributions: Conceptualization, B.T. and W.B.; methodology, B.T. and L.P.; software, L.P.; validation, B.T. and L.P.; formal analysis, B.T.; investigation, W.B.; resources, B.T. and B.B.; data curation, B.T., M.D. and L.P.; writing—original draft preparation, B.T. and L.P.; writing—review and editing, B.T.; visualization, L.P., M.D. and B.B. All authors have read and agreed to the published version of the manuscript

Funding: This research was partly funded by the Polish National Centre for Research and Development (Project No. POLTUR2/1/2017) and AGH Project No. 16.16.140.315.

Conflicts of Interest: The authors declare no conflicts of interest.

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