Pre-Feasibility Study
Geothermal District Heating in Oradea, Romania

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National Energy Authority

Oradea

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2017

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Introduction

The Project Team
This project constitutes a Pre-Feasibility Study of Geothermal District Heating in Oradea, ongoing from late 2015 to April 2017 It has been supported by the Rondine EEA Grants Program. The Project promoter was the Municipality of Oradea, and the people managing the project on behalf the municipality were Daniel Tigan, Ovidiu Guler, and Oana Nicula.

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

Geothermal resources experts were Guðni Axelsson, Silvia R. Gudjónsdóttir and Sæunn Halldórsdóttir and his team, creating the text in chapter 5. Geothermal district heating experts were, Arni Gunnarsson, Sigurður Lárus Holm and Viktor Hava, making the text of chapters 3 – 8.

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

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 Oradea.

What will the project achieve?
Pre-Feasibility Study of Geothermal District Heating will achieve:
- Re-evaluate and update the production potential of the Oradea 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?
1. The following key elements of the project were:
   a. Assessment of the current status of utilization in Oradea; capacity of wells used, energy produced, utilization for district heating, other direct uses, etc. as well as highlighting framework barriers for GeoDH possibilities.
   b. Potential assessment with simple reservoir models and predictions for some relevant future sustainable utilization scenarios with special emphasis on benefits of reinjection.
   c. 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 Oradea.
   d. 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.
   e. Analysis of geothermal district heating (GeoDH) development – international comparisons.
   f. Evaluation of geothermal policy options and opportunities.
   g. 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.

2. The beneficiaries of the program are the municipality of Oradea and its citizens.

How will bilateral relations be strengthened?
1. Increased cooperation in the area of geothermal capacity building between the Municipality of Oradea 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 Oradea.
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.

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.

Executive Summary

Resource assessment

1. The geothermal resources located below the city of Oradea are of the sedimentary type, in fractured Triassic dolomitic limestone layers. The main reservoir layers are at a depth of 1700 – 2600 m, with reservoir temperature of 85 – 135°C. The Oradea reservoir block is estimated to be about 60 km^2 in area.
2. The Oradea geothermal resources have been utilized for almost 55 years, presently at a yearly rate close to 50 L/s, partly through wells that are still artesian.
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 are in agreement with the results of previous assessments, e.g. performed by Transgex.
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.
5. The assessment results indicate that the Oradea geothermal resources can sustain a utilization increase of the order of 100% (average annual production of 140 L/s, assuming a 50-year utilization period, from the present.

Recommendations

1. The main recommendation regarding future geothermal utilization in Oradea, is that the utilization be increased in steps. First by about 50%, to about 100 L/s) and soon afterwards (one year or more) by another 50%, to about 140 L/s. This cautious approach is necessary because of considerable 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 very likely be increased through further steps.
2. Monitoring of production, water-level (or well-head pressure if a well is artesian), temperature and chemical content must be comprehensive and accurate. This will provide basis for future increase in utilization.
3. A detailed numerical modelling should be set up for the Oradea geothermal system and neighboring reservoir blocks, with which accurate future predictions can be calculated.
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 specific production wells.
5. Lessons learned in Oradea, 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. First alternative to increasing geothermal usage is to connect additional PT substations to the geothermal heating system in Iosia and operate it as a base heat source by fully utilize the capacity of existing well
7. Second alternative is to increase the utilization of the existing wells in Nufarul by deliver also heat to district heating in the PT substations
8. Third alternative is to increase the utilization of the University well by connection buildings along site the pipe rout to PT 902.
9. Fourth alternative is to connect well 1720 in Santandrei to the Iosia district heating system.
10. Unified strategy for the utilization of the geothermal sources,
11. Maintain focus on renovation decreasing the water and heat losses in the primary and secondary municipal district heating pipe networks. At present around 40 l/s of annual average geothermal water is needed to prepare make-up water to cover the water leakages in the primary network.

Additional International Recommendations

International Framework Recommendations

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

Geothermal Development and Lessons Learned in Iceland

The following elements of policy priority have been shown to be important regarding geothermal development:
1. Awareness raising among policymakers, stakeholders and municipalities.
2. Education and capacity building.
3. Evaluation of geothermal resources.
4. Promotion of geothermal power generation and district heating projects.
5. Development of legal and regulatory framework.
6. Financial support for early stage development and exploration.
7. International cooperation, geothermal and financial expertise.

The economic savings from geothermal district heating in Iceland from 1914 – 2014 is equal to 2.680 billion ISK. (19 billion €), 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.

Geothermal Options, Opportunities and Benefits

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

1. Background of Geothermal District Heating in Oradea

Geothermal energy is based on exploiting the earth's internal heat supply. Currently, there is only limited use of geothermal energy in district heating systems and spa applications in Romania. Natural gas and coal are the main sources of the district heating. Large parts of Romania are well suited for geothermal district heating, with developed existing district heating networks. Many of the existing district heating systems can run on renewable, emission-free geothermal energy, as is the case for this project in Oradea. Geothermal energy could locally generate much of energy needs, while considerably eliminating dependence on foreign supplies of gas and the economic pressures associated fossil fuels. The main benefits of geothermal heating are the provision of local base load and flexible renewable energy, diversification of the energy mix and protection against volatile and rising fossil fuel prices. Using geothermal resources can provide economic development opportunities for Romania, in the same time as cutting CO_2 emissions. In this context, Romania, has set national targets of reducing CO_2 emissions by 19% and increasing the use of renewables to 24% by 2020 out of total energy consumption. Currently, Romania's dependency on carbon intensive fossil fuel energy resources is high and drastic measures are required to meet the designated targets. Implementation of the Oradea Geothermal Heat project will be an important step in the right direction.

This pre-feasibility study provides an evaluation and analysis of the Oradea Geothermal Heat project, based on the available information on the geothermal resource, the projects location and the existing system in place. Four possible scenarios are evaluated, they show the best way to extend the utilization of geothermal energy in Oradea, however the statements are provided are correct for the whole city. This study deals with the most

The project promoter is the Icelandic National Energy Authority, the project will be implemented in cooperation with Oradea Municipality and Termoficare, the local municipal heating company.

Currently, heat stations 512, 513 and 514 are supplied by Geothermal Station North Iosia exploiting two geothermal wells acting as a geothermal subsystem within the greater district heating system. Approximately 99% of the heat demand of the subsystem is covered by geothermal energy. Back up gas boilers are operated in the coldest days of the year. Since, in the remaining part of the heating season the geothermal wells have unused potential, the involvement of two additional district heating stations is considered to further utilise the emission free geothermal energy. Geological survey showed that a new, third geothermal well can produce geothermal fluid with favourable parameters near the subsystem. The connection of this well to the geothermal subsystem can provide additional heat energy therefore it is also considered.

The feasibility study analyses four potential scenarios for utilizing the geothermal resource within the North Iosia perimeter in Oradea.

- Scenario 1, connecting two additional heat stations to the geothermal subsystem;
- Scenario 2, connecting two additional heat stations and connecting a new artesian geothermal production well to the geothermal subsystem;
- Scenario 3, connecting two additional heat stations and connecting a new geothermal production well with increased flow rate;
- Scenario 4, connecting additional heat stations and connecting a new geothermal production well with increased flow rate.

2. Geothermal Resources in Oradea[1]

2.1 General background

2.1.1 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-

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

dominated. This report focusses on low-temperature geothermal resources, which are always low-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 1). Some convective systems may, however, be embedded in sedimentary rocks, especially where tectonic activity has created extensive vertical permeability (near-vertical faults/fractures).
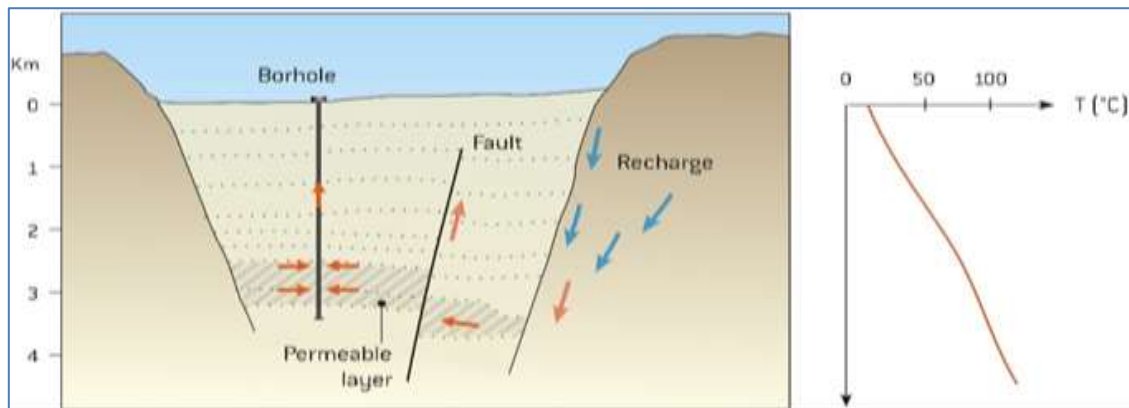

Figure 1: *Schematic figure of a sedimentary basin with a geothermal reservoir at 2 – 4 km depth (modified from Saemundsson et al., 2009). Note that the vertical/horizontal scale is exaggerated, as sedimentary basins usually are quite extensive horizontally. The temperature profile to the left shows 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.

2.1.2 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 2) 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 2: *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). This 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 2.1.3).
- The Oradea geothermal system and its utilization are described in detail later in this report.

- The Beius fractured carbonate geothermal system and its utilization are described in detail in an associated feasibility 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 located 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 located 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.

2.1.3 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 particular 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 Oradea, 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. A number of 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 a several decade 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 ground-water 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 Oradea.

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 3). 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.

In the lumped parameter model of Figure 3, 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.
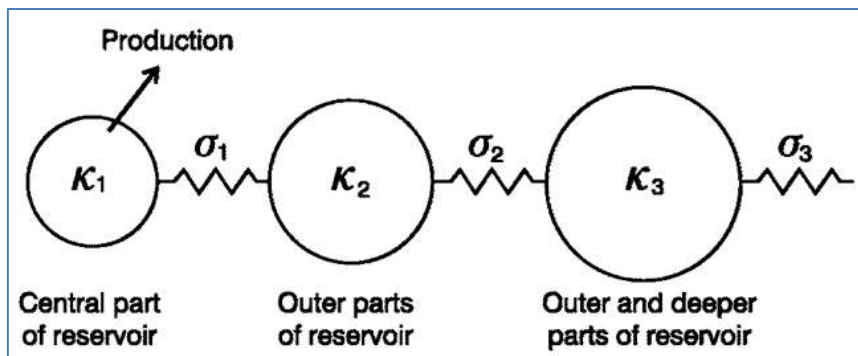
Figure 3: *A 3-tank lumped ladder model commonly used to simulate geothermal systems (Axelsson et al., 2005)*

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 actually 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 particular 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 Oradea and Romania in general.

2.2 Geothermal Resources in Oradea

This subchapter describes the geological framework of the geothermal resources in Oradea, 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 Western part of the Apuseni Mountains hosts an important source of geothermal energy, especially around the City of Oradea. The City is situated in the NW part of Romania (Figure 2), in the region of the Cris Rivers, where the main rivers are the Crisul Repede River and the Peta River. At a regional level, Oradea is situated in the SE part of the Carpathian-Pannonina region (Figure 4). The geo-tectonic evolution of this area is related to the general background of formation and long lived formation of the Northern Apuseni Mountains and of the Pannonia Depression.

This evolution is divided into three main phases, starting in Permian and ending in the low Cretaceous era (Pre-Alpine phase), where the area develops within the Bihor-Codru geosynclines. Next came the upper Cretaceous and Paleogene formations (middle-Alpine formations), displayed within the marginal basins of the Apuseni Mountains, with separation of the northern and western parts, which today is submersed. Finishing by the areal submersion of the Pannonia Depression in the western part of the region, where the eastern part remained mostly at surface, occurring in Neogene (The-Neo Alpine phase) (Bratu et al., 2017).
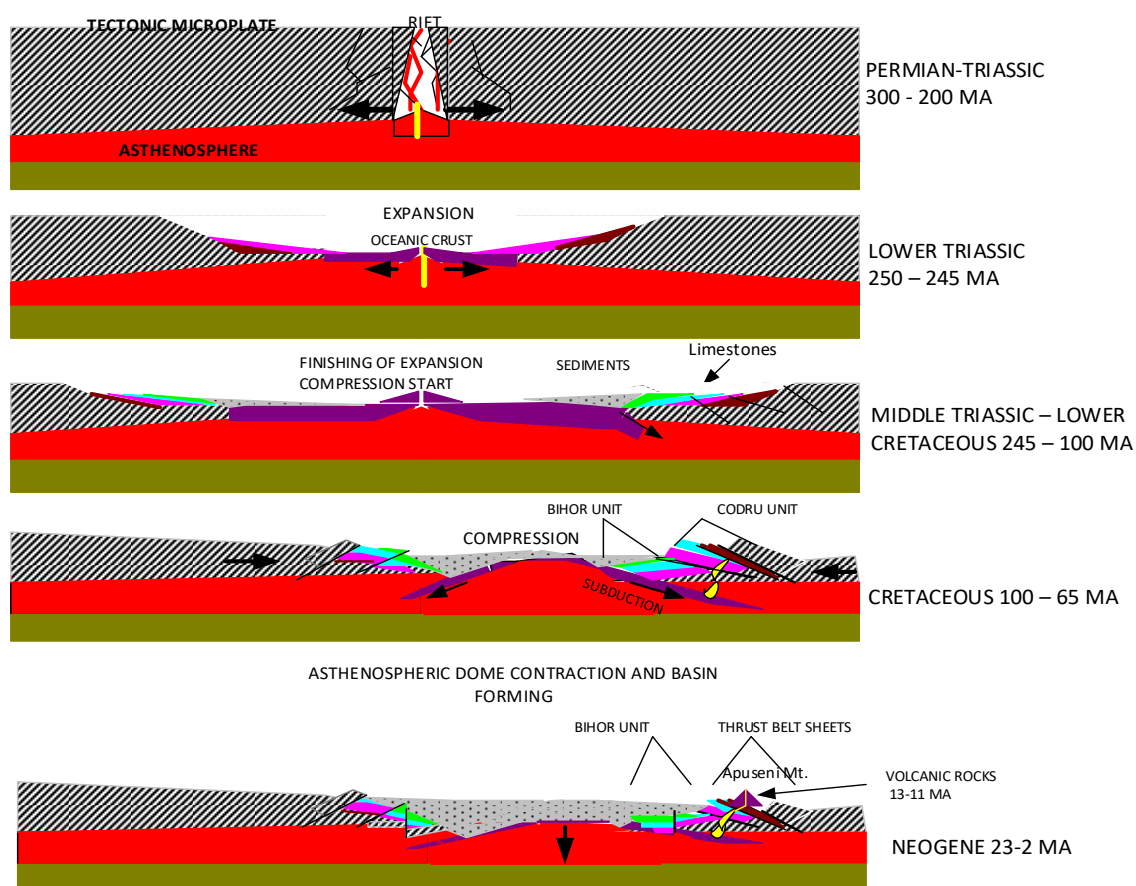
Figure 4: *Evolution of the intra Carpathian basin in Romania (Transgex, 2015).*

The age of the sedimentary formations in the Oradea area span from the Triassic period to the Quaternary. The Triassic rocks are composed of sedimentary limestone and dolomite. The Jurassic rocks are detrial and limestone formations. The Cretaceous era formations has a mixture of limestone, detrial, marl-siltic and sandy formations. The Neogene formations are placed in the lower parts of the depression and consist of a marl-sandy complex. The most recent deposits in the area are from the Quaternary, characterized by terrace deposits and delta proluvial deposits (Bratu et al., 2017).

The geothermal activity in the Oredea area is caused by the abnormally high thermal flow in the area, which is related to the entire structural unit of the Pannonian Depression (Bratu et al., 2017). Even though the area is located on the eastern border, at the contact with the Northen Apuseni mountains, it is considered that the conductive heat input in the area is relatively constant (Bratu et al., 2017). The variations of the thermal gradient are from 2.6°C/100 m in the eastern part of Oradea to 4.1°C/100 m in the western part, with only 10 km apart. That is explained by the circulation of cold waters, coming from east to the north, by the means of a major fracture system. The wells drilled in the east have a temperature ranging from 70-80°C and the ones in the west 100-110°C, at the same depth. The Oradea Triassic aquifer is hydrodynamically connected to the Felix Spa Cretaceous aquifer. The water is around 20,000 years old (of calcium-bicarbonate type) and the recharge area is in the northern part of the Padurea Craiului Mountains and the Borod basin (Bendea et al., 2015; Antics and Rosca, 2003).

The main Oradea geothermal reservoir (average thickness 800 m, Figure 5) is located in the subsiding Oradea-Alesd area, in a fractured Triassic limestone and dolomite at depths of 2,200-3,200 m (Bratu et al., 2017; Bendea et al., 2015; Antics and Rosca, 2003). The diastrophism related tectonics in the Oradea area play a major role in the existence of the geothermal reservoir. The area hosts many tectonic subunits, forming a complex tectonic and geological structure (Figure 6). The current structure in the Oradea area is the consequence of the sin and post-paroxysm motions of the alpine orogenesis, the

Oradea and the Bors structures. The presence of cracks within the Triassic rock pile provides favourable paths for the circulation of water.

