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Main Reservoir, Production and Energetic Aspects of Geothermal Aquifer Exploited for District Heating and Other Uses in Poddębice Town, Poland

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ABSTRACT

The paper presents main reservoir, production and energetic parameters, as well as some issues and conditions of efficient sustainable geothermal water and energy production for the needs of current and future district heating and other uses in Poddębice, Poland. These topics were elaborated in the framework of the EEA project 'Geothermal utilization potential in Poland – the town of Poddębice'. It was the first project dedicated to geothermal energy in Poland funded by the EEA financial mechanism. Poddębice town has both prospective geothermal water resources and ambitious plans of their use in municipal district heating and for wide range of other applications. They will contribute to low-emission heating, improvement the living conditions and modern local economy. Poddębice is a good study case for other localities in Poland with geothermal resources prospective for heating and other uses. An insight into the reservoir, exploitation and energetic analyses, outcomes as well as recommendations that resulted from common research for Poddębice and Poland conducted by Icelandic and Polish experts involved in the project are given.

1. INTRODUCTION

District heating is the most important sector for geothermal energy development is Poland. This is because of several reasons, e.g. urgent need to implement low-emission heating, combat the climate changes, improving leaving conditions, increasing the use of renewable energy sources. The country has both geothermal resources prospective for such type of uses and significant number of operating district heating systems. To some of them geothermal heat can be introduced and replace, partly at least, fossil fuels (mostly coal). So far six geothermal district heating systems (geoDH) have been operating in the country. Among them is the geoDH in Poddębice (central Poland). The paper present selected outcomes of geothermal research and pre-feasibility study conducted for that town by Icelandic and Polish experts in 2017 in a framework of the bilateral project "Geothermal utilization potential in Poland – the town of Poddębice" supported by the European Economic Area and Norwegian Financial Mechanism 2009–2014 (www.eeagrants.agh.edu.pl). The results and recommendations are important for Poddębice, other geoDHs, as well as some next installations expected to be launched in coming years (as a result of state support program aimed at introducing geothermal into several next district heating systems).

2. GEOTHERMAL AQUIFER IN PODDĘBICE – BASIC CHARACTERISTICS

The Town of Poddębice is located in the central part of Poland (Fig. 1). From geostructural point of view it is situated within Permian–Mesozoic Mogilno–Łódź trough – part of large the Szczecin–Łódź–Miechów trough, extending from the Fore–Sudetic monocline to the mid–Poland swell. From the east the Łódź basin borders with Kujawy swell – a tectonic unit with strongly developed salt tectonics. The basin touches the Mogilno through from the NW.
The geological structure of the Łódź basin is complex, connected mainly to salt tectonics. That phenomenon caused local disconformities, rapid changes of sediments' thickness, especially in the proximity of anticline structures that were formed during the Upper Triassic, Upper Cretaceous and Tertiary periods. The creation of anticlinal structures in the Poddębice area was caused by underlying salt layers' tectonic dislocations that used to be active during the sedimentation of Mesozoic rocks. The incomplete development and small thickness of surrounding sediments (e.g. Lower Cretaceous formations) was caused by regional salt structures which penetrated or uplifted those sediments (e.g. salt anticlines of Koło and Poddębice; Fig. 2).

Geothermal aquifer – the subject of exploitation in Poddębice – is hosted by the Lower Cretaceous sandstones (Albian, Aptian and Barremian stages). They are located at a depth interval of 1962–2063 m beneath the surface in the Poddębice GT-2 well, with claystone interbed in the interval of 2001–2004 m. The top part of the sandstone (above the clay layer) contains a rock skeleton of high purity with locally occurring glauconite, and is characterised by better reservoir parameters (porosity 17.0%). In the lower part of the profile, that is deeper than 2027 m beneath the surface, interlayers of mudstone are present, quartz grains are smaller, whilst porosity is of about 14%. The clay content in the footwall of the sandstone reaches a level of 23%. The thickness of the sandstone layers is 98 m (including the clay layer of 3 m thickness).
Geothermal water is under artesian pressure – a static water table occurs at 26 m above the surface. The top part of the water-bearing complex (up to the surface) is composed of grey, fine-grained, comparatively pure sandstones aged at Lower Albian.

An intercalation of fuscous claystone and mudstone is present in the 2001–2004 m depth interval. grey fine-grained sandstones occur at a lower level, deeper than 2027 m beneath the surface – with a scant amount of mudstones.



Figure 1: Location of the Poddębice geothermal project in Poland and in Europe

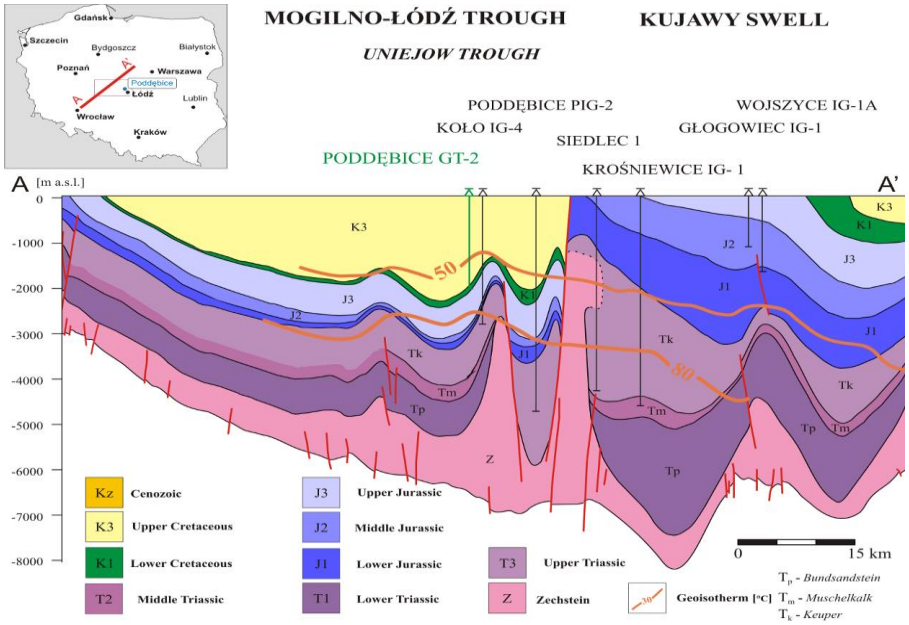


Figure 2: Geological cross-section through the Polish Lowlands with location of wells in Poddębice area (based on Górecki [sc. ed.] & Hajto et al., 2006)

