Pre-Feasibility Study

Geothermal District Heating

Beius, Romania

April

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Picture at the cover: Handmade Tale, Beius

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1. Introduction

The Project Team
This project constitutes a Pre-Feasibility Study of Geothermal District Heating in Beius, ongoing from late 2015 to April 2017. It has been supported by the Rondine EEA Grants Program. The Project promoter was the Municipality of Beius, and the people managing the project on behalf the municipality were Petru Mlendea, Popa Gabriel Catalin and Dan Serban.

The Donor Project Partner was Icelandic National Energy Authority, and the person managing the project was Baldur Pétursson, contributing the text in chapters 9 – 12.

Geothermal resources experts were Guðni Axelsson and his team (Sylvía R. Guðjónsdóttir, Sæunn Halldórsdóttir and László Ádám), creating the text in chapter 5. Geothermal district heating experts were Árni Gunnarsson, Viktor Hava, András Barabás, Béla Kátai and Sigurður L Hólm, making the text of chapters 6 – 8.

Chapter 13 was prepared by Codruta Bendea, Cornel Antal and Marcel Rosca, at the University of Oradea, Romania.

1.1 Project summary

Why was the project needed?
To promote early stage development, strategy planning, capacity building, networking and awareness of geothermal utilisation, to increase possibility of utilisation of geothermal resources, energy security, savings and quality of life in Beius.

What will the project achieve?
Pre-Feasibility Study of Geothermal District Heating will achieve:

- Re-evaluate and update the production potential of the Beius 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 the city and surrounding communities.
- Evaluation of the potential increase of geothermal utilization in the city and surrounding communities.

How was it achieved and who are the beneficiaries?

- The following were the key elements of the project:
- Assessment of the current status of utilization in Beius; capacity of wells used, energy produced, utilization for district heating, other direct uses, etc. as well as highlighting framework barriers for Geothermal District Heating (GeoDH) system possibilities.
- Resource appraisal based on information on geological and hydrological conditions, the 1999 assessment and the utilization experience (monitoring of production, temperature and water-level) since 1999. Potential assessment with simple reservoir models and predictions for some relevant future sustainable utilization scenarios.
- Potential improvements to the current utilization, in particular district heating. Involves the design of surface installations with emphasis on the economic and energy efficiency - for the benefits of the citizens of Beius.
- Evaluation of the potential for expansion of the current utilization, both concerning district heating and other possible direct uses. Report includes e.g. engineering and financial benefits of GeoDH in comparison to gas and oil.
- Analysis of geothermal district heating (GeoDH) development – international comparisons.
- Evaluation of geothermal policy options and opportunities.
- Dissemination of results locally and countrywide - to increase awareness of geothermal utilisation, to increase possibility of utilisation of geothermal resources, energy security, savings and quality of life in concerning regions.
- The beneficiaries of the program are the municipality of Beius and its citizens.

How will bilateral relations be strengthened?

1. Increased cooperation in the area of geothermal capacity building between the Municipality of Beius and the National Energy Authority in Iceland and other people connected to the project.
2. Romanian experts, policymakers and people in Romania and Iceland working on the project will be able to establish relationships and increased understanding on geothermal utilisation, options and possibilities in Beius.
3. Both Icelandic and Romanian experts will take part in the work and they will have an opportunity to share experiences, learn from each other and forge new ties. Furthermore, Icelandic and Romanian participants in the project will have an opportunity to form ties.
4. Shared results regarding geothermal utilisation resulting in increased energy security, savings and better quality of life.
5. Increased knowledge and mutual understanding of geothermal options and possibilities.
6. The cooperation can also motivate wider effects e.g. extending the cooperation into related activity, regarding renewable energy, energy security, savings and quality of life.

1.2 Relevance of the project

The project will contribute to the overall objective of the EEA Financial Mechanism, contributing to reducing social and economic disparities in Romania, by supporting education, capacity building, networking and awareness of geothermal utilisation. As geothermal resources are local and often quite economical over the long term in comparison with fossil based energy resources, in addition to being environmentally friendly, their utilization has the potential to increase energy security, contribute to savings on community and/or family scales, reduce greenhouse gas emissions and improve air quality.

In addition, the quality of life may increase with the establishment of swimming centres and spas based on geothermal resources. The utilization of geothermal resources can in some communities be used to enhance tourism, and thereby economic activity, by the establishment of swimming centres and spa services. Furthermore, geothermal resources can be used to elevate temperatures in greenhouses to enhance production of flowers, vegetables, fruits, spices, etc. and for various industrial processes requiring heat. All of these potential uses should serve to increase economic activity.

Bilateral relations will be strengthened by: increased cooperation in the area of geothermal education and capacity building, sharing results regarding geothermal utilisation, increased knowledge and mutual understanding of geothermal options and possibilities. The cooperation can also motivate wider effects e.g. extending the cooperation into related activities.

Romanian legislation is harmonized with European Union principles and supports renewable energy sources, geothermal being specifically mentioned. The European Renewable Energy Roadmap adopted in 2007 defines clear targets and goals to reach a 20% contribution of renewable energy to the energy mix by 2020. Further utilization of geothermal resources will help to reach this target in Romania and capacity building is an important component in an effort to realize this.

Romania supports the stance of the European Union on the second commitment period under the Kyoto Protocol. The utilization of geothermal resources for space heating and other uses in place of fossil fuels can lead to decreased carbon dioxide emissions and thus strengthens the country in conforming to international agreements.

2. Executive Summary

2.1 Resource Assessment

1. The geothermal resources located in the Beius region are of the sedimentary type, in fractured Triassic dolomitic limestone layers. The main reservoir layers are at a depth of 1600 – 2500 m, with reservoir temperature of 80 – 90°C. The Beius reservoir is estimated to be about 40 km^2 in area.
2. The Beius geothermal resources have been utilized for about 17 years, presently at a yearly rate of about 25 L/s, through two wells with down-hole pumps.
3. In this study, the production capacity of the Oradea geothermal system has been estimated by lumped parameter modelling, and other simple modelling methods. The results of a comparable assessment performed in 1999, Axelsson e. al. (2000) is still fully valid.
4. The production history of the system and the modelling performed show that the geothermal system is open, with natural recharge which has sufficed to maintain stable reservoir conditions for the whole utilization history. Furthermore, pressure interference between the two production wells appear to be minimal (because of a separating fault).
5. The assessment results indicate that the Beius geothermal resources can sustain an utilization increase of the order of 50 - 100% (average annual production of 50 - 70 L/s, assuming a 50-year utilization period, from the present). Most likely the potential is considerably bigger, Bradu e. al. (2017).

2.2 Recommendations Regarding Increased Geothermal Utilization

1. The main recommendation regarding future geothermal utilization in Beius, is that the utilization be increased in steps. First by about 50% and later by another 50%. This cautious approach is necessary because of uncertainties in model predictions and limited data access. A clear benefit from a stepwise approach is that by monitoring carefully the response of wells and the geothermal reservoir to the production increase, associated with the first step, the response to a further increase can be predicted much more accurately than now. Consequently, the utilization may perhaps be increased even further.
2. Monitoring of production, water-level, temperature and chemical content must be comprehensive and accurate. This will provide basis for future increase in utilization.
3. Simple models, such as lumped parameter models, and perhaps These models, should be set up to simulate and predict reservoir pressure changes in the Beius system. A detailed numerical modelling can be set up for the Beius geothermal system and neighbouring reservoir blocks, in due time. This isn't urgent at the present time, as only a few wells are available at present.
4. Reinjection should be increased hand-in-hand with increased utilization and pressure draw-down. Increased reinjection should be accompanied with extensive reinjection research, in particular tracer testing, which can be used to evaluate the cooling danger for production wells.
5. The geothermal district heating system in Beius, currently serving 60% of all buildings, should be expanded to all buildings, making Beius the first geothermal city on mainland Europe.
6. First step to increase the capacity of one of the existing production wells with bigger deep well pump.
7. Second step is to drill a new production well to increase the GeoDH system capacity to be able to heat all houses in Beius, hence system reliability with three production wells and over capacity.
8. Build and connect a 500 m^3 storage accumulator to the new production well on a hill at city outskirt should be considered and evaluated. It would increase the geothermal district heating system's short time capacity, operation reliability in case of power outages and accommodating daily system demand variations.
9. With current market prices for wood for heating and GeoDH state regulated heating tariffs the citizens of Beius enjoy between 30% - 50% reduction in annual heating cost, when connected

to the GeoDH system, a tremendous advantage for the citizens in addition to better air quality, clean, safer and almost zero manpower operation of their house heating.

10. Step by step renovate the three old substations with appropriate control system and pipe insulation to increase their energy efficiency.
11. Improve thermal insulations of buildings, house installations and temperature control for better energy efficiency.
12. Expansion of the GeoDH system will improve the air quality in the city and reduce annual GHG emissions by an estimate of 10,000 t CO_2/year.
13. Expansion of the geothermal system towards to the nearest villages should be evaluated. The GeoDH system with a new production well is estimated to be able to supply additionally around 180 single houses in a nearby village, as an example. Lessons learned in Beius, both in the past and associated with its future development to full coverage, will have great relevance for other geothermal resources in Romania.

2.3 Additional International Recommendations

2.3.1 International Framework Recommendations

Following recommendations are highlighted for Romania:

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. Make sure that there is fair competition between geothermal resources and other fossil fuels.
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.

2.3.2 Geothermal Development and Lessons Learned in Iceland

The following elements of policy 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 €), or 33 million ISK (240.000 €) 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.

2.3.3 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.

3. Background of Geothermal District Heating in Beius

SC Transgex holds the concession contract no. 3524 / 29.08.2001 for supplying heat in Beius. Before geothermal heating started, the city district heating system served the centre of the city based on three oil fired heating plants using fuel CLU using two separate distribution loops, one for district heating (DH) and one for hot sanitary water (HSW).

The geothermal heat production was started in 1999. With the support from European Commission, DG XVII energy resources, contract no. INCO-DEMO-4012-98, led by VÁG Ltd. in cooperation with Transgex, ISOR (Orkustofnun), Edilul (the district heating company in Beius) and GTN Ltd., a deep well pump was purchased and installed in well 3001 drilled by Transgex. The well was pumped at full capacity over 5 months, chemical quality of water analysed and response of the reservoir evaluated.

The main results were:

- the long-term production potential of well 3001 is estimated to be 60 and 90 l/s, for pump depths of 150 and 250 m, respectively;
- the chemical quality of geothermal water and its temperature are very suitable for direct utilisation such as district heating, etc.

Following these positive results and the fact that three oil fired heating plants in the city had sadly low availability, the city council contracted Transgex to connect the well 3001 to the existing heating plants by replacing the oil burners. In 2004, the second production well was drilled and furnished with deep well pump. In 2008, the deep well pump in well 3001 was replaced by bigger pump and later, 2011, a bigger pump was installed in well 3003. This step wise increase in production capacity over the last 17 years was followed by expansion of the GeoDH district heating system, today serving around 65% of the population, enjoying house heating and HSW all the year around. The GeoDH system cannot yet be extended to those houses not connected, since the existing capacity of the well pumps is already more than fully exploited.

The citizens of Beius, not connected to the GeoDH, use mostly wood as a fuel for house heating and HSW. The existing two production wells do not have capacity to supply heat to the rest of the population. The proposed first development scenario is to increase the capacity of one of the existing wells, followed by the drilling of a new production well to be able to supply GeoDH to all the population in Beius.

4. Location

In this chapter, some general information is given about the location of Beius and some average meteorological data as well.

4.1 Geographical Location

Beius (Figure 1.) is a city in Bihor County, Romania near the Apuseni Mountains. It lies in the western part of Romania, and the river Crisul Negru flows through Beius. Coordinates of the town is 46°39`N 22°21'E, total area is 24,46km^2. Total population of Beius is 10.667 (2011).

Figure 1. *Map of Romania and the location of Beius*

4.2 Meteorological Information

Annual average temperature is 10.6°C. In July, the average is about 21°C, while in January the average is 1.4°C. Rainfall is enough to support the woods and vegetation of the zone, registering an annual average of about 585.4 mm. Rainfall is variably distributed throughout the year, with a maximum in June and a minimum in the late autumn and winter months. Table 1 shoves the climate data for the area. In this favorable climate zone, traditionally the district heating period is annually between middle of October and middle of April.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Temp [C°]	-1.9	1	5.9	11.2	16.1	18.9	20.6	20.4	16.9	11.5	5.6	0.5
Avg. Max Temp. [C°]	1.4	4.7	10.7	16.9	22.1	24.9	27.1	26.8	23	17.1	9.3	3.4
Avg. Min Temp. [C°]	-5.2	-2.7	1	5.5	10.1	12.9	14.2	13.9	10.8	5.9	1.9	-2.4

Table 1.: *Meteorological information from Beius*

5. Geothermal Resource in Beius[1]

5.1 General background

5.1.1 Geothermal Resources

Geothermal energy stems from the Earth's outward heat-flux, which originates from the internal heat of the Earth leftover from its creation as well as from the decay of radioactive isotopes in the Earth's mantle and crust. Geothermal systems are regions in the Earth's crust where this flux, and the associated energy storage, are abnormally great. In the majority of cases the energy transport medium is water and such systems are, therefore, called hydrothermal systems. Geothermal resources are distributed throughout the Earth's crust with the greatest energy concentration associated with hydrothermal systems in volcanic regions at crustal plate boundaries. Yet exploitable geothermal resources may be found in most countries, either as warm ground-water in sedimentary formations or in deep circulation systems in fractured crystalline rocks. Shallow thermal energy suitable for ground-source heat-pump utilization is available world-wide and attempts are underway at developing enhanced geothermal systems (EGS) in places where limited permeability precludes natural hydrothermal activity.

The theoretical potential of the Earth's geothermal resources is, furthermore, enormous when compared to their use today and to the future energy needs of mankind. Geothermal resources should, therefore, be able to play a significant role in the essential future sustainable development of mankind. In many cases geothermal energy is found in populated, or easily accessible, areas. But geothermal activity is also found at great depth on the ocean floor, in mountainous regions and under glaciers and ice caps. Numerous geothermal systems probably still remain to be discovered, since many systems have no surface activity. Some of these are, however, slowly being discovered.

The understanding of the nature of hydrothermal systems didn't really start advancing until deep drilling commenced and their large-scale utilization started during the 20th century. The successful exploration, development and utilization of a geothermal resource rely on comprehensive understanding of their nature as well as quantification of their response to utilization and accurate assessments of their production capacity. This, in turn, relies on efficient collaboration between various scientific and engineering disciplines during all stages. During the exploration stage of a geothermal resource research focuses on analysis of surface exploration data; mainly geological, geophysical and geochemical data, while this emphasis shifts to reservoir physics/engineering research during development and utilization. The fundamental challenge of geothermal reservoir physics/engineering is actually assessment of the long-term production capacity of geothermal resources.

It is important to differentiate between the following definitions related to geothermal resources. ***Geothermal Field*** is a geographical definition, usually indicating an area of geothermal activity, or production well drilling, at the earth's surface. The term ***Geothermal System*** refers to all parts of the hydrological system involved, including the recharge zone, all subsurface parts involving flow and storage, as well as the outflow of the system. Finally, ***Geothermal Reservoir*** indicates the hot and permeable part of a geothermal system that may be directly exploited.

Geothermal systems and reservoirs are classified on the basis of different aspects, such as reservoir temperature or enthalpy, physical state, their nature and geological setting. Saemundsson et al. (2009) discuss these classifications in detail, but a common classification is based on reservoir temperature at a depth of 1 km or more. They are classified as low-temperature if the reservoir temperature is less than 150°C but high-temperature if it's greater than 200°C. Systems with temperature in the range of 150 – 200°C are usually classified as medium-temperature systems. A related classification is based on energy content of the reservoir fluid, in fact its enthalpy, and systems are thus classified as either low- or high-enthalpy, with the cut-off generally at about 800 kJ/kg (190°C). Based on the physical state of the reservoir fluid, geothermal systems are classified as liquid-dominated, two-phase or steam-dominated. This report focusses on low-temperature geothermal resources, which are always low-

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[1] This chapter was prepared by G. Axelsson, S.R. Gudjónsdóttir and S. Halldórsdóttir, ÍSOR.

enthalpy and liquid dominated. Only high-temperature systems can be high-enthalpy and consequently two-phase or steam-dominated. These are discussed further by Saemundsson et al. (2009).

Geothermal systems are also classified based on their nature and geological setting as:

A. Volcanic systems are in one way or another associated with volcanic activity. The heat sources for such systems are hot intrusions or magma. They are most often situated inside, or close to, volcanic complexes such as calderas and/or spreading centres. Permeable fractures and fault zones mostly control the flow of water in volcanic systems.
B. In fracture-controlled convective systems the heat source is the hot crust at depth in tectonically active areas, with above average heat-flow. Here the geothermal water has circulated to considerable depth (> 1 km), through mostly vertical fractures, to extract the heat from the rocks.
C. Sedimentary systems are found in many of the major sedimentary basins of the world. These systems owe their existence to the occurrence of permeable sedimentary layers at great depths (> 1 km) and above average geothermal gradients (> 30ºC/km). These systems are conductive in nature rather than convective, even though fractures and faults play a role in some cases. Some convective systems (B) may, however, be embedded in sedimentary rocks.
D. Geo-pressured systems are sedimentary systems analogous to geo-pressured oil and gas reservoirs where fluid caught in stratigraphic traps may have pressures close to lithostatic values. Such systems are generally fairly deep; hence, they are categorised as geothermal.
E. Hot dry rock (HDR) or enhanced (engineered) geothermal systems (EGS) involve volumes of rock that have been heated to useful temperatures by volcanism or abnormally high heat flow, but have low permeability or are virtually impermeable. Therefore, they cannot be exploited in a conventional manner. However, experiments have been conducted in a number of locations to use hydro-fracturing to try to create artificial reservoirs in such systems, or to enhance already existent fracture networks. Such systems will mostly be used through production/reinjection doublets.
F. Shallow resources refer to the thermal energy stored near the surface of the Earth’s crust, partially originating from solar radiation. Recent developments in the application of ground source heat pumps have opened up a new dimension in utilizing these resources.

Numerous volcanic geothermal systems (A) are found for example in The Pacific Ring of Fire, in countries like New Zealand, Indonesia, The Philippines, Japan, Mexico and in Central America, as well as in the East-African Rift Valley and Iceland. Geothermal systems of the convective type (B) exist outside the volcanic zone in Iceland, in the SW United States and in SE China, to name a few countries. Sedimentary geothermal systems (C) are for example found in France, Germany, Central Eastern Europe and throughout China. Typical examples of geo-pressured systems (D) exist in the Northern Gulf of Mexico Basin in the U.S.A. and in SE-Hungary. The early Fenton Hill project in New Mexico in the U.S.A. and the Soultz project in NE-France, which is now in the pilot demonstration phase after 2 decades of intense research and testing, are well known HDR and EGS projects (E). Shallow resources (F) can be found all over the globe.

Saemundsson et al. (2009) discuss the classification and geological setting of geothermal systems in more detail than done here. They present a further subdivision, principally based on tectonic setting, volcanic association and geological formations. Volcanic geothermal systems (A) are e.g. subdivided into systems associated with rift-zone volcanism (diverging plate boundaries), hot-spot volcanism and subduction-zone volcanism (converging plate boundaries).

Sedimentary geothermal resources are the focus of the present study with sedimentary geothermal systems existing in many of the major sedimentary basins of the world. Sedimentary basins are layered sequences of permeable (carbonate rocks such as limestone, dolomite, sandstone) and impermeable strata (shale or mudstone) which alternate (Saemundsson et al., 2009). The water in such systems is interstitial water, commonly brine, and fresh water recharge is often limited. Temperature is variable, depending on depth of permeable rocks in basin. These systems owe their existence to the permeable sedimentary layers at great depth (>1 km), often above average geothermal gradients (>30°C/km) due to radiogenic heat sources in the shallow crust, tectonic uplifting (folding) in the region or for other reasons. These systems are conductive in nature rather than convective, even though fractures and faults play a role in some cases (Figure 2). Some convective systems may, however, be embedded in sedimentary rocks, especially where tectonic activity has created extensive vertical permeability (near-vertical faults/fractures).