Tests performed on the Triassic rock pile in the Oradea area show that the geothermal aquifer is situated between two levels that resemble an aquitard. The Werfen formation of the lower Triassic and the Gresten facies of the lower Jurassic in the upper part (Bratu et al., 2017). The reservoir covers around 75 km^2 and is exploited by 12 production wells and two injection wells, and has been in production since 1963 (Bratu et al., 2017). The water in the system has a temperature between 70 and 110°C and is mainly used for heating, house-hold warm water and for spa-activities. The annual utilization of geothermal energy in Oradea represents around 30% of the geothermal heat produced in Romania (Bendea et al., 2015).
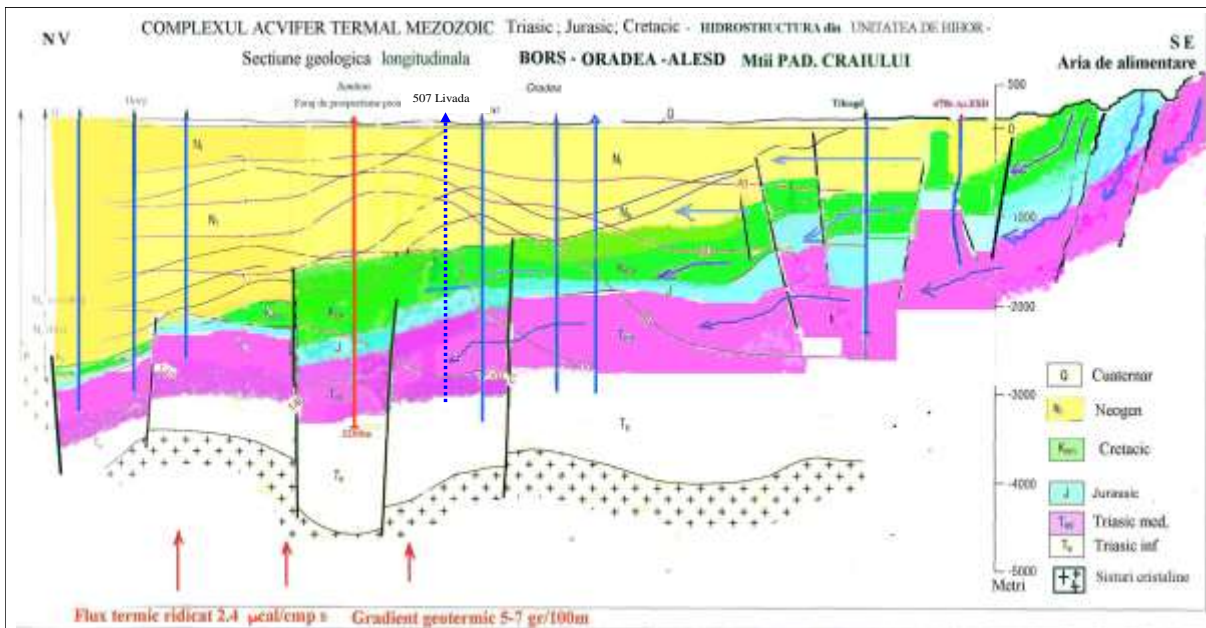

Figure 5: *Geological cross-section of the Bors-Oradea-Alesd area (Transgex, 2015).*
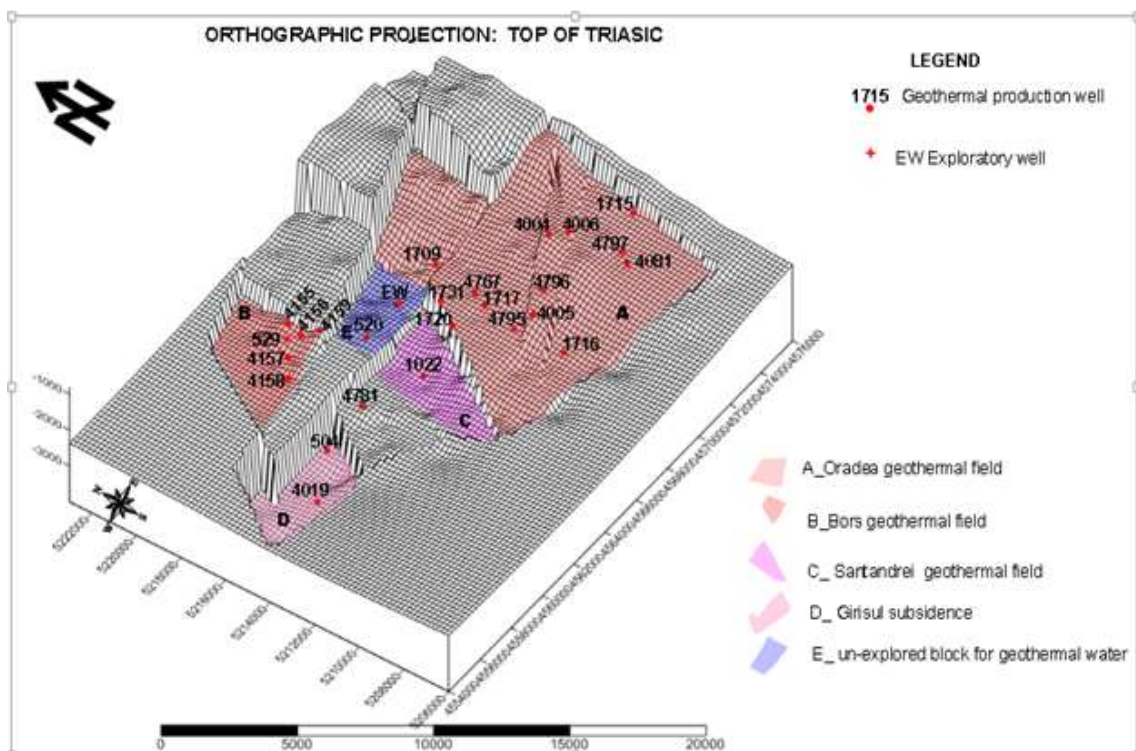

Figure 6: *Top of the Triassic reservoir formation in Oradea and surrounding reservoir blocks (Foghis, 2016)*

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2.3 Previous Assessments

Several assessment aimed at estimating the production capacity of the Oradea geothermal system, or the capacity of specific wells, have been performed. These have used some of the methods described in sub-chapter 1.1.3 above, including volumetric assessment, simple analytical modelling and detailed numerical modelling. Unfortunately, only a few these have been accessible to the present project, for different reasons (simple availability, classification, language, etc.). The internationally published papers by Antics (1997) and Rosca and Antics (1999), are directly available, but of limited use here, because of their limited scope, the fact that important results aren't presented in the papers and because of their outdated nature.

A very important evaluation of the Oradea geothermal system was performed on the basis of data collected during a large-scale interference test conducted in 1984 (Bratu et al., 2017). It involved shutting down all production wells for 28 days, and consequently starting production (23 – 35 L/s) from the centrally located well 4796 and concurrently observing the pressure changes in all other wells. Many of the wells demonstrated a clear and rapid pressure interference, while others appeared to be less directly connected. Thus, a certain main reservoir block was defined for the Oradea geothermal system (see also Figure 6), hydrologically uniform, surrounded by other units, not as directly connected. The detailed data from the testing wasn't available for the present study.

Another important study performed in 1985, which involved the connection between the Oradea geothermal reservoir and the one in Băile-Felix (Bratu et al., 2017). The latter has an important economic, cultural and societal role because of the spas operated there. Therefore, it was considered important to evaluate the possible pressure interference between the two reservoirs, which are located approximately 8 km apart. On basis of that study, a maximum production limit was set for Oradea, in order to minimize the possible negative effect of production there on the flow from wells in Băile Felix. This study wasn't available for the present work, but the result were used by the Romanian authorities to set a conservative initial limit for the geothermal exploitation in Oradea of 90 L/s on the average annually, since possible influence on other geothermal reservoirs nearby were not well understood.

In 1999 Transgex completed geological and hydrogeological modelling of the Oradea geothermal system, which included the development of a two-dimensional numerical model (see sub-chapter X1.3 above) simulating temperature and pressure conditions in the system Bratu et al. (2017). Through the geological model, the boundaries of the system were defined, consequently used for the numerical model. Future predictions were calculated by the numerical model for several 30-year utilization scenarios, with the following results (Bratu et al., 2017):

1) Average production of 60 – 70 L/s (comparable to present utilization) from 11 production wells, with 1 reinjection well. Predictions indicated only minor pressure decline.
2) Average production of 180 – 190 L/s, utilizing the same wells as in 1). Predictions indicated a pressure decline of 0.5 – 4.5 bar in 5 years.
3) Average production 170 L/s from 8 production wells and 140 – 150 L/s injection into 6 reinjection wells. Predictions indicated limited pressure draw-down, except in the NW-section of the model (~2 bar). Cooling due to reinjection doesn't reach production wells during prediction period.
4) The fourth scenario involved an even greater increase in production (~240 L/s), but with a corresponding increase in reinjection (~210 L/s), i.e. no increase in net mass extraction. Predictions, therefore, indicate limited pressure draw-down, but some location specific cooling.

It should also be pointed out that some volumetric assessments have been performed for the Oradea geothermal system, e.g. by Transgex (2015).

Bratu er al. (2017) and Transgex (2015) present the following principal parameters of the Oradea geothermal reservoir, some of which are derived from the evaluations mentioned above:

- The reservoir rock (dolomitic limestone) is characterized by double porosity; a fracture porosity of about 10% and matrix porosity of about 2%, with an average of about 7%.
- Matrix permeability is estimated to equal 0,01 mDarcy, on the average.
- Average reservoir hydraulic conductivity 0,05 m/day, corresponding to 15 mDarcy.
- The surface area of the Oradea block is estimated to be 60 km^2.
- The Oradea reservoir block is bounded on the south, west and north by apparently impermeable boundaries.
- On the east it appears to be bounded by a constant pressure boundary, supplying extensive recharge (pressure = 247 bar, temperature = 70°C).
- Reservoir depth range 1700 – 2600 m, average thickness 800 m.
- Reservoir base temperature 85 – 135°C; base pressure 230 – 315 bar.
- Bratu er al. (2017) also present values for other formation parameter such as density, compressibility, heat capacity, thermal conductivity, etc., which are not of particular relevance here.

2.4 Utilization

The Oradea geothermal resource has been utilized since 1963, or for almost 55 years. The utilization history is, therefore, amongst the longer low-temperature geothermal utilization histories world-wide. Such a long history provides very valuable experience, partly due to the apparent stability in reservoir conditions.

The Oradea utilization history can be divided into three basic periods:

1. 1963 – 1982: Exploration and drilling period; 11 wells drilled and 5 wells utilized; average total production approximately 30 L/s.
2. 1983 – 1998: Experimental production period; 11 production wells utilized; average yearly total production increased from 70 L/s to 130 L/s, but later decreased again due to restriction imposed by utilization licence.
3. 1999 – present: Utilization period; 11 production wells and 1 reinjection well utilized; yearly average utilization ranges from about 30 L/s to about 65 L/s; see table 1 and Figure 7 for detail.

For the production wells utilized in Oradea the well-head temperature is in the range of 70 – 105°C while the well-head pressure is in the range of 2.5 – 8 bar. The production well capacity is, furthermore, 5 to 30 L/s by artesian flow, but 30 – 40 L/s by pumping.

The utilization in Oradea today is presented in more detail below (chapter 3), even though specific well data won't be presented here, as they are classified.

2.5 Reassessed Capacity

The capacity of the Oradea geothermal system has been reassessed during the present study. This reassessment has been based on the following:
   a) Available data on production from individual geothermal wells and accompanying water-level changes in a few wells, reflecting changes in reservoir pressure.
   b) Other information on pressure changes in the geothermal system through the years, provided by TransGex.
   c) Results of previous assessments of the capacity of the Oradea geothermal system (see subchapter 1.3 above.
   d) Estimated capacity of existing wells.
   e) The potential benefit of reinjection.

Table 1. *Average yearly production from the Oradea geothermal system during 1998 – 2015.*

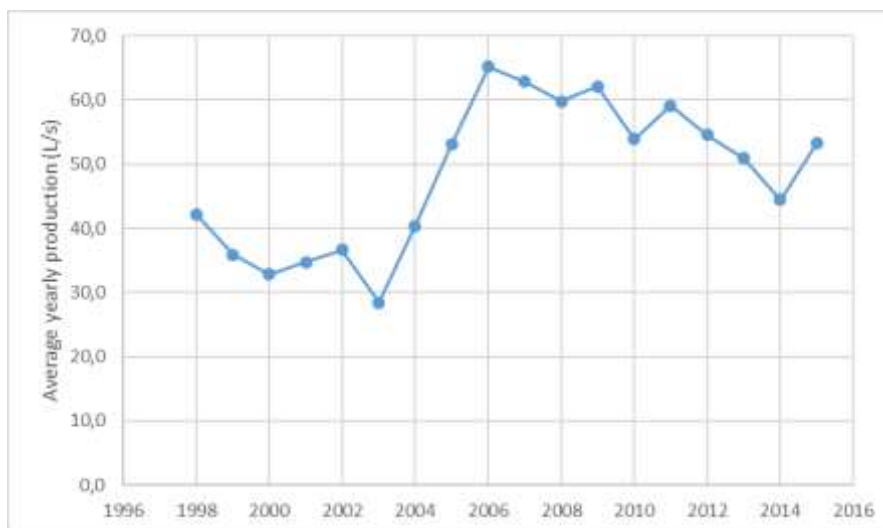| Year	Average production (L/s)	Cumulative prod. (m³)
1998	42.2	1330639
1999	35.9	1132015
2000	32.9	1037281
2001	34.7	1095932
2002	36.7	1157609
2003	28.5	897828
2004	40.4	1273616
2005	53.0	1673405
2006	65.2	2056682
2007	62.8	1982529
2008	59.8	1887905
2009	62.1	1960251
2010	53.9	1699759
2011	59.1	1866445
2012	54.5	1720877
2013	50.9	1606994
2014	44.4	1402661
2015	53.2	1679220

Figure 7: *The utilization history of the Oradea geothermal reservoir 1998 – 2015.*

Based on the data under a) above lumped parameter models (see sub-chapter 1.2 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 Oradea production wells since 1998, with details increasing as the present was approached. It turned out, however, that the water level data made available for this study were quite limited; they were only available from two wells and only extended back to 2011, but the modelling yielded quite specific indications.

More importantly, information provided (mainly by Transgex) on long-term changes in well conditions indicates that a significant long-term change in reservoir pressure hasn't occurred since large-scale utilization started in Oradea (in the 1960s). This is mainly supported by (a) the rate of artesian flow from specific wells, which doesn't appear to have changed much over time, (b) the well-head pressure of

artesian wells as well as (c) the length of time some production wells need to recover (build pressure) once production from them is stopped.

This information clearly indicates, particularly because of the very long production history, that the Oradea geothermal system is an open system (see classification above). This is supported by the lumped parameter modelling of the pressure changes in recent years. The limited chemical datamade available for this study suggests, furthermore, that general reservoir conditions haven't changed significantly during the long utilization history of the Oradea geothermal system.

In this study future reservoir pressure predictions were calculated with the lumped parameter models of the Oradea geothermal system for two future production scenarios, with the apparent open nature as a constraint. The first scenario assumed a slightly more than 50% increase in average production (based on the 2006 – 2009 period, see Figure 7), or 100 L/s average yearly production. The second scenario assumed a 100% increase, corresponding to 140 L/s annual average production. Both scenarios assumed a 50-year utilization period, from the present.

The predictions indicate that the Oradea geothermal reservoir can sustain the utilization according to both scenarios. This is because the predicted reservoir pressure changes are not too great (< 10 bar) and the production can be maintained with down-hole pumps placed at reasonable depth. The prediction results are also in an overall agreement with the results of Transgex's 1999 modelling study, presented above. It also appears that the existing wells in Oradea can support the increased production. This is because many of them are only utilized through artesian flow.

The production capacity of these wells can be increased considerably by equipping them with down-hole pumps, which would increase their capacity by a factor of approximately 2 – 3. It should be emphasised here that the characteristics of individual wells were not studied thoroughly in the present study, both because of the classified nature of the data and because of lack of information. Detailed production and water-level data from two wells were analysed accurately, however, indicating that turbulence pressure losses were quite high in both wells for some reason, not known to us (small well diameter, narrow feed-zones, scaling in wells, etc.). This needs to be kept in mind before wells, artesian at present, are equipped with down-hole pumps. It may also be pointed out, that in some cases turbulence pressure losses can be reduced, and productivity of wells increased, through acidizing (acid stimulation).

Based on the above results, our main recommendation regarding future geothermal utilization in Oradea, is that the utilization be increased in steps. First by about 50% and later (after one or more years) by another 50% (100% in all). This involves a cautious approach, necessary because of considerable 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 perhaps be increased even further.

The above recommendations must be viewed with two constraints in mind. First, Transgex's utilization licence, which may need to be expanded. Second, the possible interference from increased production in Oradea in the Băile-Felix area (lowered pressure and reduced flow). Assessing this is beyond the scope of the present work, but it's our understanding that a research project aimed at evaluating this is ongoing (see www.ahgr.ro).

It's clear that increased production in Oradea will require increased reinjection in the future. One reinjection well is already in use and another will soon be added to the operation (ongoing Rondine / EEA-grants project "Development of geothermal energy to produce heat for consumers connected at the substation PT 902 and the reinjection of the geothermal water in the reservoir"). 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.

- Minimizing interference in the Băile-Felix area.

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 Oradea geothermal resources have now been utilized for 55 years, without major changes in reservoir conditions. This clearly indicates that the Oradea 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 this need to be confirmed through accurate modelling of the geothermal system. It should also be pointed out that sustainable development also needs to incorporate economic, environmental and social issues (Axelsson, 2016b).

5.6 Recommendations

- Geothermal utilization in Oradea should be increased in steps, the first one of the order of 50%, which can soon be followed by another 50%.
- 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.
- A detailed numerical modelling should be set up for the Oradea geothermal system and neighbouring reservoir blocks, with which accurate future predictions can be calculated.
- 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 specific production wells.
- Lessons learned in Oradea, 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.

3. Current status of the utilization

3.1 Central District Heating in Oradea

The district heating system is extended in the city, which consist of the primary and secondary heating network together with the heat substations (PT). Currently the heat source is a combined heat and power plant (CET) which has been in operation since 1966. The plant is now running on natural gas, the boilers and turbines were renovated 2016 by replacing coal as an energy source. The primary system (SACET) consists of 88 km transport network from the heat plant to the 149 heat exchanger substations (PT) which serve the secondary networks of 142 km distributing district heating (DH) and hot tap water (HTW) to the local population. The pipeline system consists of pre-insulated buried pipeline and classical pipeline above surface or in concrete canals.

Due to the old pipeline system, the heat and water losses are significant in the system, which means serious economic losses for the heating company hence the local population. Ongoing projects aiming to decrease these losses is a main target for Municipality, however the renovation depends on their financial capacity and support from EU countries.

In the city, the district heating supplies approximately 145 000 people with district heating (DH) and hot tap water (HTW), comprising around 65 000 apartments and houses. The renovation of the heat substations PT is in progress. The production of DH and HTW is in co-generation with electrical production at CET where the demand for heat is the governing operation parameter delivered via plate exchangers in the substations with heat meters installed at the entry point of them.

