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# Geothermal Energy Country Update - Lithuania

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## ABSTRACT

Lithuania is situated in the western periphery of the East European Craton (EEC) that was consolidated during the Archean and Proterozoic eons. This type of geotectonic structure is characterized by a low intensity geothermal field owing primarily to a low tectonic activity. There is an exceptional high heat flow anomaly mapped in west Lithuania that is the most intense in the EEC. The heat flow is as high as 70-95mW/m$^2$, while the background value of the craton is assessed at about 40mW/m$^2$. The origin of the anomaly is related to the Middle Proterozoic hot granites hosted by the Lower Proterozoic metamorphic rocks composing the basement of the Baltic sedimentary basin. Some activity is also suggested below the Earth's crust of west Lithuania at the mantle level. There are several large geothermal aquifers identified in the sedimentary pile of the basin. The Middle Cambrian and the Lower Devonian sandstones are considered as the most prospective low enthalpy geothermal reservoirs. The temperatures reach 70-95$^o$C and 35-45$^o$C in the Cambrian and Devonian aquifers, respectively, with depths respectively about 2km and 1km. Also, the Middle Devonian reservoir (30-35$^o$C) is considered as a prospective body when combined to the balneological applications.

The information on the situation of Klaipeda geothermal demonstration plant (KGDP) and the growth of installed capacity of ground-source heat pump systems are presented in this paper.

Two case studies, representing good practice examples of Lithuania, are also discussed:

*First* - the logistics center of the Lithuanian company SANITEX in Riga is presented. For the 40,000 m$^2$ warehouse with refrigerators - the 700 kW heat pump ground source system with a drilled probe field under the building is implemented. The field of drilled probes is regenerated by the heat extraction from food refrigeration equipment. The heat pump ground source system fully covers the heating, hot water and ventilation needs in the building with Seasonal Performance Factor (SPF) > 5 of heat pumps.

*Second* - the first re-circulating marine aquaculture system for shrimp cultivation was established in Klaipeda as a part of the EU South Baltic projects InnoAquaTech and Baltic Blue Biotechnology Alliance. The system of eight tanks, 40 m$^3$ is designed to grow whiteleg shrimps. The task of this pilot project is to carry out shrimp growing experiments, to obtain knowledge and competences, to get expertise in marine re-circulating aquaculture technology, and transfer these competences to the aquaculture business.

## 1. INTRODUCTION

The main aim of the national Energy Independency Strategy (National, 2018) is to ensure Lithuanian energy security and competitiveness. In the year 2016 the situation was as presented in Fig.1:

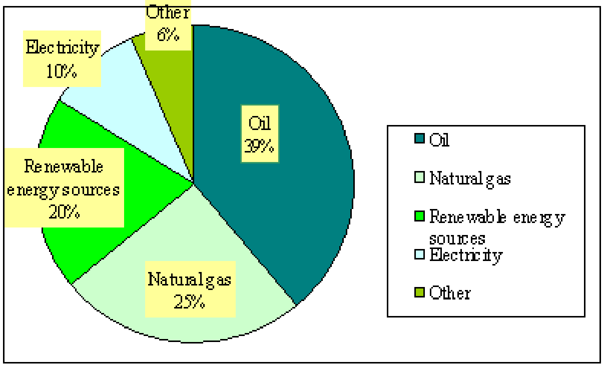


**Figure 1: Total consumption of fuel and energy in Lithuania in 2016, (National, 2018).**

The guidelines of future up until the year 2050 can be evaluated as very ambitious (Fig. 2). Electricity imports will be replaced by local electricity generation: it is planned that in 2020 electricity generation in Lithuania will account for 35% of the total final electricity consumption; in 2030 – 70%; and in 2050 – 100%.
As technologies develop, the share of RES energy will be increasing due to more participants in the market. In 2020, 30% of the country's final consumption will be from RES; in 2030 – 45%; and in 2050 – 80%. RES will become the main source of energy in the electricity, heating and cooling, and transport sectors.