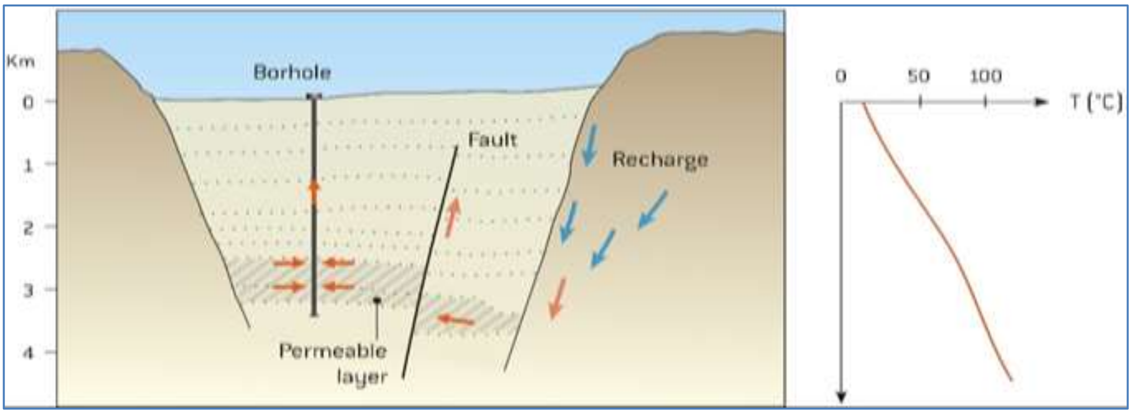


Figure 2. *Schematic figure of a sedimentary basin with a geothermal reservoir at 2 – 4 km depth (modified from Saemundsson et al., 2009). Note that the vertical/horizontal scale is exaggerated, as sedimentary basins usually are quite extensive horizontally. The temperature profile to the left shows a typical sedimentary geothermal gradient profile.*

Examples of geothermal systems in sedimentary basins are the Molasse Basin north of the Alps, the Paris Basin, the Pannonian Basin, the Great Artesian Basin in Australia, the sediment filled Rhine Graben and several basins in China to mention only a few. These systems are of different origin and the heat flow differs widely. The depth to useful temperatures may vary from 1 up to 5 km. The fluid salinity is also different from relatively fresh water to high salinity brine (250,000 ppm). Natural recharge of the geothermal fluid is minimal and reinjection is needed to maintain reservoir pressure and is often a mandatory way to dispose of the geothermal water after passing through heat exchangers. Doublets (production-injection) boreholes are commonly used.

Some sedimentary basins contain sedimentary rocks with pore pressure exceeding the normal hydrostatic pressure gradient. These systems are classified as geo-pressured geothermal systems. They are confined and analogous to geo-pressured oil and gas reservoirs where fluid caught in stratigraphic traps may have pressures close to lithostatic values. Such systems are fairly deep; hence they are categorized as geo-pressured geothermal systems. The known geo-pressure systems are found in conjunction with oil exploration. The most intensively explored geo-pressured geothermal sedimentary basin is in the northern part of the Gulf of Mexico and in Europe in Hungary. Geo-pressured geothermal fields have not yet been exploited.

5.1.2 Geothermal Resources in Romania

Bendea et al. (2015) and Tanase (2016) describe the geothermal resources of Romania and their utilization today. The description in this sub-chapter is based on their work.

The known geothermal resources of Romania (Figure 3) are of the sedimentary type described above. They are low-temperature geothermal systems, either in porous permeable formations such as the Pannonian sandstone layers in the Western Plain and Olt Valley or in fractured Triassic carbonate formations, best known in the Oradea, Bors and North Bucharest (Otopeni) areas. The first well for geothermal utilisation in Romania was drilled in 1885 at the Felix Spa, close to the municipality of Oradea, to a depth of 51 m, yielding 195 L/s of 49°C water. This well is still in operation. During the next two decades, 3 more geothermal wells were drilled in Romania.

The geothermal resources of Romania were discovered during extensive hydrocarbon resource exploration during the middle of last century. Consequently, large scale geothermal research started in the 1960s. Since then, over 250 wells have been drilled ranging in depth from 800 to 3,500 m, through which resources with a temperature between 40 and 120°C were discovered. Most are located in the western part of Romania. A little more than 220 wells have been drilled since 1965, with over 80% of them being artesian producers. About 1/3 of the wells were drilled in the Pannonian Basin. The total installed geothermal production capacity (existing wells) in Romania is about 480 MW_{th} (reference temperature 25°C). Currently, only about 200 MW_{th} capacity is used (less than 100 production wells). This demonstrates the great potential for greatly increased use, both through the already existing production capacity as well as through further exploration, drilling and utilization development.

During the last decade only about 10 geothermal wells have been drilled in Romania, the deepest down to 3100 m depth. Three of these were non-productive while two were drilled specifically as reinjection wells, one in Oradea and one in Beius. Only a few other reinjection wells exist in Romania and the new reinjection wells hopefully signal increased geothermal reinjection in the country and its increased role in the sustainable management of the geothermal resources in Romania.

Figure 3. *Simplified map of Romania showing the main geothermal localities (from Bendea et al., 2015).*

Tanase (2016) describes some of the geothermal systems and reservoirs in considerable detail. Briefly listed these include the following:

- The Pannonian sandstone geothermal reservoirs are distributed over an area of approximately 2,500 km^2 along the western border of Romania. The main geothermal areas are, from north to south, Satu Mare, Tasnad, Acas, Marghita, Sacuieni, Salonta, Curtici-Macea- Dorobanti, Nadlac, Lovrin, Tomnatic, Sannicolau Mare, Jimbolia and Timisoara. Over 100 geothermal wells have been drilled in the area, with 33 being currently utilized (mainly artesian). These reservoirs are found in the depth range of 800 to 2400 m, with a thermal gradient of 45-55°C/km, and wellhead temperatures of 50 – 85°C. The geothermal water is of the sodium-bicarbonate-chloride type, with a TDS (total dissolved solids) of 4-5g/L. Therefore, carbonate scaling is a dominating utilization problem that is in most cases prevented by using chemical inhibitors. Utilisation involves space heating, sanitary hot water, greenhouse heating, fish farming and balneology. The Pannonian reservoirs are mainly confined, with limited natural recharge. Reinjection is, therefore, essential for their increased and sustainable utilization. Sandstone reinjection faces serious clogging problems, however, while an efficient solution is available, as will be discussed below (end of subchapter 5.1.3).
- The Oradea geothermal system and its utilization are described in detail in an associated feasibility report.
- The Beius fractured carbonate geothermal system and its utilization are described in detail later in this report.
- The Bors carbonate geothermal reservoir is located approximately 6 km north-west of Oradea and has quite different characteristics compared to other carbonate geothermal systems in the general region. The Bors reservoir, which covers an area of 12 km^2, is a closed reservoir with a TDS of 13 g/L and high gas content (CO_2 and CH_4) and high scaling potential. The reservoir

temperature at Bors is over 130°C at a depth of 2,500 m. Full reinjection is required to maintain artesian production. Utilization in Bors has mainly involved greenhouse heating and industrial heat.

- The Ciumeghiu geothermal reservoir is located in the Western Plain of Romania, about 50 km south of Oradea. The aquifer is embedded in Lower Pannonian gritstone, at an average depth of 2,200 m. Wellhead temperature is about 105°C and TDS equal 5-6 g/L, with strong carbonate scaling potential. This resource has been used to some extent for greenhouse heating.
- The Cozia-Calimanesti geothermal reservoir (in Olt Valley) is in fissured siltstones of Senonian age. The reservoir depth is 2,700-3,250 m, wellhead temperatures 70-95°C and TDS 15.7 g/L, without major scaling problems. This reservoir has been exploited for more than 25 years with limited interference between wells and no significant pressure draw-down. The utilization is mainly for space heating and balneology. The available wells are, however, not used at full capacity and the limited pressure draw-down indicates and even greater capacity.
- The Otopeni geothermal system is in the northern part of the Bucharest area. The productive aquifers are found in fissured limestone and dolomites (carbonate rocks) at a depth of 2,000 to 3,200 m. It is within the Moesian Platform and estimated to extend about 300 km^2. Twenty-four geothermal wells have been drilled into the system, 18 of which are potential production or reinjection wells. Downhole pumps are used in the Otopeni wells utilized and well flow rates are between 22 and 28 L/s, with a wellhead temperature of 58-84°C.

5.1.3 Geothermal Capacity Assessment

The long-term response and hence production capacity of geothermal systems is mainly controlled by (1) their size and energy content, (2) permeability structure, (3) boundary conditions (i.e. significance of natural and production induced recharge) and (4) reinjection management (Axelsson, 2016a). Their energy production potential, in the case of hydrothermal systems, is predominantly determined by pressure decline due to production. This is because there are technical limits to how great a pressure decline in a well is allowable; because of pump depth or spontaneous discharge through boiling, for example. The production potential is also determined by the available energy content of the system, i.e. by its size and the temperature or enthalpy of the extracted mass. The pressure decline is determined by the rate of production, on one hand, and the nature and characteristics of the geothermal system, on the other hand.

Natural geothermal reservoirs can often be classified as either open or closed, with drastically different long-term behaviour, depending on their boundary conditions. ***Closed systems*** have limited, or no, natural recharge so their reservoir pressure declines continuously with time. The production potential of such systems is limited by lack of water rather than lack of thermal energy, and they are therefore ideal for reinjection, which provides manmade recharge. Many sedimentary geothermal systems provide the best examples of closed systems. In ***open systems*** recharge eventually equilibrates with the mass extraction and their reservoir pressure stabilizes. Their recharge may be both hot deep recharge and colder shallow recharge. The latter will eventually cause reservoir temperature to decline and production wells to cool down. The production potential of such systems is limited by the energy content (temperature and size) of the reservoir rocks, in addition to the pressure decline. Sedimentary systems are commonly of the closed type, as they usually have limited natural recharge. But there are exceptions, especially in the case of fractured and/or karstified carbonate sedimentary rocks. The geothermal system in Beius, the subject of this report, is a good example of an open sedimentary system.

For EGS-systems and sedimentary systems utilized through production-reinjection doublets (well-pairs) with 100% reinjection the production potential is predominantly controlled by the energy content of the systems involved. But, permeability, and therefore pressure variations, is also of controlling significance in such situations. This is because it controls the pressure response of the wells and how much flow can be achieved and maintained, for example through the doublets involved. In sedimentary systems the permeability is natural but in EGS-systems the permeability is to a large degree man-made, or at least enhanced.

Water or steam extraction from a geothermal reservoir causes, in all cases, some decline in reservoir pressure, as already discussed. Consequently, the pressure decline manifests itself in further changes.

These include direct changes such as changes in surface activity, decreasing well discharge, increased boiling (increased enthalpy) in high-enthalpy reservoirs and changes in non-condensable gas concentration. Increased recharge due to the drop-in reservoir pressure causes indirect changes such as in the chemical composition of the reservoir fluid, changes in scaling/corrosion potential, changes in reservoir temperature conditions and changes in temperature/enthalpy of reservoir fluid. The pressure drop can also cause surface subsidence, which may be detrimental.

Production and response histories, as discussed above, are essential for understanding the nature and estimating the properties of geothermal systems. This reflects the importance of comprehensive and careful monitoring of the response of geothermal systems to energy extraction during long-term utilization (Monterrosa and Axelsson, 2013), otherwise the relevant information is lost. The information is important for conceptual model development, for resource assessment and resource management. It is, in particular, important for model development (see later) aimed at estimating the production capacity of a geothermal system, including the assessment of the sustainable production capacity of a geothermal system. In that case, the longest data-series are logically most valuable, providing the most reliable capacity estimates. Many long and well documented utilization and response case histories are, in particular, available, many spanning more than 30 years, which are extremely valuable for studying the nature of geothermal systems, e.g. their renewability and potential sustainable utilization.

Various methods are available, and have been used the last several decades, to assess geothermal resources during both exploration and exploitation phases of development. These range from methods used to estimate resource temperature, surface energy flux and resource size to complex numerical modelling aimed at predicting the production response of systems and estimating their production capacity or potential. The main methods that involve actual modelling are (Axelsson, 2016a):

(a) Volumetric methods (adapted from mineral exploration and oil industry);
(b) Simple mathematical modelling (often analytical);
(c) Lumped parameter modelling; and
(d) Detailed numerical modelling of natural state and/or exploitation state.

The purpose of geothermal modelling is firstly to obtain information on the conditions in a geothermal system as well as on the nature and properties of the system. This leads to proper understanding of its nature and successful development of the resource. Secondly, the purpose of modelling is to predict the response of the reservoir to future production and estimate the production potential of the system as well as to estimate the outcome of different management actions.

The diverse data/information, which is the foundation of all reservoir-modelling, need to be gathered continuously throughout the exploration and exploitation history of a geothermal reservoir. Information on reservoir properties is obtained by disturbing the state of the reservoir (fluid-flow, pressure) and by observing the resulting response, and is done through well and reservoir testing and data collection (Axelsson, 2013). It is important to keep in mind that the longer, and more extensive the tests are, the more information is obtained on the system in question. Therefore, the most important data on a geothermal reservoir is obtained through careful monitoring during long-term exploitation, which can be looked upon as prolonged and extensive reservoir testing.

The modelling methods may be classified as either static modelling methods or dynamic modelling methods, with the volumetric method (a) being the main static method. Both involve development of some kind of a mathematical model that simulates some, or most, of the data available on the system involved. The dynamic modelling methods ((b) – (d) in the list above) are based on modelling the dynamic (changing with time) conditions and behaviour (production response) of geothermal systems.

The **volumetric method** is the main static modelling method, as already stated. It is presented and discussed in detail by Sarmiento et al. (2013). It is often used for first stage assessment and is increasingly being used through application of the Monte Carlo method, which enables the incorporation of overall uncertainty in the results. It involves assigning probability distributions to the different parameters of the equations above and estimating the system potential with probability. The main drawback of the volumetric method is the fact that the dynamic response of a reservoir to production is not considered, such as the pressure response and the effect of fluid recharge and reinjection.

Reservoirs with the same heat content may have different permeability and recharge and, hence, very different production potentials.

The volumetric method is based on estimating the total heat stored in a volume of rock (referred to some base temperature), both thermal energy in rock matrix and in water/steam in pores. In the volumetric method the likely surface area and thickness of a resource are initially estimated from geophysical and geological data, and later also from well-data. Consequently, likely temperature conditions are assumed on the basis of chemical studies and well temperature data, if available. Based on these, as well as estimates of reservoir porosity and thermal properties of water and rock involved, the total energy content is estimated.

Only a relatively small fraction of the total energy in a system can be expected to be extracted, or recovered, during several decades long utilization period. This fraction is estimated by applying two factors. First so-called surface accessibility (A), which describes what proportion of the reservoir volume can be accessed through drilling from the surface. Then the recovery factor (R), which indicates how much of the accessible energy may be technically recovered. The recovery factor is the parameter in the volumetric method, which is most difficult to estimate. The results of the volumetric assessment are also highly dependent on the factor. It depends on the nature of the system; permeability, porosity, significance of fractures, recharge, as well as on the mode of production, i.e. whether reinjection is applied. It is also to some extent dependent on utilization time. Williams (2007) provides a good review of the estimation of the recovery factor, which is often assumed to be in the range of 0.05–0.25. In recent years researchers have become more conservative in selecting the recovery factor than in the past, based on experience from long-term utilization of numerous geothermal systems worldwide.

The main dynamic modelling methods applied to geothermal systems are simple mathematical (analytical) modelling methods (b), lumped parameter methods (c) and detailed numerical modelling (d), as listed above. These are reviewed briefly below, but for more details the reader is referred to Axelsson (2016a). It should be noted that the initial phase of such model development should be always based on a good conceptual model of the geothermal system in question. Numerous examples are available on the successful role of dynamic modelling in the estimation of generation capacity of geothermal resources as well as their key role in geothermal resource management (see also Axelsson, 2016a).

In simple models, such as simple analytical models and lumped parameter models, the real structure and spatially variable properties of a geothermal system are greatly simplified so that analytical mathematical equations, describing the response of the model to energy production may be derived. These models, in fact, often only simulate one aspect of a geothermal system's response. Detailed and complex numerical models, on the other hand, can accurately simulate most aspects of a geothermal system's structure, conditions and response to production. Simple modelling takes relatively little time and only requires limited data on a geothermal system and its response, whereas numerical modelling takes a long time and requires powerful computers as well as comprehensive and detailed data on the system in question. The complexity of a model should be determined by the purpose of a study, the data available and its relative cost. In fact, simple modelling, such as lumped parameter modelling, is often a cost-effective and timesaving alternative. It may be applied in situations when available data are limited, when funds are restricted, or as parts of more comprehensive studies, such as to validate results of numerical modelling studies. Such simple models are ideal in geothermal situations such as in Romania; they provide the main modelling tools used in this study.

While some **simple analytical models** have been developed specifically for geothermal applications (see e.g. Grant and Bixeley, 2011) many of these simple models have also been inherited from groundwater science or even adopted from theoretical heat conduction treatises (because the pressure diffusion and heat conduction equations have exactly the same mathematical form). A good example of the former is the well-known Theis model, which comprises a model of a very extensive horizontal, permeable layer of constant thickness, confined at the top and bottom, with two-dimensional, horizontal flow towards a producing well extending through the layer. Geothermal well-test data are often analysed on basis of the Theis model, and its variants, by fitting the pressure response of such models to observed pressure response data.

Simple modelling has been used extensively to study and manage low-temperature geothermal systems utilised in Iceland, to take a relevant example, in particular to model their long-term response to production. **Lumped parameter modelling** of pressure change data, has been the principal tool for this purpose (Axelsson et al., 2005a). Lumped parameter models can simulate such data very accurately, even very long data sets (several decades). Pressure changes are in fact the primary production induced changes in geothermal systems, as already emphasised. An efficient method of lumped parameter modelling of pressure response data from geothermal systems, and other underground hydrological systems, which tackles the simulation as an inverse problem and can simulate such data very accurately, if the data quality is sufficient, is available. It automatically fits the analytical response functions of the lumped models to observed data by using a non-linear iterative least-squares technique for estimating the model parameters. Today, lumped models have been developed by this method for up to 30 low-temperature and 4 high-temperature geothermal systems in Iceland, as well as numerous geothermal systems in China, Turkey, Kenya, Eastern Europe, Central America and The Philippines, as examples (Axelsson et al., 2005a). Lumped parameter modelling is also an ideal tool to model pressure changes (observed as water level changes) in geothermal systems in Romania, when sufficiently good data are available, such as in Beius.

The theoretical basis of this automatic method of lumped parameter modelling, and relevant equations, are presented by Axelsson (1989), with a general lumped model consisting of a few tanks and flow resistors (Figure 4). The tanks simulate the storage capacity of different parts of a geothermal system and the pressure in the tanks simulates the pressure in corresponding parts of the system. The first tank of the model in the figure can be looked upon as simulating the innermost (production) part of the geothermal reservoir, and the second and third tanks simulate the outer parts of the system. The third tank is connected by a resistor to a constant pressure source, which supplies recharge to the geothermal system. The model in Figure 3 is, therefore, open. Without the connection to the constant pressure source the model would be closed. An open model may be considered optimistic, since equilibrium between production and recharge is eventually reached during long-term production, causing the pressure draw-down to stabilize. In contrast, a closed lumped model may be considered pessimistic, since no recharge is allowed for such a model and the water level declines steadily with time, during long-term production. In addition, the model presented in Figure 3 is composed of three tanks; in many instances models with only two tanks have been used.

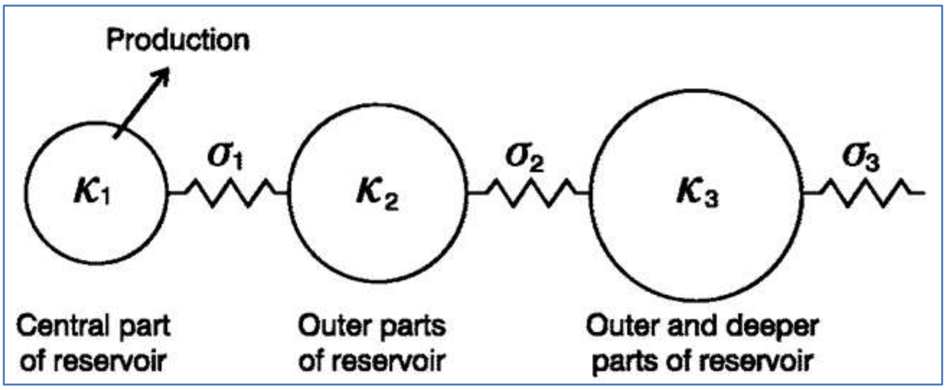


Figure 4. *A 3-tank lumped ladder model commonly used to simulate geothermal systems (Axelsson et al., 2005a)*

In the lumped parameter model of Figure 4, hot water is assumed to be pumped out of the first tank, which causes the pressure in the model to decline. This in turn simulates the decline of pressure in the real geothermal system. When using this method of lumped parameter modelling, the data fitted (simulated) are the pressure (or water level) data for an observation well inside the well-field, while the input for the model is the production history of the geothermal field in question.

Axelsson et al. (2005a) present examples of long pressure response histories of geothermal systems, distributed throughout the world, simulated by lumped parameter models. The examples show that in all of the cases the models developed simulate the pressure changes quite accurately. Yet because of how simple the lumped parameter models are, their reliability is sometimes questioned. Experience has shown that they are quite reliable, however, and examples involving repeated simulations, demonstrate this clearly (Axelsson et al., 2005). This applies, in particular, to simulations based on long data sets, which is in agreement with the general fact that the most important data on a geothermal reservoir are obtained through careful monitoring during long-term exploitation. Lumped parameter modelling is less reliable when based on shorter data sets, which is the case for all such reservoir engineering predictions.

Once a satisfactory fit with observed pressure data has been obtained the corresponding lumped parameter models can be used to calculate predictions for different future production scenarios. Future pressure changes in geothermal systems are expected to lie somewhere between the predictions of open and closed versions of lumped parameter models, which represent extreme kinds of boundary conditions. The differences between these predictions simply reveal the inherent uncertainty in all such predictions. Real examples demonstrate that the shorter the data period a simulation is based on is, the more uncertain the predictions are (Axelsson et al., 2005). They also demonstrate that the uncertainty in the predictions increases with increasing length of the prediction period.