Well number	Thermal energy [Gcal/year]	Percentage [%]
CET- thermal production	853.613	96
Geothermal production	39.022	4
Total	892.635	100

Table 2: DH and HTW production in Oradea 2015 (Foghis, UNU-GTP 2016/14)

3.2 Geothermal energy produced

In the area of Oradea thirteen geothermal wells have been drilled (eleven for production and two for reinjection), which supply heat for hot tap water production and district heating in the city in co-operation with the municipal district heating company, Termoficare. Transgex S.A. holds the geothermal utilization right and operates these wells. These wells are geographically spread within the city limits and mostly operated isolated from each other. Four main geothermal centres can be identified in the city, Iosia Nord, Nufarul, University of Oradea and Iosia South (Calea Aradului), where the utilization of the geothermal energy is leading. Due to this island mode of operation, the best target for the city to increase the use of geothermal energy is to further develop these centres, expanding their border by connecting them to additional heat stations operated by Termoficare. Out of these four geothermal centres, Iosia is the one most developed, currently operating two geothermal wells. Figure 8. shows the location of the wells, while Table 3 presents the current working parameters of these wells.
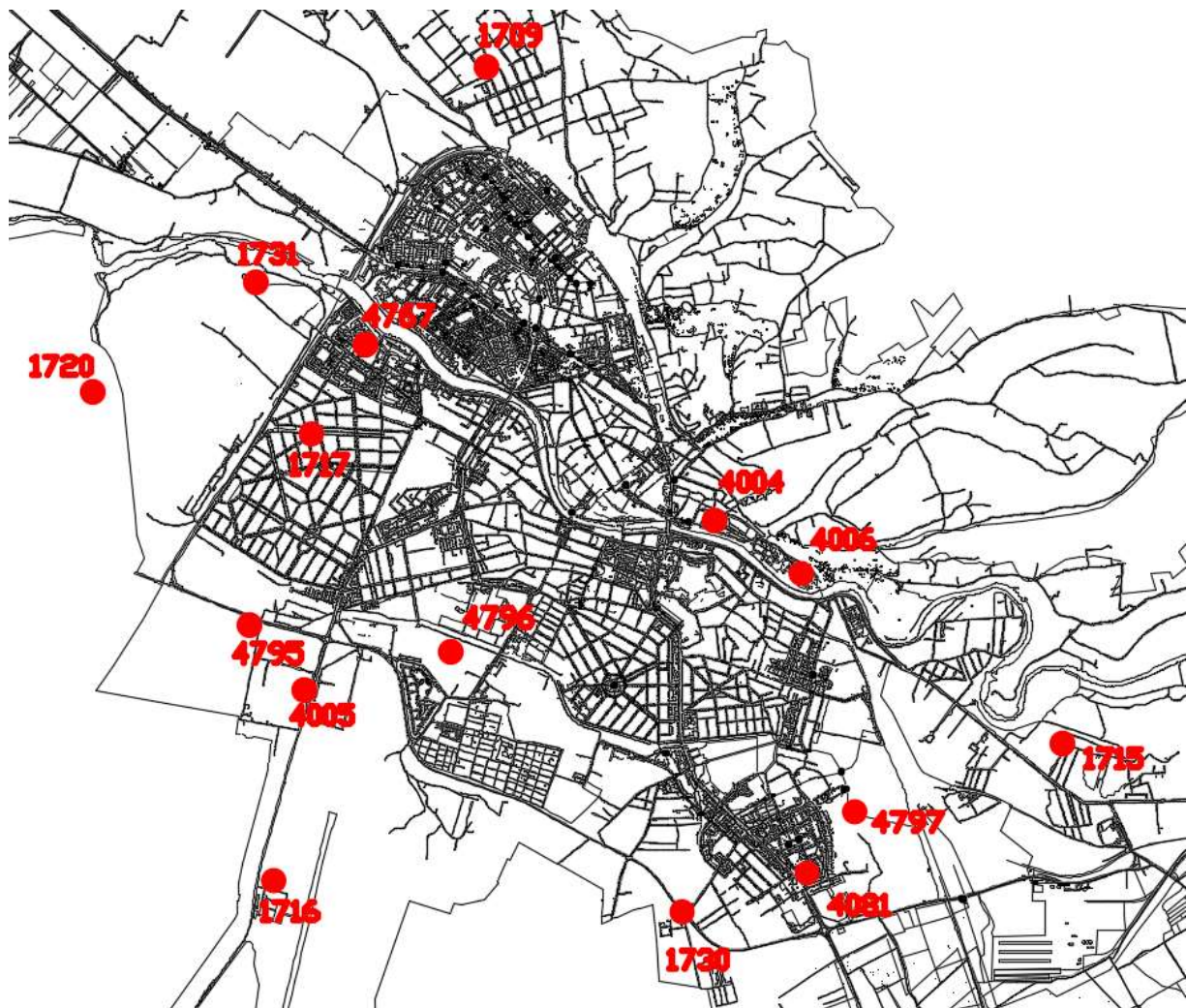

Figure 8: Location of the geothermal wells in Oradea

No.	Well number	Type	Production mode	Maximum flow rate [l/s]	Temperature [°C]
1	4005	production well	artesian flow	7	87
2	4767	production well	LSP	30	102
3	4797	production well	LSP	35	72
4	1715	production well	artesian flow	30	72
5	1716	production well	submersible pump	5	81
6	1717	production well	LSP	15	97
7	4004	production well	artesian flow	8	83
8	4006	production well	artesian flow	8	80
9	4796	production well	artesian flow	33	84
10	4795	production well	submersible pump	5	90
11	1709	production well	LSP	22	102
12	4081	reinjection well	-	-	-
13	4087	reinjection well	-	-	-

Table 3: Existing well parameters

3.3 Geothermal Heating system in Iosia Nord

The Iosia geothermal centre operates a heat plant serving the district shown on **Error! Reference s ource not found.**Figure 9. The geothermal subsystem is isolated from the greater primary district heating system of Oradea. The area is supplied by two geothermal wells covering 99% of the heat demand.

Figure 9: Area currently supplied by geothermal energy in Iosia Nord

The layout of the existing heating system is shown on Figure 10. The locations of the existing wells (1717 and 4767) are indicated in yellow, the heat plants are indicated in red. The Geothermal Heat Plant in North Iosia is marked with brown. The geothermal heat plant consists of geothermal plate heat exchanger and two 1.6 MW$_{th}$ natural gas fired boiler serving as a backup and peak source when the geothermal wells cannot cover all the demand. For example, during the last winter, which was the coldest season for a decade, one of the gas boilers had to be operated at its minimum capacity.
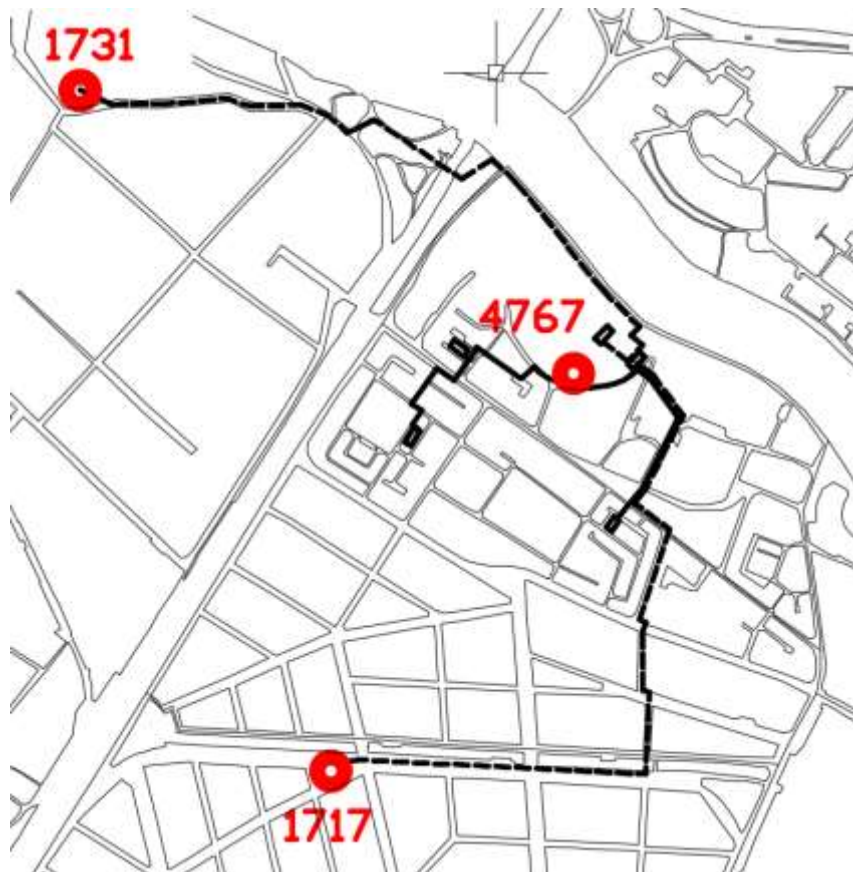
Figure 10: Layout of the existing system in Iosia Nord

The wells are connected to the geothermal heat plant by a geothermal pipeline. In the geothermal heat plant the heat is transferred to the distribution system through heat exchangers. The distribution system transports the heat energy to the heat plants, marked with red circles, where it is transferred to the secondary system supplying the buildings. The cooled fluid in the distribution system returns to the geothermal heat plant.

3.3.1 Well parameters

The following table shows the well parameters of the two wells currently in use and an unused well (1731) with potential connection to the system.

Well number	Temperature [°C]	Flow rate [l/s]
1717	97	15
4767	102	30
1731	92	9

Table 4: Existing well parameters in Iosia Nord

3.3.2 Geothermal production pipeline

The length of geothermal production pipeline in operation is 1 580 m and the diameter of the pipelines is DN125.

3.3.3 Distribution system

The heat plants are connected to the geothermal heat plant by the distribution pipeline network. The length of the network is approximately 975 m, the diameter of the pipelines is DN150 - DN250.

The forward/return temperatures vary and are controlled according to the ambient temperature.

3.4 Geothermal heating system in Nufarul

In the Nufarul district one production and one reinjection well are, which supply seven substations with geothermal energy, which is used only for hot tap water. The capacity of the geothermal substations is 5 MW$_{th}$ and the following table shows the working parameters of the production well. The heating of the buildings are supplied from the primary district heating system.

Well number	Temperature [°C]	Flow rate [l/s]
4797	72	35
4081		

Table 5: Existing well parameters in Nufarul

Figure 11: Layout of the existing system in Nufarul

The built-in heating capacity is presented in the next table:

Heat station	Heating capacity [kW)
PT839	2 275
PT840	3 088
PT844	4 225
PT845	3 705
PT863	1 625
PT878	1 495
PT883	3 640
Total	20 053

Table 6: Heating capacity of the heat stations in Nufarul

3.5 Geothermal heating system in Iosia South (Calea Aradului)

Currently production well 4005 in Calea Aradului district supplies to substations PT 911 and 913 with geothermal energy, used for only hot tap water production. The well is operating with artesian flow. The other well 4795 is operated isolated with submersible pump suppling heat to local consumers.

The opportunity to increase geothermal utilisation

Well number	Temperature [°C]	Flow rate [l/s]
4005	87	7
4795	90	5

Table 7: Existing well parameters in Nufarul

Figure 12: Layout of the existing system in Calea Aradului

The built-in heating capacity is presented in the next table:

Heat station	Heating capacity kW	Hot tap water capacity kW
PT911	1 460	320
PT913	3 480	560
Total	4 940	880

Table 8: Heating capacity of the heat stations in Calea Aradului

3.6 Geothermal heating system in University district

At the University, the well 4796 supplies DH and HTW to all the university buildings as well as PT 902 substation. In the well is a line shaft pump with the capacity of 45 l/s and water temperature 84°C. The University uses max around 18-19 l/s so the remaining well capacity can fully supply the PT 902. The PT 902 has a 100 % back-up capacity from the primary DH network, 2,7 MW$_{th}$. In conclusion, the well 4796 needs additional consumers to fully utilize its capacity.
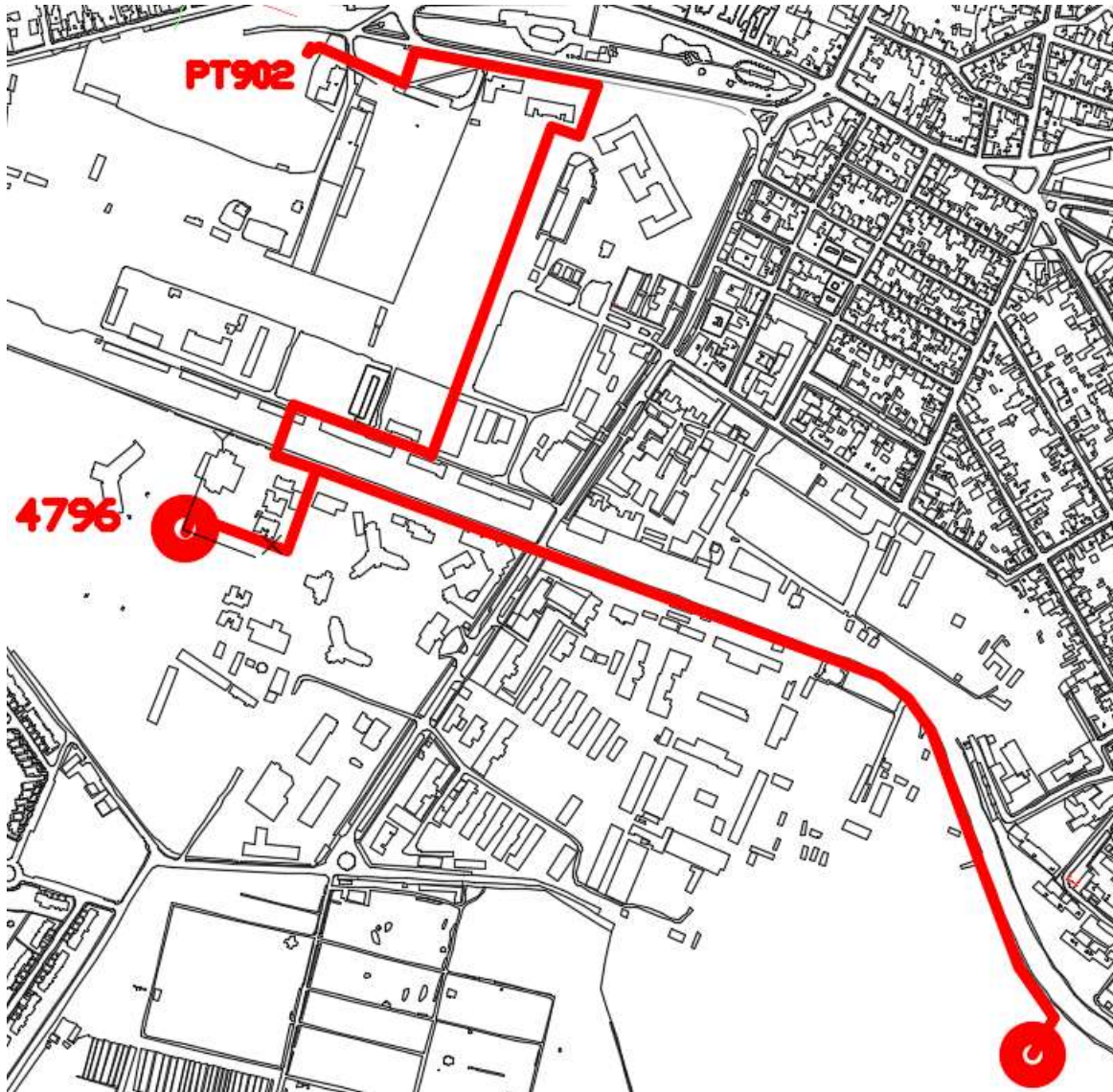

Figure 13: Layout of the existing geothermal system connected to University well 4796

4. Expand Geothermal Utilisation at Iosia Nord

4.1 Current heat market

Existing status of the CTG Iosia Nord Geothermal System:

Current geothermal system is running with two wells (4767, 1717), supplying a geothermal heat plant with a capacity of 8.2 MW$_{th}$, the provided heat amount is 112 750 GJ (located next to Well 4767) to three geothermal sub-stations (512, 513, 514).

Designation	Capacity [MW$_{th}$]	Energy [GJ/year]	CO$_2$ emission [t]
Gas	1,1	59	3,7
Geothermal	7,1	112 691	-
Total	8,2	112 750	3,7

Table 9: Data of the CTG Iosia Nord Geothermal Heat Plant, existing status

The yearly heat demand/supply diagram of the existing system is shown on Figure 14. The area with green colour indicates the energy supplied by geothermal wells and the black area shows the heat supplied by gas boilers.

As the figure shows the geothermal energy in great majority of the time is oversized compared to the heat demand of the supplied consumers.
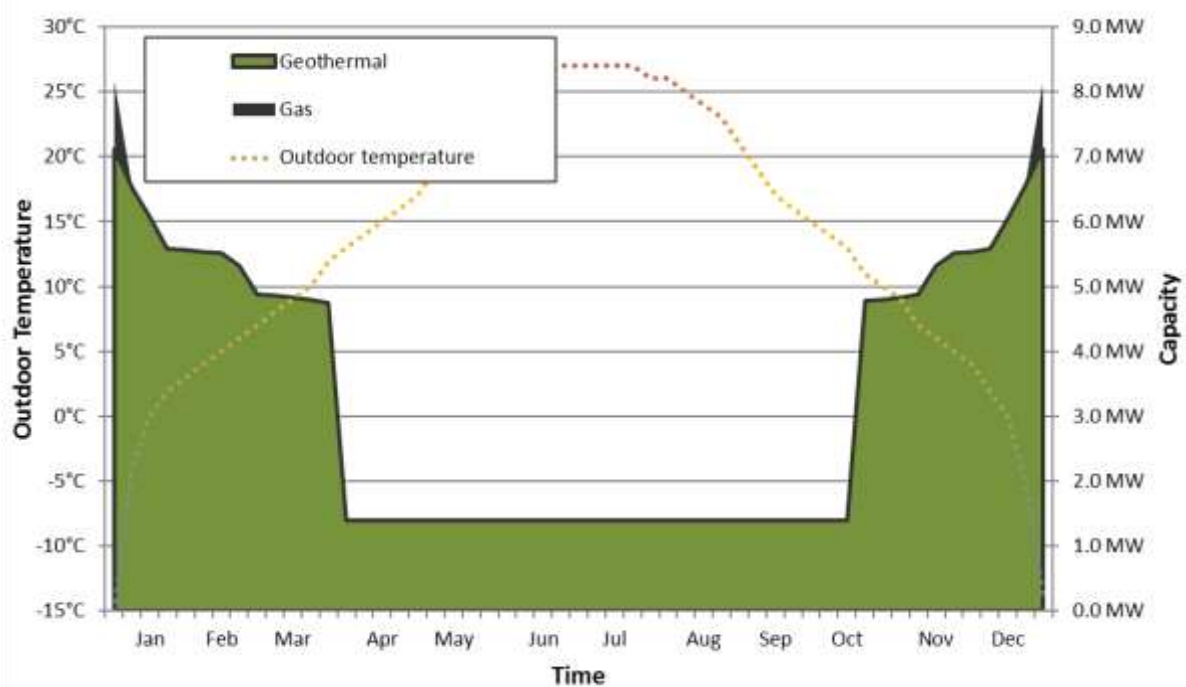
Figure 14: Current heat demand and heat supply

A system extension at Iosia Nord area includes the following points:

- Connection of the 1731 well to the geothermal subsystem;
- Remove all the gas boilers from the geothermal heat plant and attach it to the primary loop of the district heating system to receive additional heat during peak season;
- Attach as much sub-stations to the geo system as possible to make the geothermal subsystem feasible, their capacity demand is marked in the next table:

Heat station	Heating demand [kW]	Tap water demand [kW]
PT506	770	120
PT507	570	130
PT509	1500	280
PT510	3540	240
PT511	2020	200

Table 10: Demand of the nearest heat stations

Possible additional well (1731):

Currently, the well provides 92°C temperature geothermal fluid with 9 l/s flow rate. The well will be refurbished and new well pump will be installed. Due to the planned upgrade of the well, 20 – 25 l/s flow rate could be reached as maximum flow.