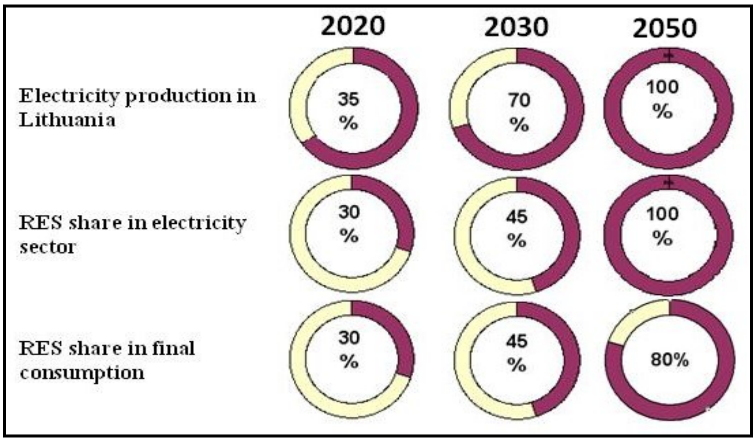


**Figure 2: Results sought for Lithuania energy sector in 2020, 2030 and 2050 years (National, 2018).**

## 2. GEOLOGICAL SETTING

Geological setting and the geothermal potential of Lithuania in detail has been described each year since 1995 in the national Country Update papers (Suveizdis et all, 1995).

The aim is in this paper to show how available geological information helps in practice to increase the injectivity rate in the well of the Klaipeda geothermal plant. The Klaipeda geothermal demonstrational plant was established in the westernmost part of Lithuania (Figure 3) and uses the lower Devonian aquifer that shows excellent reservoir properties. Since the beginning of the plant's operation there was a very high reservoir performance in terms of the geothermal water production, while the injection was systematically decreasing to reach about 10:1 ratio of the productivity and injectivity. A number of the soft acidisation stimulation campaigns were performed during the station operation, and these showed a rather high effectiveness at the beginning, but declined with each new stimulation campaign.

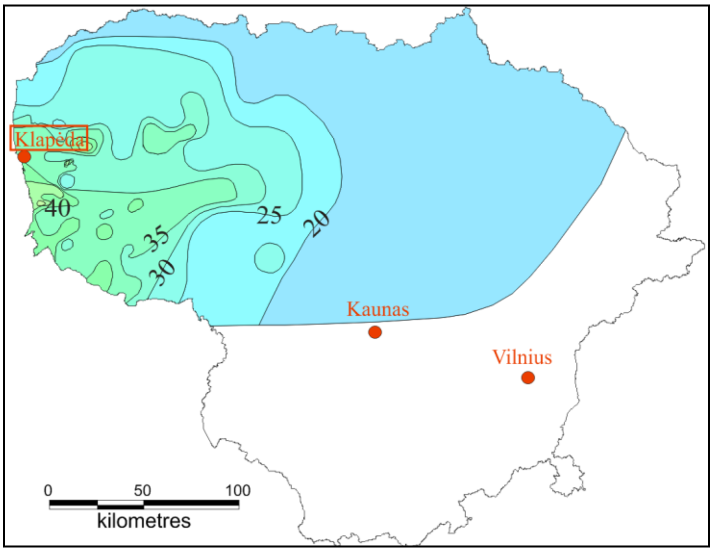


**Figure 3: Temperatures of the Lower Devonian geothermal aquifer (with location of the Klaipeda geothermal plant shown in the red box).**

The Klaipeda geothermal demonstrational plant is situated in the Baltic cratonic sedimentary basin comprising only weakly tectonized sediments of the Late Vendian to Quaternary age. In west Lithuania, where Klaipeda City is located, the geothermal anomaly is identified where the heat flow attains 70-90mW/m$^2$, against the background value of 40mW/m$^2$ of the East European platform. The thickness of the sedimentary cover of west Lithuania is about 2 km. It comprises several regional-scale geothermal aquifers. The Kemeri Formation of the Lower Devonian age was identified as a target for the Klaipeda geothermal demonstrational plant. The depth of the top of the formation is 980m, the bottom depth is 1110-1118m. Some lithological variations are recognized in the site area that have an impact on the reservoir properties.