Quartz strongly dominates mineralogical composition of sandstones (95% of the detritus volume). Accessory components are particles of silica rocks, feldspar, glauconite and clay minerals. Sandstones contain mainly a siliceous cement with the minor addition of secondary carbonate or clay (illite) cement. Quartz grains are rounded and well-sorted, their size is 0.2–1.3 mm.
The Lower Cretaceous sandstones are rather homogenous. Aquifer horizons are characterized by high porosity (14–17%) and permeability (87.98–1021.10 mD). The analysis of the core samples shows that the content of carbonates (components of cement) – calcite and dolomite is minor; in a majority of the samples lower than 2% of calcite and 1% of dolomite. Amount of clay fraction, in the bottom (Barremian sandstones) reaching 23%, increases with depth in sandstones. An impermeable Hauterivian formation occurs from the depth of 2063 m beneath the surface (mudstones and claystones) which underlies the Lower Cretaceous aquifer. Sealing beds transit into Upper Jurassic carbonates at a depth of 2070 m.

As to chemical composition of geothermal water discharged by Poddębice GT-2 well, it is a 0.043% water containing mainly sodium bicarbonate and calcium hydrogen carbonate. Neither potentially toxic ingredients of natural origin nor indicators of contamination from the external environment were indicated. Water is characterized by softness (total hardness 98 mg/L $CaCO_3$), neutrality (pH = 7) and a low iron content (0.35 mg/L). According to qualitative analysis from 2010 it contains some gasses like CO_2, N_2 and minor content of methane and ethane. Approved exploitable reserves of the Poddębice GT-2 well are Q=252 m^3/h at a dynamic water table (in heated up well) at a depth of 85.3 m b.g.l. and the water wellhead temperature is 68.4°C. The mining area equal to the concession area amounts to 7.18 km^2 (Table 1).

More details on geology, geothermal, reservoir, exploitation features and parameters of Poddębice area are given in other publications (e.g. www.eeagrants.agh.edu.pl; Kępińska et al., 2017a, 2017b, 2017c).

Table 1: Poddębice GT-2 well – main information on approved water reserves based on 2014 tests (acc. to Annex to Hydrogeological Documentation, 2015)

Well name	Approved exploitation water reserves	Wellhead temperature for approved water flow rate	Static water level in a heated-up well	Dynamic water level in a heated-up well for approved water flow rate	Water type Mineralization
Poddębice GT-2	252 m^3/h	T=68.4°C Q=252 m^3/h	h = 145.5 m a.s.l.	H = 85.3 m b.g.l. Q=252 m^3/h	HCO_3-Na-Ca 432 mg/L
Mining area = 7.18 km^2					

3. GEOTHERMAL ENERGY AND WATER USES IN PODDĘBICE – CURRENT STATE AND FUTURE PLANS

Before 2013 the main space heating sources in Poddębice town were local boiler plants fired by natural gas, fuel oil and coal. They supplied multi-family houses, single-family and own boiler rooms in public buildings. The situation changed when the Poddębice GT-2 well was drilled in 2009–2010 (Fig. 3) and in 2012–2013 a 10 MW_{th} geothermal heating plant and warm water pipelines were built. Heat supply to the consumers (all public facilities and multi-family residential buildings) started in February 2013. In 2018 geothermal heat production by Geotermia Poddębice Ltd was about 64 TJ.

Nearly 100% of all users connected to heating grid (100 buildings, 6,000 people), i.e. 50% of the town area, have been supplied by geoDH. The rest of the heat demand (including institutions, service and production establishments) was covered by individual sources. Total length of heating transmition network, distribution network and grid connections is over 12 km. Geothermal district heating in Poddębice is 'the youngest' among six such plants that have been operating in Poland so far.

The closure of 3 local boiler stations (now serving as peak and reserve sources) contributed to air protection by reducing gases and dusts' emission. The plant in Poddębice is one of the 6th geoDHs in Poland. Except for district heating geothermal water and energy had been used for balneotherapy and rehabilitation (in a regional hospital), swimming pools and for drinking (the latter on a limited scale). The total heat demand in the town of Poddębice is ca. 17 MW_{th}. So far geothermal energy covers 5 MW_{th} of it. Further geoDH's development plan (version minimum) assumes that in the coming years 2 MW_{th} will be covered by a heat pump (based on geothermal) and ca. 3–5 MW_{th} by gas peak boiler (reserve one).

Along with extension of geoDH system other geothermal uses are planned in that town. This requires that the second stage of the geothermal water use (with heat pump considered) needs to be developed, what will allow the geothermal resources in Poddębice to be managed more effectively. Planned future geothermal targets are eg.: extension of district heating networks with grid connections and nodes of a total length of 34.2 km; extension of the heat source by adding heat pump/s with ca. 14 MW_{th} capacity; extension of heat source by the second stage of heat extraction from geothermal water from 50 to 35–30°C; development of the geothermal heating grid; connection to the nearby Zoo Safari; construction of the graduating towers as successive degrees of heat extraction from geothermal water and its further cooling (to introduce it into municipal water supply system); aquaculture, agriculture development. The sketch of current and planned geothermal energy and water uses in Poddębice is shown on Fig. 4. Some selected hydrogeological and energetic considerations in the view of sustainable and efficient current and future geothermal uses development in Poddębice are presented in next chapters.



Figure 3: Geothermal wellhead Poddębice GT-2 and heating station in the background (source: Geotermia Poddębice Ltd)