4.2 Scenario analysis

In all scenarios, the existing natural gas fired backup boilers are replaced by a connection pipeline indicated in light blue to the greater city district heating system (CET). The connection will serve as a backup in peak heating demands and possible interruptions in operation of the geothermal well pumps.

4.2.1 Scenario 1

Since the capacity of the existing wells (1717, 4767) exceed the all year heat demand of the currently supplied heat stations (512, 513, 514) the connection of additional heat stations (510, 511) is evaluated in this scenario.

Designation	Capacity [MW$_{th}$]	Energy [GJ/year]	CO_2 emission [t]	Energy balance [GJ/year]	CO_2 balance
Gas	4,4	10 082	635	+10 023	+631,3
Geothermal	7,1	149 559	-	+36 868	-2 322,7
Total	11,5	159 641	635	+46 891	-1 691,4

Table 11: Data of the CTG Iosia Nord Geothermal Heat Plant, Scenario 1

Figure 15 depicts that while the supplied geothermal energy to the extended geothermal subsystem (five heat stations) is increased, the need for additional heat capacity during peak season is also increased. The peak heat demand during the coldest days of the heating season is supplied by the city district heating network through the backup connection.

It can be determined that the current geothermal heat plant can cover the heat demand of the new heat stations during summer and only small capacity increasing in needed in order to be able to supply the heat demand during winter. General it means that the current production wells exploit more energy from the reservoir without and kind of modification in the geothermal side. The CO_2 emission of CET will decrease because the energy difference will supply from geothermal source which is 36 868 GJ i.e. 1 691,4 t CO_2 emission can be saved in Oradea.
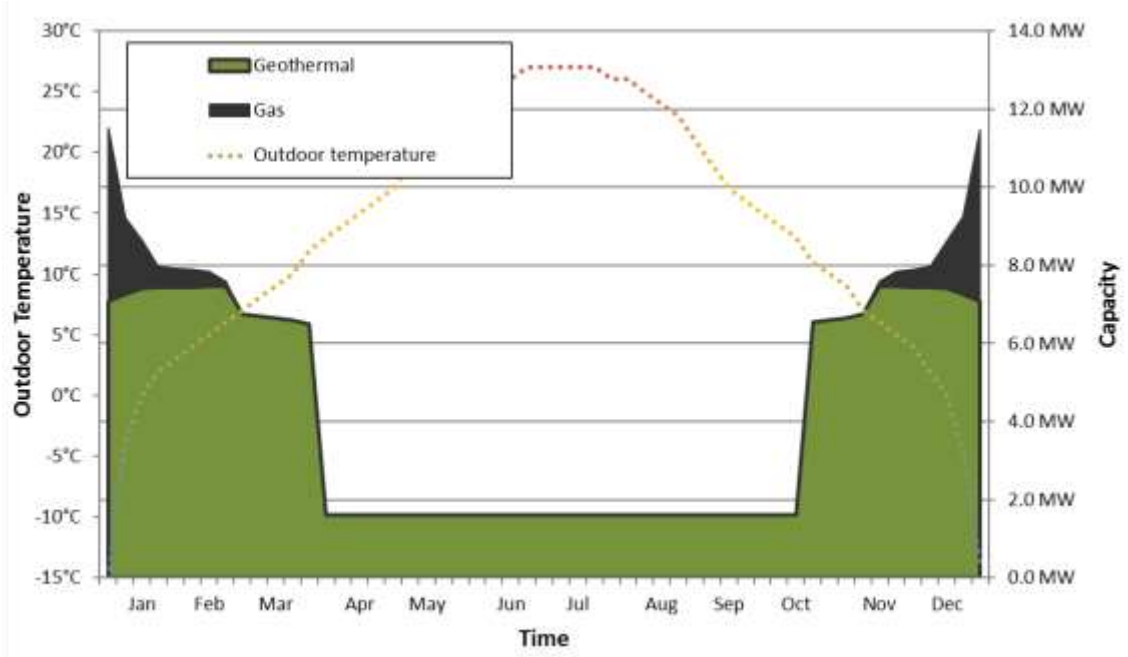
Figure 15: Heat demand and heat supply in Scenario 1

Figure 16 shows the layout of the extended network. The possible route of the extension is indicated in yellow and the newly connected heat stations are indicated with yellow circles.
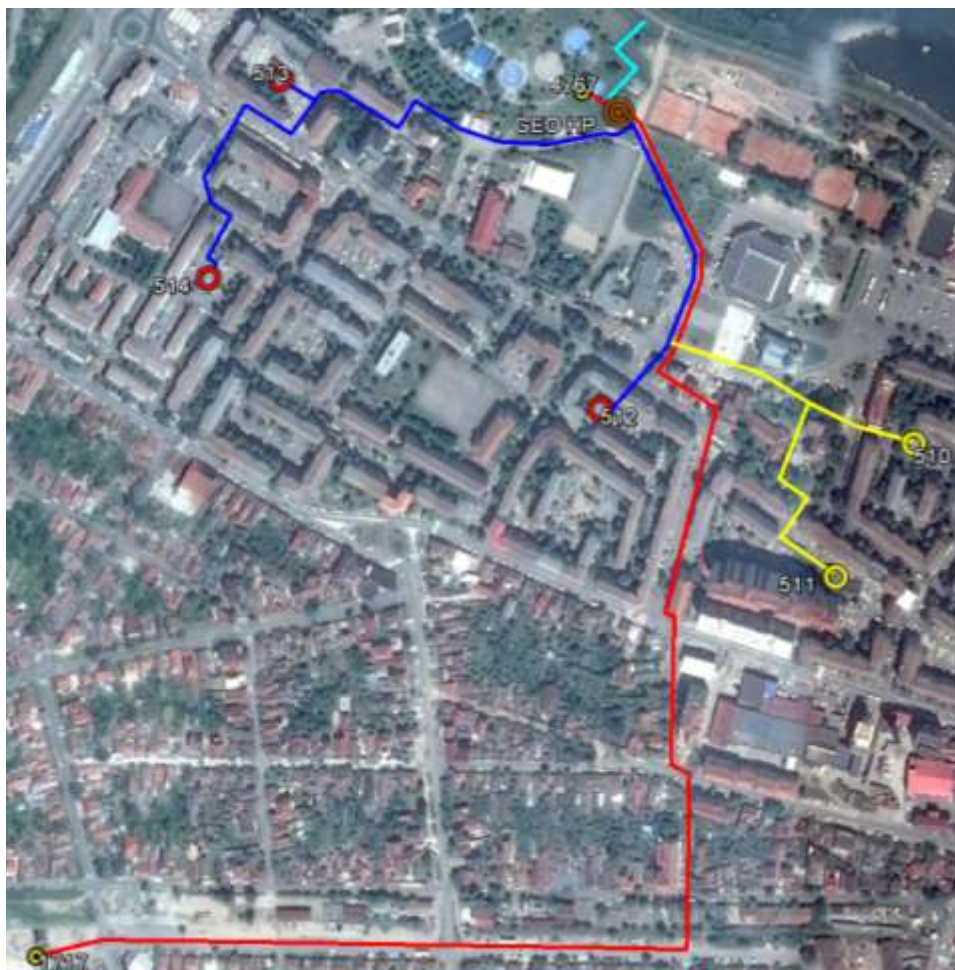

Figure 16: Layout of the extended geothermal network, Scenario 1

4.2.2 Scenario 2

In this scenario, a new artesian well (1731) is connected to the geothermal subsystem to further utilize the geothermal energy supplied to the extended heat network. The advantage of this case is that the additional well does not require a pump since there is positive pressure in the well resulting in an outflow temperature of 92°C and a flow rate of 9 l/s.

Designation	Capacity [MW$_{th}$]	Energy [GJ/year]	CO_2 emission [t]	Energy balance [GJ/year]	CO_2 balance
Gas	3,2	2 787	175,6	+2 728	+171,9
Geothermal	8,3	156 854	-	+44 163	-2 782,3
Total	11,5	159 641	175,6	+46 891	-2 610,4

Table 12: Data of the CTG Iosia Nord Geothermal Heat Plant, Scenario 2

Figure 17 shows that the energy supplied by the three wells is slightly higher than in Scenario 1. Consequently, the extra heat demand from the district heating system is decreased.
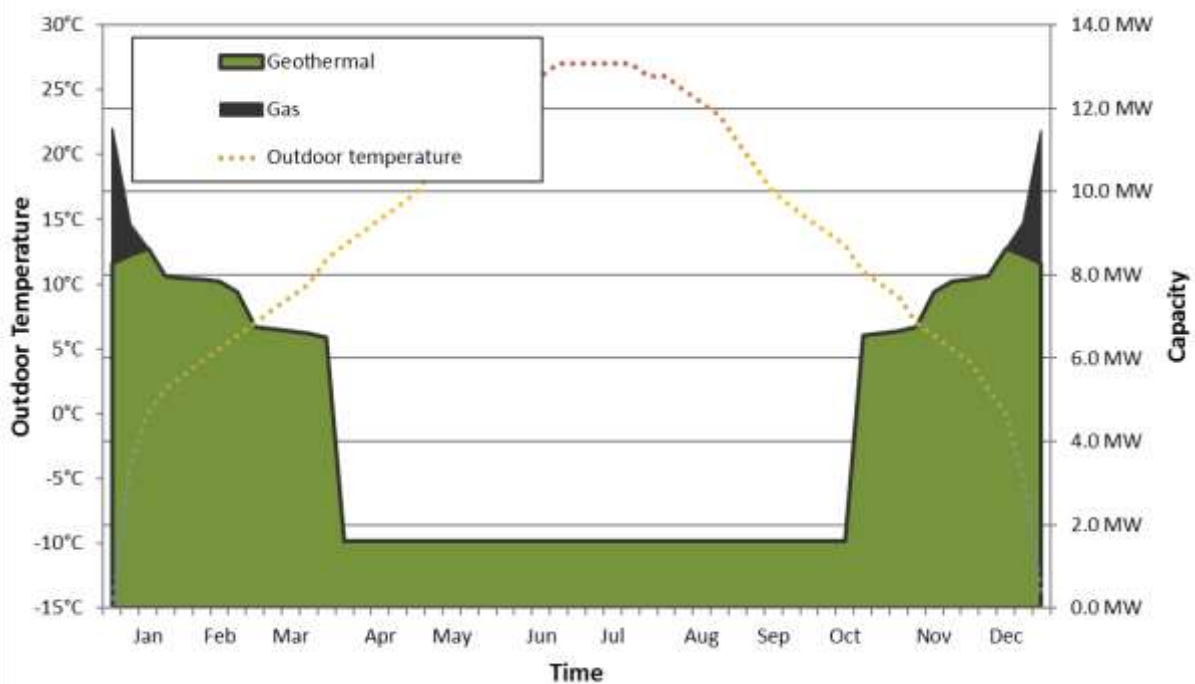

Figure 17: Heat demand and heat supply in Scenario 2

Figure 18 shows the layout of the extended network. The geothermal pipeline, indicated in green, connecting well no. 1731 is 1406 m long with DN150 diameter.
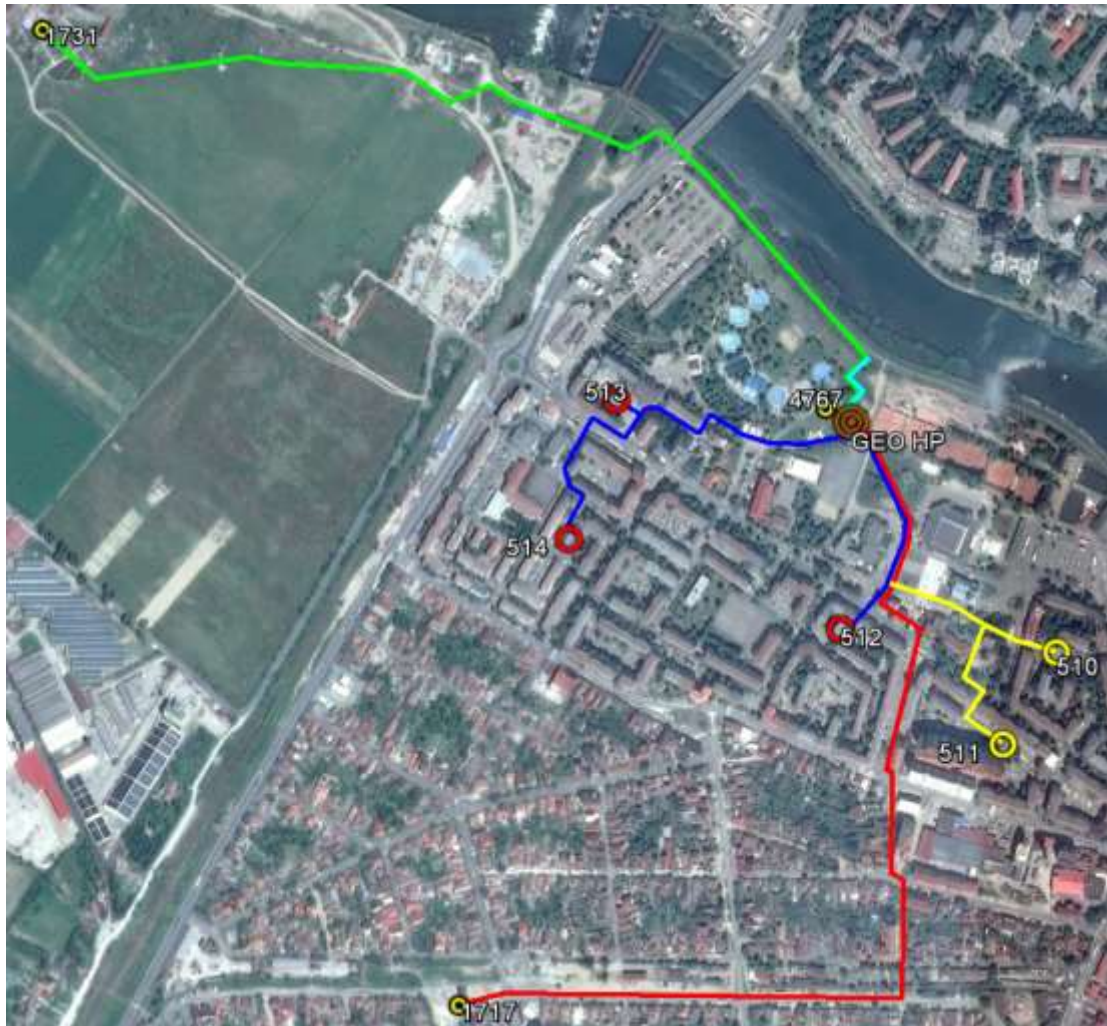
Figure 18: Layout of the extended geothermal network, Scenario 2

4.2.3 Scenario 3

This scenario evaluates the rate of heat utilization with an increased flow rate from the new well (1731). In this case, the flow rate of the new well is between 20 – 25 l/s.

Designation	Capacity [MW$_{th}$]	Energy [GJ/year]	CO_2 emission [t]	Energy balance [GJ/year]	CO_2 balance
Gas	1,6	147	9,3	+88	+5,2
Geothermal	9,9	159 494	-	+46 803	-2 948,6
Total	11,5	159 641	9,3	+46 891	-2 943,4

Table 13: Data of the CTG Iosia Nord Geothermal Heat Plant, Scenario 3

Figure 19 shows that the energy supplied by the three wells with increased flow rate from well no. 1731 is slightly higher than in Scenario 2. Consequently, the extra heat demand from the district heating system further decreased.

Considering the energy and CO_2 balance in this scenario it can be stated that this solution decrease significantly the CO_2 emission in the city while the heat stations and the new well are close to the current system.

Figure 19: Heat demand and heat supply in Scenario 3

4.2.4 Scenario 4

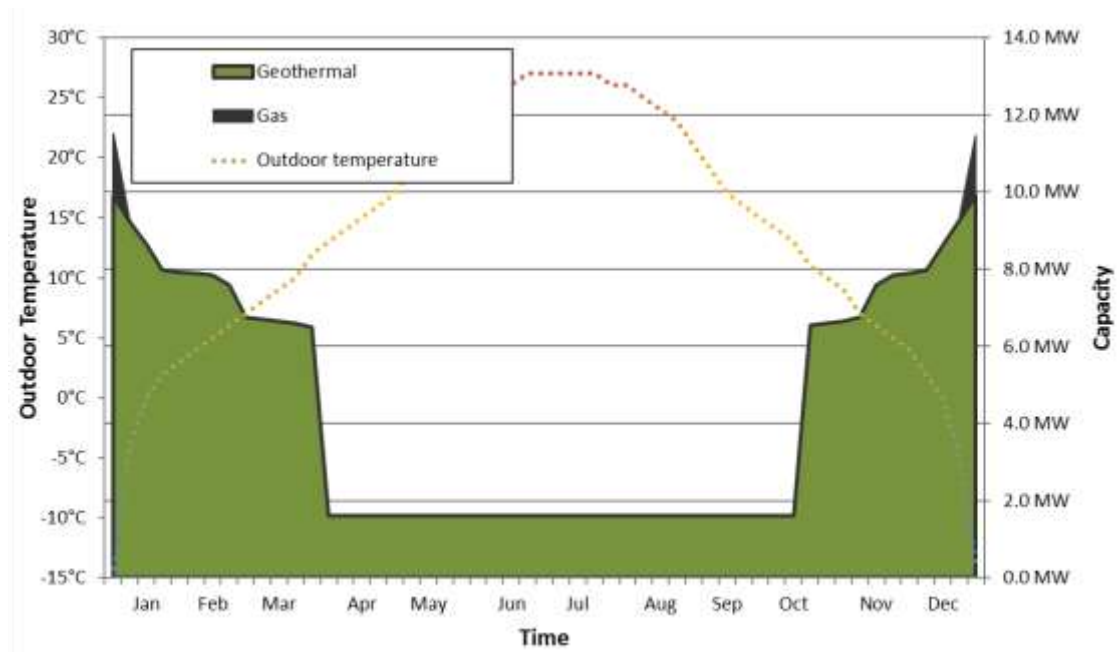Scenario 4 examines the possibility of further extending the number of heat stations that can be supplied considering the optimal proportion of geothermal energy in the system.