The Kemeri Formation represents one of three (Cambrian, Lower Devonian, Upper-Middle Devonian) major geothermal aquifers of Lithuania (Fig. 4). Temperature ranges from 15$^o$C in the east to 50$^o$C in the west (Fig. 3). This trend is due to the deepening of the aquifer and to the increase in heat flow to the west. Klaipeda geothermal plant utilizes a reservoir that has a temperature of 40$^o$C. The thickness of the aquifer increases from the south (90m) to the north (180m) in west Lithuania. The thickness of the Kemeri formation is 130-138m in Klaipeda.

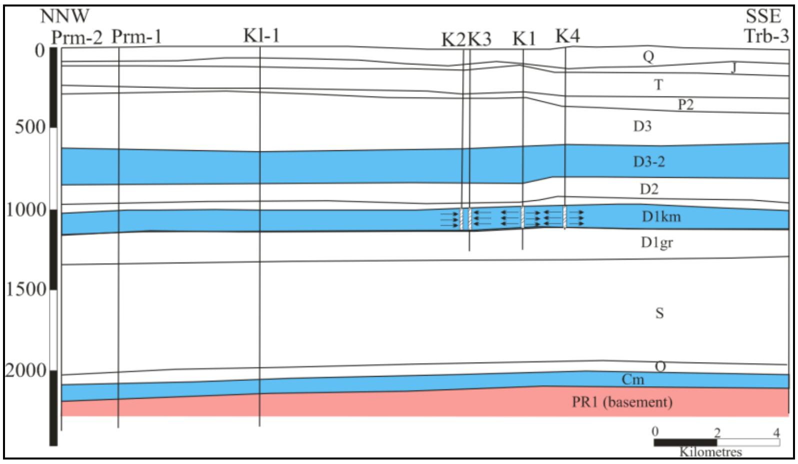


**Figure 4: Geological cross section across the Klaipeda geothermal site. Major aquifers are marked in blue colour. Deep wells (Prm-1,2, K-1, Trb-3) and Klaipeda geothermal wells (K1-4) are also shown.**

## 2.1. RESERVOIR ARCHITECTURE

The Klaipeda geothermal reservoir is formed by the Lower Devonian sandstones of the Kemeri Fm. It is hit at depths 981-1118m in the well KGDP 1I and 980-1110m in the well KGDP 4I (Fig.5). The Kemeri Fm. is overlain by the Middle Devonian marlstones, dolomites, and strongly cemented sandstones. It is underlain by the Gargzdai Group of the Lower Devonian age, dominated by siltstones and shale with subordinate sandstones and dolomites.

The Kemeri Fm. is represented by friable sandstones (with interlayers of strongly cemented sandstones) cemented by clay, carbonates, gypsum, and quartz; with siltstone and shale interlayers. Net-to-gross is evaluated 0.63-0.68. The aquifer is characterized by a rather complex architecture. No consistent sedimentological model was developed so far. These can be shallow marine sediments with sandy bars, deltaic complex, alluvial deposits. The latter model seems the most reasonable, assuming the shale dominated parts of the succession reflect the meandering river environment, while sandy parts of the succession could be indicative of the braiding river stage of the alluvial system evolution. Due to the complexity of the reservoir architecture, there is also no consistent model on a connectivity of the individual sandstone layers.

There is a good correlation of the individual layers between the production wells KGDP-2P and KGDP-3P located only 200m apart (Fig. 5). Correlation is more complex concerning the injection wells that are located at a distance of a few kilometers from the production wells. There is a remarkable difference in the reservoir architecture between injection wells KGDP-1I and KGDP-4I. The former well is characterized by the lowest net-to-gross value. Some small amplitude inverted fault is suggested between the injection wells, as indicated by sharp increase of the Upper Permian layer to the south, and some differences in the Middle Devonian Pärnu Fm. overlying the Kemeri Fm. These features can explain the different injectivity potential of both wells. Also, the extensive drilling mud infiltration is not excluded as one of the major interfering effects in the well KGDP-1I.