Detailed numerical reservoir modelling has become the most powerful tool of geothermal reservoir physics/engineering parallel with the rapid development of high-capacity modern-day computers and is increasingly being used to simulate geothermal systems in different parts of the world. This method will be reviewed briefly here, while the reader is referred to an early work by the pioneers in this field Bödvarsson et al. (1986) and a later comprehensive review by O'Sullivan et al. (2001). The numerical modelling method is extremely powerful when based on comprehensive and detailed data. Without good data, however, detailed numerical modelling can only be considered speculative, at best. In addition, numerical modelling is time-consuming and costly and without the necessary data the extensive investment needed is not justified.

Geothermal reinjection, which involves injecting energy-depleted fluid back into geothermal systems, is an integral part of all modern, sustainable and environ-mentally friendly geothermal utilization projects (Rivera-Diaz, 2016; Axelsson, 2012). It is an efficient method of waste-water disposal as well as a means to provide additional recharge to geothermal systems. Thus, it counteracts production induced pressure draw-down and extracts more thermal energy from reservoir rocks, and increases production capacity in most cases. Reinjection can also mitigate subsidence. Reinjection is also essential for sustainable utilization of geothermal systems, which are virtually closed and with limited recharge, e.g. many sedimentary geothermal systems. Reinjection is either applied inside a production reservoir, on its periphery, above or below it or outside the main production field. Several good examples of successful long-term geothermal reinjection are available, both for low-temperature and high-temperature systems (Axelsson, 2012).

Cooling of production wells is one of the problems/obstacles associated with reinjection, even though only a few examples of actual cold-front breakthrough have been recorded. This danger can be minimised through careful testing and research. Tracer testing, combined with comprehensive interpretation and cooling predictions (reinjection modelling), is probably the most important tool for this purpose (Axelsson et al., 2005b). Tracer tests actually have a predictive power since tracer transport is orders of magnitude faster than cold-front advancement around reinjection wells. Numerous examples are available worldwide on the successful application of tracer tests in geothermal systems. The tracers most commonly used in geothermal systems are fluorescent dyes, chemical substances and radioactive isotopes while new temperature-resistant tracers have been introduced and high-tech tracers are being considered.

Scaling and corrosion problems associated with reinjection can be controlled through different technical solutions, dependent on the situation. They are most efficiently dealt with by applying various chemical inhibitors. Finally, a solution is available for the rapid aquifer clogging, which often accompanies sandstone reinjection (see below).

The energy production from the sedimentary geothermal resources in the Paris sedimentary basin (the Dogger reservoir/aquifer), which has been ongoing since around 1970, provides one of the best examples of successful management of sedimentary geothermal resources worldwide, which a lot can be learned from (Lopez et al., 2010). The utilization there involves 100% reinjection, which has been managed without significant cooling of production wells these 3-4 decades. Scaling and corrosion is also successfully managed in the Paris basin. Several examples of successful 100% reinjection are also available in Germany, while in other countries the role of reinjection has been limited. The latter include

Hungary, Romania and even China, where utilization has been expanding very rapidly in recent decades. Reinjection into sandstone sedimentary geothermal systems is highly problematic due to rapid clogging of the reinjection wells involved, because of the narrow flow paths in-between the sand particles this particular sedimentary rock is composed of. An efficient method has been developed to deal with this, which is being applied successfully in several cases, mainly in Germany (Seibt and Kellner, 2003). The method involves applying efficient double filtering as well as maintaining the whole system oxygen-free by injecting nitrogen under nominal pressure. The experience and development referred to here can be built upon in expanding reinjection in Beius and Romania in general.

5.2 Geothermal Resources in Beius

This subchapter describes the geological framework of the geothermal resources in Beius, based on information made available specifically for this study as well as on information from other sources, open internationally. The most detailed geological data, derived from the wells drilled, won't be presented here, as they are classified.

The town of Beius, which is located about 60 km south-east of the city Oradea, W-Romania, at an altitude of +180-200 m a.s.l. (Figure 2), is situated above a fairly extensive sedimentary geothermal resource. It is a low temperature sedimentary geothermal system, situated in the central part of the Beius basin, in the Northen Apuseni Mountains. The basin is surrounded by the Bihor mountains in the E and SE, and the Codru Moma Mountains in the W and SW, which reach elevation between 1000 and 1800 m (Bratu et al., 2017). The Crisu Negru river crosses Beius town longitudinally. The climate is moderate for continental temperatures, with the annual temperature around 10–12°C and precipitation of 700–800 mm/m^2/year. The town of Beius has a population of around 14,000 inhabitants and is the only town in Romania heated to a large extent by geothermal energy (Bratu et al., 2017; Bendea et al., 2015).

The basement of the Beius basin is heterogeneous, consisting of sedimentary and volcanic Permian (299-252 Mya) rocks and Mesozoic (252-66 Mya) carbonate rocks, which are within the Codru folding system, belonging to the Northern Apuseni Mountains (Bratu et al., 2017; Orăşeanu, 2015). The basement has a structure of thrust folds that were formed during the Mesozoic (Codru system of folding), thrusting over the Bihor Autochthon from Turonian. The Bihor unit has large folds or NW-SE orientated monoclines. The thrust folds were than modified by a normal faulting process active in the Neozoic (65.5 Mya-present) and are covered by sediment formations from Pliocene and Miocene (23-2.6 Mya), and Quaternary (2.9 Mya-present) (see Figure 5). The sediment consists of marls, sands, micro-conglomerates, volcanic rocks and coal layers. The two types of fractures, i.e. inverse (Mesozoic) and normal gravitational fractures (Neozoic), both play a major role in the circulation of water transported within the geothermal reservoir. The inverse fracture system and thrusting planes often have W-E direction, and the normal faulting system is directed both NW-SE (at the margins of the basin) and W-E (in the central part of the basin) (Bratu et al., 2017).

The Beius geothermal resource exists due to an above average heat flow in the area, and fractured and permeable reservoir rock composed of Triassic limestone and dolomite. The fractured Triassic limestone and dolomites are the main geothermal reservoir rocks in the area, collecting and storing the geothermal water. It is situated at variable depth, generally greater than 1500 m, with a thickness range of hundreds of meters (Bratu et al., 2017; Axelsson et al., 2000). The reservoir rock reaches the surface in the Codru-Moma mountains, 8-10 km west of the Beius area. Precipitation in the mountains is believed to provide the main recharge to the Beius reservoir (Figure 6).

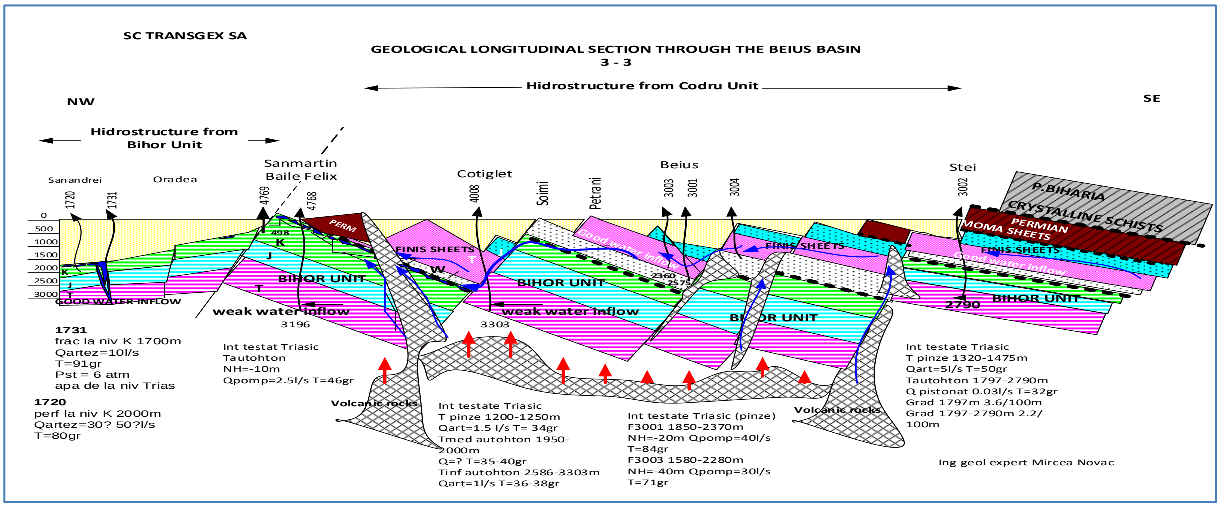


Figure 5. *Geological cross section of the Beius basin, with Beius in the centre. Note the location of the Oradea geothermal system in the NW (Transgex, 2015).*

The reservoir temperature in the centre of the basin, specifically below Beius town, lies between 75 and 88°C, and the geothermal water (bicarbonated-sulfosodic composition) is for example used for the heating system of Beius, and for hot household waters (Bratu et al., 2017). The first production well was drilled in the area in 1996. It is 2576 m deep, and reveals the complicated layer structure of the Beius basin. The Triassic reservoir rock of limestone and dolomite was found at 1887–2450 m depth and the water temperature was 84°C (Bratu et al., 2017; Transgex, 2015) (Figure 7).

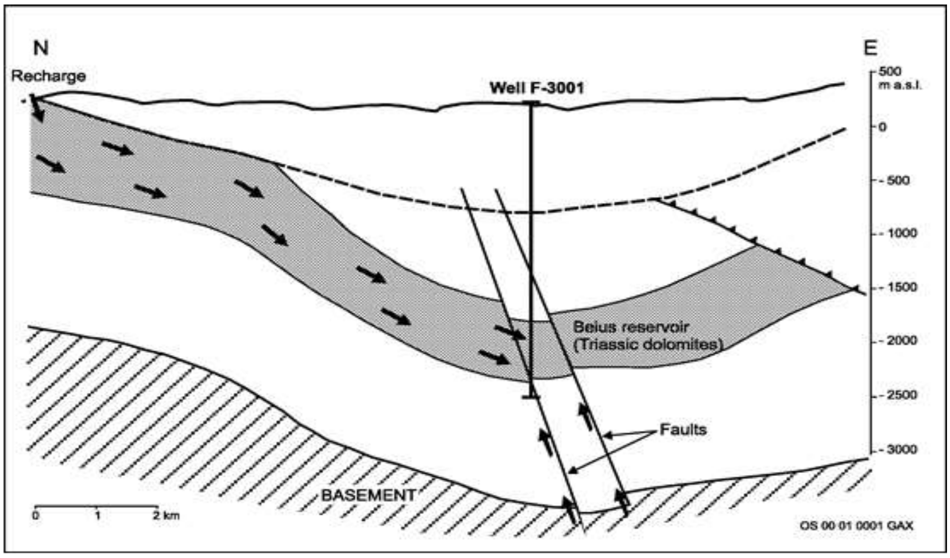


Figure 6. *A simplified conceptual model of the Beius geothermal reservoir, through a N-S cross-section (Axelsson et al., 2000).*

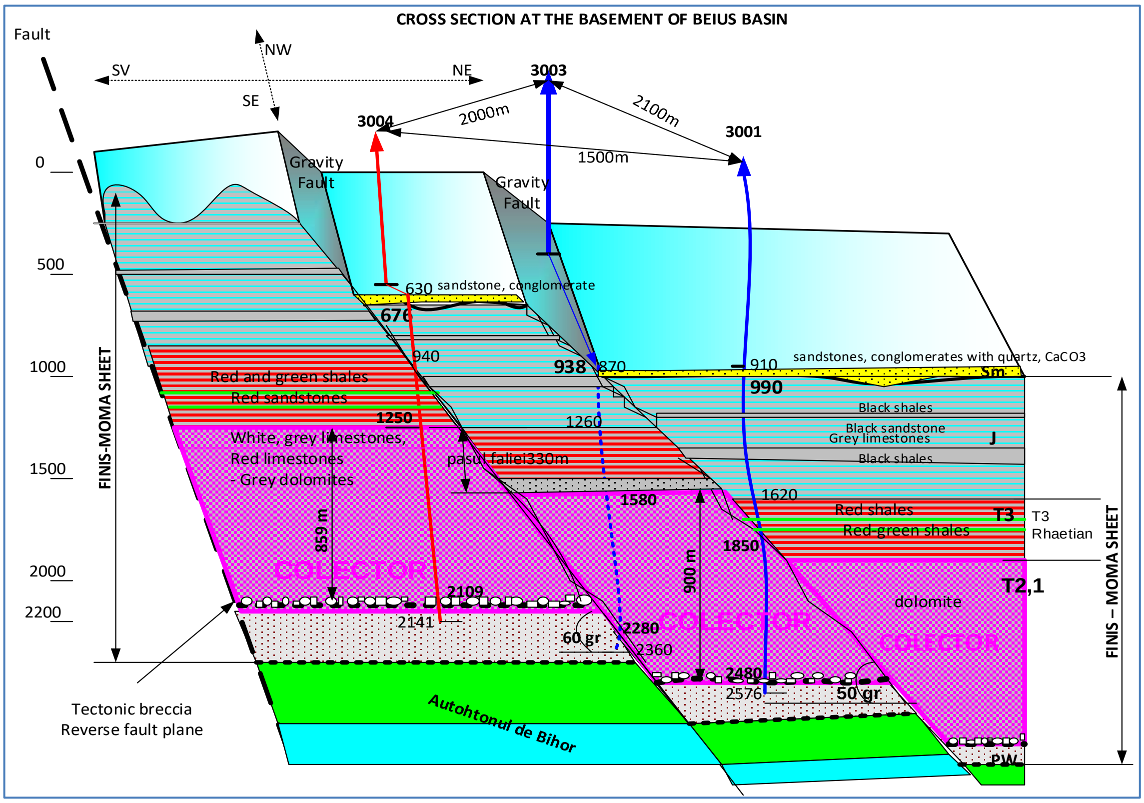


Figure 7. *A SW-NE cross-section through the part of the Beius basin lying directly below the town of Beius, showing the location and trajectories of wells F-3001, F-3003 and F-3004 (Transgex, 2015).*

5.3 Previous Assessments

Only a limited number of assessments, aimed at estimating the production capacity of the Beius geothermal system, or the capacity of specific wells, have been performed to date, to the knowledge of the authors of this report. These include in-house assessments performed by Transgex, the assessment of Axelsson et al. (2000) and the present assessment. These assessments have used some of the methods described in sub-chapter 5.1.3 above, including volumetric assessment, simple analytical modelling and lumped parameter modelling. Unfortunately, the details of the Transgex in-house assessments haven't been accessible for the present project, due to their classified nature, apart from the results of a kind of volumetric assessment (Transgex, 2015).

The first geothermal well drilled in the town of Beius, well F-3001, was extensively tested, through the use of a down-hole pump, during a period of five months in 1999. The installation of the down-hole pump, the well-testing and consequent analysis and modelling, was supported by a grant from the EU. Axelsson et al. (2000) describe the results of the testing and the following reservoir assessment. The principal purpose of the reservoir assessment was to estimate the long-term production potential of well F-3001 by predicting future water level changes for different production scenarios. In addition an attempt was made to foresee undesirable chemical changes and reservoir cooling during long-term production, if applicable.

The main phases of the reservoir assessment were:

A. Compilation of data collected during the six-month test period.
B. Analysis of production characteristics of the well, i.e. near-well and turbulence pressure losses.
C. Development of a very simple qualitative conceptual model of the geothermal system, based on available geological data and the results of the production test.
D. Simulation of the well-test data by simple but reliable models (lumped parameter models or other analytical models).
E. Simple models used to predict the water level changes in well F-3001 for different future production scenarios, including realistic scenarios with a seasonally varying rate of pumping.

F. Simple models used to investigate the effects of drilling of additional production wells. The effects of re-injection, i.e. water level recovery and declining production temperatures, will be investigated.
G. Analysis of chemical data, with emphasis on estimating the potential for scaling and corrosion, future chemical changes and possible reservoir cooling.

During the assessment of the Beius geothermal reservoir discussed here the principal emphasis was placed on estimating the long-term potential of well F-3001 itself (see Figure 8), on one hand, and developing a model of the geothermal reservoir, on the other hand. The model was, consequently, used to estimate the pressure interference between wells, the total potential of the geothermal reservoir in the Beius-area and the benefit of reinjection. The main results of the assessment were summarised as follows (Axelsson et al., 2000):

1) One of the most important results of the pumping test is that the water level draw-down in well F-3001 reaches an equilibrium after about three weeks of constant production. The reason for this is a connection of the production reservoir to some hydrological system, which maintains constant pressure. According to the conceptual model this could either be a recharge area in the mountains to the west of Beius or the recharge from greater depth through the fractures intersected by well F-3001 (Figure 8). The short time required for equilibrium to commence indicates that the recharge from depth is responsible for the equilibrium rather than the postulated recharge area in the mountains.
2) The long-term production potential of well F-3001 is estimated to be 60 and 90 L/s, for pump depths of 150 and 250 m, respectively.
3) The permeability-thickness of the Beius reservoir is estimated to be about 15 Darcy-m. A simple model of a horizontal reservoir with a constant pressure boundary intended to simulate recharge, as well as a no-flow boundary, was used to estimate the combined production potential of a few production wells. The results indicate that three production wells in Beius, separated by 1 – 2.5 km, should have a combined production potential of the order of 120 L/s and 200 L/s, for pump depths of 150 and 250 m, respectively.
4) Reinjection is a mode of utilisation that should increase the potential of the Beius geothermal reservoir, through pressure recovery, which may be used to increase pumping from production wells without increased pressure draw-down. The simple model used predicts that the yield of a production well producing 40 - 60 L/s will increase by 33 - 18%, respectively, through 50 L/s reinjection into a well located about 1100 – 1600 m away. In the case of three production wells producing a total of 120 L/s, reinjection (50 L/s) will increase their combined yield by about 40 L/s. The combined production potential of three production wells with pumps located at 250 m depth, and a reinjection well accepting 50 L/s is expected to increase about 30 L/s to 230 L/s. Reinjection will most likely need to be carried out through the use of high-pressure (0 – 10 bar) pumps, rather than by gravity flow.
5) The results on additional production wells, and the effect of reinjection, are highly uncertain and speculative at this stage. Further studies conducted once a new production well has been drilled, as well as data from the Oradea area, will greatly increase the reliability of the results.
6) Analysis of the chemical content of three water samples collected during the production test indicates that there should be no danger of silica deposition from the water. Subsurface temperature within the reservoir is expected to be 85-90°C, based on equilibrium with the silica mineral quartz. The water becomes highly supersaturated with respect to calcite if totally degassed with subsequent danger of calcite scaling. However, minor degassing followed by conductive cooling, as within a reservoir tank and a distribution system, is believed to cause little danger of calcite scaling and the water can therefore be used directly. No changes in the chemical composition did occur during the five months test. Neither a direct connection to the ground-water in Beius is, therefore, likely nor a significant cooling of the water during long-term production.

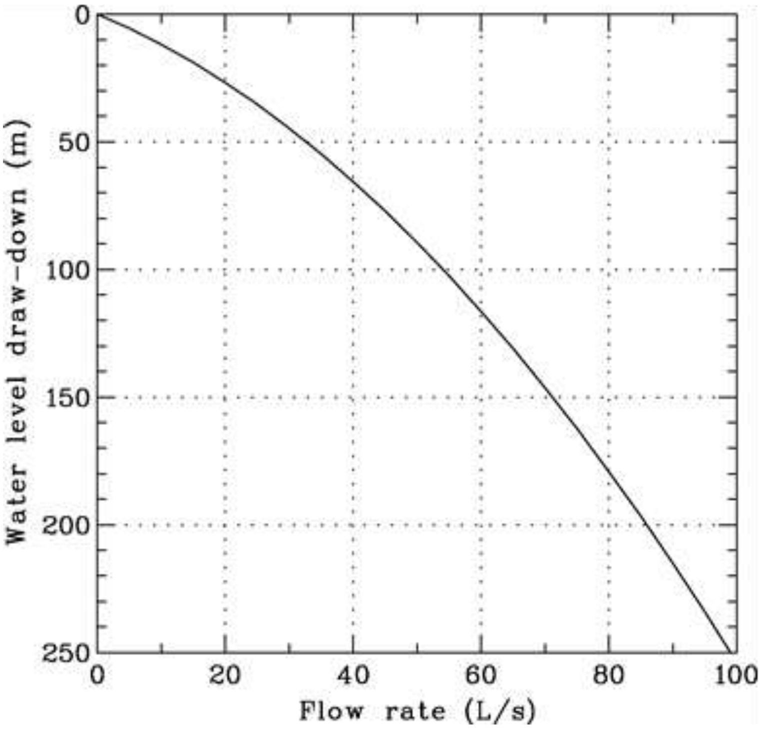


Figure 8. *Production potential of well F-3001, as assessed following 1999 test, presented as predicted water level draw-down as a function of production (from Axelsson et al., 2000).*

Axelsson et al. (2000) emphasised the importance of careful monitoring once utilisation of the Beius geothermal reservoir started. This included physical monitoring (flow-rates, water-level and water temperature), which will provide the basis for a re-evaluation of their reservoir assessment, and chemical monitoring which will enable the operators of the field to see undesirable changes such as reservoir cooling, scaling and corrosion, in advance. This appears to have been put in place by Transgex. Axelsson et al. (2000) also point out that once a reinjection well has been drilled, a tracer test must be conducted to enable reliable estimates of the danger of production well cooling, due to reinjection, which is something should be considered in the near future.