Designation	Capacity [MW_{th}]	Energy [GJ/year]	CO_2 emission [t]	Energy balance [GJ/year]	CO_2 balance
Gas	9,9	41 503	2 614,7	+41 444	+2 611
Geothermal	9,9	233 599	-	+120 908	-7 617,2
Total	19,8	275 102	2 614,7	+162 352	-5 006,2

Table 14: Data of the CTG Iosia Nord Geothermal Heat Plant, Scenario 4

As a rule of thumb the geothermal resource is used optimally if the installed capacity equates to the installed capacity of the backup gas boilers leading to covering 85% of the yearly heat demand. Considering the above-mentioned estimation an additional 115 461 GJ can be supplied to selected heat stations besides the already connected five heat stations (510; 511; 512; 513; 514). This energy is sufficient to supply approximately 2 000 apartments. Further research is needed to determine which heat stations from 500 to 508 is suitable for connecting to the geothermal subsystem.
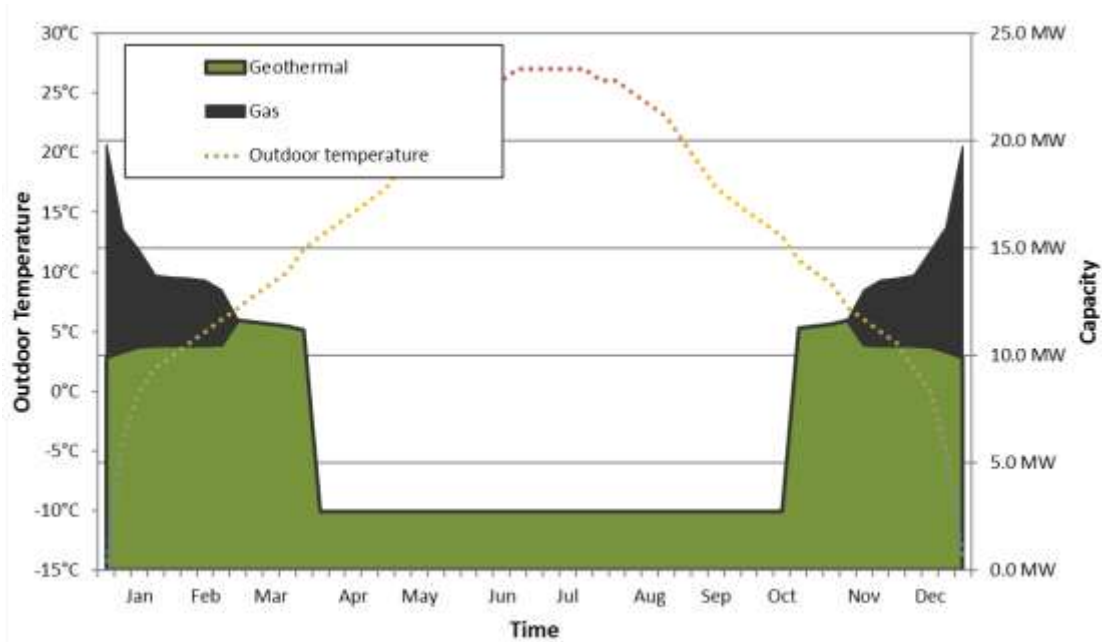
Figure 20: Heat demand and heat supply in Scenario 4

4.2.5 Summary of scenarios at Iosia Nord

The next table summarize the above calculated solutions. It can be stated generally, the better the utilization of the geothermal energy is, the more heat stations are connected to the system because in this case the production wells can run all the year almost with the same flow rate which ensure the most significant save in primary energy and CO_2 emission. The geothermal energy is prime for base heat source while the peak demand should be covered with gas boilers or from other renewable energy, e.g. biomass.

Designation	Gas [MW$_{th}$]	Energy [GJ/year]	CO_2 [t]	Geothermal [MW$_{th}$]	Energy [GJ/year]	Geo. balance [GJ/year]	CO2 balance [t]
Current	1,1	59	3,7	7,1	112 691	-	-
Scenario 1	4,4	10 082	635	7,1	149 559	36 868	-2 322,7
Scenario 2	3,2	2 787	175,6	8,3	156 854	44 163	-2 610,4
Scenario 3	1,6	147	9,3	9,9	159 494	46 803	-2 943,4
Scenario 4	9,9	41 503	2 614,7	9,9	233 599	120 908	-5 006,2

Table 15: Summary of the scenarios at Iosia Nord

These four different scenarios describing present the next possible step in Oradea however the geothermal potential is much higher in the area, so the further utilization is possible according to the geological chapter. As it is stated 50% increase is possible in the first step, which means the 80 l/s yearly average. The extension of Iosia means 23 l/s increasing in the reservoir during the heating season, while during non-heating season the estimated flow rate is 5 l/s. The potential of the reservoir is able to fulfil the heating requirements in Nufarul or other heat stations can be connected to the geothermal system in Iosia. The advantage of these area is that, that the primary heating network is on site, it can provide the backup or the peak load for the geothermal system during the coldest period in the year. As it was presented in Scenario 4. the geothermal source can supply other heat stations in Iosia so the potential is significant on this area and it is possible to increase the utilization of the reservoir. In the crossing of Lapusulum and Onestilor streets, the geothermal loop can be connected easily to the existing primary heating system. With this solution, other five heat stations (509, 516, 910, 911, 913) can be supplied from geothermal energy.

5. Other Expansion Opportunities for Geothermal Utilisation in Oradea

5.1 Expanding Nufarul geothermal

Expand the function of the geothermal heat station in Nufarul to overtake the district heating in the municipal substations, chapter 3.4. Currently the Nufarul station supplies only hot tap water for these substations by using wells 4797 as a production well in artesian mode and well 4081 as a reinjection well. Well 4797, which delivers max 15 l/s with water temperature of 72°C in artesian mode, has a line-shaft pump installed since 2008 with a capacity of 45 l/s, which has not yet been used.

If the operation of Nufarul geothermal station would be expanded to supply also DH in these substations, it could fulfil their heating demand almost half of the year. The geothermal energy can produce annually approximately 128 500 GJ energy, while other 120 000 GJ is needed from the primary district heating system. The hot tap water demand is about 40 000 GJ in the whole year, so it means addition 78 500 GJ/year can be produced from the geothermal energy. This amount of energy can save ca. 4 735 t CO_2 emission in the city. The next figure shows the splitting of the geothermal and primary district heating energy in this scenario.
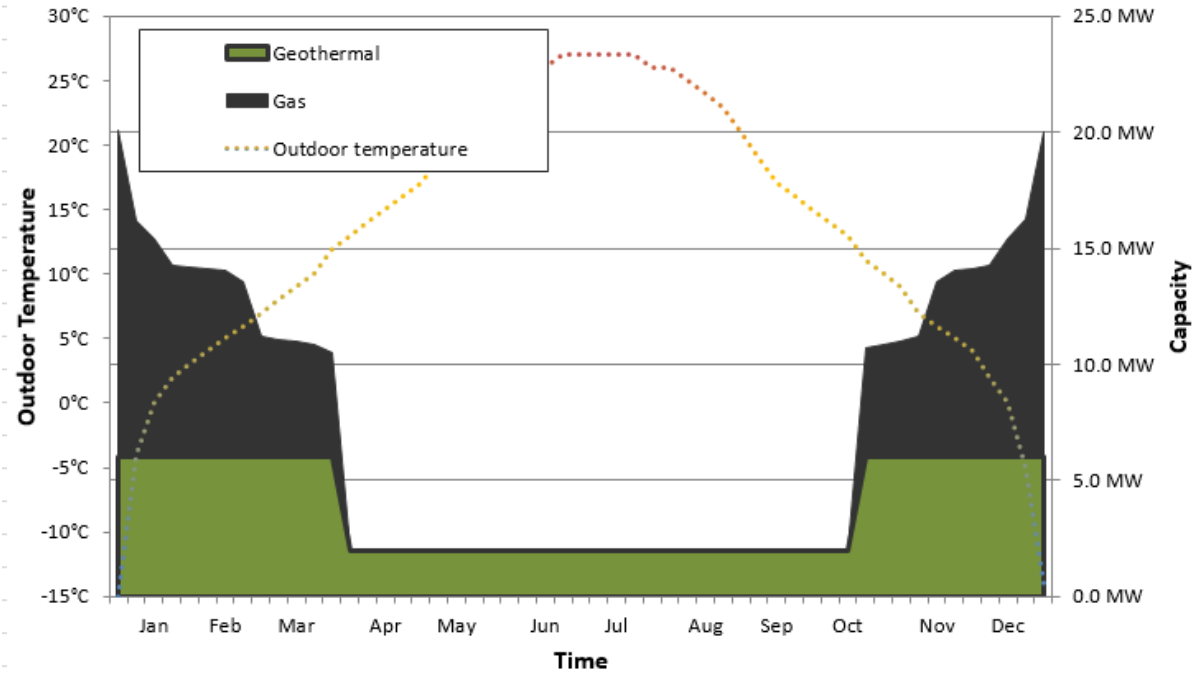
Figure 21: Heat demand and heat supply in Nufarul

This scenario can be expanded towards to the closest neighbours, to Sanmartin and Felix. Estimated annual heat demand not known. Other possibility is to expand the system toward to north-west, in the direction of the city and connect more existing heat station to the geothermal system. Most likely it will be necessary to drill an additional production well to fulfil the increase in demand.

5.2 Expanding University geothermal

Expand the utilisation of the well 4796 at the University in Oradea. It has been used in artesian mode, max 20 l/s with water temperature 76°C, from the beginning to supply DH and HTW production to the University buildings. Early 2017 a line-shaft pump was installed in the well with a capacity of 45 l/s with the purpose to deliver DH and HTW to municipal substation PT902. Additionally, one re-injection well was drilled for the spent water from the 4796 well. In order to utilize the extra capacity of the well, see chapter 3.6, a very economic opportunity exist by connecting the big government/municipal buildings

along site the pipe route from the well to PT 902, being institutions in Armatei Romane area, Cadastru, ITM, Economic High School, etc. Heat load data for these buildings were not available.

5.3 Expanding Santandrei well 1720 suppling Iosia Nord

One potential production well can be found in Santandrei, well 1720. Installing a line shaft pump into the well with an estimated capacity of 75 l/s and water temperature 80°C, and connect it to nearest heat substations at SACET, PT stations 509, 516,522, 523 and 910, with an estimated peak heat demand for combined DH and HTW of 18,9 MW_{th}.

The thermal capacity of well 1720 with a flow rate of 75 l/s is 3,7 MW_{th} and 15,3 TJ/year with 0,85 utilisation factor and cooling to 35°C (DT=45 °C), i.e. annual average flow rate 64 l/s. If the well will be utilized at this rate approximately 900 t CO_2 emission can be saved in the city annually.

Currently well 1720 is only used in artesian mode at 2-3 l/s, supplying heat to a fish farm.

In this project the viability of interconnecting operation of all the wells in and close to Iosia district should be investigated:

- well 1720 in Santandrei

- wells 4797, 1717 and 1731 in Iosia Nord

- wells 4005 and 4795 in Iosia South

- well 4796 at the University

Very interesting alternative would be to interconnect them with an accumulator of appropriate size for heat (water) storage, hence:

- Increasing the available short-time capacity of the geothermal production wells;
- Increasing the GeoDH system reliability by having spare capacity in case of power outage (the well pumps stopped) and in case of well pump failure;
- Facilitating smoother operation of the well pumps by overtaking the daily load variations.

5.4 Veletna

Expanding the use of well 1715 in Velenta by connecting it to PT 836 Dragos Voda and consumers on Clujului street for DH and HTW production. The max flow capacity of the well is 30 l/s with artesian flow at 72°C however it is possible to install line shaft pump into the well to increase the flow rate. Currently the well is used in artesian mode and 6 660 m^3 water was sold in 2015, which means 0,21 l/s yearly average flow rate, i.e. this well is almost unused. According to the law, the temperature of the spent (return) geothermal water has to be lower than 40°C, so this system should operate at least 32°C temperature difference without reinjection. This mean that the capacity of this system is about 4 MWth and can produce 4,4 TJ energy in a year, i.e. 265 t/year CO_2 can be save with the furhter utilization of this well.

5.5 Ceyrat

Ceyrat district is currently under construction and as the information says, it will be heated with district heating. The primary district heating network will be extanded from PT850 and PT834 heat stations. This means, that a new geothermal well can supply the new district and the other two heat stations. This solution can have an interesting PR value for the city council the newest construction development in the city being heated with renewable energy. In order to use the geothermal at maximum as base load the new substation should be connected to the primary DH network to kick-in at peak-load and be a back-up as well. The current demand at these two heat stations is 2,52 MW heating and 0,72 MW tap water, corresponding to approximately annual 38 400 GJ heat consumption. If this consumption is supplied by geothermal energy, about 2 300 t/year CO_2 emission can be saved in the city. This amount will be bigger, if the new buildings in Ceyrat will be connected to the geothermal system, however their demand is not known.

5.6 Connection to CET

This scenario investigates the viability of using geothermal energy to participate in heating up make-up water for the CET co-generation plant. Due to current extensive pipe leakages in the primary DH network huge amount of energy is spent at CET preparing make-up water. With reduces losses in the future the geothermal energy might be able to fully over-take the preparation of the make-up water.

There exist several options worth to investigate for this project. To name some of them drilling of new well(s) into Oradea geothermal reservoir, because existing wells are far away from CET, use existing wells in Bors area, exploiting a separate geothermal reservoir and explore a potential reservoir further to the North-East from CET.

The underlying objective is to reach the most efficient utilisation of the geothermal water, i.e. maximum cooling, which is accomplished when preparing make-up for the CET as an alternative to heat HTW for individual substations PT in the district heating system.

6. Estimated investment cost at Losia Nord

In the following sub-chapters estimated investment cost for the four scenarios is outlined based on the available market information, as well as, Mannvit data bank and Mannvit experience from implementation of similar projects in Iceland and in the Pannonian basin. Cost figures are without VAT.

6.1 Scenario 1

The estimated cost for Scenario 1 includes a new pipeline connecting heat stations no. 510 and 511 to the geothermal distribution system. The length of the new pipeline is approximately 440 meters. The diameter required to supply the heat demand is DN100-150. The cost estimation also includes the cost of backup connection to the greater city district heating network through a 104 meters long pipeline including a total 4,4 MW heat exchanger capacity in the geothermal heat plant due to the increased backup capacity demand. Additionally, the connected heat stations need to be remodelled in order to prepare them for the connection. The installation of new equipment includes heat exchangers, sensors, valves, pumps, piping etc.

Designation	EUR
Distribution pipeline to 510, 511	140 000
Backup pipeline	33 000
Extension of GHP	600 000
Heat stations 510, 511	143 000
TOTAL	916 000

Table 16: Investment cost of Scenario 1.

6.2 Scenario 2

The estimated cost for Scenario 2 includes a new pipeline connecting heat stations no. 510 and 511 to the geothermal distribution system. The length of the new pipeline is approximately 440 meters. The diameter required to supply the heat demand is DN100-150. The cost estimation also includes the cost of backup connection to the greater city district heating network through a 104 meters long pipeline including a total 3,2 MW heat exchanger capacity in the geothermal heat plant due to the increased backup capacity demand. Additionally, the connected heat plants need to be remodelled in order to prepare them for the connection. The installation of new equipment includes heat exchangers, sensors, valves, pumps, piping etc. In Scenario 2, the necessary equipment and work related costs regarding the connection of well no. 1731 to the geothermal heat plant are also included involving the extension of the existing geothermal heat exchanger capacity by 1,2 MW.

Designation	EUR
Distribution pipeline to 510, 511	140 000
Backup pipeline	33 000
Extension of GHP	550 000
Heat stations 510, 511	143 000
TOTAL	866 000

Table 17: Investment cost of Scenario 2.

6.3 Scenario 3

The estimated cost for Scenario 3 includes a new pipeline connecting heat plants no. 510 and 511 to the geothermal distribution system. The length of the new pipeline is approximately 440 meters. The diameter required to supply the heat demand is DN100-150. The cost estimation also includes the cost of backup connection to the greater city district heating network through a 104 meters long pipeline including a total 1,6 MW heat exchanger capacity in the geothermal heat plant due to the increased backup capacity demand. Additionally, the connected heat stations need to be remodelled in order to prepare them for the connection. The installation of new equipment includes heat exchangers, sensors, valves, pumps, piping etc. In Scenario 3, the necessary equipment and work related costs regarding the connection of well no. 1731 to the geothermal heat plant are also included involving the extension of the existing geothermal heat exchanger capacity by 2,8 MW.

Designation	EUR
Distribution pipeline to 510, 511	140 000
Backup pipeline	33 000
Extension of GHP	750 000
Heat plant 510, 511	143 000
Well pump	150 000
TOTAL	1 216 000

Table 18: Investment cost of Scenario 3.

6.4 Scenario 4

The estimated cost for Scenario 4 includes a new pipeline connecting heat plants no. 510 and 511 and further heat plants to the geothermal distribution system. The diameter required to supply the heat demand is DN100-150. The cost estimation also includes the cost of backup connection to the greater city district heating network through a 104 meters long pipeline including a total 9,9 MW heat exchanger capacity in the geothermal heat plant due to the increased backup capacity demand. Additionally, the connected heat plants need to be remodelled in order to prepare them for the connection. The installation of new equipment includes heat exchangers, sensors, valves, pumps, piping etc. In Scenario 4, the necessary equipment and work related costs regarding the connection of well no. 1731 to the geothermal heat plant are also included involving the extension of the existing geothermal heat exchanger capacity by 2,8 MW.

Designation	EUR
Distribution pipeline to 510, 511	190 000
Backup pipeline	33 000
Extension of GHP	900 000
Heat plant 510, 511	143 000
Well pump	150 000
TOTAL	1 416 000

Table 19: Investment cost of Scenario 4.

7. Pipe leakage

Leakage in the Oradea district heating network is a crucial problem. Although the rehabilitation of the old pipe network is ongoing, significant water losses are still measured both in the primary and secondary network. Based on the received information, the loss during heating season is 250 m³/h and 100 m³/h out of season as it is shown in Table 20.

Designation	Unit	Data
Average water loss during heating season	m³/h	250
Average water loss out of heating season	m³/h	100

Table 20: Estimated average water losses during heating season and ut of heating season

To calculate the wasted heat and the avoidable CO_2 emission, average operational data are necessary. These are listed in Table 21. and representing the heating and non-heating season of the year 2015.

Based on the received data, the average forward/return temperatures of the heating fluid, that is circulated between the CET and sub-stations, are 102.3 / 95.4°C during winter with the flow rate of 899 l/s and 85 / 60°C during summer with the flow rate of 361 l/s. These temperatures and flow rates allow us to calculate the average heat capacity that is 161 561kW during heating season and 37 823 kW during non-heating season. Calculated with 174 days below 12°C ambient temperature and 191 days above it, the provided heat amount is 2 428 840GJ in heating season and 624 167 GJ in non-heating season. As a result of this, specific heat amounts can be calculated that are listed in Table 21.

Designation	Average temperature forward °C	Average temperature return °C	Average flow rate in pipeline l/s	Average heat capacity kW	Provided heat amount per season GJ/season	Specific heat amount GJ/m³
Heating season	102.3	59.4	899	161 561	2 428 840	0.180
Out of heating season	85	60	361	37 823	624 167	0.105

Table 21: Average operational data of CET in year 2015

Calculated with the given losses which, represented in Table 20, an enormous amount of district heating water leaks out in every year. The estimated volume of it is 1 502 400 m³ that cause nearly 2 million Euros loss annually according to the received information. The required heat amount by this volume is 235 655 GJ/year. If this make-up water is heated with geothermal (assume cooling 80°C to 35°C) an annual average well flow rate of 37 l/s will be needed. Furthermore, if this heat amount is provided by natural gas burning, the emission of the heating procedure is 13 197 t CO_2 annually.