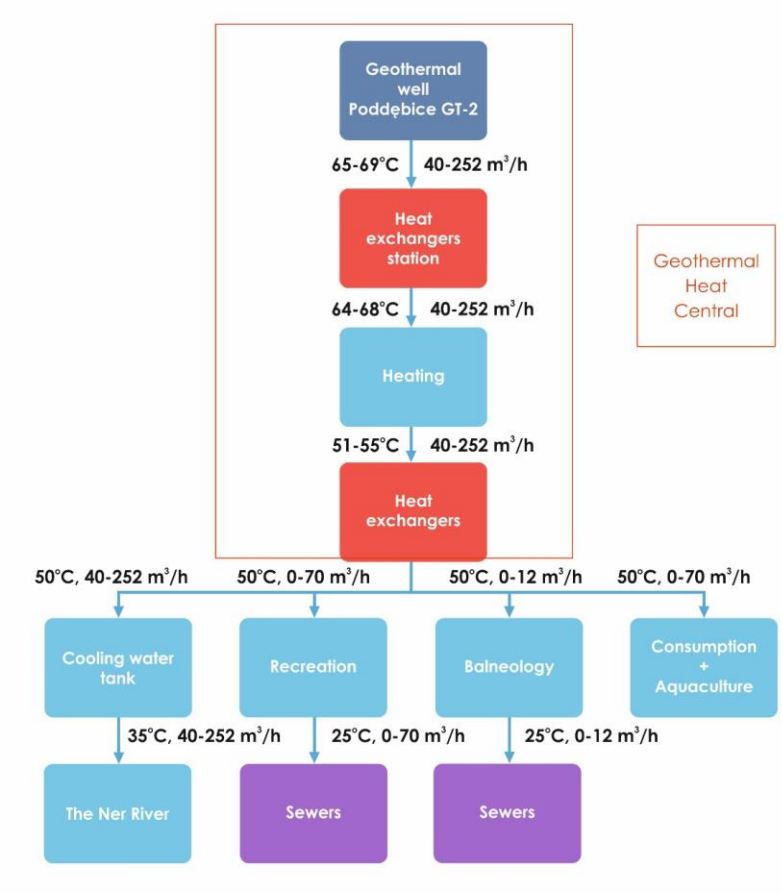


Figure 4: A sketch showing current and planned geothermal energy and water uses in Poddębice (source: Geotermia Poddębice Ltd)

4. SIMULATION OF THE WATER LEVEL DURING THE PRODUCTION OF GEOTHERMAL WATER BY THE PODDĘBICE GT-2 WELL – A LUMPED PARAMETER MODELING

Axelsson (1989) presents the theoretical background for lumped parameter modelling of pressure change (water level) as a response to production from geothermal systems. During the last three decades such models have been used quite successfully to model, and manage, geothermal systems worldwide (Axelsson et al., 2005). The lumped parameter models consist of several tanks and resistors, which simulate the fluid storage capacity and flow resistance, respectively, of geothermal systems. The pressure response of the models can, therefore, be used to simulate the pressure response of such systems, as well as other hydrological underground systems.

In the case of the Poddębice geothermal aquifer, the input data for the model came from the monitoring of the main parameters of the geothermal water produced by the Poddębice GT-2 well, monitoring at some key points of the surface geothermal system in the period from 2012–2016 (the initial period after drilling the well and the start of its production). The data and information were provided by Geotermia Poddębice Ltd.

It has become customary to simulate pressure or water level data from geothermal systems with both open and closed models (Fig. 5). The open models simulate systems where production and recharge eventually equilibrate (optimistic), while closed models have no recharge (conservative). At a constant rate of production, the pressure declines continuously in the latter. Such models are typically applied when one has pressure /water level monitoring data from one or even few wells and can be applied when only a short production history is available (as in case of the Poddębice GT-2 well).

There was little visual difference between the open and closed model. The data is rather noisy and the model does not follow the major jumps well but as we can see from Figure 5 it roughly manages to reproduce the gross trend of the water level data. The best models (open and closed systems) were used to do 5-years' predictions for three different production scenarios: (1) 20 kg/s, (2) 30 kg/s and (3) 70 kg/s – 252 m^3/h – i.e. approved water reserves planned to be fully used.

In the 3rd production scenario shown in Fig. 6: 70 kg/s (252 m^3/h), the average water level for the open system will quickly settle to 40 m, while the water level for the closed system will go below 60 m in the 5th winter (i.e. during heating seasons).

According to regional hydrogeological recognition of Poddębice area, the well supply derives most probably from the eastern direction. The recharge area most probably is related to outcrops of the Lower Cretaceous formation located ca. 15 km in the

east of Poddębice GT-2 well. No or a negligible low hydraulic connection exists between the overlying Upper Cretaceous sediments (caprock).

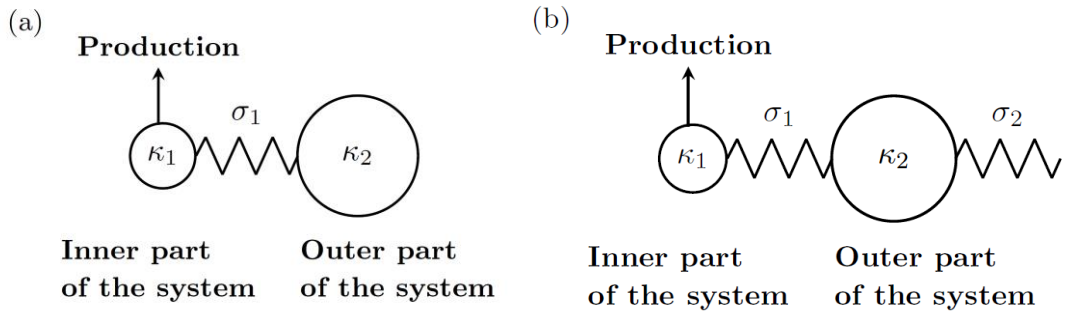


Figure 5: Schematic pictures of (a) closed two tanks model and (b) open two tanks model which are used to model the reservoir system. Both systems are composed of two tanks, that represents the inner and outer part of the geothermal system. The connection between the tanks is represented with a flow resistance. For the open two tanks system the outer part is connected to an infinite reservoir