Transgex (2015) present the following principal parameters of the Beius geothermal reservoir, some of which are derived from the evaluations mentioned above:

- The reservoir rock is composed of fractured dolomitic limestone, characterized by double porosity and about 8% fracture porosity.
- Average reservoir hydraulic conductivity 0,15 m/day, corresponding to 20 mDarcy.
- The surface area of the Beius reservoir is estimated to be about 40 km^2.
- The Beius reservoir block is bounded by several boundaries, some of which are believed to mainly while others are closed. These boundaries are created by both reverse and normal faults (gravity faults). Some such faults also divide the reservoir into separate internal blocks.
- Reservoir depth range 1600 – 2500 m, average thickness 700 m, in area of Beius town.
- Reservoir base temperature 80 – 90°C; base pressure 220 – 240 bar, in area of Beius town.

5.4 Utilization

The Beius geothermal resource (specifically the reservoir blocks below the town of Beius) has been utilized since 2001, for space heating and household use. Well F-3001 was the first well used but later two more wells were drilled, wells F-3003 and F-3004 (see Figure 7). The former has been used as a production well since 2004 and the latter as a reinjection well since late 2012. Both production wells are equipped with down-hole pumps as the reservoir pressure isn't sufficient to drive artesian flow.

The average yearly production from the Beius geothermal reservoir since 2006 is presented in Table 2 and in Figure 9 below, which show that the utilization has been steadily increasing in recent years. The production well capacity of the two wells is similar, or up to 50 L/s, even though they are usually not used at a greater flow-rate than 40 L/s. The well-head temperature is in the range of 70 – 85°C while the maximum water-level draw-down in both wells in winter-time is of the order of 80 – 90 m.

Table 2. *Average yearly production from the Beius geothermal system during 2006 – 2015.*

Year	Average production (L/s)	Cumulative prod. (m^3)
2006	14.0	441040
2007	15.9	503176
2008	21.0	663623
2009	20.8	655285
2010	21.6	681113
2011	21.8	686893
2012	24.8	783766
2013	25.4	802285
2014	23.7	747541
2015	27.8	873133

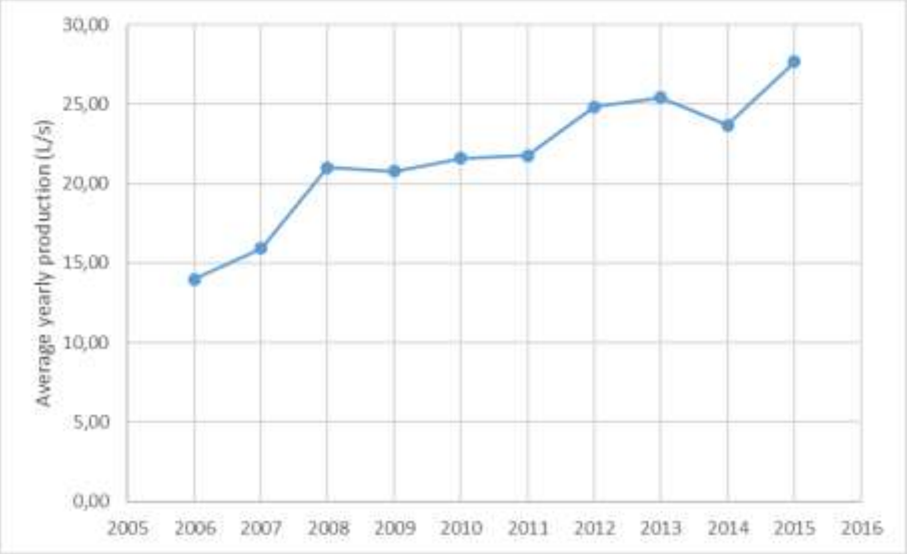


Figure 9. *The utilization history of the Beius geothermal reservoir 2006 – 2015.*

The reinjection well (F-3004) has only been utilized at the nominal flow-rate of 1 – 3 L/s. This appears to be the capacity of the well under gravity flow, while a greater injection rate (~10 L/s) can be achieved through pumping under pressure. The utilization in Beius today is presented in more detail below (chapter 6), even though specific well data won't be presented here, as they are classified.

5.5 Reassessed Capacity

The capacity of the Beius geothermal system has been reassessed during the present study. This reassessment is based on the following:

a) Available data on production from individual geothermal wells (2 wells) and accompanying water-level changes in the same wells, reflecting changes in reservoir pressure.
b) Results of previous assessments of the capacity of the Oradea geothermal system (see subchapter 5.3 above.
c) Estimated capacity of existing wells (3 wells).
d) The potential benefit of reinjection.
e) Other relevant information provided by Transgex.

Based on the data under a) above lumped parameter models (see sub-chapter X.2 above) were set up for the geothermal system and future reservoir pressure predictions calculated for different utilization scenarios. It should be pointed out that the specific well data were actually classified and only available in a particular office space at the Oradea Town Hall. The necessary data preparation and the following modelling and predictions were performed at that restricted location, during a working-session in January 2017. Therefore, neither the well-data nor the details of the modelling or predictions will be presented here. The overall, general results will be summarized below and used in subsequent chapters.

Fairly detailed production data were available for the two Beius production wells since 2006 and 2011, respectively, with details increasing as the present was approached. Water-level data from the two wells, made available for this study, only extended back to 2011.

This, however, is sufficient for accurate lumped parameter model simulations and predictions, as the Beius production history is relatively short and the pre-utilization conditions are well known (around 1999, see Axelsson et al., 2000). The 5-year water level history (made available for this study, should be 17 years) for each production well indicates no long-term pressure (water-level) changes in the geothermal reservoir. Pressure data collected during the 1999 testing of well F-3001 supports this even further, in quite a conclusive manner. Available chemical data suggests, furthermore, that general reservoir conditions haven't changed during the 17-year utilization history of the Beius geothermal system.

Another highly relevant aspect is the fact that quite limited interference is seen between the two production wells. Specifically, very little additional water-level draw-down is seen in well F-3001 when well F-3003 first starts producing. This may be caused by one of the faults separating the Beius reservoir into blocks, which actually separates the two wells (see Figure 7). It may also be pointed out that no clear pressure response signal is seen when the reinjection into well F-3004 starts in late 2012; this probably reflects the low reinjection flow-rate applied. This information clearly indicates, particularly because of the very long production history, that the Beius geothermal system is an open system (see classification above). This is supported by the lumped parameter modelling of the pressure changes in recent years.

In the present study future reservoir pressure predictions were calculated with the lumped parameter models of the Beius geothermal system for two future production scenarios, with the apparent open nature as a constraint. The first scenario assumes a 50% increase in average production from 2015, or 42 L/s average yearly production. The second scenario assumes a 100% increase, corresponding to 56 L/s annual average production. Both scenarios assume a 50-year utilization period, from the present, and also annual variations in production comparable to annual variations in recent years.

The results of the predictions indicate clearly that the Beius geothermal reservoir can sustain can sustain the utilization according to both scenarios. This is because the predicted reservoir pressure changes are not too great (< 5 – 10 bar) and the production can be maintained with down-hole pumps placed at reasonable depth (above 200 m depth). This is further supported by the fact that both these scenarios are well within the results of the capacity assessment of Axelsson et al. (2000). The results of that assessment are, furthermore, still considered generally valid.

The two production wells in Beius can't support an increase as foreseen here, so drilling of further production wells will be required. There should be ample space for this from the viewpoint of the resource size, even though finding space within a densely populated area can sometimes be difficult. For a 50% increase in production a third production well will be needed. Locating that well, or defining its drilling target, is beyond the scope of the present study, but Transgex has already proposed a drilling site and target. For a 100% increase in production 2-3 new production wells will be needed. The production characteristics of individual wells in Beius were studied in some detail during the present study, but the detailed result can't be presented here because of the classified nature of the relevant data. The results indicate that Well F-3001 had the smallest turbulence pressure losses and well F-3004 the greatest.

Based on the above results, our main recommendation regarding future geothermal utilization in Beius, is that the utilization be increased in steps. First by about 50% and later (after a few years) by another 50% (100% in all). This involves a cautious approach, necessary because of uncertainties in the predictions and the limited data access. A clear benefit from a stepwise approach is that by monitoring carefully the response of wells and the geothermal reservoir to the production increase, associated with the first step, the response to a further increase can be predicted much more accurately than now.

Consequently, the utilization may certainly be increased even further. It should be noted that increased utilization may require an expansion of the utilization license applicable for the Beius district heating system.

In view of the foreseeable increase in geothermal production in Beius, plans should be made for increased reinjection in the future. The one existing reinjection well (F-3004) should suffice for the next several years, but using it at greater capacity through pumping should be tested thoroughly. At a later stage, when utilization has been increased further, the drilling of an additional reinjection well should be considered. Reinjection will play a multiple role:

- Environmental protection, such as through reducing thermal and chemical pollution.
- Pressure support that will counteract increased pressure draw-down due to increased production (see also Axelsson et al., 2000).
- Minimizing interference in adjacent reservoir blocks, if plans for utilizing geothermal resources in those materialize.

Injection well F-3004 needs to be tested further before long-term reinjection into the well at a higher flow-rate than now is planned. This would involve both testing it at higher injection rates (an pressure) but also tracer testing to study its connection to the production wells and the associated cooling danger (see above). It may also be pointed out that acidizing of the reinjection well may be an appropriate tool to improve the well’s injectivity. It should be mentioned here that geothermal resources in The Beius area are not restricted to the Triassic limestone reservoir currently being utilized. Some additional geothermal resources are e.g. believed to exist in sandstone layers at shallower level (encountered at 650 m depth in well F-3004, 45 L/s short-term artesian flow), with lower resource temperature (35 – 40°C). They can perhaps be utilized for direct applications based on lower temperature than ideal for space-heating, e.g. for fish-farming, agricultural uses as well as spas and swimming pools.

Sustainable geothermal utilization has been defined as specific utilization of a geothermal resource that can be maintained for 100 – 300 years (Axelsson, 2010 and 2016b). The Beius geothermal resources have now been utilized for 17 years, without noticeable changes in reservoir conditions. This may be interpreted as indicating that the Beius resources can be utilized at the present rate of utilization in a sustainable manner. The 50% increase in utilization, proposed as a first step here, can likely also be managed in a sustainable manner, but the possibility of continuing that for 100 years or more needs to be confirmed through accurate modelling of the geothermal system (see, however, recommendations on modelling in subchapter 5.6 below). It should also be pointed out that sustainable development also needs to incorporate economic, environmental and social issues (Axelsson, 2016b).

5.6 Recommendations

1. Geothermal utilization in Beius should be increased in steps, the first one of the order of 50%.
2. Monitoring of production, water-level (or well-head pressure if a well is artesian), temperature and chemical content must be comprehensive and accurate. Will provide basis for future increase in utilization.
3. Simple models, such as lumped parameter models, and perhaps Theis models, should be set up to simulate and predict reservoir pressure changes in the Beius system.
4. A detailed numerical modelling can be set up for the Beius geothermal system and neighbouring reservoir blocks, in due time, with which more accurate future predictions can be calculated. This isn’t urgent at the present time, as only a few wells are available at present.
5. Reinjection should be increased hand-in-hand with increased utilization and pressure draw-down.
6. Increased reinjection should be accompanied with extensive reinjection research, in particular tracer testing, which can be used to evaluate the cooling danger for specific production wells.
7. Lessons learned in Beius, both in the past and associated with future increase in production, will have great relevance for other geothermal resources in Romania, as well as in neighbouring regions.

6. Current Status of GeoDH system in Beius

The focus of this chapter is to give an overview of the existing Geothermal District Heating (GeoDH) system comprising two production wells, one reinjection well, heat transfer stations and district heating network. All data in this chapter is based on the information from the local operator, Transgex S.A. and the city authorities.

6.1 Existing wells

There are already two geothermal production wells, 3001 and 3003 which feed the GeoDH in Beius and one re-injection well, 3004.

Production wells are equipped with deep well line shaft pumps. The well water temperature is different in these two production wells due to the different depth at which they intersect the geothermal aquifer. Thus, in well 3001 the temperature is 80°C at the well head and it is 72°C in 3003. In total, the geothermal energy production was 153 TJ (36,5 Tcal) in 2016.

The location of all three geothermal wells is shown in Beius on Figure 10, all within the city limit.

Figure 10. *Location of the existing wells in Beius*

6.1.1 Capacity of wells used

The pumps in both production wells are capable to deliver 65 l/s. The well 3003 cannot sustain its installed pump capacity of 65 l/s flow rate due to sand carry-over, its maximum flow rate being only around 50-55 l/s without carry-over. During summer, usually only well pump in 3001 is operated.

The re-injection well 3004 is connected to a pump station with installed capacity of 10 bar_g and 15-20 l/s. The pumping unit comprises 5+1 pumps. The purpose of the re-injection well is to deliver partly the used geothermal water back into the reservoir to support the reservoir pressure. Currently, spent geothermal water is re-injected only gravitationally at a rate around 3 l/s, while the rest is led to the river. At current utilisation, the reservoir pressure has been stable and does not need a pressure support from the re-injection system.

6.2 Existing GeoDH system

6.2.1 Distribution network

The geothermal heat energy is delivered to the consumers either indirectly via substations with heat exchangers feeding double closed loop distribution pipe networks, one for Domestic Heating (DH) and the other for Hot Sanitary Water (HSW), or directly to the individual buildings with their own heat exchangers. The biggest individual closed loop distribution systems are old, remains from the time when the central part of the city was heated by three oil fired heat stations. Additionally, around 35 modern compact micro modular substations have been installed. The layout of the main district heating pipe system in the city is shown on street map in Figure 11.

Figure 11. *Map of the GeoDH pipeline system in Beius*

6.2.2 Thermal substations

There are 38 thermal substations in Beius. Three of them are big (the old oil-fired heating stations with old distribution networks):

- PT3 (18 block houses),
- PT4 (10 block houses),
- PT5 (2x4 block houses).

These thermal substations are without automation, hence manually operated. Most of the other 35 substations are compact micro substations, typically each serving 1-3 block houses. Not all the substations have automatic control, several stations are still manually controlled. 22 substations out of 38 are equipped with metering system, flow and thermometers. All flats in block houses, industrial and public buildings have energy meters and are charged per energy consumed. Most of the single houses are connected directly with a single pipeline to the geothermal distribution pipelines and are accordingly charged per volume consumed. The price/m³ varies depending on were from it comes due to different water temperature from the two production wells 3001 and 3003.

The GeoDH substation system is schematized in Figure 12.

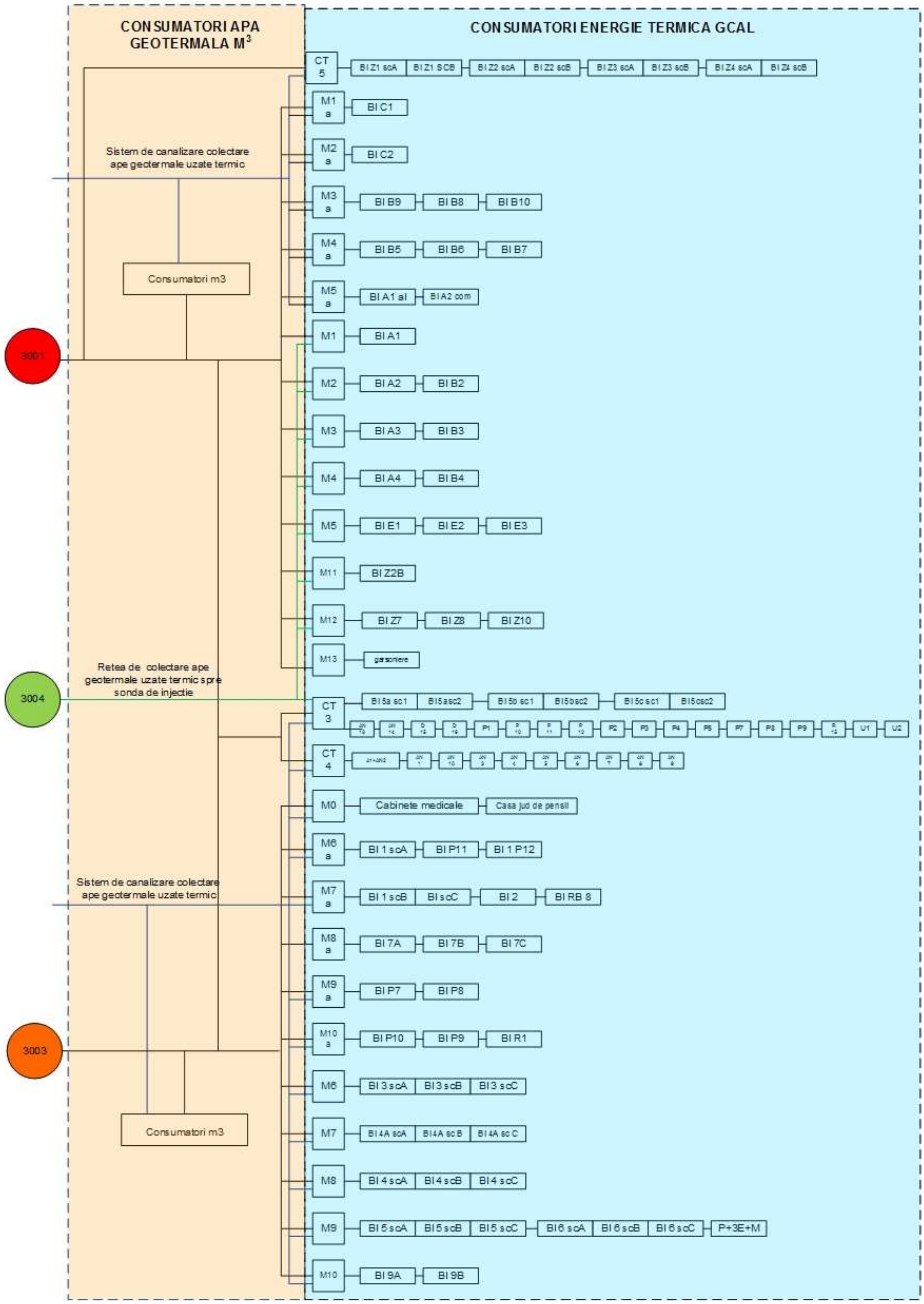


Figure 12. *Schematic diagram of Beius GeoDH substations and the main distribution pipelines*

6.2.3 Geothermal District Heating (GeoDH) system

Today the GeoDH system in Beius supplies heat to about 70 % of the population, covering around 60% of the city heating demand. All major public buildings are geothermally heated. The GeoDH network is connected to 1.415 flats in 81 block houses, 5 churches, 10 public institutions, 5 schools, 2 hospitals and approximately 3.400 individual homes. Only one block house, some 10 industrial and commercial buildings and approximately 733 single houses remain not yet connected to the GeoDH system.

The supply of geothermal heat to the GeoDH system in 2016, measured at the end users, is summarised in Table 3.

Year	Production well	Energy delivered 2016		Volume delivered	2016 production/ well	2016 production/ well	2016 average / well
Beius Geothermal		[GJ/year]	[m3/year] calculated	[m3/year]	[m3]	[GJ/year]	[l/s]
2016	3001	49 591	305 144	338 038	643 182	104 529	20,4
	3003	24 861	202 713	193 084	395 797	48 541	12,6
TOTAL		74 452	507 857	531 122	1 038 979	153 070	32,9

Table 3. *Operational parameters of the GeoDH system in 2016*

Error! Reference source not found. summarizes the production capacity of existing pumps in both production wells 3001 and 3003 as well as their utilization in the year 2016, based on energy and volume delivered to the GeoDH consumers, see table 3. The calculation of energy delivered by the geothermal water assumes its cooling at the consumers down to 40°C, stipulated by ANRM, National Agency for Mineral Resources, which manages resources of hydrocarbons and mineral resources as public property, defined by Law no. 85/2003, and Law no. 238/2004.

Well	Temp. [°C]	Well pump capacity [l/s]	Well Capacity [MW_{th}]	Well Capacity [TJ/year]	2016 Average Utilisation [l/s]	2016 Production [TJ/year]	2016 Capacity Utilisation %
3001	80	65	10,6	333	20,4	105	31
3003	70	55	6,7	211	12,6	49	23
Total	-	120	17,3	545	32,9	153	

Table 4. *Current available geothermal production capacity-base case*

Error! Reference source not found. depicts the calculated monthly GeoDH heat demand based on annual average monthly ambient temperature, inclusive both demand for DH and HTW. This calculation is used as a reference base case for evaluated extension scenarios in Chapter 7. The average annual heat load in Beius requires an annual peak load utilization ratio of around 30 %.