The calculation represents the worst scenario, namely, full amount of the lost water is heated and leaks from the forward pipeline network. The purpose of this calculation is to highlight the different aspects of the leaking and draws attention that immediate action shall be taken.

Designation	Duration		Water leakage m³	Estimated cost of loss € / year	Heat loss by leakage GJ	Avoidable CO_2 emission t CO_2
	Days	Hours				
Heating season	174	4 176	1 044 000	1 389 776	187 642	10 508
Out of heating season	191	4 584	458 400	610 224	48 013	2 689
Total (yearly)	365	8 760	1 502 400	2 000 000	235 655	13 197

Table 22: Estimated characteristic data of the annual water leakage

8. Leak detection and sealing technologies

There are a variety of methods that can detect leaks in pipelines, ranging from manual inspection to advanced computer based imaging. These methods are divided into two main categories: hardware based methods and software based methods as it is shown in Figure 22.
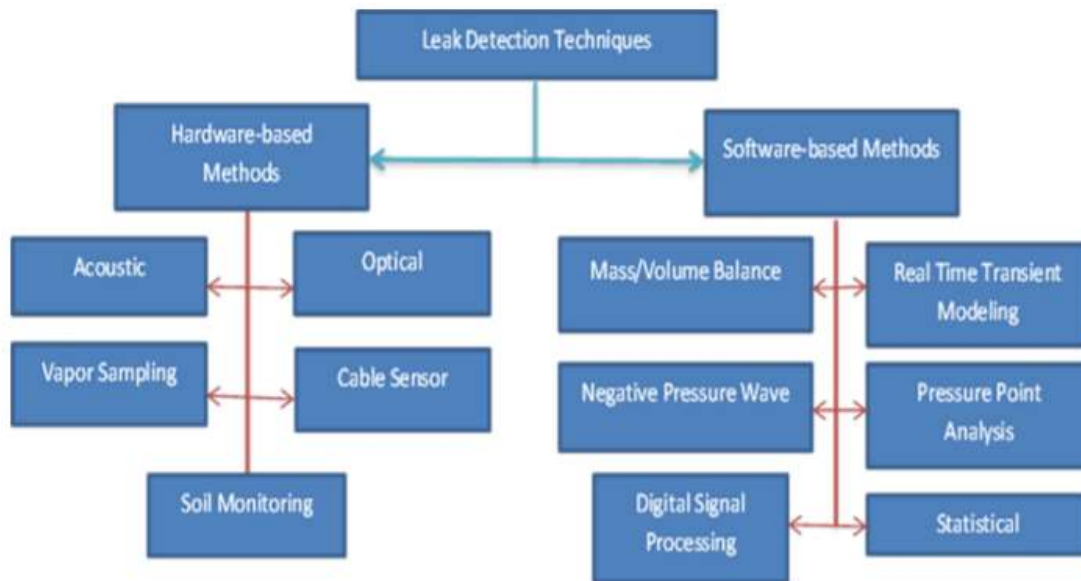

Figure 22: Leak detection techniques

The hardware based techniques detects the leaks from outside of the pipe using specific devices, in which some cases the cost is very high. On the other hand, there is the software based techniques, which deals with Software programs at their core implements algorithms continuously to monitor the state of pressure, temperature, flow rate or other pipeline parameters and can infer, based on the evolution of these quantities, if a leak has occurred. This methodology is most popular among the researchers due to the cost effective. Hardware based leak detection systems are expensive. To install this kind of hardware along pipelines that expand over hundreds of miles is expensive regardless of where the pipe is situated or what elements it runs through. It also adds more equipment that needs service and repairs. The software based systems usually only need flow, pressure and maybe temperature measurements at the inlet and outlet.

In this report, two unique methods will be discussed that are not just cost effective but the accuracy of these in leak localization are very good.

8.1 Smart Ball Technology

8.1.1 Overview

SmartBall technology combines the sensitivity of acoustic leak detection with the 100% coverage capability of in-line inspection.

The free-swimming device is spherical and smaller than the pipe bore allowing it to roll silently through the line and achieve the highest responsiveness to small leaks. It can be launched and retrieved using conventional pig traps, but its size and shape allow it to negotiate obstacles that could otherwise render a pipeline unpiggable. The SmartBall technology was originally developed and successfully implemented for the water industry, and now refined for oil and gas pipelines over 100 mm in diameter. SmartBall has been proven capable of detecting leaks in liquid lines of less than 0.006 l/s where conventional methods can detect leaks no smaller than 1 % of throughput. Development work is continuing to reduce the detection threshold still further. Whereas traditional acoustic monitoring techniques have focused on longitudinal deployment and spacing of acoustic sensors, the SmartBall uses only a single acoustic sensor that is deployed inside the pipeline. Propelled by the flow of product in the pipeline, the device will record all noise events as it traverses the length of the pipeline. This allows the acoustic sensor to pass in very close proximity to any leak whereby the sensor can detect

very small leaks, whose noise signature can be clearly distinguished. Figure 23 shows a typical SmartBall survey.
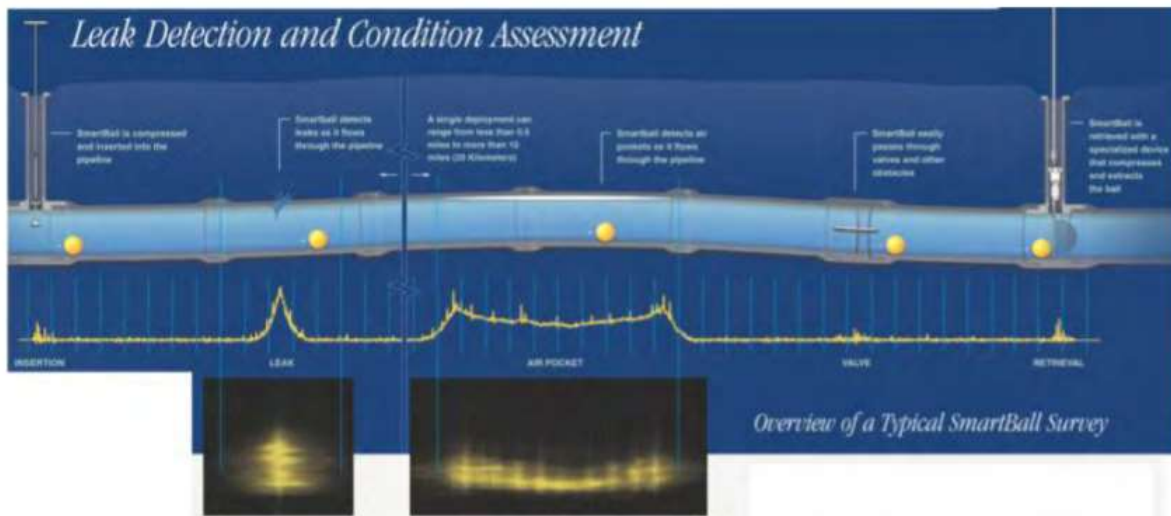

Figure 23: Overview of a typical SmartBall survey

8.1.2 Advantages of the technology

Since the SmartBall passes right past each anomaly individually from each acoustic anomaly of interest, significant advantages are recognized.

Pipe Diameter

SmartBall can be used to detect leaks on medium and large diameter pipes in the range of (>100 mm and over 2000 mm diameter) have been successfully inspected by SmartBall. Many conventional leak detection technologies (e.g. correlators) have limitations that preclude their use on medium and large diameter pipe.

Pipe Material

SmartBall's leak detection ability is not affected by pipe material. Because the tool passes by the point at which the acoustic event is being created the pipe wall is not relied on to transmit the acoustic event through the line to a sensor located far away from the actual event of interest which greatly increases it sensitivity and ability to distinguish between separate events.

Sensitivity

The sensitivity of all leak detection technologies is a function of several variables and as a result, no resolute thresholds can be established. However, the acoustic sensor inside the ball always passes within one pipe diameter of a leak and therefore it can be used to identify very small leaks due to the proximity of the tool to the leak. For example, on a 10 bar pipeline during a blind simulation was confirmed that a leak of 0.0002 l/s could be detected. Other experiences have confirmed this ability, however variables associated with a specific leak should be understood. For pipes with significant pressure of 3.5 bar or more, under ideal conditions (low ambient noise), SmartBall may detect leaks as small as 0.0002 l/s.

Length of survey

SmartBall has the ability to record acoustic data for over 12 hours. Depending on flow rates, the tool can inspect long lengths of pipe during a single deployment. The longest single recording within a water pipeline with a single deployment had the SmartBall record acoustic data and inspect a length of pipeline exceeding 48 km.

8.1.3 Limitation of the technology

Pressure

The acoustic activity associated with a leak is derived from the pressure differential across the pipe wall. With little to no pressure differential the device will not detect leakage as there will be no associated acoustic activity. Pressure is not required to identify locations of trapped gas.

Ambient Noise

SmartBall detects and reports anomalies that have acoustic characteristics similar to leaks on pressurized pipelines. However, other forms of ambient noise may be identified during the data analysis. For medium and large leaks, there is very little that can match these acoustic characteristics and therefore, these events are almost certainly leaks. For small leaks, there may be other forms of ambient noise that are difficult to evaluate. Pure has invested significant resources into characterizing acoustic anomalies and consequently believes leaks described in this report are leaks, unless otherwise noted. However, unknown pressure reducing valves, cracked valves in close proximity, interconnected pipelines that have not been completely isolated and leaks in pipelines immediately adjacent to the subject pipe do contain a similar acoustic signature and could be reported as leaks in this report. Cars, pumps, boat traffic and other forms of common ambient noise should not be reported as leaks as they contain different acoustic signatures.

Reported Locations

Reported locations contained in this report are believed to be accurate to within +/- 1.5m. This is based on project experience and the limitations of the technologies used to calculate location.

About Gas Pockets

The SmartBall detected pockets of trapped gas along this pipeline which could indicate the pipeline may benefit from additional air release valves.

8.2 Platelet Technology

8.2.1 Overview

Platelet Technology is a unique and innovative method of sealing and locating leaks in pressurised pipelines; and is adapted from the human body's own leak sealing method whereby platelets in the blood stream initiate the mechanism for sealing cuts and wounds.

The technology involves the remote injection of discrete particles known as "PlateletsR" into a pipeline which are carried to the leak site due to the flow. Designing these particles with the necessary material properties would enable fluid forces to draw them into the leak and hold them against the pipe wall, thus facilitating sealing. By embedding a remote tagging device into these discrete particles prior to deployment they can also be used to locate leaks. Once the particle is entrained into the defect the embedded tag is uniquely positioned at the leak site and can be detected by running a suitable device either externally or internally along the length of the pipeline. Platelet Technology enables leaks to be sealed and located in a single integrated process. This reduces the lifetime of the leak, which helps to limit any consequential environmental damage. Platelet particles are implemented remotely, removing the need for direct access to the leak site. In addition, Platelets require no disturbance to pipeline operation meaning that, in some cases, costly shutdowns can be avoided.

Figure 24: Platelet technology visualized

Development of a platelet solution uses an engineering process that includes analytical and numerical modeling, physical testing, and material compatibility analysis.

Computational Fluid Dynamics (CFD) analyses fluid flow within the pipeline to determine platelet behaviour within the leaking line. This analysis has two parts: modelling of platelet conveyance through the system infrastructure to ensure they reach the leak site without obstruction, and simulation of platelet behaviour in the immediate vicinity of the leak to assess platelet entrainment. CFD simulation is vital to develop a solution as it allows the platelet density to be tuned for a high entrainment probability with a minimum number of platelets.

From the output of the CFD analysis, a high-pressure flow loop gives "real life" assurance of the platelet design. A flow loop that is representative of the pipeline system (and the defect within it) can be set up and simulation of the operation conducted. While this is not required in every case (as CFD can often give enough information), more complex leakage situations often justify physical testing.

8.2.2 Advantages and limitation of the technology

All non-destructive testing technologies have unique capabilities and limitations that affect the accuracy and efficiency of the technology. Platelet Technology has the following ones:

Implementation

Field implementation of a Platelet solution generally does not require specialist equipment. Pig launchers and double block and bleed valves are some of the pipeline elements that can be used as injection points.

Material

Platelets utilise the turbulent flow in pipelines to become evenly distributed across the pipeline cross-section, enabling leaks at any location to be targeted. To do this they need to be neutrally buoyant in the carrier fluid (i.e. the same density) and therefore this too affects the choice of material for each application. As such, there is no hard and fast rule which governs what a Platelet is made from; however, polymeric and elastomeric materials have demonstrated a good combination of properties for most applications.

Pressure

The operating pressure of the line also has a strong bearing on the selection of Platelet material – if the material is too soft it may be entirely extruded through the leak, but if the material is too hard a complete seal may not be attainable. For this reason, a wide variety of materials have been used on Platelet operations to date, for which the pressures have varied from 2 to over 500 bar. Once the particles are implemented and the custom formulation is entrained into a leak, it will form a seal which remains in position as long as there is a positive pressure differential acting across it; therefore, pressure fluctuations in the line do not present a problem. At present, Platelets® system cannot guarantee to withstand substantial negative pressure differentials (i.e. if the pressure outside the line is greater than that inside).
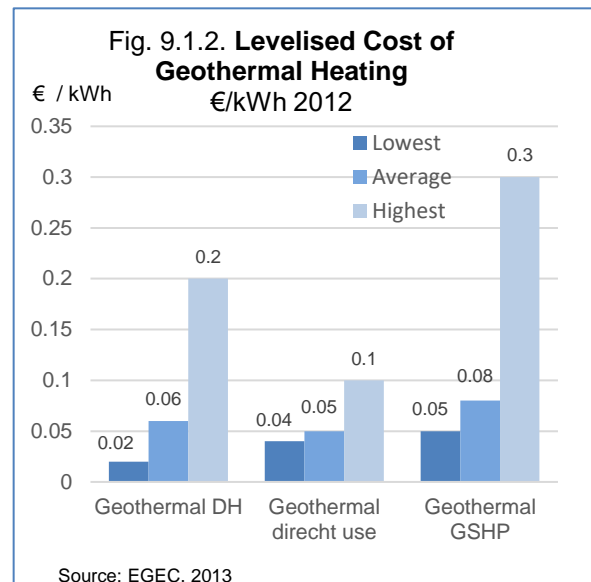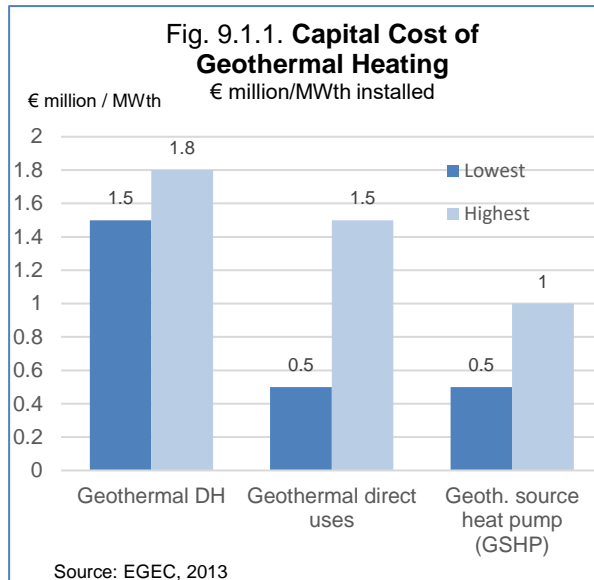
Size and shape of the defects:

The exact size and shape of a Platelet cannot be defined because it varies from operation to operation. For each operation, unique batches of Platelets are manufactured with properties which are specifically tuned to give the optimum results under the operating conditions in question. To give some idea, in projects carried out to date, defect sizes ranging from 0.3 mm to 50 mm diameter have been successfully sealed.

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

€ million / MWth

Source: EGEC, 2013

Fig. 9.1.2. **Levelised Cost of Geothermal Heating**
€/kWh 2012

€ / kWh

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 100m² Household in Europe**
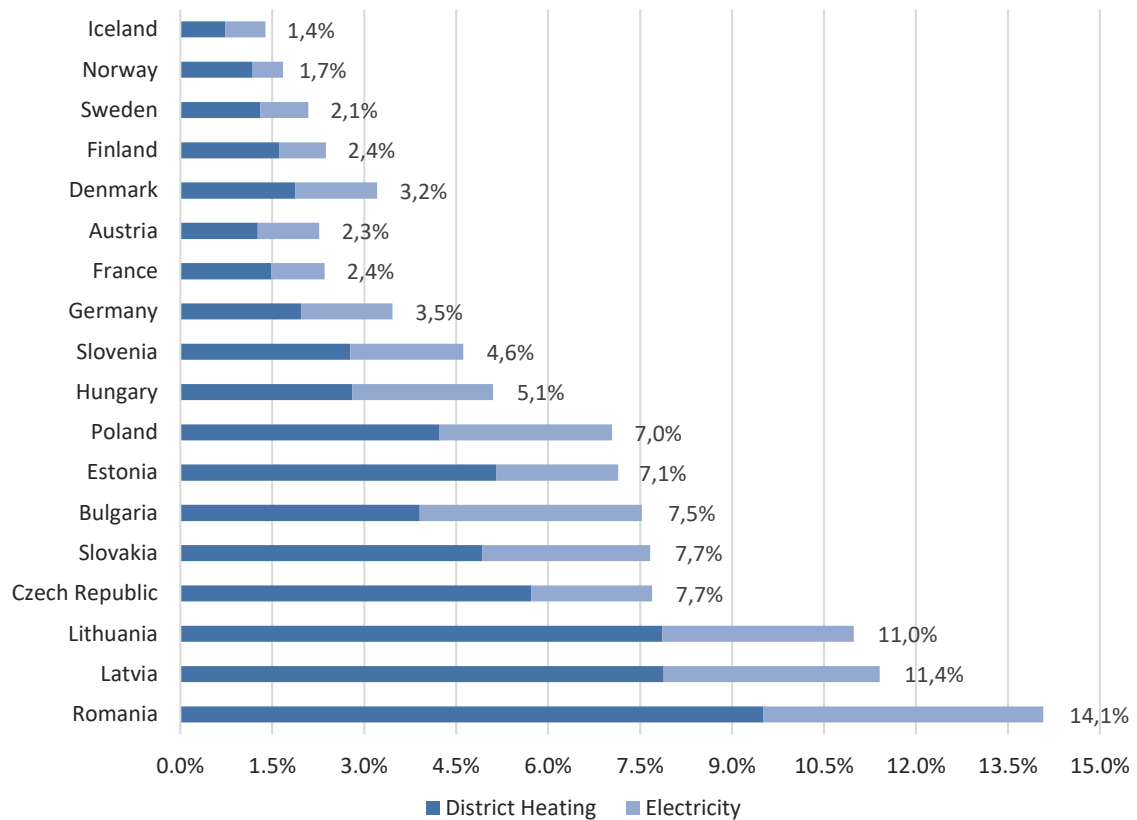
In a calculation presented in a GeoDH paper from 2014, it is estimated that, *"a private investor who would be given the opportunity to invest 20 million Euros in the building, and receives a feed-in tariff of 90-96 Euros/ MWh would earn around 9-10% per annum on the 20 million € invested. If that investor 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.
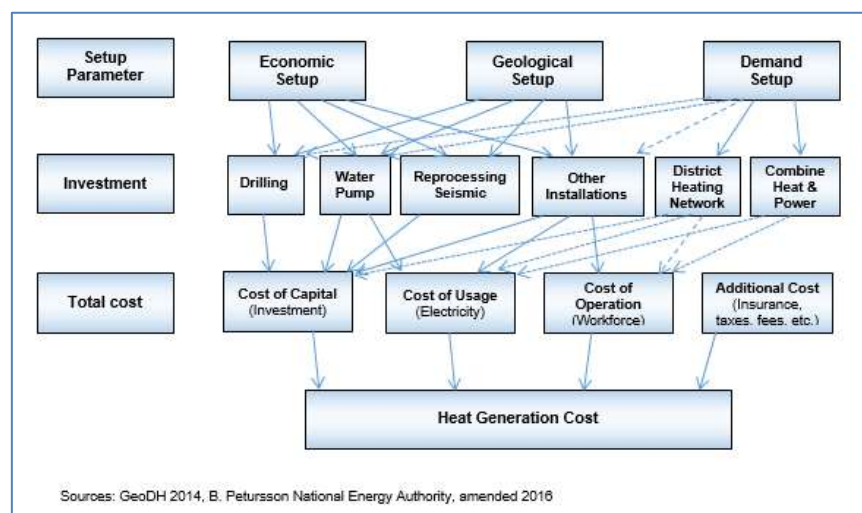
Key factors for geothermal district heating projects are:
- geological framework,
- economic conditions and
- demand.