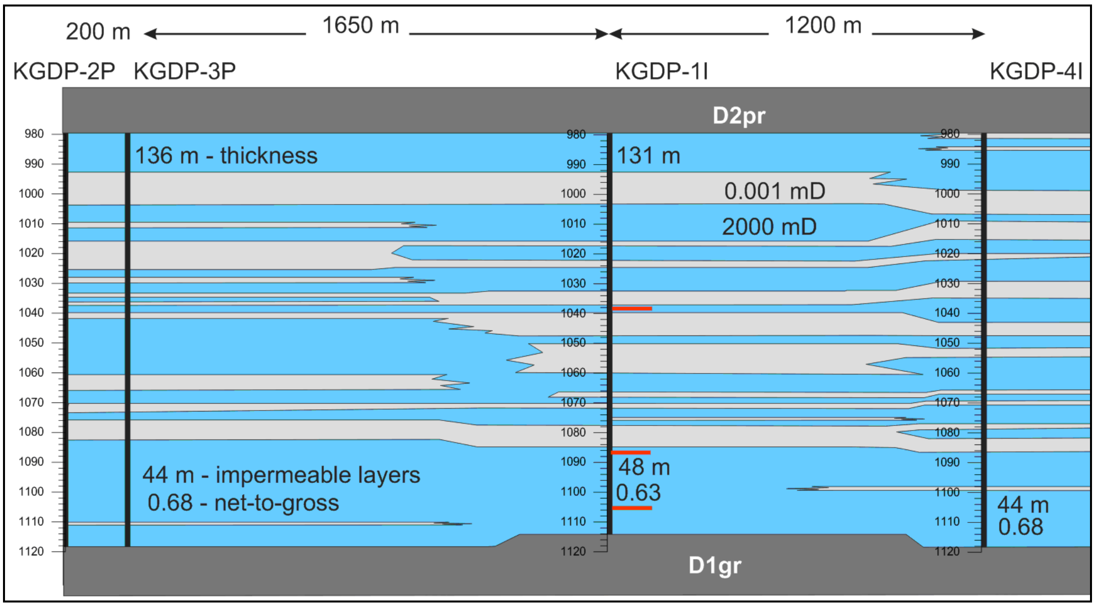


**Figure 5: Geological cross section of the Kemeri geothermal aquifer. Grey layers show aquitards, blue are sandstones. The jetted intervals are indicated (red horizontal lines) in the injection well KGDP-1I.**

Five lithological packages can be defined in the Klaipeda wells (Fig. 6):

**Lowermost package**. The lowermost sandstone body (indexed IV) of about 30m thick is well correlated across all Klaipeda geothermal wells. It is also distinct in the rest of the west Lithuanian wells. This package is characterized to be of the best reservoir properties - larger grain size, low amount of thin shaly interlayers, high porosity and permeability. Laterals at two levels were jetted in this best part of the Kemeri reservoir (well KGDP-1I).

**Lower package**. The lower package grades upwards to intercalation of shales (correlated layers D, C, B), siltstones, and sandstones (correlated layers III, II). It is about 55m thick. Well KGDP 4I shows higher sandstone proportion in the section compared to the well KGDP 1I. Laterals were jetted in this part of the section in the well KGDP-1I at the depth 1039m. This package can also be traced across all west Lithuanian wells. It is still difficult to suggest to what extent the individual layers are continuous or discontinuous.

**Middle package**. It is characterized by increased abundance of siltstones and sandstones. It is as thick as 27m in the well KGDP 1I, while only 14m in the well KGDP 4I. Siltstone lithologies seem to be predominant in the well KGDP 1I, while sandstone is dominating lithologies in the well KGDP 4I. This package can also be traced across west Lithuanian wells.