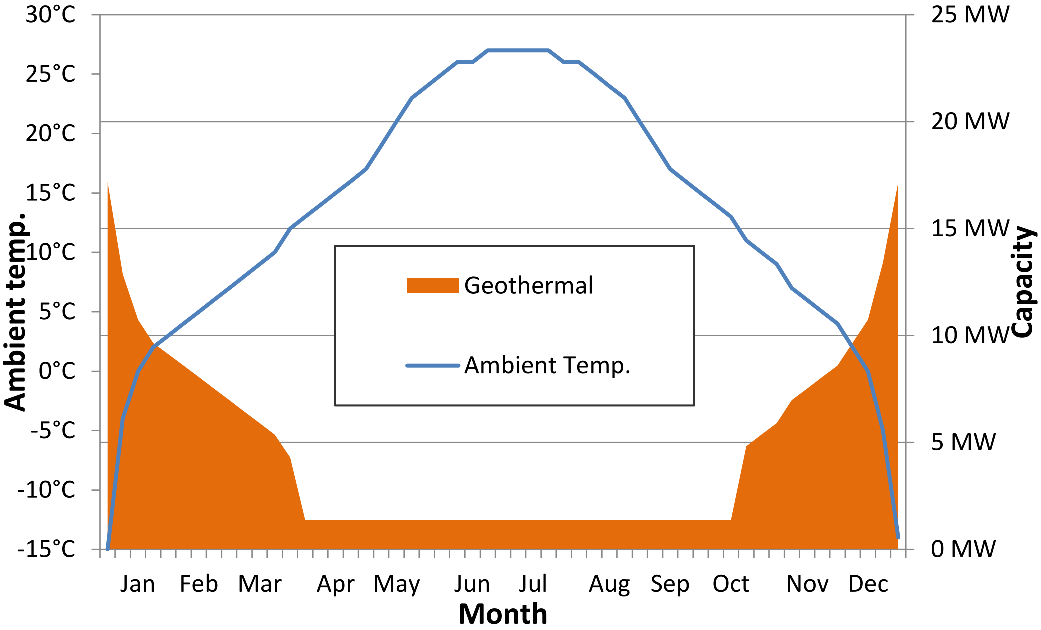


Figure 13. Monthly *GeoDH heat demand MW_{th} based on ambient temperature*

6.3 Cascaded use of geothermal energy

The developing of the geothermal GeoDH system in Beius started in the year 2000. Until today all available funds have been used for the expansion of the system. No other direct and/or cascaded use of the geothermal water has been developed so far, except possible in some single houses which receive the geothermal water directly. The potential for cascaded use, to name a few such as swimming pools, Spas, greenhouses etc., is of considerable potential since more than 40% of the spent geothermal water is available centrally at a temperature around 40°C. An interesting prospect for the nearest future to develop.

6.4 Extension of the GeoDH system

There are no known administrative or resource based barriers, see Chapter 5, for further extension of the GeoDH system in Beius. At present the combined capacity of the deep well pumps in both production wells cannot sustain further increase of the GeoDH system. During the cold spell in January / February this year, its capacity was not enough during peak demand of the system. Connection of new consumers to the system has been put on hold until its geothermal production capacity has been increased.

Due to recent increase in the wood prices for heating, see Chapter 8, there has been an increasing interest by single house owners, not yet connected to the GeoDH system, to be connected.

The population in Beius not yet connected to the geothermal district heating system have been identified and listed in Table 5, as well as their estimated heat demand, annual fuel consumption and corresponding annual CO_2 emission. There is only one block house left, some 10 industrial and commercial buildings and approximately 733 single houses remaining not yet connected to the GeoDH system. There is no central gas supply system in the city. Some single houses use gas for heating of hot sanitary water (HSW) but major heat source for HSW and domestic heating (DH) is wood burning. Their estimated annual heat demand is 93 TJ/year to be compared to 153 TJ/year consumption of geothermal heat delivered (measured at consumers) in 2016 in existing GeoDH system. For the existing GeoDH system to serve those not yet connected it needs to increase its annual production by 60 %.

Houses not yet connected to GeoDH Heated with wood	Annual heat demand TJ/year	Annual wood consumption m3/year (wood)	Annual CO_2 emission t CO_2/year
733 single houses	72,6	7 559	7 982
One block house with 12 apartments	0,8	81	86
10 Warehouses and institutions	19,2	2 000	2 112
Total	92,5	9 640	10 621

Table 5. *Estimated heat demand for potential new GeoDH consumers*

The streets not yet with GeoDH distribution pipelines are marked with red lines and those without are with purple lines in **Error! Reference source not found.**.

Figure 14. *Layout of the current GeoDH main distribution pipe system in Beius*

7. Extension of the GeoDH system

This chapter explores the improvement and extension possibilities of the geothermal district heating system, GeoDH, in Beius, with the ultimate objective to supply all buildings in the city with geothermal heating. In Chapter 6.4 we were informed that the annual load on the geothermal reservoir must increase around 60% compared to the current load to feed all buildings in Beius. Since the potential of the geothermal reservoir is very likely greater than the heating demand in the city, see results of reservoir assessment in Chapter 5.5, the economics of further extension of the GeoDH system to nearby communities should be evaluated as well, in detail being out of scope of this study. In evaluation of Beius geothermal reservoir the ANRM team, Bradu et al. (2017), estimates its potential within the range of 100 – 300 l/s, with three production wells.

Following extension alternatives evaluate stepwise increase in the geothermal production capacity and operation reliability, with the objective to connect the GeoDH system to all buildings in the city.

Scenario 1	Increase production capacity of well 3001 in order to fulfil peak demand of existing GeoDH system and possible some new consumers to be connected;
Scenario 2	Drill a new production well 3005 in order to fulfil the need of all buildings in Beius city. In case of excess capacity connection to nearby villages is considered.

In addition to above referred extension scenarios, necessary actions to improve the efficiency of the GeoDH system, its reliability and peak capacity will be identified. These comprises the installation of an accumulator on top of a hill etc.

7.1 Scenario 1 – Increase production capacity in existing well

The production capacity of well 3003 is limited to 55 l/s due to sand carry-over from the well formations. This scenario assumes that the pumping capacity of well 3001 will be increased from 65 l/s to around 85 l/s by installing in it a higher capacity well pump. The water temperature from the well is assumed to stay intact at 80°C.

shows the monthly GeoDH heat demand in MW_{th} based on ambient temperature. The distribution of the heating capacity is shown on Figure 15 namely the geothermal production capacity is higher than in the base case. The ambient temperature curve is same but the heat production duration curve has been modified accordingly.

Well	Temp. [°C]	Well pump capacity [l/s]	Well Capacity [MW_{th}]	Well Capacity [TJ/year]	2016 Average Utilisation [l/s]	2016 Production [TJ/year]	2016 Capacity Utilisation %
3001	80	85	13,8	436	26,7	137	31
3003	70	55	6,7	211	12,6	49	23
Total Scenario 1		140	20,5	647	39,2	185	

Table 6. Scenario 1 - *Geothermal production capacity based on base case well capacity %-utilization*

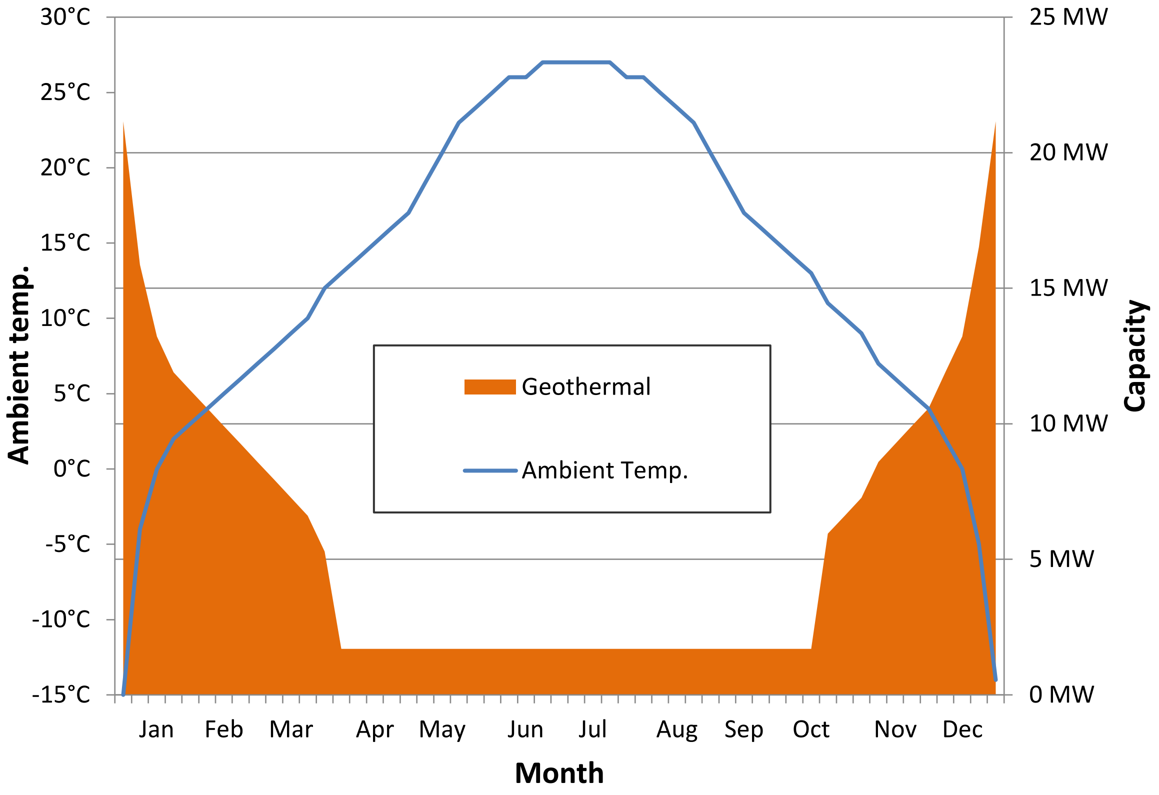


Figure 15. *Scenario 1* - Monthly *GeoDH heat demand MW$_{th}$ based on ambient temperature*

The estimated total annual production is now around 185 TJ/year (44 Tcal/year) being 21% higher than in the base case, see Chapter 6.4. This additional annual energy of 31 TJ/year is capable of heating around 300 single houses and the only remaining block house in the city.

Error! Reference source not found. shows the further benefit of the extended utilization of the g eothermal energy i.e. the reduction of the CO_2 in the city, hence improved air quality. It replaces existing wood heating which has very high CO_2 emission, being worse than for example gas based heating. Geothermal heating has the lowest CO_2 emission possible, coming only indirectly from electricity, if produced by fossil fuels, used for operation of its pumps.

Buildings connected to GeoDH replacing wood heating	Annual heat demand TJ/year	Reduction of CO_2 t CO_2 / year
Single houses (~300)	29,7	3 267
Block of house with 12 apt.	0,8	86
Annual Total	30,5	3 353

Table 7. *Estimated CO2 reduction in Scenario 1*

7.2 Scenario 2 - Expansion of the GeoDH by drilling additional production well

The results of the assessment of the capacity of Beius reservoir, see Chapter 5.5, a cautious step wise load increase is recommended, the first step being around 50 %. In Chapter 6.4 it is estimated that the annual heat demand of those buildings not yet connected to the GeoDH system is 93 TJ/year, which corresponds approximately to 60% increase compared to current load on the geothermal reservoir. In this scenario, a new well, well 3005, is drilled and connected to the existing district heating system. Figure 16 represents monthly heat demand in MW$_{th}$ based on annual ambient temperature. The predicted capacity of the new well is 65 l/s with a temperature of 80°C. Estimated production capacities of all three production wells is summarized in Table 8.

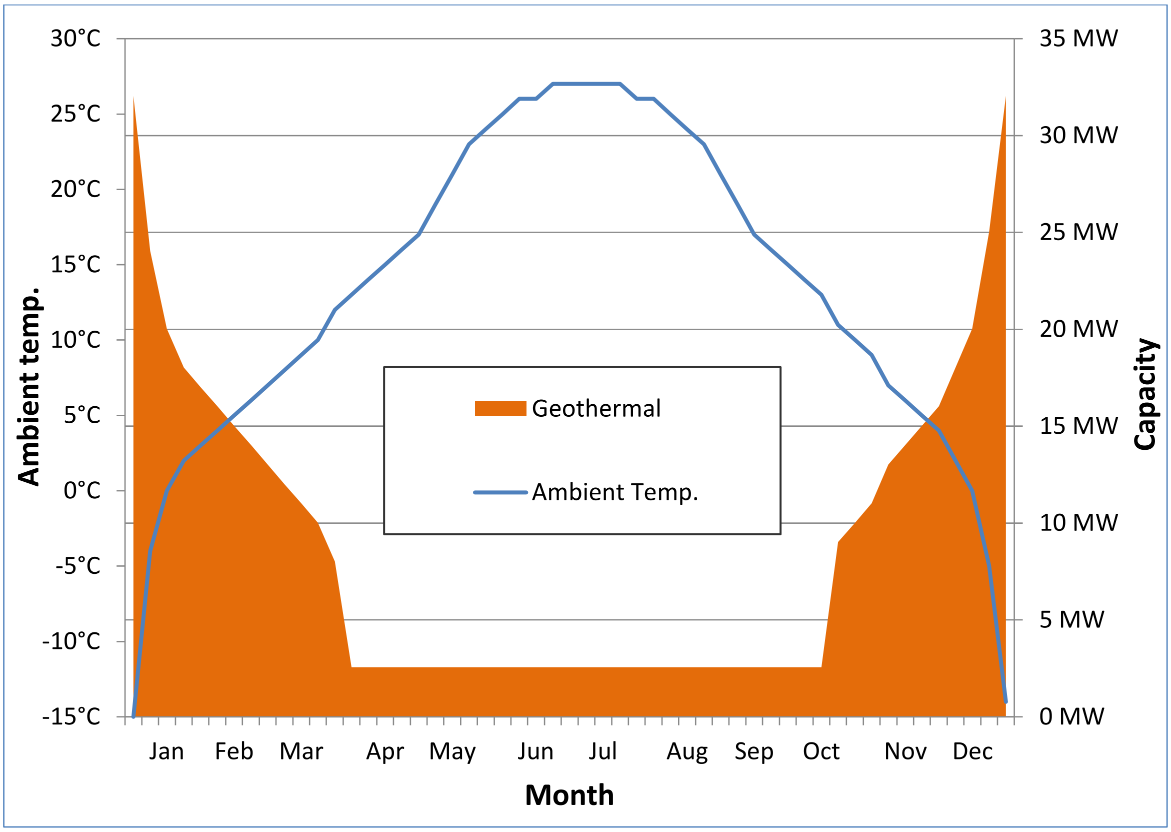


Figure 16. *Scenario 2* - Monthly *GeoDH heat demand MW$_{th}$ based on ambient temperature*

Well	Temp. [°C]	Well pump capacity [l/s]	Well Capacity [MW$_{th}$]	Well Capacity [TJ/year]	2016 Average Utilisation [l/s]	2016 Production [TJ/year]	2016 Capacity Utilisation %
3001	80	85	13,8	436	26,7	137	31
3003	70	55	6,7	211	12,6	49	23
3005	80	65	10,6	333	20,4	79	31
Total Scenario 1		205	31,1	980	59,6	264	

Table 8. Scenario 2 - *Geothermal production capacity based on base case well capacity %-utilization*

The estimated total annual production is now around 264 TJ/year being 72% higher than in the base case, see Chapter 6.4. This additional annual energy of 111 TJ/year can heat all the houses not yet connected to the GeoDH system in Beius, see Table 8. In Chapter 6.4 their annual heat demand was estimated to be around 93 TJ/year, with a peak demand around 31 MW$_{th.}$

Error! Reference source not found. shows the further benefit of the extended utilization of the g eothermal energy i.e. the reduction of CO_2 emission in the city by around 10 kt CO_2 / year, leading to a major improvement in Beius city air quality.

Buildings connected to GeoDH replacing wood heating	Annual heat demand TJ/year	Reduction of CO_2 t CO_2 / year
Single houses (733)	72,6	7 982
Block of house with 12 apt.	0,8	86
Warehouses (10)	19,2	2 112
Annual Total	92,5	10 179

Table 9. *Estimated CO2 reduction in Scenario 2*

The potential location of the new well 3005 is shown in Figure 17.

Figure 17. *Proposed location of the new production well 3005 and its supply pipeline*

The selected route of the main distribution pipeline from well 3005 to be connected to the existing GeoDH system is highlighted in red color. The estimated length of the new pipeline is 1.980 meters.

In this scenario, the Beius GeoDH system has approximately 18 TJ/year over capacity which can be used to deliver heat energy to nearby villages. This annual capacity can fulfil the heating needs of around 180 single houses. All potential villages around Beius are listed in Table 10, with distances from Beius centre and population numbers.

Distance between Beius and surrounding villages		Population
Beius – Delani:	3 km	369
Beius – Draganesti:	5 km	2 800
Beius – Curatele:	7 km	2 700
Beius – Pocola:	6 km	1 600
Beius – Budureasa:	12 km	2 600
Beius – Finis:	4 km	3 600
Beius – Tarcaia:	5 km	2 100
Beius – Remetea:	9 km	3 100

Table 10. Villages around Beius city

The surrounding villages listed in Table 10 are located on the map in Figure 188, with proposed connection pipe routes

Figure 18. *Surrounding towns around Beius*

7.3 GeoDH system improvements

One option to increase system reliability of the GeoDH system and peak load capacity is to install a thermal energy storage tank, an accumulator, connected to the main geothermal distribution pipeline. The main advantages of the accumulator for the district heating system are the following:

- Increasing short-time capacity of the heating system
- Increasing system reliability by providing reserve capacity in case of power outage (the well pumps idle) or well pump failure at peak demand conditions
- Facilitating smoother operation of the well pumps by overtaking GeoDH system daily load variations.

Proposed location of the accumulator is on top of the hill close to proposed location of the new production well 3005, shown in Figure 19.

Figure 19. *Potential location of the storage tank*

It is foreseen that the pump in well 3005 will deliver the water up to the accumulator were from it will flow gravitationally into the GeoDH main distribution pipeline in the city, elevation difference being around 30-35 metres. The proposed accumulator's volume is 500 m^3. In case of power outage, this size of accumulator can feed the district heating system with for example 65 l/s (8,7 MW_{th}) for 2 hours or 20 l/s for 7 hours.

Other urgent projects needed to improve the efficiency of the district heating system in Beius city have been identified. These projects are not evaluated further in this pre-feasibility study, some of them being already in progress.

- Improve insulation in the block houses; one project is ongoing funded 50% (5 m€) by an EU fund, 25% by the municipality and 25% by flat owners;
- Improve insulation in single houses, optimise element sizes and heating control equipment (more than 50% of the houses have manual on/off control). In this study, according to ANRM practice, it is assumed that houses using geothermal water cool it down on average to 40 °C. This is very low efficiency based on old houses with poor insulation and heating installations. With modern technology cooling down to 30 °C is easily accomplished, hence reducing the heating cost (consumption) by 25 -30%.
- An investigation regarding abandoning the three central heat exchanger stations, PT-3, PT-4 and PT-5, is needed, due to their poor efficiency and bad condition. The alternative instead is to connect each flat directly to the geothermal supply network like the connection of the individual houses.

7.4 Conclusion

The Directive 2009/28/EC of the European Parliament and of the Council specify clear target for the EU members for 2020. Target for share of energy from renewable sources in gross is 24%. The utilization of the geothermal energy can support the country to reach this target. Romania signed the Paris Agreement on 22nd April 2016 not yet being ratified. Its main target being reduction of greenhouse gas (GHG) emissions.

The use of low temperature geothermal energy in Beius has very limited CO_2 equivalent emission, coming indirectly mainly from the production of the electricity used for its pump operations, in case it is produced by burning fossil fuel. Limited amount of GHG follow the geothermal water and leave it during utilisation.

It must only be a question of short time for Beius city to reach its goal of being 100% heated with geothermal water from its geothermal reservoir underneath its grounds. When accomplished, the local air pollution from district heating will come to an end in the city with enormous improvement in air quality, especially during the heating season. In next chapter, the economics of district heating will be evaluated.

Estimated annual heat consumption in Beius is 246 TJ/year which corresponds to annual burning of wood around 25,600 [m^3/year], emitting 27,000 [t CO_2/year].

8. District Heating Costs

This pre-feasibility study does not have access to the economic data of the company operating the GeoDH system in Beius. The city council has contracted SC Transgex S.A., which holds the local geothermal utilisation licence, to operate and expand the GeoDH system. The tariffs for the delivery of central geothermal district heating in Beius is regulated by the state authorities reflecting the real cost of its operation. Therefore, the only realistic way to evaluate the economic advantages of the GeoDH operation, is to look at it from the consumer perspective and compare it with the cost and user friendliness of other heating alternatives, being mainly wood burning in Beius.

8.1 State Regulated District Heating Tariffs in Beius

The geothermal energy is delivered and consequently charged in two different ways at the Beius consumers.

Those who receive the heat from a secondary distribution loop from a substation are charged per used energy, which is metered in Gcal.

Those who receive the heat directly from the GeoDH system are charged per used amount of geothermal water metered in m^3. The existing two production wells, 3001 and 3002, have different water temperature, hence two different prices/m^3, depending on wherefrom the geothermal water comes, see Table 11.

Selling prices for the GeoDH system are regulated by the state organization, National Authority of Regulatory for Community Services (NARCS), according to the Romanian law no. 325/2006.