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

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.

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

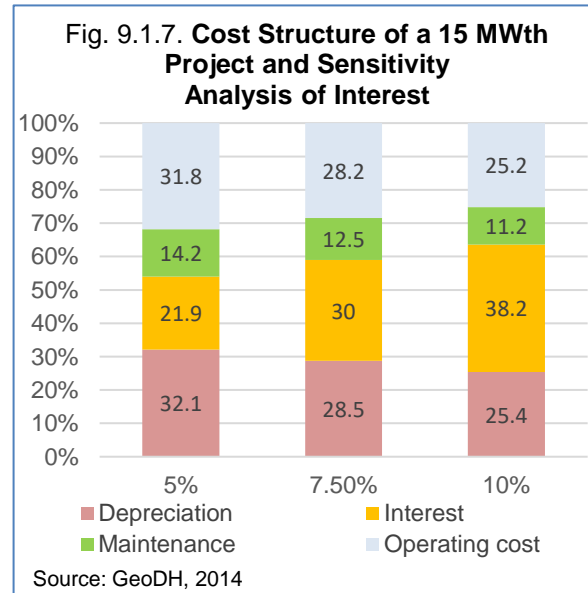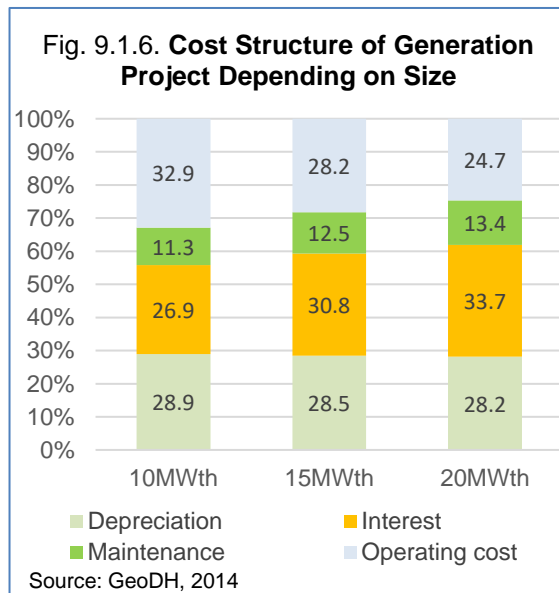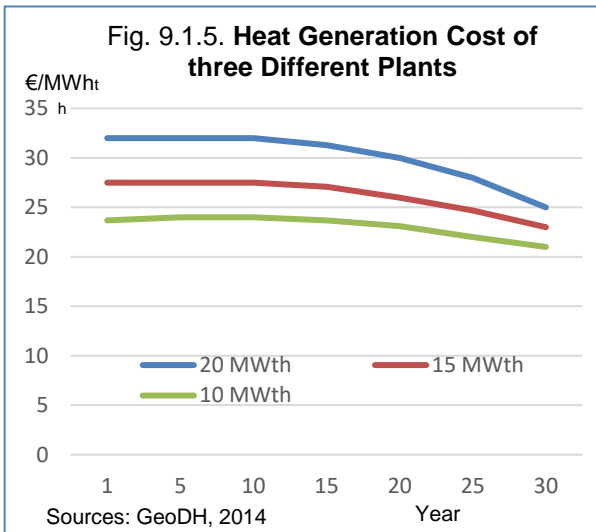The demand aspect plays an important role in defining the project and the investments e.g. drilling, size of the water pump, buildings, district heating network and a power plant's mechanisms. In addition, the evaluation of heat production costs depends on the geothermal energy resource. It should also 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]

Calculations on geothermal heat generation cost carried out for GeoDH in 2014, involved three projects 10, 15 and 20 MWth 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. 9.1.5. **Heat Generation Cost of three Different Plants**

Sources: GeoDH, 2014

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 Sensitivity Analysis 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 MWth 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.
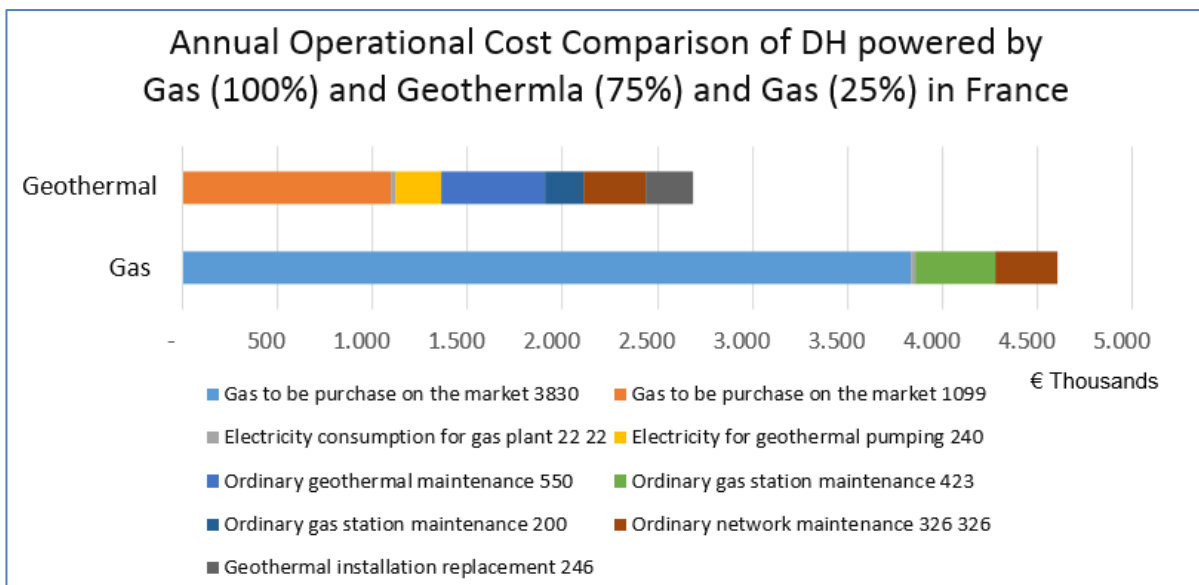

Fig. 9.1.8. **Heat Generation Cost for District Heating Network by Fuel**

Source: GeoDH 2014.
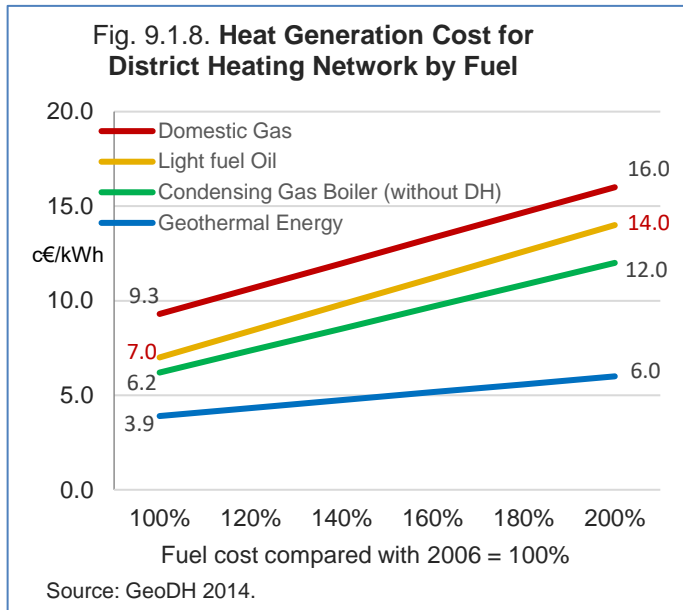
Business Model for Geothermal District Heating and Gas
**Cost Comparison – kWh Produced by Natural Gas and Geothermal Heat**

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

- Gas to be purchase on the market 3830
- Gas to be purchase on the market 1099
- Electricity consumption for gas plant 22 22
- Electricity for geothermal pumping 240
- Ordinary geothermal maintenance 550
- Ordinary gas station maintenance 423
- Ordinary gas station maintenance 200
- Ordinary network maintenance 326 326
- Geothermal installation replacement 246

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.
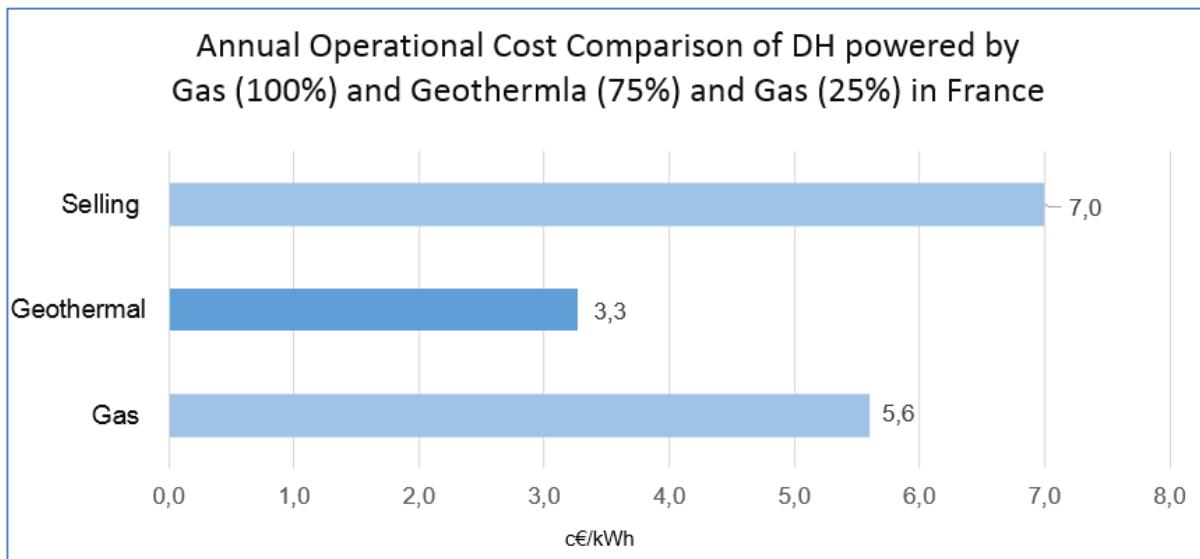
As can be seen from the case in France, the actual annual operational / production cost of the heat generated using 100% gas is about 4,6 M€ (5.6 c€/kWh) - but only 2,7 M€ (3,27 c€/kWh) with a combination of geothermal (75%) and gas (25%).

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

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

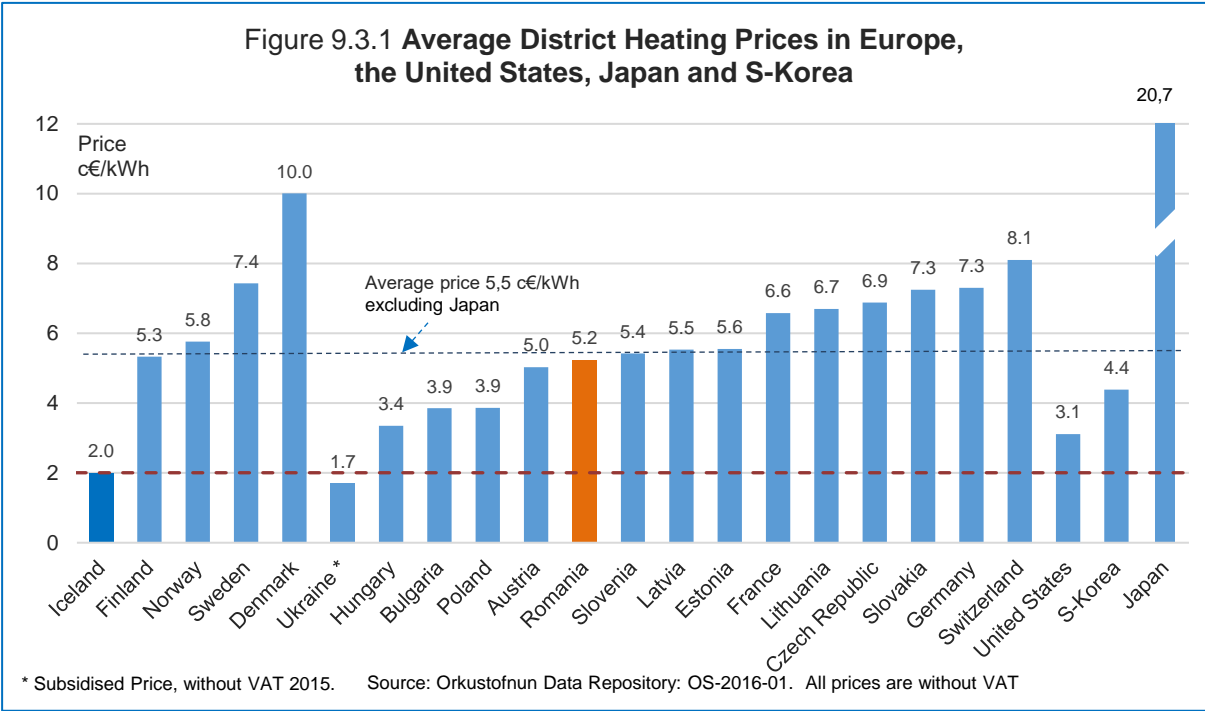Sources: GeoDH 2014, B. Petursson National Energy Authority amended 2016
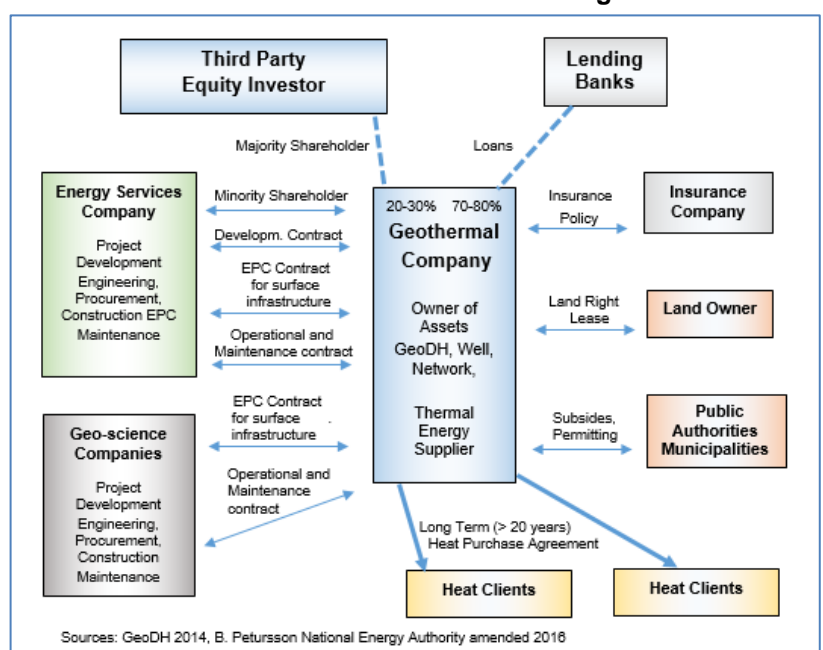
years), heat purchase agreements with end users with a fixed charge (capacity charge) linked to kW of capacity subscribed, and a variable charge ("consumption charge") proportional to kWh supplied.

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.
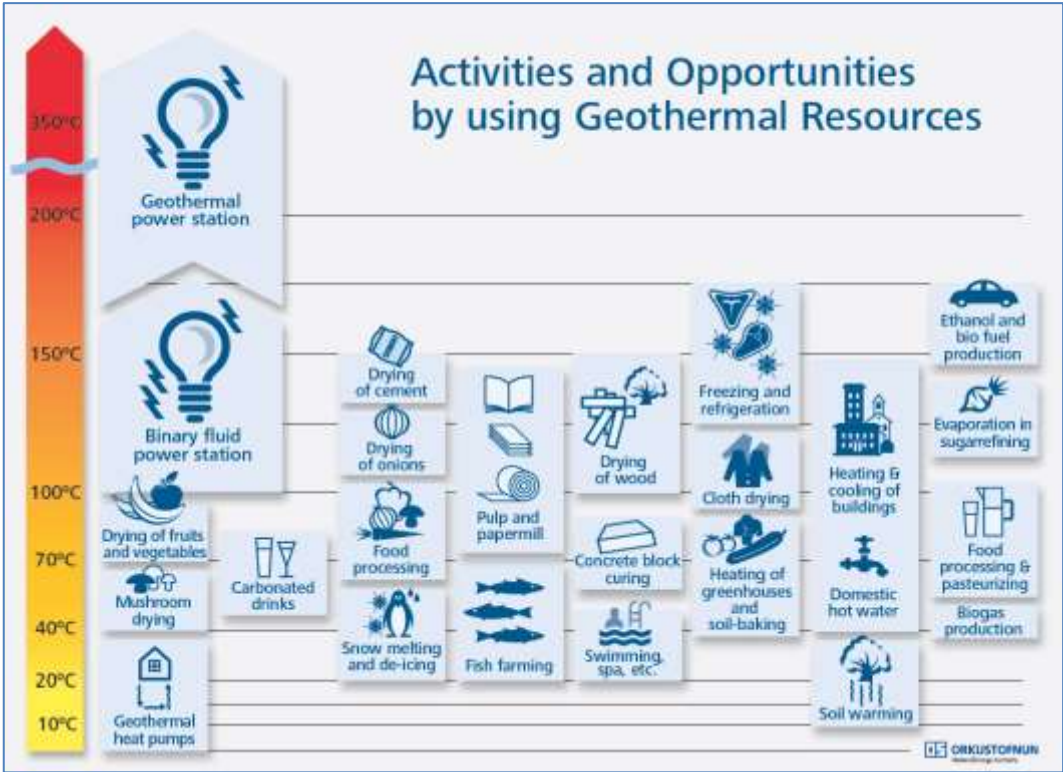
10. Policy towards Geothermal District Heating in Europe

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.