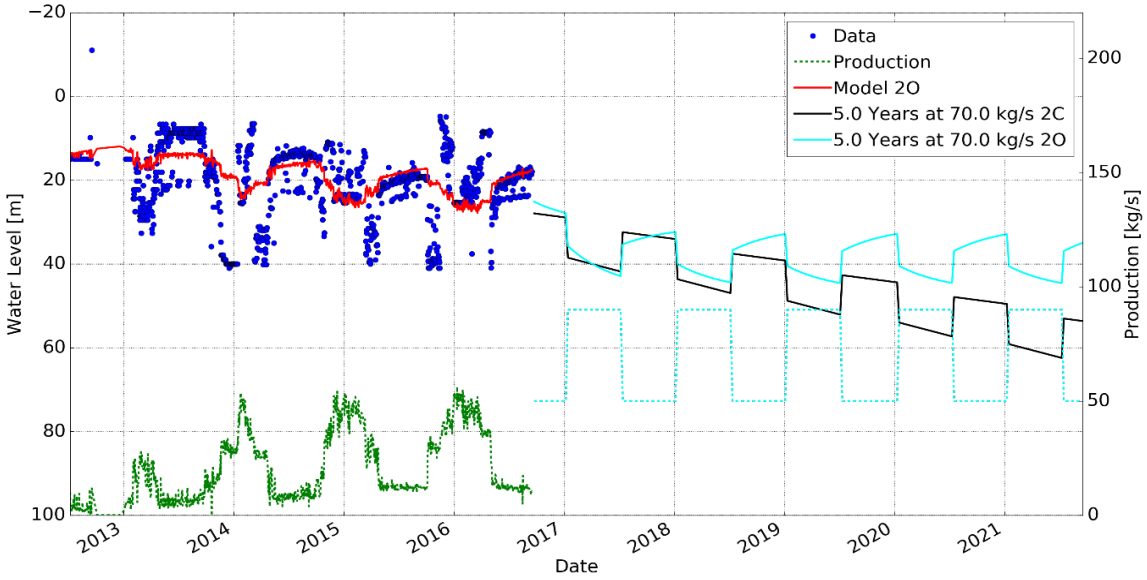


Figure 6: Projection of the water level for the system in response to periodic step like production. The production has a yearly average of 70 kg/s and is shown with a dashed black line. The projected water level is shown with a solid black line. 2O – open tanks' reservoir model, 2C – closed tanks' reservoir model

The main conclusions that can be drawn for these simulations are that the previous production was not aggressive, and the water level was not decreasing. Since the production is not aggressive it is difficult to predict the water level/pressure changes in the system, but these predictions shown here are indications of what can happen if the production is increased. However, the short production history implied short reliable predictions for the future (2017–2022). Further modeling based on current production data is recommended.

In addition – taking the geological and hydrogeological situation of the Poddębice area into account, one may expect that the considered geothermal aquifer can be placed somewhere between 2O and 2C models. This suggestion is, among others, due to the tectonics of its area (see cross-section in the former chapter) where both continuous and discontinuous forms (faults) are present. They resulted from halotectonics (i.e. tectonics caused by unstable salt layers and structures) as well as other tectonic events. Therefore, locally they can modify (or act as a kind of barrier) and affect recharge and low conditions even if the structures and aquifer itself are generally of an open character in a regional scale.

Geological and hydrogeological circumstances are important for the interpretation of the current simulation, future predictions and recommendations (as to optimal production rates, injection/no injection of spent water, a need for proper further monitoring, measurements, etc.).

The interpretation and prediction for next several years of the water level in Poddębice GT-2 well's simulation shall take into account and indicate that – even in the case of a forecasted stable water level in the 2O model – some decrease of water level / pressure may appear. It is also recommended to repeat the water level simulation using the Lumpfit program in course of further geothermal water production when more monitoring data are available thus more information on real geothermal reservoir's response for long-term water production.

Further well tests and interference tests should be performed and more advanced reservoir and production model of Poddębice aquifer and its response for long-term production / exploitation specially in the view of planned extension of geoDH system and development of several other types of direct uses (as given in chapter 3). This shall be done by applying e.g. the advanced numerical code TOUGH (international standard for geothermal reservoir modelling and simulation): with all the information already available (geology, hydrogeology, production, well parameters, etc.) it can be used to simulate the natural state and the production history of geothermal aquifer in Poddębice.

5. GEOTHERMAL DISTRICT HEATING

The geothermal district heating in Poddębice has been in operation for several years, using hot geothermal water from production well Poddębice GT-2, which was drilled in 2010. The current capacity of the heating system is around 4-5 MW_{th}, with an additional peak load boiler capacity of around 2 MW_{th}. The future plans of Geotermia Poddębice Ltd are to expand the system to all of Poddębice, with a total estimated peak load of 18 MW_{th}.

The Poddębice GT-2 well has been in operation since 2013. The production rate (2016–2017) was 190 m^3/hr during winter peak load. A 110 kW_e downhole pump is installed at a depth of 90 meters below the ground. The pump has so far been operated at around 50% capacity at max. flow, so it can easily deliver a higher flow rate for the proposed increase from 190 to ca. 250 m^3/hr, which is the planned increase in the near future. No long-term drawdown of water in the reservoir has so far been observed, so there appears to be no need for water re-injection to the reservoir for now. This may, however, become necessary if the flow rate is increased in the future expansion of the system to 18 MW_{th} if most of the energy comes from geothermal water.

5.1 Heat Central and Proposed Peak Load Installation

The geothermal Heat Central is equipped with 2 heat exchangers (2 x 5 MW_{th} capacity) and 3 circulation pumps. It has been in operation since 2012. The supply temperature to the distribution system is approx. 60–65°C and the flow rate is 220 m^3/hr during peak load. Return geothermal water from heat exchangers (approx. 47–52°C) is partly used in the nearby swimming pool but most of it is discharged to a large cooling pond beside the station, where it is cooled down to around 35°C. The expansion of the sub-station to approx. double the current size and to add a heat pump, which extracts heat from the 50°C return geothermal fluid and heats the supply water from 65°C to 75–80°C during coldest days is planned.

5.2 Distribution System and Current Peak Load Installations

The distribution system is made entirely from pre-insulated steel piping. It branches to the north and south of Poddębice, each half is 2xDN 250 mm of the main pipeline, each transporting 100–120 m^3/h. The size of the piping can easily transport around 2–3 times higher flowrate. Currently, around 12 km of piping have been installed, future expansion assumes another 33 km. There are currently 3 peak load boilers in the district heating system, each delivering around 1 MW_{th}. The plan is to disconnect these installations from the system in the future, when the heat pump has been installed in the Heat Central.

Most of the users have heat exchangers in their house connections, which lowers the supply temperature by a couple of degrees. Radiators were earlier designed for higher supply temperatures (90°C supply, 70°C return) than nowadays. Radiators have since been retrofitted, allowing for lower district heating system temperatures.

5.3 Heat Demand

The population of Poddębice is approximately 7900 people. The average number of people per household is estimated to be 2.7 prs/household. This corresponds to approx. 2930 households, each with average size estimated to be around 100 m^2. With -20°C design load outside temperature, the heating load is estimated to be 60 W/m^2 in each household, so the total peak load in all of Poddębice is estimated to be 17.56 MW_{th} (2930 apt 100 m^2/apt 60 W/m^2). This corresponds quite well to the estimated 18 MW_{th} total heat demand in the town. Other potential large users in the system are the Safari Park in Borysew village and Sports' Centre in the outskirts of Poddębice.

