Geothermal Energy Utilisation Potential in Poland – town Poddębice

Study Visits' Report

ORKUSTOFNUN National Energy Authority

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Geotermia Poddębice

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National Energy Authority, Iceland
Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Poland
AGH University of Science and Technology, Poland

June 2017

Framework of the Project

Geothermal utilisation potential in Poland – town Poddębice – is co-financed by the European Economic Area Financial Mechanism 2009-2014 under the Fund for Bilateral Relations, Operational Programme PL04 „Energy savings and promoting RES.

Project Agreement 115/2016/Wn05/OA-XN-04/D, EOG 2009-2014, dated 18.10.2016, between National Fund for Environment Protection and Water Management, Warszawa, Poland (PL04 Programme Operator) and Mineral and Energy Economy Research Institute, Polish Academy of Sciences in Kraków (Beneficiary and Project leader).

Project Partners:

Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Kraków, Poland
AGH University of Science and Technology, Kraków, Poland
National Energy Authority, Iceland
Cooperation: Poddębice Town Council, Geotermia Poddębice Ltd., Poland

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Introduction

The basis for Report preparation

The presented Report was prepared in frame of the Project" Geothermal utilisation potential in Poland town Poddębice" under the Fund for bilateral relations, Operational Programme PL04 „Energy savings and promoting RES" (European Economic Area and Norwegian Financial Mechanism 2009-2014 in Poland).

The Project activities were realized on a basis of the Project Agreement (115/2016/Wn05/OA-XN-04/D, EOG 2009-2014, dated 18.10.2016) between National Fund for Environment Protection and Water Management, Poland (Project operator) and Mineral and Energy Economy Research Institute of the Polish Academy of Sciences (Project leader) and the Partnership Agreement between MEERI PAS and NEA dated 24 August 2016. The Project was conducted between 1 August 2016 and 30 June 2017.

The Project parties

The parties of this bilateral Project were:
Project promoter: Mineral and Energy Economy Research Institute of the Polish Academy of Sciences (MEERI PAS) in consortium with AGH-University of Science and Technology (AGH UST) and in cooperation with the representatives of Geotermia Poddębice Ltd. and Poddębice Town.

Project partner: National Energy Authority (NEA), Iceland.

Project objectives and scope

In general, the Project promoted.

- an early stage development, strategy planning, capacity building, networking and awareness of geothermal energy use
- in order to increase the possibility of geothermal resources applications for heating, energy security, energy savings and quality of life in Poland on a basis of selected town – Poddębice.
- It was aimed to transfer the knowledge, technologies and best practices of geothermal district heating systems in buildings from Iceland to Poland.
- Iceland is a leader of this sector in Europe and the world, while in Poland such applications and approach have been at a preliminary stage.

The Project contributed to:

- capacity building, increase the competence and knowledge among local stakeholders like operators of geothermal plant, municipal officers, citizens of Poddębice town and others
- on the opportunities and benefits of the use of geothermal energy as a renewable local source;
- energy savings and increased security supply;
- effective implementation of a low-carbon economy;
- building the bilateral Polish – Icelandic cooperation; stimulate the development of geothermal heating in Poland.

The Project allowed also to create some guidelines for development of the geothermal sector in Poland, identifying obstacles for greater use of geothermal energy and presenting it to a liable stakeholder with aim of achieving a positive and stimulating business environment.

Project outcomes

Thanks to Project realization, a cooperation among Polish and Icelandic project partners was initiated which may result in common activities on geothermal heating systems and other uses in Poland with the implementation of proven solutions and technologies applied in Iceland. The Icelandic partner gained the knowledge and experience of geothermal heating sector based on parameters and reservoirs typical for Poland and other European countries.

This will strengthen its position in possible projects on international scene. The Project contributed also to increase the awareness of geothermal energy in Poland, specially in Poddębice, feature its possible usages with special focus on district heating and presenting it to relevant stakeholders.

Project tasks

To achieve the Project objectives, the following tasks were realized:

I. Study visit to Poland of representatives of Icelandic side
II. Study visit to Iceland of representatives of the Polish side
III. Study visits' report
IV. Summary Conference
V. Project management

A brief description of the-above-listed tasks follows.

I. Study visit to Poland of representatives of Icelandic side

Study visit was intended to assess geothermal potential for district heating in Poland with special focus on Town Poddębice. It was focused on cognition and evaluation by the experts from both sides the potential for geothermal district heating in Poland, especially in selected Poddębice town; gathering information to elaborate a pre-feasibility study assessment of geothermal for heating in Poland and especially in Poddębice. The visit was held on 5–9 September 2016 and was attended by the representatives on Icelandic and Polish project partners:

Icelandic side (National Energy Authority):
Baldur Petursson – international projects manager,
Helga Tulinius – expert, geothermal resources,
Oskar P. Einarsson – expert, geothermal heating,
Jón Ragna Gudmundsson – engineer.

Polish side:
Beata Kępińska – MEERI PAS, Project manager,
Leszek Pająk – MEERI PAS,
Marek Hajto – AGH UST Kraków,
Piotr Sęczkowski Mayor of Poddębice Town,
Anna Karska – Geotermia Poddębice Ltd., head of the BoD,
several observers, including: Andrzej Peraj – Geotermia Poddębice Ltd., deputy head of the BoD, representatives of the Ministry of Environment, local administration interested in geothermal heating projects, consulting companies, NGOs.

The Agenda of Study Visit to Poland is given in Attachment 1.

II. Study visit to Iceland of representatives of the Polish side

That activity was intended to visit selected best practices of geothermal space heating, other direct uses, and enable contacts with relevant stakeholders in order to provide opportunities for future cooperation and project developments. The visit was held on 24-28 April 2017 and participated by the representatives on Polish and Icelandic project partners:
Polish side:
Beata Kępińska, – MEERI PAS, Project manager,
Marek Hajto – AGH UST Kraków,

Piotr Sęczkowski – Mayor of Poddębice Town, expert,
Anna Karska – expert, Geotermia Poddębice Ltd., head of the BoD,
And observers: Andrzej Peraj – Geotermia Poddębice Ltd., deputy head of the BoD, Marcin Mazurowski, Piotr Bogusz, Wojciech Łysik, Marek Dec – Ministry of Environment, Edyta Kuźmińska – National Found for Environmental Protection and Water Management

Icelandic side (National Energy Authority):
Baldur Petursson – manager international projects and PR,
Jónas Ketilsson – senior manager - Deputy Director General,
Helga Tulinius – expert, reservoir engineering, senior geophysicist,
Oskar P. Einarsson – expert, geothermal heating,
Jón Ragna Gudmundsson – specialist , engineering management of district heating,
Jón Ásgeir H. Þorvaldsson – specialist, geothermal information analyst,
Maria Gudmundsdóttir – specialist, geothermal energy economics,
and several additional guests, as speakers at meetings and visits to geothermal fields.

The Study visits allowed to achieve the following:

- Evaluate the potential geothermal utilization for heating in Poland – with special focus on Town Poddębice,
- Evaluate and update the geothermal production potential of Town Poddębice – geothermal resource and update earlier evaluation,
- Increase the awareness of the local authorities, as well as the public, of the potential and benefits of sustainable geothermal utilization in Poland with focus on Town Poddębice.
- Familiarise with several geothermal successful types of uses in Iceland with can be implemented in Poddębice and in Poland (with geothermal district heating as a leading one)

The Agenda of Study Visit in Iceland is given in Attachment 2.

III. Study Visits' Report

The Report was elaborated on a basis on information, observations and discussions collected during Study visits to Poland and to Iceland, bilateral exchange of knowledge and expertise among the Project partners from Iceland and Poland (in forms of direct contacts during study visits, electronic contacts via internet, phone talks). Their results are presented in form of pre-feasibility study of geothermal uses and potential for district heating in Poland (in general) and pre-feasibility study of geothermal district heating in Poddębice town.

The Report gives an insight into current state of geothermal uses deployment in Poland and selected town – Poddębice with focus on district heating. It contains also some guidelines for geothermal district heating, and opportunities for further Polish–Icelandic cooperation. Hence it shall be helpful in the activities for further development of this sector in Poland.

IV. Summary Conference

The Conference was aimed to present the main findings and outcomes of Study visits Report, i.e.:
1. Summary of geothermal heating possibilities in Poland,
2. Summary of geothermal heating development possibilities and related benefits in Town Poddębice.

The Conference was held in Poddębice, Poland, on 13 June 2017 and was attended by 36 various stakeholders: representatives of Polish and Icelandic partners, Geotermia Poddębice Ltd., Mayor and officers of Poddębice town council, representatives of several municipalities interested in next geothermal projects from EEA/NFM grants, servicing and consulting companies, the Ministry of the Environment, National Fund for Environment Protection and Water Management – EEA/NFM operators in Poland, and other participants.

The event enabled the dialog on geothermal development issues. The proposal on next geothermal project funded by EEA/NFM was also presented. This project proposal can be treated as a follow-up of successful realisation of the reported EEA Project on Poland – Poddębice.

The Agenda of Summary Conference is given in Attachment 3.

V. Project management

That task embraced coordination of Project activities, contacts and cooperation among Project partners, organisation and logistics, handling with formal, administration and financial issues.

Executive Summary

Resource assessment in Poddębice

1. Good reservoir and production parameters of geothermal aquifer
2. Necessary further careful monitoring of reservoir and production(exploitation) parameters – a basis for proper current and planned exploitation of geothermal water reservoir
3. A need to construct a geothermal reservoir model (MODFLOW, TOUGH, etc.) and its use for the purposes of long-term sustainable exploitation, prediction of its possible reaction for long-term exploitation, optimal location of next wells, etc.,
4. There is much noise in the water level data that reduces the quality of modelling.
5. The current production is not aggressive and the water level is not predicted to decrease if continued.
6. Predictions also indicate that if production is doubled water level will drop 20 – 40 m, which should be manageable.

District Heating System for Poddębice – Next Steps

1. Increase low temperature use (e.g. floor heating) in distribution system, possibly with mixing stations.
2. Avoid heat exchangers in houses, if possible
3. Drilling a 2nd production well+6 MW_{th} gas boiler will mean lower production cost in EURcent/kWh than installing a 12 MW_{th} gas boiler in the long run (30+ year lifespan)
4. Installing a 12 MW_{th} gas boiler has the lowest project CAPEX
5. The former option is a long term investment and also means lower CO2 release
6. Difference between the two is approx. 6–7% in production cost and 7–8% in CAPEX
7. Both these options appear to be more economical than installing a heat pump

Other Geothermal Possibilities in Poddębice

1. Extension of district heating system
2. Agriculture – greenhouses, foil tunnels
3. Algae cultivation
4. Fish farming
5. Recreation / balneotherapy
6. Drinking/mineral water/cosmetics production
7. Other: e.g. Safari Park,

Geothermal Options and Possibilities in Poland

Main types of wider geothermal energy use in Poland

- Space heating, specially district heating (geoDH) – the most needed for many reasons,
- Agriculture, aquaculture, ecologic food production,
- Recreation/balneotherapy.

The most prospective areas for geothermal district heating in Poland

- **The Polish Lowlands:** main resources of geothermal waters are related to the Mesozoic formations (mostly sandstones) where particularly the most promising are Lower Jurassic and Lower Cretaceous formations.
- **The Inner Western Carpathians – the Podhale Region:** geothermal water resources are predominantly found in the Mesozoic (mostly Middle Triassic) carbonates in the basement of the Palaeogene Flysch formation.
- For further improvements – see additional international recommendation – next page.

Additional International Recommendations

International Framework Recommendations

Following recommendations are highlighted:

1. Simplify the administrative procedures to create market conditions to facilitate development.
    a. Separate law regarding geothermal resources and other fossil fuels resources.
    b. Improve access to geothermal data - to improve development of geothermal utilization.
2. Develop innovative financial models for geothermal district heating, including a risk insurance scheme, and the intensive use of structural funds.
3. Establish a level playing field, by liberalizing the gas price and taxing greenhouse gas emissions in the heat sector appropriately.
4. Train technicians and decision makers from regional and local authorities in order to provide the technical background necessary to approve and support projects.
5. Increase the awareness of regional and local decision-makers on geothermal potential and its advantages.
6. Modernize the district heating system.
7. Improve the role of independent regulators.
8. Improve the role of district heating companies.
9. Consider additional elements of public authorities, energy efficiency etc.
10. Harmonization with EU Law.
11. Consider, what international financing institutions can do to help.

Geothermal Development and Lessons Learned in Iceland

The following elements of policy priority have been shown to be important regarding geothermal development:

1. Awareness raising among policymakers, stakeholders and municipalities.
2. Education and capacity building.
3. Evaluation of geothermal resources.
4. Promotion of geothermal power generation and district heating projects.
5. Development of legal and regulatory framework.
6. Financial support for early stage development and exploration.
7. International cooperation, geothermal and financial expertise.

The economic savings from geothermal district heating in Iceland from 1914 – 2014 is equal to 2.680 billion ISK (19 billion EUR), or 33 million ISK (240.000 EUR) per family (four persons). Furthermore, the CO_2 savings by using geothermal district heating instead of oil are approx. 100 million tons since 1944, which is equal to CO_2 bindings in 240.000 km^2 of forest. The savings of CO_2 in 2014 was 3 million tons, which is equal to CO_2 bindings in 7.000 km^2 of forest. Geothermal district heating has therefore been an important contribution to fighting climate change, which is increasing temperatures and sea levels around the world.

Geothermal Options, Opportunities and Benefits

The geothermal heat generation has several advantages, such as:

1. Economic opportunity and savings.
2. Improvement of energy security.
3. Reducing greenhouse gas emissions.
4. Harnessing local resources.
5. Reducing dependency on fossil fuels for energy use.
6. Improving industrial and economic activity.
7. Develop low carbon and geothermal technology industry, and create employment opportunities.
8. Local payback in exchange for local support for geothermal drilling.
9. Improving quality of life based on economic and environmental / climate benefits.

1. Pre-feasibility study assessment of geothermal in Poland

1.1. Desk review of documents

Desk review of documents was related to several sources of the following data, information and observations which served as sources of input data and information for the presented Report:

- collected during Study visit to Poland – Poddębice and shared by Geotermia Poddębice Ltd., Poddębice Town, and by Project partners – MEERI PAS and AGH UST,
- collected during Study visit to Iceland,
- from screening and studies of available publications,
- from archive documentations and materials made accessible by Poddębice Town Council and Geotermia Poddębice Ltd. and by Project partners – MEERI PAS and AGH UST,
- other supplementary data and information.

1.2. Assessment of available geothermal resources in Poland

From geothermal point of view, Poland is characterized by low-temperature conditions (temperatures at 1 km below ground level are below 150ºC).

Geothermal water and energy resources predominantly occur within the Polish Lowlands and the Inner Carpathians (the Podhale region), and, to some extent, also in selected areas in Outer Carpathians, the Carpathian Foredeep, and in the Sudetes Region (Fig. 1.1). The best geothermal conditions for direct applications are found in the Polish Lowlands and in the Inner Carpathians (Podhale Region).

In case of the Polish Lowlands (being a part of large geostructural unit known as European Lowlands) sedimentary formations (mostly of Mesozoic age) dominate the extensive area stretching from the Baltic Sea coast towards central and southern part of a country. In case of the Sudetes region geothermal aquifers sometimes occur in fractured parts of some crystalline and metamorphic formations.

The water temperatures at the outflows from the wells (depths up to ca. 3.5 km) recorded so far vary from ca. 20 to 97°C while proven geothermal water reserves amount from several up to 150 L/s from particular wells.

Geothermal potential of Poland has been evaluated for a long time, based on information and data derived from several thousands of geological exploration and oil&gas wells, information from other research and measurements, including, among others, thousand kilometres of seismic profiles.

Comprehensive information about Polish geothermal resources is provided, inter alia, by seven geothermal atlases of different part of Poland issued by the Department of Fossil Fuels at the Faculty of Geology, Geophysics and Environmental Protection, AGH UST in Krakow over the years 1990–2013 (Górecki [ed.] et al., 1990–2013). These works contain a synthesis of research and works done over long span of time by several institutions like AGH UST, as well as Polish Geological Institute, MEERI PAS, Polish Oil & Gas Company, etc. In 2013 the last Atlas (Górecki [ed.] and Hajto et al., 2013) on Polish sedimentary basins was published thereby closing the series of geothermal atlases of Poland. Altogether these works cover ca. 80% of Polish territory.

In recent years (2012–2014) two next comprehensive works were published: on prospects for HDR structures (Wójcicki [ed] et al., 2012) and for geothermal heat and power co-generation in binary schemes (Bujakowski, Tomaszewska, [eds] et al., 2014).

The Polish Lowlands, the Carpathians and the Carpathian Foredeep form extensive sedimentary-structural basins. They are characterized by significant low–enthalpy geothermal potential. Some parts of them (mostly of Mesozoic age) are filled with geothermal waters of diversified reservoir temperatures, from 20 to 80–90ºC, in some cases even over 100ºC.

From geological point of view Poland is situated at the interface between three main European geostructural units (Fig. 1.1):

- Precambrian platform of Northwestern Europe (occupying over half of the total area of the continent),
- Palaeozoic folded structures of Central and Western Europe (Caledonian and Variscian) partly covered by the Permian, Mesozoic and Cainozoic sediments (the Polish Lowlands),Alpine system running through Southern Europe from the Iberian Peninsula to the Caucasus Mts. In Poland it is represented by part of the Carpathian range.

Each of these structures is characterized by distinct geothermal conditions. Sedimentary rocks cover almost whole territory of Poland, main exception is the area located in of Poland (Sudety Mts.) where mostly crystalline and metamorphic rocks occur.

The studies conducted for years at the Department of Fossil Fuels of the AGH UST in cooperation with Polish Geological Institute – National Research Institute, with contribution of MEERI PAS and some other institutions show that the most prospective areas for geothermal energy uses including district heating (geoDH) in Poland are connected with the Polish Lowlands and with the Inner Western Carpathians. The estimates of the geothermal resources in the classes of the accessible, static (heat in place), and static-recoverable (recoverable geothermal energy) resources in different part of Poland confirm the biggest geothermal potential of the Polish Lowlands.

In the text below main attention is paid on the geological and geothermal details of the Polish Lowlands – since this structure (including Poddębice area) is the most promising for geothermal district heating applications to which this Report is dedicated.

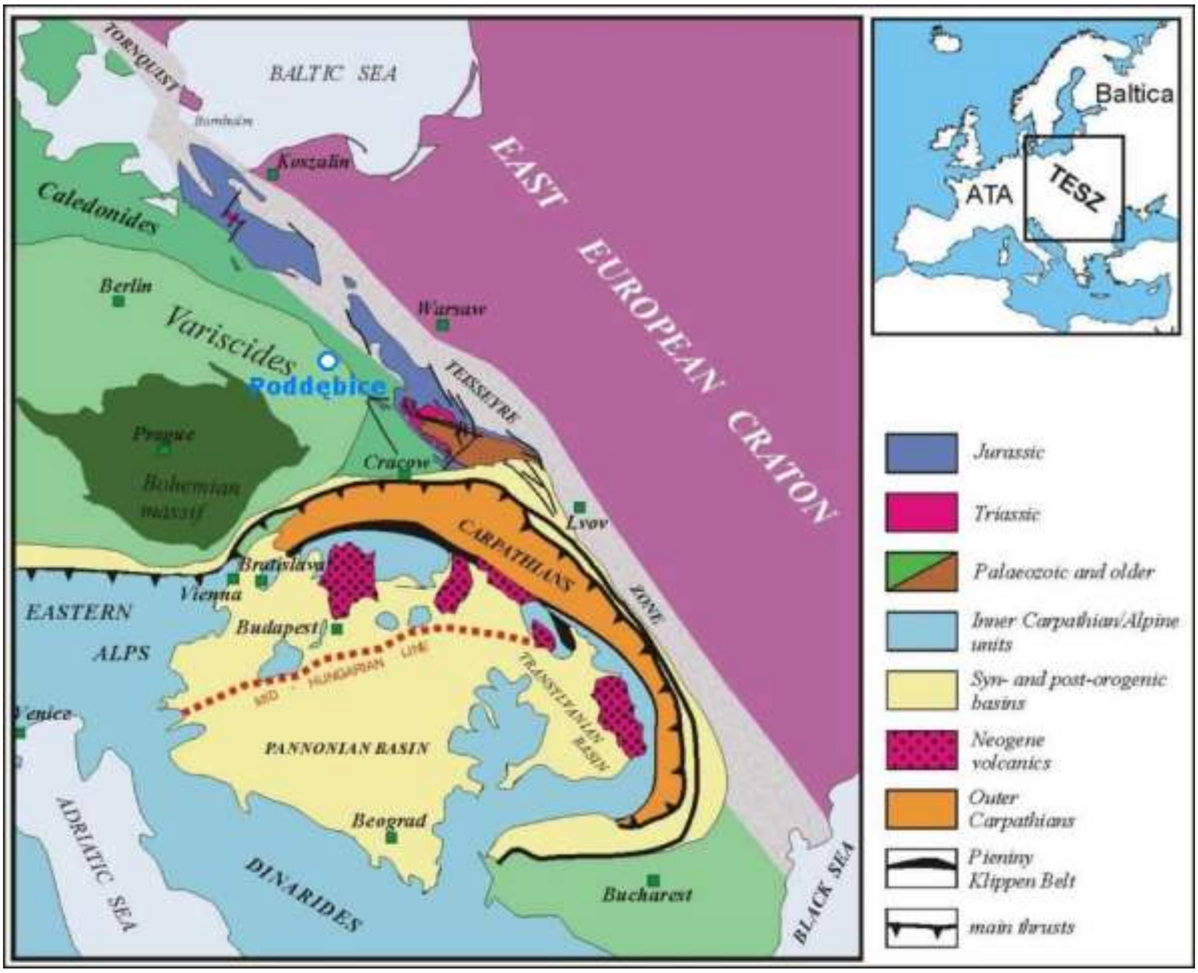


Fig. 1.1. Tectonic map of Central Europe showing its main components and location of Poddębice Town (source of map: Institute of Geophysics PAS)

1.2.1. The Polish Lowlands – geological and geothermal characteristics

Based on seismic investigations, the total thickness of the sedimentary cover in the deepest area of the Palaeozoic part of the Polish Lowlands' basin can reach as much as 20 km (Guterch et al., 1997). The area of the East European Craton (EEC) is characterized by a thin, about 1–2 km thick sedimentary cover. In the region of Mazury–Suwałki elevation (NE Poland), the depth to basement is only 0.3–1 km but increases southwestwards to 7–8 km along the margin of the EEC. In the area of Poland, the Teisseyre–Tornquist Zone (TESZ) the sedimentary succession attains thicknesses of up to 9–12 km. Its upper parts consist of Permian and Mesozoic sequences that reach maximum thicknesses of 7–8 km, whereas Devonian and Carboniferous epicontinental deposits form its lower part.

Variscian consolidated crust (Palaezoic platform) with a 1–2 km thick sedimentary cover crust has a much simpler structure than the crust of the EEC and TESZ due to the absence of a high velocity lower crust (Guterch and Grad, 2006).

The basement of the Permian-Mesozoic sedimentary basin within the Palaeozoic Platform consists of Carboniferous, Devonian and older formations, folded during the Variscian Orogenesis. The large Mesozoic sedimentary basin was deformed during the Laramide tectonic phase between the Cretaceous and Tertiary periods. During this phase the plastic salt layer was pressed up to the surface, piercing almost 6 km thick overlying Triassic, Jurassic and Cretaceous deposits. Increasing tectonic movements split the basin into two subbasins: the Szczecin-Łódź-Miechów synclinorium and the Grudziądz–Warsaw synclinorium. Between them the Central–Polish anticlinorium was formed. Mesozoic structures were eroded after that deformation, and later covered by flat-lying Palaeogene-Neogene and Quaternary sediments (Hajto and Górecki, 2010). Figure 1.2 shows the map of tectonic units of Poland under Cenozoic cover.

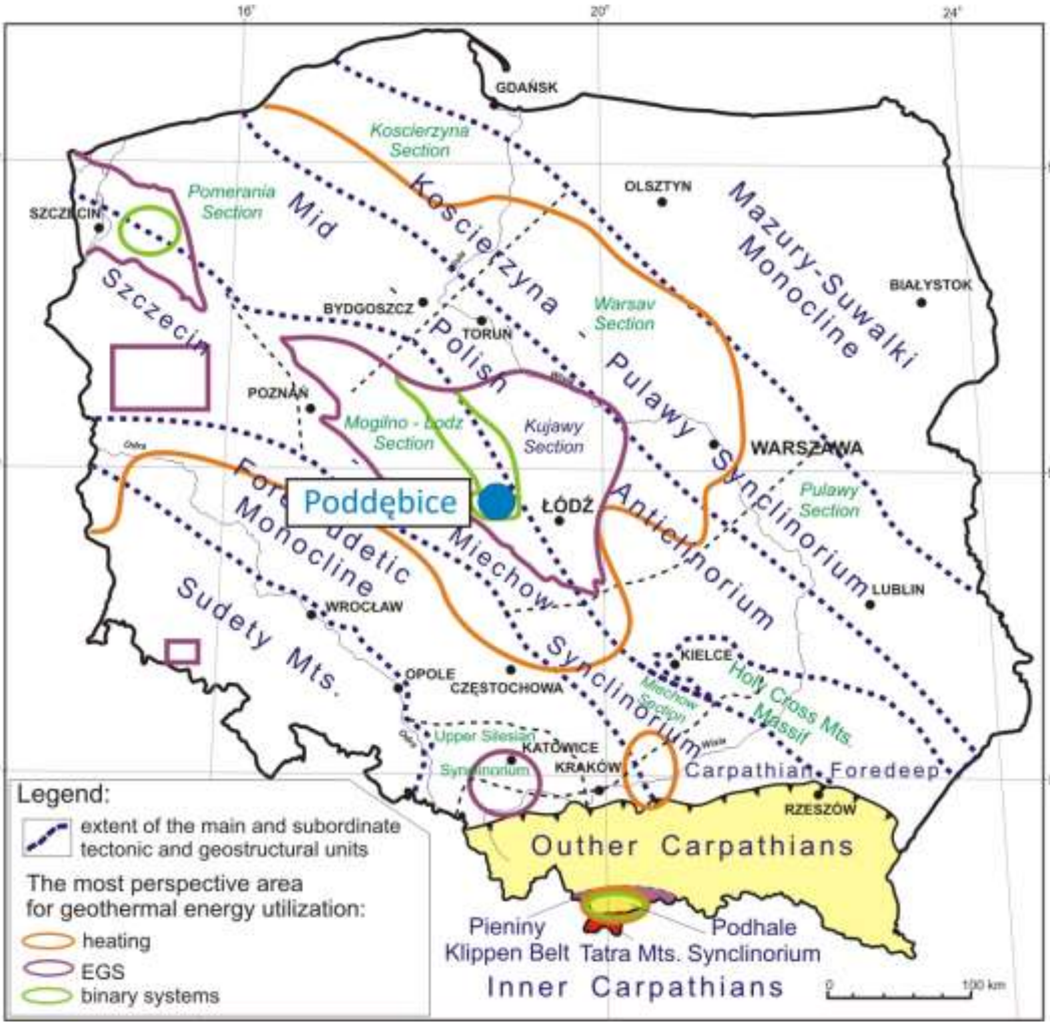


Fig. 1.2. Tectonic units of Poland under Cenozoic cover (after Żelaźniewicz et al., 2011 – modified by Hajto) with the most perspective areas for geothermal energy uses in Poland

Within the Lower Jurassic aquifers permeable rocks constitute 40–80% of the total thickness of the Liassic sequence. The temperature of geothermal waters divers from those typical of subsurface waters to 120°C at the depths, below 3000 m (axial part of the Łódź Trough). The TDS of groundwater in the Lower Jurassic aquifers is closely related to the depth of occurrence and change from few to over 200 g/L, however, in the whole aquifer dominating are values from 10 to 100 g/L. In most part of Lower Jurassic aquifer discharges over 100 m^3/h can be expected.

The second of regional scale relevance with a significant extent aquifer in the Polish Lowlands is the Lower Cretaceous one. Total thickness of Lower Cretaceous formation varies from several to over 400 m with dominating values between 20 and 200 m. Geothermal water temperatures vary from 20 to over 90°C. The higher temperatures recorded so far were in the north–east of Konin town (NW from Poddębice). Regional analysis of hydrogeological data sets indicates that potential discharges of wells vary from beneath 25 m^3/h to over 100 m^3/h (Górecki [ed.] and Hajto et al., 2006a).

Significant resources of geothermal energy are accumulated also in the Upper Jurassic, Middle Jurassic, Upper Triassic and Lower Triassic formations. Geothermal waters of Devonian, Carboniferous, Lower & Upper Triassic, Lower & Middle Jurassic reservoirs may be used both for recreation, bathing and balneotherapy purposes.

Those brines characterize of high content of bromine, sometimes also potassium and magnesium. Due to the results of the research the prospects for the use of geothermal waters of the Carpathian Foredeep as well as Eastern Carpathians for recreation and/or balneotherapy are much higher than that related to heating purposes. It results as well from the lower energy demand of geothermal water intakes as from favorable physicochemical parameters of these waters, confirmed by numerous wells drilled especially over vast areas of the Carpathian Foredeep. In some regions, it is possible to develop the groundwater also for heating purposes (space heating, agriculture, agribusiness), usually in association with other sources, including heat pumps. The most perspective areas for geothermal energy utilization are shown on Fig. 1.2.

The scale of these uses will depend on numerous factors. Very important problem is to break the still existing bad habits and improper standards, which have dominated the state energy policy in last decades. Geothermal waters can be utilized for heat generation used in houses and industrial buildings, greenhouses, agriculture, for generation of warm water, and for therapeutic and recreational purposes. The use of ecologically clean geothermal energy resources is real and economically justified in vast areas of the Poland.

The estimates of the geothermal resources in the classes of the accessible, static (heat in place), and static-recoverable (recoverable geothermal energy) resources in different part of Poland confirm the biggest geothermal potential of the Polish Lowlands (Fig. 1.3). The lowest potential (expressed by value of disposable geothermal resources) is related to the Eastern Carpathians. Analysis of geological, hydrogeological, and petrophysical/volumetric parameters of the flysch rocks, Miocene deposits and the Mesozoic – Palaeozoic basement of the Eastern Carpathians, supplemented by the economic indicator analysis considering the present economic conditions (including the geothermal drilling costs), are indicative of very limited potential for utilization of heat from geothermal waters for heating purposes in the study area. However, hydrogeological parameters of the analyzed geothermal aquifers of the Eastern Carpathians, first of all discharges of intakes and predicted water temperatures, indicate the possibility of building small heating installations with thermal powers ranging from several hundred kilowatts to 5 MW_{th} at the outmost (Górecki [ed], Hajto et al., 2013).

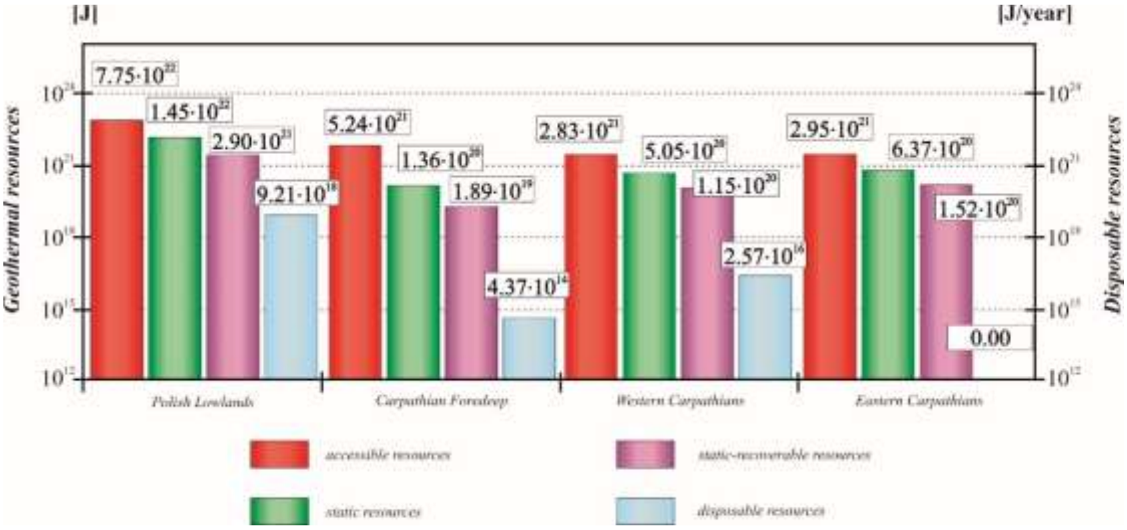


Fig. 1.3. Distribution of geothermal resources within particular resources classes for different areas of Poland (after: Hajto, 2013)

1.2.2. Main types of wider geothermal energy use in Poland

Geothermal waters represent the carriers of environmentally clean energy which can be important for numerous regions in Poland. They can be used for heat production for houses and industrial buildings, greenhouses, agriculture, tap warm water preparation, for therapeutic and recreational purposes, etc. The use of geothermal resources is economically justified in vast areas of the Poland.

As the most prospective uses in the country (on a scale larger than now) one shall give the following:

- Space heating, specially district heating (geoDH) – the most needed for many reasons,
- Agriculture, aquaculture, ecologic food production,
- Recreation/balneotherapy.

Among other types of geothermal water and energy uses one shall add locally possible heat & power cogeneration in low-temperature binary schemes (electric capacities hundreds kW_e – 1–2 MW_e), mineral and drinking water production, production of cosmetics, etc.

In many cases the optimal and most efficient shall be multipurposed (cascaded) schemes, in hybridization with other energy sources (other renewables but also fossil fuels).

1.2.3. The most prospective areas for geothermal district heating in Poland

The Polish Lowlands: main resources of geothermal waters are related to the Mesozoic formations (mostly sandstones) where particularly the most promising are Lower Jurassic and Lower Cretaceous formations. Significant resources of geothermal energy are accumulated also in the Upper Jurassic, Middle Jurassic, Upper Triassic and Lower Triassic formations but they characterize by significantly less geothermal potential when heating purposes are considered.

Waters are characterized by favorable reservoir and outflow temperatures (even above 90°C) and relevant values of wells' discharges (to several hundred m^3/h). Water mineralization vary in a wide range: from less than 1 g/L up to 150 g/L or even more.

The Polish Lowlands is an area where Poddębice Town is located – subject of detailed considerations of the reported Project.

Within these area five geothermal district heating plants have been operating as well as several spas and recreation centers (more: some of next subchapters). However, the opportunities are much bigger.

The Inner Western Carpathians – the Podhale Region: geothermal water resources are predominantly found in the Mesozoic (mostly Lower Triassic) carbonates in the basement of the Palaeogene Flysch formation. The Podhale Region is a part of larger geothermal system surrounding the Tatra Mts. both on Polish and Slovakian sides. That Region has very good reservoir and exploitation parameters: outflow temperatures reach up to 80–87°C, flow rates are up to 290–550 m^3/h (artesian) while TDS do not exceed 3 g/L. These resources have been exploited for regional district heating system as well as for recreation.

1.2.4. Geothermal conditions and prospects for space heating in other geological structures in Poland

The Carpathians and Carpathian Foredeep: in case of other regions like the Outer Carpathians and Carpathian Foredeep low discharges of wells are fundamental problem when considering potential applications of geothermal energy specially for heating (which are possible in some particular areas).

The lowest potential has the Eastern part of the Outer Carpathians (expressed by value of disposable geothermal resources). Analysis of geological, hydrogeological, and petrophysical parameters of the flysch rocks, Miocene deposits and the Mesozoic–Palaeozoic basement of the Eastern Carpathians, supplemented by the economic indicator analysis considering the present economic conditions (including the geothermal drilling costs) indicate very limited potential for the use of heat from geothermal waters for heating purposes in that area. However, hydrogeological parameters of the geothermal aquifers of the Eastern Carpathians, first of all discharges of water intakes and predicted water temperatures, indicate the possibility to setup small heating plant with thermal capacity ranging from several hundred kW up to 5 MW (Górecki (ed.), Hajto, et al., 2013).

The Sudetic region, SW Poland: in this region geothermal aquifers sometimes occur in fractured parts of some crystalline and metamorphic formations. It includes the Sudetes Mts. and the Fore – Sudetic Block – limited to the NE by the Odra fault – is an exception as compared to the rest of Poland's geological setting. Instead of large sedimentary basins of the Polish Lowland and the Carpathian foredeep or folded flysch formations of the external Carpathians, the Sudetes Mts. consist mainly of old crystalline rocks covered with younger sediments. Precambrian and Lower Palaeozoic gneisses and schists with not uncommon marble intercalations were intruded by Upper Carboniferous granitoids which form among others the core of the

Karkonosze – Izera massif. In synclinal structures the crystalline rocks are covered with Phanerozoic sediments (Silurian-Quaternary) (Dowgiałło, 2000).

Geothermal waters occur in this region only in the crystalline formations. Most of the fragmentary hydrogeothermal investigations carried out so far in the Polish part of the Sudetes were limited to zones of occurrence of geothermal waters used for therapeutic purposes, or to a few areas in which prospection has been carried out for such waters (Dowgiałło, 2002). However, the Sudetic region is characterized by favorable geothermal conditions. For instance: in Cieplice town and area water with temperature 86.7ºC was obtained from the depth 2002.5 m. For this reason, the Cieplice area was a subject of a study to identify a perspective location for the HDR project in Poland (Wójcicki et al., 2013) as well as to identify a location of binary systems (Bujakowski, Tomaszewska [eds.] et al., 2014).

The earliest information about geothermal water in the Sudetic region is related to reservoir in Cieplice Śląskie-Zdrój and Lądek Zdrój. First analysis of the Cieplice waters date back to 1572 (Ciężkowski 1994, 1998). In the late 60s of the XX century more studies were initially carried out. Currently, waters of this region are used in some health resorts for balneotherapy and recreation (Cieplice, Lądek, Duszniki). In two other localities geothermal waters are expected to be applied for recreation and balneotherapy soon. Moreover – these waters started to be considered for heating purposes, like e.g. Lądek Zdrój (the oldest spa on Polish territory (dated back at least to 13th century) – this would allow to reduce low emissions generated by burning fossil fuels thus improving living conditions and boost local sustainable economy.

Selected information on geothermal water parameters in Sudetes region is shown on Figure 1.4.

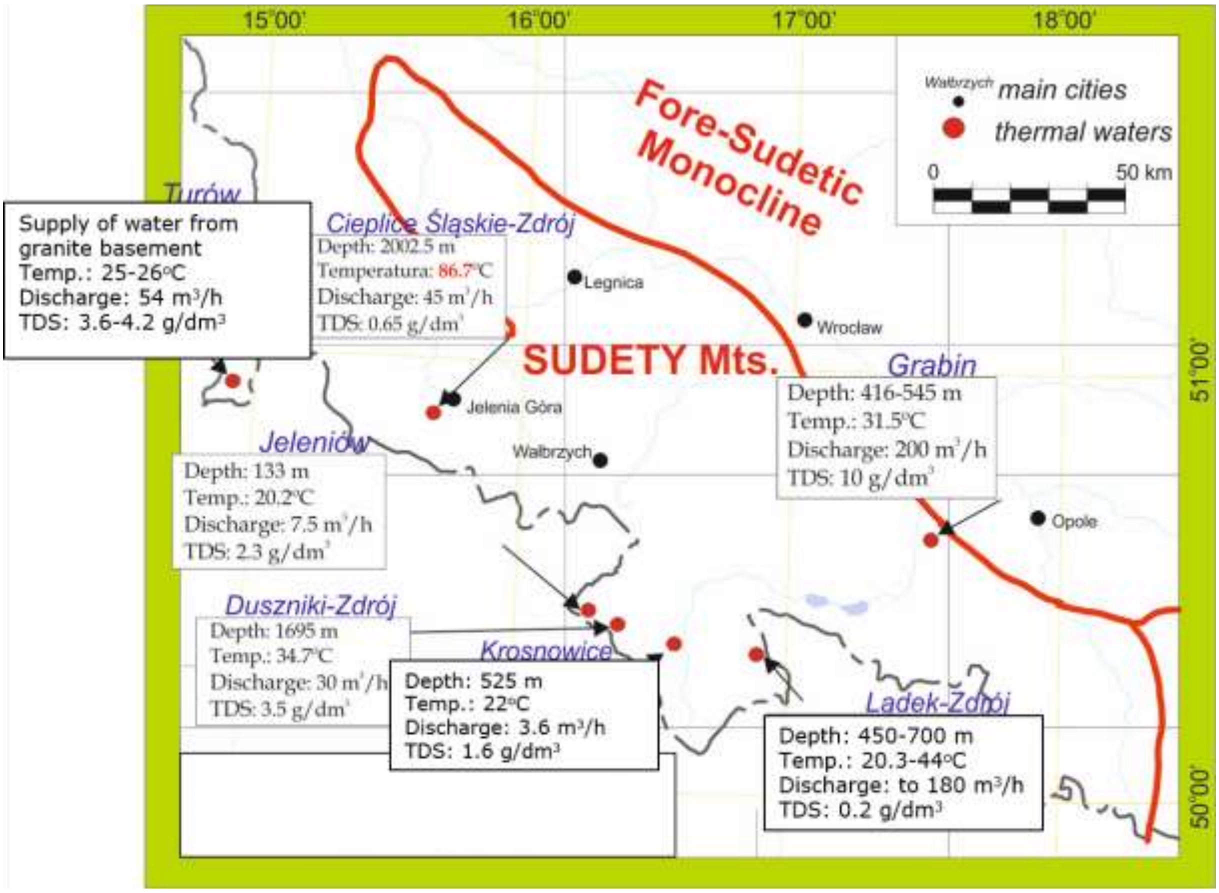


Fig. 1.4. The Sudetic geothermal region - localities where geothermal waters were found (based on Dowgiałło, 2001, Ciężkowski 2011)

To sum up the above considerations on areas the most prospective from geothermal point of view:

The prospects for wider geothermal district heating systems development in Poland are predominantly connected with the Polish Lowlands and with the Podhale Region (Inner Carpathians). In case of first from listed regions, specially promising is the vast area located within the contour showing the underground temperatures above 60ºC mostly in the Lower Cretaceous and Lower Jurassic formations. At this same time – in that area numerous district heating systems are operating and at least to some of them geothermal energy can be introduced (Fig. 1.5). Main parameters that characterize this area of a country are following:

- Reservoir temperatures >60ºC,
- Depths of aquifers up to 3–4 km,

One shall also point out that the geothermal space heating systems will be feasible mainly in localities with already operating district heating grids, preferably with wells located close to grids and customers. These conditions, if existing, present particular chances to increase number of geoDHs in Poland in close future.

To supplement this information and illustrate the theoretical potential – there are ca. 5 000 district heating systems in Europe, ca. 500 of them – 10% are located in Poland (Fig. 1.6). Particular chance for geoDH both in Europe and Poland lies in introducing to existing DH systems located in the areas where this is possible.

Taking into account the current number of geoDH systems in Europe: ca. 270 were operating in 2014 and many investments were in progress while in Poland only 6 geoDH have been operating, far beyond resource potential and needs.

These statements follow the findings and outcomes of the EU–project "Promote geothermal district heating in Europe" (Report on Geothermal DH Potential in 14 EU-countries, 2014; www.geodh.eu). Poddębice are among the localities within this very suitable area.

These facts urge to undertake proper activities to speed up geothermal heating development in Poland. Very strong arguments for that were supported by very heavy atmospheric pollution (smog) in winter heating season 2016/2017 in many localities caused by burning coal while clean and ecologically friendly geothermal potential remained untouched.

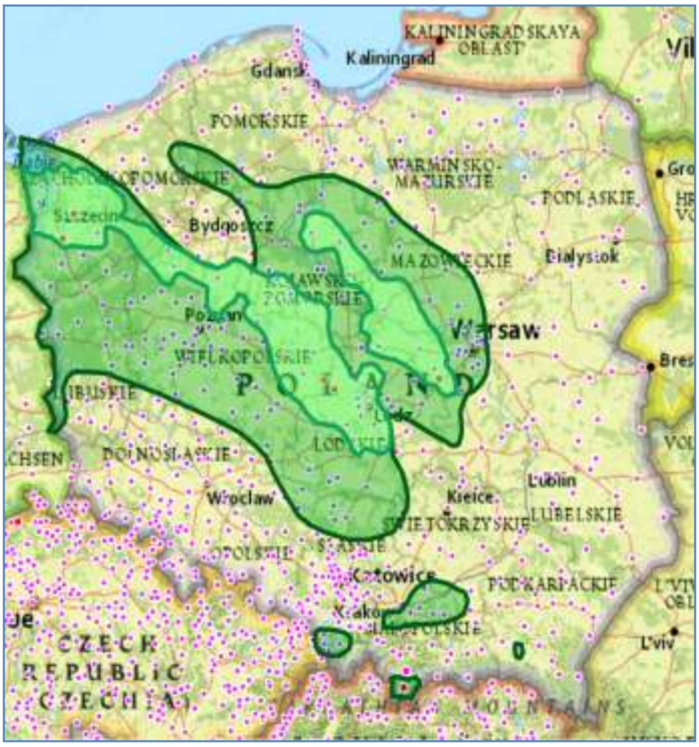


Fig. 1.5. Poland – the most prospective areas for geothermal district heating systems [in:] Report on Geothermal DH Potential in 14 EU-countries, 2014 (www.geodh.eu).

Dark green line – isotherm 60ºC underground. Marked by green – areas with underground temperatures above 60ºC, depths to 3-4 km b.g.l. (mostly in the Lower Jurassic and Lower Cretaceous formations). Red dots – operating district heating systems

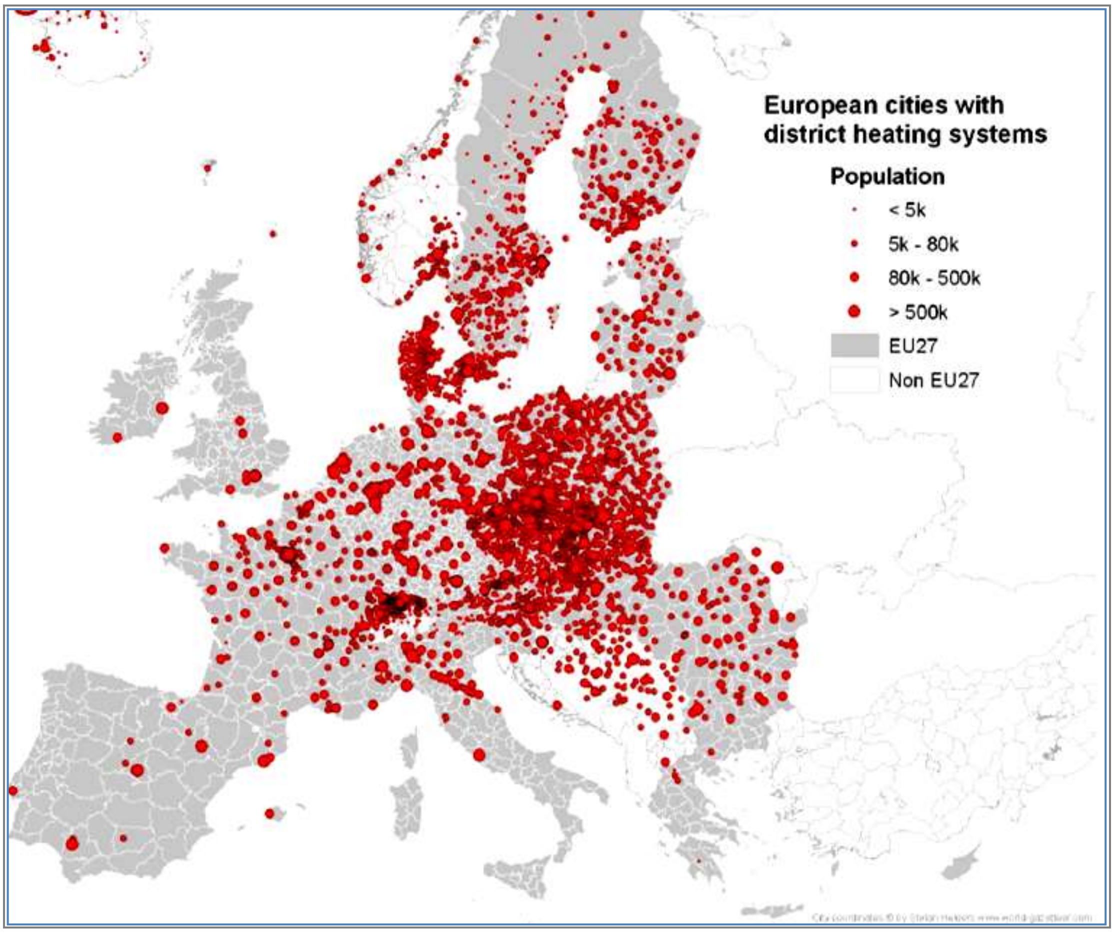


Fig. 1.6. District heating systems in Europe (red dots) according to HUDC database (June 2012).
[in:] Report on Geothermal DH Potential in 14 EU-countries, 2014 (www.geodh.eu)
Source of map: Persson et al. (2012) – HUDC Database 2012 (The Halmstad University District Heating and Cooling Database). Note very high density of district heating systems in Poland.