Secondary deliv. PT-substations	Price
Energy metering	RON/Gcal
Production	40.92
Transport	19.79
Distribution	19.57
Total w/ 19% VAT	**95.53**
€/Gcal incl. VAT	21.00
€/GJ incl. VAT	5.01

Direct delivery to houses	Price	Price w/ 19% VAT	Price w/ 19% VAT	Utilisation	Energy content
Volume metering	RON/m3	€/m3	€/GJ	DT [°C]	MJ/m3
From Well 3001	3.30	0.86	5.31	80-40	163
From Well 3003	2.75	0.72	5.86	70-40	123
	NARCS-price regulation 2017				
Exchange rate RON/€ = 4.55			Based on information from Transgex/ANRM		

Table 11. *GeoDH consumer heat tariffs for Beius in 2017*

Attention should be given to the apparent difference in energy prices for those consumers who are directly connected to the GeoDH depending on from which production well they receive the geothermal water. In this pre-feasibility study conversion of energy consumption data measured at consumers by the system operator, Transgex, are based on ANRM guidelines (information submitted by Transgex), namely consumers are assumed to cool the geothermal water to 40°C. As pointed out in Chapter 7.3 consumers which improve their house heating installation and cool the geothermal water to 30°C as an example, instead of 40°C, as the tariffs are based on, will reduce their heating cost by 25-30%.

8.2 Estimated investment cost for increased production capacity

The estimated investment cost for both Scenarios in Chapter 7 is given in Table 12.

Item	[kEUR]
Well 3001- bigger Well Pump, electricity and control system	250
Drilling of well 3005 - 2800 m, 13 3/8" production casing	3 000
Well 3005 – Well Pump, house, electricity and control	450
Main Pipeline into city from 3005 - 2000 m	300
Accumulator 500 m^3	500
TOTAL INVESTMENT w/o VAT	4 500

Table 12. Investment *Cost – summary*

The estimated cost comprises a new and bigger line shaft pump for well 3001, the drilling cost of a new production well (3005) with well pump, all necessary auxiliaries, storage tank up on the hill and the pipeline connecting well 3005 to the geothermal distribution system in the city. The estimated length of the new pipeline is approximately 2,000 meters, size DN250.

The investment cost for expansion of the distribution system in the city is not accounted for in this report as well as the connection and house installation costs for the individual new consumers. The GeoDH company is supposed to covers reasonable portion of the distribution system cost by consumer connection fees charged.

8.3 Consumer Heating Costs

Majority of single house owners in Beius which are not yet connected to the GeoDH, as earlier stated, burn wood for heating. Estimated annual heating cost for them is summarized in Table 14. The interest of these house owners has increased a lot lately to be connected to GeoDH system due to the rapid increase in the price for wood. On average, a single domestic house consumes 10-15 m^3 of wood during the heating season, which typically lasts between 15th October and 15th April. However, houses with modern insulation need less. For hot sanitary water, house owners use mostly wood, some use gas, even electricity and solar energy by few. Development of market prices for wood for house heating over the last five years in the area is shown in Table 13.

Year	2013	2014	2015	2016	2017
€/m^3	26	33	33	38	63

Table 13. *Market price escalation for m^3 of wood in Beius*

Houses not yet connected to GeoDH Heated with wood	Annual heat demand GJ/year	Annual wood consumption m3/year	Annual heating cost €/year
Single house - 110 m2	99	10.3	650
Block house - one apartment 90 m2	65	6.8	425
Warehouse - 1939 m2	1,920	200.0	12,597

Table 14. Estimated annual heating cost for those using wood burning

If these houses were direct-connected to the GeoDH system their estimated annual heating cost is summarized in Table 15, based on the heating tariffs presented in Table 11 in Chapter 0.

Houses not yet connected to GeoDH Heated with direct geothermal	Annual heat demand GJ/year	Annual water consumption m3/year - (DT=40°C)	Annual heating cost €/year
Single house - 110 m2	99	609	442
Block house - one apartment 90 m2	65	399	289
Warehouse - 1939 m2	1,920	11,812	8,563

Table 15. Estimated annual heating cost for GeoDH direct connected consumers (DT=40°C)

These calculations of estimated annual heating cost before and after these houses have been connected to the GeoDH in Beius, see Table 14 and Table 15, demonstrates that the GeoDH is around 30% cheaper than wood burning for house heating (DT=40°C).

Houses not yet connected to GeoDH Heated with direct geothermal	Annual heat demand GJ/year	Annual water consumption m3/year - (DT=50°C)	Annual heating cost €/year
Single house - 110 m2	99	487	353
Block house - one apartment 90 m2	65	532	385
Warehouse - 1939 m2	1920	15,749	11,418

Table 166. Estimated annual heating cost for GeoDH direct connected consumers (DT=50°C)

Calculation of estimated annual heating cost for those houses with modern heating system and house insulation capable of cooling the geothermal water by 50°C will manage to lower their heating cost close to 50%, compared to wood heating, see Table 16.

8.4 Economic Conclusion

With current market prices for wood for heating and GeoDH state regulated heating tariffs the citizens of Beius enjoy between 30% - 50% reduction in annual heating cost, when connected to the GeoDH system, a tremendous advantage for the citizens in addition to better air quality, clean, safer and almost zero manpower operation of their house heating.

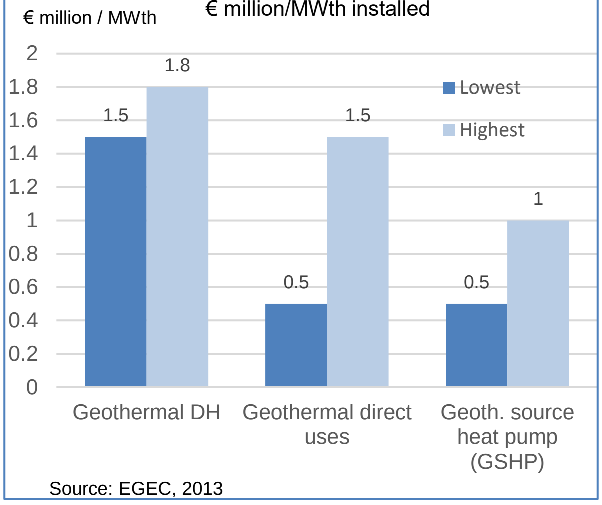
9. Geothermal District Heating in Europe

9.1 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).

Fig. 9.1.1. **Capital Cost of Geothermal Heating**

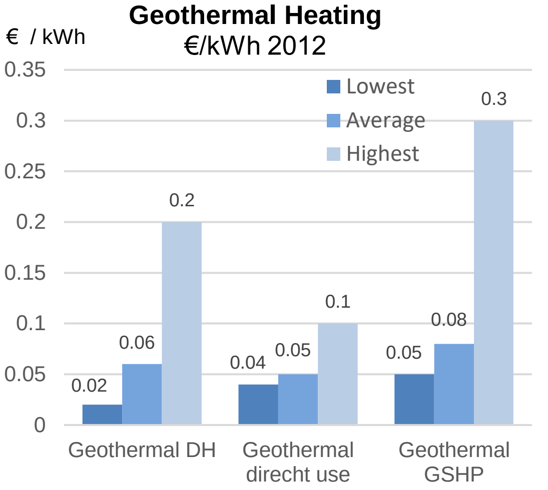
€ million/MWth installed



Source: EGEC, 2013

Fig. 9.1.2. **Levelised Cost of Geothermal Heating**

€/kWh 2012



Source: 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.

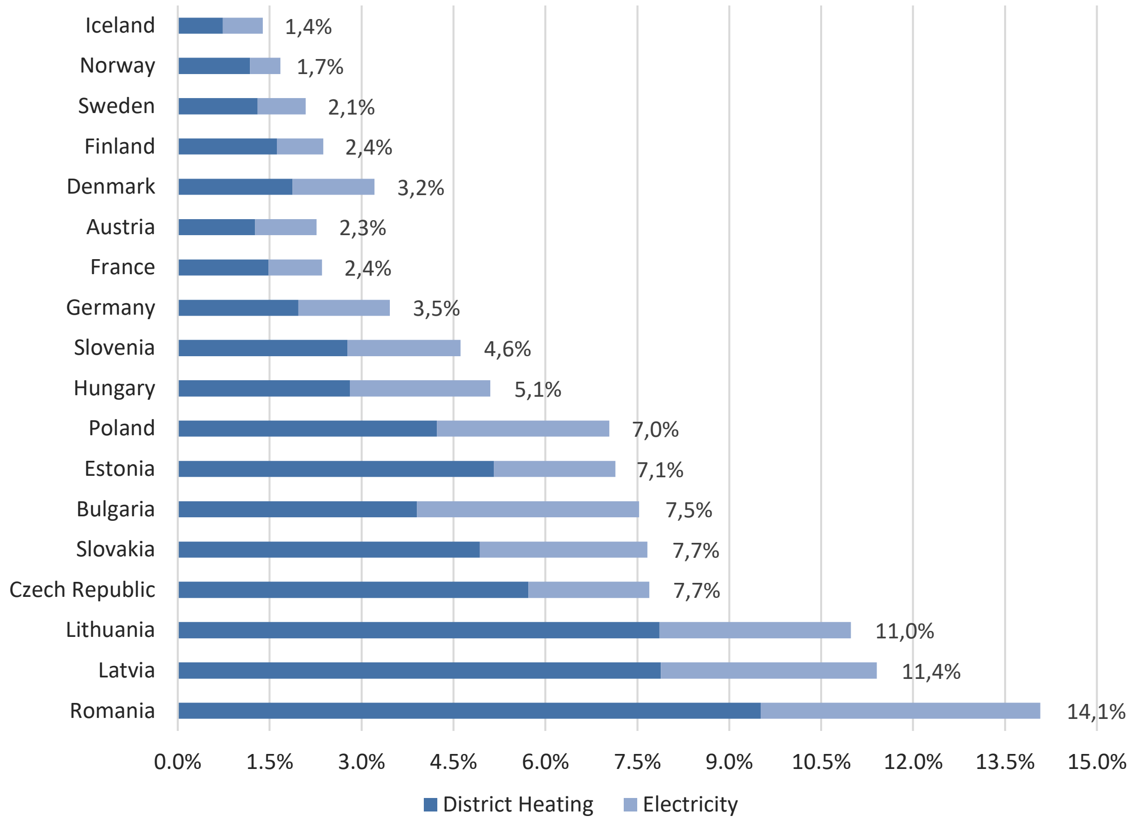
In many cases, geothermal district heating projects face the same issues as geothermal power plants, the need of capital and risk mitigation is therefore also valid for this technology. Moreover, notably because of the drilling, geothermal heat pumps can also be considered as a capital intensive technology 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. 9.1.3 **The Proportion of Annual's Salaries of people for buying District Heating and Electricity for 100m^2 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 € 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.

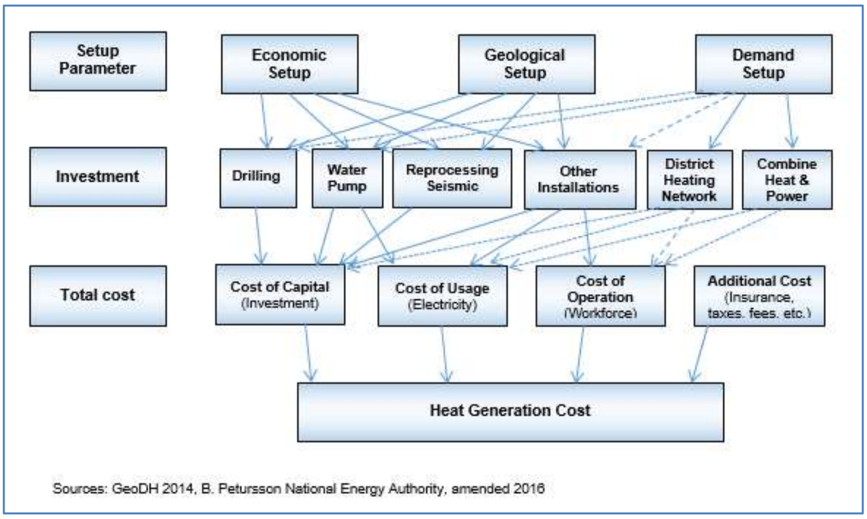
It is difficult or impossible to present standard costs of geothermal district heating projects, as the cost vary between regions and variable conditions. Nevertheless, the costs of such a project can be estimated, based on the most important parameters for the understanding of the individual projects,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

Figure 9.1.4. **Cost Structure of Geothermal Heat Generation Project**



Sources: GeoDH 2014, B. Petursson National Energy Authority, amended 2016

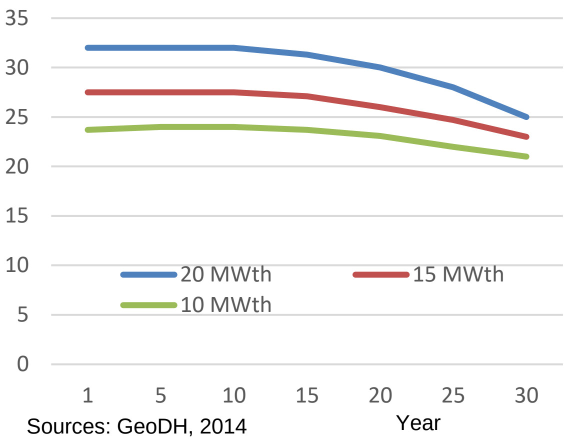
Although it is difficult to estimate the profitability of such projects, the cost for each project can be based on the demand structure, the geological conditions, the costs of capital and the existing geological data, as is shown in figure, 9.1.4. The demand aspect plays an important role in defining 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 9.1.5.[2]

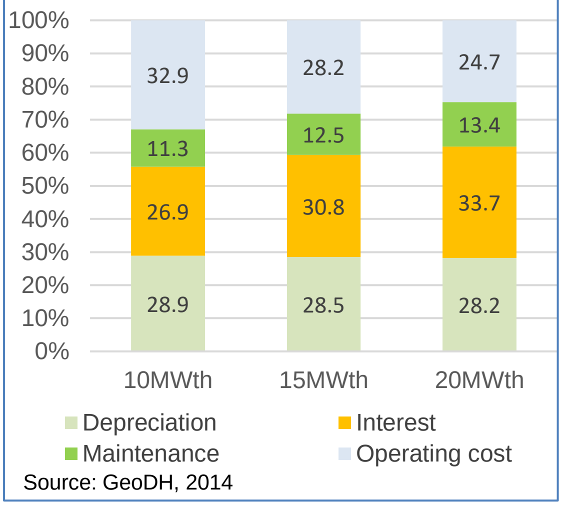
Fig. 9.1.5. **Heat Generation Cost of three Different Plants**



Sources: GeoDH, 2014

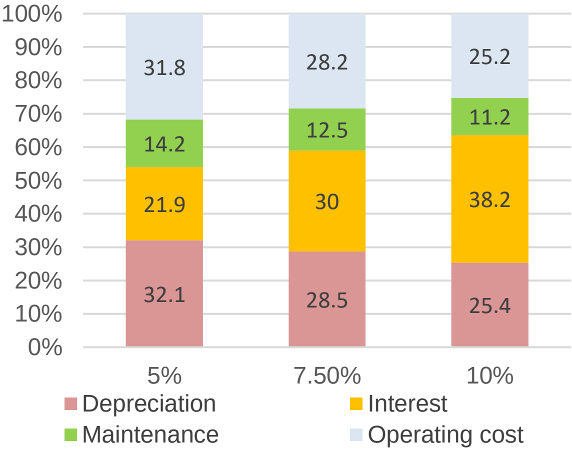
Calculations on geothermal heat generation cost carried out for GeoDH in 2014, involved three projects 10, 15 and 20 MW_{th} as shown in figure 9.1.5. It is interesting that the figure illustrates that the generation cost is stable for a period of 30 years, (due to lower costs of capital over time), 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. 9.1.6. **Cost Structure of Generation Project Depending on Size**



Source: GeoDH, 2014

Fig. 9.1.7. **Cost Structure of a 15 MWth Project and SensitivityAnalysis of Interest**



Source: GeoDH, 2014

As can be seen from figure 9.1.6, 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 9.1.7, 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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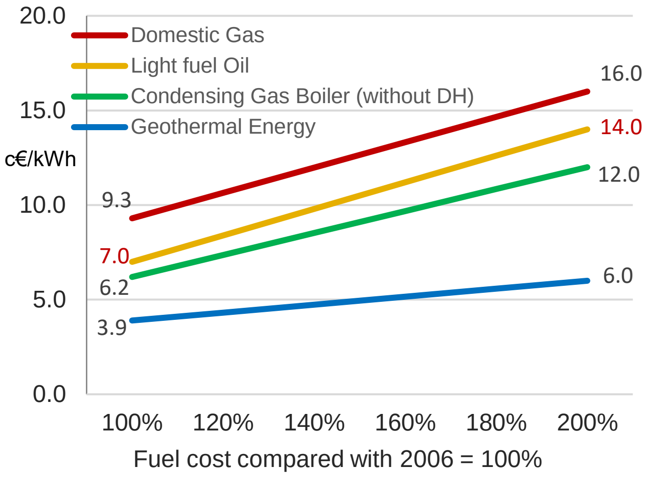
[2] The geothermal generation heat project provides the base load energy for district heating, which will be delivered to the district heating network, total hours of the plant will be 8.000 hours/year. The focus will be on generation cost so no revenues will be calculated. Life time of the project is 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 9.1.8.

Fig. 9.1.8. **Heat Generation Cost for District Heating Network by Fuel**



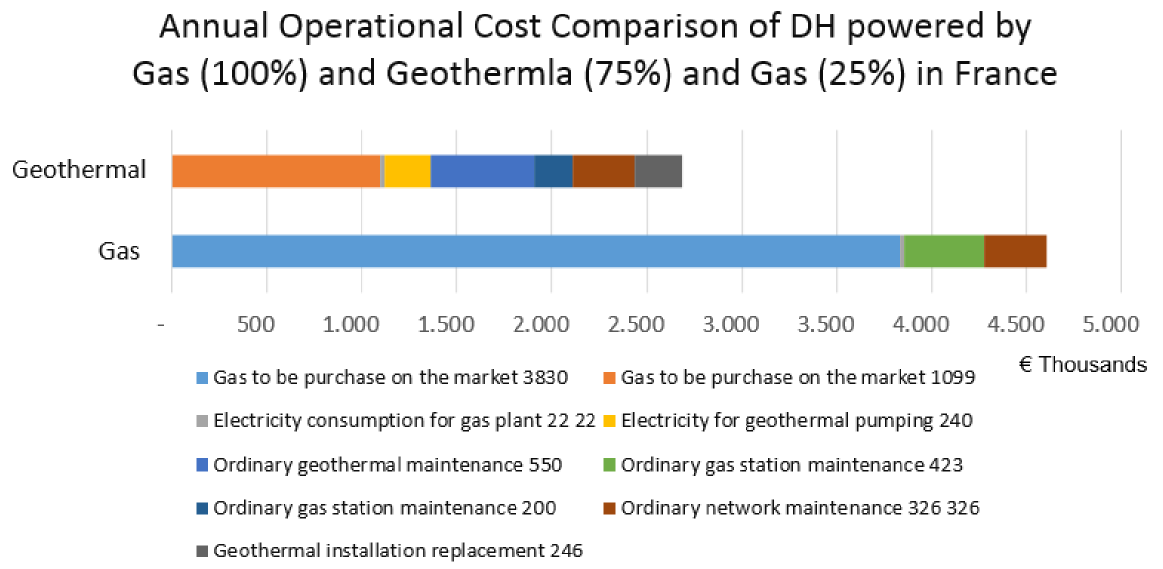
Source: GeoDH 2014.

Business Model for Geothermal District Heating and Gas
Cost Comparison – kWh Produced by Natural Gas and Geothermal Heat

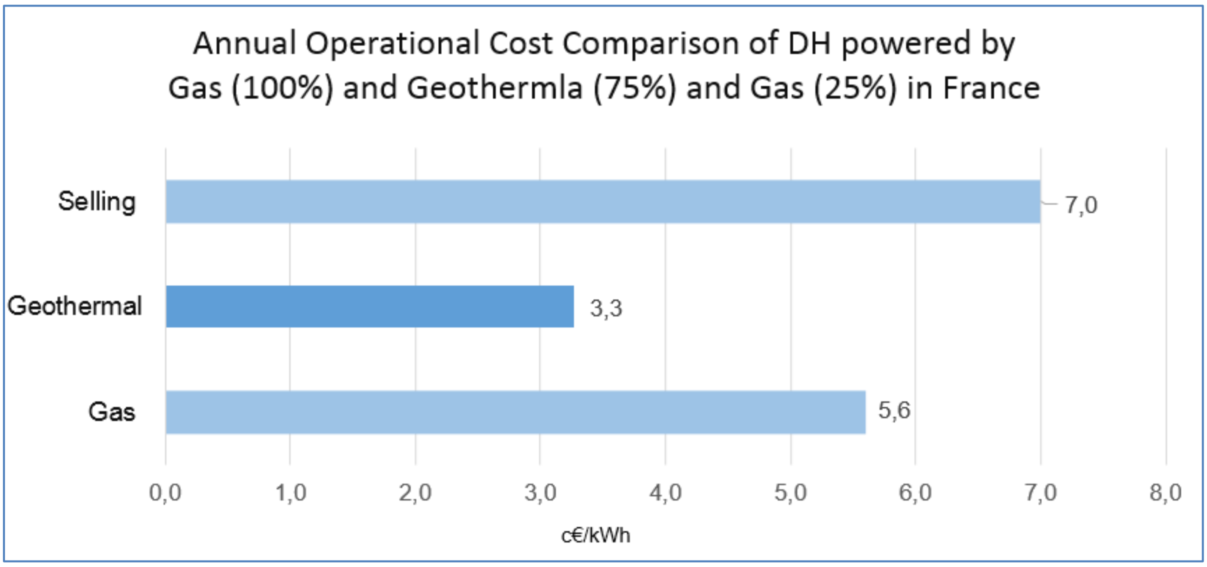
Following business model is based on comparison between a district heating network using natural gas and a geothermal district heating network, in the Paris area, described in GeoDH paper from 2014. The project (geothermal doublet) has been running for 31 years. However, the geothermal water flow rate 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 c€/kWh for a final selling price to the consumer at 70 c€/kWh, all inclusive.