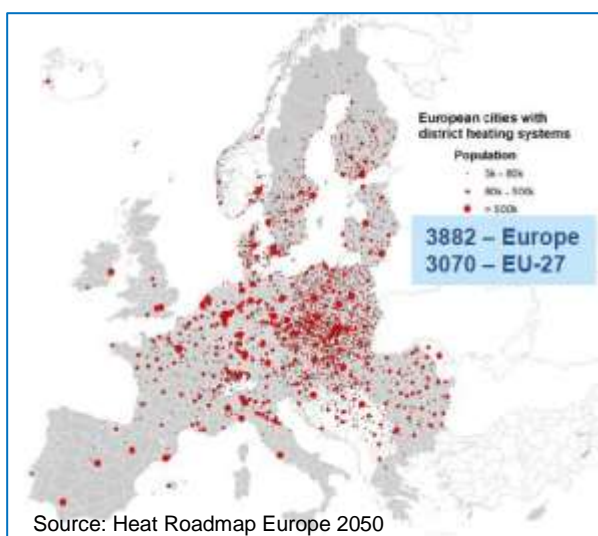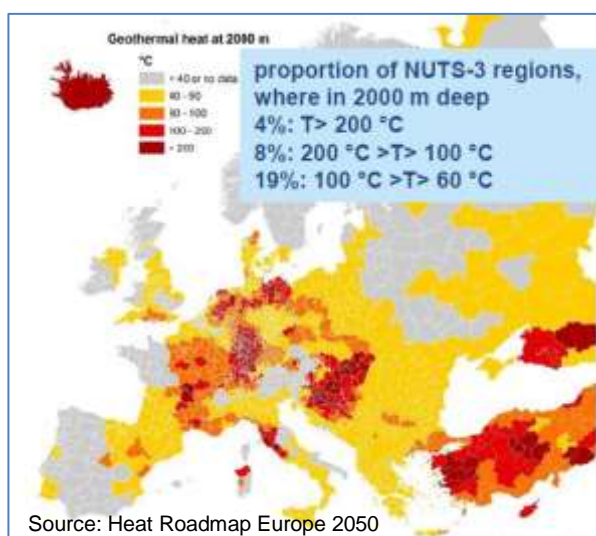**Figure 10.1.** *Geothermal Cities with District Heating Systems*

Figure 10.2. *Geothermal Heat at 2000 meters*

Source: Heat Roadmap Europe 2050

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 general recommendations are highlighted:

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

Geothermal Options, Opportunities and Benefits

The geothermal heat generation has several advantages, such as:

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

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
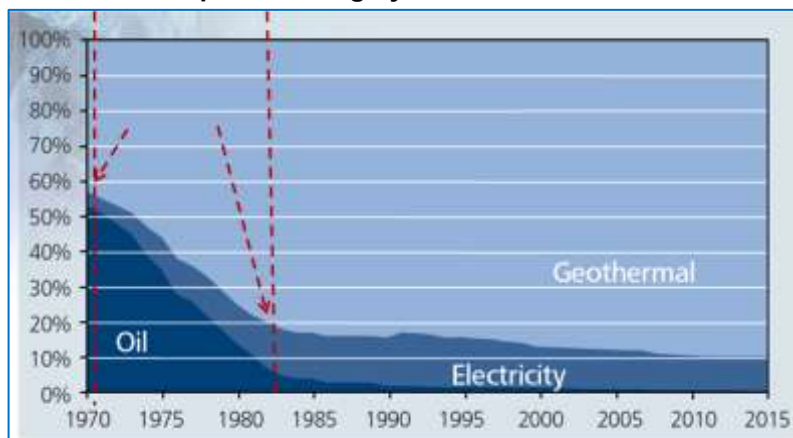
- Biggest steps in GeoDH were taken during the oil & war crises 1970 – 1982
- External conditions – raised the need of evaluation and GeoDH Planning
- Policy goals to increase geothermal – both national and within main cities
- It took only **12** years to increase GeoDH from **40% to 80%** of total 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
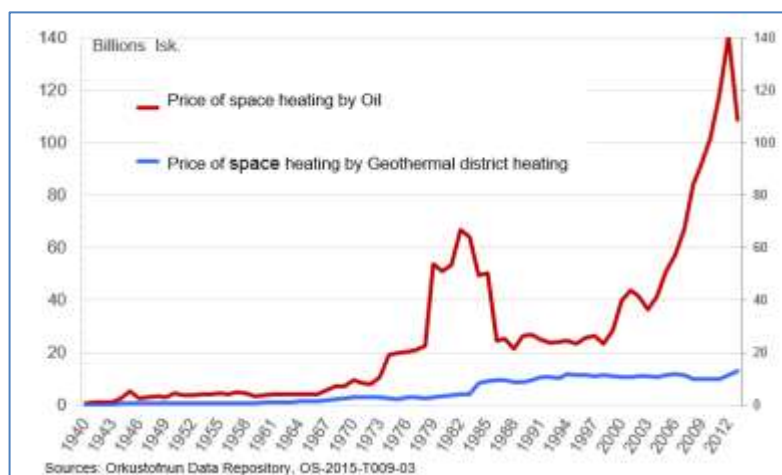
Oil heating is 2-6 times more expensive than geothermal heating throughout most of the period but peaks to 16 times more expensive in the period 1973 to 1985 and has risen again since 2007 to a present ratio of 10. In 2012 the difference in cost amounted to 80% of the state budget cost of health care 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**

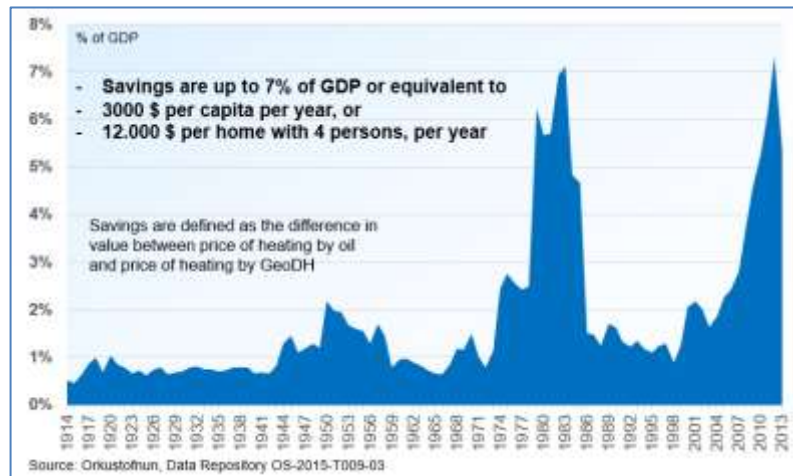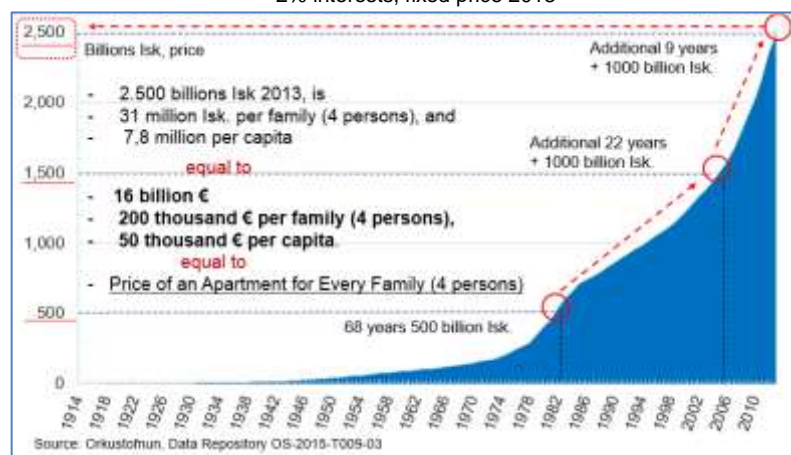National Savings by Geothermal District Heating as % of GDP

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.
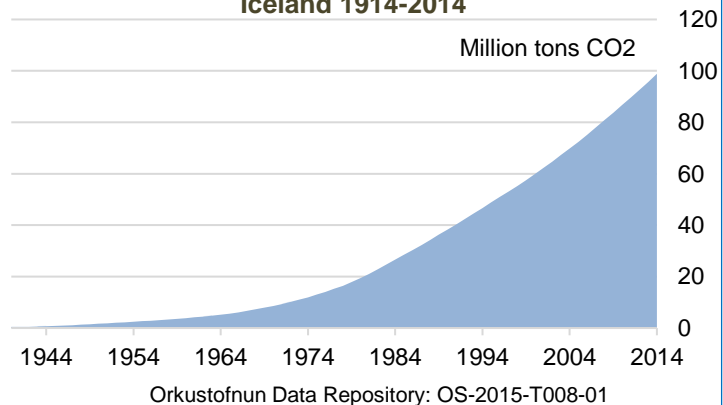
12.3 CO_2 Savings due to Geothermal District Heating

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

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

Since 1940 to 2014 the CO_2 savings by using geothermal district heating

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

Million tons CO2

Orkustofnun Data Repository: OS-2015-T008-01

have been around 100 million tons, which is equal to saving of using 33 million tons of oil.

Reykjavík 1933   Reykjavík today

In 2014 the geothermal district heating savings of CO_2 in Iceland was about 3 million tons of CO_2, or equal to 1 million tons of oil, equal to CO_2 bindings in 1,5 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. 12.3.2. **Accumulative CO2 Savings using Renewables instead of oil in Iceland 1914-2014**

Million tons CO2

Geothermal Power Plants

Geothermal District Heating

Hydropower

1944 1954 1964 1974 1984 1994 2004 2014

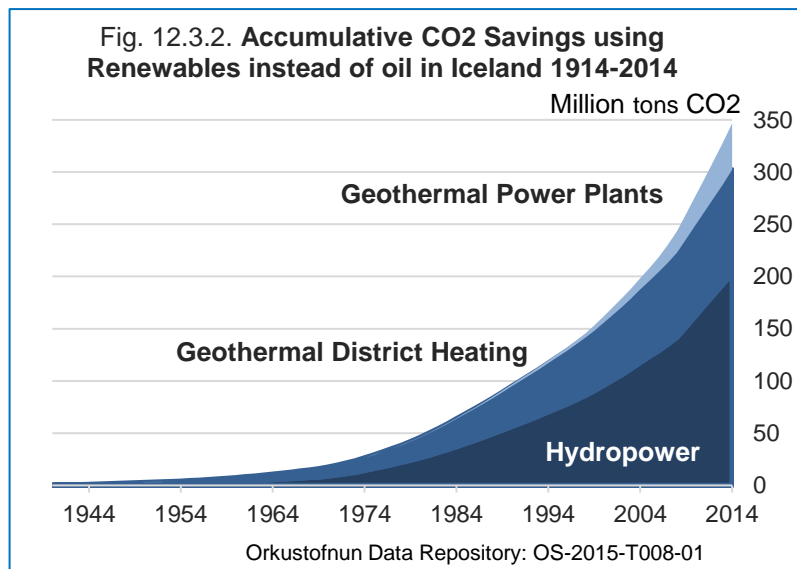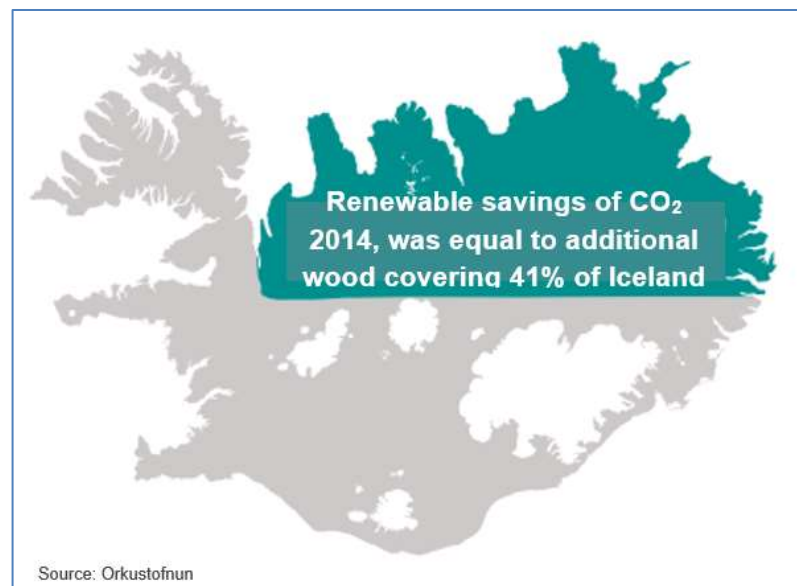Orkustofnun Data Repository: OS-2015-T008-01

Fig. 12.3.3. **The Annual Savings of CO₂ 2014 from Renewables in Iceland was equal to bindings of CO₂ in 9 billion trees, equal to 43.000 km² of Forest or 41% of Iceland**

Renewable savings of CO₂ 2014, was equal to additional wood covering 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
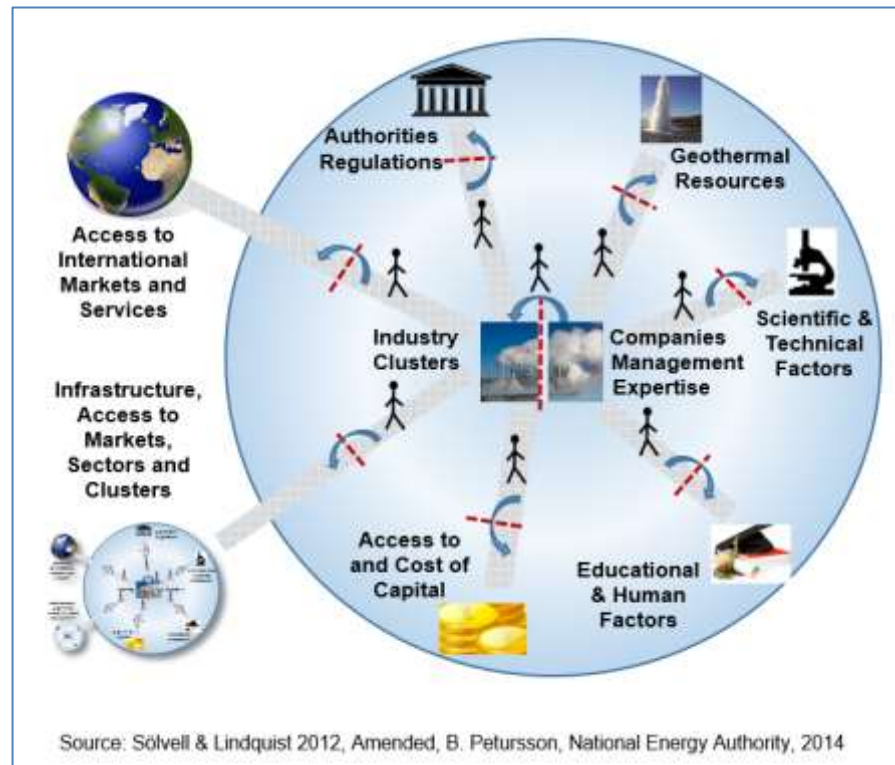
The cluster competitiveness model can be used in many different ways to increase competitiveness and growth of companies. One possibility is to use the enclosed model to analyse the seven main framework conditions in the geothermal sector;

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).
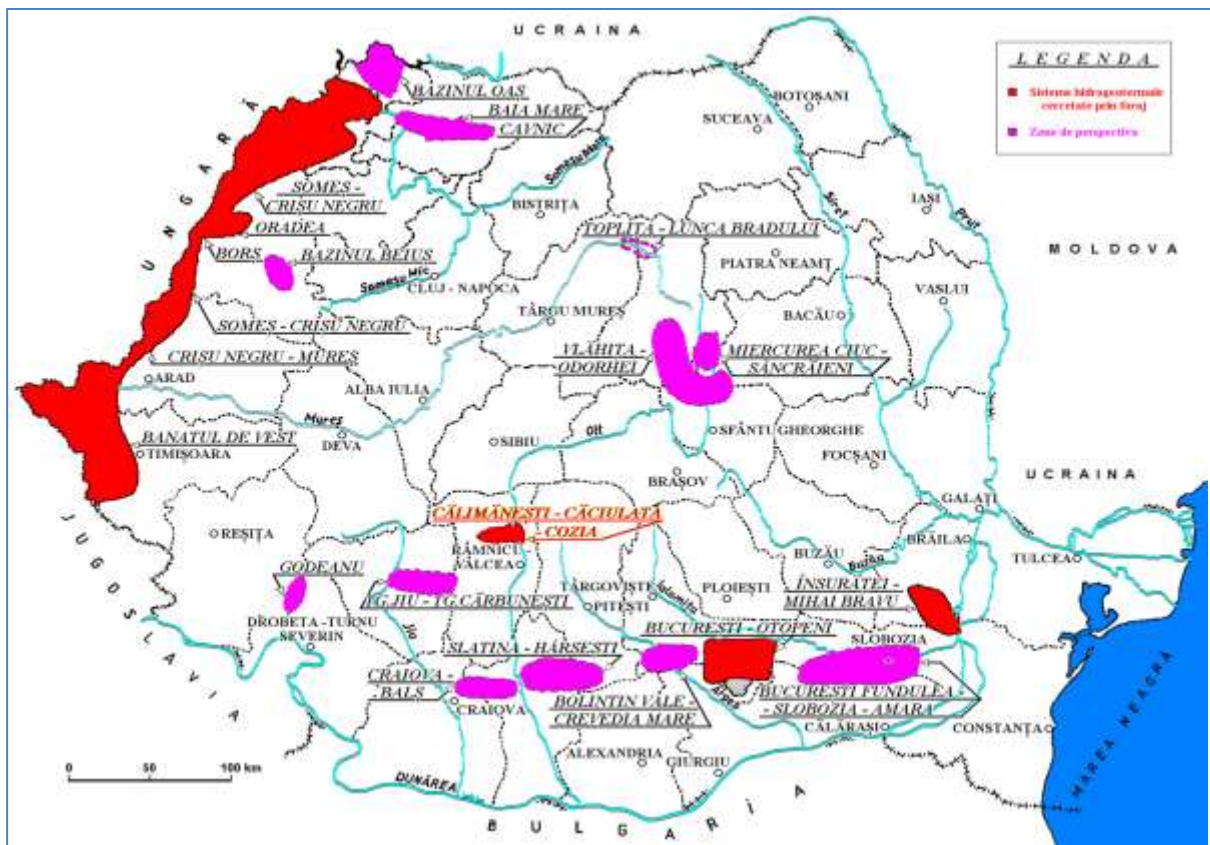
Map of Romania with geothermal reservoirs

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.

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