1.2.5. Overview of current geothermal energy uses in Poland

Even though Poland has a substantial geothermal potential when it comes to geothermal energy so far it has been harnessed far beyond reservoir potential. Currently geothermal direct uses which base on the-so-called deep geothermal (i.e. harnessed by 1– 4 km wells) involve:

- space heating,
- balneotherapy, recreation,
- fish farming,
- some minor uses.

Figure 1.7 shows the location of geothermal uses in Poland. The overview presented below is based on Kępińska (2016) and updated in some cases.

District Heating

In case of district heating – first plant was opened in last decade of 20th century. It was in the Podhale region (S–Poland) and it has been under constant development till now. At the end of 2016 six geothermal district heating plants were operating (opened between 1993–2015): in the Podhale Region and in five towns in the Polish Lowlands: Mszczonów, Uniejów, Poddębice, Pyrzyce, Stargard.

(More detailed characteristics of district heating plants in Poland is given later in this subchapter).

Balneotheraphy and recreatoion

Ten health resorts are using geothermal water for treatment. Some have old historical roots dating back to 13th century while the youngest one was established in 2012 (Uniejów). In recent decade (2006–2016) fourteen new recreation centres were constructed. Some of them apply geothermal water both for the pools and other facilities and for heating their objects and warm water preparation (sometimes with ca. 1 MW_{th} compressor heat pumps' usage).

In 2016–2017 several further investments oriented for recreation were at various stages of realization or under projects' elaboration.

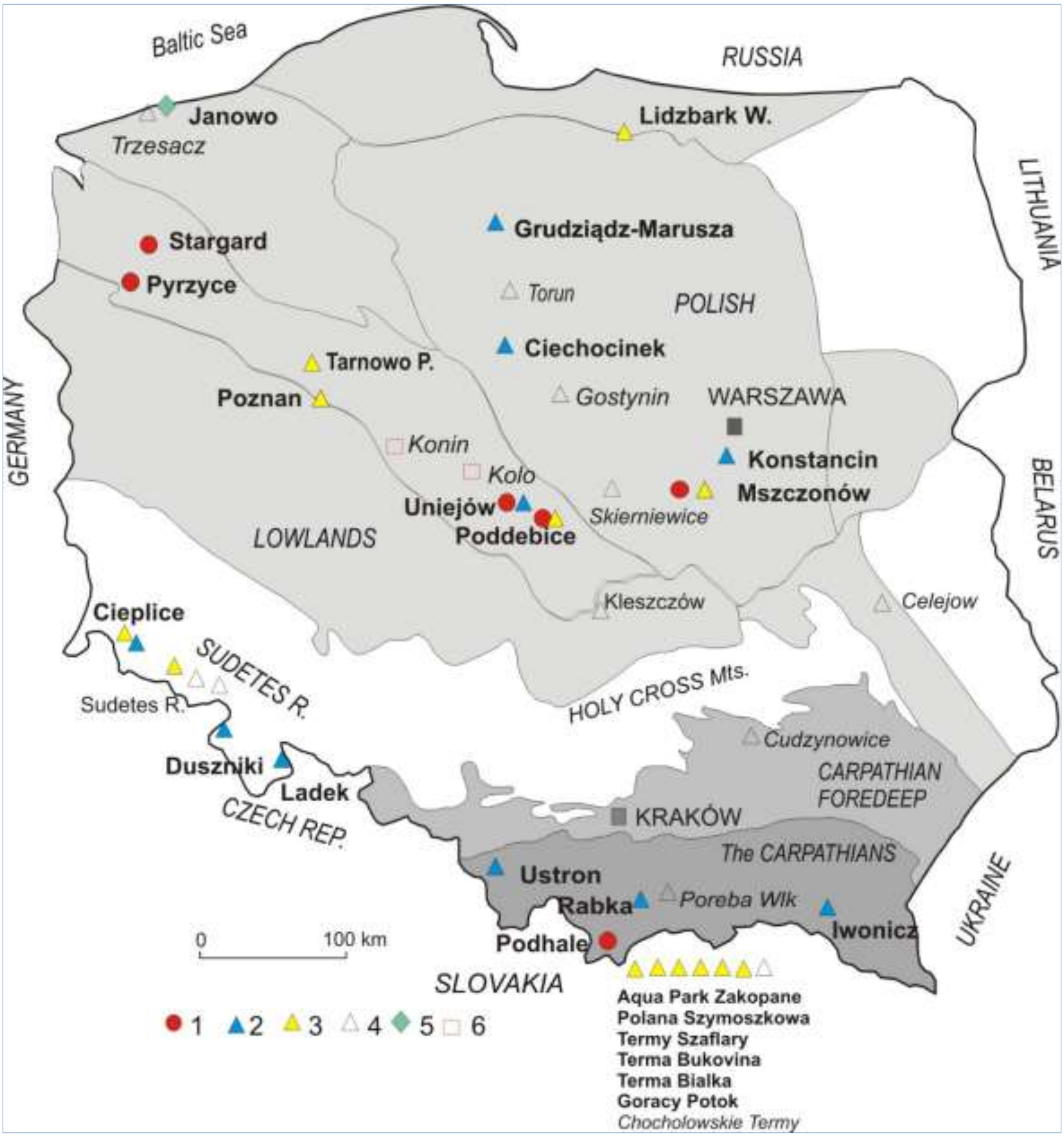


Fig. 1.7. Poland – geothermal direct uses, 2016 (Kępińska, 2016):
1. district heating plants in operation, 2. health resorts, 3. recreation centers in operation, 4. some recreation centers under construction, 5. fish farming, 6. co–generation plants at early stages of investment projects

Fish farming

In several past years by (2012) a semi-technical fish farming (a part of R+D cascaded system) was operating by MEERI PAS in the Podhale Region – that facility initiated geothermal aquaculture in Poland.

In 2015a a large-scale modern atlantic salmon's farm using geothermal water (Janowo at the Baltic coast) was opened. Water comes from the well drilled in 2012 and is applied both for culturing and for heating the farm's facility. At initial stage of farm's operation, the average water flow rate was ca. 20 L/s. Target fish production will reach 1000 T/y (without GMO, antibiotics, etc.; Kępińska, 2016).

Other uses

Other direct geothermal uses comprise semi-technical wood drying (MEERI PAS installation in the Podhale Region; earlier in integration with other R+D scale applications like fish farming, greenhousing, foil tunnels), and heating up of a football playground (Uniejów).

Shallow geothermal

In recent years the constant progress of shallow geothermal – ground sourced heat pumps' sector (GSHP) has been observed (part of the progress in whole heat pumps' branch) in contrast to many previous years. In 2015 it was expressed by average 14% growth of sales compared with 2014 (the most spectacular 70% market growth was in case of air heat pumps in 2015.In case of GSHPs the average market growth was ca. 5% (information based on *www.portpc.pl*). At the end of 2015 the number of GSHP was estimated for ca. 45 000 units (at least 500 MW_{th} and heat production at least 695 GWh / 2500 TJ; Kępińska, 2016). The largest single units reach 1 MW_{th}, some of them work in geothermal district heating plant in Mszczonów and in some recreation centres).

1.2.6. Geothermal district heating plants – an overview

As mentioned above, at the end of 2016 six geothermal district heating plants were operating in Poland. In 2015 their total installed geothermal capacity was 76.2 MW_{th} and geothermal heat production ca. 820 TJ (Kępińska, 2016). In particular localities geothermal water parameters as well as installed capacities and heat production vary considerably – e.g. the highest geothermal water temperature discharged by the production wells is 82-86ºC C and 85ºC (Podhale region and Stargard town) while the lowest one is 42ºC (Mszczonów town). The Podhale geoDH is (probably) the largest geothermal heating system in Europe (except Iceland) for its geothermal capacity and annual heat sales (41 MW and 393 TJ/2015). The main data on geoDH operating in Poland are given in Table 1.1.

All plants represent good examples of clean geothermal energy applications resulting in significant reduction of GHG emissions generated before by burning fossil fuels (coal) for heating purposes.

Table 1.1. Poland - geothermal district heating plants, 2015 (based on Kępińska, 2016)

Locality	Opening year	Outflow water temperature (°C)	Maximum water flow rate (m^3/h)	TTDS (g/L)	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2015 geo-heat sales (TJ)	Geoth. share in total sales (%)
Podhale R.	1993	82-86	960	22.5	40.7	82.6	393	90.5
Mszczonów	2000	42	60	00.5	3.7	8.3	15.8	38.2
Poddębice	2013	68	252	00.4	10	10	15	100
Uniejów	2006	68	120	66-8	3.2	7.4	19.2	80
Pyrzyce	1994	61	360	1120	6	22	54.6	63
Stargard	2012	83	180	1150	12.6	12.6	168	100
Total					76.2	142.9		

The Podhale region – the plant has been operating by PEC Geotermia Podhalańska SA since 1994 (on a larger scale since 2001) as the biggest geoDH in the country and one of the biggest in Europe. It was preceded by comprehensive geological, drilling and geothermal exploration and by Experimental Geothermal Plant Bańska – Biały Dunajec (designed and operated by MEERI PAS). Geothermal aquifer is hosted by Middle Triassic limestones/dolomites and Middle Eocene limestones (top aquifer's part) situated between depths 2–3.7 km b.g.l. The total maximum flow rate (artesian!) produced by 3 wells is 960 m^3/h of 82–86°C water. Water mineralization (TDS) is ca. 2.5 g/L. These are very good reservoir and exploitation parameters. Technological sketch of the described heating system is shown on Fig. 1.8.

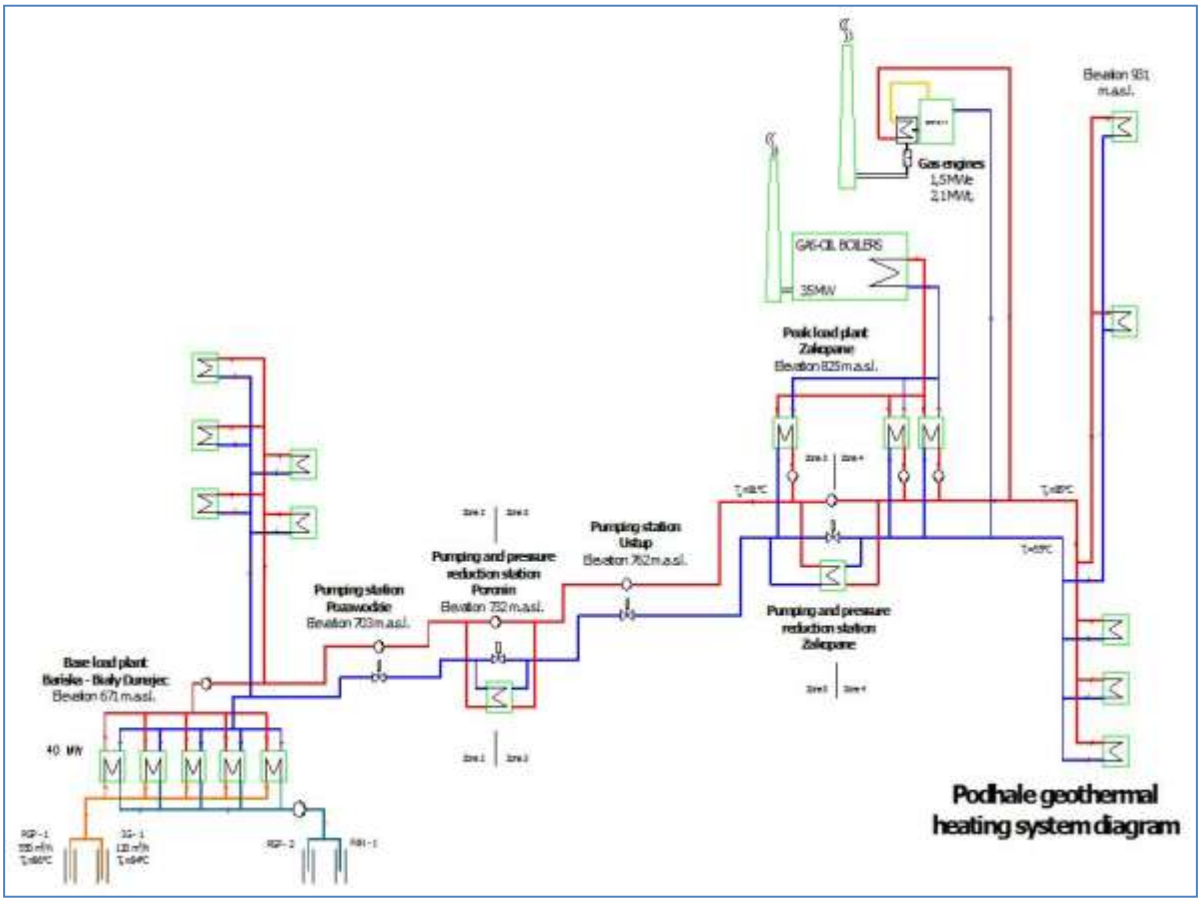


Fig. 1.8. The Podhale Region – technological sketch of the geothermal district heating system (source: PEC Geotermia Podhalańska SA)

In 2015 the installed geothermal capacity was 40.7 MW_{th} (total 82.6 MW_{th} including gas and fuel peaking boilers). The total heat sales amounted to 394 TJ and geothermal 357 TJ in 2015. Ca. 1600 receivers are hooked to geoDH (mostly in Zakopane – the main city of that region and main heat market; geoDH meets ca. 35% of its heat demand). Part of spent geothermal water is injected back while part supplies 2 recreation centres. The geoDH system in Podhale has resulted in significant reduction of CO_2 emissions generated early by coal burning (Fig. 1.9). The system is planned to be extended, what will be possible thanks to more efficient heat management and increasing thermal capacity supplied by fourth production well planned to be drilled in 2017–2018 (total depth ca. 5.3 km, both for heat and electricity generation).

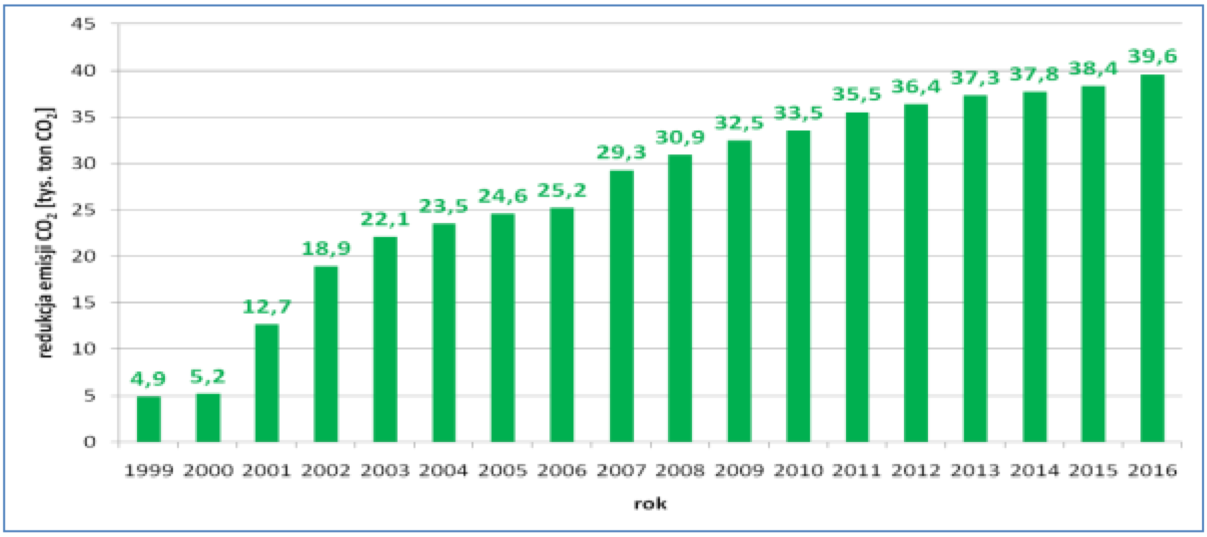


Fig. 1.9. The Podhale Region – CO_2 reduction achieved thanks to geothermal district heating introduction (source: PEC Geotermia Podhalańska SA)

Other five geoDH plants are situated within the Polish Lowlands and all are based on sandstones as reservoir rocks.

Mszczonów – the geoDH has been operating since 2000. Maximum flow rate is ca. 60 m3/h of 42.5°C water, while TSD are 0.5 g/L. Geothermal aquifer is hosted by Lower Cretaceous sandstones at the depth 1.6–1.7 km b.g.l.

Water is discharged by a single well and it is not injected back. This is a former oil&gas exploration well from the 1970s, reconstructed and adopted for geothermal water production (project by MEERI PAS and Geotermia Mazowiecka SA).

In 2015 the total installed capacity was 8.3 MW_{th} (4.6 MW_{th} gas boilers, 2.7 MW_{th} absorption heat pump and 1 MW_{th} compressor heat pump). The plant extracts heat from geothermal water in a very efficient way – from 42 to ca. 10ºC for three purposes:
- district heating,
- drinking (water cooled down by compressor heat pump is sent to local water works),
- for the pools in local recreation centre.

Technological sketch of the described heating system is shown on Figure 1.10.

Projects of further innovative applications (e.g. mineral water production; construction of large recreation water center) are in progress.

The system in Mszczonów, despite low water temperature, represents a good example of a very efficient heat extraction and multi-purposed geothermal energy and water management.

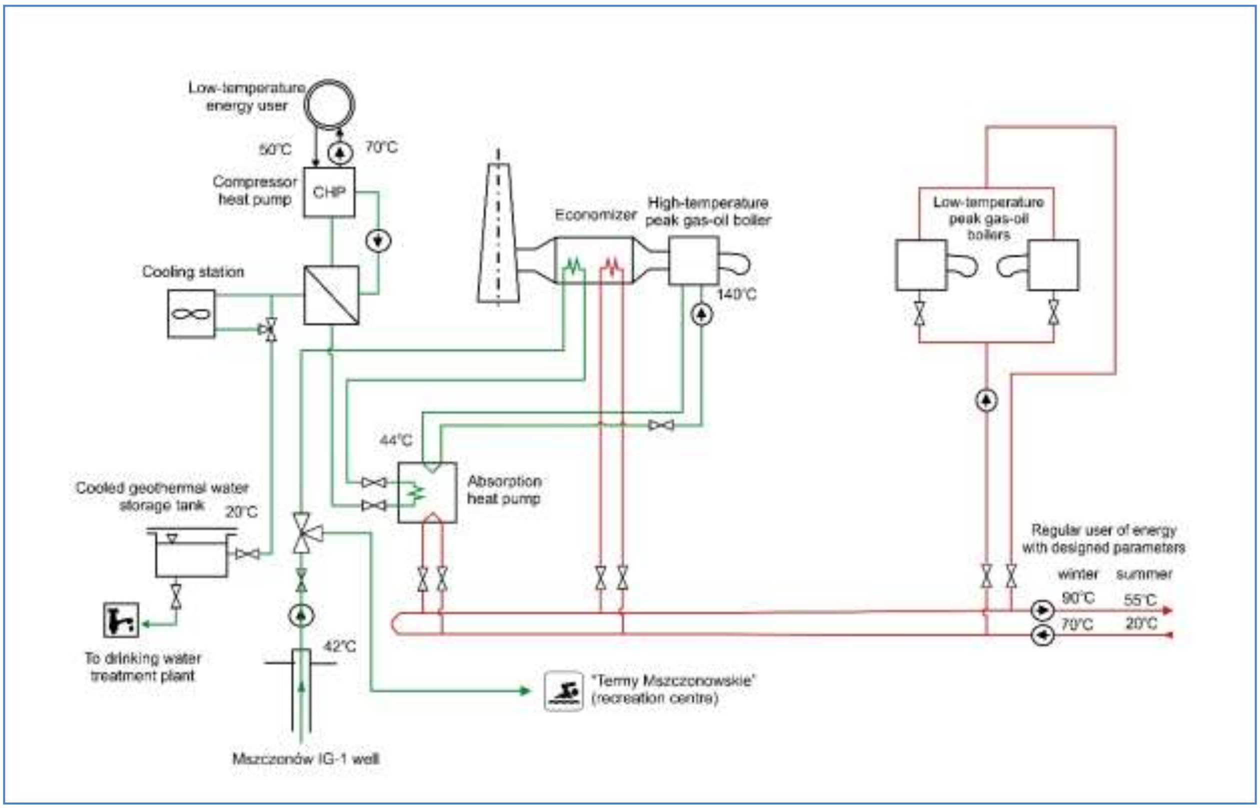


Fig. 1.10. Mszczonów – technological sketch of the geothermal district heating system (source: Geotermia Mazowiecka SA, 2014)

Poddębice. In that town the construction of geothermal district heating plant was commissioned in 2012. Geothermal aquifer is hosted by Lower Cretaceous sandstones at the depth 1.95–2.06 km b.g.l.

The geoDH of 10 MW_{th} geothermal capacity is based on 68°C water (maximum ca. 250 m3/h, mineralization 0.4 g/L). Since 2014 the plant supplies some public buildings, school, hospital (and its rehabilitation part), several multi-family houses. Some part of water stream is sent to swimming pool. Poddębice have very prospective geothermal conditions therefore the extension of geoDH as well as other further investments are being considered. Thanks to low mineralisation and high quality water is also used for drinking (so far on a limited scale).

Poddębice represent a good study case and argument for wider geothermal energy development for space heating and introducing the low-emission heating systems into the buildings. These aspects were in focus of the project "Geothermal Energy

Utilization Potential in Poland – Town Poddębice" (2016–2017) under the Fund for bilateral relations, Operational Programme PL04 „Energy savings and promoting RES" EEA and Norwegian Financial Mechanisms 2009-2014 in Poland. The Project has been conducted by MEERI PAS, AGH UST and National Energy Authority, Iceland, with active participation of Poddębice Town Council and Geotermia Poddębice Ltd. (www.eeagrants.agh.edu.pl). The Poddębice case is treated in details *in Chapter 3.2. of this Report.*

*Pyrzyce***.** The geoDH plant has been operating since 1996. Geothermal aquifer is hosted by Lower Jurassic sandstones at the depth 1.4–1.6 km b.g.l. The maximum flow rate from two production wells is ca. 100 dm^3/s of 61°C water (spent water is injected back by two wells). After recent optimisation works the plant's maximum installed capacity is 22 MW_{th} including 16 MW_{th} high–temperature gas boilers and 6 MW_{th} geothermal heat exchangers (which cooperate with 20.4 MW_{th} absorption heat pump.

The plant supplies heat and domestic warm water to over 90% users of the town's population (13,000) meeting ca. 60% of total heat demand. In 2015 geothermal heat production was ca. 66.54 TJ and total heat production was 105.61 TJ/2015 (Kępińska, 2016).

Uniejów. The geoDH has been operating since 2001. Geothermal aquifer is hosted by Lower Cretaceous sandstones at the depth 1.9–2.1 km b.g.l.

The maximum discharge from one production well is 33.4 L/s of 68°C water while TDS are ca. 6–8 g/L. The exploitation system includes also two injection wells. The total installed capacity of the plant is 7.4 MW_{th} including 3.2 MW_{th} from geothermal, 1.8 MW_{th} from biomass boiler and reserve 2.4 MW_{th} fuel oil peak boilers. In 2015, 80% of all buildings in that town were supplied by the geoDH. Geothermal heat production / sales was 6.82/15.89 TJ, respectively (80% of total coming from the biomass boiler) (Kepińska, 2016).

Since 2008 a part of geothermal water has been used in geothermal spa and recreation centre "Termy Uniejów" for pools and curative treatments (ca. 8.4 L/s of 42°C water; ca. 1 MW_{th}, 7.7 TJ). The centre is also heated by geothermal energy. Some amount of spent water (ca. 5.6 L/s, 28°C) is than used to heat up a lawn of football playground (ca. 1 MW_{th}, 8.7 TJ) and walking paths. In 2012 Uniejów received a formal status of health resort thanks to curative geothermal water. Some new types of geothermal uses are at various stages of project preparation and planning.

Stargard. The plant was re-open after refurbishment in 2012 (closure in 2008–2012) after, among others, some rehabilitation works in wells and surface equipment. It is based on a doublet of production and injection wells. Geothermal aquifer is hosted by Lower Jurassic sandstones (total well depths 2.6 – 2.9 km b.g.l.

The maximum production is ca. 50 L/s of 87°C water. In 2015 the geothermal capacity was 12.6 MW_{th} and geothermal heat production was 213.61 TJ, entirely sold to the municipal district heating plant for heating and domestic warm water preparation (Kepińska, 2016). This plant is coal-fired (total capacity 116 MW_{th} serving about 75% of local population (75,000). Geothermal meets ca. 30% of total heat demand of that municipality.

To sum up basic data on six geoDH systems in Poland: in 2015 total installed geothermal capacity was ca. 76 MW_{th} and geothermal heat production ca. 227 GWh (818 TJ). In individual cases geothermal share in total heat production was from 38 to 100%.The biggest installed total (82.6 MW_{th}) and geothermal capacity (40.7MW) had the geoDH in the Podhale region. It produced the biggest volume of geothermal heat in the country(in 2015 there was 128.59 GWh (463 TJ) from total 142 GWh. It is one of the biggest geoDH systems in Europe (continental).

However, Poland is on 12th place only among 30 European countries embraced by the statistics presented at European Geothermal Congress 2016 (Fig. 1.11). It is far beyond geothermal potential, real needs, ecological and social interest.

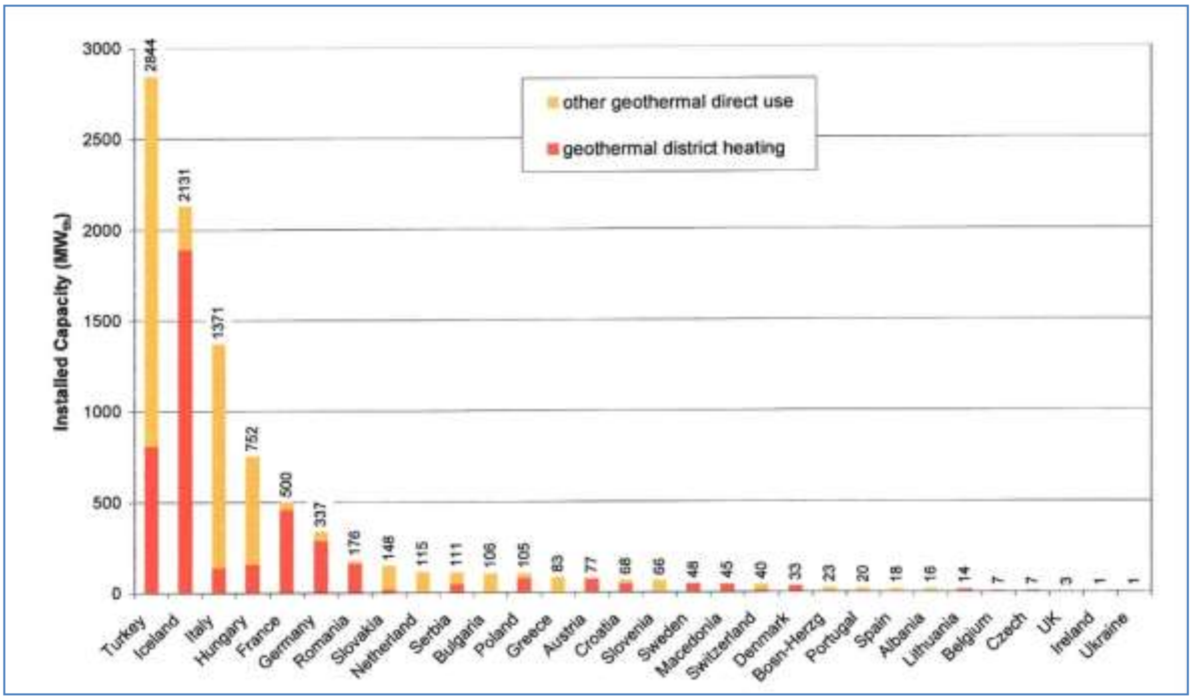


Fig. 1.11. Installed capacity in geothermal direct uses in Europe 2015 showing the share of district heating and position of Poland (Antics et al., 2016)

1.2.7. Geothermal investment projects, 2016–2017

Among investment activities in 2016–2017 one may list here:

- Several investments oriented for recreation and balneotherapy,
- Initial stages of a few projects aimed at CHP plants (based on ca. 90–110ºC water),
- Modernization, optimization of some operating geoDH plants (surface infrastructure, downhole equipment),
- Works on extension of existing geoDH systems. Some operators considered or prepared for drilling next wells (conditioned by the availability of financial support),
- Several pre-investment works and feasibility studies for various sites in the country (mostly recreation, sometimes space heating, also in the hybrid systems with other RES and fossil fuels),
- Projects of several deep new drillings: thanks to state support program introduced in 2016 more investments are expected in the coming years: by end 2016 over a dozen projects applications for supporting the drillings new wells (exploration, exploitation) were submitted to the National Fund for Environment Protection and Water Management and were in review process during preparation of this Report (spring 2017).

1.2.8. Overview of heat energy market in Poland

The main energy carriers used for heating purposes in Poland are fossil fuels. Approx. ¾ of thermal energy is produced from these carriers. The structure of fuel consumption for heating in 2015 is shown on Fig. 1.12. The share of other energy carriers, including RES, does not exceed 8%.

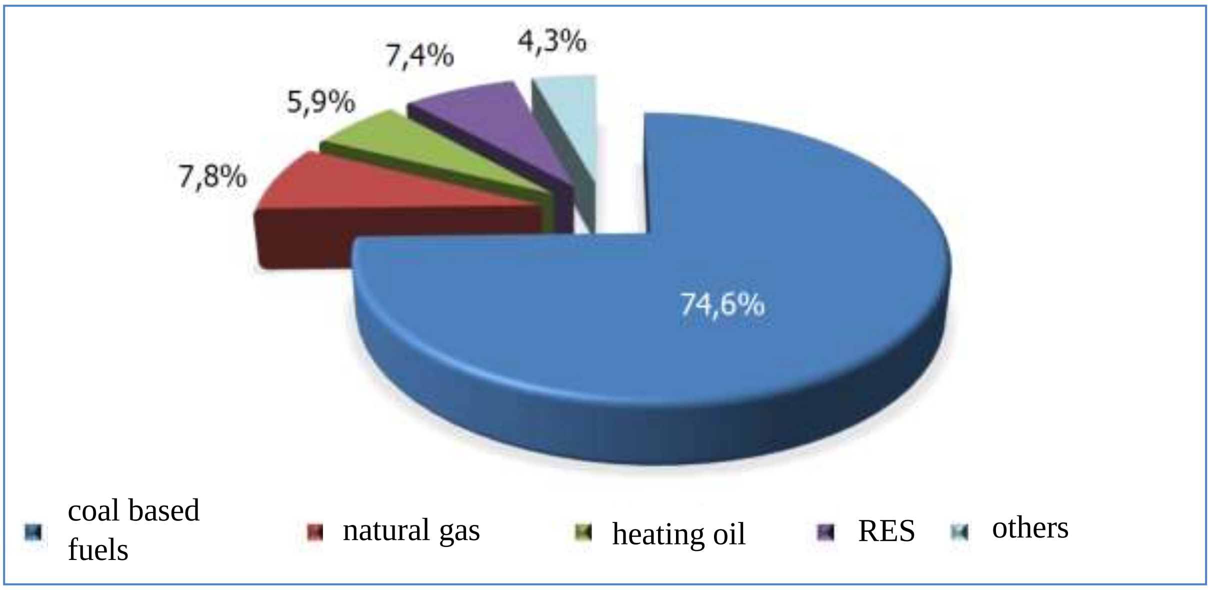


Fig. 1.12. The structure of fuels used for heat generation in Poland, 2015 (Buńczyk, 2016)

The price of energy used for heating strongly depends on the type of energy carrier. Table 1.2 shows the average price of thermal energy in the years 2014 and 2015 for selected heat carriers. The cheapest energy is related to lignite and hard coal as the primary energy carriers. The biomass price is approaching the price of energy from coal. Recently a dynamic dropdown of oil prices was observed, accompanied by a decline in energy prices generated by its use. Figure 1.13 shows average prices of thermal energy in the basic administrative territorial units of Poland – voivodships (regions). The average prices in these units differ because, *inter alia,* of different structure (types) of fuels used to produce heat. In 2015, these prices varied in the range from 46 to 62 PLN/GJ.

Table 1.2. The price of heat for chosen energy carriers, net values without distribution (Buńczyk 2016)

Type of fuel	Thermal energy price [PLN/GJ]	Dynamics of price changing 2015/2014 [%]	
	2014	2015	
Mean value	37.92	38.57	101.7
Hard coal	36.96	37.70	102.0
Lignite	25.84	26.42	102.2
Light fuel oil	102.07	84.77	83.1
Heavy fuel oil	38.02	37.63	99.0
High methane natural gas	61.45	55.41	90.2
High nitrogen natural gas	41.18	40.16	97.5
Biomass	39.60	40.94	103.4
Other RES	40.95	37.48	91.5
Other	37.03	37.00	99.9

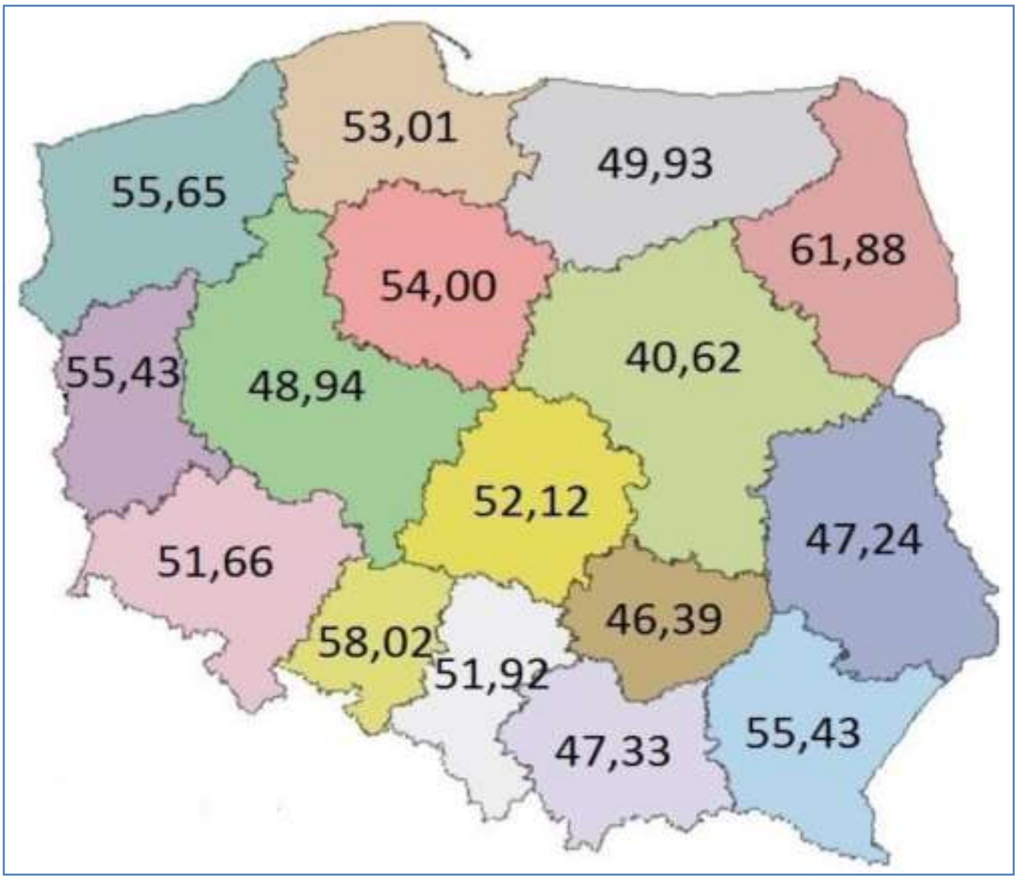


Fig. 1.13. The average net heat prices in particular voivodships (regions) in Poland, 2015 [PLN/GJ] (Buńczyk, 2016)

The Energy Law is a basic legal act obligatory for all large energy producers in Poland. According to it each energy producer of above 5 MW capacity must have a billing tariff approved by the President of the Energy Regulatory Office.

In case of companies dealing with energy transmission and distribution in instalments of capacity above 5 MW need to have legal licenses and tariffs, too.

Therefore, the billing tariff consists of two basic components:

1. Corresponding to the energy production costs,
2. Corresponding to the distribution costs.

Both the production and distribution costs contain both constant part of tariff (price related to ordered power) and variable part (price of energy consumed in real).

1.2.9. Geothermal heat prices vs. prices of heat derived from fossil fuels

Right at the beginning one shall point out that the prices of heat supplied by geothermal district heating plants are competitive with the costs of heat generated by incineration of fossil fuels – natural gas, fuel oil and even coal This fact creates a very important argument for wider geothermal heating sector development in Poland (specially in the cities where district heating systems are already existing).

The examples of billing tariffs are shown in Table 1.3 for the space heating companies based on conventional energy sources and geothermal energy. Fig. 1.14 shows the heat prices (approved on the bases of tariffs) for the final user. Fig. 1.15 corresponds with Table 1.3. The final price includes the cost of energy production and transmission. The presented data suggest that the price of geothermal energy is located within the interval typical for conventional energy carriers. In case of good reservoir conditions (temperature higher than 80°C and high flow geothermal water flow, e.g. Stargard and Podhale) the heat prices are comparable with those offered by coal-based heating plants. In other cases the prices are close to the heat prices originated from natural gas or fuel oil.

Table 1.3. The heat prices for final energy user in geothermal district heating plants and selected district heating plants based on fossil fuels (acc. to approved billing tariffs, net values as on June 2016 (Pająk, Bujakowski 2016)

No	Name of the tariff \ kind of the payment	Constant payment for ordered power (energy fee) c_{smz} $\left[\frac{PLN}{MW \cdot yr}\right]$	Payment for real energy used (energy fee) c_{ec} [PLN/GJ]	Price of energy carrier (fee for using the treated water from the district heating) [PLN/m^3]	Constant payment for ordered power (energy distribution fee) c_{sop} $\left[\frac{PLN}{MW \cdot yr}\right]$	Payment for Energy used (energy distribution fee) c_{zop} [PLN/GJ]
Geothermal district heating plants						
1	Geotermia Pyrzyce (the group of users A)	136138.44	40.90	18.03	42423.00	15.31
2	Geotermia Pyrzyce (the group of users B)	136138.44	40.90	18.03	31755.00	11.53
3	Geotermia Pyrzyce (the group of users B1)	136138.44	40.90	18.03	38628.48	15.47
4	Geotermia Pyrzyce (the group of users B2)	136138.44	40.90	18.03	16557.24	6.91
5	Geotermia Mazowiecka (the group of users M1 80/60°C)	114313.89	46.52	13.78	33203.06	10.98
6	Geotermia Mazowiecka (the group of users M2 70/50°C)	114313.89	46.52	13.78	29196.79	11.92
7	Geotermia Podhalańska (M1 an individual heating node)	74969.80	19.75	17.22	47107.40	14.65
8	Geotermia Podhalańska (M2 a heating node maintained by district heating operator PEC)	74969.80	19.75	17.22	51897.86	19.94
9	Geotermia Podhalańska (M4 a heating node maintained by district heating operator PEC)	74969.8074 969.80	19.75	17.22	59256.95	19.94
10	Geotermia Podhalańska (G direct energy supply)	47751.73	16.83	3.30	0.00	0.00
11	PEC Stargard (B1 PEC Stargard)	60572.13	26.26	44.99	20526.61	11.93
12	PEC Stargard (B2/1 PEC Stargard)	60572.13	26.26	44.99	37703.62	17.79
13	PEC Stargard (B2/2 PEC Stargard)	60572.13	26.26	44.99	31076.17	14.21
14	PEC Stargard (B3 PEC Stargard)	60572.13	26.26	44.99	39069.29	18.34
Selected district heating plants based on fossil fuels						
15	MPEC Kraków (KO–w, heating oil)	118169.64	72.48	-	0.00	0.00
16	MPEC Kraków (KG–w, natural gas)	126723.00	59.05	-	0.00	0.00
17	Dalkia Warszawa SA (A12B1C3, natural gas, Nurzynska Str. 1)	100814.64	59.34	13.23	23490.72	8.07
18	Geotermia Mazowiecka (S1 hard coal and biomass)	125211.16	34.44	12.09	35030.88	10.23
19	Dalia Warszawa SA (A15B1C1 hard coal)	71542.80	33.27	4.29	8247.84	3.17
20	Dalkia Warszawa SA (A3B1C221 district heating, MPO)	35801.88	25.65	7.72	28241.64	8.81
21	MPEC Kraków SA (S1 WGP a heating node maintained by MPEC)	67819.56	24.92	16.38	44205.24	16.38

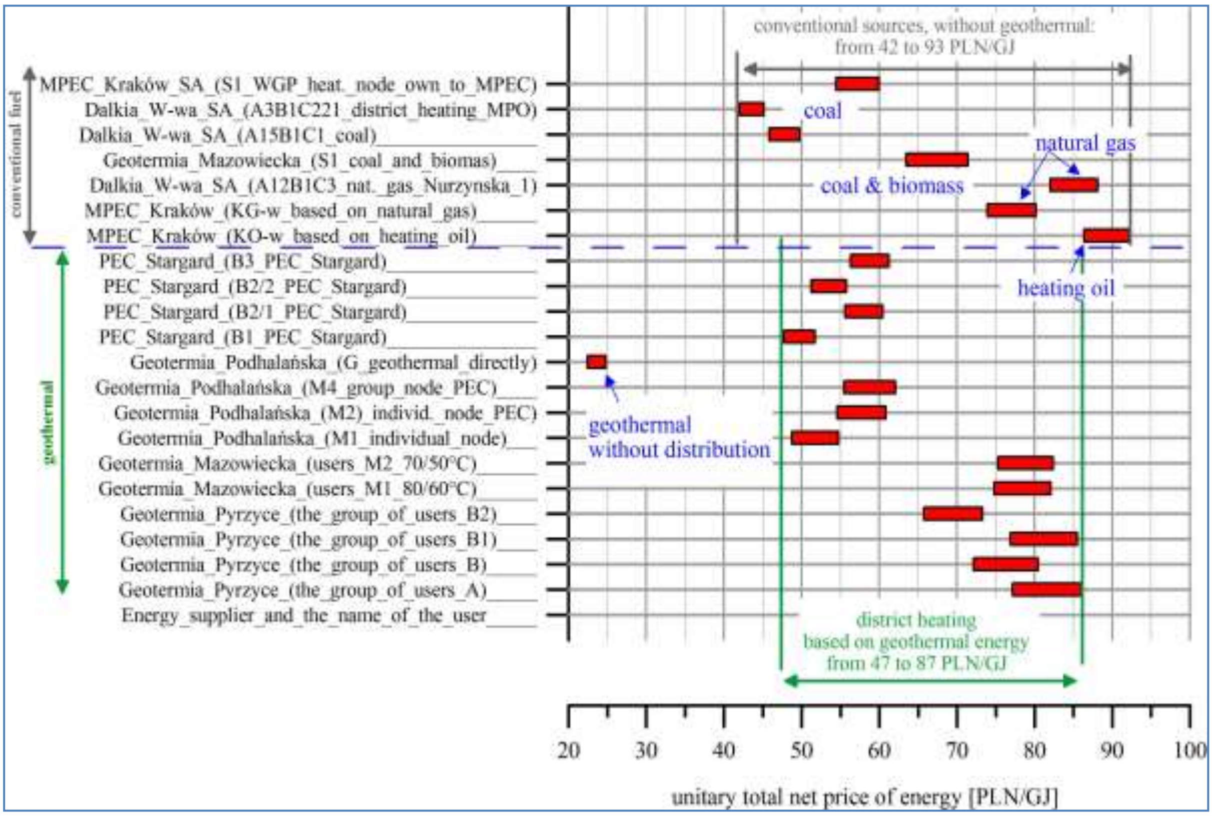


Fig. 1.14. Total net final thermal energy prices (including energy production and distribution) – geothermal district heating plants vs. selected district heating plants based on fossil fuels, June 2016 (Pająk, Bujakowski, 2016)

Selected technical parameters describing the heat market in Poland are shown in Table 1.4. The average efficiency of thermal energy production is approx. 87%, and a similar value is for the average efficiency of energy transmission and distribution. In connection with the dominating share of fossil fuels (Fig. 1.13) the indicators of emissions associated with the thermal energy production are similar to the emission factors associated with combustion of coal.

Table 1.4. Selected technical parameters of heat production in Poland (Buńczyk, 2016)

Parameter	Unit	Values in year			Dynamic of changes	
		2002	2014	2015	2015/2014	2015/2002
Efficiency of heat production	[%]	79.7	86.0	86.7	100.81	108.78
Efficiency of heat distribution		88.2	86.3	86.3	100.00	97.85
CO_2 emission	[Mg/TJ]	120.8	104.2	100.0	95.97	82.78
SO_2 emission		0.73	0.41	0.27	65.85	36.99
NO_X emission		0.26	0.15	0.21	140.0	80.77
Total particular matter emission		0.14*	0.04	0.03	75.00	28.57

*based on 2003 data

All geothermal heating plants operating in Poland are working as the part of a hybrid energy sources. Also heating plants in Stargard and Poddębice (which do not have other sources themselves i.e. as parts of geothermal heating stations) are working in combination with conventional heating stations (boilers). Geothermal parts serve as basic energy sources and conventional ones – as peak sources. The main problem in the wider use of geothermal in cooperation with district heating networks in Poland is the lack of coherence between the available parameters of geothermal resource (mainly in terms of temperature) and the design parameters of the existing heating systems. In large cities the most common heating systems are designed on the parameters of 130/70°C or even higher. Smaller heating plants usually are designed for the parameters of 90/70°C or 95/70°C. As Table 1.1 shows the highest temperatures of geothermal waters are a somehow over 80°C – but the use of heat exchangers limits the real temperature up to approx. 80°C. Geothermal plants' working as the parts of hybrid systems is usually a necessity, not a matter of choice. Unfortunately – the entities maintaining heating networks do not have the will to cooperate in reducing the required temperature parameters. The common approach is rather to match the source to the requirements of the recipient.

1.2.10. The cost structures of geothermal installations

A precise and universal evaluation of the share of capital (CAPEX) and operating (OPEX) costs in the case of geothermal energy in Poland – considering geological conditions is not possible.

CAPEX depend mainly on the expenditure on geothermal well. There are two possible ways to possess a well: to drill a new one or reconstruct the-already-existing (abandoned) well. The costs' approximation dependent on that part of the investment can be estimated based on Figure 1.15. Contribution of the well cost to the overall costs associated with the geothermal investment can be identified taking into account the lifetime of the well – it can be assumed as approx. 20–25 years.

OPEX are mainly related to energy consumption driving the peak boilers and electricity consumed by geothermal pumps. These costs can be estimated by knowing the amount generated by the source of peak energy and purchase primary carriers (Table 1.3). The price of electricity (not included in Table 1.3) can be assumed as 500 PLN/MWh net.