However, the same kWh produced with a mix of natural gas (24,82%) and geothermal (75,18%) is 3.27 c€/kWh. The benefits and difference, which is 2,33 c€/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 k€. The annual profit using geothermal is 1.918 K€.


Annual Operational Cost Comparison of DH powered by Gas (100%) and Geothermla (75%) and Gas (25%) in France

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 c€/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 M€ (5.6 c€/kWh) - but only 2,7 M€ (3,27 c€/kWh) with a combination of geothermal (75%) and gas (25%).

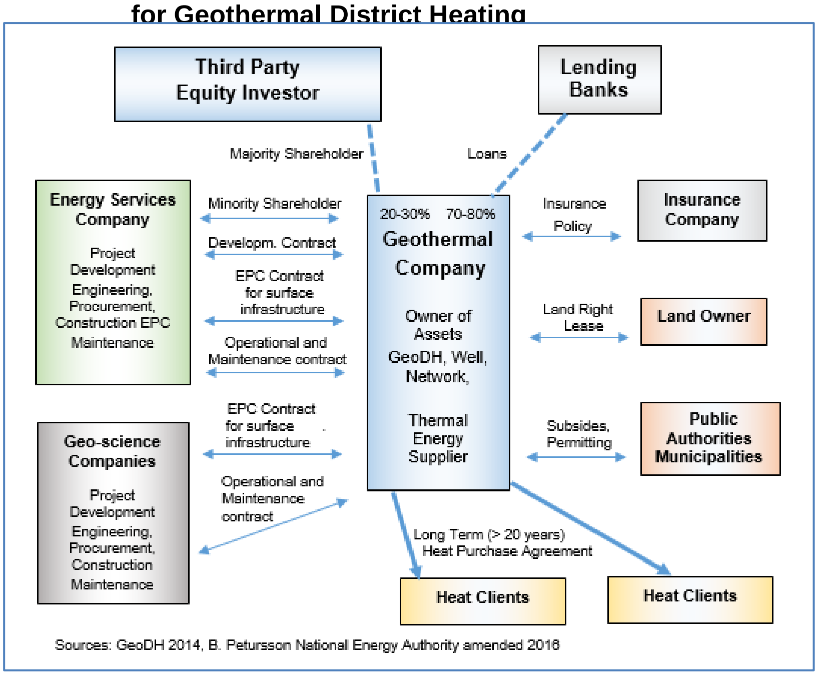
The benefits and difference which is 2,33 c€/MWh will allow to finance the construction of the doublet – and the profit will pay back the investment cost in 7,45 years – meaning that after 8 years the community will start to gain about 2 million euros per year – or it would be possible to lower the price of 2,33 c€/kWh and keep the profit as before.

9.2 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 9.2.1.

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

Fig. 9.2.1. **Legal and Financial Framework for Geothermal District Heating**



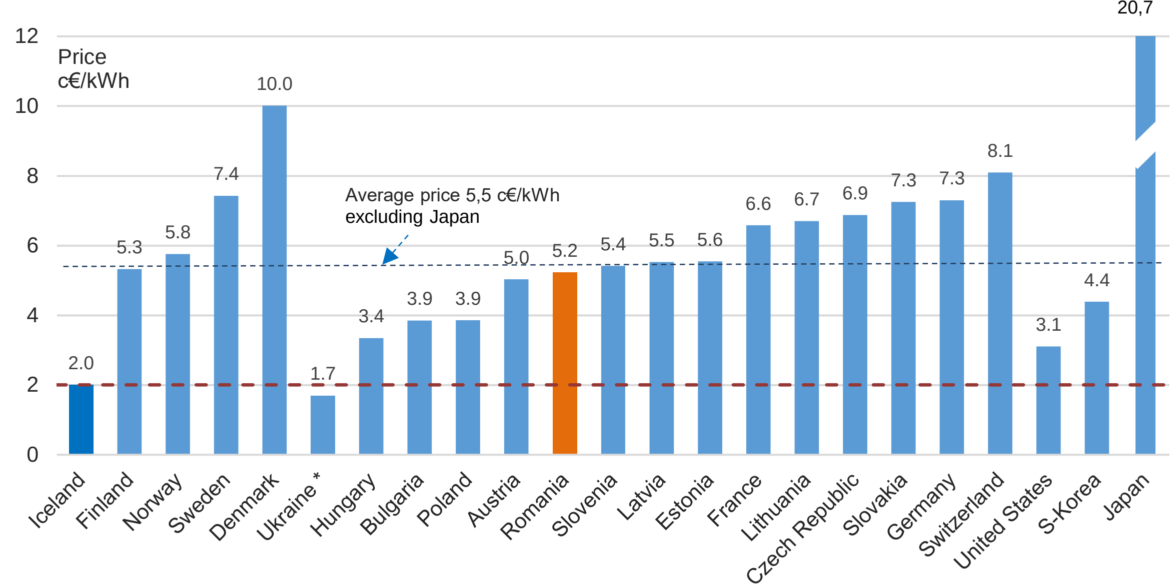
Sources: GeoDH 2014, B. Petursson National Energy Authority amended 2016 end users with a fixed charge (capacity charge) linked to kW of capacity subscribed, and a variable charge (“consumption charge”) proportional to kWh supplied.

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).

9.3 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 kilometres 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 kilometres.

Figure 9.3.1 **Average District Heating Prices in Europe, the United States, Japan and S-Korea**



* Subsidised Price, without VAT 2015. Source: Orkustofnun Data Repository: OS-2016-01. All prices are without VAT

Nevertheless, local resources are commonly used where possible, which results in substantial differences in the energy mix between countries. Figure 9.3.1. 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 €¢/kWh compared with an average value of 5,5 ¢€/kWh, and a maximum value of 20,7 ¢€/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 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.

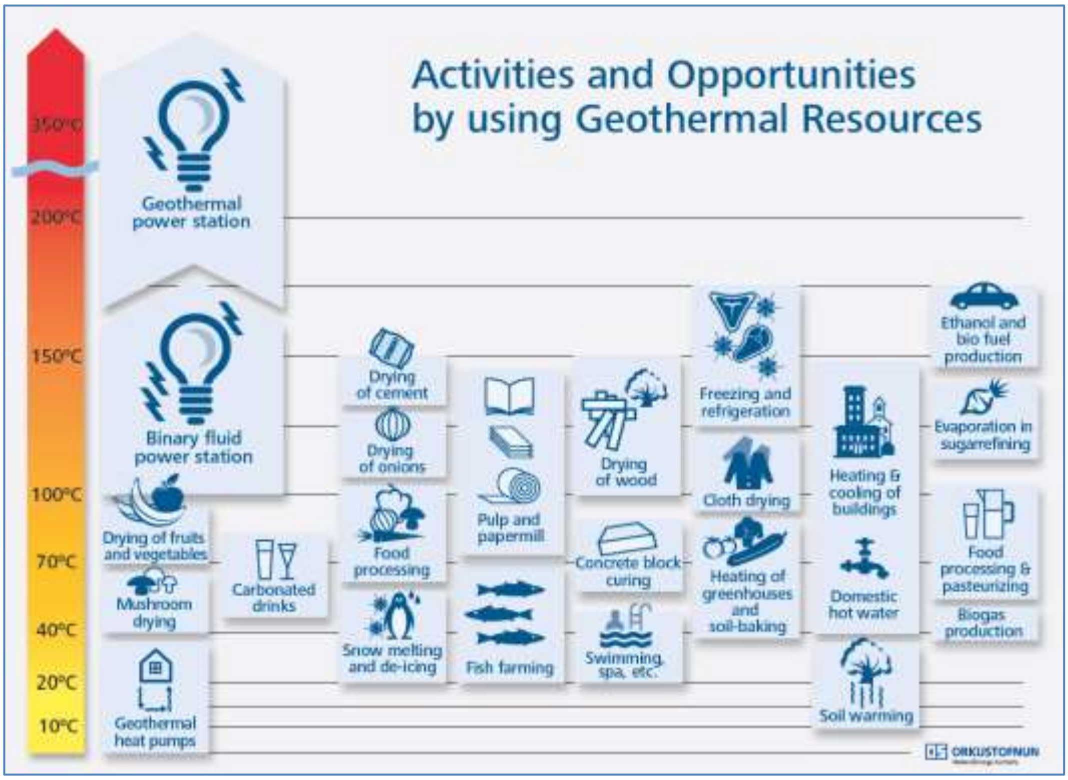
This translates to 5.33 EUR¢/kWh, or 7.12 USD¢/kWh, which is slightly above the average price for district heating in Europe, and substantially higher than the price in Iceland. From these comparisons, it is evident that Icelandic geothermal district heating prices are very competitive.

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.

9.4 Geothermal for Industrial use

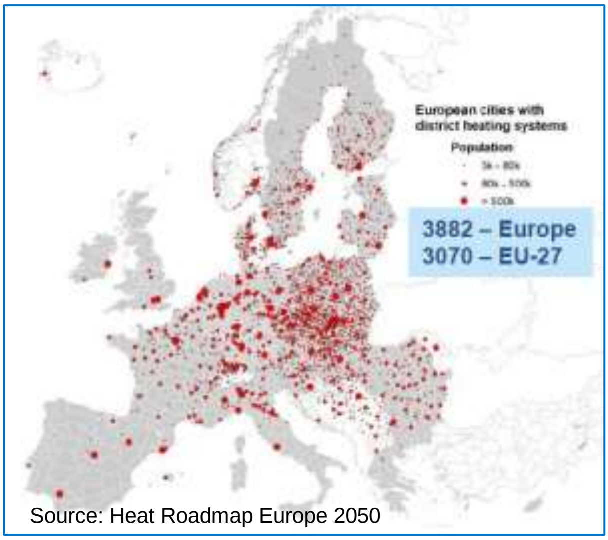
Geothermal resources can be used for various activities, as can be seen from the picture. In Iceland it has also been done, e.g. for greenhouses, fish farming, bathing etc.



10. Policy towards Geothermal District Heating in Europe

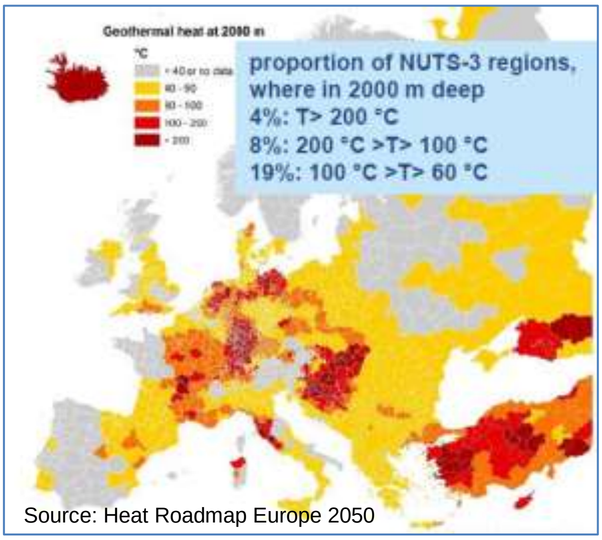
AEBIOM, EGEC and ESTIF, organizations representing the biomass, geothermal and solar thermal sectors respectively, addressed an open letter to the EU Heads of State and Government, 19th of March 2014. The letter states that "...Investing in renewables for heating and cooling will bring security of supply 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.

Figure 10.1. *Geothermal Cities with District Heating Systems*



Source: Heat Roadmap Europe 2050

Figure 10.2. ***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.

11. 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 recommendations are highlighted for Ukraine:

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:

10. Economic opportunity and savings.
11. Improvement of energy security.
12. Reducing greenhouse gas emissions.
13. Harnessing local resources.
14. Reducing dependency on fossil fuels for energy use.
15. Improving industrial and economic activity.
16. Develop low carbon and geothermal technology industry, and create employment opportunities.
17. Local payback in exchange for local support for geothermal drilling.
18. Improving quality of life based on economic and environmental / climate benefits.

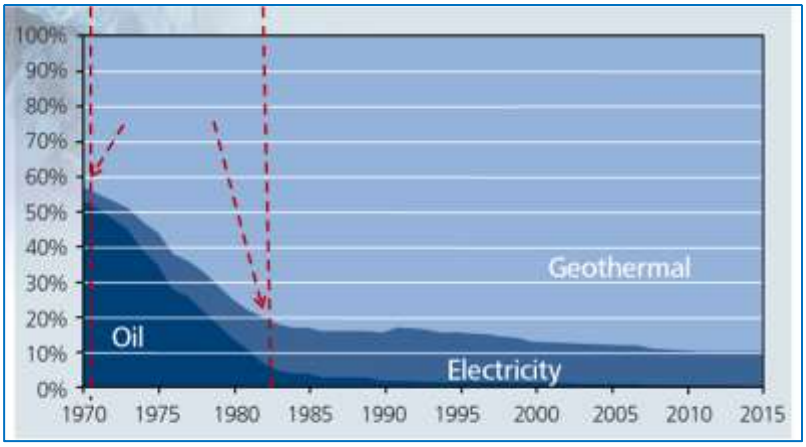
12. Geothermal Utilisation - lessons learned - Iceland

12.1 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.

Figure 12.1.1. 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.

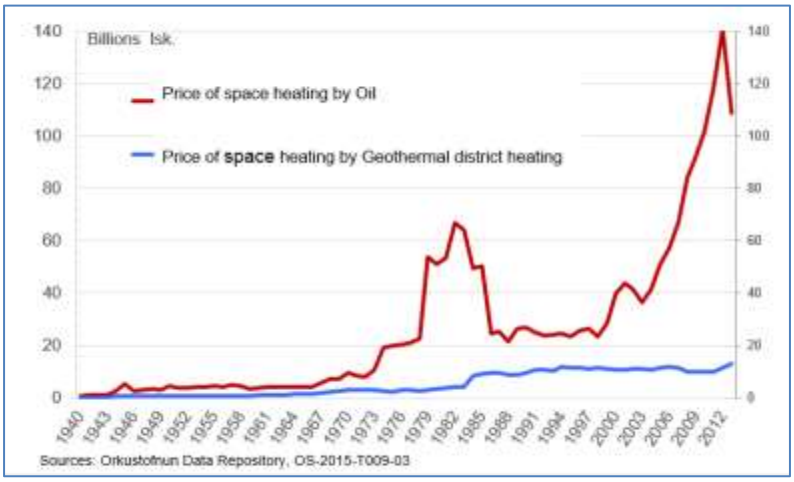
12.2 Economic benefits of using Geothermal

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. 12.2.1. 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).

Figure 12.2.1. **Economic Benefits of Geothermal District Heating**

Price of a space heating by geothermal district heating and by oil 1914 – 2013.



Sources: Orkustofnun Data Repository, OS-2015-T009-03

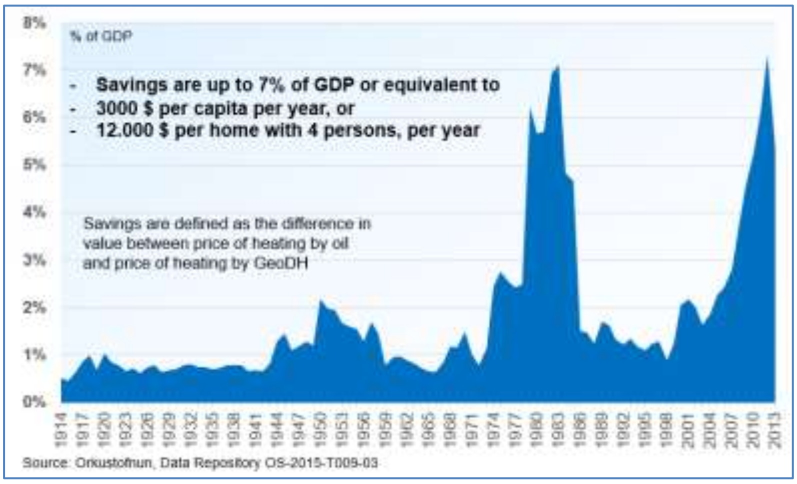
Oil heating is 2-6 times more expensive than geothermal heating throughout most of the period but peaks to 16 times more expensive in the period 1973 to 1985 and has risen again since 2007 to a present ratio of 10. In 2012 the difference in cost amounted to 80% of the state budget cost of health care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

Figure 12.2.2. **Economic Benefits of Geothermal District Heating**

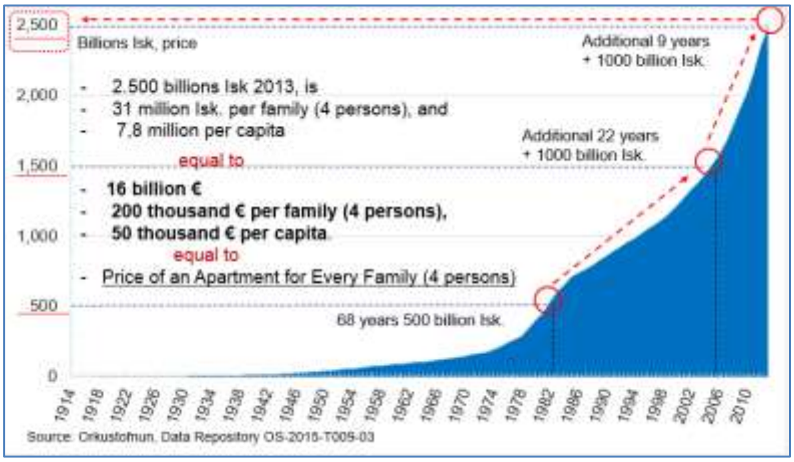
National Savings by Geothermal District Heating as % of GDP



Source: Orkustofnun, Data Repository OS-2015-T009-03

Figure 12.2.3. **Cumulative Savings from Geothermal District Heating in Iceland, 1914 – 2013**

2% interests, fixed price 2013



Source: Orkustofnun, Data Repository OS-2015-T009-03

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 (€200.000), 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. (€412.000.000) per year, or 800.000 ISK (€5.160) per family, or about 70.000 ISK. (€450) per month per family, after taxes.

Figure 12.2.4**. 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.

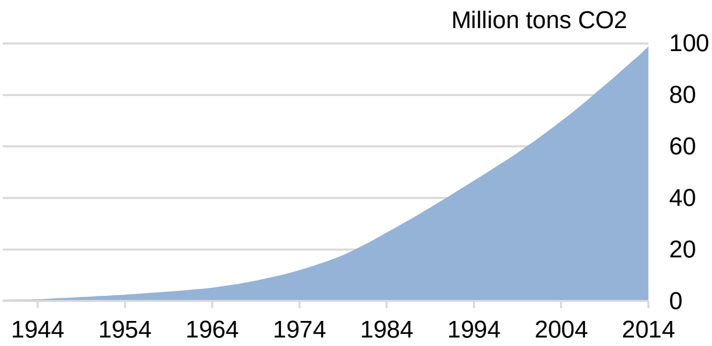
12.3 CO2 Savings due to Geothermal District Heating

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



Orkustofnun Data Repository: OS-2015-T008-01

In 2014 the geothermal district heating savings of CO_2 in Iceland

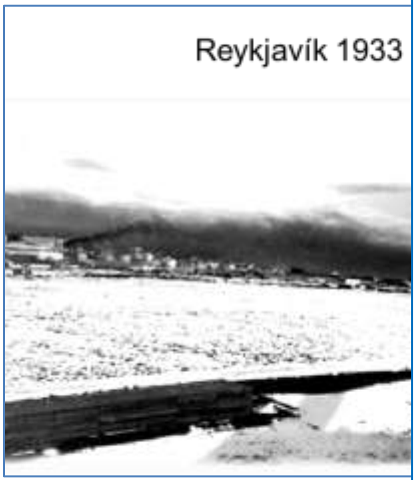
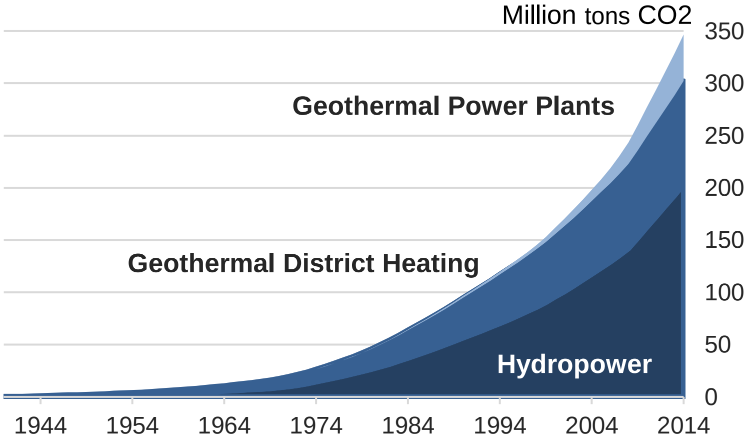


Fig. 12.3.2. **Accumulative CO2 Savings using Renewables instead of oil in Iceland 1914-2014**



Orkustofnun Data Repository: OS-2015-T008-01 was about 3 million tons of CO_2, or equal to 1 million tons of oil, equal to CO_2 bindings in 1,5 billion trees and 7.150 km^2 of forest.