5.3.1 Measured Heat Load 2014-2016

The following is based on a data log from Geotermia Poddębice, which consists of daily averages of flow, temperatures in the system, measured at the sub-station. Data from September 2014 to September 2016 (a continuous 2 year period) was used.
Heat demand was calculated by multiplying daily average flow from well Poddębice GT-2 (30–190 m^3/hr), heat capacity of water (4.18 kJ/(kg·K)) and temperature drop from supply temperature from well (around 65°C) down to return temperature from heat exchangers (50–55°C). The outdoor temperature and estimated heat demand duration curves over a 2 year period are shown in Figure 7.

The heat sold to users might be estimated as 48 TJ/yr (assumed 10% of annual heat losses in the system). The peak load installation is only used when the outdoor temperature drops below -10°C, so in this period this seems not to have occurred, except for extremely short periods. However, the system is designed for -20°C, so a peak load installation is needed for this coldest period.

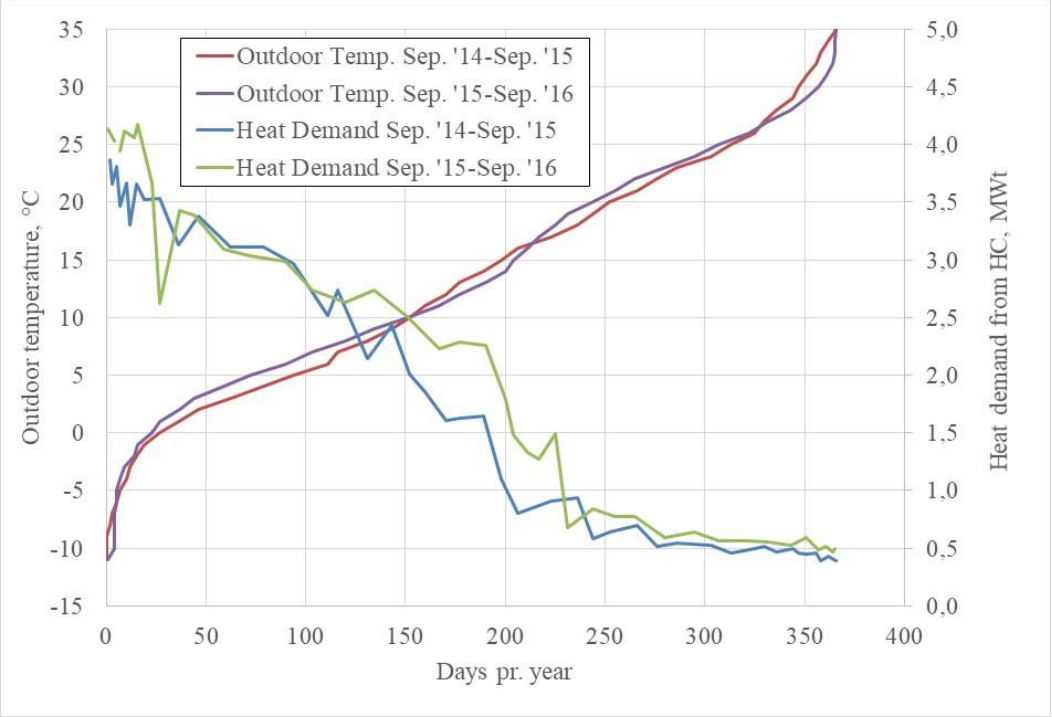


Figure 7: Heat demand and outdoor temperature over a 2 year period, Sep. 2014-Sep. 2016. Red and purple lines – outdoor temperatures [°C], blue and green lines – estimated heat demand [MW_{th}]

5.4 Overview of District Heating System Configuration

The following is an overview of the current configuration of the Poddębice district heating system and the planned expansion by approx. 1.4 MW_{th}. The proposed future peak load in all of that town is expected to reach 18 MW_{th}. Two alternative configurations of the system are proposed with regards to ease of implementation of the 18 MW_{th} heating of the entire town.

The maximum power that may be extracted from the geothermal fluid, based on 70/50 supply/return temperatures, is 4.0 MW_{th} – the current heating capacity of the Geotermia Poddębice Heat Central. There are 3 peak load installations in the distribution system (1 biomass fired, 2 oil fired). The flow in the distribution system heating circuit is 220 m^3/hr. The capacity of the peak load boilers for heating is approximately 1 MW_{th} each. This means that the current peak load capacity is approximately 7 MW_{th}, of which a little less than half comes from the 3 peak load boiler plants.

The proposed expansion of the DH system in Poddębice is to increase the flow rate from the Poddębice GT-2 well from 190 to ca. 250 m^3/hr. Current peak load installations in the distribution system are decommissioned and a heat pump is installed at the sub-station instead.

The geothermal power increases from 4.0 to 5.5 MW_{th} from the increased flow. The heat pump ensures a 75°C supply temperature to the expanded DH system. With an approximately 4.3 MW_{th} heat pump this amounts to roughly 10 MW_{th} peak load capacity of the system. With a COP (Coefficient of Performance, the ratio of heat produced vs. electricity used) of the heat pump around 3–4, so electrical connection should be 1.2–1.5 MW_e. Installing a different kind of heat source for peak load, such as gas or oil fired boilers, may also be possible.

The future 18 MW_{th} system in Poddębice might be as in Figure 8. Four 5 MW_{th} heat exchangers are expected and 5–6 circulation pumps. A 4 MW_{th}/1MW_e heat pump could be connected as shown, although final configuration is not known yet.

At least 2 production wells are needed, if a significant portion of heat is to be extracted from geothermal fluid. This setup would mean a system, where 90–95% of the energy for heating comes from geothermal fluid but only 5–10% from peak load (electricity or gas) annually. Direct use of water in distribution system is recommended but depending on project implementation details, there may be a 2nd set of heat exchangers in each house connection.

Depending on the environmental regulations in the future, a cooling pond may or may not be used. The current 2,400 m^2 pond may has to be expanded to ensure adequate water cooling, as the fluid temperature from the pond has proven to be higher when the heat demand (and flow of return geothermal fluid) is high. In any case, it may be expected that a re-injection may be needed in the unforeseeable future. A reinjection well may be more likely than a 3rd production well.