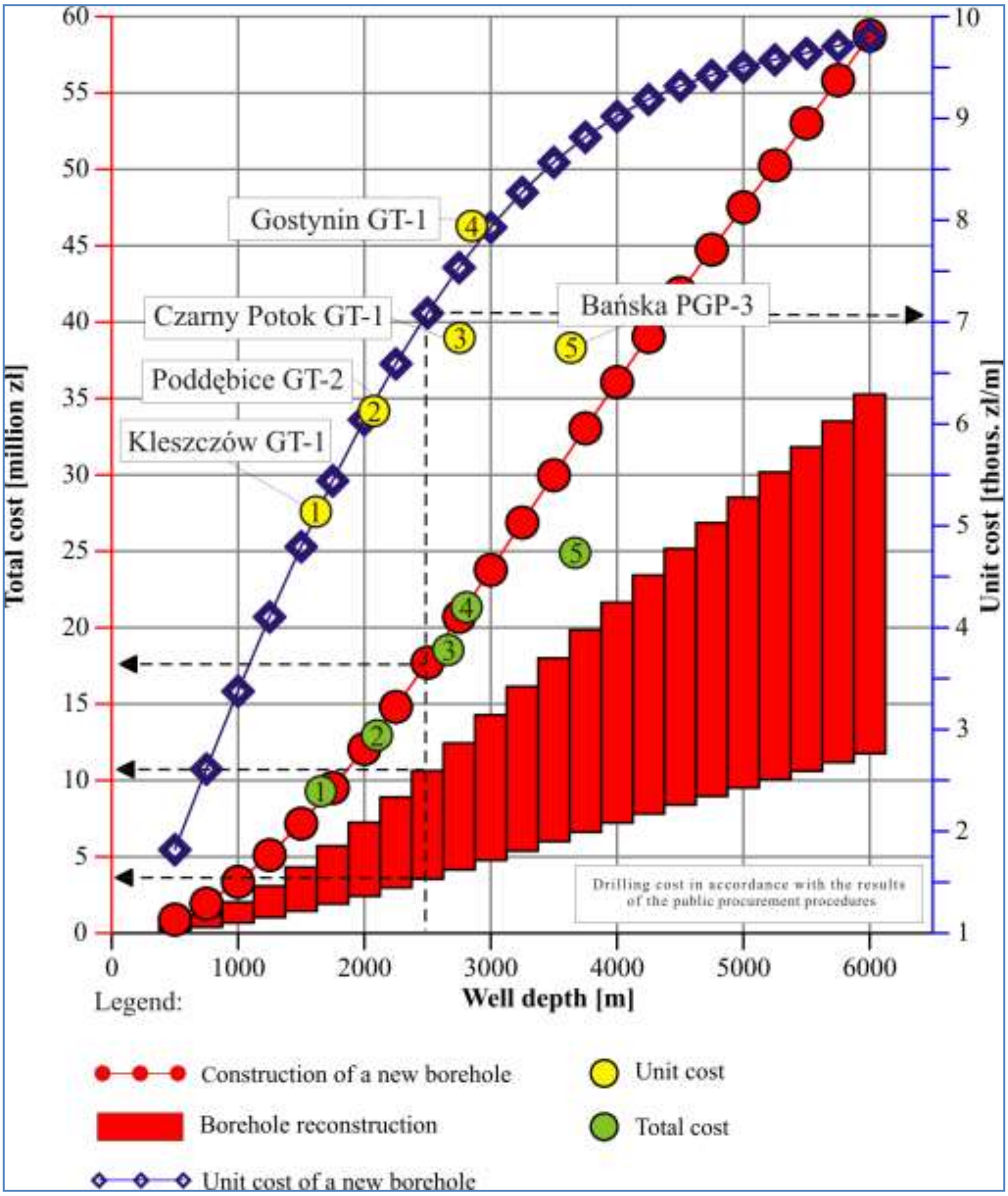


Fig. 1.15. Estimation of net costs of drilling a new geothermal well drilling or reconstruction of existing well (Barbacki et al. 2013 – modified by Hajto

1.2.11. Forecast of energy prices changes

Observing the trends of energy prices changes over the time it can be presumed that energy prices will constantly growing. Of course, in short periods of time it can be observed temporary reductions in energy prices - as for example happens in the last 2-4 years with the price of heating oil and in the last two years with the price of natural gas. Fig. 1.17 shows the energy prices' changes for selected carriers in the last 10 years. The reasonable assumptions of energy price changes with time for selected media are presented in the document "Updating the draft guidelines to plan the supply of heat, electricity and fuel gas for the city of Katowice" (in Polish) made by the company Energoprojekt Katowice (http://www.katowice.energiaisrodowisko.pl/energia-w-twoim-miescie/13-dynamika-wzrostu-cen). It was assumed there that the price of natural gas for individual consumers will rise by 4%/year, coal prices will grow by 3%/year, fuel oil by 3.5%/year. Net energy price change for the listed media is shown on Fig. 1.17. Open and so far ambiguous is the question of fees for CO_2 emissions. The introduction of such fees will be associated with the hock significant increase in energy prices of conventional media. At the moment estimation of the term of such growth is not possible because we do not known event the rates for the fees for emission of CO_2 into the atmosphere.

One also needs to point out that – following expected increase of prices for permission to CO_2 emissions by 2020 – the increase of prices for heat generated from fossil fuels (specially coal) is stipulated and, possibly, disconnections from the heating grids based on fossils' combustion. Since this situation will not occur in the case of geothermal – its prices will remain stable (and can be even more competitive than now) this is also one of the chances to increase its share in space heating sector in Poland.

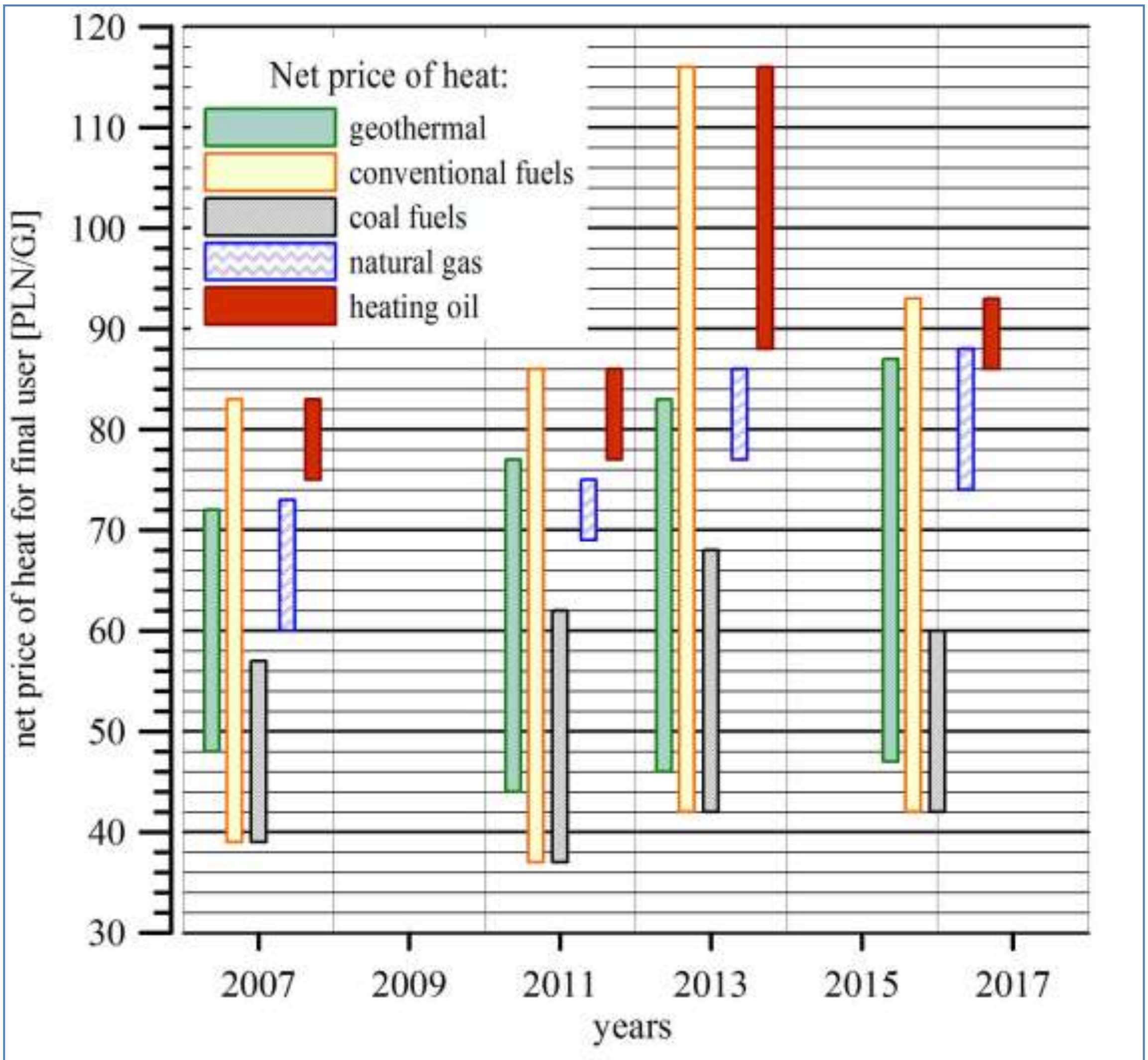


Fig. 1.16. Range of changes of net heat price for final energy consumers - real values based on approved tariffs (Pająk, Bujakowski, 2016)

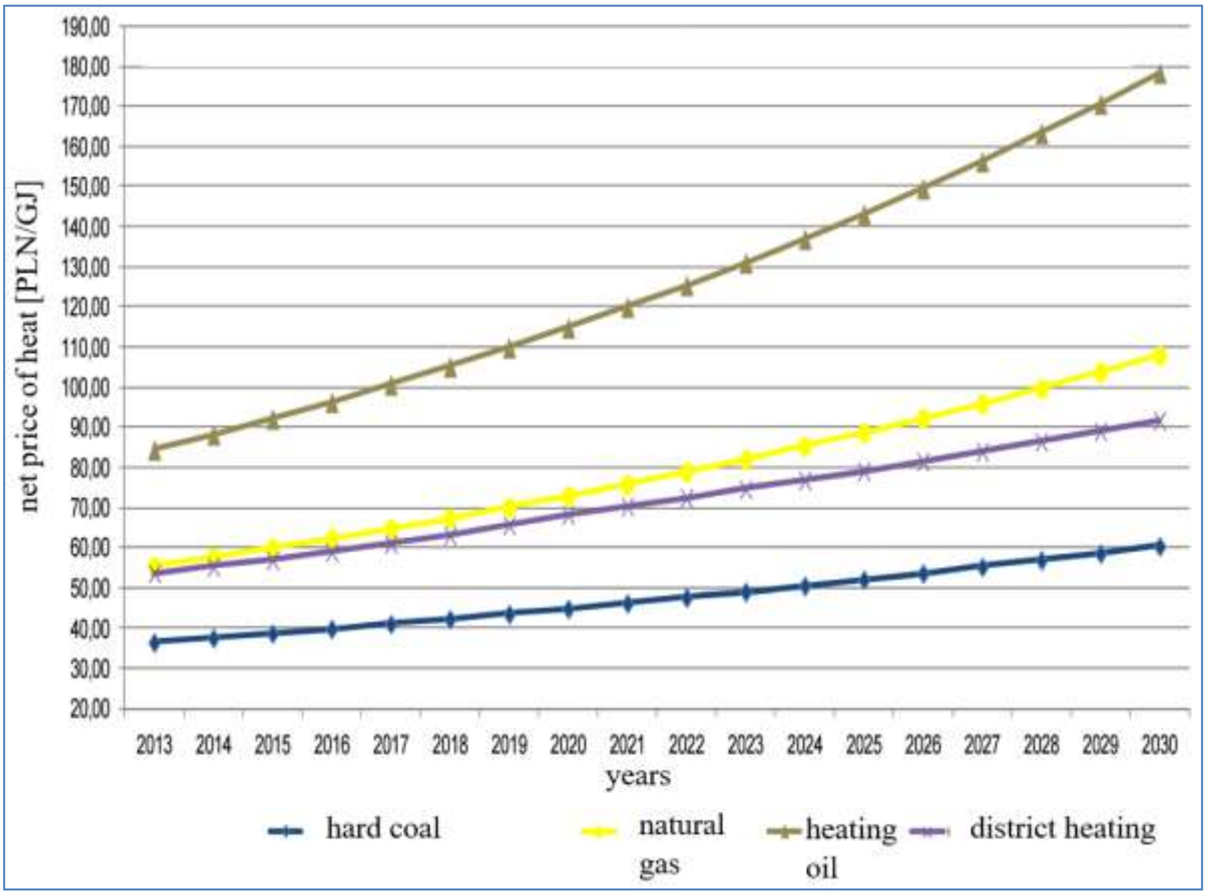


Fig. 1.17. Forecast of heat price changes in time for selected energy carriers (based on Energoprojekt Katowice; http://www.katowice.energiaisrodowisko.pl/energia-w-twoim-miescie/13-dynamika-wzrostu-cen)

1.2.12. Current geothermal share in RES mix and official prognoses

According to the EU-Directive "3x20" as well as Polish documents like "Energy Policy of Poland by 2030" and "National Renewable Energy Action Plan" (NREAP), in 2020 the share of renewable energy sources (RES) shall reach 15.5% in gross final energy consumption in Poland.

In case of heating and cooling sector, final energy consumption in 2020is expected to be 5921 ktoe, with the dominance of biomass – 86% share of all RES. The share of solar energy is set at 8.5%, while the forecasted share of geothermal energy is very low: 3% (without heat pumps), similar as heat pumps' share – 2.5% (including geothermal, hydrothermal and aerothermal ones). The NREAP does not include geothermal electricity generation (binary systems), even on a small scale (single devices with a capacity of tens – hundreds of kWe).

Taking into account the 2014 geothermal share ("deep") in RES heat production, i.e. approx. 0.35% and 0.5% for the heat pumps (Berent-Kowalska et al., 2015), it is clear that in order to achieve even this relatively low assumed geothermal share by 2020 further investments are needed, specially in district heating sector.

To illustrate the situation:
In 2011the total RES energy acquisition in Poland achieved ca. 325 234 TJ, i.e. 11,2% of total primary energy acquisition (Berent-Kowalska et al., 2012). The energy sector is dominated by coal with growing contribution of natural gas. The dominant share in RES mix came from solid biomass (85.57%). The next were: liquid biofuels(5.54%), wind (3.55%), hydro (2.58%), biogas (1.76%), biodegradable municipal wastes (0.41%), solar (0.13%) while geothermal energy was 0.16% only and heat pumps (all types) – 0.29% (installations in private households were not included in this latter share). Final brutto RES energy consumption was 303 698 TJ including 218 141 TJ for heating sector (cooling being a small portion), 46 479 TJ for electricity generation and 39 078 TJ for transport. The domination of heating sector in RES mix is striking but the geothermal contribution to it is very small; this is because the fact that geothermal so far has been not developed accordingly to the resources' potential, market and social interest.

In several past years the stagnation of geothermal investments oriented for space heating was noticeable despite the country has the appropriate potential and many arguments in favor of geothermal deployment (even if coal is and will remain the primary energy source accompanied by clean-coal technologies). The situation was largely the result of lack of public support system (former program operating by 2012 was closed), as well as the lack of a clear conducive state policy.

Currently one may expect wider geothermal deployment and coming closer to the NREAP 's numbers assumed by 2020. It is expected to be possible to some extent thanks to new state support program, as well as some amendments in RES Law, and other regulations introduced in 2016.

1.3. Evaluation of policy options for geothermal energy in Poland

1.3.1. Factors conducive to the wider geothermal uses development in Poland

Although the-so-far geothermal applications in Poland have been on a very 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 (a true "sleeping giant"),
- potential receivers,
- urgent need to shift from coal/fossil fuels heating systems into clean heating technologies in order to limit the smog phenomena and stop devastation of living conditions in many localities – winter period 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.,
- high public acceptance,
- the need to fulfill international and domestic obligations to increase the RES use and follow the rules of sustainable energy development,
- recently introduced (2016, 2017) state 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.

As already pointed out, 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 the country. In some of them it is possible to introduce geothermal what will bring important results, i.e.:

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

Moreover – as described before, geothermal heat prices are competitive with those obtained from fossil fuels, much more stable and slightly lower than heat from burning natural gas. This fact also justifies the purposefulness of geothermal heating development on much wider scale.

Currently one may expect wider geothermal deployment and coming closer to the target numbers assumed by 2020. It is possible thanks to new public support program, some amendments in RES Law, and other regulations introduced in 2016. The priority of geothermal uses shall have given to space heating - as a real chance to avoid or at least to limit the low-emissions generated by burning fossil fuels for heating in many localities (how it looked like in heating season 2016/2017 is shown on Fig. 1.18).

Fig. 1.18. Low-emission generated by coal-burning for heating in some Polish city. January 2017 (www.googlr.pl/search?q=smog, +2017 […])

1.3.2. Legal and regulatory environment for geothermal activities in Poland

In 2012 some regulations and faster administrative procedures were put into force in new Geological and Mining Law to facilitate geothermal deployment, including district heating, e.g.:

- One-staged license for exploitation, no license for exploration / prospecting of geothermal water,
- No royalty for geothermal water exploitation,
- No fee for the geological information for project purposes,
- Reduction of fees for geological information's use to exploit geothermal water (up to 1% of its value to end 2020).

It was expected that these provisions would effectively work thanks to introduction of complementary relevant provisions e.g. in Law on RES and at least by maintaining the measures of public support for the drillings (available for some years before 2012). It was pointed out by the experts that not only single provisions but a coherent *system* would be indispensable to make geothermal more competitive and marketable than the heat coming from other energy sources – specially coal (which dominates energy sector in Poland).
At this point one has to say that some Polish teams (e.g. MEERI PAS) took active part in several European projects addressing legal and regulatory geothermal aspects with strong intention to that their findings and recommendations would be welcome by decision makers to introduce them in Poland, too. Unfortunately, it did not happen.

It was only in 2016 when more long-awaited provisions and decisions facilitating geothermal energy development for heating were introduced:
- Some amendments into RES Law and other acts referring to RES sector (including geothermal), e.g.:
- introducing the legal concepts of specific /*sui generis/* autonomous Energy Regions (clusters, cooperatives) – as opening the possibility of new forms of business,
- several other regulations facilitating, among others, connecting the RES/geothermal heat to district heating systems (DH) – in that respect a regulation was proposed by the Minister of Energy on detailed scope of obligation and technical conditions of connection of installation and purchase of RES heat. This regulation contains e.g. the mechanisms that initiate the development and use of RES in heating networks, like (inter alia) possibility that RES heat can be supplied to return water from the heating grid
- this is important also for geoDH development.

- Strategy for Responsible Development (announced by the Ministry of Development, end 2016) – it contains the acations in energy and RES sectors which shall facilitate geothermal deployment, like e.g.:
- Promoting and initiating local projects (clusters) for energy production (->indication for RES' development) and energy efficiency in order to strive for energy self– sufficiency of municipalities and counties ("microgrids"),
- Introduction of energy– saving and high–efficient technologies,
- Support electricity and heat co-generation (CHP).

These provisions open the space and prospects for geothermal development, too.

The-above-listed provisions, together with earlier introduced (2012) positive regulations in Geological and Mining Law, allow to state that altogether they contribute to building the system facilitating geothermal energy development, specially for heating.

To give an impulse for taking-off of this sector, a state program of financial support for geothermal development – heating, was also introduced in 2016.

1.3.3. Program of financial support for geothermal development introduced in 2016

In 2016 the program of public support for geothermal (energetic uses) was launched by the Ministry of Environment to enhance wider development of this sector. It contains, inter alia, 200 mio PLN (ca. 45 mio Euro) allocated for drilling first exploration well and 500 mio PLN (ca. 113 mio euro) for drilling next well and for heating infrastructure (www.nfosigw.gov.pl). The beneficiaries will be local authorities, other investors, entities. Types of support are in form of grants (up to 100% for LAs), loans, capital investments. The program has already resulted in fact that over 30 projects applications for drillings and other works were prepared and submitted to program operator in end 2016 and beginning of 2017. Some part of them will be decided for funding in course of 2017.

Other funding opportunities for geothermal sector one can find in frames of national, EU-, NFM and EEA programs by 2020 and beyond (related to various thematic areas/objectives, etc. where one may find the space for geothermal).

1.3.4. Some constraints for geothermal energy development

Among some measures – still missing but indispensable to assure proper work and to maintain long term exploitation of geothermal plants one shall mention the risk guarantee fund (already operating in several states), common technical and consulting background for all plants, etc.

One shall also indicate still lacking sufficient level of knowledge and awareness of geothermal resources, development opportunities and manifold benefits among some circles of decisions makers, local administration, other potential stakeholders. Therefore, further dissemination and training activities tailored to the particular groups of receivers are needed.

In this respect one of the best opportunities are related with possibility to make use and transfer the best-practices examples, proven technologies and professional expertise from Iceland in frame of bilateral Polish – Icelandic cooperation in the framework of the EEA grants.

One shall also remember that energy sector in Poland – power generation, co-generation, heat production – has been based of coal (hard, brown) and natural gas. Therefore, to enter the market by other energy sources, like geothermal, is a challenging task all the more that market conditions are still not equal for all players. From the other hand, competitive heat prices, several benefits, ecological role, other factors and – last but not least – current political will shall ease to extend the geothermal share on several local and regional heat markets in Poland.

1.4. Conclusions, recommendations – prospect for geothermal energy uses for heating in Poland

1. Poland has prospective low-temperature geothermal potential (waters generally below 100ºC to the depths of 3-4 km b.g.l.) suitable for many direct uses, including space heating sector. However, geothermal uses' development is at an early stage so far. Only 6 geothermal heating systems have been operating (Poddębice is one of them). More dynamic development has been observed in recreation sector expressed by about 15 recreation centres put on-line in recent years (and 12 health resorts operating for many years or even centuries).

   Geothermal energy shall be used on much wider scale than now for district heating in many localities (this has to be treated as a priority) as well as for agriculture, aquaculture (specially organic food production), health treatment, recreation, etc. Locally co-generation of heat and power is possible (in binary schemes applying geothermal water from 80–100ºC; several hundred kWe to 1–2 MWe). Promising line of geothermal water uses can be created by production of mineral, drinking waters and several mineral by-products.
   These would give important results, like in Iceland, i.e.: low-emission heating (decrease of CO_2 emissions), improvement living conditions, increased use of local energy sources, sustainable innovative local and regional development. Geothermal can be part of hybrid energy systems, i.e. in integration with other both traditional and renewable energy sources, heat pumps, etc.

   Moreover – to increase energy saving and efficiency, it is recommended to approach more intensively the issues related to energy storage – like underground ATES, UTES technologies.

2. One can even state – as one of the conclusions from the bilateral EEA Project "Geothermal utilisation potential in Poland – town Poddębice" – that Poland can play a central role for geothermal development in Central Europe. Further Polish – Icelandic cooperation can greatly contribute to achieve this objective.

3. Several factors meet in Poland to start wider geothermal deployment for heating, i.e.:
   - suitable geothermal water resources' base,
   - existing district heating systems – ca. 500 in total in the country (!) – to some of them one can introduce geothermal heat,
   - good experiences, ecological effects, competitive heat prices offered by already operating geothermal heating systems,
   - need to follow low-emission and sustainable economy,
   - recently introduced by the government economic supportive tools to enhance geothermal energy development specially for heating (e.g. support for drilling the wells, other heating infrastructure),
   - opportunities for valuable international cooperation with top-class experts which would support professional and stable long-term geothermal deployment in Poland – Iceland is among the important ones among them. This will greatly contribute to build public awareness, apply modern and proven technologies, transfer best practices, making use of international funds – like EEA and Norway Grants – where Iceland is one of the donor states.

   There are also several missing instruments which shall be introduced to ensure stable geothermal development (in many aspects) in Poland – among them is geological / drilling risk guarantee fund (as in several other countries) and an institution / centre which would serve R&D and technical consultancy and services for geothermal operators and investors.

4. Geothermal energy shall be in a centre of further Polish – Icelandic cooperation. There are several important reasons for that, including the fact that Iceland is the European and world leader in geothermal energy uses also for heating. They result in zero-emission heating, good living conditions, cheap energy, sustainable development.

As main areas of mutual cooperation in geothermal sector one can give:

- Capacity building by study visits, specialised education and training by Icelandic side for current and future operators, investors, decision makers, local / regional administration, etc.;
- Technical assistance, consulting,
- Transfer of experiences, technologies, good practices in drilling, borehole measurements, well equipment, well stimulation, proper wells' exploitation reservoir modelling, energetic aspects, surface infrastructure, geoDH, technologies and methods of uses, etc.,
- R+D+I (research – development – innovation),
- Pilot and investment projects.

One shall add the existing basis for wider cooperation (inter alia):

- Interest of specialists (scientists, practitioners), potential investors, and governmental bodies in both countries.
- Introduction geothermal energy into expected new EEA / NFM period for Poland
- Successful realisation of EEA Project for Poland – Poddębice (subject of this Report). It paved the way for next EEA/NFM project proposal "Geothermal energy – a basis for low-emission heating, improving living conditions and sustainable development: study cases for selected areas in Poland". The core partners will be MEERI PAS, AGH UST and NEA joined by the partners from Norway, EGEC, Wroclaw University of Technology and four towns in Poland,

5. The-so-far geothermal heating in Poland has resulted in positive economic, environmental, social and other effects. Even though Polish energy sector is based on fossils / coal there are many opportunities for geothermal development and for international cooperation – also with Iceland.

6. Iceland and Poland can work together through the EEA Grants platform to invest in solid and long lasting geothermal infrastructure increasing energy security and independence and reducing carbon emissions lasting a lifetime.

The Project works for Town Poddębice also lead to recommendations and conclusions of a general nature for the whole Poland:

7. Introducing (also by state/ local regulations) the provision to install lower-temperature heating systems in newly-constructed buildings,

8. Heat price tariffs shall be conditioned by „Delta T" achieved by receiver – this as a very needed provision in Energy Law, other documents (!),

9. The-above-proposals shall be submitted as amendmends / provisions for relevant state regulations / documents and be subjects of serious considerations,

10. Other, e.g.: FiT; obligation to purchase geothermal heat; including geothermal / RES into return technological water.

11. The Project results lead to the conclusion and recommendation that the analysed topics shall be the subjects of further comprehensive analyses and works with the participation of its partners (may also others ones), as well as a pilot project,

12. It is of significant importance both for Poddębice and for other localities where geothermal wells and installations are operating or planned,

13. Opportunities to deepen and continue works initiated and done in this Project – e.g. in a framework of recent project proposal (another ppt) as well as next EEA/NFM for Poland.

2. Pre-feasibility study assessment of geothermal in Town Poddębice

Poddębice Town and Commune

In case of Poddębice town, the geoDH operator and local authority are interested in increase of geothermal energy uses by introducing geothermal heat to much more buildings than now through the extension of existing district heating grid. This project idea is also prospective for the purposes of this EEA bilateral Icelandic – Polish project (Poddębice town is a proper locality as a selected study case).

Main tasks (topics) of 2 as in Project proposal:
2.1. Geothermal reservoir
2.2. Geothermal utilization
2.3. District heating
2.4. Evaluation of policy options and opportunities

Poddębice Town and Commune – introduction

Location. Poddębice Town is located in the north-western part of the Łódź province in Poland. It is situated at a distance of approx. 10 km north of Poddębice *A2* motorway and approx. 1 km from the city railway line so-called "carbon line connecting Silesia with Gdynia" passes. Through the city runs a network of local roads. The project and headquarter of Geothermia Poddębice Ltd. is located at Mickiewicza 17 street in the south-western part of the city. This area is adjacent to the training area of sport club "LKS Ner." From the west, at a distance of about 160 m, the "Ner" river flows. Figure 2.1 shows location of Poddębice at the background map of Poland.

Fig. 2.1. Location of Poddębice Town (source of map: http://d-maps.com/carte.php?&num_car=4303&lang=en – modified by Hajto)

Population

Poddębice Town has about 7 750 residents while Poddębice Community – about 15 870. A positive natural growth amounts to 6.62. For a surface area equal to 225 km² population density is 71 people / km². The average age is 40.2 years being comparable to the average age of the inhabitants of the whole Poland.

Economy

The main sectors of the local economy and employment are:
- Agriculture, forestry, hunting and fishing (60.8% of economically active residents),
- Industry and construction (14.6%),
- Services (trade, repair of motor vehicles, transport, information and communication, etc.) (6.4%),
- Financial sector (financial and insurance activities, real estate services) (1.6%).

Approximately 2 950 people are economically active in Poddębice Community.

Electricity, gas and heat supply

These community's responsibilities were defined in the Strategy of Poddębice Community Development by 2023 and in the Program and Low Emission Economy of Poddębice Municipality.

Electricity. Municipality of Poddębice is powered through two 110/15 kV substations and main lines of medium voltage 15 kV. In the municipality are located 2 substations 110/15 kV, 162 substations 15/0.4 kV, 21.6 km of overhead lines of 110 kV and 201.1 km of overhead lines 15 kV, 27.1 km of 15 kV cable, 256.3 km of overhead lines 0.4 kV, 66 km of cable lines 0.4 kV. Lines of medium and low voltage, transformer stations and other electricity infrastructure are in good condition.

Gas supply

The operator of the gas distribution system in the municipality is the Polish Gas Company Ltd.. Branch in Warsaw. In the area of the municipality ca. 63 km of gas network (with connections) in operated, 741 gas connections, including 671 to residential buildings (as of 31.12.2015.).

Space heating

Before 2013 as main heat sources served local boiler plants fired by natural gas, fuel oil and coal. They supplied multi-family housing, single-family and own boiler rooms in public buildings. In 2012 the well Poddębice GT-2 was drilled and a geothermal district heating plant was built (2 heat exchangers, 5 MW each). From 2013 this plant supplies district heating grid (for space heating, hot tap water) including many public buildings (Poddębice Health Centre, schools, Complex of Poddębice Palace, outdoor swimming pools in sport centre).

Geothermal district heating system covers 100% of all users connected to heating grid, i.e. 50% of town area. The rest of demand (including institutions, service and production establishments) is covered with individual heat sources. Further geoDH's expansion is planned as well as drilling a second geothermal borehole (more information on geothermal heating system and other plans are given in further chapters of this Report).

Current heating market in Poddębice town.

The total heat demand in Poddębice town is ca. 17 MW. Currently geothermal energy covers 5 MW of this total demand. The further development plan (version minimum) assumes that in the coming years 2 MW will be covered by heat pump (based on geothermal heat) and ca. 3–5 MW by gas peak boiler (reserve one).

2.1. Geothermal reservoir

2.1.1. Historical background of Poddębice geothermal project

The beginnings of the project date back to 2000 year when the first "Project on geological prospecting of geothermal water resources in The Town of Poddębice" (Górecki, et. al., 2000) was prepared by "Geos" (Geosynoptics Society), associating mainly the researcher from AGH UST. It assumed the exploitation of geothermal waters by the doublet of production and injection wells.

Later on in the period 200–2007 several changes of the concept of use of geothermal waters in the Poddębice have been made. In 2007 the final version led to implementation of the geological project approved by the municipal authorities and the company of Geotermia Poddębice Ltd. In the end of the preliminary stage, in February 2008, the project has gained an approval of the Commission for Hydrogeological Documentation of the Ministry of Environment of Poland. According to the project the development plan assumed drilling of one borehole to the depth of 2039 m, and production of geothermal water from the Lower Cretaceous aquifer (the lower and middle Albian, Aptian and Barremian ages). The project assumed the use of 62ºC water with mineralization around 8–13 g/L, and the outflow of about 180–190 m^3/h for wide range of applications: from recreational through balneotherapy to heating purposes as well. Project also assumed that after extraction of the heat and cooling down to about 30–35ºC geothermal water would be discharged into the Ner river.

The 50% of the funds for drilling came from the National Fund for Environment Protection and Water Management and the remaining 50% from the Poddębice Community as the only owner of the Geotermia Poddębice Ltd. The Poddębice GT-2 well was drilled in 2009–2010 (Figs. 2.2 and 2.3).

Fig. 2.2. Poddębice GT-2 well drill rig in 2009 (arch. Geotermia Poddębice Ltd.)

Fig. 2.3. First tasting of fresh geothermal water in 2010 (arch. Geotermia Poddębice Ltd.)

2.1.2. Geological background of Poddębice geothermal project

Poddębice GT-2 well is located in the central part of Permian–Mesozoic geological unit called the Mogilno–Łódź trough, which is a part of bigger syncline structure – the Szczecin–Łódź–Miechów trough, extending from the Fore–Sudetic monocline to mid–Poland swell. From the east the Łódź basin borders with Kujawy swell – a tectonic unit with strongly developed salt tectonics. From NW the basin touches the Mogilno through.

Geological structure of the Łódź basin is complex, what is mainly connected to the salt movement. This phenomenon causes local disconformities, rapid changes of sediments' thickness, especially in proximity of anticline structures, that were formed here during upper Triassic, upper Cretaceous and during cusp of Cretaceous and Paleogene. Creation of anticlinal structures in the Poddębice area was caused by underlying salt layers' tectonic dislocations that used to be active during sedimentation of Mesozoic rocks. In complete development and small thickness of surroundings salt pillows sediments, e.g. Lower Cretaceous formations was caused by regional salt tectonics where salt structures are penetrating or uplifting Cretaceous layers, among others – salt anticlines of Koło and Poddębice (Fig. 2.4).

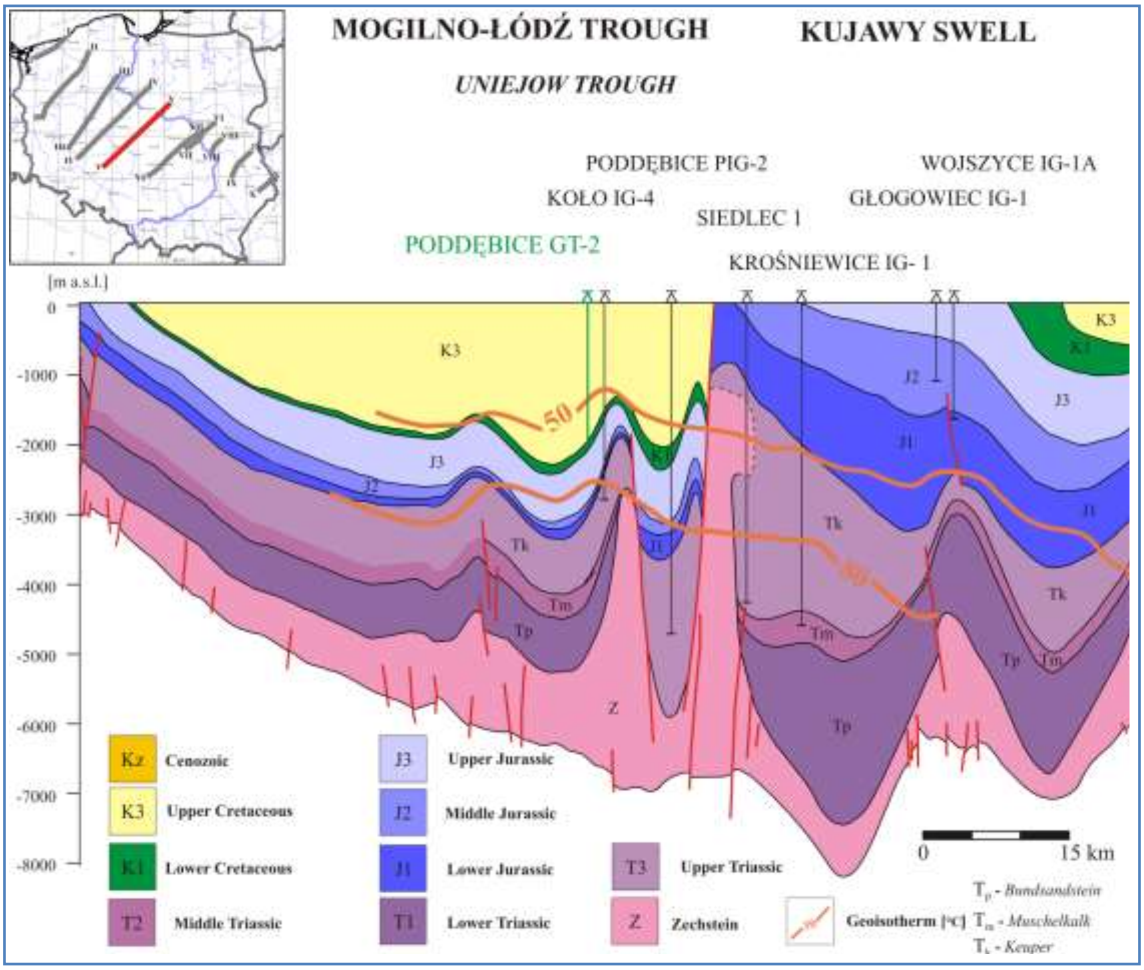


Fig. 2.4. Geological cross-section through the Polish Lowlands with location of Poddębice GT-2 well ([in] Górecki [ed], Hajto et al., 2006a)

The Łódź basin area was crossed by an axis of maximal subsidence of Upper Cretaceous basin. Thus its sediments in the Poddębice area are of its maximum thickness, approaching up to 2600 and 3000 m (near Koło and Turek, respectively), whilst in the Poddębice vicinity ca 1952 m.

Rock formations aged from Triassic to Quaternary are present in geological structure of described area. The oldest recognized sediments are fine-grain sandstones and mudstones of lower Triassic, interbedded with limestones, underlying by Zechstein formations. Overburden consists of evaporite-clastic series of Röt, composed of anhydrite, dolomite and mudstone layers. Muschelkalk is developed as pelitic and marble limestone facies. Upper Triassic is build up with fine-grained sandstones with clayish interlayers, melting into claystone. The series of pelitic sandstone with uncommon mudstone interbeds close Triassic sedimentation. Total thickness of Triassic formations reaches about 2000 m.

Above Triassic occur strongly reduced Lower Jurassic (Lias) sediments, which thickness of c.a. 37 m, mainly developed as sandstone with claystone interbeds.

The Dogger (middle Jurassic) is represented by dolomitic mudstone, shading into glauconite sandstone. The Upper Jurassic (Malm) formations are thicker, up to 600 m, and are developed in carbonate facies – limestones, marbles and dolomite, mudstone and collaterally – sandstone. The Poddębice GT-2 well reached top of Upper Jurassic formations, formed as limestone facies, represented mainly by light-grey marbles and marble limestone, locally containing sand. Top of Upper Jurassic was reached at depth of 2072 m beneath the surface.

The Lower Cretaceous formations in the Poddębice area lack older stratigraphic stages. The profile starts with Hauterivian, formed as clay–mudstone facies. Occurring here dark fuscous mudstones are interlayered with claystone, are sediments specific for shelf part of sedimentary basin. Insubstantial is thickness of Hauterivian equal to 7.0 m. Hauterivian deposits, together with Upper Jurassic marbles constitute natural sealing between geothermal reservoir in overburden and Jurassic aquifer.

Over Hauterivian present are grey fine- and medium-grained sandstones of terrigenous origin, constituting geothermal aquifer complex of Albian, Aptian and Barremian stages – found also in Poddębice area. In the Poddębice GT-2 well they are located at depth interval 1962–2063 m beneath the surface, with claystone interbed in the interval of 2001–2004 m. Top part of the sandstone (above the clay layer) contains rock skeleton of high purity with locally occurring glauconite, and is characterised by better reservoir parameters (porosity of 17%). In lower part of the profile, that is deeper than 2027 m beneath the surface, present are interlayers of mudstone, quartz grains are smaller, whilst porosity is of about 14%. Clay content in the footwall of the sandstone reaches level of 23%. Thickness of sandstone layers is 98 m (considering clay interbed of 3 m thickness).

Deposits of Upper Cretaceous – mainly marles, creamy–grey limestones and marble limestones, locally with dark fuscous claystone occur in the depth interval 10–1962 m beneath the surface. Cenomanian is represented with specific limestones and creamy marble limestone, which together with Upper Albian. Turonian is dichotomous/bipartite: bottom part is marble-clayish, whilst top part is marble-limestone. Upper Turonian deposits are marked with presence of siliceous rocks (flints) within marble limestones and marbles. Coniacian, Santonian and Campanian complex are layers of alternant marble limestones and marbles of grey colour.

Maastricht, the latest part of Upper Cretaceous, is represented only by its earliest facies, later deposits were eroded. Maastricht formation mainly consists of marble limestones with marble claystones and marble mudstones in the overburden. At depth of 10 m beneath the surface Cretaceous formation reaches its top and is covered by yellow, medium-grained sand.

The vicinity of the Poddębice GT-2 well lacks the Paleogene and Neogene deposits. Their erosion was caused by glacial processes, intensity of this process was increased by uplifting Mesozoic formation.

Lithostratigraphical characteristics of Lower Cretaceous geothermal reservoir

In Poddębice area the main geothermal aquifer is hosted by Lower Cretaceous sandstones – porous fine-grained, locally medium-grained. The top of the reservoir in the Poddębice GT-2 well was confirmed at depth 1962 m beneath the surface, whilst its base at depth 2063 m.

Geothermal water is under high pressure – static water table occurs at 26 m above the surface (assessment based on wellhead static pressure). The top part of the water-bearing complex (up to the surface) is composed of grey, fine-grained, comparatively pure, aged at Lower Albian. In 2001– 2004 m depth interval there is an intercalation of fuscous claystone and mudstone. Lower, occur grey fine-grained sandstones, deeper than 2027 m beneath the surface – with scant amount of mudstones.

In mineralogical composition of sandstones quartz is strongly dominating, constituting 95% of detritus volume. Accessory components are particles of silica rocks, feldspar, glauconite and clay minerals. Sandstones contain mainly a siliceous cement with minor addition of secondary carbonate or clay (illite) cement. Quartz grains are rounded and well-sorted, their size is in range 0.2 to 1.3 mm. With depth in sandstones increasing is the amount of clay fraction, in the footwall (Barremian sandstones) reaching 23%. From the depth of 2063 m beneath the surface impermeable Hauterivian formation occurs (mudstones and claystones) which underlies Lower Cretaceous geothermal aquifer. At depth of 2070 m beneath the surface, sealing beds are transiting into carbonate Upper Jurassic formation.

Basic reservoir parameters of Lower Cretaceous aquifer in the Poddębice area

The Lower Albian-Aptian-Barremian (Lower Cretaceous) sandstones recognised at depth interval 1962-2063 m of Poddębice GT-2 well are rather homogenous. Aquifer horizons are characterized by high porosity (13.7–17.0%) and permeability (87.98–1021.10 mD). Analysis of core samples shows the content of carbonates – calcite and dolomite. Content of carbonates is minor, in majority of samples lower that 2.0% of calcite and 1.0% of dolomite. Carbonates in sandstones of Lower Cretaceous are component of rock's cement, thus are minor component of the rock.

The reservoir sandstones are characterized by relatively good reservoir properties:

- Intergranular porosity equal to 16–23% (lack of secondary porosity);
- Low clay minerals content (average VCL=9.8%);

- Good general permeability (average PERM=176.5 mD);
- High resistivity of reservoir water (average Rwa=2,6 Ωm) resulting from its low mineralization;
- Significant effective thickness NET=98.0m;
- Good productivity coefficient PJI*NET=17.76 nV/V;
- 100% of sandstones saturated with reservoir water.
- Exploitation parameters of geothermal water reservoir in Poddębice
- Exploitable reserves of geothermal water discharged by well Poddębice GT-2
- Exploitable resources of the Poddębice GT-2 water intake were determined by “Dodatek nr 1 do dokumentacji hydrogeologicznej otworu Poddębice GT-2” (“Appendix 1 to hydrogeological documentation of Poddębice GT-2 well”). That document was accepted by the Łódź Voivodeship Marshal (decision RŚV.7437.3. 2015.BC, 5 March 2015). As a basis of determining exploitable resources of Poddębice GT-2 well were the results of well testing conducted on 29–30 October 2014.
- Approved exploitable resources of the Poddębice GT-2 water intake amount to Q=252 m^3/h, at dynamic water table (in heated up well) at depth of 85.3 m b.g.l. and the water wellhead temperature equal to 68.4°C. The mining area equal to concession’s area amounts to 7.18 km^2.

During the first stage of reservoir’s utilization, exploitation is planned to be performed with artesian outflow. Artesian pressure of geothermal water with current liner (well screen) allows exploitation of 116.5 m^3/h, what is enough to cover the heat demand at the summer time.

2.1.3. Drilling and well design

The drilling of Poddębice GT-2 well was was conducted from 10 October 2009 to 28 of January 2010 with TD–160 type drilling rig, rotational method with drilling mud down to 2101 m. Drilling begun with drilling tricone bit of 580 mm diameter (0.0–84.0 m), then has been continued with 444.5 mm diameter drilling bit down to 450 m. In interval down to 1974.0 m the 311.0mm diameter drilling bit was used, to the top of Lower Cretaceous sandstones. The sandstones were drilled through with 216.0 mm drilling bit and diamond core drilling bit of 141.0 mm diameter for core extraction.

Drilling stopped after drilling through the Cretaceous formation (base at depth of 2070 m b.g.l.) within Jurassic formation at depth of 2101 m with 216.0 mm diameter drilling bit. In interval 2070.0–2101.0 m, within clay–carbonate formation of Upper Jurassic the clay plug was made. Then, widening of the well with hydraulic drill bit of 381 mm (15”) diameter has begun in interval 1970.0–2070.0 m depth in order to obtain increased well’s diameter for sand gravel and increased well’s productivity. The Johnson’s type well screen (filter) have been set within 1914.5–2065.0 m depth interval. The space around the screen was lined with sand of 0.71–1.25 mm granulation. When well construction had been finished, a hydrogeological test was conducted.

During the well drilling, succeeding casing sets were inserted following the instructions from Project of geological works. This action allowed safe continuing the drilling process, in compliance with expected geothermal purpose further exploitation conditions. Condition of the cementing was examined in geophysical survey with RBT type acoustic cement bond logging tool.

When drilling process was over, liner has been inserted into the well and fixed with hanger on 9 5/8” casing set in 1914.5–2065.0 m depth interval. Active part of the Johnson’s filter was placed in 1957.0– 2059.0 m depth interval. Top part of the liner (1957.0–1964.0 m) has been located within 9 5/8” casing.

After inserting the liner and conducting entire set of research and reservoir’s tests, the wellhead on 13 3/8” casing was installed. Simplified well design of Poddębice GT-2 well is shown in Table 2.1.

Table 2.1. Simplified casing design of Poddębice GT-2 well

Casing	**Casing diameter**	**Depth of interpose (m beneath the surface)**	**Cementing depth (m beneath the surface)**
	18 5/8"	84	84
	13 3/8"	450	450
	9 5/8"	295-1964	305-1964
Liner	Type and diameter of pipe	depth (m below the surface)	Length (m)
	Hanger 7" with a sealant	1914.5-1916.7	2.2
	Crossover 7"x 6 5/8"	1916.7-1917.0	0.3
	Dielectric connector 6 5/8"	1917.0-1921.0	4.0
	Subfilters pipe 6 5/8"	1921.0-1933.0	12.0
	Safety filter 6 5/8"	1933.0-1939.0	6.0
	Subfilters pipe 6 5/8"	1939.0-1957.0	18.0
	Johnson filter 6 5/8"	1957.0-2059.0	102.0
	Subfilters pipe 6 5/8"	2059.0-2065.0	6.0

Fig. 2.5 shows hydrogeological cross-section of Poddębice area and location of geothermal aquifer in well Poddębice GT-2, while Fig. 2.6–2.9 illustrate the results of interpretation of geophysical borehole measurements within reservoir section of that well: temperature (quasi-stable conditions); lithological-reservoir characteristics; reservoir formation's porosity and permeability.