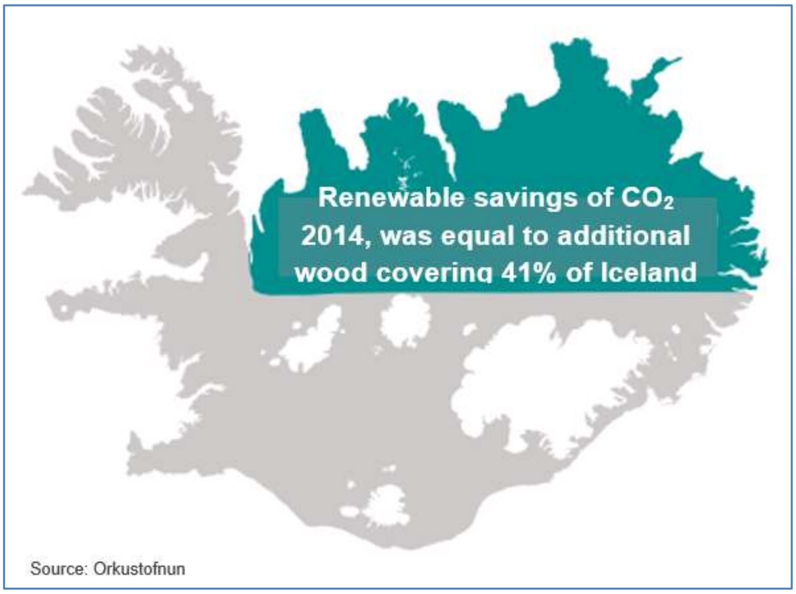
If we look at the accumulated savings of CO_2 by all renewables in Iceland 1914 – 2014, that savings is about 350 million tons, mostly since 1944. That is equal to CO_2 bindings in 175 billion trees, or 850 km^2 of forest and is equal to 120 million tons of oil.

In 2014 the annual savings of CO_2 from renewables in Iceland was 18 million tons, equal to bindings of CO_2 in 9 billion 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. 12.3.3. **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**



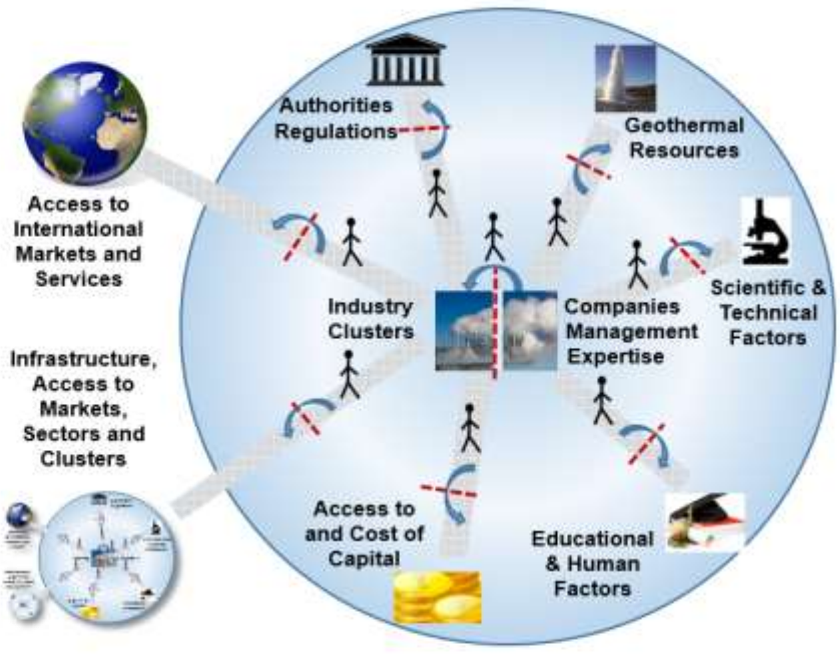
Source: Orkustofnun

13. International Competitiveness of the Geothermal Sector

13.1 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.

Figure 13.1. **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.

13.2 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 IFI for 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.

14. Geothermal Possibilities in Romania

This chapter was prepared by Codruta Bendea, Cornel Antal, Marcel Rosca, at the University of Oradea, Romania, cantal@uoradea.ro

14.1 Introduction

Romania has significant low enthalpy (40-120°C) geothermal resources suitable for direct heat utilisation: space heating, tap water heating, greenhouse heating, fish farming, animal husbandry, aquaculture, health and recreational bathing etc.

The difficult transition from a centrally planned economy to a free market one has considerably hindered the development of the direct uses of geothermal resources in Romania

The current Romanian legislation relevant to geothermal development is harmonized with European Union principles and supports renewable energies, among which geothermal energy is specifically mentioned. The mineral resources (including geothermal) are owned by the State.

In 2007, the Romanian Government approved the “Strategy for the development of renewable energy sources for the 2007-2020 period”, which sets short and medium term targets in accordance with the EU principles and directives (20% contribution of renewable energy in 2020).

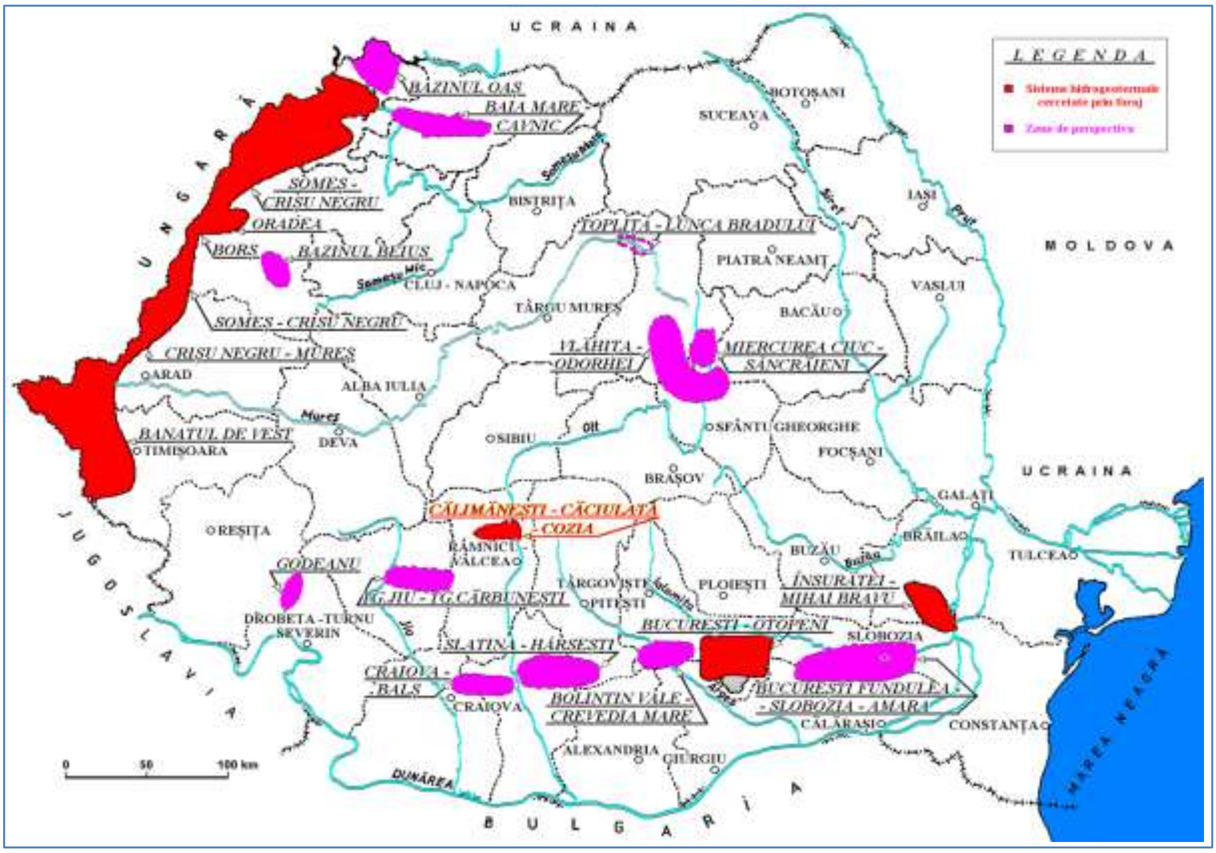
At the moment, except for small hydro, all other renewable energy sources have minor contributions to the Romanian energy mix. The main energy sources are still fossil fuels.

14.2 Geothermal resources

There are over 250 wells drilled with depths between 800 and 3,500 m, that shows the presence of low enthalpy geothermal resources (50÷120°C), which enabled the identification of 9 geothermal areas, 7 in the Western part and 3 in the Southern part. The total installed capacity of the existing wells is about 480 MWt (for a reference temperature of 25°C). Of this total only 246 MWt are currently used, from 96 wells. The annual energy utilisation from these wells was about 1900 TJ (in 2014)

The geothermal systems discovered on the Romanian territory are located in porous permeable formations such as Pannonian sandstone, specific for the Western Plain, and Senonian specific for the Olt Valley.

The main geothermal reservoirs in Romania are located in 4 counties from the N-W part of Romania, in Olt Valley and Otopeni (near Bucharest).



Map of Romania with geothermal reservoirs

14.3 Utilisation of Geothermal Energy

The main direct uses of the geothermal energy are:

- space and district heating 39.7%
- bathing 32.2%
- greenhouse heating 17.1%
- industrial process heat (wood and grain drying, milk pasteurisation, flax processing) 8.7%
- fish farming and animal husbandry 2.3%

More than 80 % of the wells are artesian producers, 18 of them require anti-scaling chemical treatment, and 6 are reinjection wells.

Use	Installed Capacity (MWt)	Annual Energy Use (TJ/yr)	Capacity Factor
Space Heating	108	823	0.24
Greenhouse Heating	16	80	0.16
Fish and Animal Farming	5	10	0.06
Industrial Process Heat	10	20	0.06
Bathing and Swimming	67	492	0.23
Geothermal Heat Pumps	40	480	0.38
TOTAL	246	1905	0.25

Two main companies are currently involved in geothermal operations:

- Foradex S.A., located in Bucharest, a state owned drilling company (privatised in 2008) that has both exploration and exploitation concessions for the geothermal reservoirs located in the Southern half of Romania (Banat county, Olt Valley-Valcea County and North Bucharest).
- Transgex S.A., located in Oradea, is also mainly a drilling company privatised in 2000, and has exploration and exploitation concessions for the geothermal reservoirs located in the Western part of Romania (mainly Bihor county).

SPACE HEATING IN ORADEA

University of Oradea

City Hospital

Continental Hotel

Lotus Market

BATHING AND SWIMMING IN ORADEA

Ioşia Swimming Pool – Oradea

Sports Palace - Oradea

Wellness Complex Termal Nymphaea, Oradea

FELIX SPA – near Oradea

THERME Bucharest, the largest thermal wellness center in Europe

THERME Bucharest

Greenhouse heating – Livada, Bihor County

50 kWe Binary Cycle ORC Geothermal Power Plant installed in Oradea by Transgex Company

14.4 Opportunities

In the shallow geothermal domain, the Law 372/2005 on the Energy Performance of Buildings (new version of this Law is 159/2013) contains a mandatory request regarding the presence of heat pumps as an alternative in the feasibility study for new buildings larger than 1000 m^2.

The Romanian Geoexchange Society is a non-profit organization established in 2002, whose objectives are to promote the GSHP systems (Ground Source Heat Pumps), to create a national regulatory frame, to represent the Romanian market abroad and to present its achievements, to train the Romanian specialists, and to bring the Romanian technical and managerial experience into the European projects.

The University of Oradea is a state university. Some of its faculties have geothermal related training and/or research among their activities, such as the Faculty of Energy Engineering, the Faculty of Environment Protection and the Faculty of Medical Sciences. The Faculty of Energy Engineering currently offers B.Sc. training in Renewable Energy Resources and M.Sc. training in Geothermal and Solar Energy Utilisation.

Five members of its current academic staff followed the six months UNU Geothermal Training Programme in Iceland. The university also has a number of research and training departments, including the Geothermal Research Centre and the International Geothermal Training Centre.

14.5 Conclusions

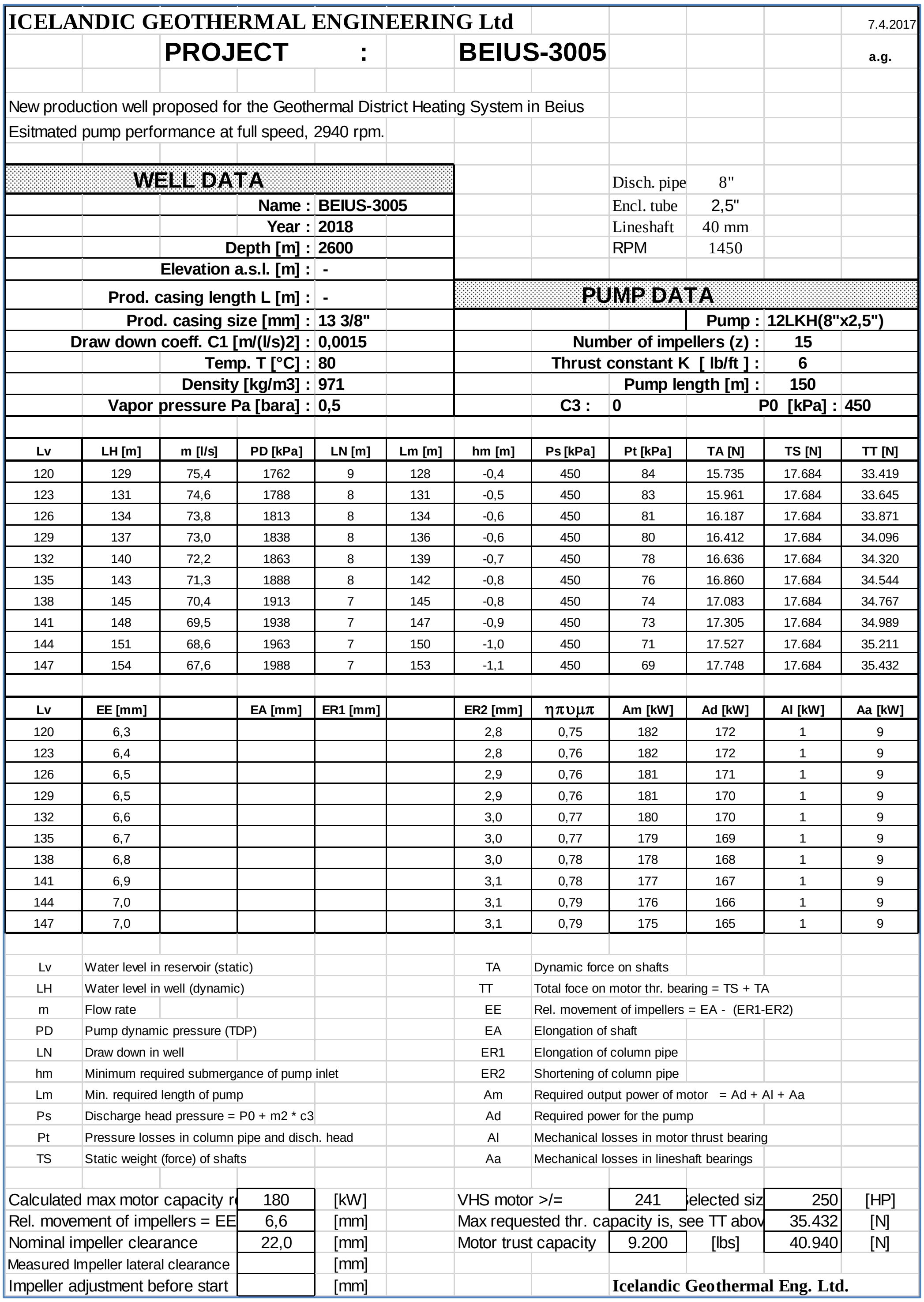
Romania was gifted by nature with a considerable geothermal resource. In several areas (North-Western Romania, Olt Valley, Northern Bucharest), this resource is already exploited, but not to its true potential. The big advantage is that there are many wells that had been drilled for research purpose and exploration, but now, since they prove the existence of the geothermal reservoir, they may be used for exploitation, too. Therefore, there are a lot of geothermal possibilities and opportunities in Romania, which involve less investment costs than other countries.

Also, as state policy, Romania is a country open to European geothermal projects. Several Romanian entities, private companies or universities, were and still are involved in projects financed by the European Commission that led to the development of geothermal energy utilization. Also, private Romanian companies together with Local Councils are using their own funds to extend the use of geothermal water for district heating and sanitary tap water, in order to increase the population living standards.

Nevertheless, Romania needs more investors in this field, either Romanian or foreigners. There is a growing market for renewable energies, mainly for thermal energy, and the economic analysis show a good return of investment rate.

Annexes

Annex 1 – Deep Well Pump for a new production well Beius-3005



ICELANDIC GEOTHERMAL ENGINEERING Ltd 7.4.2017

PROJECT : BEIUS-3005 **a.g.**

New production well proposed for the Geothermal District Heating System in Beius

Esitmated pump performance at full speed, 2940 rpm.

WELL DATA		Disch. pipe	8"		
Name :	**BEIUS-3005**	Encl. tube	2,5"		
Year :	**2018**	Lineshaft	40 mm		
Depth [m] :	**2600**	RPM	1450		
Elevation a.s.l. [m] :	**-**				
Prod. casing length L [m] :	**-**	**PUMP DATA**			
Prod. casing size [mm] :	**13 3/8"**	**Pump :**	**12LKH(8"x2,5")**		
Draw down coeff. C1 [m/(l/s)2] :	**0,0015**	**Number of impellers (z) :**	**15**		
Temp. T [°C] :	**80**	**Thrust constant K [lb/ft] :**	**6**		
Density [kg/m3] :	**971**	**Pump length [m] :**	**150**		
Vapor pressure Pa [bara] :	**0,5**	**C3 :**	**0**	**P0 [kPa] :**	**450**

Lv	LH [m]	m [l/s]	PD [kPa]	LN [m]	Lm [m]	hm [m]	Ps [kPa]	Pt [kPa]	TA [N]	TS [N]	TT [N]
120	129	75,4	1762	9	128	-0,4	450	84	15.735	17.684	33.419
123	131	74,6	1788	8	131	-0,5	450	83	15.961	17.684	33.645
126	134	73,8	1813	8	134	-0,6	450	81	16.187	17.684	33.871
129	137	73,0	1838	8	136	-0,6	450	80	16.412	17.684	34.096
132	140	72,2	1863	8	139	-0,7	450	78	16.636	17.684	34.320
135	143	71,3	1888	8	142	-0,8	450	76	16.860	17.684	34.544
138	145	70,4	1913	7	145	-0,8	450	74	17.083	17.684	34.767
141	148	69,5	1938	7	147	-0,9	450	73	17.305	17.684	34.989
144	151	68,6	1963	7	150	-1,0	450	71	17.527	17.684	35.211
147	154	67,6	1988	7	153	-1,1	450	69	17.748	17.684	35.432

Lv	EE [mm]		EA [mm]	ER1 [mm]		ER2 [mm]	ηπυμπ	Am [kW]	Ad [kW]	Al [kW]	Aa [kW]
120	6,3					2,8	0,75	182	172	1	9
123	6,4					2,8	0,76	182	172	1	9
126	6,5					2,9	0,76	181	171	1	9
129	6,5					2,9	0,76	181	170	1	9
132	6,6					3,0	0,77	180	170	1	9
135	6,7					3,0	0,77	179	169	1	9
138	6,8					3,0	0,78	178	168	1	9
141	6,9					3,1	0,78	177	167	1	9
144	7,0					3,1	0,79	176	166	1	9
147	7,0					3,1	0,79	175	165	1	9

Lv	Water level in reservoir (static)	TA	Dynamic force on shafts
LH	Water level in well (dynamic)	TT	Total foce on motor thr. bearing = TS + TA
m	Flow rate	EE	Rel. movement of impellers = EA - (ER1-ER2)
PD	Pump dynamic pressure (TDP)	EA	Elongation of shaft
LN	Draw down in well	ER1	Elongation of column pipe
hm	Minimum required submergance of pump inlet	ER2	Shortening of column pipe
Lm	Min. required length of pump	Am	Required output power of motor = Ad + Al + Aa
Ps	Discharge head pressure = P0 + m2 * c3	Ad	Required power for the pump
Pt	Pressure losses in column pipe and disch. head	Al	Mechanical losses in motor thrust bearing
TS	Static weight (force) of shafts	Aa	Mechanical losses in lineshaft bearings

Calculated max motor capacity r	180	[kW]	VHS motor >/=	241	;elected siz	250	[HP]
Rel. movement of impellers = EE	6,6	[mm]	Max requested thr. capacity is, see TT abov			35.432	[N]
Nominal impeller clearance	22,0	[mm]	Motor trust capacity	9.200	[lbs]	40.940	[N]
Measured Impeller lateral clearance		[mm]					
Impeller adjustment before start		[mm]					

Icelandic Geothermal Eng. Ltd.

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