Another possibility for the future system is not to drill any more wells and install a very large heat pump or gas boiler peak load installation. The energy from the geothermal fluid would thus be around 65–70% of the total energy produced for heating, the rest – around 30–35% – would come from electricity or gas. This would result in lower project CAPEX but higher OPEX (fuel purchases) and CO_2 discharge.

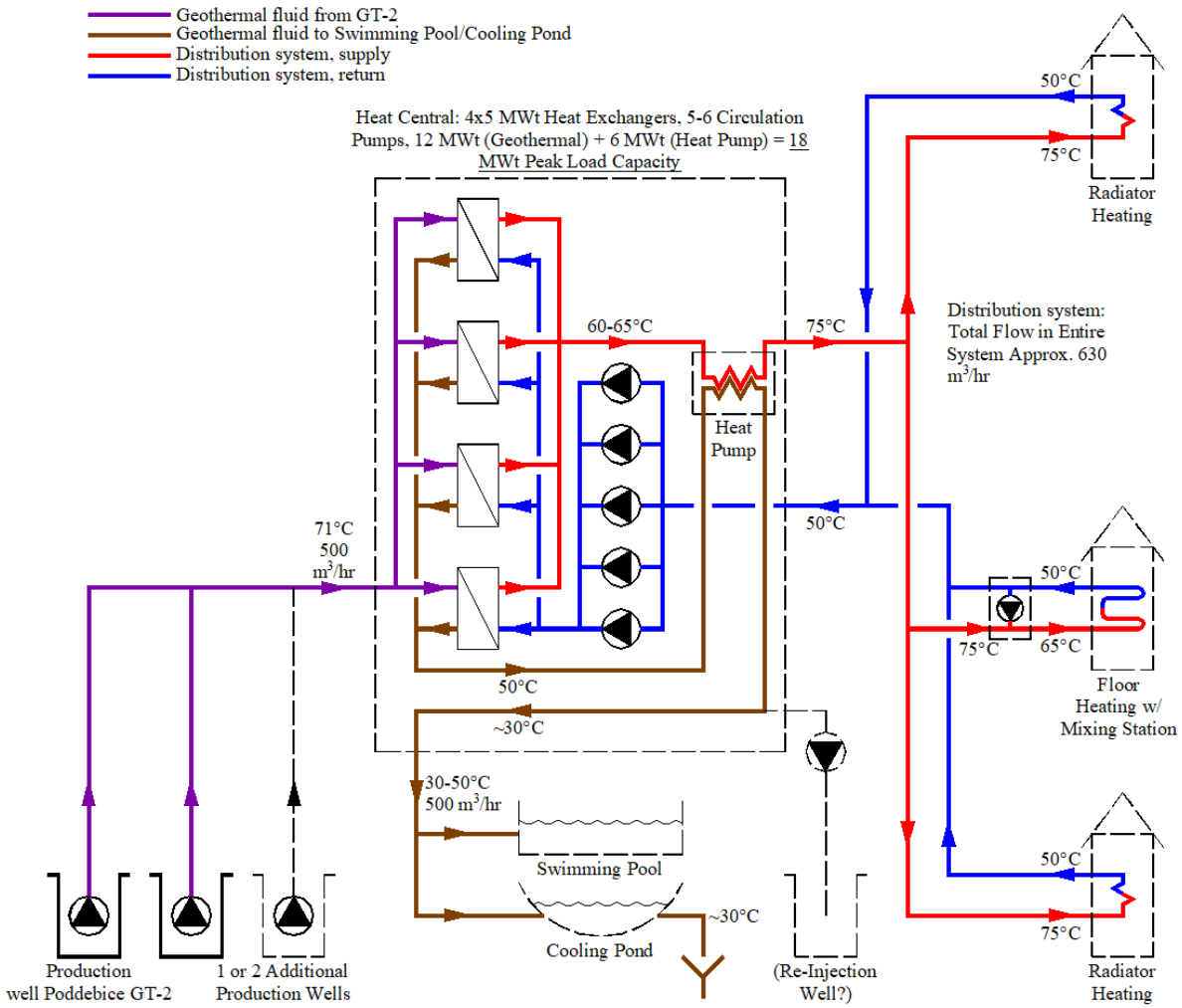


Figure 8: Proposed configuration of entire geothermal DH system in Poddębice. Purple/brown lines – geothermal supply/return fluid, red/blue lines – distribution system supply/return

6. EVALUATION OF POLICY OPTIONS FOR GEOTHERMAL ENERGY DEVELOOPMENT IN POLAND

6.1 Factors conducive to the wider geothermal use development in Poland

Although current geothermal applications in Poland have been on a rather limited scale (what is also reflected in low share in the RES mix), it should be pointed out that the country possesses the circumstances conducive to the wider geothermal uses deployment, specially for heating:

- prospective resources – particularly in the Polish Lowlands,
- potential receivers and public acceptance,
- urgent need to shift from coal/fossil heating systems into clean heating technologies to limit the smog phenomena and stop devastation of living conditions in many localities – winter 2016/2017 demonstrated it very emphatically,
- high level and scientific commitment of scientific manpower,
- experience of geological, drilling, consulting, servicing companies, contractors of installations, etc.,
- need to fulfill international and domestic obligations to increase the RES use and follow sustainable energy deployment,
- recently introduced state supportive programs and strategies (e.g. the Strategy for responsible development).

The-so-far geothermal uses – even on a rather limited scale compared with other countries – have already resulted in positive economic, environmental, social and other effects. Despite the Polish energy sector is based on fossil fuels (coal) there is a space and many opportunities for wider geothermal development, specially in heating sector. Operating plants, environmental effects, social and economic benefits suggest that more dynamic geothermal development is possible.

In Poland energetic use of geothermal energy shall focus on heating sector specially that ca. 500 district heating systems based on fossil fuels' burning (mostly coal, than natural gas) are operating. In some of them it is possible to introduce geothermal what will bring important results, i.e.:

- contribution to increased use of renewable energy sources and pushing local economies into sustainable innovative ways,
- significant reduction of GHG emissions,
- increased energy efficiency,
- higher comfort of life and health conditions for local citizens.

Moreover – as described before, geothermal heat prices are competitive with those obtained from fossil fuels, much more stable and in some cases slightly lower than heat from burning natural gas. This fact also justifies the purposefulness of geothermal heating development on much wider scale. The situation in Poland is similar as in other EU-countries where geothermal energy can be introduced to many district heating grids (Fig. 9).