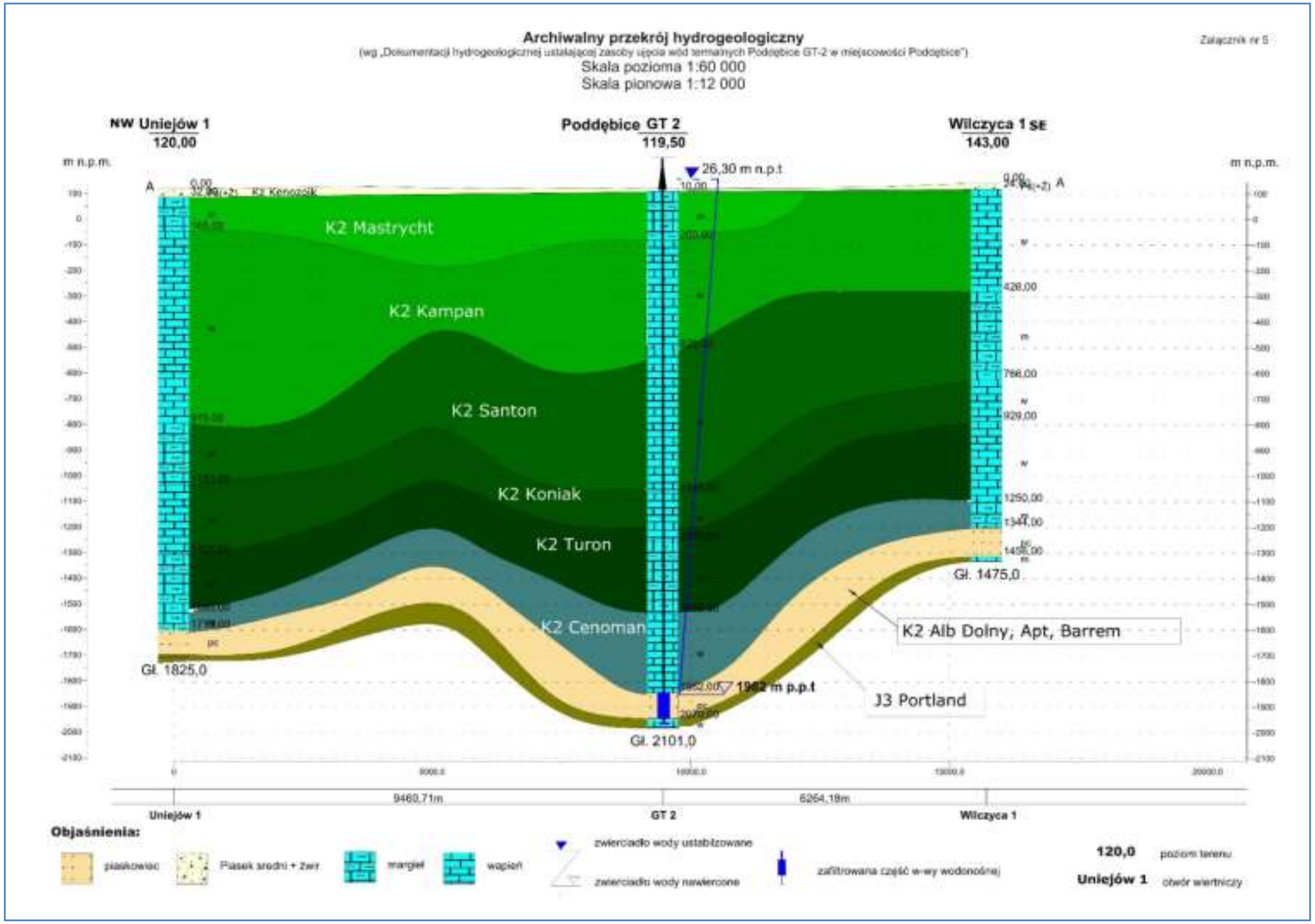


Fig. 2.5. Hydrogeological cross-section of Poddębice area and location of geothermal aquifer in well Poddębice GT-2 (in: Hydrogeological documentation …, 2010)

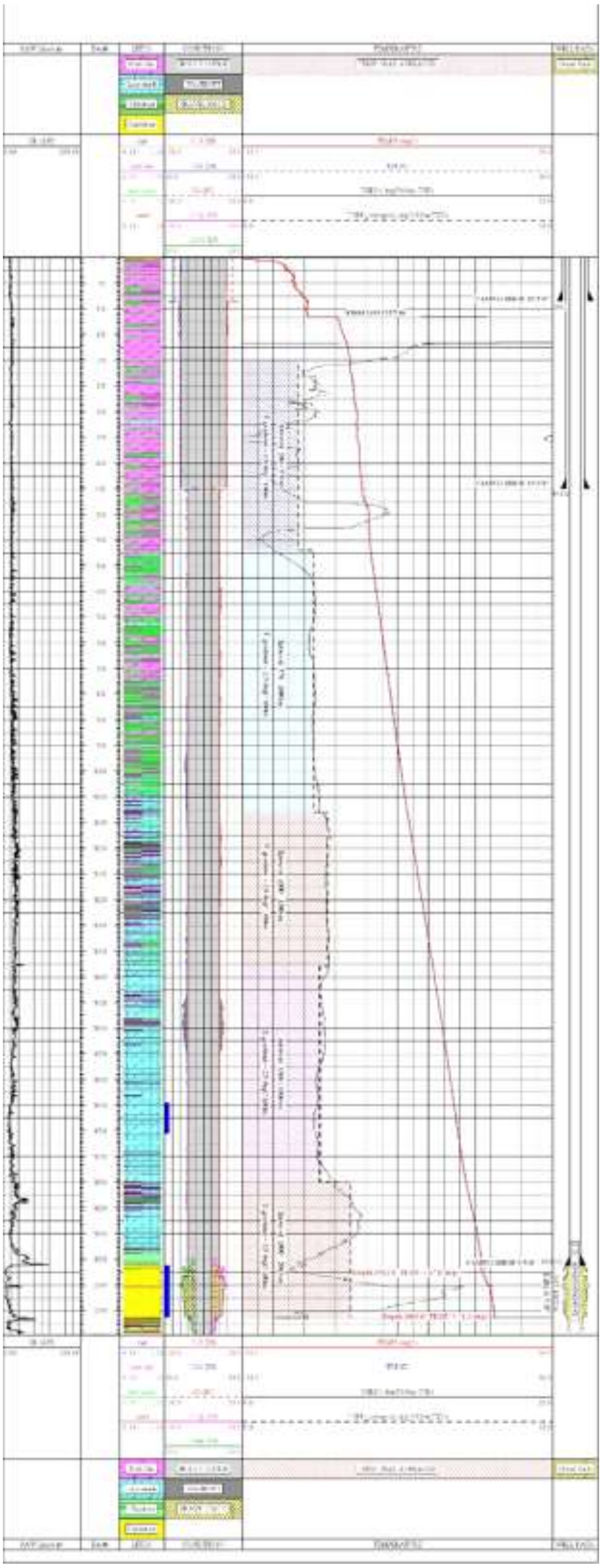


Fig. 2.6. Temperature log (in quasi-stable conditions) in Poddębice GT-2 well (in: Hydrogeological documentation …, 2010)

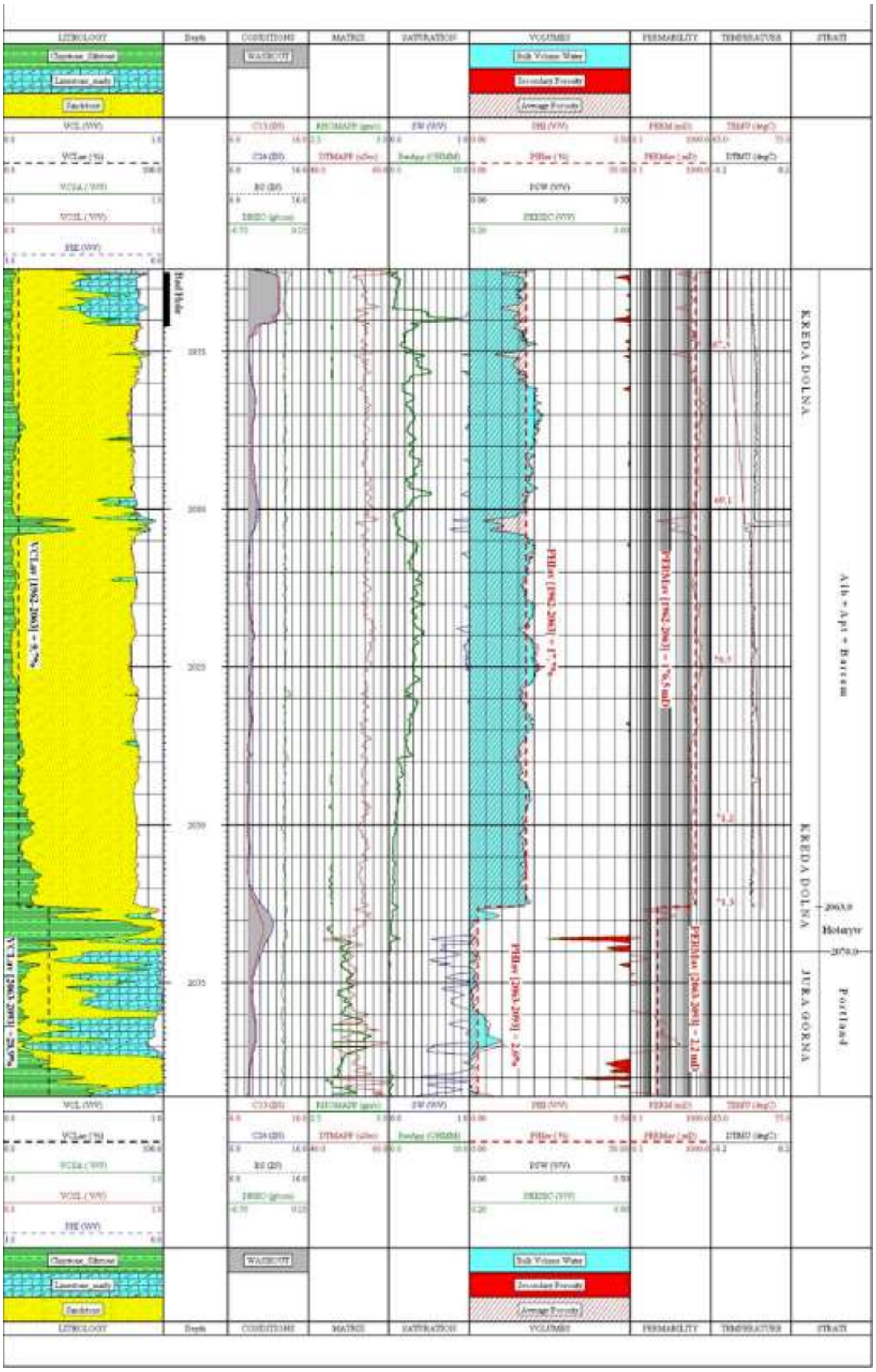
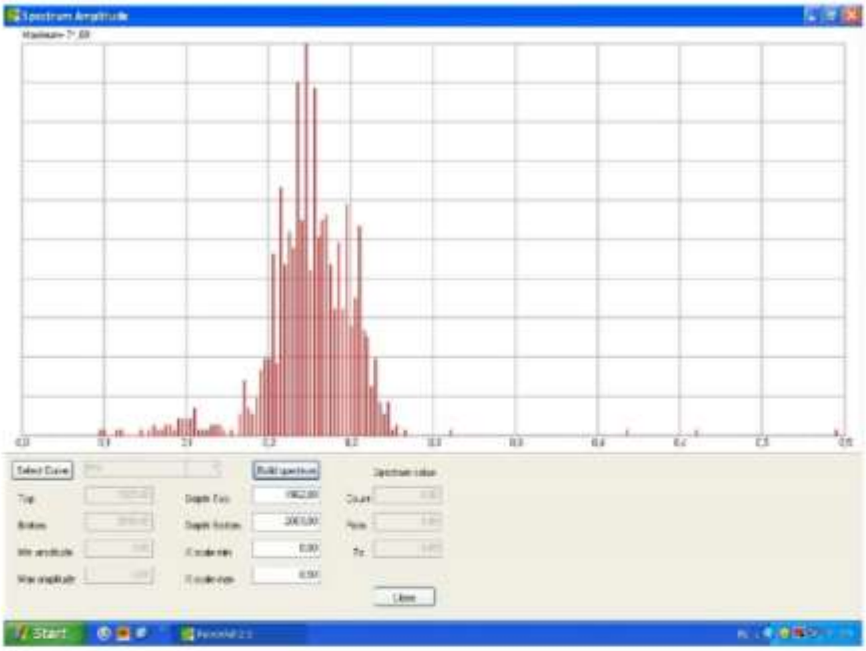


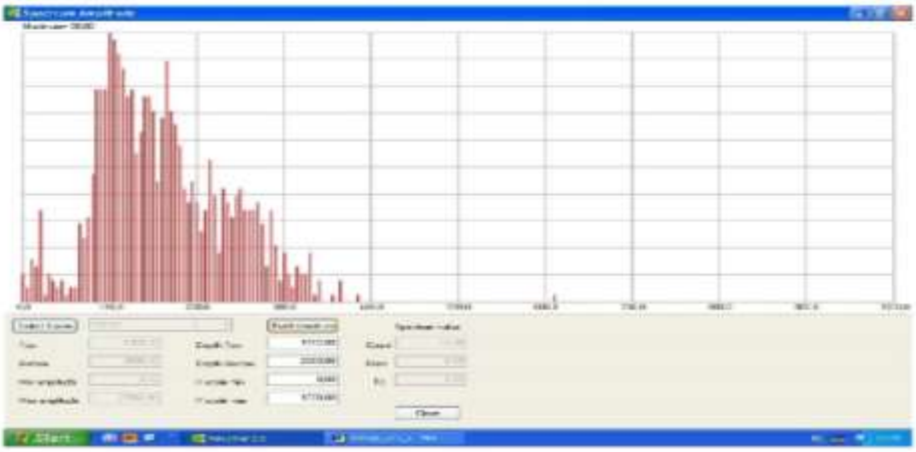
Fig. 2.7. Lithological-reservoir characteristics of reservoir section in well Poddębice GT-2 (in: Hydrogeological documentation …, 2010)



Wyniki histogramu:

Curve	Top	Bottom	Net	Min	Max	Mean	Median	Mode	Std Dev
PHI	1962.0	2063.0	101.0	0.049	0.410	0.177	0.176	0.175	0.036

Fig. 2.8. Formation porosity in reservoir section of well Poddębice GT-2 (interval 1962 – 2063 m) (in: Hydrogeological documentation …, 2010)



Wyniki histogramu:

Curve	Top	Bottom	Net	Min	Max	Mean	Median	Mode	Std Dev
PERM	1962.0	2063.0	101.0	2.141	363.8	176.498	151.583	183.148	683.078

Fig. 2.9. Formation permeability in reservoir section of well Poddębice GT-2 (interval 1962 – 2063 m) (in: Hydrogeological documentation …, 2010)

Well Poddębice GT-2 – basic information on well and hydrogeological parameters evaluated on the bases of pumping tests in 2010 and 2014:

- Drilling period: 10.10.2009 – 28.01.2010;
- Total depth of the well: 2101.0 m;
- Position of wellhead / ground level: 120.83 m a.s.l. / 119.5 m a.s.l.);
- Depth of geothermal aquifer: 1957.0 – 2059.0 m;
- Total reservoir fm thickness: 102 m;
- Effective thickness: 98 m;
- Location of Johnson screen /active production interval/: 1957.0 - 2059.0 m (102.0 m).
- Reservoir rocks: Lower Cretaceous (Lower Albian–Aptian–Barremian) sandstones: fine-grained, sometimes medium-grained, from 2027 m down some intercalations of clays and mudstones (intercalation of clay layer in 2001–2004; 3 m). Sandstones: grains dominated by quartz /95%/, accesoric – siliceous clasts, feldspars, glauconite, clay minerals. Quartz grains are well rounded and sorted, radius 0.2–1.3 mm. Matrix: siliceous, minor contribution of carbonates (less than 2% of calcite and less than 1% of dolomite) and clays;
- Integranular porosity: 16–23% (no secondary porosity);
- Effective porosity of sandstones: 13.7–17.0% (primary porosity, no secondary) (Hydrogeological documentation …., 2010);
- Low clay content: average VCL = 9.8%;
- Permeability: 87.98-1021.10 mD, (average PERM = 176.5 mD),
- Productivity index PHI*NET = 17.76 nV/V;
- Artesian outflow: 116.5 m3/h, s=26 m a.g.l (above ground level), calculated wellhead static pressure 2.6 at – values at particular construction/dimensions of wellhead (observed during pumping tests both in 2010 and 2014);
- Note: short after drilling, after several pumpings in January 2010: s=26.3 m a.g.l., calculated static wellhead pressure was 2.63 at);
- Bottom reservoir pressure – not measured (neither in 2010 nor in 2014 – technical reasons);
- Water age: ca. 10 000–14 000 years (most likely);
- Water mineralization: 432 mg/L

Well tests results

In 2010 well tests were performed in several series:

1. Cleaning pumping – 19 Jan 2010 (airlift, Q = 115 – 150 – 200 – 250 m^3/h; (each level – 3 hrs). After each pumping the pressure (artesian) stabilized fast up to 26.3 m a.g.l. (above ground level)
2. Pumping tests – 1-2 Feb 2010 – with downhole pump TVS 10.2-4/2A:
   - Q = 120 – 180 – 240 – 290 (3 hrs each) (preceded by artesian flow for 20 hrs, Q=115 m3/h);
   - taking samples for physico–chemical analyses, isotopic, gas content, etc.;
   - Self-flowing (Q = 115 m^3/h, no pump) – for 30 days from 9.02-10.03.2010 - long-lasting test to evaluate the stability of physico–chemical water composition;
   - 10.03.2010 – water sampling for chemical analyses (at the end of test);
   - 27.08–15.09.2010 - self-flowing (Q = 112 – 132 m^3/h – finally stabilized at 116.5, no pump) - test to observe and measure hydrogeological parameters (Q, T, p) and take samples for physico-chemical water analyses.
3. Pumping test – exploitation test 28.09 – 5.10.2010 – with downhole pump TVS 10.2-4/2A placed at depth of 110 m b.g.l. (results are in Table 2.2):
   - Q = 150 – 190 – 240 – 290 m^3/h (24 – 72 – 24 – 24 hrs, 24hrs break between pumpings – during each break the pressure recovered to initial one, i.e. 0.26 MPa, 26 m a.g.l.) (preceded by artesian flow for 20 hrs, Q=115 m^3/h);
   - Water sampling for physico–chemical analyses (end of 2nd and 3rd pumping stage).

Table 2.2. Pumping production tests – main results (28.09 – 5.10.2010)

Pumping stage	Approved exploitation reserves	Max. out flow temperature	Depression	Productivity index	Duration of pumping
I	Q = 150 m^3/h	70.5°C	S1 = 39.4 m	q1 = 3.80 $m^3/h/1m$	24 h
II	Q = 190 m^3/h	71°C	S2 = 50.2 m	q2 = 3.78 $m^3/h/1m$	72 h
III	Q = 240 m^3/h	71.5°C	S3 = 69.1 m	q3 = 3.47 $m^3/h/1m$	24 h
IV	Q = 290 m3/h	72.0°C	S3 = 85.5 m	q3 = 3.39 $m^3/h/1m$	24 h

Tests on 28.09–9.10.2010 gave a basis for formally approved water reserves (exploitation reserves) as follows: Q = 190 m^3/h, depression in the well s = 50.2 m, outflow water temperature 71°C.
Water reserves increased to 252 m^3/h were approved after tests in 2014 – see brief summaries in Table 2.3.

Table 2.3. Main information on approved reserves as on 30 Nov 2010 (acc. to Hydrogeological documentation, 2010)

Name of well	Approved exploitation reserves	Wellhead temperature for a given flowrate	Static water level in a heated-up well	Dynamic water level in a heated-up well for a given flow rate	Water type Mineralization
Poddębice GT-2	190 m^3/h	T = 71°C Q = 190 m^3/h	h = 145.5 m a.s.l.	h = 95.3 m a.s.l. Q = 190 m^3/h	HCO3-Na-Ca 432 mg/L
Exploitation reserves of water intake	190 m^3/h				
Resource area = 4.21 km^2					
Mining area = 4.2 km^2					

After completion of tests in 2010, the well was closed and started in 2012 (but initially it was flowing not constantly). Regular exploitation started in 2013 initially under artesian conditions, than the downhole pump was installed – for higher flow rates (in some cases / periods exploitation was again without pump – artesian, specially during summer period).

29-30.10.2014 – next pumping / hydrodynamical test:

- Maximum flowrate from the well Q=252 m^3/h, s=85.3 m, i.e. 60.2 m a.s.l. (heated-up well), outflow water temperature T=68.4°C (stable in relation to flow rate and temperature);
- Water transmissivity: 4.184 m^2/h – representative for Poddębice GT-2 well;
- Radius of depression cone for Q=252 m^3/h, R=857 m;
- Effective porosity of sandstones (average): ηe=0.155, 98 m of effective aquifer thickness.

Pumping test done on 29–30.10.2014 gave a basis to increase the formally approved water reserves (approved exploitation reserves), which are presented in Table 2.4.

Table 2.4. Well Poddębice GT-2 – main information on approved water reserves based on 2014 tests (acc. to Annex to Hydrogeological documentation, 2015)

Name of well	Approved exploitation reserves	Wellhead temperature for a given flowrate	Static water level in a heated-up well	Dynamic water level in a heated-up well for a given 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 = 60.2 m a.s.l. Q=252 m^3/h	HCO3-Na-Ca 432 mg/L
Exploitation reserves of water intake	252 m^3/h				
Mining area = 7.18 km^2					

Summary of main parameters of water intake in Poddębice GT-2 well, according to 2010 and 2014 pumping tests documentation is presented in Table 2.5.

Table 2.5. Summary of main parameters of the water intake of well Poddębice GT-2 (acc. to 2010 and 2014 pumping tests)

Year of well tests	2010		2014
Source of information	Hydrogeological Documentation, 2010		Annex no. 1 to Hydrogeological Documentation, 2015
Parameter	Unit	Value	Value
Exploitation reserves (approved) Qe	m^3/h	190	252.0
Productivity index, q	$m^3/h/1$ m of depression	3.78	
Water transmissivity	m^2/h		4.184
Depression during exploitation, Se	m	50.2	85.3
Radius of depression cone, R	m	556.0	857
Static water level	m a.g.l. (above ground level)	26.0	26.0
Elevation of static water table	m a.s.l. (above sea level)	145.5	145.5
Depth of dynamic water table	m b.g.l.	24.2	59.3
Elevation of dynamic water table	m a.s.l.	95.3	60.2
Elevation of ground	m a.s.l.	119.5	119.5
Elevation of water intake (outlet of pipe)	m a.s.l.	120.83	120.83
Hydraulic conductivity (k_{ave})	m/s	0.0000137	
Water mineralization	mg/L	432	432
Outflow water temperature	°C	71 (temporal flow 300 m^3/h)	68.4 (69ºC)
Stratigraphy of reservoir rocks	Lower Cretaceous		
Depth of reservoir	m b.g.l.	1962–2063	
Type and diameter of screen (filter) in reservoir		Johnson 6 5/8'	Johnson 6 5/8'

Physico-chemical parameters of geothermal water discharged by Poddębice GT-2 well

2.1.4. Geothermal water chemistry

The analysis of geothermal water from Poddębice GT-2 well presented here was done for the sample taken on 14 January 2015. The analysis was performed in National Institute of Public Health – National Institute of Hygiene, Warsaw, Poland. Sampled water temperature at the intake was 67.7°C, discharge was 151 m^3/h. The results of the analysis of main ions and physicochemical parameters of the geothermal waters are given in Tables 2.6–2.8 and on Figure 2.10.

Table 2.6. Main physico–chemical parameters of geothermal water from well Poddębice GT-2

Colour (mg Pt)	1
Odour	without foreign odor
Taste	without foreign taste
pH	6.96
Total hardness (mg/L CaC03)	98
Oxygen consumption (ChZT - mg O_2/L)	1.0
Conductivity (mS/cm)	0.4780

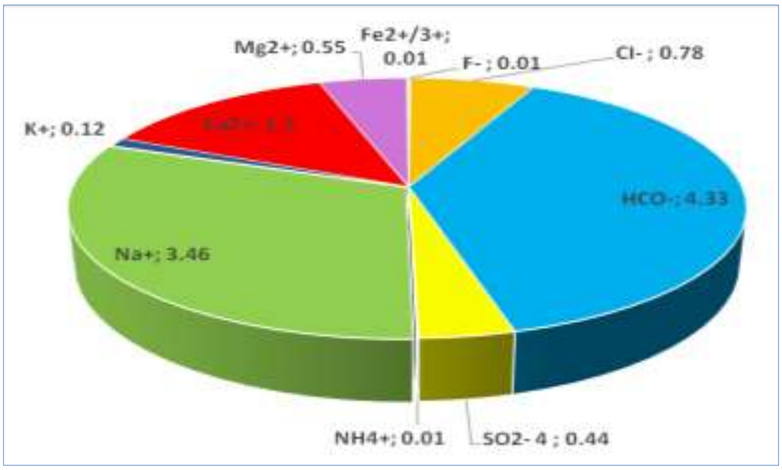


Fig. 2.10. Chemical composition of geothermal water from Poddębice GT-2 well (mval/L)

Table 2.7. Contents of chemical ions in 1 liter of geothermal water, well Poddębice GT-2

ANION	mg/L	mval	mval%
F^-	0.11	0.01	0.18
Cl^-	27.65	0.78	1.03
Br^-	<0.05		
J^-	<0.02		
HCO_3^-	263.80	4.33	77.88
SO_2^{-4}	20.88	0.44	7.91
NO_2^-	<0.02		
NO_3^-	<0.88		
CN^-	<0.01		
SUM	**312.44**	**5.56**	**100**

CATION	mg/L	mval	mval%
NH_4^+	0.25	0.01	0.18
Li^+	< 0.01		
Na^+	79.70	3.46	61.24
K^+	4.80	0.12	2.12
Ca^{2+}	30.06	1.50	26.55
Mg^{2+}	6.68	0.55	9.73
$Fe^{2+/3+}$	0.25	0.01	0.18
Sa^{2+}	< 0.10		
Mn^{2+}	< 0.02		
Ai^{3+}	< 0.01		
Cu^{2+}	< 0.01		
Ni^{2+}	< 0.01		
Zn^{2+}	< 0.01		
Cd^{2+}	< 0.003		
Pb^{2+}	< 0.01		
$Cr^{3+/6+}$	< 0.01		
Hg^{2+}	< 0.001		
Se^{2+}	< 0.01		
$As^{3+/5+}$	< 0.01		
$Sb^{3+/5+}$	< 0.005		
SUM	21.74	5.65	100

Table 2.8. Undissociated components in geothermal water from Poddębice GT-2 well (mg/L)

HBO_2	< 0.50
H_2SiO_3	33.98
CO_2	< 1.00
$H_2S + HS^-$	< 1.00

Sum of undissociated components amounts 468.16 mg/L (mainly sodium bicarbonate $NaHCO_3$ and calcium hydrogen carbonate $Ca(HCO_3)_2$), relative error of analysis was 0.8% and permissible relative error of analysis was ca. 5%. Summary of main physicochemical parameters of described geothermal water is presented in Table 2.9.

Table 2.9. Results of physico-chemical analysis of geothermal water from Poddębice GT-2 well (sample taken on 14 January 2015)

		Results	**Expanded uncertainty**	**Analysis' procedure identification**
pH	-	7.0	±0.3	PN-EN ISO 1 OS23:2012 (A)
Temperature in the field	°C	60.1	±9.1	KJ-I-S.7-43 (A)
Electric conductivity in temperature of 20°C	µS/cm	478	±48	PN-EN 27888:1999 (A)
Na	mg/L	66.5	±6.7	PN·EN ISO 17294-2:2006 (A) ,(E)
Mg	mg/L	4.43	±0.89	PN·EN ISO 17294-2:2006 (A) ,(E)
K	mg/L	4.60	±0.92	PN·EN ISO 17294-2:2006 (A) ,(E)
Ca	mg/L	26.4	±5.3	PN·EN ISO 17294-2:2006 (A) ,(E)
Mn	mg/L	11.6	±1.2	PN·EN ISO 17294-2:2006 (A) ,(E)
Fe	mg/L	0.20	±0.02	PN·EN ISO 17294-2:2006 (A) ,(E)
HCO_3	mg/L	253	±26	PN-EN ISO 9963-1:2001 +Api :2004 (A)
CO_2^{3-}	mg/L	< 2.0		(NA)
SO_4^{2-}	mg/L	13.3	±2.7	PN-EN ISO 10304-1 :2009 (A)
F^-	mg/L	23.3	±4.7	PN-EN ISO 10304-1 :2009 (A)
Cl^-	mg/L	0.18	±0.04	PN-EN ISO 10304-1 :2009 (A)
Br^-	mg/L	<0.05	-	PN-EN ISO 10304-1 :2009 (A)
General hardness	mg CaCO3/L	<5.0	-	PN-ISO 60S9:1999 (A)
Colour	mgPt/L	<5.0	-	PN-EN ISO 7887:2012 (A)
Threshold odor number (TON)	-	<1.0	-	PN-EN 1622:2006 (A)
Permanganate index	mg/L	10.2	±1.1	PN-EN ISO 8467:2001 (A)
NH_4^+	mg/L	0.38	±0.08	PN-EN ISO 11732:2007 (A)
NO_3^-	mg/L	<4.50	-	PN-EN ISO 1339S:2001 (A)
NO_2^-	mg/L	<0.03	-	PN-EN ISO 1339S:2001 (A)
TDS	mg/L	218	±44	KJ-I -SA-1S4 (A)

According to hydrogeological criteria water discharged by Poddębice GT-2 well shall be characterized as 0.046% geothermal water containing mainlysodium 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 $CaC0_3$), neutrality (pH=7) and a low iron content (0.35 mg/L). Particular advantage of water from the Poddębice GT-2 well is its high temperature at the intake and original purity.

Gas contents

Gas analysis was done in February 2010. Gas sample was taken from above water level. Gas volume above water was 371 ml. The sample contained 89% of atmospheric 0_2. That quantitative analysis was done without contaminating 0_2 content. The results (shown in Table 2.10) are related to temperature of 0°C and pressure of 101.325 kPA for real gas.

However, one shall note that the 2010 conditions of gas sampling and significant contamination by external atmospheric oxygen made that analysis not representative from quantitative point of view. Hence gas analysis shall be done again for sample taken in proper way.

Thermodynamical state of geothermal water from Poddębice GT-2 well

Table 2.10. Results of gas analysis, geothermal water from Poddębice GT-2 well (sample taken on February 2010)

Gas	Volumetric %	g/L
CH_4	0.007	0.607
C_2H_6	<0.0005	0.065
CO_2	1.552	370.525
N_2	6.716	1014.263
He	0	0
H_2	0	0
CO	0	0

General thermodynamical analysis of geothermal water discharged by Poddębice GT-2 well was done using chemical analyses from 2013 and 2015 (the latter fully representative). The aim was to evaluate tendency for precipitation of secondary minerals from that water during exploitation and cooling (as effect of heat extraction). The evaluation was done by NEA.

The chemical composition of the water is shown in Table 2.5. The measured water temperature during sampling was between 70–60°C, with low silica content as well as most of the major elements. Total dissolved solids are low as well as the salinity.

Relatively high is a magnesium concentration – there are two possible explanations of this fact:
(i). cold water contamination at present time (similar like in Icelandic conditions) or (ii). taking into account geological situation in Poddębice and vast areas of Poland – glaciated several times in geological past (Pleistocene): high Mg content (specially in presence of relatively high Na) in HCO3 – water type can indicate the recharge in inter-glacial periods colder than now. This could be also the case of Poddębice (specially that water age was estimated for at least 10 000 yrs or even more).

However, if first option would take place, i.e. cold water contamination / inflow is really occurring currently it can be a concern for Poddębice geothermal system and needs more detailed studies.

The WATCH program (Arnorsson et al., 1982) was applied to calculate whether amorphous silica or calcite would precipitate at utilization at above mentioned temperatures. The calculation indicated no precipitation what is a good information from production and utilization point of view.

In case of gasses dissolved in geothermal water produced by Poddębice GT-2 well, CO_2 was detected. This gas has corrosive features. One shall avoid also water de-gassing at the outflow specially when flow rate is planned to be increased. Because of very poor quality of former sample taken in 2013 (air-contaminated), new gas analysis and gas/water ratio shall be done soon to look more accurately if gases can cause any corrosion problems.

2.2. Geothermal utilization

2.2.1. Overview of current geothermal uses in Poddębice town

At the first phase of the project implementation AGH UST team has made an inventory and analysis of basic reservoir data and exploitation parameters of Poddębice GT-2 geothermal water intake reported during 6 years of production history. Information was collected both during the study visit in Poddębice held on 5-9th of Sept. 2016 and later on, while desk review of the data was performed. Essential part of the data and information came from the research on archive, hydrogeological documentation and reports on assessment of geothermal reserves that have been made twice in 2010, just after completion of drilling and during the second phase operation of the system and preparation of appropriate documentation and reports on assessment of exploitation reserves made in 2015, assuming the increase of geothermal water exploitation rate of Poddębice GT-2 intake to 252 m^3/h.

(Information, data and figures provided by Anna Karska and Andrzej Peraj, Geotermia Poddębice Ltd.)

In Poddębice for the first time geothermal water was discharged by Poddębice GT-2 well on January the 18th, 2010. Geothermal reservoir and exploitation parameters were as follows:

- Water flow rate: from 116.5 m^3/h (artesian) to 190 m^3/h (with downhole pump; that capacity was approved in exploitation license issued in 2010),
- Maximum water well head temperature: 71^{o}C (for temporary water flow rate ca. 300 m^3/h),
- Water mineralization and type: 0.442 g/L, bicarbonate-sodium-silica-calcium type.

Currently (2016–2017) geothermal water is used for:

- district heating,
- balneotherapy,
- swimming pools (recreation),
- drinking (on a limited scale).

Heat supply to the consumers started in February 2013. The sketch showing current and planned geothermal energy and water uses in Poddębice is shown on Fig. 2.11.

In 2012–2014, a 10 MW_{th} geothermal heating plant as well as hot water pipelines were built. They allowed to transport geothermal heat to all public facilities and multi-family residential buildings. In total Geotermia Poddębice Ltd. heats nearly 100 buildings (5,000 people). The closure of 3 local boiler stations (which currently serve as peak and reserve sources) contributed to air protection by reducing gases and dusts' emission. The total length of heating transition network, distribution network and grid connections which enabled the geothermal heat delivery to consumers is over 12 km (Fig. 2.12). The company employees 7 persons.
The total investments costs 12 Mio PLN included: drilling the well (12 mio PLN), heat exchangers station and 1.5 km of network and 5 connections (7.3), 4 km of transmission pipelines (7.8).

Further geothermal water uses are swimming pools (attended by tens of thousands of people every summer season); rehabilitation treatments in the hospital; possibility of tasting an originally pure 27,000 years old water in Geothermal Water Drinking Bar.

In 2015 the new license increased the maximum production up to 252 m^3/h of 68.4^{o}C (up to 69ºC) geothermal water.

2.2.2. Depth of down hole pump in well Poddębice GT-2

At the initial stage of water production (2013) the flow from the was artesian (up to 110–116 m^3h) and no downhole pump needed. In January 2014 along with the increased heat demand, the geothermal water production increased (up to 190 m^3/h) via downhole pump placed 36 m b.g.l. Later on - for approved water reserves 252 m^3/h – it was moved down to the depth of 90 m b.g.l.(exact depth – while in hydrogeological documentation the depth of ca. 100 m b.g.l. is given).

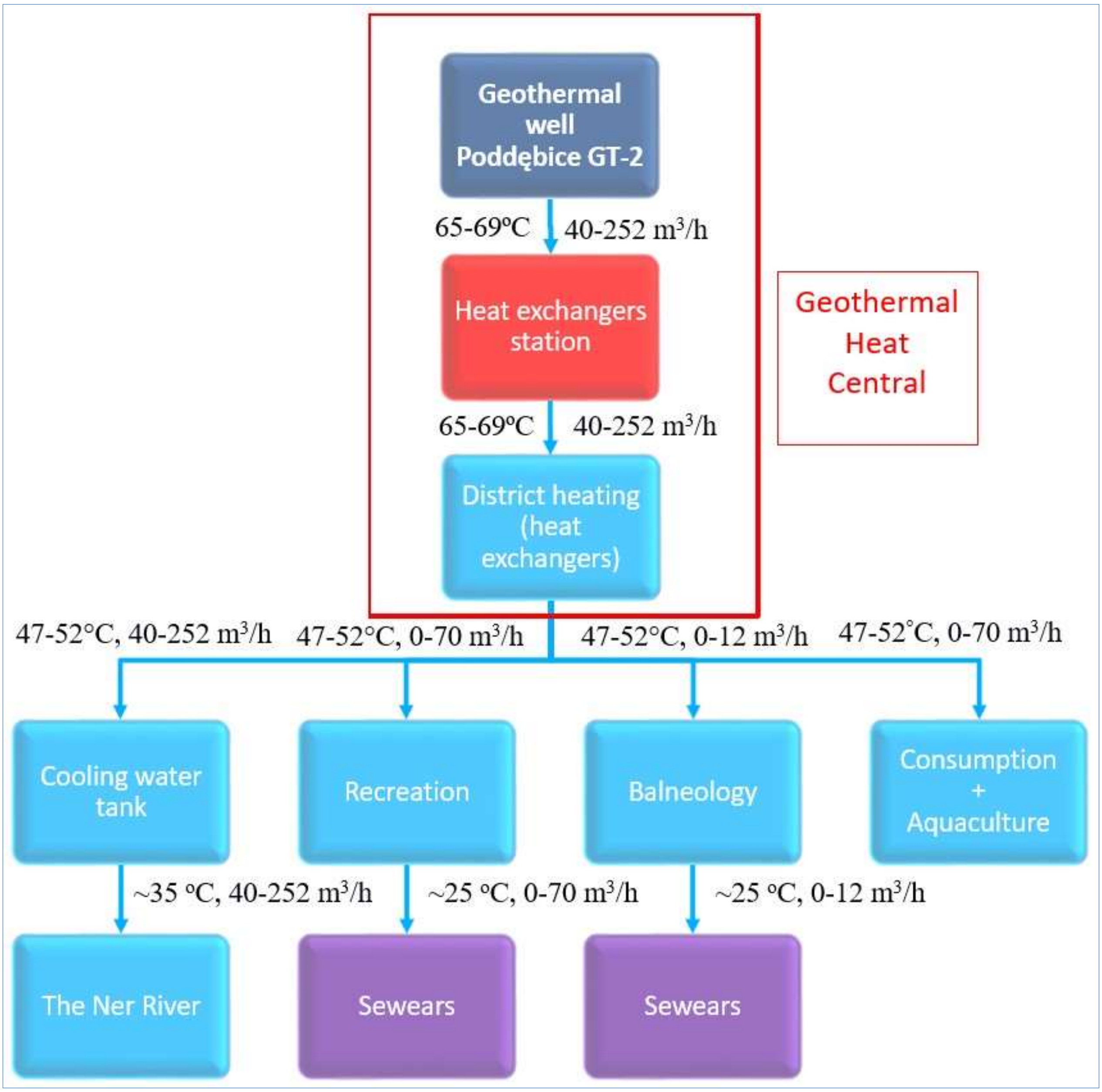


Fig. 2.11. A sketch showing current (2016-2017) and planned geothermal energy and water uses in Poddębice town

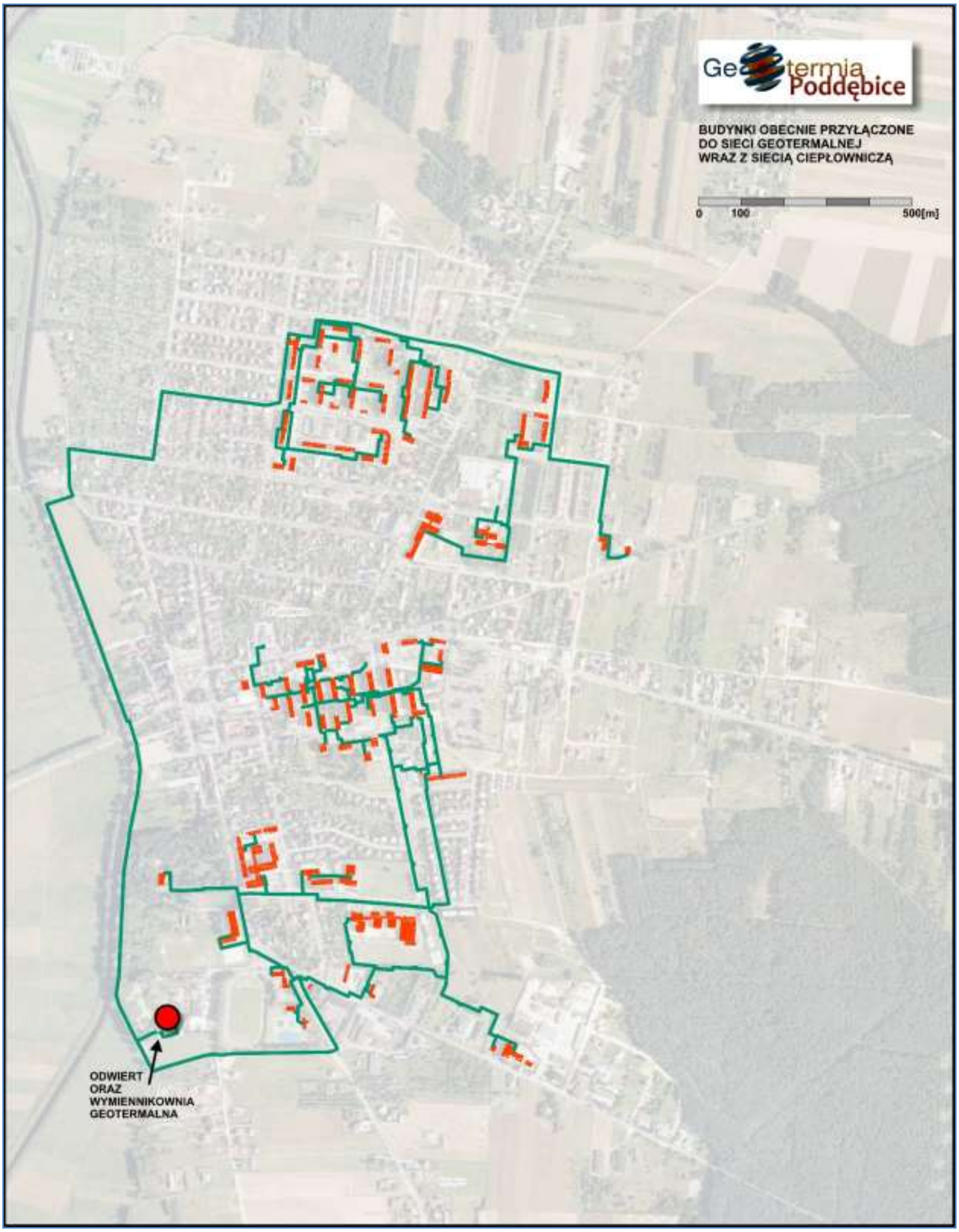


Fig. 2.12. Buildings connected to the geothermal district heating network in Poddębice town, 2016. GeoDH serves ca. 6000 people in residential buildings, public and office buildings.

Part of current geoDH was constructed by Geotermia Poddębice Ltd., part – constructed by Municipality, part – had been existing before geothermal was introduced (supplied by 3 local coal-gas boiler plants)

2.2.3. Geothermal heat sales and ecological effect

The geothermal heat sales in 2013–2016 and obtained ecological effect in Poddębice are shown in Table 2.11 (annual heat losses in the distribution network are ca. 10%).

Table 2.11. Geothermal heat sales in Poddębice, 2013–2016

Year	Heat sales [TJ/y]
2013	15.002
2014	39.733
2015	47.277
2016	56.470

According to Geotermia Poddębice Ltd. the annual 2016 ecological effect – reduction of emissions can be given as follows:
- dust – 6.3 t/y,
- sulphur dioxide SO_2 – 6.2 t/y,
- nitrogen oxides NO_x – 4.4 t/y,
- carbon monoxide CO – 54.7 t/y,
- carbon dioxide CO_2 – 4,297.6 t/y.

The ecological effect as aggregated values of reduced / avoided pollutants thanks to replacement of hard coal by geothermal heat corresponding to heat sales at the level of 56.47 TJ in whole 2016 year (as provided by Geotermia Poddębice Ltd.; Table 2.11) can be also estimated as follows: CO_2: 5500 T; CO: 25.8 T; SO_x: 42.1 T; TSP (total suspended particles): 25.8 T; NO_x: 8.3 T.

Detailed information is shown in Table 2.12.

The above-calculations consider coal with a calorific value of 25 MJ/kg, ash content of 5%, sulfur content of 1.02%. The emission factor values used in calculations were taken according to the guidelines "Emissions from combustion of fuels – boilers with a nominal thermal capacity up to 5 MW" developed by the National Center for Balancing and Emissions Management, KOBiZE (Warsaw, January 2015).

Table 2.12. Ecological effect – estimated values of reduced/avoided atmospheric pollutants thanks to replacing coal combustion with geothermal heat in Poddębice (for geothermal heat sales as in Table 2.11)

Year (geothermal heat sales) / Pollutant coal equivalent	**2016 (56.47 TJ/a) [Tons]**	**2015 (47.277 TJ/a) [Tons]**	**2014 (39.733 TJ/a) [Tons]**	**2013 (15.002 TJ/a) [Tons]**
Coal equivalent	2 580.96	2 160.80	1 816.00	685.70
Carbon dioxide (CO_2)	5 497.45	4 602.50	3 868.07	1 460.47
Sulphur dioxide (SO_x)	42.12	35.26	29.64	11.19
Carbon monoxide (CO)	25.81	21.61	18.16	6.86
Total suspended particles (TSP)	25.81	21.61	18.16	6.86
Nitrogen oxides (NO_x)	8.26	6.91	5.81	2.19

2.2.4. Geothermal heat prices

At the beginning of 2017 the geothermal heat prices supplied by Geotermia Poddębice Ltd. belonged to 3 main groups of tariffs (approved by City Council Office – Mayor; Table 2.13):

- Tariff group A :
Ordered capacity: 0.00 zł/MW, heat = 38.85 zł/GJ netto

- Tariff group B :
Ordered capacity: 7 345.5 zł/MW, heat = 40 zł/GJ netto

From B group of tariff the Municipal Services Company (PUK Ltd.) creates its own tariffs presented in Table 2.13. This Company distributes ca. 80% of heat purchased from Geotermia Poddębice.

In 2017 Geotermia Poddębice applied for the license for heat production and distribution. The Company shall also to construct new heat tariff (subject of approval by the Energy Regulatory Office).

Table 2.13. Prices and rates of generation, transmission and distribution of heatacc. to 3 tariff groups without VAT (23%) approved by the Energy Regulatory Office (Tariff group B of Geotermia Poddębice, heat distributions and sales by Municipal Servicing Company), 2016

Prices and fee rates	Unit measure	Groups of receivers		
		Z-14 Receivers supplied by Zielona 14 boiler plant	K-15 Receivers supplied by Krasickiego 15 boiler plant	C-4 Receivers supplied by Cicha 4 boiler plant
1. Price for ordered capacity Monthly installment	zł/MW/y zł/MW/y	103 176.36 8 598.03	159 694.32 13 307.80	103 811.40 8 650.95
2. Heat prices	zł/MW/GJ	53.76	52.94	51.24
3. Prices of heat carrier	zł/m^3	17.40	17.40	18.33
4. Rates of fixed fee for transmission services Monthly installment	zł/MW/y zł/MW/month	13 841.18 1 153.43	18 369.51 1 530.79	23 011.90 1 917.66
5. Rates of variable fee for transmission services	zł/GJ	5.78	5.51	9.36

2.2.5. Strategic development plans of geothermal energy use in Poddębice

The Board of Geotermia Poddębice together with the Poddębice Town Council plan to develop the district heating system also in other parts of the city (a single-family residential area) aimed at reduction of low emission (Figs. 2.13–2.14). This requires that the second stage of the geothermal water use (a heat pump) needs to be developed in the heating plant, what will allow to manage geothermal resources in Poddębice more effectively and rationally.

Due to that reason, a functional-utility programme “Construction of the second stage of geothermal water’s heat recovery and the development of district heating networks with grid connections and nodes for Poddębice city” was elaborated in 2015. It included the development of the heating network and (optionally) the use of technology allowing heat recovery and much more rational use of geothermal energy.

The costs of the-above-mentioned programme realisation were assumed as follows:
- extension of the district heating networks with grid connections and nodes of total length of 34.2 km – ca. 59 million PLN (14.2 million EUR);
- extension of the heat source by adding heat pump/heat pumps with ca. 14 MW_{th} capacity – ca. 10 million PLN (2.4 million EUR).

The team which elaborated the-above-mentioned functional-utility programm) proposed for the forthcoming years the indicative investment cost on the level of 52% of all inventoried town’s territory possible to connect for the geothermal district heating.

The second functional-utility programme is “The Land Without Barriers – The Centre of Hydrotherapy and Recreation in Poddębice based on the use of geothermal waters. Adaptation of the infrastructure of sport, tourism and recreation centre”. This programme includes upgrading the seasonal swimming pools complex to a year-round pool with the focus to modern

technologies in the field of delivery and circulation of geothermal water for recreational and rehabilitation purposes as well as heating of the swimming pools, technical and accompanying objects (gastronomy, accommodation). The programme aims the wide access to recreation for people with disabilities. It would be the first such a facility in Poland.
An effort to gain EU and other funds on the implementation of the programme will be made. Preliminary estimation of the cost is 30,351,204 PLN (ca. 7.6 million EUR).

At the beginning of 2017 the strategic development plans included:

- Extension the tank for cooling geothermal water – by increasing its volume by approx. 1 500 m^3 and two-staged transmission (length 9 m x 50 m wide) – in 2017,
- Expansion of heat source by second stage of heat extraction from geothermal water from 50 to 35– 30ºC – in 2–3 years,
- Development of geothermal heating grid in order to limit the low emission – in 2–15 years,
- Construction the connection to the Zoo Safari Borysew (geothermal water and likely heat) – 1–2 years,
- Construction of the graduating towers as successive degrees of heat extraction from geothermal water and its further cooling this will allow to send it to local waterworks (MPWiK) and introducing into municipal water supply system – 1–3 years,
- Construction of the facility for farming fish, shellfish, algae, etc. Such activities are intended to be developed in partnership with the investor possessing the know-how and with financial investor.

In case of some from planned investments the costs were estimated as follows:

- Expansion of heat source by second stage of heat extraction from geothermal water investment costs were estimated for ca. 70 mio PLN (including expansion of heating networks as well as connections and nodes).

According to the inventory related to geoDH expansion for the whole town:

- 1050 buildings are possible to be connected to extended geoDH,
- More than 33 km of distribution networks with connections,
- A 14 MW heat source needed,
- Total cost: 97 mio PLN gross.

As given before, current geothermal capacity is 5 MW (from geothermal water – heat exchangers) and this will not change in the coming years.
The highest investment costs, i.e. 97 mio PLN gross was estimated for constructing the heating grid for the remaining part of the town, connecting 1050 buildings and the use of the most expensive heating source – *i.e. absorption heat pump.*

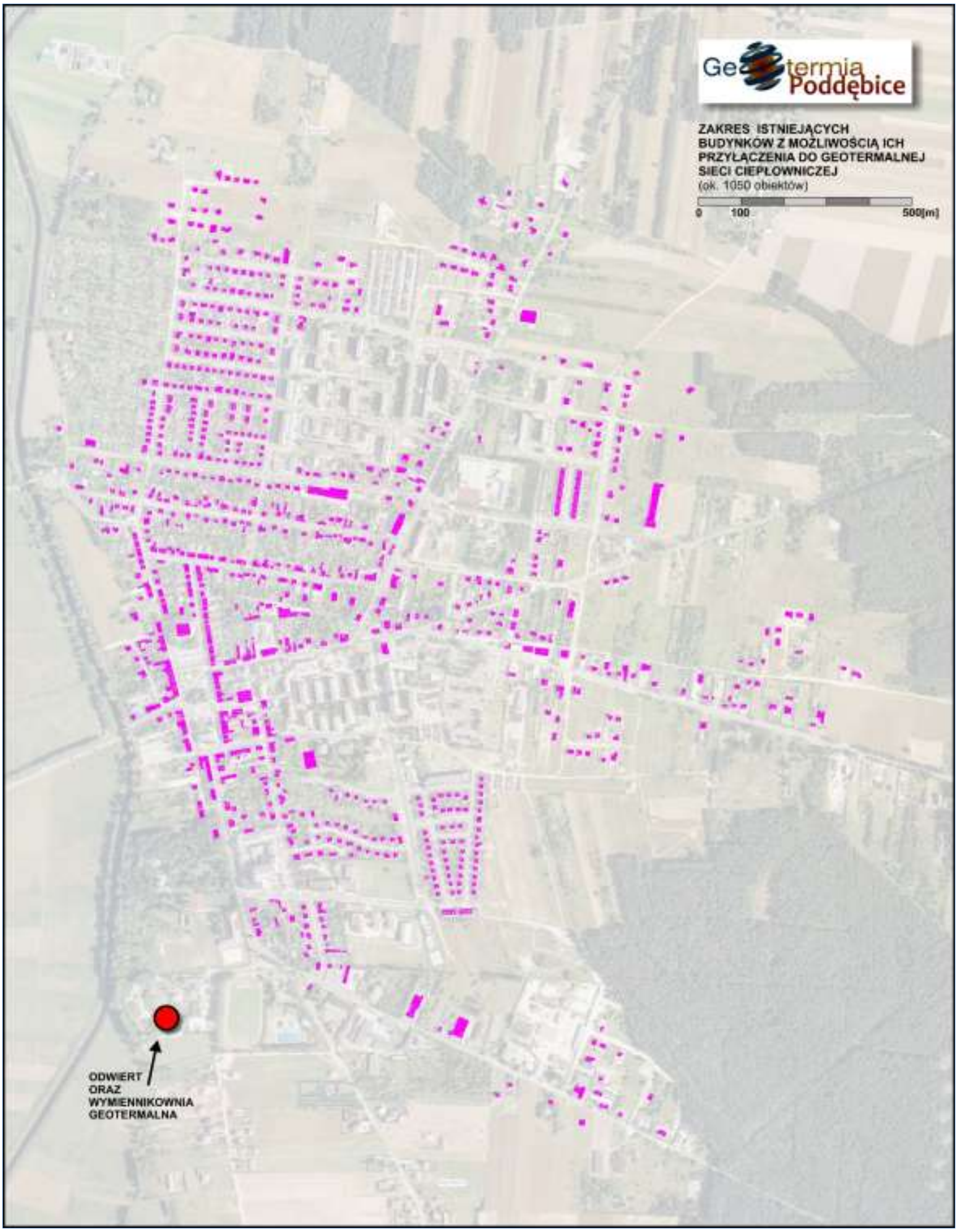


Fig. 2.13. Existing buildings (in violet) and possibility of their connection to geoDH system, Poddębice Town

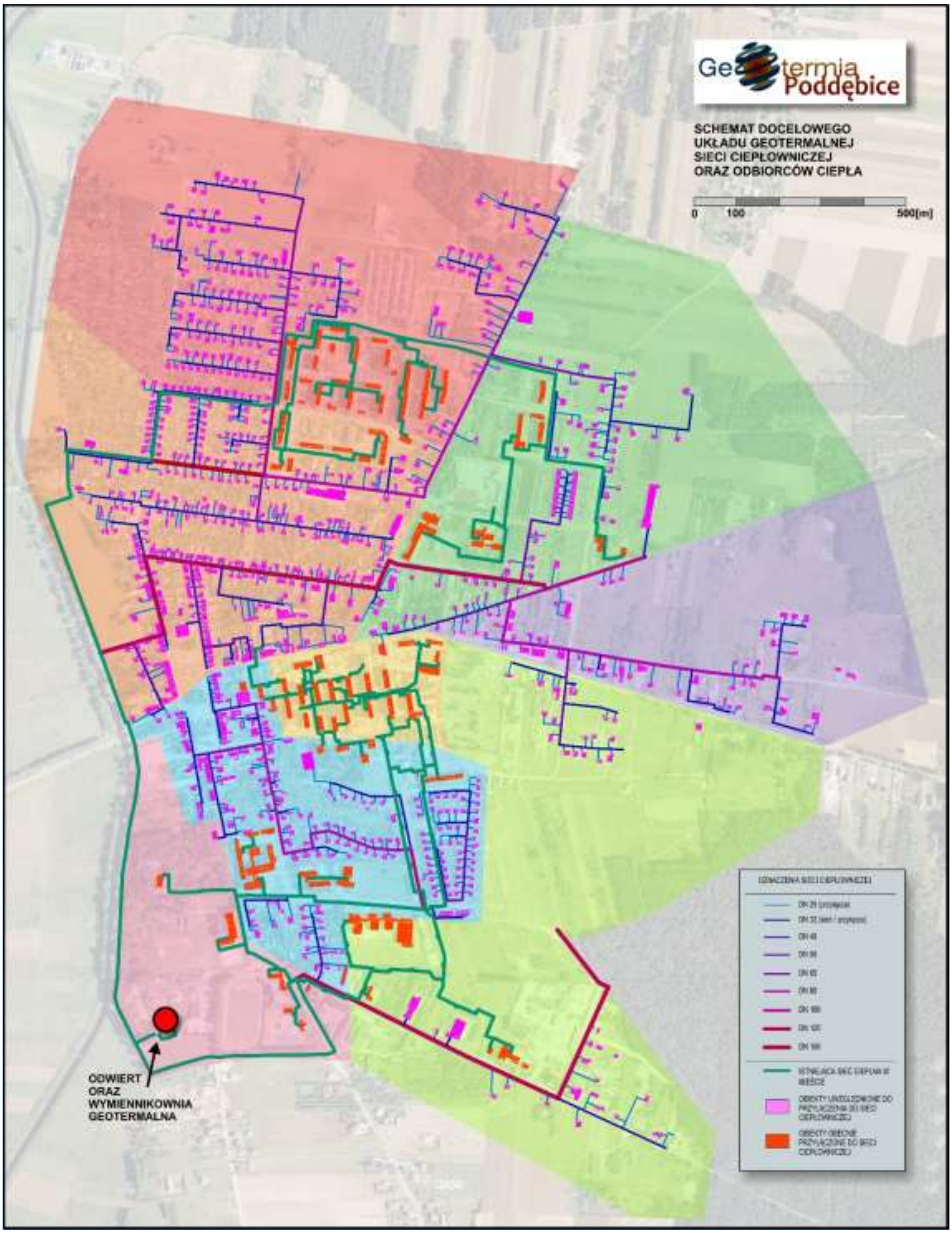


Fig. 2.14. Target geoDH system in Poddębice

Some pictures showing elements of already operating geoDH system and infrastructure in Poddębice are shown on next pages (Figures 2.15–2.19).

Fig. 2.15. Poddębice geothermal district heating plant – general view

Fig. 2.16. Geothermal well head (Poddębice GT-2)

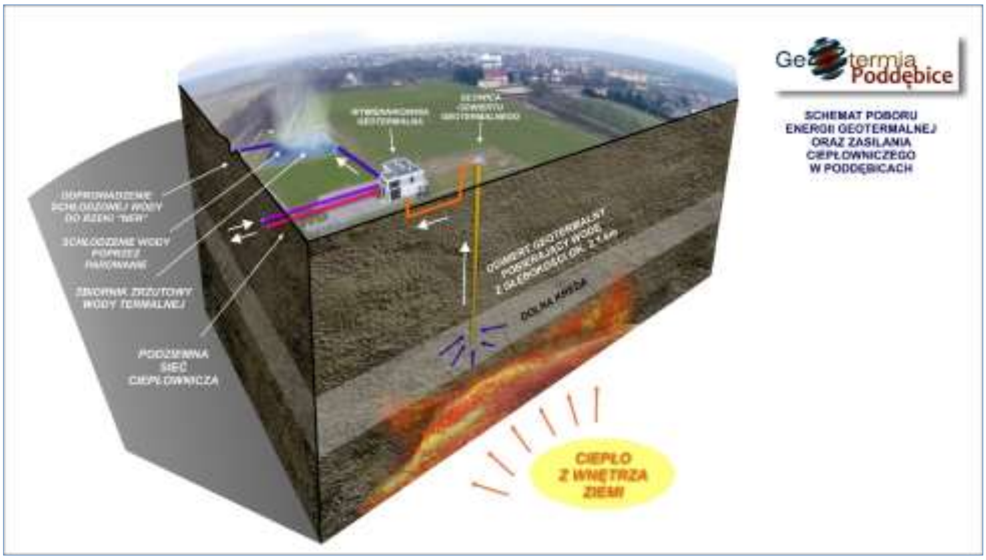


Fig. 2.17. The scheme of geothermal energy intake and heat supply in Poddębice

Fig. 2.18. Geothermal heating plant – an inside

Fig. 2.19. Geothermal swimming pools

Figures 2.15 – 2.19: archives of Geotermia Poddębice Ltd.

2.2.6. Simulation of geothermal water production from well Poddębice GT-2 using Simple Lumped Parameter Modeling

In case of Poddębice geothermal aquifer, the input data for the model came from monitoring of main parameters of geothermal water produced by well Poddębice GT-2, monitoring at some key points of surface geothermal system in the period 2012-2016 (initial period after drilling the well and starting its production). The data and information were provided by Geotermia Poddębice Ltd. during the Study visit to Poland – Poddębice in September 2016 as well as in course of further contacts (via internet, phone calls).

Data simulation

Axelsson (1989) presents the theoretical background of lumped parameter modelling of pressure change data 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). Lumped parameter models consist of a few 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 geothermal systems, as well as other hydrological systems underground.

It has become customary to simulate pressure or water level data from geothermal systems with both open and closed models (Fig. 2.20). The open models simulate systems where production and recharge eventually equilibrate, while closed models have no recharge. At a constant rate of production pressure declines continuously in the latter. Calculating future predictions with both model versions, therefore, provides conservative as well as optimistic predictions.

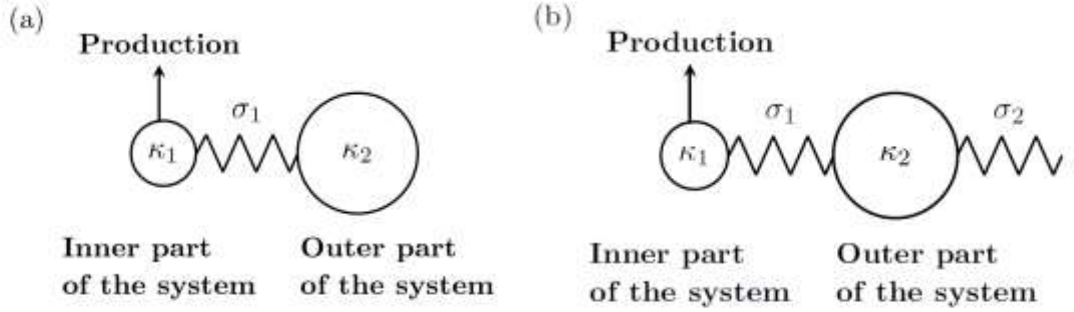


Fig. 2.20. Schematic pictures of (a) two closed tanks and (b) two open tanks which are used to model the reservoir system. Both systems are composed of two tanks κ_1 and κ_2, that represents the inner and outer part of the geothermal system. The connection between the tanks is represented with a flow resistance σ_1. For the open two tank system the outer part is connected to an infinite reservoir with a flow resistance σ_2.

The models were fitted via least square norm to the water level and production data. The result can be seen visually in Fig. 2.21 for the open model and numerically for both in Table 2.14. There was little visual difference between the open and closed model. The residuals of the open model, or the difference between model and data can be seen in Fig. 2.22. The data is rather noisy and the model does not follow the major jumps well but as we can see from Figure 2.21 it manages to roughly reproduce the gross trend of the water level data.

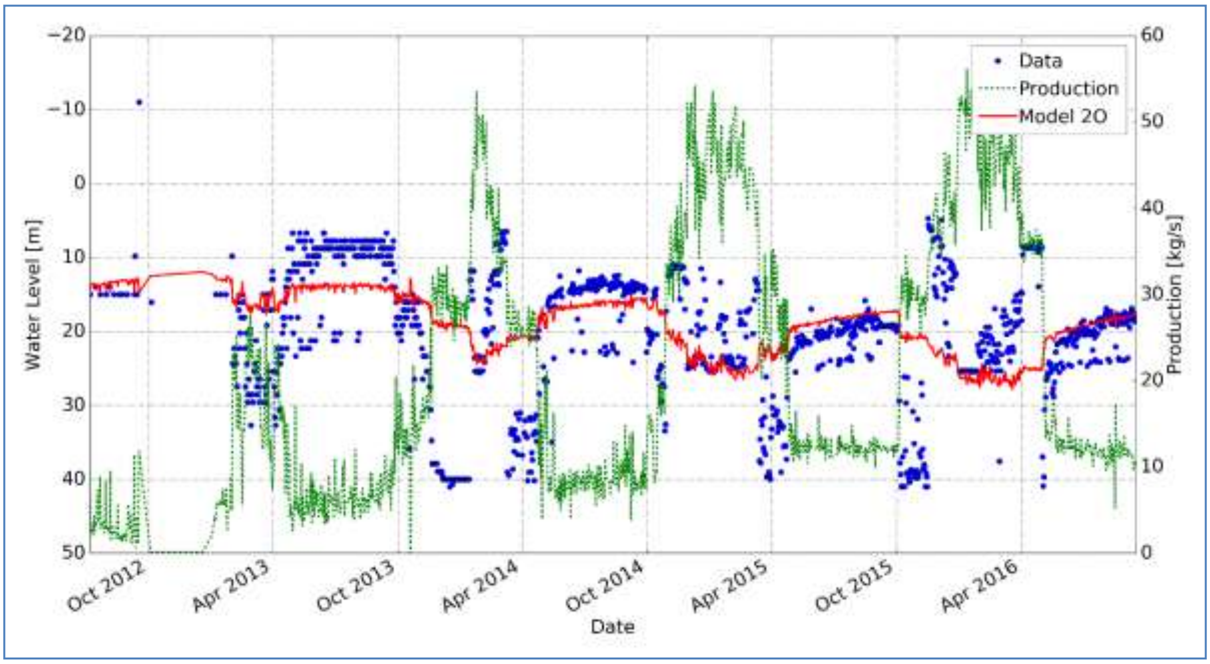


Fig. 2.21. Measured production and water level shown with a green dashed line and blue dots respectively. The model result for the water level is shown with a solid red line

Table 2.14. Variables used and calculated in the two models

Variables used in model	Two Tanks Closed	Two Tanks Open
A_1	5.4×10^{-6}	7.3×10^{-6}
L_1	2.28×10^{-5}	3.95×10^{-5}
B	2.73×10^{-9}	
A_2		1.5×10^{-8}
L_2		7.09×10^{-8}
Variables calculated from A_i, V_i, and B		
$Kappa_1$ [kg/Pa]:	19.3	14.2
$Sigma_1$ [kg/s/Pa]:	4.39×10^{-4}	5.61×10^{-4}
$Kappa_2$ [kg/Pa]:	3.81×10^{4}	6.95×10^{3}
$Sigma_2$ [kg/s/Pa]:		4.94×10^{-4}
Statistic		
RMS deviation [m]	8.6	8.5
Secondary variables		
Storativity [kg/m^3/Pa]:	6.2×10^{-5}	6.2×10^{-5}
V_1 [km^3]:	0.313	0.231
V_2 [km^3]:	619	113
$Permeability_1$ [mDarcy]:	551	579
$Permeability_2$ [mDarcy]:		169

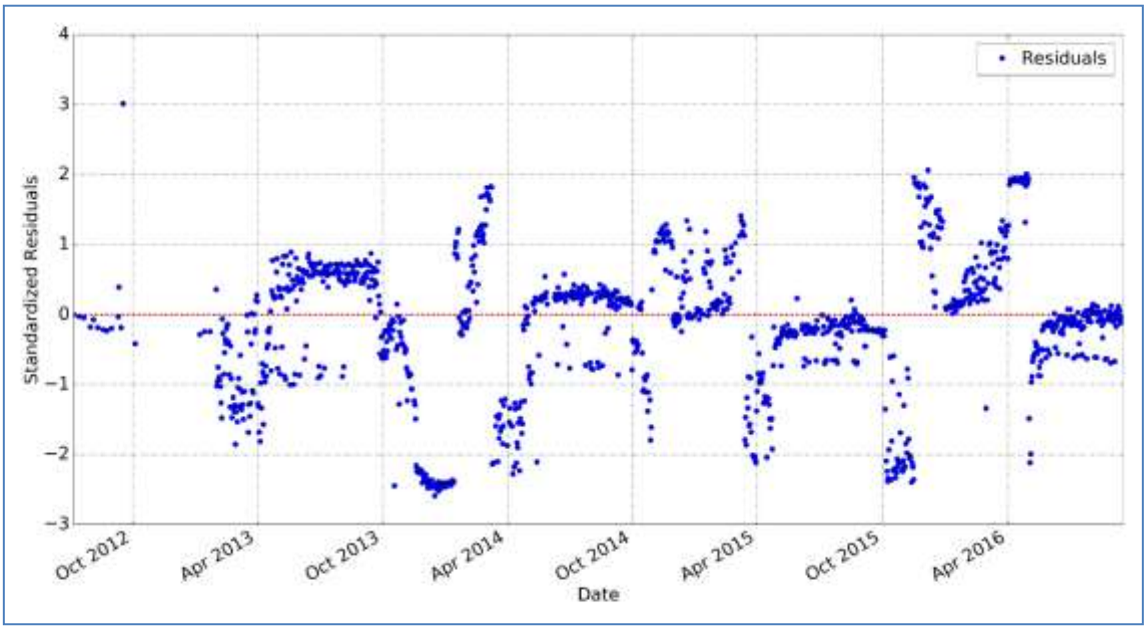


Fig. 2.22. Standardized residuals of the modeled water level compared to measured water level

The model that was produced from the fit is used to do five year projections for three different production scenarios. Both the open and closed systems are simulated and presented in Figs 2.22 – 2.25; the open system with a solid light blue line and the closed system with a solid black line. In all the scenarios the simulated production oscillates in a square like way between summer and winter with a 20 kg/s amplitude. In Figures 2.23–2.25 it is shown with a dashed light blue line.

The first production scenario is shown in Figure 4. There the yearly average production is set at 30 kg/s, which resembles the current production. We see that the open system settles to a water level close to the present one, while for the closed system the water level drops by roughly 5 m.

For the second scenario shown in Fig. 2.24 the yearly average production is increased to 50 kg/s. For this scenario the average water level for the open system settles to around 35 m while the average water level for the closed system approaches 45 m.

In the final production scenario shown in Fig. 2.25 the average production is ramped up to 70 kg/s. For this scenario the average water level for the open system quickly settles to 40 m, while the water level for the closed system is starting to go below 60 m in the winters.

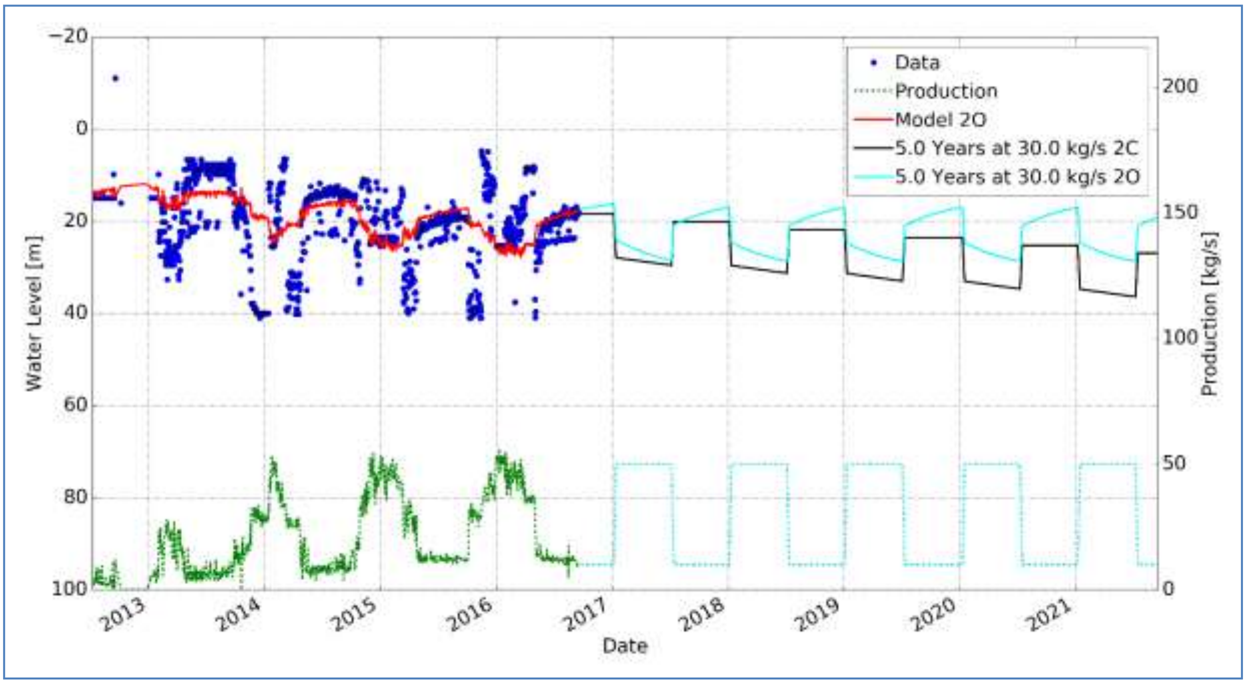


Fig. 2.23. Projection of the water level for the system in response to a periodic step like production.

The production has yearly average of 30 kg/s and is shown with a dashed blue line. The projected water level is shown with a solid black line

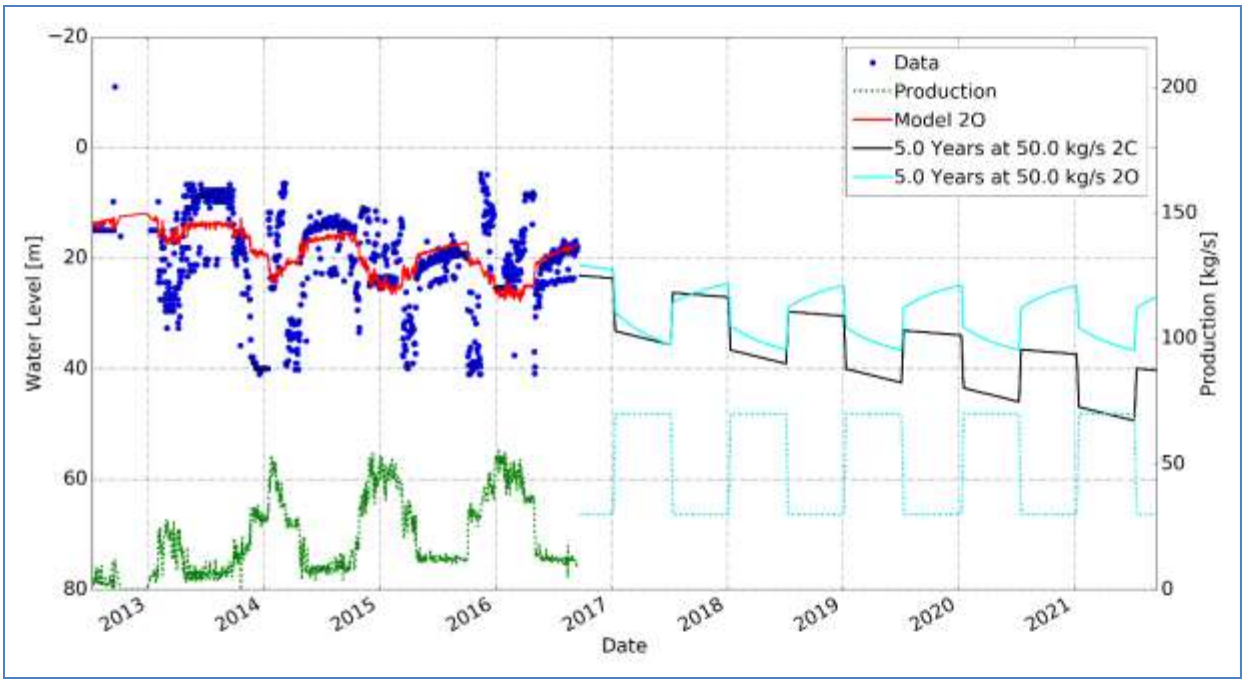


Fig. 2.24. Projection of the water level for the system in response to a periodic step like production.

The production has yearly average of 50 kg/s and is shown with a dashed blue line. The projected water level is shown with a solid black line.

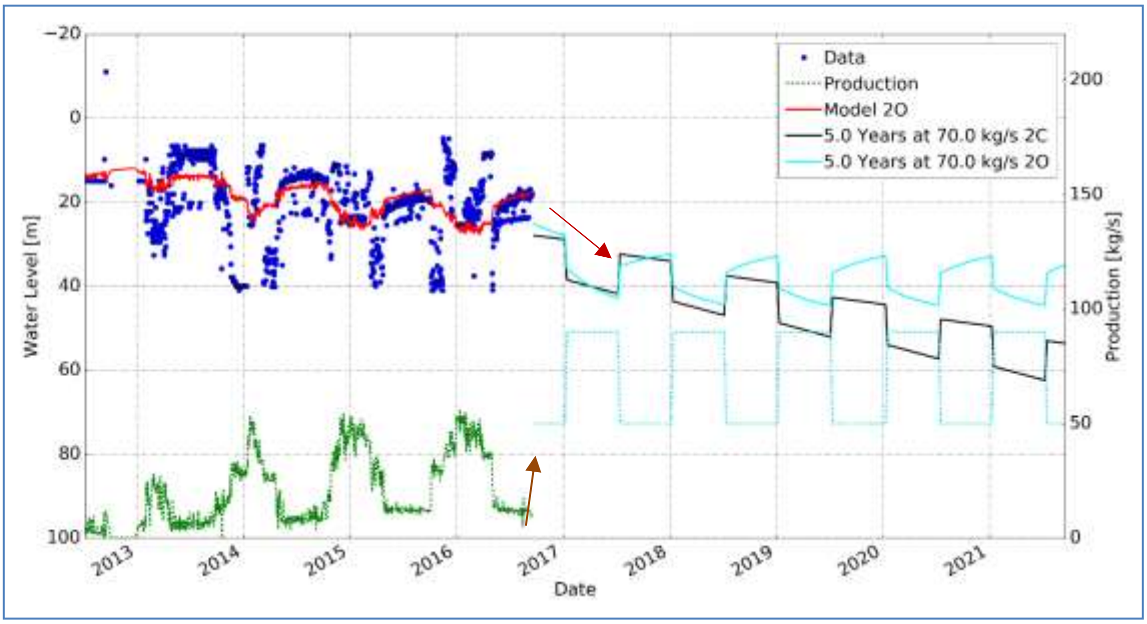


Fig. 2.25. Projection of the water level for the system in response to a periodic step like production.
The production has yearly average of 70 kg/s and is shown with a dashed black line. The projected water level is shown with a solid black line.

Conclusions and recommendations

The water level data is not very good as can be seen from the figures. The measured water level above the pump was used when the water was pumped from the well, but well head pressure (WHP) during the artesian flow period. Both data set show much scatter in the data. The measured flow rate data is much better. It would be great if there is a possibility to find out why there is so much scatter in the data and fix it if possible for future predictions.

The simulation of the-so-far geothermal water production was done using Lumpfit program assuming two models of aquifer – an open one (optimistic) and a closed one (pessimistic). Such models are typically applied especially when one has pressure /water level monitoring data from one or even few wells and only short production history is available (like in case of Poddębice GT-2 well). The main conclusions that can be drawn for these simulations is that the-so-far production was not aggressive and the water level was 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, short production history implied short reliable predictions for the future (2017–2022).

In addition – taking into account geological and hydrogeological situation in Poddębice area one may expect that the considered geothermal aquifer can be placed somewhere between 2O and 2C models. This suggestion is, among others, because of the tectonics of its area (see cross-section in next subchapter – Fig. 2.26) whereboth 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 open character in a regional scale.

More considerations and picture of such possible situation are given in next subchapter.
Geological and hydrogeological circumstances are important for interpretation of current simulation, future predictions and recommendations (as to optimal production rates, injection/no injection of spent water need for proper monitoring, measurements, etc.).

The interpretation and prediction for next several years of water level in Poddębice GT-2 well's simulation shall take into account and indicate that – even in case of prognosed stable water level in 2O model – some decrease of water level / pressure may appear. This probability shall be taken into account by the geothermal system operator and further careful monitoring of reservoir and production parameters is of utmost importance.

If the heating system will be enlarged and more water is needed, then at least one production well should be drilled and one or two injection wells also. It is very important to reinject the spent water into to geothermal system 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.

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 fluid does give pressure support to the system but minimize the cooling effect.

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. This shall be done applying e.g. 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.

2.2.7. Regional hydrogeological aspects of Poddębice area that may affect conditions of long-term geothermal water production

According to regional hydrogeological recognition of Poddębice area, the well supply derives most probably from the eastern direction. Recharge are is related to outcrops of the Lower Cretaceous formation located ca 15 km in the east of Poddębice GT-2 well (Figs 2.26–2.27). No or negligible low hydraulic connection exist between overlying Upper Cretaceous sediments (caprock).

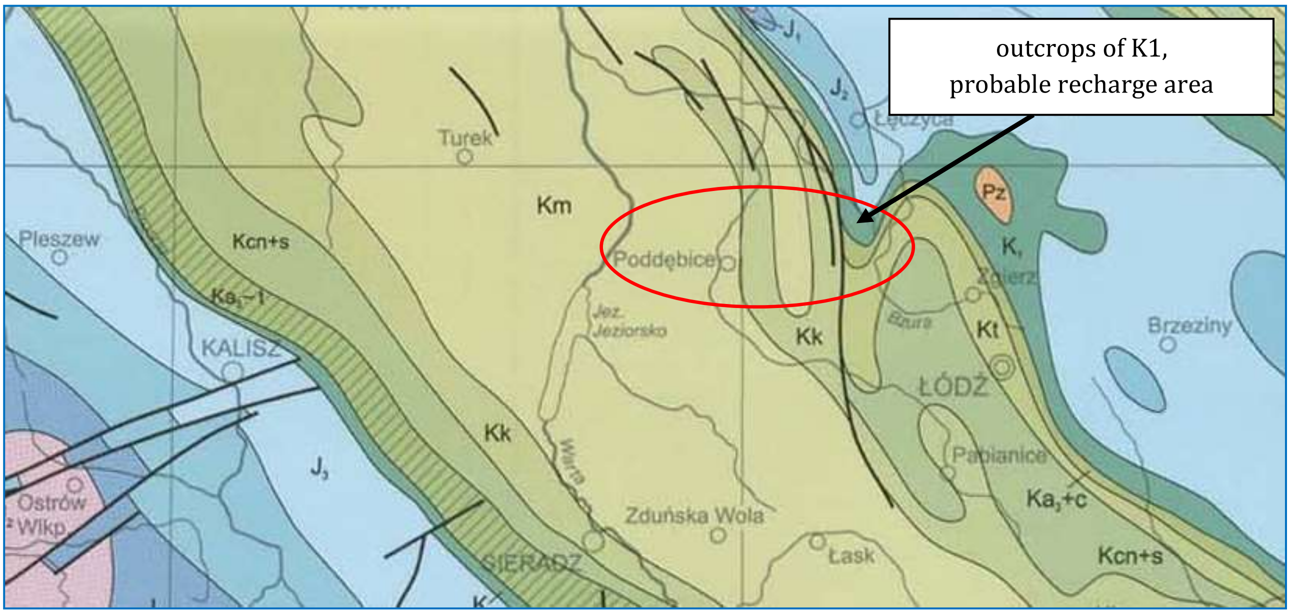


Fig. 2.26. Geological map of central Poland without Cainozoic deposits and location of Poddębice area (map in: Górecki [ed], Hajto et al., 2006)

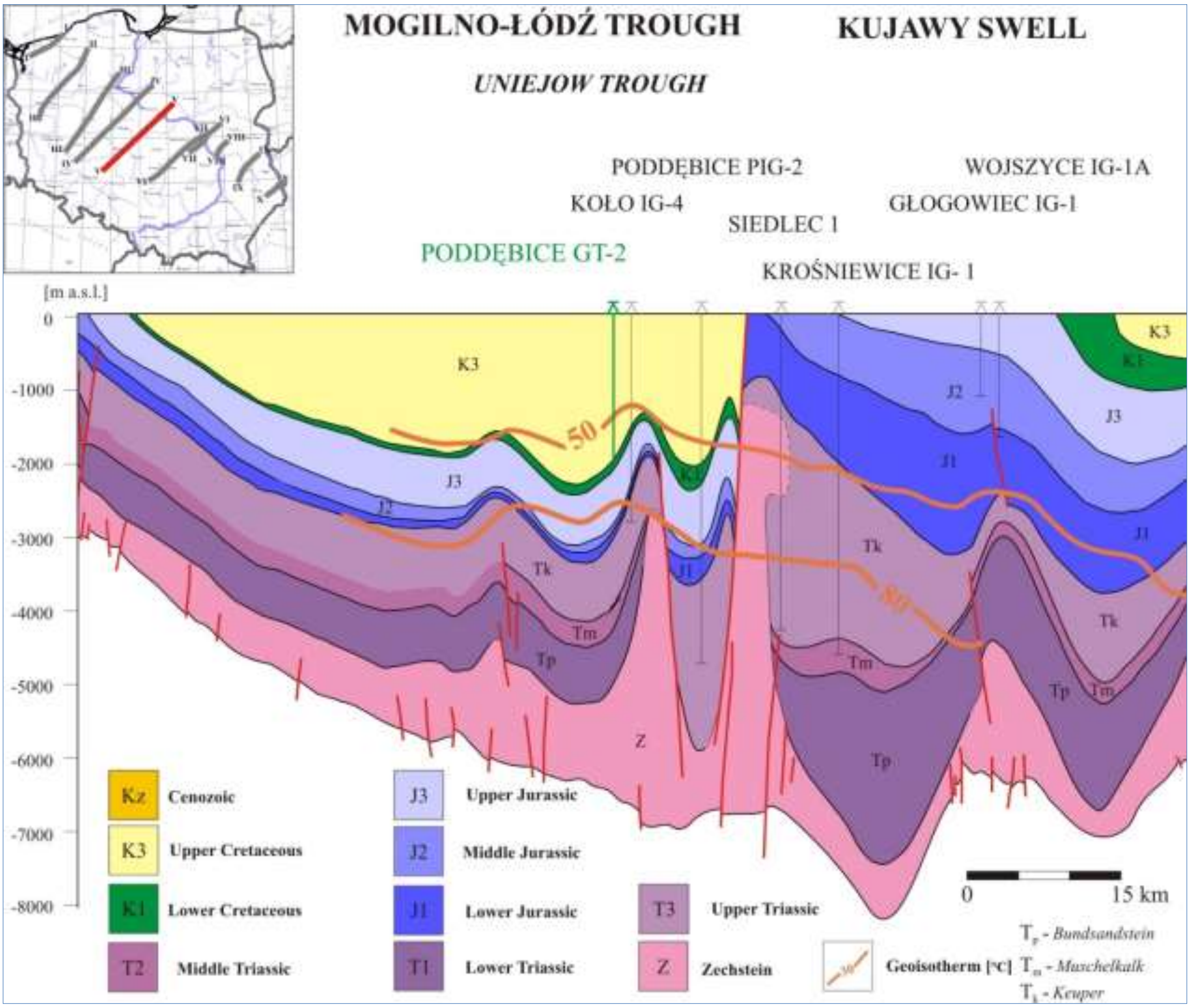


Fig. 2.27. Geological cross-section through Poddębice area (background map: Górecki [ed], Hajto et al., 2006)

The mineralisation value of the Lower Cretaceous waters increases precipitously in the north-west direction, i.e. in the area of Uniejow 1 well where it totals 21.9 g/L (Figs 2.28-2.29).

This phenomenon may be related to the elevation of the Lower Cretaceous formation between Poddębice and the area of Uniejow 1 well, resulting in the accumulation of “heavy” waters high in TDS in the vicinity of the Uniejow 1 well, which due to the structural elevation (barrier) does not flow down towards Poddębice town. Moreover, the water does not flow down also towards Uniejow town as the mineralisation of exploited water varies between 6.7-8.8 g/L and water reveals on chloride-sodium type.

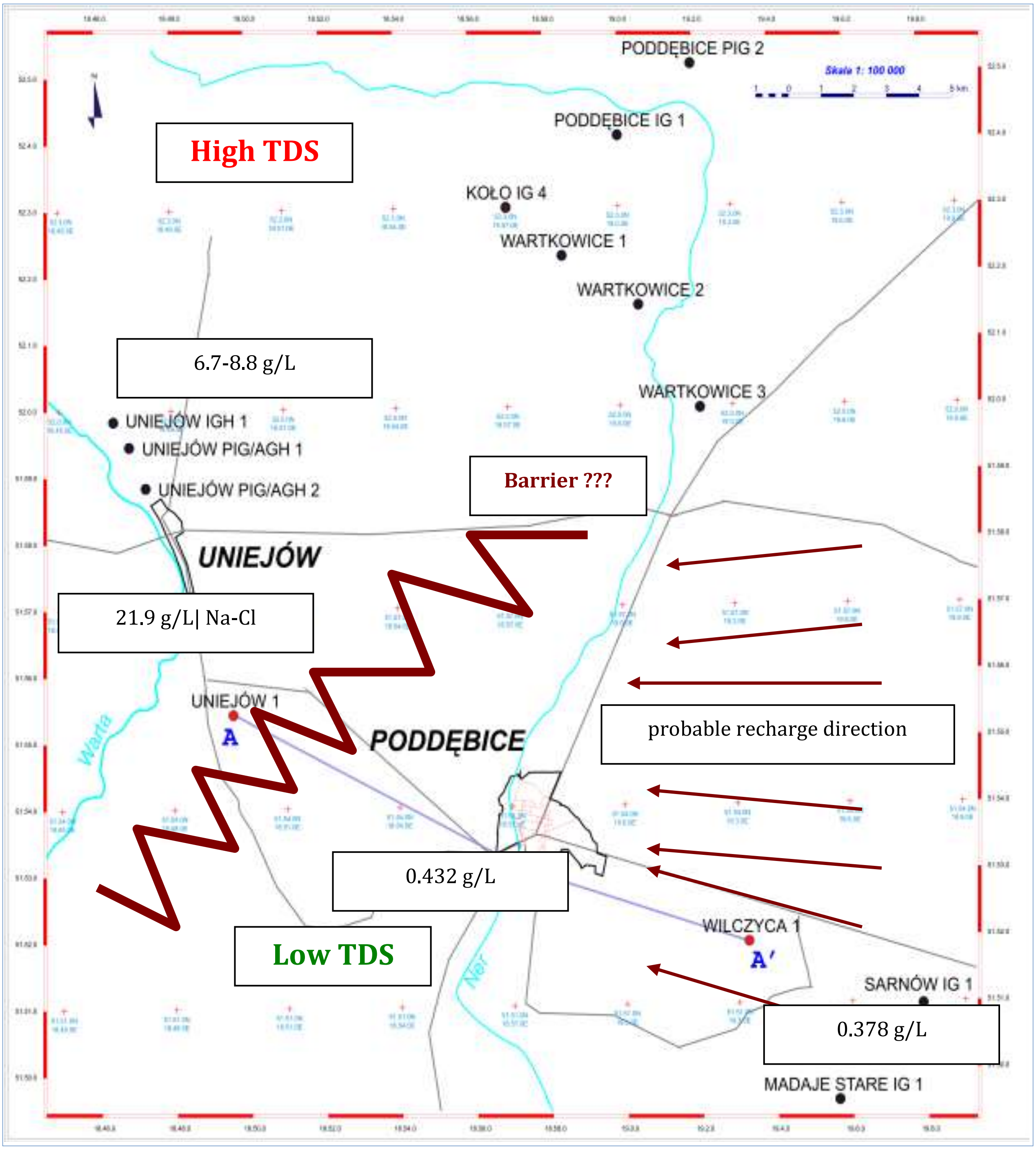


Fig. 2.28. Conceptual model distribution of mineralisation on the background of deep boreholes location in the area of Poddębice

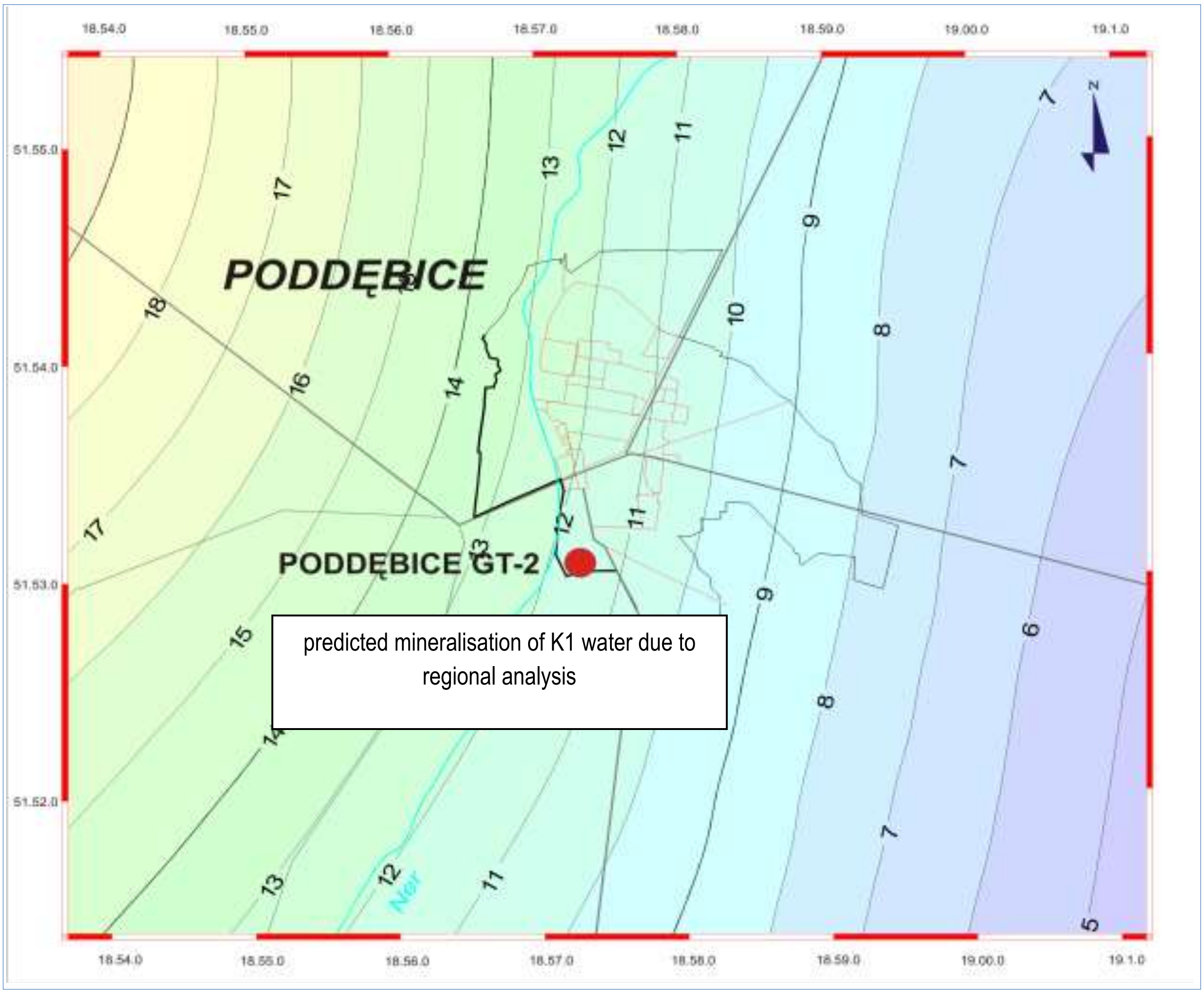


Fig. 2.29. Mineralisation map at the top of the Lower Cretaceous aquifer in Poddębice area (at the preliminary stage of the project – before drilling Poddębice GT-2 well)

2.3. District heating

2.3.1. Introduction

A pre-feasibility study of the current district heating system in Poddębice, operated by Geotermia Poddębice Ltd. and a proposed expansion of the system to 18 MW_{th} is included in this chapter. It covers surface installations of the system consisting of production well Poddębice GT-2, heat central, cooling pond and distribution system. A 3–day site visit in September 2016, meetings with Geotermia Poddębice, and data acquisition from this company and MEERI PAS were used as a basis for the overall pre-feasibility. Data logs from the heat central in Poddębice were compared to the information presented in the September meetings and overall, data from these two sources is in agreement. A schematic diagram of the future expansion, cost estimate and calculation of heat production cost and key project risks are outlined at the end of the report.

Since 2013, a geothermal production well and distribution system has been operated in the town of Poddębice, in Łódź Voivodeship in Poland. The operator of the installation is Geotermia Poddębice. During the week of 5th to 9th September 2016, a series of working meetings and site visits were performed by NEA. The visit was attended by the Mineral and Energy Economy Research Institute, Polish Academy of Sciences (MEERI PAS), and the AGH University of Science and Technology in Kraków, as well as representatives of Geotermia Poddębice Ltd., Mayor of Poddębice Town, and several other attendees including representative of the Department of Ecological Funds, Ministry of Environment, Poland, some local authorities and companies. The geothermal reservoir was studied by Icelandic side in parallel with writing this report.

The current capacity of the heating system is around 4-5 MW_{th}, with additional peak load boiler capacity of around 2 MW_{th}. The future plans of Geoterma are to expand the system to all of Poddębice, with 14 MW_{th} geothermal heating capacity and a 4 MW_{th} peak load installation (heat pump), a total of 18 MW_{th}.

Below is a summary of the main findings regarding the surface installations of Geotermia Poddębice Ltd. (geothermal well pump, heat exchanger station, distribution system, peak load installations and heat demand), both the current system and an outlook for future expansion. Information presented in this document is partly from documented data and partly from verbal communication in work meetings. A data log, spanning around 4 years is used to evaluate performance of the system. It contains daily average values of flow, temperature and pressure in various points of the system, both on the geothermal and the distribution side. The report concludes with a preliminary cost estimate and a summary of best practices recommended for the implementation of the DH system in Poddębice.

2.3.2. Summary of site visits

The main site visits of the installation were carried out on 6th to 8th of September and are summarized below.

6th September – Geotermia Poddębice and Well Poddębice GT-2

Most of the day was an introductory meeting with participants in this visits, from MEERI PAS, AGH, Geotermia Poddębice and the Mayor of Poddębice. Each party had a short introduction on the company profiles and the main features of the heating system in Poddębice, as well as a summary of geological and hydrogeological conditions in various geothermal sites around Poland.

The meeting was followed by a visit to the Poddębice GT-2 well and the heat central (pumping and heat exchanger station) located at the ground floor of the Geotermia Poddębice office building. The visit concluded at the Palace in Poddębice near the heat central, one of the largest heat users in the system.

7th September – DH System, Peak Load Installations and Large Users

An in-depth presentation of the district heating system at Poddębice was presented by the staff of Geotermia Poddębice in a working meeting. System temperatures, current and future heat loads, distribution system sizes and configuration, energy cost, cost of house connections and various other pieces of information were collected in the meeting. Fluid chemistry, house connection implementation and other issues were discussed in the meeting, as well. The conclusion from Geotermia Poddębice was that in the current situation, no additional production well is required in the near future and that the project must not lose money after the expansion from 4 to 5.5 MW_{th}, by increasing flow from the Poddębice GT-2 well.

The afternoon was spent visiting the current peak load installations in the distribution system (oil and biomass fired boiler stations) and the local hospital, which is a large user of heating energy.

8th September – New districts, Sports Centre and Swimming Pool.

A morning meeting at Geotermia Poddębice offices was used to summarize findings from the visit. Later in the day, a large sports centre was visited. This building uses ground source heat pumps and a very innovative central heating system and air conditioning. A new district, planned for the system expansion was also visited, followed by a visit at the local swimming pool, which uses geothermal fluid from the heat exchangers (50-55°C) at the heat central. The swimming pool is using the return geothermal water, after covering district heating demand. During summer the energy is used for hot tap water heating. The swimming pool uses the return geothermal water directly, not through a heat exchanger.

2.3.3. Well Poddębice GT-2 and downwhole pump

Production well Poddębice GT-2 was drilled in 2010. It is 2.1 km deep, and has a 9 5/8" production casing. The well head and covering glass are shown in Fig. 2.30.

The well has been in operation since 2012, when the heat central was put into operation. Current production rate is 190 m^3/hr during winter peak load. According to information in work meetings, static pressure is around 2 bar (20 meters above well head) while water level is 36 m below well head during maximum flow. This gives a total dynamic drawdown of 56 meters during 190 m^3/hr flow.

Fig. 2.30. Production well Poddębice GT-2, well head and connection piping

A 110 kW downhole pump is installed at a depth of roughly 90 meters below ground. The pump is shown on the right hand side on Figure 2.31.

The pump has so far been operated at around 50% capacity at max. flow, so it can easily deliver higher flow rate for the proposed increase from 190 to 260 m^3/hr, which is the planned increase in the near future. Also, 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. It may, however, become necessary if the flow rate is increased further to over 500 m^3/hr in the future expansion of the system to 18 MW_{th}.