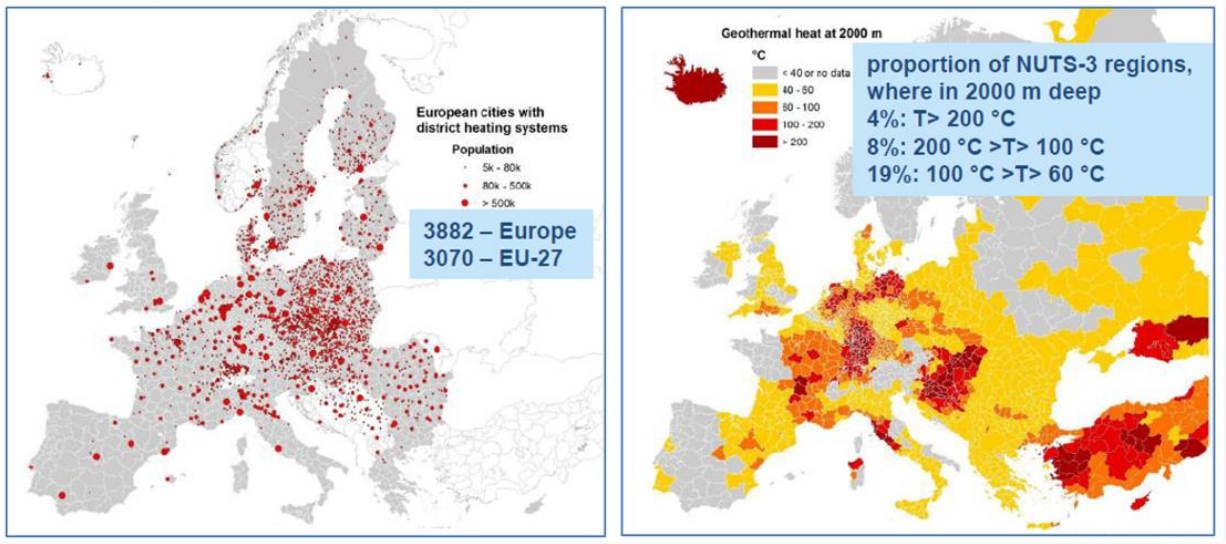


Figure 9: Geothermal cities in Europe (left) and cities with district heating systems (right). (in: Kępińska [ed] et al., 2017a)

7. GEOTHERMAL AND RENEWABLES ARE A POWERFUL TOOL TO LIMIT THE CLIMATE CHANGES

7.1 Climate change

According to the Intergovernmental Panel on Climate Change the following statements can be made:
From 1880 to 2012, average global temperature increased by 0.85°C (Fig. 10). To put this into perspective, for each 1 degree of temperature increase, grain yields decline by about 5 per cent. Maize, wheat and other major crops have experienced significant yield reductions at the global level of 40 megatons per year between 1981 and 2002 due to a warmer climate.

Global emissions of carbon dioxide (CO_2) have increased by almost 50 per cent since 1990. Emissions grew more quickly between 2000 and 2010 than in each of the three previous decades. It is still possible, using a wide array of technological measures and changes in behavior, to limit the increase in global mean temperature to two degrees Celsius above pre-industrial levels. Major institutional and technological change will give a better than even chance that global warming will not exceed this threshold" (http://www.un.org/sustainabledevelopment/climate-change-2/, The UNU Sustainable Goals Regarding Climate Change).

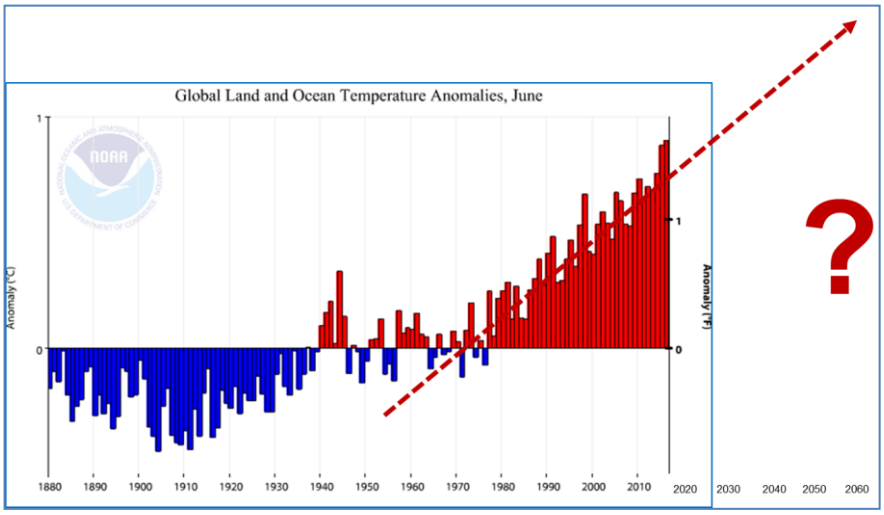


Figure 10: Global land and ocean temperature anomalies (NOAA, National Centers for Environmental Information, USA. https://www.ncdc.noaa.gov/sotc/global/201906)

7.2 International competitiveness of the geothermal sector – the cluster competiveness model

When formulating policy recommendations for the geothermal sector in many countries, including Poland, the enclosed model of 8 factors of geothermal competitiveness, challenges and opportunities, was used to highlight the key elements for policy recommendations and options in the concerning countries (Pétursson [ed] et al., 2017). Success for the geothermal sector in the particular countries is not only based on geothermal resources, but also on these factors for competitiveness.

The cluster competitiveness model can be used in many different ways to increase competitiveness and growth of companies. One possibility is to use the enclosed model (Fig. 11) to analyze eight main framework conditions in the geothermal sector:

1. Authorities and regulations.
2. Geothermal resources.
3. Scientific and technical factors.
4. Companies, management, expertise –industry, clusters assessment.
5. Education and human factors.
6. Access to capital.
7. Infrastructure and access to markets, sectors and other clusters.
8. Access to international markets and services.

By evaluating these eight factors of the geothermal competitiveness in the concerning country, it is possible to highlight the key weaknesses and strengths of the frameworks conditions as a base for the formulation of a better competitiveness policy for geothermal sector; increase competitiveness, growth, jobs, productivity and life quality.