Fig. 2.31. Well pump from Poddębice GT-2 and pressure pipes

2.3.4. Well drawdown

From data logs at the heat central, the water level in the last 2 years (Sept. 2014-Sept. 2016) has been measured, either as water pressure when well is artesian (low flow rate) and as water depth over pump when water level is below water surface. These are two separate measurements, taken from two pressure sensor measurements. It appears that water level is measured over a sensor at 36 meters below the surface, otherwise the well drawdown vs. flow data do not match. The results from these measurements are shown on Fig. 2.32 below, from flow ranging between 30-190 m³/hr.

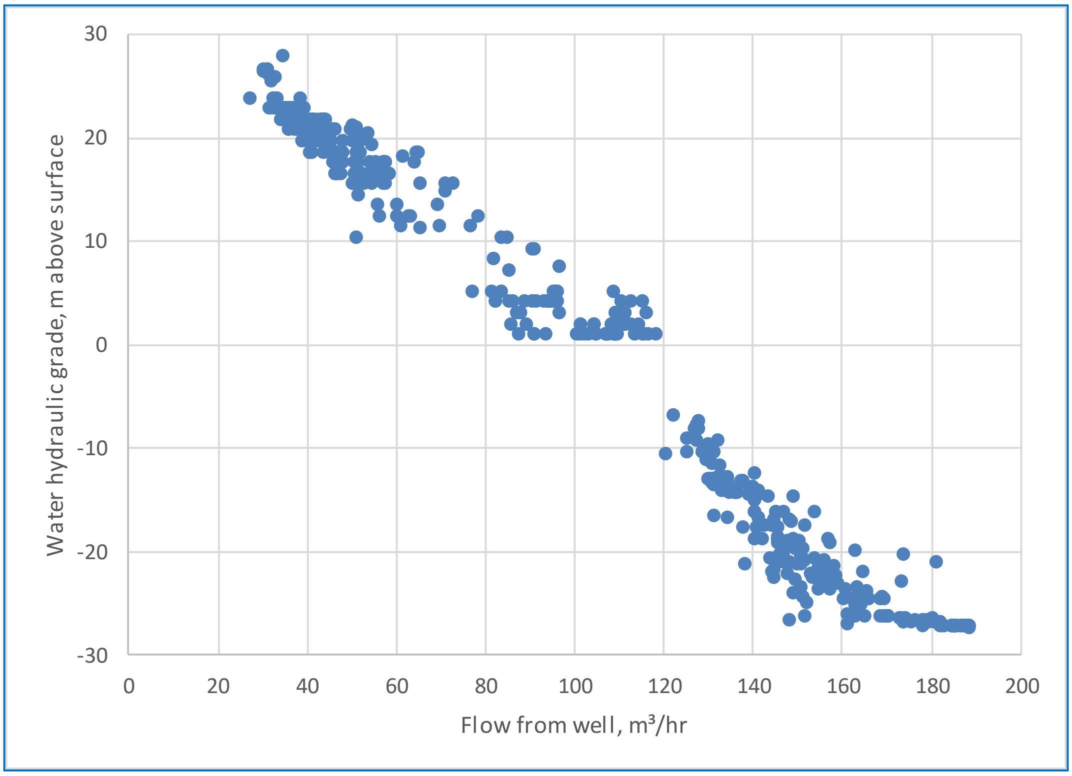


Fig. 2.32. Well drawdown vs. flow rate

The drawdown appears to be linear with flow, suggesting that the pressure drop is mainly through the reservoir (Darcy flow), not through the casing. The calculated water hydraulic grade over the surface is linearly fitted to the above data, giving:

Water hydraulic grade over surface [m] = 35,9 m – 0,36·Q,
where Q is flow from the well in m³/hr.

Increasing the water flow from the well to 260 m³/hr therefore gives a drawdown of 35,9-0,36·260 = -58 meters (below the surface). As the pump in well Poddębice GT-2 is installed at a depth of 90 m, there appears to be no foreseen pumping problems from the well. The long term effect on the water reservoir, however, has to be further analysed to confirm that the annual flow rate can be increased, without permanently lowering the reservoir water level.

2.3.5. Heat central and proposed peak load installation

The Geotermia Poddębice office is located on top of a heat central station, with 2 heat exchangers (2 x 5 MW_{th} capacity) and 3 circulation pumps. It has been in operation since 2012 and is shown in Fig. 2.33.

The supply temperature to the distribution system is approx. 60–65°C and flow rate is 220 m³/hr during peak load. The heat central station is very neat and well built, with adequate thermal insulation on piping and heat exchangers. Return geothermal water from heat exchangers (approx. 50–55°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 30°C, before it is released to the environment.

It is planned to expand the heat central 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.

Fig. 2.33. Poddębice heat central, circulation pumps (left) and heat exchangers (right)

A snapshot of the screen from the SCADA system in Geotermia Poddębice heat central is shown in Fig. 2.34.

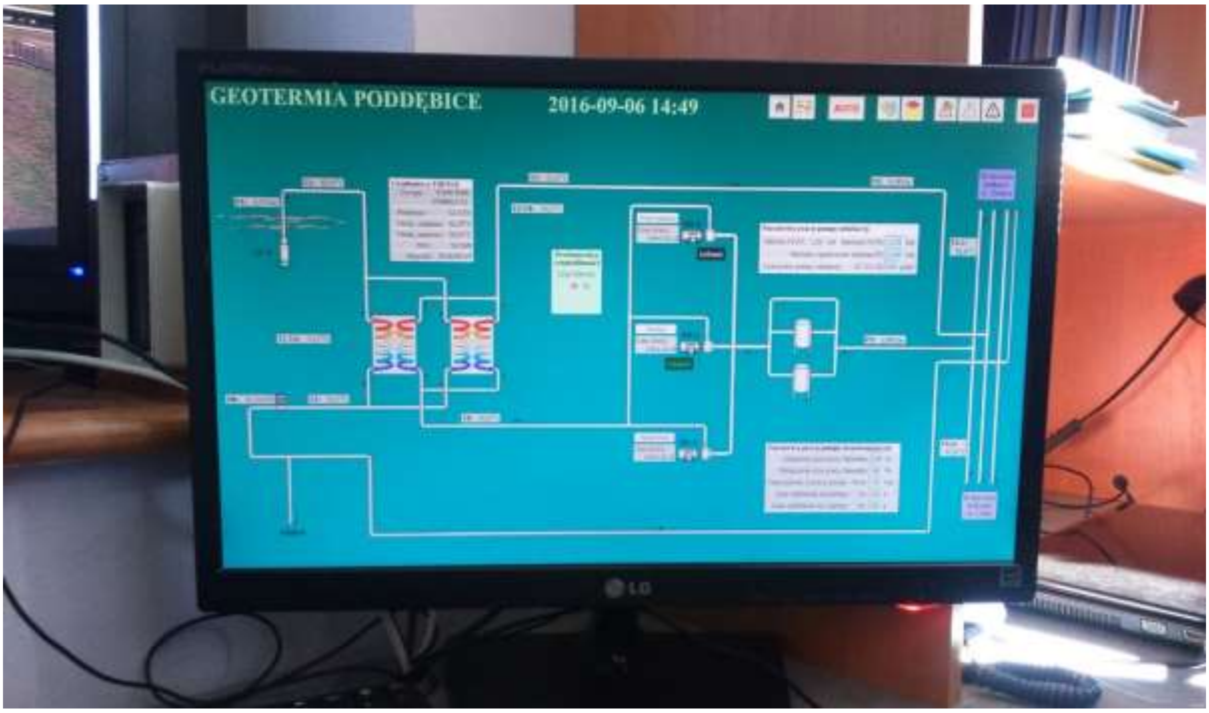


Fig. 2.34. Screenshot of SCADA system, current Poddębice heat central

The cooling pond, shown in Fig. 2.35, is located beside the heat central, into which geothermal fluid from heat exchangers (50–55°C) is discharged. The area of the pond (measured from Google Maps, w/ aerial view of the town and pond) is approximately 2400 m², so it holds a large body of water.

Fig. 2.35. Discharge pond for cooling of return geothermal fluid

The inlet/outlet temperature and flow of geothermal fluid to the pond have been logged since 2012. The only useful measurements, spanning a full 2 year period (Sept. '14–Sept. '16) are used to show the effectiveness of the cooling pond. Flow to the pond ranges from 20–170 m³/hour and it cools from 50-55°C down to 20–35°C, depending on flow rate and outdoor temperature. Results from measurements are shown in Fig. 2.36.

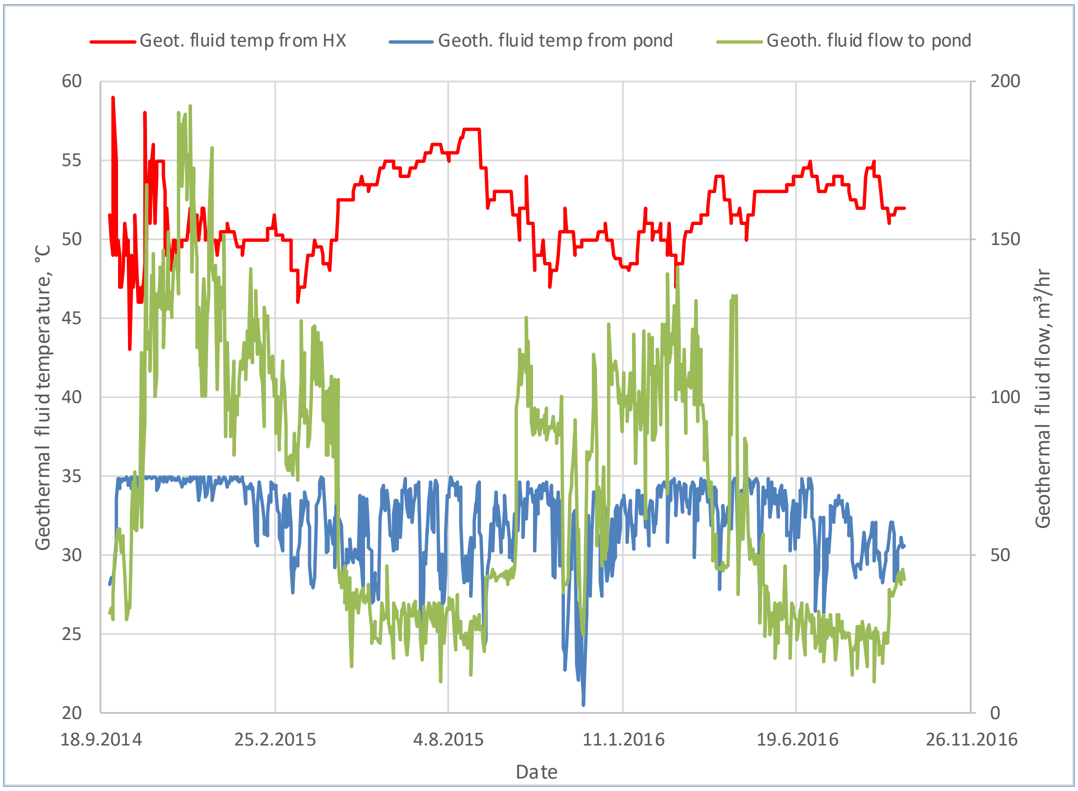


Fig. 2.36. Fluid flow and cooling through discharge pond

The effect of cooling in MW_{th} (product of flow, heat capacity and temperature drop) versus outdoor temperature is shown in Fig. 2.37. Although the data is extremely scattered (due to very infrequent logging of return temperature from heat exchangers), it is evident that cooling in the pond is most pronounced when outdoor temperature drops below 20°C. In these cases, the water temperature drops well below 30°C before leaving the cooling pond. During warmer days, the water temperature from the pond lies in the range of 30 to 35°C.

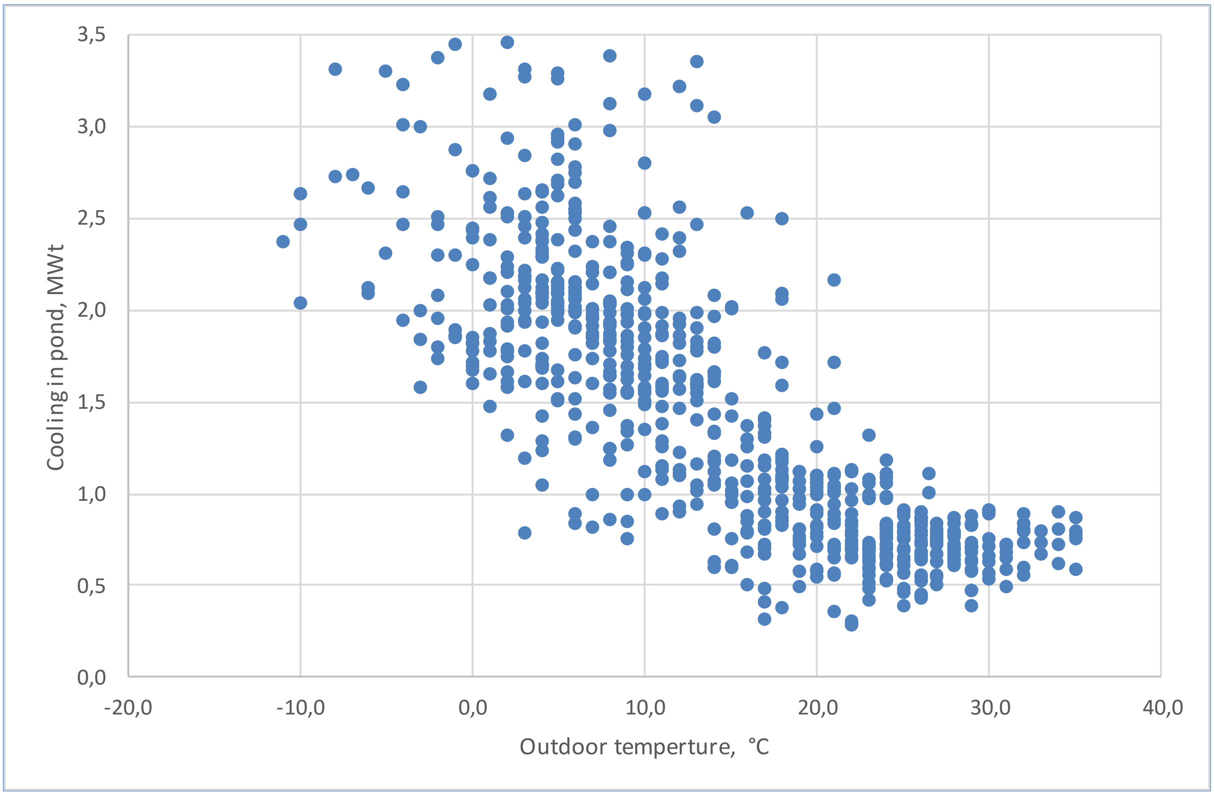


Fig. 2.37. Cooling in discharge pond vs. outdoor temperature

Distribution System and Current Peak Load Installations

The distribution system is made entirely from pre-insulated steel pipes (polyurethane foam and plastic coating), a tried and tested method for transporting hot water. It branches to the north and south of Poddębice, each half is 2xDN 250 mm main pipeline, each transporting 100–120 m^3/hr. The size of the piping can easily transport around 2–3 times that flow rate in the future, based on this design. Currently, around 12 km of piping have been installed, future expansion assumes another 33 km. There are currently 3 peak load boilers in the DH system, two oil fired, one fired with biomass. These heat the supply water up to 75–80°C during the coldest days. Each station has approx. 1–2 MW_{th} heating capacity. These stations are shown in Fig. 2.38. The plan is to disconnect them 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. The reason for this is historical, as the house connections were earlier designed for higher supply temperatures (90°C supply, 70°C return). Radiators have since been retrofitted, so the design supply/return temperatures are currently assumed to be 75/50°C, assuming 20°C indoor temperature and -20°C outdoors temperature during peak heat load. This may not apply to all users in the system, though.

Installing floor heating in new apartments should also be considered. These systems can operate at lower supply temperature (around 50–60°C), so that should be suitable for the temperatures in the network. It is, however, foreseen that these users would require local mixing stations in the network (which has a common supply temperature from the heat central), where return water is mixed with supply water to cool it from 60–75°C down to 50–55°C. This kind of system has, for example, been implemented in Xianyang in China in the past.

Fig. 2.38. Biomass peak load boiler station – district heating boilers

Fig. 2.39. Elements of district heating system

Currently, there are 3 peak load stations operated in the district heating system, located in the northern part of town. Each station – oil or biomass fired – has a heating capacity of around 1 MW_{th}. They are used both for house heating and utility (tap) water heating. There used to be around 5-6 boiler stations in the system, connected to the current distribution system in the town but have been decommissioned, one by one. In the future, a single, central peak load heat pump is planned for the entire system and all the current peak load stations will be decommissioned. One such station is shown in Figure 2.40.

Fig. 2.40.Decommissioned coal fired peak load station in district heating system

2.3.6. Heat demand

The population of Poddębice is approximately 7900 people and has been fairly constant in the last years. 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 m². With -20°C design load outside temperature, the heating load is estimated to be 60 W/m² in each household, so the total peak load in all of Poddębice is estimated to be 2930 apt · 100 m²/apt · 60 W/m² = 17,56 MW_{th}. This corresponds quite well to the estimated total heat demand in the town, presented by MEERI PAS, AGH and Geotermia Poddębice, as 18 MW_{th}. Other potential large users in the system are the Safari Park and Sports Centre in the outskirts of Poddębice.

Currently, the thermal power of the Geotermia Poddębice heat central is approximately 4 MW_{th}, including one large user (Poddębice Health Center). The current plan to increase flow from the production well Poddębice GT-2 from 190 to 260 m³/hr will increase the heating capacity to approx. 5,4 MW_{th}, or 30% of the total heat load of Poddębice.

Fig. 2.41.shows the heating system in the Municipality Hospital in Poddębice. Fig. 42 shows the heat pumps installed at the Poddębice Sport Center.

Several users, such as the Sports Centre, have local heat pumps installed, using the ground as a heat source. It will be fairly easy to modify these systems so that geothermal heat is used as an additional heat source.

Fig. 2.41. Heating centre at Poddębice Health Center

Fig. 2.42. Heat pumps at Poddębice Sports Centre

2.3.7. Measured heat load 2014-2016

The following is taken from a data log from Geotermia Poddębice, which consists of daily averages of flow, temperatures in the system, measured at the heat central. The data from September 2014 to September 2016 (a continuous 2 year period) is used, as earlier data has lot of missing measurements.

One of the parameters – the return temperature of geothermal fluid from heat exchangers – is only taken once a week, so the estimated heat load is highly uncertain. The intermediate values used are averages between the weekly values. Other quantities, such as outdoor temperature, supply/return temperatures to/from district heating system, temperature from cooling pond, etc. are taken daily.

Heat demand is calculated by multiplying daily average flow from well Poddębice GT-2 (30–190 m³/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 variation of these values over the 2 year period is shown in Fig. 2.43.

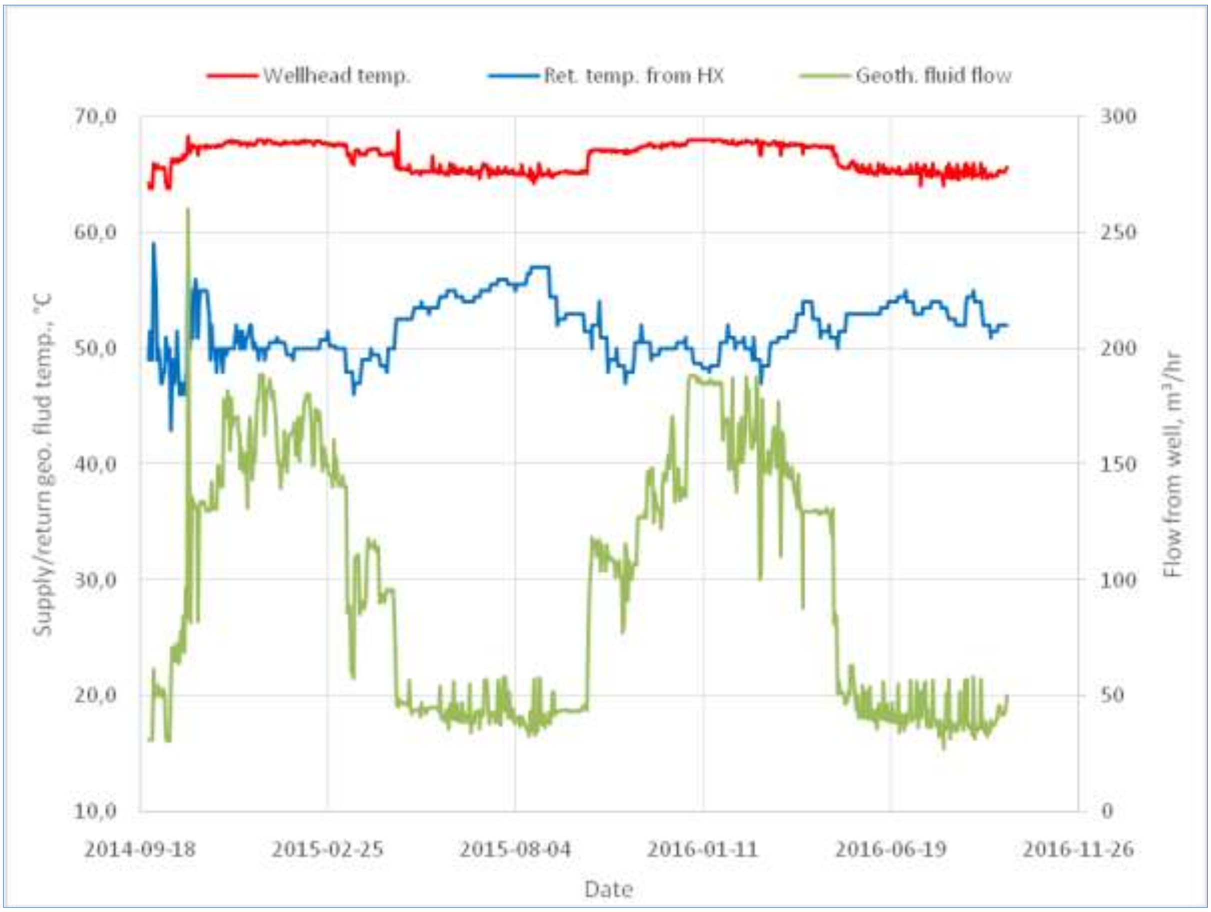


Fig. 2.43. Flow and temperature from Poddębice GT-2 and return temperature from heat central

The outdoor temperature and heat demand duration curves over a 2 year period are shown in Fig. 2.44.

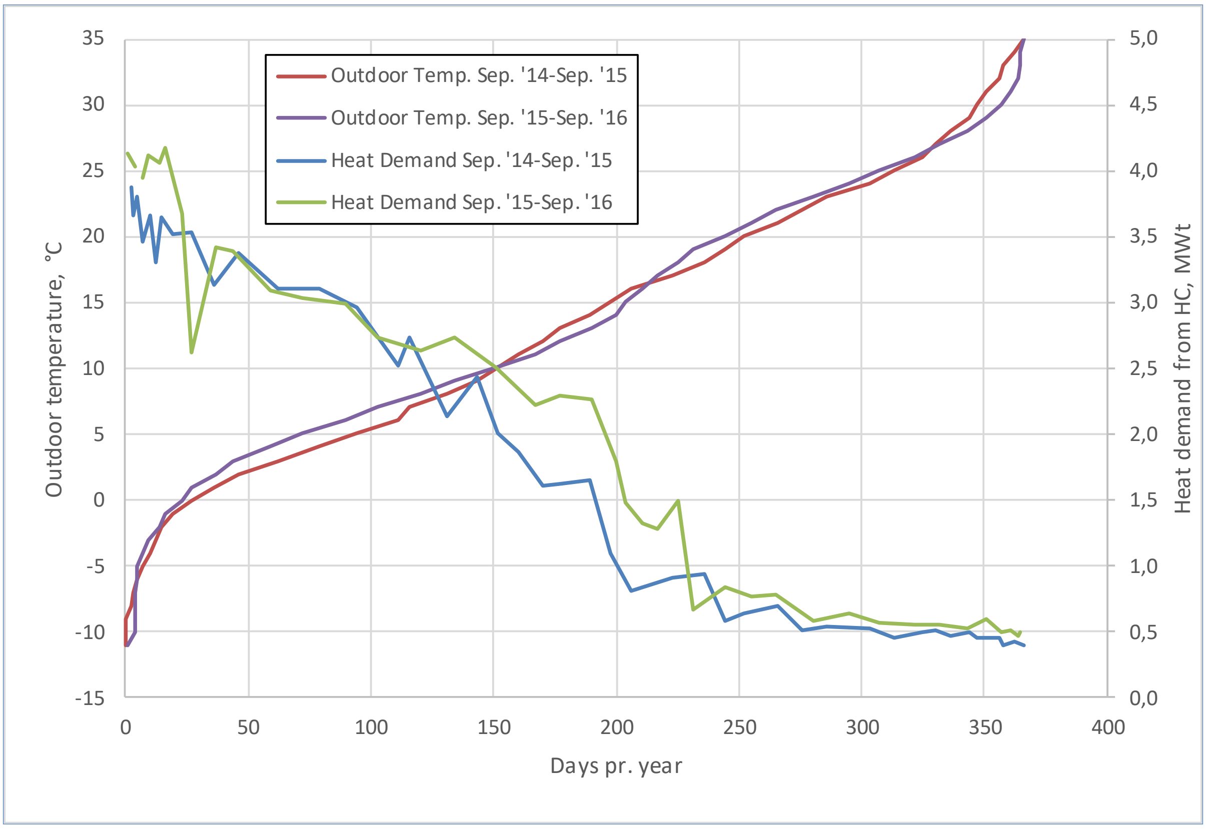


Fig. 2.44. Heat demand and outdoor temperature over a 2 year period

According to information from Geotermia Poddębice, the peak load installation is only used when outdoor temperature drops below -10°C, so in this period it seems not to have occurred, except for extremely short periods. However, the system is designed for -20°C, so a peak load installation is definitely needed for this coldest period.

2.3.8. Overview of various DH system configurations

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 Poddębice is expected to reach 18 MW_{th}. Two alternative configurations of the system are proposed, with regards to the ease of implementation of the 18 MW_{th} heating of the entire town.

Current DH System, 2016
A schematic diagram showing the current geothermal DH system and peak load installations in Poddębice is shown in Fig. 2.45. Geothermal d. Information for this diagram was assembled during the site visit and later on, during writing of this report.

The maximum amount of heat 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 m³/hr, divided as shown in Fig. 2.45. Geothermal d. 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.

Some (most) heat users have a heat exchanger and circulation pump installed, which lowers the supply temperature to the house radiators by some 2°C.

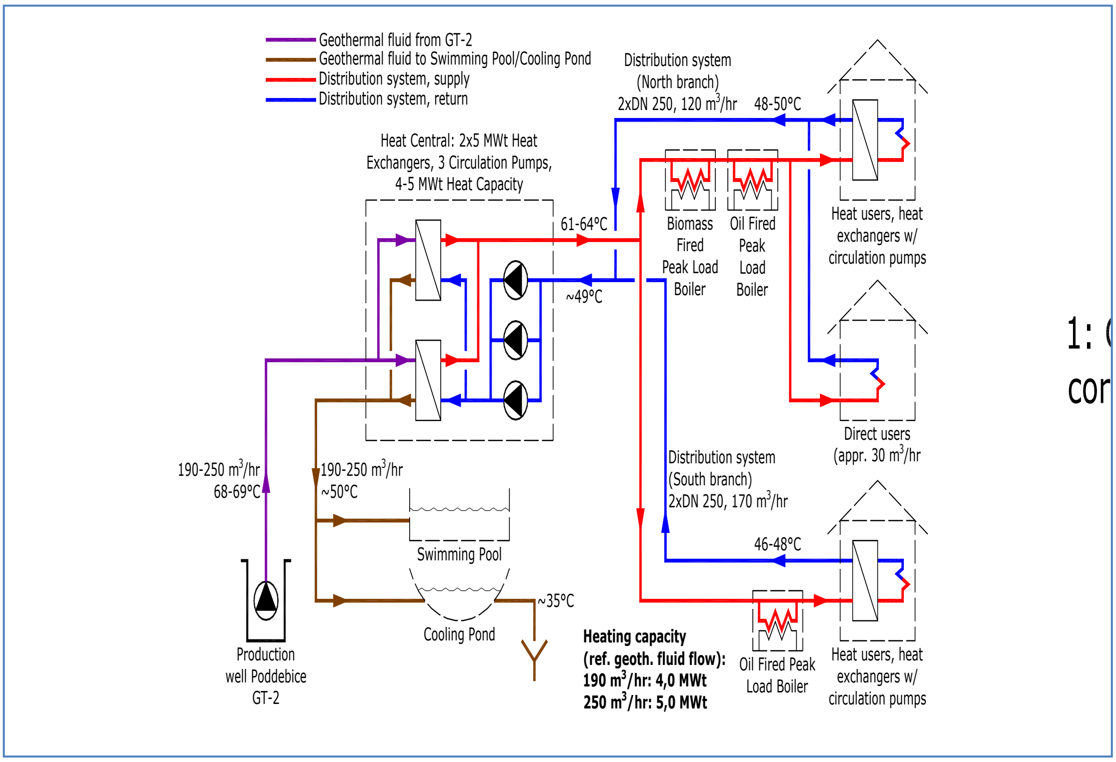


Fig. 2.45. Geothermal district heating system in Poddębice, current installation

2.3.9. Expanded DH system – increased flow and heat pump

The proposed expansion of the DH system in Poddębice is shown in Fig. 2.46, where flow rate from the Poddębice GT-2 is increased from 190 to 260 m³/hr. As noted in Fig. 2.46, peak load installations in the distribution system are decommissioned and a heat pump is installed at the heat central in their stead.

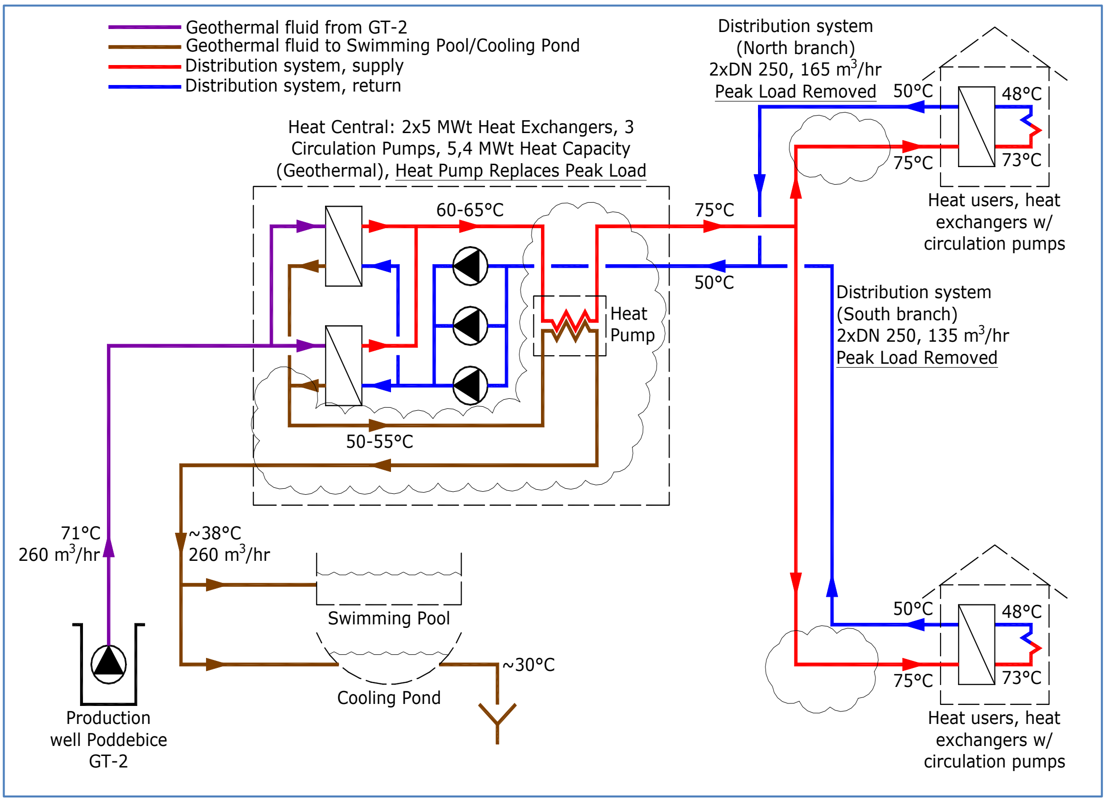


Fig. 2.46. District heating system Poddębice, increased well flow and installation of heat pump

The energy from geothermal fluid now increases from 4.0 to 5.4 MW_{th} from the increased flow. The heat pump ensures 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(Co-efficient 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. As discussed at the end of this report, installing a different kind of heat source for peak load, such as gas or oil fired boilers, may be more suitable.

Alternative 1: Heat Exchangers in Houses Removed, Mixing Stations

One of the two variations from the proposed DH system, as presented at the visit to Poddębice is as follows: It is suggested that all heat exchangers in houses and other users be removed or at least by-passed, to ensure as high a supply temperature to radiators as possible. Replacing small radiators with large ones is also recommended, where it is possible. That way, a common supply temperature from the heat central can be used, which would normally lie between 60–65°C when only geothermal energy is used but raised to 75°C or even higher during peak load. This configuration is shown in Fig. 2.47.

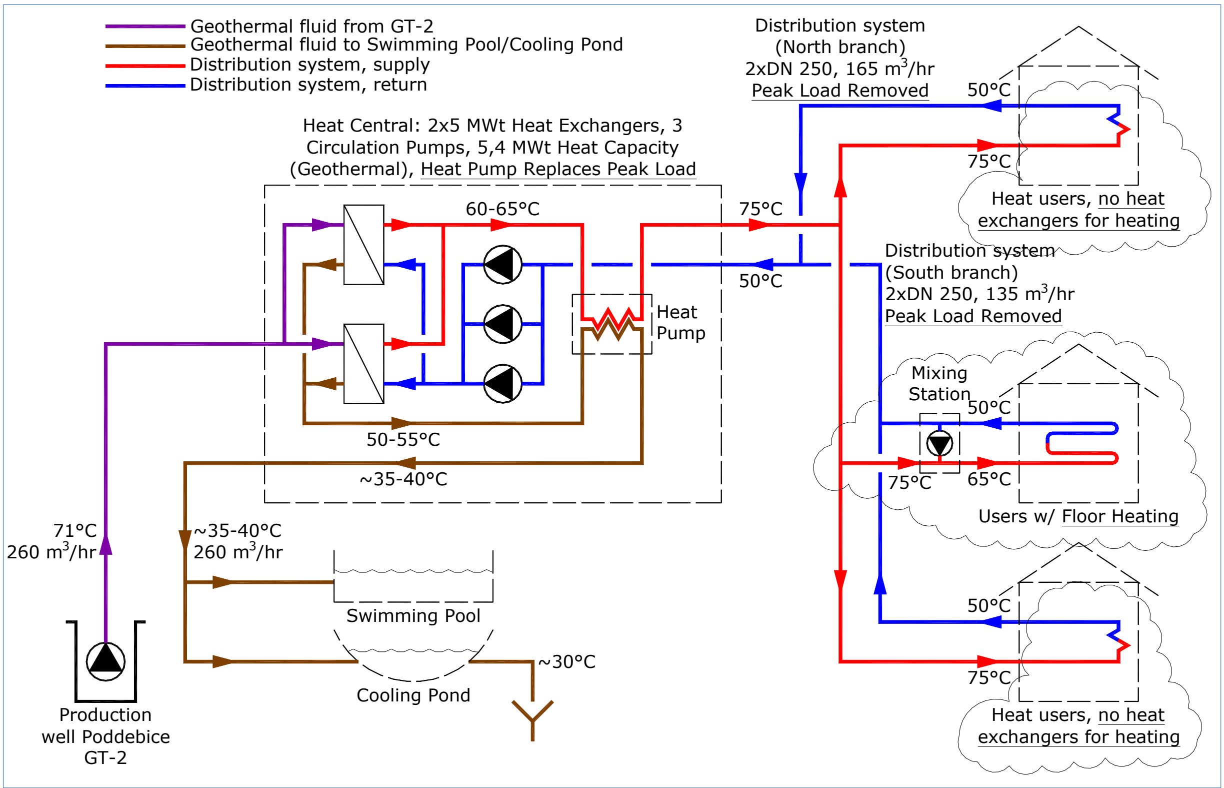


Fig. 2.47. Expanded geothermal district heating system in Poddębice, Alternative 1

One problem with this configuration is, if users have floor heating. These heating systems are commonly designed for around 60-65°C supply temperatures at most, so a high supply temperature from the heat central may prove problematic for these users. The solution – as has been implemented in Xianyang in China, where geothermal temperatures are very similar to those in Poddębice – is to install mixing stations on branches connected to house districts with floor heating. These would typically be new neighbourhoods, as floor heating is largely uncommon in the town at the moment. The mixing station takes a portion of the return fluid (around 50°C), mixing it with the supply fluid (up to 75–80°C), producing 60–65°C supply temperature to the floor heating system. It so happens that this type of re-mixing is used in old Polish buildings, built around 1960–1980, so this solution is known in Poland as well.

Another cause for concern is the distribution system pressure, used directly in radiators. Care needs to be taken so that supply pressure does not exceed radiator pressure classes. Safety valves may be needed in some parts of the system and supply pressure may have to be variable with flow.

Pros

- Increased supply temperature, lower fluid flow to users
- Minimized energy consumption of peak load installation (electricity or fuel)
- No changes required at heat central

Cons

- Mixing stations required for floor heating installations
- Pressure control in distribution system may be complicated

Alternative 2: Direct Use of Geothermal Fluid in Distribution System

Another way to further increase utilization of geothermal resource is to remove heat exchangers altogether from the heat central and use the geothermal fluid directly, as shown in the diagram below (Fig. 2.48).

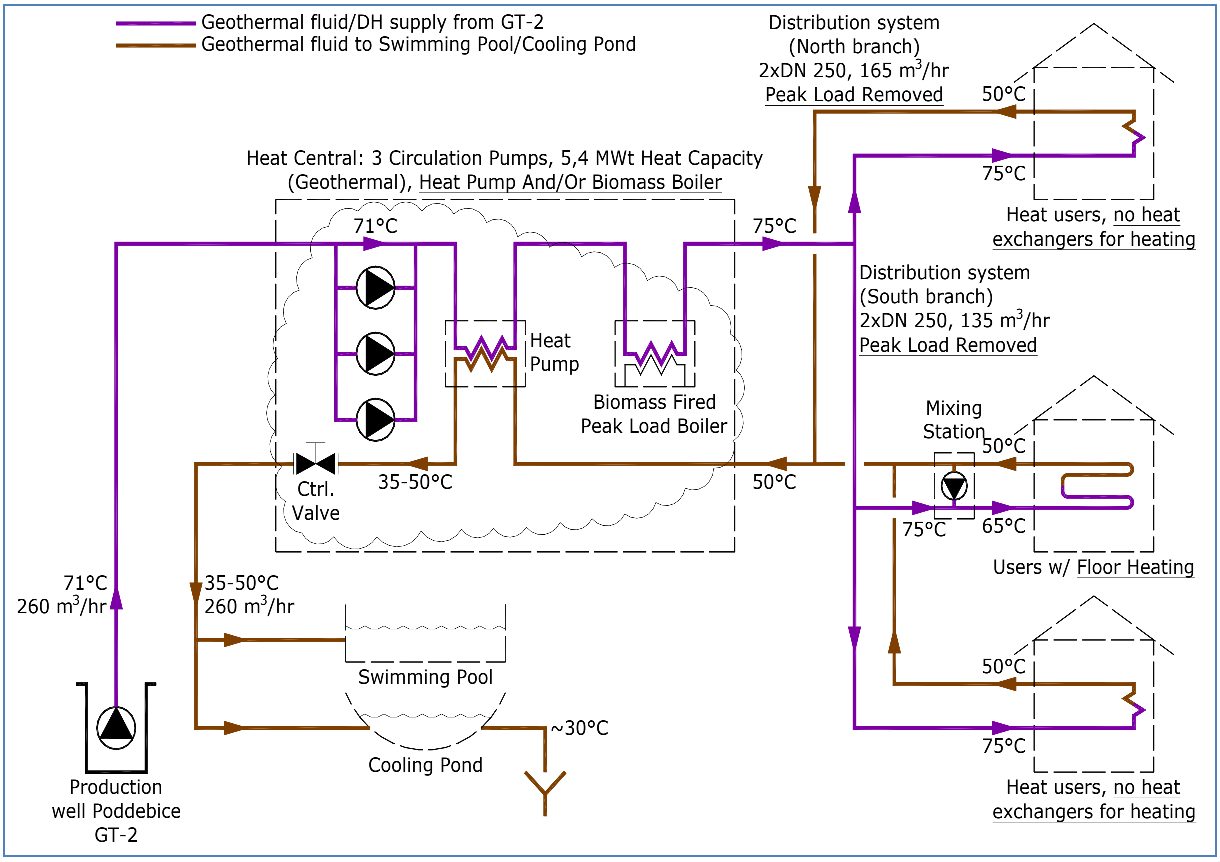


Fig. 2.48. Expanded District heating system in Poddębice, Alternative 2

This configuration is common in Icelandic distribution systems, where geothermal fluid is relatively clean. However, chlorine content in the fluid in Poddębice is rather high, at 28 mg/L, so this configuration is highly unlikely to be selected.

Pros

- Increased supply temperature, significant reduction of fluid flow in system.
- Geothermal resource (water) utilized to the max

Cons

- Chemical problems in system (scaling, corrosion, etc.) likely, due to chlorine content
- Fluid most likely unsuitable for end users (radiators, heat exchangers, etc.)
- Mixing stations required for floor heating installations
- Pressure control in distribution system even more complicated

2.3.10. Future district heating system in all of Poddębice

The future 18 MW_{th} system in Poddębice might be as shown in Fig. 2.49. Four 5 MW_{th} heat exchangers are expected and 5–6 circulation pumps. A 4 MW_{th}/1MW_{e} heat pump will probably be connected as shown, although the final configuration is not known at the moment.

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% if the energy for heating comes from geothermal fluid but only 5–10% from peak load (electricity or gas) annualy. Direct use of water in distribution system is recommended but depending on project implementation details, there may be a 2nd set of heat exchanger in each house connection.

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

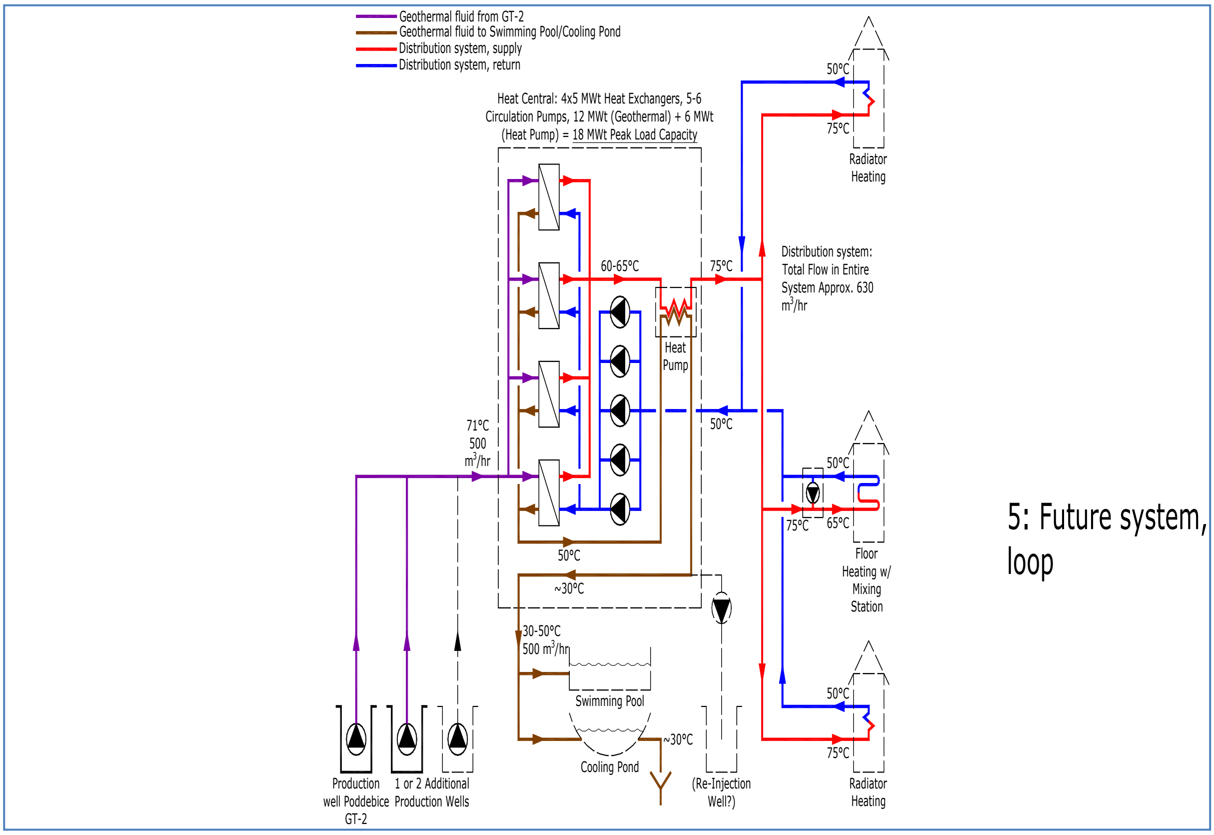


Fig. 2.49. Proposed configuration of entire geothermal DH system in Poddębice

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 is shown in Fig. 2.50: The red line indicates the cumulative heat demand, varying from 1,8 to 18 MW_{th}. The thin black line shows the separation between geothermal heating (5,5 MW_{th}) and peak load. The area above the black line indicates the energy input from peak load installation, the area below the black line indicates energy input from geothermal energy. The former – heat from peak load – is around 33% of the total annual energy input, the latter – heat from geothermal energy – is around 66%.

The decision of not drilling a second production well will reduce the project CAPEX in the beginning as the cost of drilling a well is significantly high. Annual expenditure for peak load electricity or gas would be somewhere around 300.000-500.000 PLN/yr, depending on the peak load installation, heat pump or gas boiler. Installing a large heat pump, which would be approximately 12 MW_{th}, will require large space and will cost millions of PLN. Still, it appears to be a cheaper alternative to drilling a new production well. Installing a smaller heat pump, around 6 MW_{th}, would still cost a considerable amount in addition to a new production well for geothermal water. The energy savings, however – using 5–10% of annual energy as peak load instead of 30–35% – would not recoup these additional costs.

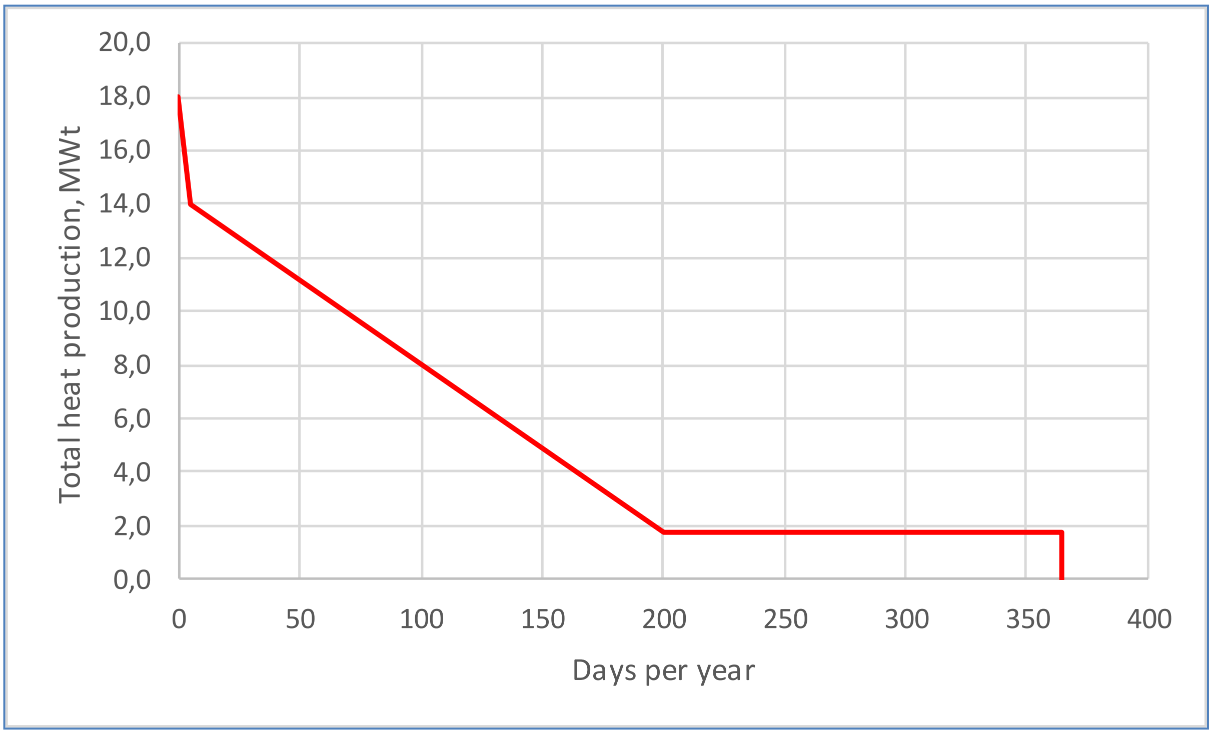


Fig. 2.50. Heating duration for the future DH system in Poddębice

Distribution system configuration

Due to rather high chlorine content in the geothermal water, it will not be possible to use it directly in the heating system. It is therefore recommended that the system be designed as proposed in Fig. 6 above, rather than having a second set of heat exchangers in every house. If proper measures are taken for pressure control, this will reduce the fluid flow in the system, both on the geothermal and distribution side, extracting more energy from the geothermal fluid. Also, not installing complex house connections (not using heat exchanger, pump, etc. for secondary heating circuit) in every building may also reduce overall cost in the system expansion.

The case of the extension considered for the system be developed is shown in Fig. 2.49. At least 2 production wells will be needed and one reinjection well. It is not known at this stage if using a cooling pond will be permitted in the future, as a very large amount of geothermal fluid – at a considerable temperature – is being discharged into the environment.

The selection of the peak load installation is also not known at this point but as a central unit, a heat pump is being considered. In any case, an optimal combination of peak load installation CAPEX vs. annual energy consumption (OPEX) will have to be selected, where a certain ratio of energy is from non-geothermal resources. A final recommendation of the future system of Poddębice geothermal heating system is therefore not available at this stage.

General SWOT analysis of applying gas boiler and absorption heat pump as peak load sources

Table 2.15 contains a general SWOT analysis of applying gas boiler in geothermal district heating system or absorption heat pump to cover peak load demand in Poddębice. Final decision which option to select belongs to the operator and / or owner of the heating system in Poddębice and depends on several factors.

Table 2.15. General SWOT analysis of applying gas boiler or absorption heat pump to cover peak load demand in Poddębice geothermal district heating system

Gas boiler		
	Positive	Negative
Internal	**S**trengths 1. Low investment. 2. Stable and failure-free work.	**W**eaknesses 1. Relatively expensive fuel purchase price.
External	**O**pportunities	**T**hreats 1. Probable fuel price increase with time.

Compressor heat pump driven by electricity		
	Positive	Negative
Internal	**S**trengths 1. Better (more complete) use of geothermal energy (RES).	**W**eaknesses 1. Very high purchasing price of the driving energy carrier. Electricity is the most expensive carrier of energy. 2. Very high investment expenditures. 3. Without a changes in the customer's heating installations, it will be necessary to have and use the peak source of energy. The peak source needs to have significant power. This results in increase of capital costs associated with depreciation.
External	**O**pportunities 1. Less sensitivity to the increase of the purchase price of the driven energy carrier (only about 1/4 - 1/3 of sold energy is drive energy, the rest origin on RES) 2. Positive marketing tone - utilising RES, 3. Possible improvement of ecological effects over the time due to increase the share of RES in the structure of electricity generation.	**T**hreats 1. Probable increase of prices of electricity with time. 2. Problematic demonstration of a positive ecological effect on a global scale (the reference energy carrier that is natural gas is a pure source of energy). It may effect with difficulties in obtaining subsidies.

Simplified house connection and more direct use in system

Another CAPEX item under consideration is the house connection cost. Using the district heating fluid directly to houses will result in hotter heating fluid, higher temperature drop and lower fluid flow. It can be roughly estimated that each 1°C increase of supply temperature will reduce fluid flow by over 12%. This reduced pump power consumption, lowering CAPEX by something around 50.000–100.000 PLN/year. Most importantly, though, by using the district heating fluid directly to radiators, the cost of house connections – which appears to be borne by Geotermia Poddębice – might be reduced. Currently, it is roughly estimated to be between 12000-15000 PLN/household, or 11% of the overall project CAPEX, based on connecting 1050 homes. It is hard to say but should the house connection cost be reduced by 50-70% by eliminating heat exchangers and pumps (using only tap water heat exchangers), the CAPEX may be reduced by an order of 10% and production cost (taking into account lower CAPEX) may be lowered from 7.25 EURcent/kWh down to 6.63 EURcent/kWh.

However, there will be need for re-thinking the pumping in the secondary heating circuit. Safety valves may be needed and perhaps pumping the hot water may need to be done in 2 stages, to keep water pressure within acceptable levels at each house. At this stage of the project, it is not known how this may be solved in detail but we see a much larger potential for reducing costs this way than to focus on the type of peak load installation will be used (heat pump vs. gas/oil boiler).

Summary and conclusions

The district heating system in Poddębice has been analyzed, based on site visits, meetings and data acquisition from Geotermia Poddębice Ltd. and MEERI PAS in Poland. The current system of around 4–5 MW_{th} has been in operation for 4 years and overall, it appears to be well implemented and operated. Pending further studies and confirmation on the geothermal reservoir capacity, there still appears to be adequate water supply, that can sustain annual heat production of 163,9 TJ/yr for a 18 MWth system with peak load installed, whether the peak load installed is from a heat pump or gas/oil boiler.

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 the high cost of a production well.All of the above findings have been compared to data logs from a continuous 2 year period and are found to correspond well with information presented at site visit meetings.

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.

The net price of gas heating to households is around 4,0 EURcent/kWh. The goal, however, of using geothermal energy should be to reduce CO_2 emission, which may be of higher concern in the near future.

There are also two key project risks that need to be kept in mind when the project is developed:

Geothermal reservoir hydrogeology

Although the reservoir appears to show no signs of long term drawdown (only dynamic drawdown that appears to fully recover), the reservoir will have to be fully analyzed for future exploitation of 45 GWh of heat annually, where water is utilized from 70 down to 50°C. This has to be ensured before drilling any additional production wells. This is a critical component of the geothermal district heating system. Without a -secure water supply the pumping will become problematic and perhaps re-injection wells may be needed to recharge the system, resulting in additional project and exploratory costs.

Cooling ponds vs. re-injection wells

Environmental regulations are constantly being reviewed and the current configuration of discharging 50–55°C geothermal fluid into a cooling pond and cooling it down to 30–35°C may not be permitted in the future. This may require a re-injection well, which will increase the project costs.

These project risks can be mitigated through proper monitoring and modelling of the geothermal reservoir and environmental impact assessment studies.

Additional geothermal energy use

Additional geothermal energy recovery can be achieved by the use of heat pumps. It is possible to use both compressor and absorption pumps. The use of heat pumps allows connect additional energy customers. It is envisaged to expand the district heating network. To achieve this goal, it is necessary to bring natural gas and purchase peak boilers to the Geothermal Poddębice system. It will also be necessary to extend the existing facility to a new building for boilers and/or heat pumps. The presented variant of the energy source development and heat distribution system will involve significant financial expenditures. It is anticipated that especially capital investments will be high for the installation of compressor heat pumps. Because of short operating time of the equipment long return time of investments is expected?

The alternative of the system expansion by connections of single family houses is use of existing gas-oil and biomass boilers as the peak sources. In this variant it is proposed to use heat pumps in existing heating stations, where gas connections were made earlier. This solution avoids interruptions in heat supply due to geothermal failure. Another element of this variant is the increase the surface or the numbers of radiators in heated objects. This element, however, can be difficult to fulfill due to social reasons (habits of consumers). Perhaps it may be a good idea to make the necessary changes to the selected pilot facility?
In conclusion it might be said that there is no simple solution and financially accessible to improve the energy efficiency of the geothermal system in Poddębice. The decision to adopt such a solution is also not easy.

As regards the visit to Iceland and the experiences that can be implanted in Poddębice, it might be said that there are favorable conditions both for terrain and temperature of geothermal water for the construction of greenhouses. Initially, this could be a cognitive and educational greenhouse, both in terms of installation, which would be based on thermal water at a temperature of about 40-50°C (after the geothermal heat exchangers) and the selection of special untypical plants.

2.4. Evaluation of policy options and opportunities

Evaluation of geothermal policy options and opportunities in Poddębice Town fall into several main groups of aspects and in such an order are presented further in this Chapter (which contains also conclusions and recommendations), i.e.:
- Reservoir and exploitation aspects,
- Energetic, district heating aspects,
- Increase efficient geothermal energy uses – multipurposed uses,
- Other observations, proposals, recommendations.

Reservoir and exploitation aspects

1. Poddębice town has very good reservoir conditions and production parameters of geothermal aquifer hosted by Lower Cretaceous sandstones.
2. The-so-far geothermal water production by Poddębice GT-2 well has not caused the change of exploitation parameters, including water level ((however: geothermal aquifer is at initial stage of exploitation).
3. Geothermal water's production simulation using Lumpfit programe indicates that when production is doubled water level will drop by 20 – 40 m, which should be manageable.
4. Further careful monitoring of reservoir and production (exploitation) parameters is necessary – since this is an indispensable basis for proper current and further planned exploitation of geothermal water reservoir (with flow rate bigger than now).
5. Prediction of potential water level change during long-term production by Poddębice GT-2 shall be periodically simulated by Lumpfit program (shared with Geotermia Poddębice Ltd. by NEA).
6. There is much noise in the-so-far monitoring data on water level what reduces the quality of any modelingand predictions – data acquisition should be improved in the forthcoming production period.
7. There is a need to construct a geothermal reservoir model (MODFLOW, TOUGH, other) and its use for the purposes of sustainable exploitation, prediction of its possible reaction for long-term exploitation, optimal location of next wells, etc.
8. In view of the long-term sustainable exploitation of the discussed geothermal reservoir it is advisable to consider the drilling of injection well. There are several reasons for this: injecting eliminates the discharge of geothermal water to the outside environment, helps to maintain the aquifer stability and water level in the well, especially during long-term exploitation. The legal requirements in this regard may also change.

Energy, district heating aspects

1. Geothermal waters in Poddębice are characterized by temperature slightly lower than the maximum temperature required during peak demand periods (geothermal water has 65–71°C – depending on the water flow rate, while the maximal temperature needed by the users equals 90°C). The heat transmission and distribution system is well suited to the heating installations used by customers. Temperature depletion, during periods of peak power demand, necessitates the use of a peak source of energy. An alternative to the current solution is to decrease the required inlet maximum temperature of the heating system. Measured benefits should also bring down the return temperature of the customer's heating installation. High temperature of return water characterise the return water (50°C). The recommended heating systems are large surface heating installations - e.g. floor heating, wall heating and ceiling heating or the use of radiators with large heat exchange surfaces. In this context, it may be a good idea to introduce demonstration installations showing the ability to efficiently heat objects with low power supply temperatures. Changing the customer characteristics (lowering the required flow temperature and reaching low return temperature). It can results in lowering the cost of meeting the heat demand (downward energy price). This may be an incentive to use such heating systems by customers.

2. Depending on the analysed time interval, the recommended solution for increasing the installed capacity is: in the short term (about 15 years) the recommended solution is to use boilers used natural gas while in long-term (20-30 years) profitable might be drilling of an additional geothermal well (power increase of approx. 12 MW) and installation of a small power in a gas boiler (about 6 MW). These variants assuming the use of peak boilers or new well differ in a cost structure. In the case of use of peak boilers, operating costs (OPEX) are dominant, and CAPEX is dominated for the second option.
3. Using heat pumps as a peak aid device, gives possibility to reduce the temperature of the geothermal water which is to be discharged (after cooling down). However, bearing in mind the short period of work of the peak source - and therefore a small amount of energy produced by them, with of high capital expenditure at the same time, this solution does not seem to be profitable. The qualitative SWOT analysis for the variant of boilers and heat pumps is rather the use of gas boilers.
4. A possible solution that requires further details and analyses is the use of a hybrid power source to meet the needs of peak power demands including heat pumps and gas boilers. Finding the optimal way of installed power dividing between these devices requires taking into account forecasts of energy price changes over the time and performing optimization calculations.
5. The analyses presented do not take into account the possible CO_2 emissions into the atmosphere. Taking into account these charges may increase the attractiveness of the variant assuming the use of a new geothermal well.

In addition to the-above general statements, the following detailed items are therefore recommended, also based on results from the conference held in Poddębice on June 13th. 2017:

- Further modelling and exploration of geothermal reservoir are needed,
- Based on the above, decision whether or not to drill 2nd geothermal production well,
- **Install a demo project, where 40–50°C return water is used for floor heating, e.g. in a block of flats,**
- If only 1 geothermal production well is used (GT-2), use gas boiler instead of heat pump, as it is a simpler installation with lower initial CAPEX,
- Consider using biomass fuel instead of gas. This will mean slower response time during sudden demand increase (due to sudden cold weather) but should be manageable through integrating weather forecasts with the operation of the system.

Increase efficiency of geothermal energy extraction – wider uses, innovative energy managements forms

On a basis of Study Visits to Poland, Iceland, exchange of experience, transfer of knowledge, Project works one can state that incresed geothermal energy uses in Poddębice is both of purpose and creadible. It will contribute to increase ecological effect, energy efficiency and innovative sustainable economic development. The proposed possible scope of the expanded use of geothermal energy and water in Poddębice includes:

- Extension of district heating system to the whole town,
- Agriculture – greenhouses, foil tunnels,
- Algae cultivation,
- Fish farming,
- Recreation and balneotherapy,
- Drinking, mineral water and cosmetics production,
- Other: supply heat and water to eg. Sport centre premisses, Safari Park in Borysew.

Moreover - in the view of Project partners, Poddębice as a city and county have many arguments to set up an energy cluster or other form of co-operation in the field of common efficient and innovative energy management, with geothermal energy being and axis, with other renewable energy sources (solar, biomass) as well as traditional ones.

Other proposals, recommendations

Increased energy efficiency and geothermal energy uses in Poddębice is conditioned, e.g., by:

- Introduction of some measures to enhance the clients to change the heating systems into lower-temperature ones - pilot installation would be very helpful, other incentives,

- Education and actions towards social awareness' increase and cooperation with Geotermia Poddębice and Poddębice Town,
- Important is a cooperation among Geotermia Poddębice Ltd., experts of geology, reservoir, exploitation and experts of heating, Town development, inhabitants...
- Effective and good eco-adviser in the Town,
- Continuation of cooperation with Icelandic and other experts (including Norwegian) in a framework of EEA/NFM funds.

General recommendations and conclusions

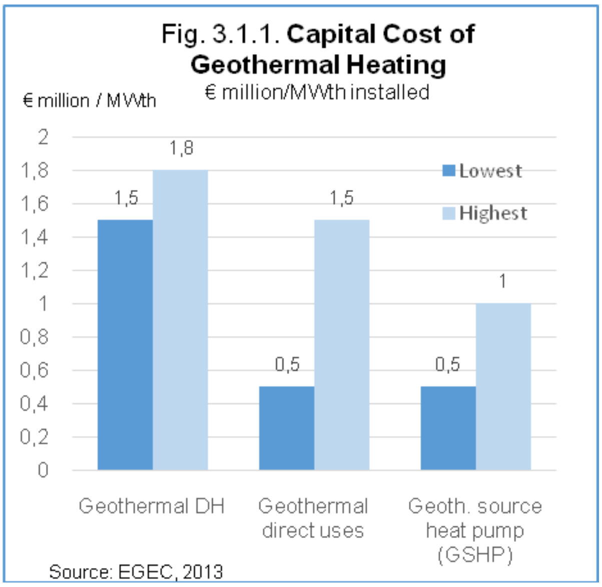
The Project works for Town Poddębice also lead to recommendations of a general nature for the whole Poland (given also in chapter 1.4):

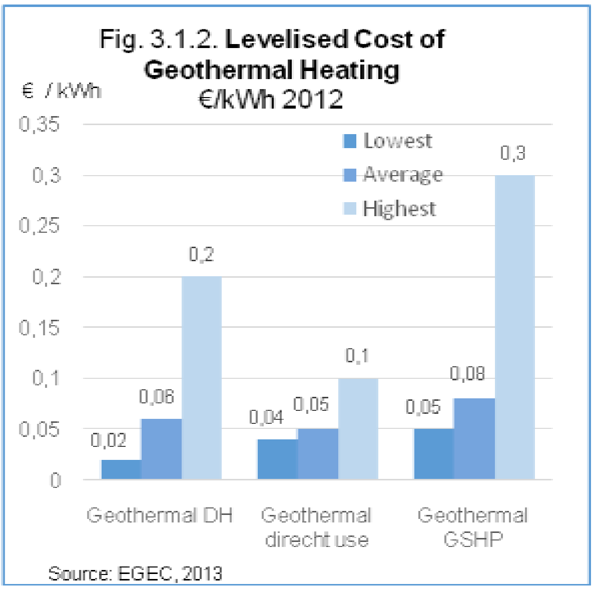
- Introducing (also by state/ local regulations) the provision to install lower-temperature heating systems in newly-constructed buildings,
- Heat price tariffs shall be conditioned by „Delta T" achieved by receiver – this as a very needed provision in Energy Law, other documents (!),
- The-above-proposals shall be submitted as amendmends / provisions for relevant state regulations / documents and be subjects of serious considerations,
- Other, e.g.: FiT; obligation to purchase geothermal heat; including geothermal / RES into return technological water.
- The Project results lead to the conclusion and recommendation that the analysed topics shall be the subjects of further comprehensive analyses and works with the participation of its partners (may also others ones), as well as a pilot project,
- It is of significant importance both for Poddębice and for other localities where geothermal wells and installations are perating or planned,
- Opportunities to deepen and continue works initiated and done in this Project – e.g. in a framework of recent project proposal (another ppt) as well as next EEA/NFM for Poland.

3. Geothermal district heating in Europe

3.1. Geothermal district heating – cost structure

In most cases, geothermal district heating projects face the same issues as geothermal power plants. Furthermore, geothermal heat pumps can also be considered as a capital intensive technology in comparison with other small scale applications. (EGEC, 2013).





Geothermal heat is also important and competitive for district heating, where a resource is available, especially where a district heating system is already in place. Geothermal heat can also be competitive for industrial and agriculture applications. Geothermal heat pumps can also be profitable, in comparison with fossil fuel heating systems.

Geothermal heat may be competitive for district heating where a resource with sufficiently high temperatures is available and an adaptable district heating system is in place. Geothermal heat may also be competitive for industrial and agriculture applications (greenhouses). As geothermal heat pumps can be considered a mature and competitive technology, a level playing field with the fossil fuel heating systems will allow phasing out any subsidies for shallow geothermal in the heating sector.

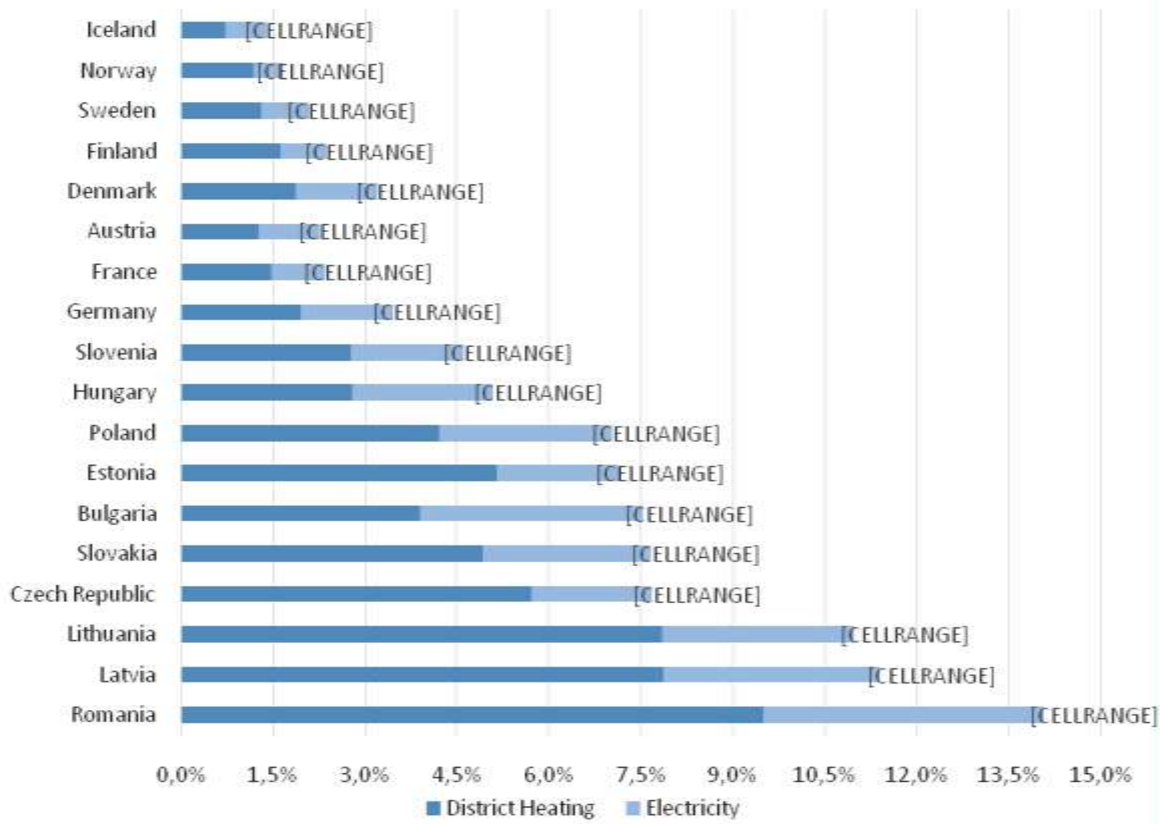
In many cases, geothermal district heating projects face the same issues as geothermal power plants, the need of capital and risk mitigation is therefore also valid for this technology. Moreover, notably because of the drilling, geothermal heat pumps can also be considered as a capital intensive technology in comparison with other small scale applications. Geothermal heating and cooling technologies are considered competitive in terms of costs, apart from the notable exception of EGS for heating.

In addition, an important barrier for both electricity and heating and cooling sectors is the unfair competition with gas, coal, nuclear and oil, which is the primary reason justifying the establishment of financial support schemes for geothermal.

If we look at the proportion of annual's salaries of people for buying district heating and electricity for 100m^2 household in Europe, we can see that Iceland is paying the lowest proportion for both district heating and electricity, and Romania is paying the highest.

The risk characteristics of a geothermal heating project are different depending on the three stages of the projects, which are: 1. Exploration, 2. Drilling, and 3. Building, which is less risky.

Fig. 3.1.3 **The Proportion of Annual's Salaries of people for buying District Heating and Electricity for 100m² Household in Europe**



Source: Orkustofnun Data Repository: OS-2016-T006-01

In a calculation presented in a GeoDH paper from 2014, it is estimated that, *"a private investor who would be given the opportunity to invest 20 million Euros in the building, and receives a feed-in tariff of 90-96 Euros/ MWh would earn around 9-10% per annum on the 20 million EUR invested. If that investor financed two-thirds of this investment with debt, as is common practice for such investments, the return on equity can rise to 20%. This observation leads us to the conclusion that a feed-in tariff, such as is already available in the wealthier member states of the European Union, is sufficient to attract investment for the building and operation stage of a geothermal electricity generating plant, if only the exploratory and drilling stages are completed."*(Christian Boissavy, 2014).

It is therefore an important element of a geothermal heating project that there are options and possibilities of support from public authorities towards the exploration and the drilling stage of such a project. In the above mentioned paper it is recommended that the support should cover 75%-80% of the exploration and drilling cost if the project fails. This is especially important due to the risk of test drilling.

In Iceland for example, the test drilling for such projects can be refunded by the Energy Fund if the test drilling is not successful.

Regarding heat generating geothermal plants, the benefits are greater when high temperature resources is used to generate both heat and electricity than when it is used for heat alone.

The geothermal heat production has several advantages, such as:

1. Economic opportunity and savings.
2. Improvement of energy security.
3. Reducing greenhouse gas emissions.
4. Harnessing local resources.
5. Reducing dependency on fossil fuels for energy use.
6. Local payback in exchange for local support for deep drilling.
7. They complement existing district-heating networks offering an alternative to other fuels.
8. They can be combined with smaller binary cycle (if reservoir and economics allow) electricity generating plants to bring the utilisation of the reservoir to the maximum.
9. May be a useful complement to regional and local economic development programmes with positive effect on employment and the viability of public infrastructure.
10. They raise public awareness for the geothermal energy to a broader section of the public
11. Improving quality of life based on economic and environmental / climate benefits.

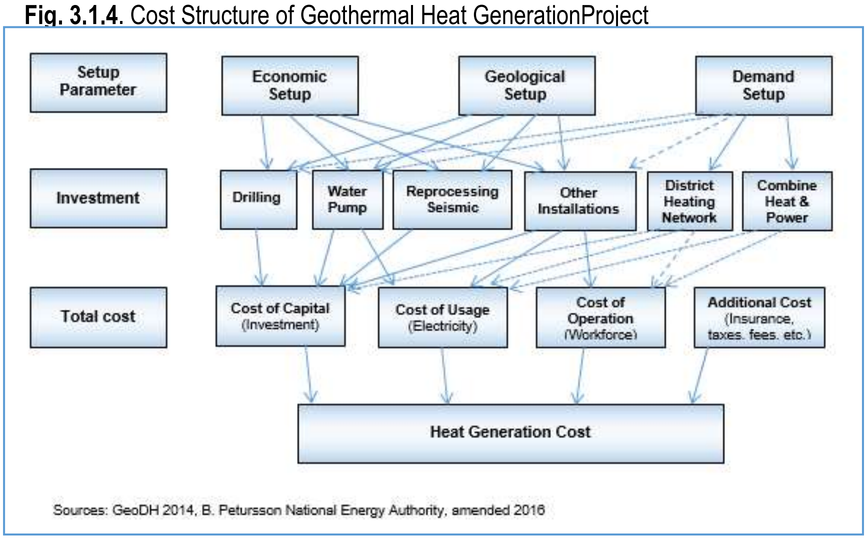
It is difficult or impossible to present standard costs of geothermal district heating projects, as the cost vary between regions and variable conditions. Nevertheless, the costs of such a project can be estimated, based on the most important parameters for the understanding of the individual projects, by:

- first defining the basic conditions affecting the heat generation cost,
- secondly by developing theoretical projects in order to explore economic viability.

Key factors for geothermal district heating projects are:

- geological framework,
- economic conditions and
- demand.

Fig. 3.1.4. Cost Structure of Geothermal Heat GenerationProject



Although it is difficult to estimate the profitability of such projects, the cost for each project can be based on the demand structure, the geological conditions, the costs of capital and the existing geological data, as is shown in figure, 3.1.4.

The demand aspect plays an important role in defining the project and the investments e.g. drilling, size of the water pump, buildings, district heating network and a power plant's mechanisms. In addition, the evaluation of heat production costs depends on the geothermal energy resource. It should also be noted that many of these cost elements are the same as for a standard heat production installation.

However, due to the fact that every location has different demand conditions, it is not possible to incorporate these factors in a general heat production cost calculation. Moreover, many costs are equal to those of a conventional heat generation installation. A paper for GeoDH from 2014 presented a calculation estimating the cost of a geothermal heat production project. The calculation was based on the following costs elements:

- capital cost (investments for drilling, water pump, substation, depreciation),
- operational cost (electricity for pumping & equipment, maintenance).

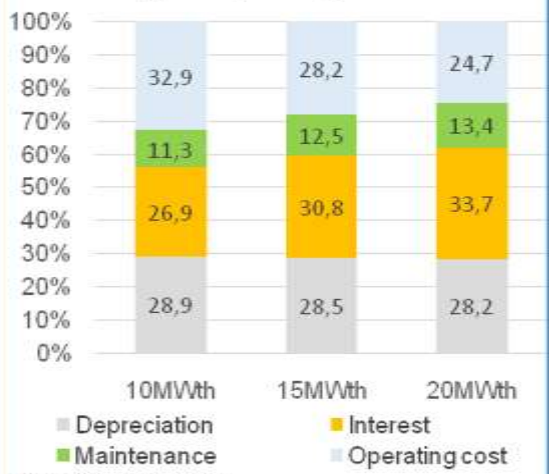
However, in addition to these costs, geothermal heat generation plants have to be connected to a network of plants using other energy sources, like a gas-fired or coal-fired power plant to be able to cope with peak loads. That kind of cost is not included in the project example that will be described in figure 3.1.5.[1]

Calculations on geothermal heat generation cost carried out for GeoDH in 2014, involved three projects 10, 15 and 20 MW_{th} as shown in figure 3.1.5. It is interesting that the figure illustrates that the generation cost is stable for a period of 30 years, (due to lower costs of capital over time), which is opposite to the trend for forecasted prices for fossil fuels. Higher cost for 15 and 20 MWth projects than 10 MWth, is due to a higher capital cost in form of interests due to more expensive drilling.

Fig. 3.1.5. **Heat Generation Cost of three Different Plants**

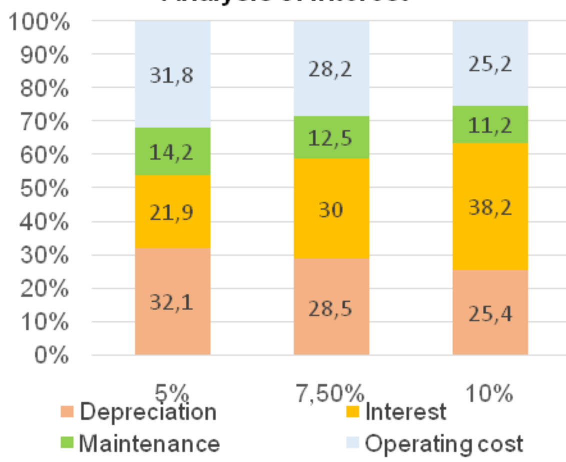
Sources: GeoDH, 2014

Fig. 3.1.6. **Cost Structure of Generation Project Depending on Size**



Source: GeoDH, 2014

Fig. 3.1.7. **Cost Structure of a 15 MWth Project and Sensitivity Analysis of Interest**



Source: GeoDH, 2014

As can be seen from figure 3.1.6, the cost structure is different depending on size of project, but for all projects the capital cost (depreciation and interests) is the biggest part of the overall cost, as this is a capital intensive sector. For the 10 MW_{th} case, the biggest single cost factor is operation coming from electricity cost to run the water pump.

For the biggest project the largest cost factor is capital cost - interest. As these projects are capital intensive, interest plays a major role regarding profitability, as can be seen for the sensitivity analysis in figure 3.1.7, where the 5% interests cost go from 21,9% up to 38,2% if the interests are 10%. Rates of interest are therefore one of the biggest risk factors.

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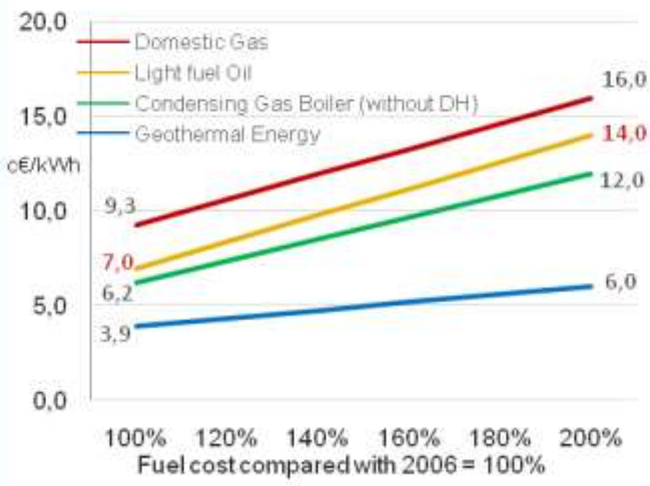
[1] The geothermal generation heat project provides the base load energy for district heating, which will be delivered to the district heating network, total hours of the plant will be 8.000 hours/year. The focus will be on generation cost so no revenues will be calculated. Life time of the project is estimated 30 years of operation; repayment of loans is 30 years, depreciation off the drilling is 50 years, depreciation of the substation is 30 years, depreciation of the pump is 3 years and interest rate will be 7,5%.The costs for a district heating network and special installations, as well as taxes and fees, are not included.

Fraunhofer Institute for Environmental, Safety and Energy Technology carried out a study for Germany, comparing the heat generation costs between fossil fuels and geothermal heat plants delivering heat to district heating networks, (2006 prices). The study shows, that cost structure of generating heat from fossil has higher operating costs than geothermal which has higher fixed costs. Total heat generation costs of geothermal energy are low in absolute terms due to the high utilisation rate and low variable cost. During increase of primary energy prices, the total costs of generating heat from fossil fuels are rising more rapidly due to high variable cost, than from geothermal, as can be seen on figure 3.1.8.

Fig. 3.1.8. **Heat Generation Cost for District Heating Network by Fuel**



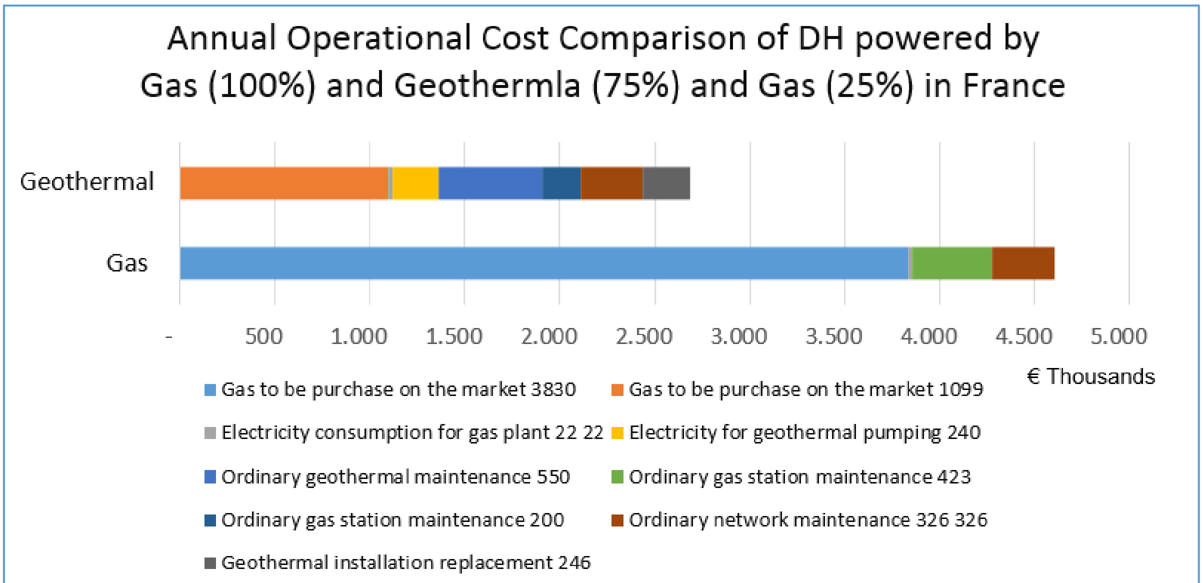
Source: GeoDH 2014

Business Model for Geothermal District Heating and Gas

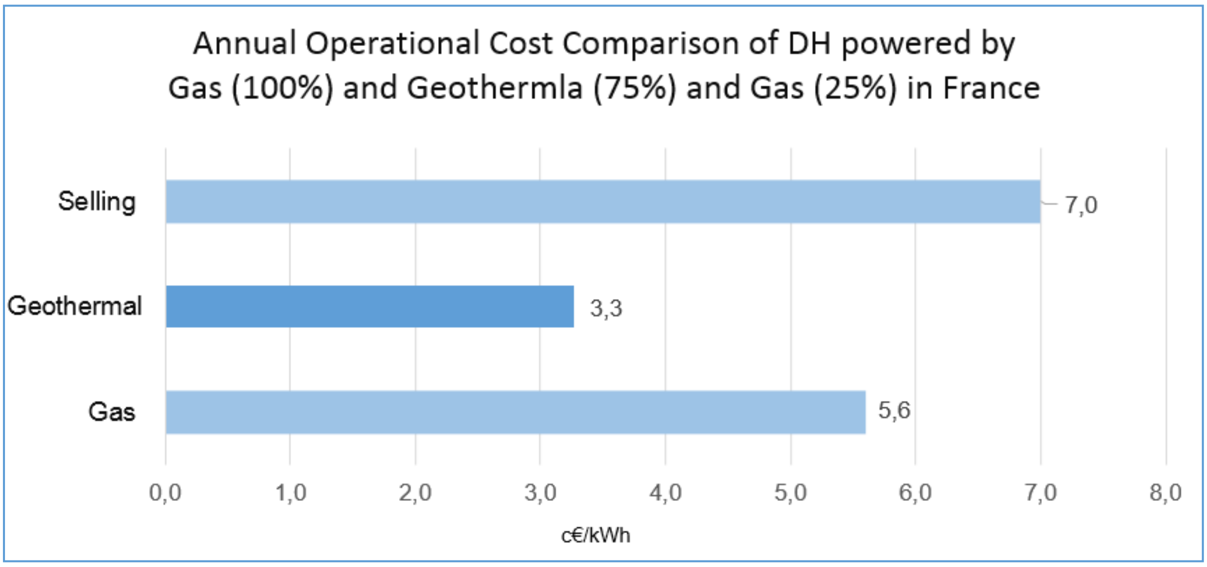
Cost Comparison – kWh Produced by Natural Gas and Geothermal Heat
Following business model is based on comparison between a district heating network using natural gas and a geothermal district heating network, in the Paris area, described in GeoDH paper from 2014. The project (geothermal doublet) has been running for 31 years. However, the geothermal water flow rate is decreasing. (GeoDH, 2014).

The key findings of this demonstrative example in France is that the actual production cost of the heat produced using 100% gas is about 5,6 cEUR/kWh for a final selling price to the consumer at 70 cEUR/kWh, all inclusive.

However, the same kWh produced with a mix of natural gas (24,82%) and geothermal (75,18%) is 3.27 cEUR/kWh. The benefits and difference, which is 2,33 cEUR/MWh, will allow to finance the construction of the doublet. The annual production of the project is 81.980 kWh/ year with a turnover of 5,739 kEUR. The annual profit using geothermal is 1.918 KEUR.



This profit will pay back the investment cost in 7,45 years, meaning that after 8 years the community will start to gain about 2 million euros per year, or it would be possible to lower the price of 2,33 cEUR/kWh and keep the profit as before (GeoDH, 2014). This demo example, shows the opportunities and economic benefit that may be gained from geothermal resources in combination with other energy resources in district heating.



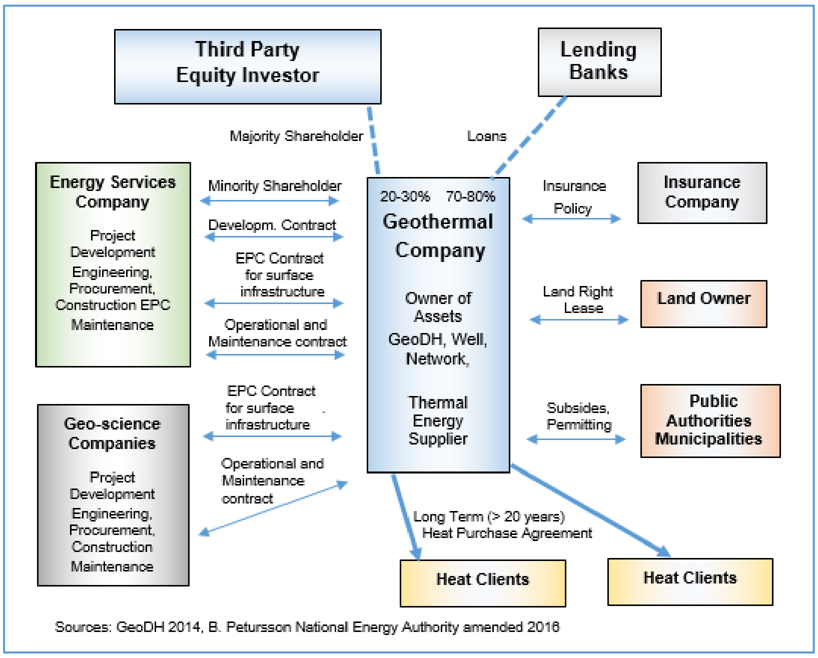
As can be seen from the case in France, the actual annual operational / production cost of the heat generated using 100% gas is about 4,6 MEUR (5.6 cEUR/kWh) - but only 2,7 MEUR (3,27 cEUR/kWh) with a combination of geothermal (75%) and gas (25%). The benefits and difference which is 2,33 cEUR/MWh will allow to finance the construction of the doublet – and the profit will pay back the investment cost in 7,45 years – meaning that after 8 years the community will start to gain about 2 million euros per year – or it would be possible to lower the price of 2,33 cEUR/kWh and keep the profit as before.

3.2. Geothermal district heating – legal structure

Legal and financial structure and planning are main elements of geothermal district heating planning and risk assessment. However, risk assessments depend on each type of project which can be different based on location, regulation, technology, management, finance etc. Nevertheless, there are also general similarities for such projects regarding legal and financial frameworks for geothermal district heating – as can be seen in enclosed figure 3.2.1.

A Geothermal Company (GC) financed by the equity investor (20-30%) and by bank by loans (70-80%), is established to centralise the assets, rights and operational agreements. This company signs long term (>20 years), heat purchase agreements with end users with a fixed charge (capacity charge) linked to kW of capacity subscribed, and a variable charge ("consumption charge") proportional to kWh supplied.

Fig. 3.2.1. Legal and Financial Framework for Geothermal District Heating



The company should also sign key contracts regarding engineering, procurement and construction and operating and maintenance, for both the geothermal well and the district heating network. The company also has to have insurance policies (civil liability, damage, geothermal resource risk if possible, etc.). Finally, the company has to secure land rights, permitting and subsidies with the land owners and public authorities or municipalities. (GeoDH, 2014).

3.3. Global price comparison of geothermal district heating

Due to its diffusive nature, there are economic limits to the geographic transport of heat. As a result, the utilization of geothermal resources for direct applications is quite localized, as demonstrated by the fact that the longest geothermal heat transmission pipeline in the world, found in Iceland, is 64 km in total (Georgsson et al., 2010). In contrast, electricity can be transmitted thousands of kilometers and oil can be shipped around the globe. In Europe, gas is a common source of heat that can be transported in pipelines over thousands of kilometers.

Nevertheless, local resources are commonly used where possible, which results in substantial differences in the energy mix between countries. Figure 3.3.1. shows this variation for heating in the Nordic countries. District heating systems are in many of the regions, with the exception of Norway, where electricity covers 70-80% of heating demand, with the remainder primarily met by bioenergy (7%), oil (7%) and district heating (4%) (NVE, 2013).

Out of all countries surveyed by Euroheat & Power, Iceland has the lowest unsubsidised, district heating price of 2,0 EUR¢/kWh compared with an average value of 5,5 ¢EUR/kWh, and a maximum value of 20,7 ¢EUR/kWh. The great variation in prices within the Nordic countries, which all have cold climates and therefore a considerable need for heating, is of particular interest.

Out of the 20 surveyed countries, the highest price is encountered in Denmark (except Japan) and the second highest in Sweden. It is probable that the reasons are not only economic, but also political. In general, taxes tend to be high in the Nordic countries and countries with limited domestic energy options, such as Denmark, have been supporting and subsidising renewable energy such as wind, which have resulted to higher price to customer. The fortune of Icelandic consumers is therefore the abundance of low-price, environmentally friendly geothermal heat that translates to the lowest average district

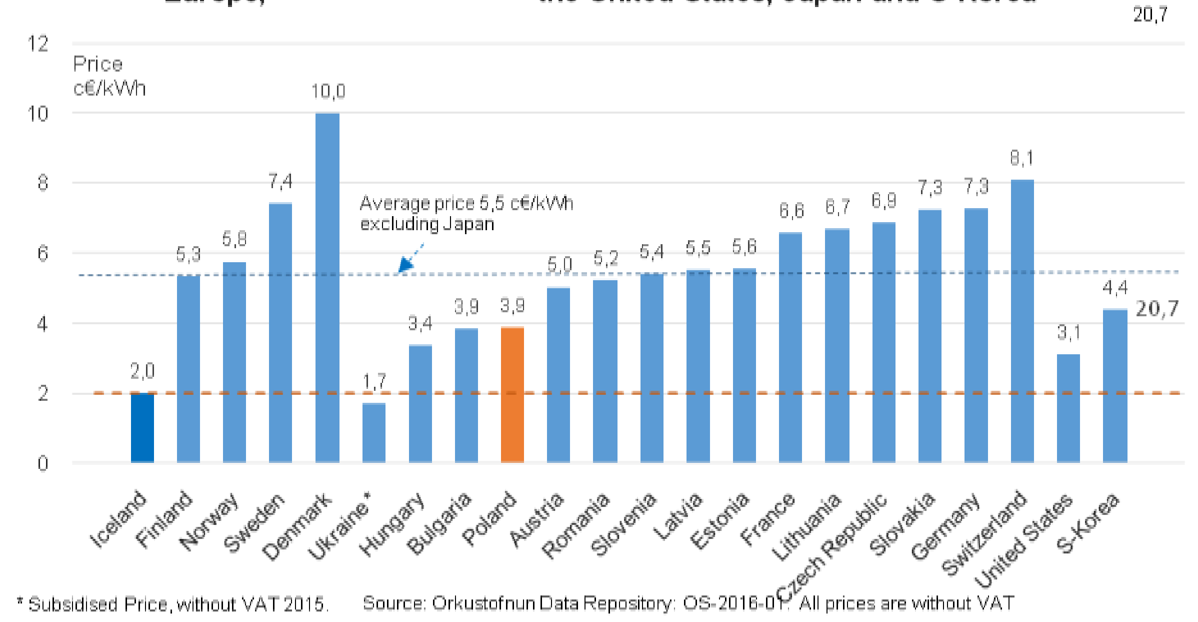


Figure 3.3.1 Average District Heating Prices in Europe, the United States, Japan and S-Korea

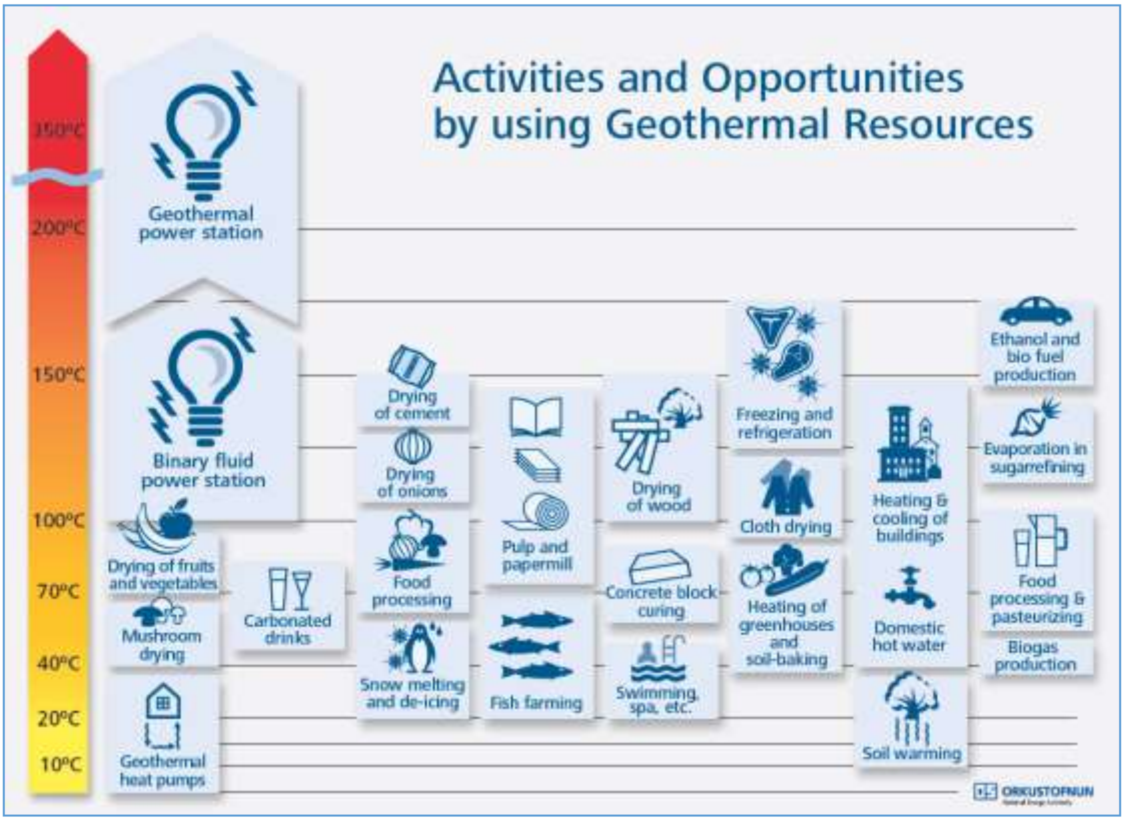
heating price on record in Europe and possibly the wider world. In the United Kingdom, one of Iceland's neighbouring countries, the main source of energy for heating is gas (Association for the Conservation of Energy, 2013). In 2009, the average gas price in the UK was 11.84 EUR/GJ, including all taxes and levies (Eurostat, 2014). Assuming 80% efficiency (Association for the Conservation of Energy, 2013), brings the price up to 14.80 EUR per GJ of usable heat. This translates to 5.33 EUR¢/kWh, or 7.12 USD¢/kWh, which is slightly above the average price for district heating in Europe, and substantially higher than the price in Iceland. From these comparisons, it is evident that Icelandic geothermal district heating prices are very competitive. However, it is important to be aware of differences in climatic conditions between countries that lead to differences in the length of the heating season. Shorter heating seasons may lead to higher unit prices, as district heating companies must cover incurred costs based on sales over a limited time period each year. Other factors that influence heat demand, and thus consumers' wallets, include:

- ***Ambient temperature:*** The heat flow through a building wall is directly related to the temperature difference over the wall, indicating that year-to-year fluctuations in ambient temperature affect heat demand as was clearly observed in Norway in 2010 (NVE, 2013).
- ***Indoor temperature*,** which is influenced by personal comfort choices, habits, prices and other factors, and can therefore vary over the population of a country.
- ***Insulation and airtightness of buildings*,** which may vary between countries.
- ***Ventilation,*** preferences of home owners.