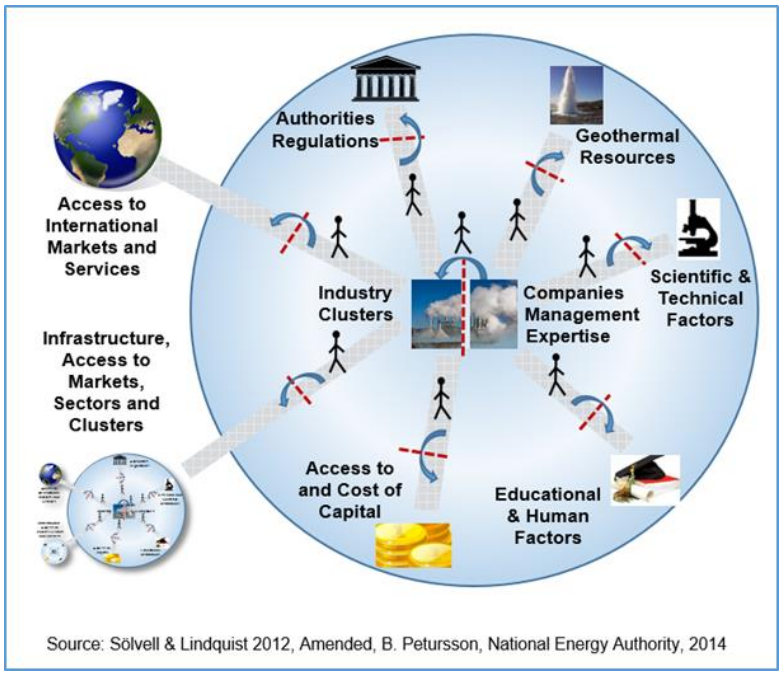


Figure 11:Competitiveness of the geothermal sector.
Success of geothermal district heating is based on 8 key factors (Pétursson [ed] et al., 2017)

8. SUMMARY AND CONCLUSIONS

1. Poddębice town and its area have prospective geothermal water potential for many types of direct uses. They have been already initiated for district heating system, as well as balneotherapy and some other uses. Further wider development has been underway.
2. The results of 3D modeling of geological and petrophysical parameters confirm a complex geological structure in the surroundings of the Poddębice town.
3. The performed studies and analyses of geothermal conditions and aquifer in Poddębice may contribute to understanding of the presence of low mineralized water (0.4 g/L) at a depth of ca. 2000 m b.g.l. This issue still remains unexplained despite considering the already existing older boreholes' data sets, documenting a behaviour of the Lower Cretaceous aquifer in the vicinity of the Poddębice, etc.
4. In the view of the plans to extend the geothermal heating system and increase the heat production to about 45 GWh_t/a, a monitoring of hydrochemical composition of geothermal water discharged by the Lower Cretaceous aquifer and regular laboratory analyses are strongly recommended.
5. Further well tests and interference tests should be done and more advanced reservoir and production model of Poddębice reservoir and its response for long-term production / exploitation specially in the view of planned extension

of geoDH system and development of several other direct uses. This shall be done by applying e.g. *Visual Modflow* or advanced numerical code TOUGH (international standard for geothermal reservoir modeling and simulation): with all the information already available (geology, hydrogeology, production, well parameters, etc.) it can be used to simulate the natural state and production history of geothermal aquifer in Poddębice. In this context a careful monitoring of operating parameters, interpretation and periodic simulations by means of Lumpfit programme is also recommended.

6. In case of planned heating system extension resulting with the need of more water volume exploitation, drilling the second production well and injection wells should also be considered. Introduction of the principles of sustainable development and following a good practice rules may significantly influence the stabilization of the main exploitation parameters, including water pressure (water level) in the reservoir, finally to ensure a long-lasting exploitation.
7. The need for heating in Poddębice is relatively high, as the heating season reaches approximately 200 days per year. The peak load installation is designed for relatively cold days, at -20°C. Although the peak load installation is approximately 2/3 of the total proposed future capacity (or heating power), the number of days where the temperature is below -10°C is not expected to be high. The peak load energy production, therefore, is only a relatively small fraction of the annual heat production, or 30-35%. Installing a second production well and using 1/3 of capacity from a peak load installation will mean that energy from peak load will be only 5–10%, instead of 30–35%. This reduction, however, will not result in significant savings in annual fuel/electricity cost, compared to high cost of production well.
8. For the reason same as above, the use of heat pumps as a peak energy source in Poddębice seems to be unprofitable. At least with the current users structure/characteristics. Consistency between the required supply temperature of heating system and the temperature of geothermal resources is good. Short-term use of heat pumps as the peak energy sources seems unprofitable from an economic point of view (high CAPEX and a rather small amount of energy generated by heat pumps per year).
9. By reconsidering the type of peak load installation (gas boiler instead of heat pump) and re-thinking/simplifying the type of house connection (using fluid more directly and therefore lowering house connection costs and fluid flow), the CAPEX may be reduced by a few percent. It is still rather uncertain at this point and further investigation is needed in order to find the most optimal geothermal heating system.
10. If the heating system in Poddębice will be enlarged and more water is needed, then at least one production well should be drilled and one or two injection wells as well. It is very important to inject the spent water back into to geothermal reservoir when more water is produced from the geothermal reservoir to make sure the water-level/pressure does not decrease too much. The effect could be that the pumps have to be lowered below the casing of the wells and the cost of pumping can become too big a portion of the management cost of the system.
11. Surface explorations such as magnetotelluric (MT), shallow gradient wells, gravity or other methods are needed before further drilling is decided on. It is important to locate the production and injection wells carefully to make sure that the injected water does give pressure support to the system but minimizes the cooling effect.
12. The lessons learnt from Poddębice case show that in order to create market conditions and facilitate further geothermal energy uses development in Poland it is recommended, among others, to simplify the administrative procedures.
13. Develop innovative financial models, including a risk insurance scheme, and the intensive use of structural funds are among key factors to enhance geothermal district heating deployment in the country.
14. It is also necessary to establish a level playing field, by liberalizing the gas and coal price and taxing green-house gas emissions in the heat sector appropriately.
15. In order to provide the technical background necessary to approve and support geothermal projects it is necessary to train technicians and decision-makers from regional and local authorities in order to provide the technical background necessary to approve and support projects.
16. Increase international cooperation with experts and the awareness of regional and local decision-makers on deep geothermal potential and its advantages will facilitate more dynamic geothermal development in Poland.
17. Geothermal and renewable energy sources are very important and powerful tools to limit the global warming.

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