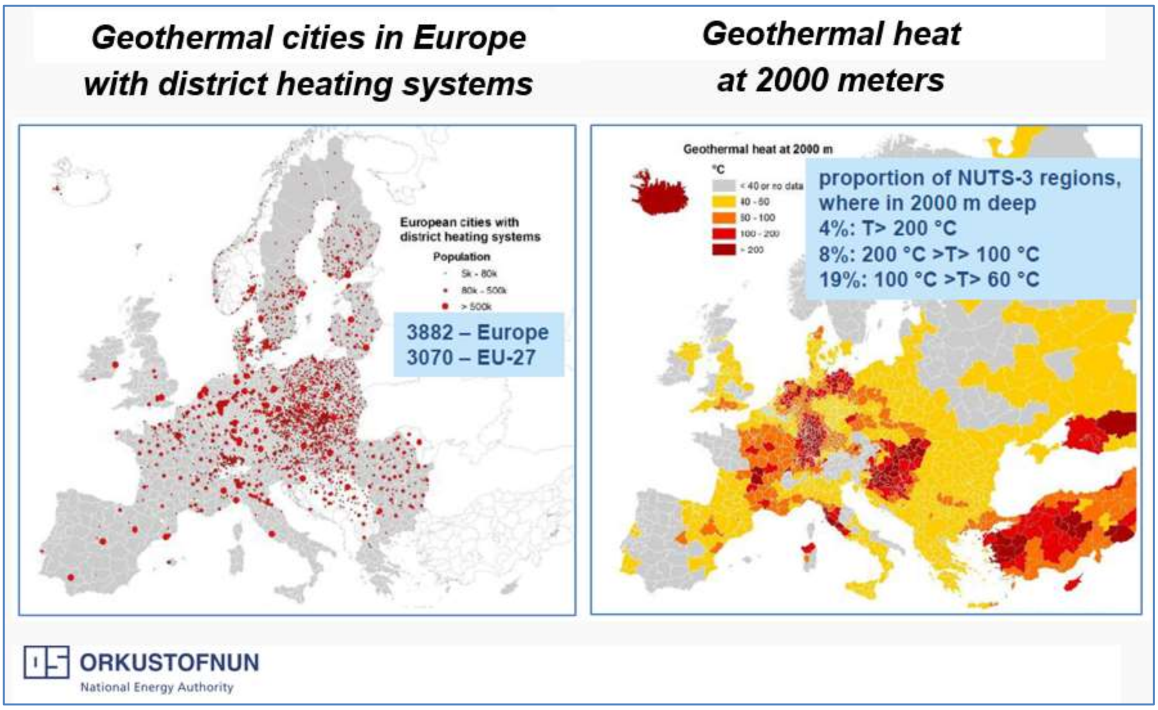
Heat metric and pricing system (HMPS). The HMPS is a key element regarding the price and consumption. In some less developed countries there is no individual HMPS, and even confusing management and ownership of the GeoDH companies, damaging price, demand and efficiency.

3.4. Geothermal for industrial use

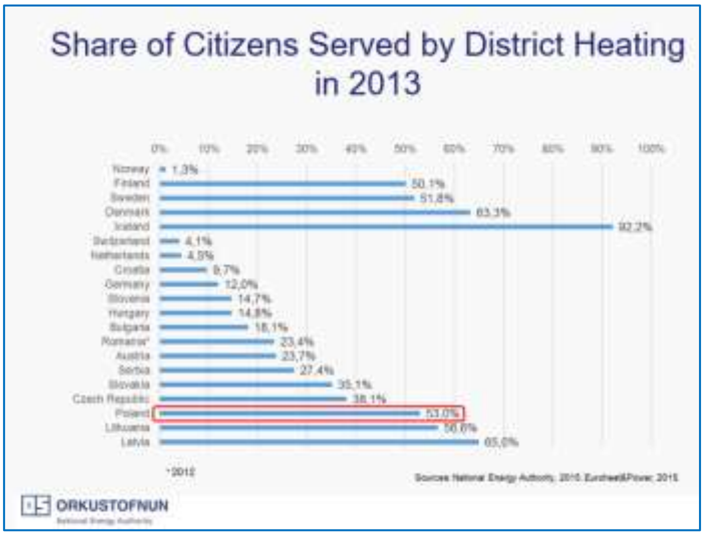
Geothermal resources can be used for various activities, as can be seen from the picture. In Iceland it has also been done, e.g. for greenhouses, fish farming, bathing etc.



3.5. Geothermal opportunities in Poland

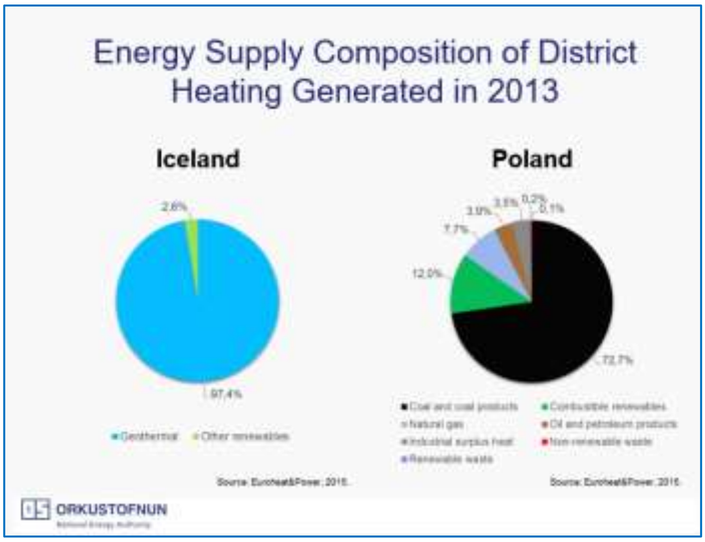


According to Heat Road Map Europe 2050, untapped geothermal resources in Europe could significantly contribute to the decarburization of the district heating market as it has been estimated that geothermal district heating would be available to 25% of the EU-27 population.



Nearly 4000 cities in Europe have district heating systems and about 500 in Poland. In addition, in many of these areas and cities, there are geothermal resources that can be utilized for district heating.

In Poland there are relative high number of citizens that are served by district heating, or about 53%. In addition, Poland has one of the highest district heating sources coming from coal.

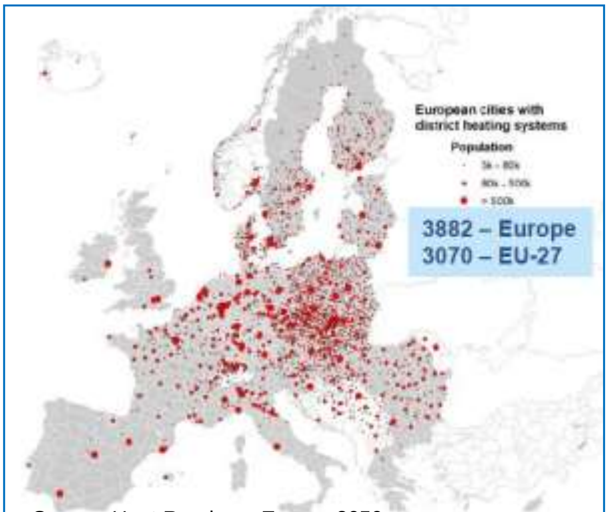


- Poland has therefore exceptional and great opportunities to increase use of geothermal resources for district heating that are available.
- Poland can also shift district heating resources from coal to geothermal – and at the same time reduce greatly CO_2 for heating.
- Therefore, Poland can play a key role for geothermal district heating development in Central Europe - and contribute to mitigate climate change and constantly increasing temperature in the world, due to climate changes – see chapter 8.

4. Policy towards geothermal district heating in Europe

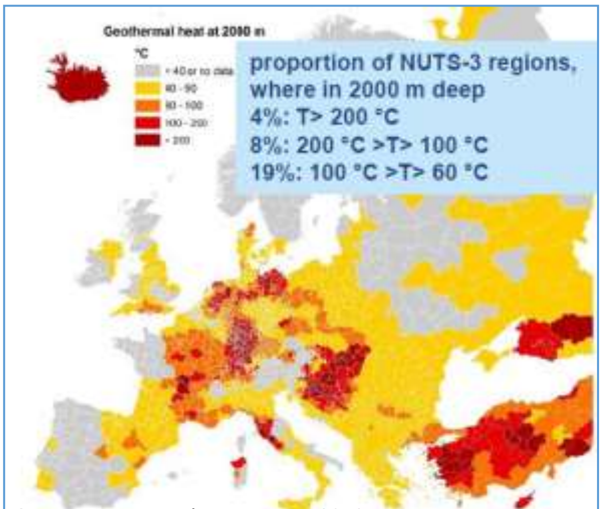
AEBIOM, EGEC and ESTIF, organizations representing the biomass, geothermal and solar thermal sectors respectively, addressed an open letter to the EU Heads of State and Government, 19th of March 2014. The letter states that "...Investing in renewables for heating and cooling will bring security of supply and more competitiveness, and could save EUR 11,5 billion per year, announces the industry. Over recent years, the lack of awareness and political support to renewables for heating and cooling has meant only modest market development in the sector. However, in view of the upcoming discussion of the European Council on EU climate and energy policies beyond 2020, there is a great opportunity to invert this trend." Dr. Guðni A. Jóhannesson Director General of the National Energy Authority of Iceland, also stated in the ERA NET Newsletter in May 2014 that, "It is important for policymakers and others to recognize the great opportunity regarding geothermal heating for savings for countries, as it is estimated that geothermal heating in Iceland is saving equal to 7% of GDP or 3000 US$ per capita or close to 1 billion US$ for the economy only for 2012.

Fig. 4.1. *Geothermal Cities with District Heating Systems*



Source: Heat Roadmap Europe 2050

Fig. 4.2. *Geothermal Heat at 2000 meters*



Source: Heat Roadmap Europe 2050

Untapped geothermal resources could significantly contribute to the decarburization

According to Heat Road Map Europe 2050, untapped geothermal resources in Europe could significantly contribute to the decarburization of the district heating market as it has been estimated that geothermal district heating would be available to 25% of the EU-27 population. It has been estimated that 12% of the communal heat demand is from district heating and heat supply to district heating systems is 17% from power plants, 7% from waste, 3% from industrial heat, 1% from biomass and only 0,001% is coming from geothermal resources. According to Eurostat, about one third of the EU's total crude oil (34,5%) and natural gas (31,5%) in 2010 was imported and, 75% of that gas was used for heating (2/3 in households and 1/3 in the industry). Geothermal district heating therefore has potential possibilities to replace a significant part of imported oil and gas for heating households and industry. GeoDH consortium has proposed policy priorities towards such development which are: (GeoDH, 2014).

1. **Simplify the administrative** procedures to create market conditions, to facilitate development;
2. **Develop innovative financial models for geothermal district heating**, including a risk insurance scheme, and the intensive use of structural funds.
3. **Establish a level playing field**, by liberalizing the gas price and taxing green-house gas emissions in the heat sector appropriately.
4. **Train technicians and decision-makers** from regional and local authorities in order to provide the technical background necessary to approve and support projects.
5. **Increase the awareness** of regional and local decision-makers on deep geothermal potential and its advantages.

5. Geothermal utilisation – international framework recommendation

In many countries in Europe, geothermal district heating has potential possibilities to replace a significant part of imported oil and gas for heating in households and industry. The following general recommendations are highlighted:

1. Simplify the administrative procedures to create market conditions that facilitate development;
    a. Separate law regarding geothermal resources and other fossil fuels resources.
    b. Improve access to geothermal data - to improve development of geothermal utilization.
2. Establish a level playing field, by liberalizing the gas price and taxing greenhouse gas emissions in the heat sector appropriately;
3. Increase the awareness of regional and local decision-makers on geothermal potential and its advantages.
4. Modernize the district heating system:
    a. Better quality of service.
    b. Lower cost.
    c. Improved transparency.
    d. Following improvements of financial viability of district heating companies.
    e. Reduce cost of supply.
    f. Increase revenue.
    g. Quality service should be affordable.
5. Improve the role of independent regulators.
6. Improve the role of district heating companies.
7. Additional elements of public authorities.
    a. Finance energy efficiency programs.
    b. Support public awareness campaigns for benefits of metering.
    c. Providing incentives for demand-side management.
    d. Providing target support to poor customers.
8. Harmonization with EU Law.
9. Train technicians and decision makers from regional and local authorities in order to provide the technical background necessary to approve and support projects.
10. Develop innovative financial models for geothermal district heating, including a risk insurance scheme, and the intensive use of structural funds;
    a. Grants / risk loans to geothermal district heating for exploration and test drilling to lower the risk.
    b. Grants to individuals (apartments) for changing to geothermal district heating.
    c. Grants to district heating companies for transformation to geothermal district heating.
    d. Loans to district heating companies' tor transformation to geothermal district heating.
11. What can international financing institutions do to help?
    a. Financing / Support district heating transformation towards geothermal district heating
    b. Financing and implementing heat metering and consumption based billing.
    c. Financing energy efficiency measures along the supply line.
    d. Technical assistance to newly established regulators.
    e. Technical assistance for the design of targeted social safety nets.
12. Access to International Geothermal Expertise, Markets and Services.

Geothermal Options, Opportunities and Benefits

The geothermal heat generation has several advantages, such as:

1. Economic opportunity and savings.
2. Improvement of energy security.
3. Reducing greenhouse gas emissions.
4. Harnessing local resources.
5. Reducing dependency on fossil fuels for energy use.
6. Improving industrial and economic activity.
7. Develop low carbon and geothermal technology industry, and create employment opportunities.
8. Local payback in exchange for local support for geothermal drilling.
9. Improving quality of life based on economic and environmental / climate benefits.

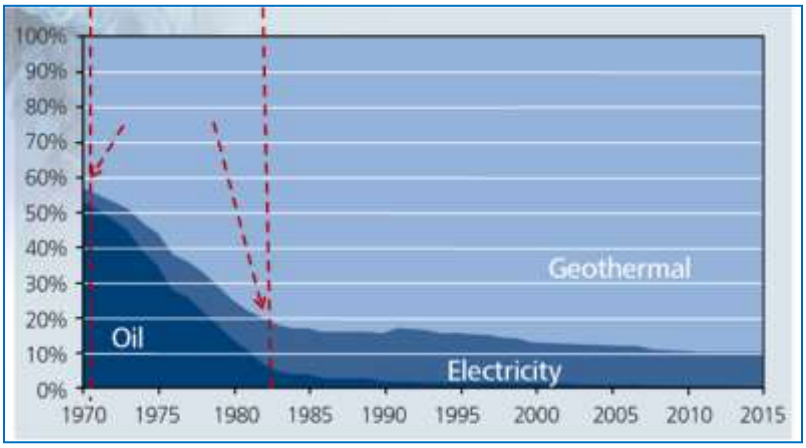
6. Geothermal utilisation – lessons learned – Iceland

6.1. Expansion of geothermal district heating 1970 – 2015

Expansion of Geothermal District Heating

When the oil crisis struck in the early 1970s, fuelled by the Arab-Israeli War, the world market price for crude oil rose by 70%. At the same time, close to 90.000 people enjoyed geothermal heating in Iceland, about 43% of the nation. Heat from oil served over 50% of the population, the remainder used electricity. In order to reduce the effect of rising oil prices, Iceland began subsidizing those who used oil for space heating. The oil crises in 1973 and 1979 (Iranian Revolution) caused Iceland to change its energy policy, reducing oil use and turning to domestic energy resources, hydropower and geothermal.

Fig. 6.1.1. Expansion of GeoDH Space Heating by Source 1970–2015



- Biggest steps in GeoDH were taken during the oil & war crises 1970 – 1982
- External conditions – raised the need of evaluation and GeoDH Planning
- Policy goals to increase geothermal – both national and within main cities
- It took only **12** years to increase GeoDH from **40% to 80%** of total space heating

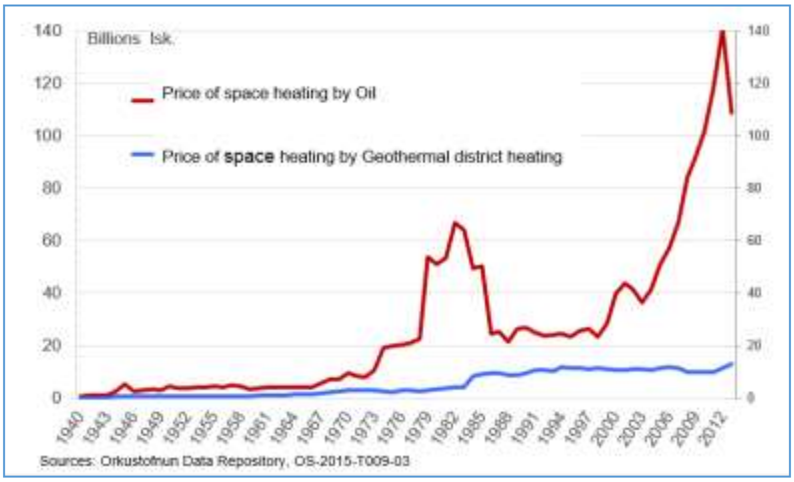
This policy meant exploring new geothermal resources, and building new heating utilities across the country. It also meant constructing transmission pipelines (commonly 10-20 km) from geothermal fields to towns, villages and individual farms. This involved converting household heating systems from electricity or oil to geothermal heat. But despite the reduction in the use of oil for space heating from 53% to 7% from 1970 to 1982, the share of oil still remained about 50% to 60% of the total heating cost due to rising oil prices.

6.2. Economic benefits of using geothermal

The economic benefits of the government's policy to increase the utilisation of geothermal energy can be seen when the total cost of hot water used for space heating is compared to consumer cost if oil would be used, as shown in Fig. 6.2.1 The stability in the hot water cost during strong variations in oil cost is noteworthy.

In Figure the blue line shows price for geothermal district heating, and the red line the calculated price for heating by oil,(adjusted to the consumer price index 1 USD = 120 ISK).

Fig. 6.2.1. Economic Benefits of Geothermal District Heating Price of a space heating by geothermal district heating and by oil 1914 – 2013.



Oil heating is 2-6 times more expensive than geothermal heating throughout most of the period but peaks to 16 times more expensive in the period 1973 to 1985 and has risen again since 2007 to a present ratio of 10. In 2012 the difference in cost amounted to 80% of the state budget cost of health care in the same year.

Evaluations of the estimated savings might vary somewhat as some might claim that sources other than oil could be used for heating. Heating energy could have been obtained through an increased generation of electricity with hydropower, as is done in Norway.

Nevertheless, it is beyond dispute that the economic savings from using geothermal energy are substantial, have had a positive impact on the currency account and contributed significantly to Iceland's prosperity, especially in times of need. The annual savings have been in the range of 1-2% of GDP for most years but rise to 7% in the period 1973 to 1985, and have been nearing that peak again in recent years. The 7% of GDP is equivalent to 3.000 USD per capita.

Fig. 6.2.2. Economic Benefits of Geothermal District Heating
National Savings by Geothermal District Heating as % of GDP

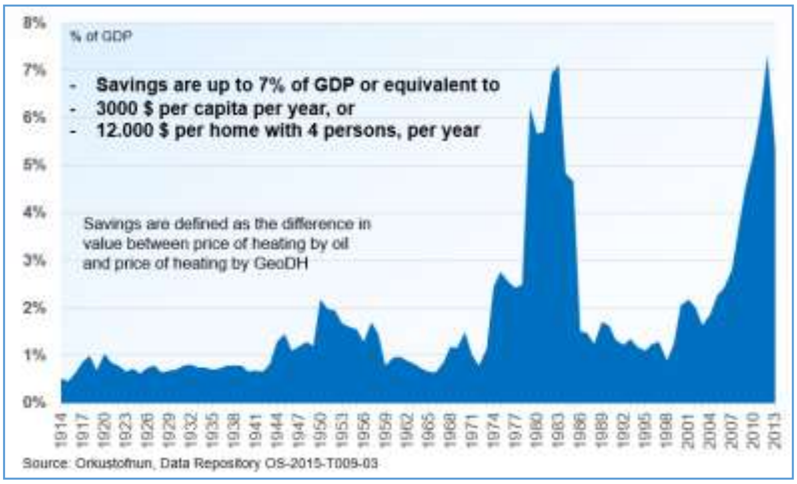
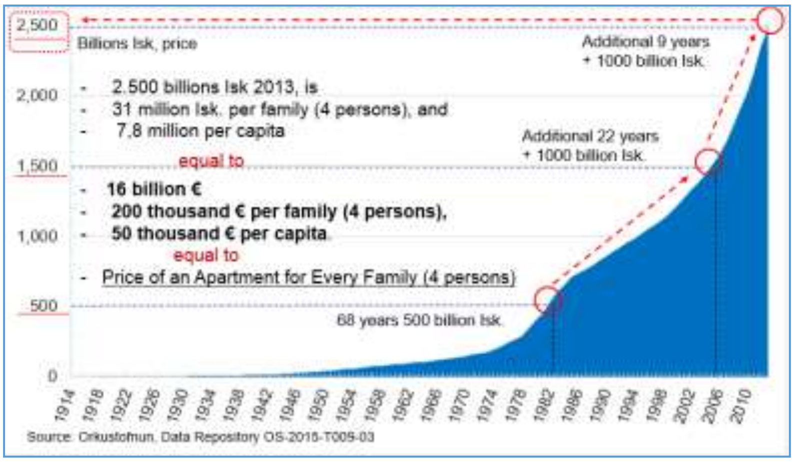


Fig. 6.2.3. Cumulative Savings from Geothermal District Heating in Iceland, 1914 – 2013
2% interests, fixed price 2013



Besides the economic and environmental benefits, the development of geothermal resources has had a desirable impact on social life in Iceland. People prefer to live in areas where geothermal heat is available, in the capital area and in rural villages where thermal springs can be utilised for heating dwellings and greenhouses, schools, swimming centres and other sports facilities, tourism and smaller industry. Statistics show improved health of the inhabitants of these regions.

In recent years, the utilisation of geothermal energy for space heating has increased mainly as a result of the population increase in the capital area, as people have been moving from rural areas to the capital area. As a result of changing settlement patterns, and the discovery of geothermal sources in the so-called "cold" areas of Iceland, the share of geothermal energy in space heating is still rising. It is also possible to evaluate cumulative savings of geothermal district heating mainly from 1950 – 2013, based on real price (fixed price 2013) and 2% annual interest rate**.**

Based on these calculations, the overall cumulative savings is equal to 31 million ISK per family (EUR200.000), which is equal to the price of an apartment for a family (4 persons) in Iceland.

From 1982 – 2013 the majority of savings has happened after the geothermal district heating implementation and is about 2.000 billion ISK. This is equal to 64 billion ISK. (EUR412.000.000) per year, or 800.000 ISK (EUR5.160) per family, or about 70.000 ISK. (EUR450) per month per family, after taxes.

Fig. 6.2.4. Reykjavik

According to information from Statistics Iceland, 2.500 billion ISK, is equal to 80% of the total value of all residential houses and apartments in Iceland which was estimated around 3.200 billion ISK in 2013.

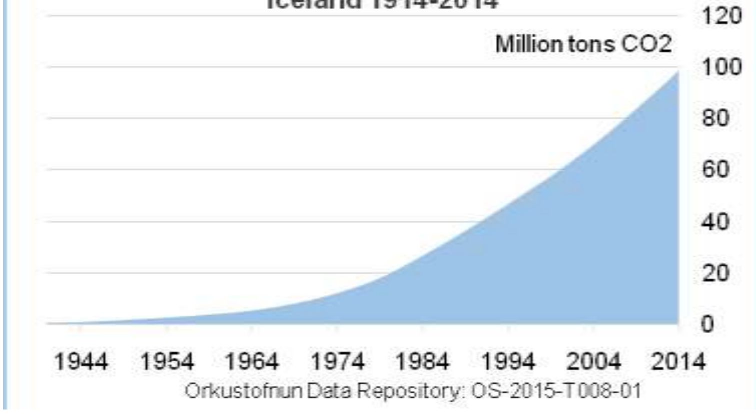
6.3. CO_2 savings due to geothermal district heating

The use of geothermal energy for space heating and electricity generation has also benefited the environment, as both geothermal energy and hydropower have been classified as renewable energy resources, unlike carbon fuels such as coal, oil and gas.

The benefit lies mainly in relatively low CO_2 emissions compared to the burning of fossil fuels.

Since 1940 to 2014 the CO_2 savings by using geothermal district heating have been around 100 million tons, which is equal to saving of using 33 million tons of oil.

Fig. 6.3.1. **Accumulative CO2 Savings using Geothermal District Heating instead of oil in Iceland 1914-2014**



In 2014 the geothermal district heating savings of CO_2 in Iceland was about 3 million tons of CO_2, or equal to 1 million tons of oil, equal to CO_2 bindings in 1,5 million trees and 7.150 km^2 of forest.

If we look at the accumulated savings of CO_2 by all renewables in Iceland 1914 – 2014, that savings is about 350 million tons, mostly since 1944. That is equal to CO_2 bindings in 175 million trees, or 850 km^2 of forest and is equal to 120 million tons of oil.

In 2014 the annual savings of CO_2 from renewables in Iceland was 18 million tons, equal to bindings of CO_2 in 9 million trees, equal to 43.000 km^2 of forest. It is also equal to 6 million tons of oil.

These saved tons of CO_2 have been an important contribution for mitigation of climate change, not only in Iceland but on a global level as well, as climate change has no border between countries or regions.

Geothermal District Heating in Iceland and the use of other renewables, contributes towards economic savings, energy security and reduction of greenhouse gas emissions.

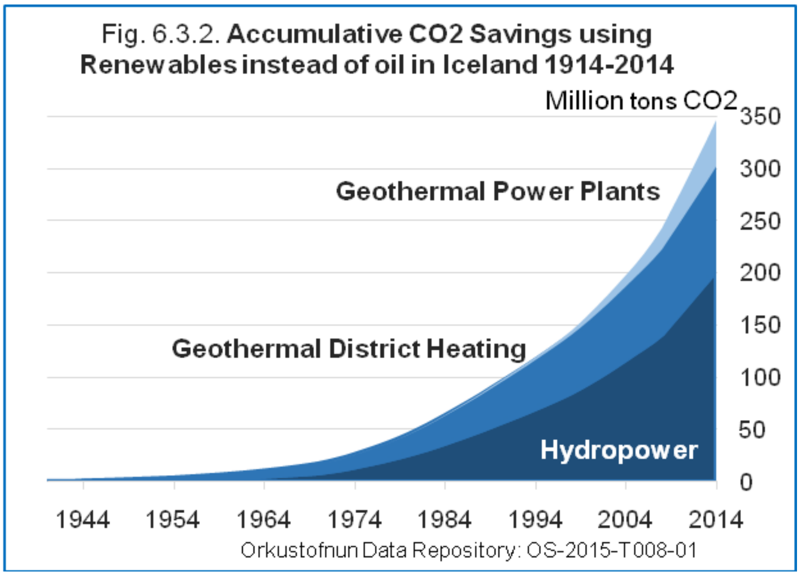
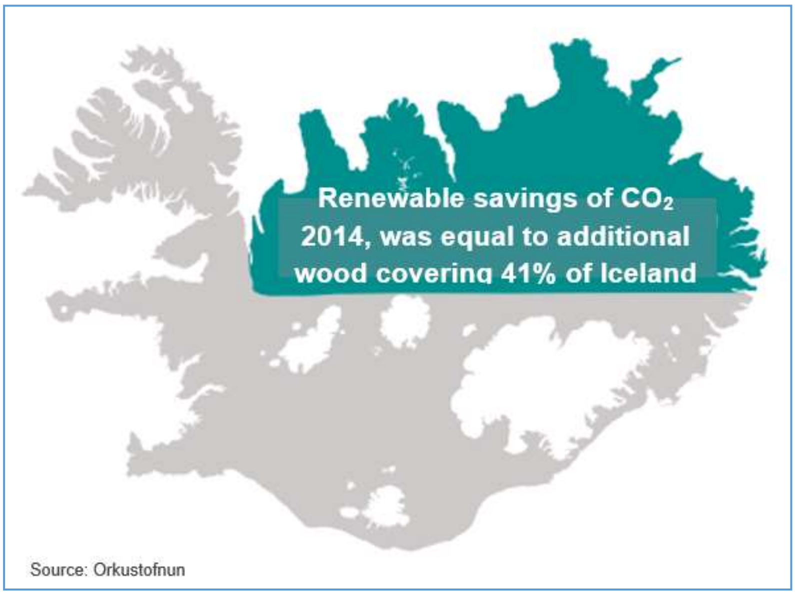


Fig. 6.3.3. The Annual Savings of CO_2 2014 from Renewables in Iceland was equal to bindings of CO_2 in 9 billion trees, equal to 43.000 km^2 of Forest or 41% of Iceland

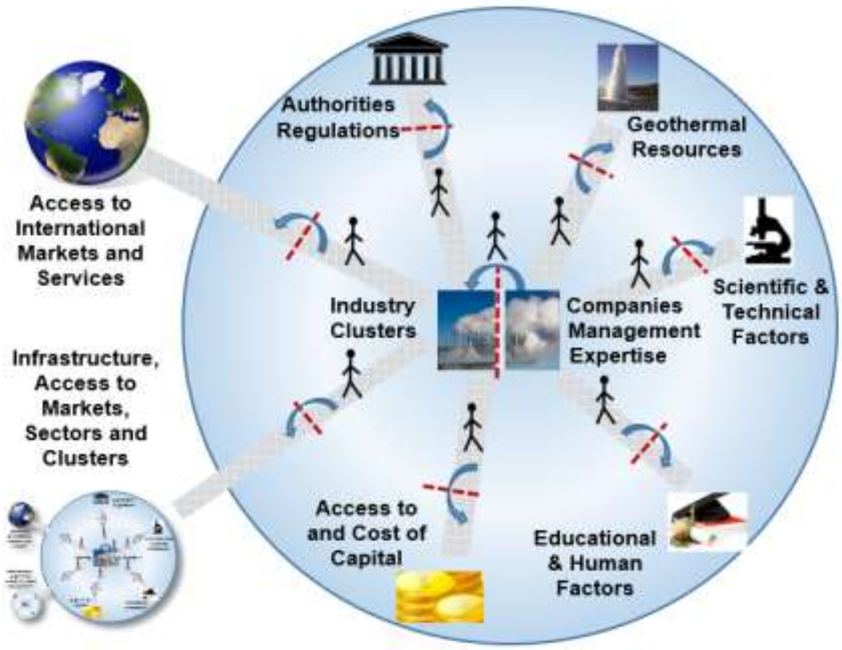


7. International competitiveness of the geothermal sector

7.1. Cluster competitiveness

When recommending formulating policy recommendations for the geothermal sector in Romania, 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. (Petursson, 2014, 2012). Success for the geothermal sector in the concerning countries is not only based on geothermal resources, but also on these factors for competitiveness.

Fig. 7.1. Competitiveness of the Geothermal Sector



Source: Sölvell & Lindquist 2012, Amended, B. Petursson, National Energy Authority, 2014

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 to analyse the seven main framework conditions in the geothermal sector;

1. Authorities and regulation.
2. Geothermal resources.
3. Scientific & technical factors.
4. Companies, management, expertise - industry, clusters assessment.
5. Education & 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 seven 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 the geothermal sector; to increase competitiveness, growth, jobs, productivity and quality of life.

7.2. Opportunities and policy options

There are several options regarding geothermal possibilities and policy formulation, based on opportunities and by steps towards overcoming barriers and challenges already identified.

1. **Authorities and Regulatory Factors**
   - Simplify the administrative procedures to create market conditions that facilitate development;
   - Separate law regarding geothermal resources and other fossil fuels resources.
   - Improve access to geothermal data - to improve development of geothermal utilization.
   - Publicise the characteristics and benefits of geothermal energy for regional development
   - Design regulation specific to the promotion of direct uses of geothermal energy.
   - Promote cooperation with international organisations.

2. **Geothermal Resources**
   - Improvement of geothermal regulation.
   - Separate law on geothermal and fossil fuels – to speed up access to geothermal data and avoid hindering geothermal development, and problems due to secrecy of oil and gas information.
   - Improvements for data analysis of reservoirs in regions.

3. **Scientific and Technical Factors**
   - Promote relationships with industry.
   - Promote alliances with research centres and educational institutions for the formation of specialised human resources.

4. **Companies, Management, Expertise – Industry Clusters**
   - Promote alliances with research centres and educational institutions for the formation of specialised human resources.
   - Promote cooperation with IFIfor financing, donor support and consulting.
   - Organize workshops and conferences to improve knowledge on geothermal energy.
   - Identify geothermal energy-related productive chains.

5. **Educational and Human Factors**
   - Support for the generation of the human resources needed for the geothermal industry.
   - Creating seminars and specialized courses on the different stages of a geothermal project and adding them to the existing engineering degrees.
   - Give the personnel technical training to participate in the different stages of a project.
   - Implement programs for scientific and technical development.

6. **Access to, and Cost of Capital**
   - Promote additional access to financing geothermal projects – domestic and international.
   - Increase access to capital by providing capital to exploration and test drilling and DH networks e.g. soft loans or donor grants, to lower the risks at the beginning of projects.
   - See also additional elements page 15.

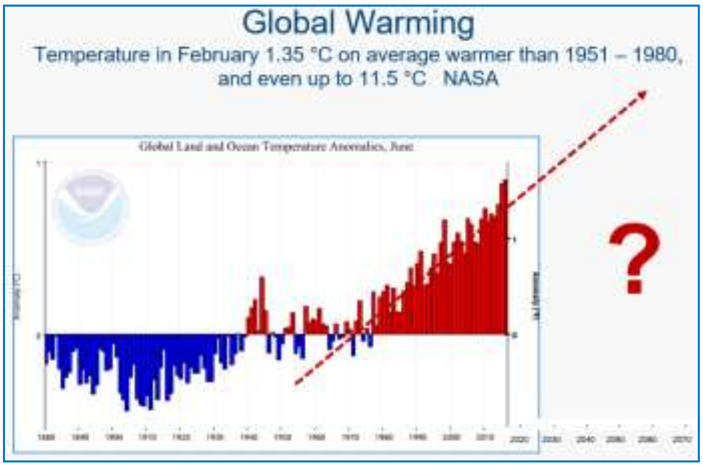
7. **Infrastructure, Access to Markets, Sectors and Clusters**
   - Promote training in the banking system for the development of financial mechanisms specific to geothermal energy.
   - Awareness; organize workshops & conferences to improve knowledge of geothermal energy.
   - Increase the available knowledge about opportunities and benefits of geothermal resources.

8. **Access to International Markets and Services**
   - Support international cooperation in area of geothermal knowledge, training and service.
   - Promote international cooperation with IFI and donors on finance, grants and funding.
   - Support international consulting cooperation on various fields of geothermal expertise.

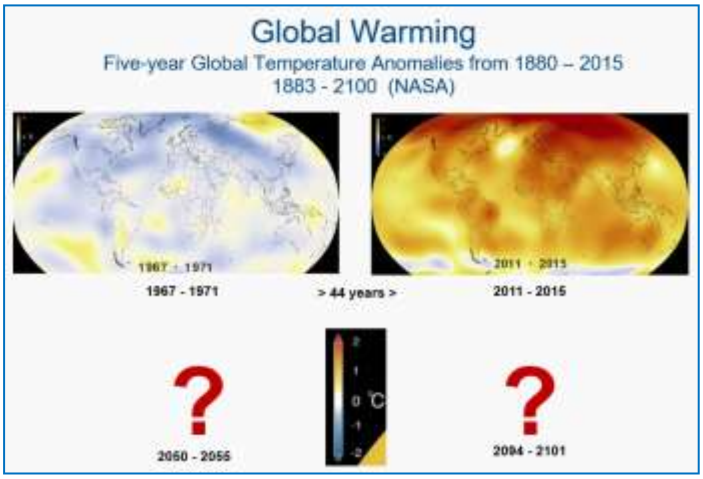
8. Geothemal is a powerful tool to fight climate changes

According to the Intergovernmental Panel on Climate following statemens can beb made:

“From 1880 to 2012, average global temperature increased by 0.85°C. 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 megatonnes per year between 1981 and 2002 due to a warmer climate.



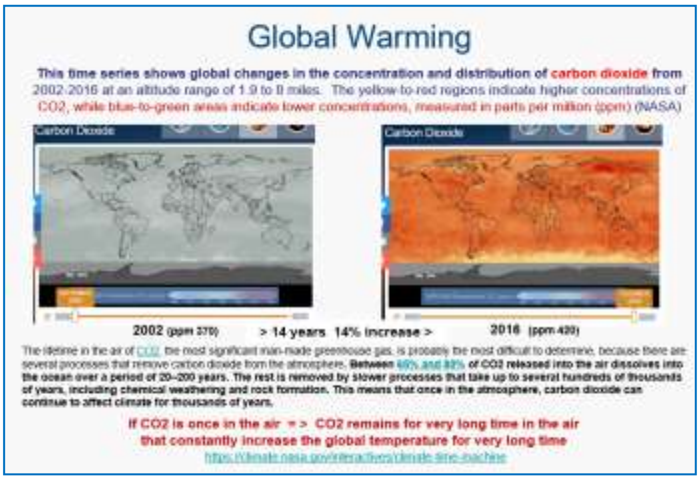
Oceans have warmed, the amounts of snow and ice have diminished and sea level has risen. From 1901 to 2010, the global average sea level rose by 19 cm as oceans expanded due to warming and ice melted. The Arctic’s sea ice extent has shrunk in every successive decade since 1979, with 1.07 million km² of ice loss every decade.



Given current concentrations and on-going emissions of greenhouse gases, it is likely that by the end of this century, the increase in global temperature will exceed 1.5°C compared to 1850 to 1900 for all but one scenario. The world’s oceans will warm and ice melt will continue. Average sea level rise is predicted as 24–30cm by 2065 and 40–63cm by 2100. Most aspects of climate change will persist for many centuries even if emissions are stopped.

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” [2]

[2]http://www.un.org/sustainabledevelopment/climate-change-2/, The UNU sustaaniable Goals, regarding Climate Change.

"Climate change is now affecting every country on every continent. It is disrupting national economies and affecting lives, costing people, communities and countries dearly today and even more tomorrow.

People are experiencing the significant impacts of climate change, which include changing weather patterns, rising sea level, and more extreme weather events. The greenhouse gas emissions from human activities are driving climate change and continue to rise. They are now at their highest levels in history. Without action, the world's average surface temperature is projected to rise over the 21st century and is likely to surpass 3 degrees Celsius this century—with some areas of the world expected to warm even more. The poorest and most vulnerable people are being affected the most.

Affordable, scalable solutions are now available to enable countries to leapfrog to cleaner, more resilient economies. The pace of change is quickening as more people are turning to renewable energy and a range of other measures that will reduce emissions and increase adaptation efforts.

But climate change is a global challenge that does not respect national borders. Emissions anywhere affect people everywhere. It is an issue that requires solutions that need to be coordinated at the international level and it requires international cooperation to help developing countries move toward a low-carbon economy.

To address climate change, countries adopted the Paris Agreement at the COP21 in Paris on 12 December 2015." [3]

Implementation of the Paris Agreement is essential for the achievement of the Sustainable Development Goals, and provides a roadmap for climate actions that will reduce emissions and build climate resilience.

Renewables and geothermal district heating solutions area powerful tool to fight against global warming.

[3] http://www.un.org/sustainabledevelopment/climate-change-2/, The UNU sustaaniable Goals, regarding Climate Change.

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Attachments 1-3

Att. 1.

Agenda of Study Visit to Poland, 5-9 September 2016

Monday 5 September 2016

21:05 – Arrival of Icelandic delegation to Warszawa.
Transfer from airport. Overnight
Arrival of Polish partners from MEERI PAS and AGH UST to Poddębice. Overnight

Tuesday 6 September 2016

09.30 – Start of meeting at Geotermia Poddębice headquaters
09.30 – 09.45 – Welcome by representatives of Poddębice Town, Geotermia Poddębice, Project partners. Presentation of Study Visit's objectives – Beata Kepinska, Baldur Petursson
09.45 – 10.30 – Introduction of Study Visit's participants, presentations of Project parties
10.30 – 11.00 – Introduction to EEA project Poland - Poddębice – B. Kepinska
11.00 – 11.45 – Geothermal energy resources and uses in Iceland, with focus on district heating - Icelandic side
11.45 – 12.00 – Coffee break
12.00 – 12.30 – Presentation on Poddębice Town – Piotr Sęczkowski, Mayor
12.30 – 13.00 – Presentation of Geotermia Poddębice Ltd. Company – Anna Karska, Head of the BoD
13.00 – 13.30 – Geothermal resources in Poland and their applicability for heating, specially in the Polish Lowlands and Poddębice area – M. Hajto
13.30 – 14.00 – Current geothermal energy uses in Poland, specialty in district heating – B. Kepinska, L. Pajak
14.00 – 14.45 – Visiting the plant and installation of Geotermia Poddębice Ltd.
14.45 – 15.00 – Visiting the Geothermal water drinking bar, and garden of sesnses
15.00 – 16.00 – Lunch break
16.00 – 18.00 – Disscussion, summary of 1st day of visit. Establishing direct contacts and talks of possible cooperation, transfer of knowledge and experience in geothermal

Wednesday 7 September 2016

09.30 – Start of meeting at Geotermia Poddębice Headquaters
09.30 – 11.30 – Meeting with the BoD of Geotermia Poddębice Ltd. and Polish partners to learn the details of the geothermal heating system's working and expansion plans, to collect information and data needed for works foreseen in the project
11.30 – 12.00 – Coffee break
12.00 – 14.00 – Visiting selected geothermal installations and objects supplied with geothermal district heating, as well as sectors of the Town already connected to geoDH and planned to be connected to geoDH
(District Hospital, Boiler Plant Cicha-4, Conversion of the building of the former boiler house on housing estate's geothermal SPA)
14.00 – 15.00 – Discover the natural and tourist values of Poddębice vicinity as important elements supporting possible geothermal energy development
15.00 – 16.30 – Lunch break
16.30 – 18.00 – Discussion, continuation of talks on possible cooperation, transfer of knowledge and experience in the field of geothermal energy

Thursday 8 September 2016

10.00 – 11.30 – Project partners meeting at Geotermia Poddębice headquarters for the review and initial discussion of information, data and observations collected during the study visit; determination of further joint work, the way of the flow of information and contacts for the Project implementation.
Discussions and findings concerning the details of the participation and partners' input to the preparation of pre-feasibility study on geothermal energy uses in heating in Poland and especially in Poddębice

11.30 – 12.00 – Coffee break

12.00 –14.30 – Partners' meeting cont.

14.30 – 15.30 – Lunch break

15.30 – 17.30 – Visiting the objects of Poddębice County; City Council, sport facility, partners' meeting cont.   Disscussion, summary of 3rd day of visit

Friday 9 September 2016

13.00 – 15.00 – Meeting with Mr. Marcin Mazurowski – deputy director, Dept of Geology and Geological Concessions, Ministry of Environment, other representatives of this Dept and Dept of Ecological Funds (EEA pperators in Poland), Warszawa

22.00 – Departure from Warszawa

Att. 2.

Agenda of Study Visit to Iceland, 24-28 April 2017

Date	Time	Name	Focus	Location / contacts
24 April	19:35	Arrival to Iceland	FlyBus	CenterHotel Plaza Reykjavik
25 April	9:00	OSand EEA Grants Activity, Deputy Director General Jónas Ketilsson	Geothermal in Iceland EEA Grants – the role of OS	Orkustofnun (OS) National Energy Authority Grensásvegi 9, OS - Afhellir
	9:30	View from the Polish Delegation Ministry of Environment	Polish Geothermal Agenda 2014 - 2021	OS - Afhellir
	10:30	EEA Grants Process Ministry for Foreign Affairs Iceland Sveinn K. Einarsson, Specialist	Main elements of the EEA Grant Programme Main steps forward 2014 – 2021	OS– Afhellir
	11:00	Geothermica Alicja Wiktoria Stokłosa Project Manager	Geothermica main activities	OS - Afhellir
	11:15	Málfríður Ómarsdóttir Editor of UNU GTP - Environmental Specialist	Activity of United Nation University Geothermal Program	OS - Afhellir
25 April	11:30	Lunch break		
	13:00 13:10 13:20 13:45	Baldur Pétursson, Manager International Projects & PR, OS Dr. Sc. Beata Kępińska, MEERI PAS, Poland Geothermal Cluster in Iceland Hannes Ottósson Project Manager innovation Centre 10 min sharp - various presentations from companies Resource Park Reykjanes (Blue Lagoon, etc) , Jarðboranir, Matís - Geothermal and food Verkís, Mannvit, Efla Arni Gunnarsson, etc. Networking opportunities	Geothermal - Poland Icelandic - cooperation Geothermal options in Poland Cluster possibilities Key elements of each company	OS – Víðgelmir
	15:00 – 16:00	Working group meeting Iceland Poland – Key factors	Main partners of the projects	

26 April	9:00	Departure to Hellisheidi geothermal plant from Hotel	Bus	
	9:30 10:30	Hellisheiðarvirkjun Departure from Hellisheidi	Geothermal Power Plant and Heat	
	11:00	Geothermal Direct use – Agriculture Garðyrkjuskólinn Reykjum, Hveragerði	The use of Geothermal in Agriculture	
	12:00	Lunch break		
	13.40	Friðheimar – Reykholt, Biskupstungum	The use of Geothermal in Agriculture	
	18:00	Arrival at Reykjavik		
27 April	9:45	Departure from Hotel	Bus	
	10:00	District Heating – Municipality Seltjarnarnes	Operation of a small district heating system The DH system, boreholes and pumps	
	11:30	Transport - back to hotel		
	12:00 -	Free time		
28 April	9:00	Departure from Hotel	Bus	
	10:00-11:00 11:15-12:00	HS Orka Reykjanes Haustak Vitabraut 3, 233 Reykjanes	Reykjanes Resources Park,	
	12:30-14.00	Lunch break		
	13.30 16.40	Blue Lagoon – the use of geothermal water, brine for balneotherapy and innovative agriculture	Reykjanes Resource Par k	
	16:40	Departure to Keflavik airport		
	17:00	Arrival Keflavik Airport	Keflavik Airport	
	20:15	Departure from Iceland		

Att. 3.

Summary Conference – the EEA Project
„Geothermal energy utilisation potential in Poland – town Poddębice", Poddębice 13.06.2017
Agenda

	13.06.2017 - Summary Conference
09.00 – 10.00	Registration of Conference participants
10.00 – 10.20	Conference opening, guests' speeches
	Introductory session:
10.20 – 10.40	Geothermal projects in Europe funded by EEA/NFM – B. Petursson (NEA)
10.40 – 11.10	Geothermal heating development in Poland from the perspective of the Ministry of Environment – M. Mazurowski (Ministry of Environment, DG&GC)
11.10 – 11.30	Financing geothermal projects in Poland by state and foreign sources, including EEA /NFM – B. Kuś (NFEP&WM)
11.30 – 11.50	Geothermal energy uses for district heating in Iceland – O.P. Einarsson, B. Petursson (NEA)
11.50 – 13.45	Visiting objects planned for geothermal energy uses in Poddębice and surroundings. Lunch break
	Session presenting the EEA Project results
13.45 – 14.10	Project EEA "Geothermal energy utilisation potential in Poland – Town Poddębice" – introduction B. Kępińska (MEERI PAS)
14.10 – 14.30	Geothermal energy in Poddębice: current state and development plans – P. Sęczkowski (Mayor of Poddębice), A. Karska, A. Peraj (Geotermia Poddębice Ltd.)
14.30 – 14.50	Geothermal reservoir in Poddębice – M. Hajto, A. Sowiżdżał (AGH UST)
14.50 – 15.20	Simulation of geothermal water level during production from Poddębice GT-2 well based on a Lumpfit parameter modelling – H. Tulinius, G. Þorgilsson (NEA), M. Hajto (AGH UST)
15.20 – 15.50	Geothermal district heating in Poddębice – selected topics of pre-feasibility study – O.P. Einarsson (NEA), L. Pajak, W. Bujakowski (IGSMiE PAN), A. Karska, A. Peraj (Geotermia Poddębice Ltd.)
15.50 – 16.10	Coffee break
16.10 – 16.30	Recommendations for optimal further geothermal district heating and other uses' development in Poddębice – O.P. Einarsson, H. Tulinius, G. Þorgilsson, B. Petursson (NEA), L. Pająk, B. Kępińska, W. Bujakowski (IGSMiE PAN), M. Hajto, A. Sowiżdżał (AGH UST), A. Karska, A. Peraj (Geotermia Poddębice)
16.30 – 16.50	Proposals for geothermal projects' realisation in Poland supported by EEA/NFM in the coming years – B. Kępińska (MEERI PAS), B. Petursson (NEA)
16.50 – 17.30	Summary discussion
17.30	Conference closure