**Upper package**. Shale package is distinct in west Lithuanian wells, as it also is in the Klaipeda area. It is 12-17m thick and it is likely to provide and an important hydrodynamic barrier in the Kemeri aquifer.

**Uppermost package**. It is composed of sandstones (with shales and siltstone) in the well KGDP 4I, while siltstones predominate in the well KGDP 1I. It is about 14m thick and it can be suggested that this package is isolated from overlying sandy packages.

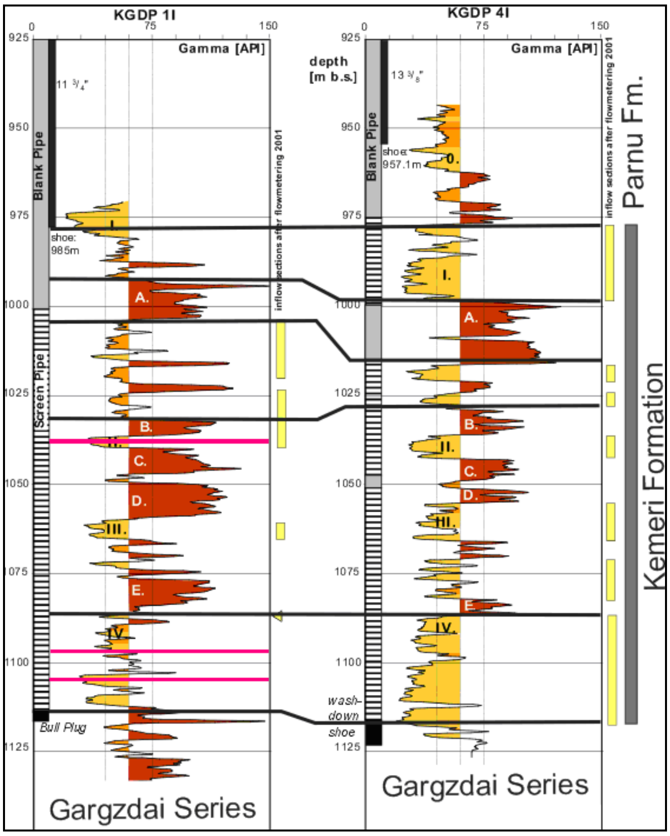


**Figure 6: Logging vs lithology and the well design of the injection wells KGDP 1I & 4I. Bold lines indicate boundaries of lithological packages. Yellow-sandstones, orange-siltstone, red-shale (after Wolfgram, Seibt, Sliaupa, 2008, unpublished report). Radial jetting depths are indicated (pink lines).**

### 2.2. RESERVOIR PROPERTIES

No samples are available for petrophysical studies of Kemeri sandstones from the Klaipeda wells, although the well logs provide some information on the porosity of Kemeri lithologies. The calculated average porosity of sandstones averages 28% showing only minor variations between 25-32%. The average permeability was assumed 1.0-1.3 D when designing Klaipeda geothermal wells. It is in concert to the well testing data provided from Vilkyciai-3, 5 oil exploration wells located 20km to the SSE of the Klaipeda station. These old oil exploration wells were re-opened for the injection of Cambrian waste water produced during the oil exploitation. The permeability of the lower sandy package was defined by well testing as high as 4 D, while permeability of the upper sandy package was calculated 2 D. This data confirms the best reservoir quality of the Lowermost package. It should be noted that the Kemeri reservoir was likely to have been strongly affected by drilling mud as it was considered as not a prospective body for the oil industry. It should also be stressed that productivity ranges from 29 to 51m$^3$/h/bar, while injectivity was only 0.76-1.17 m$^3$/h/bar. These are still high values of injectivity.

Laboratory studies of the Kemeri Fm show close correlation between the permeability and porosity measured in other wells of west Lithuania (Fig. 7). The minimum porosity values were measured in strongly carbonate or gypsum cemented sandstone interlayers (amounting to about 11%). In most samples, the carbonate/gypsum content is in the range of 0.3-3.2%.

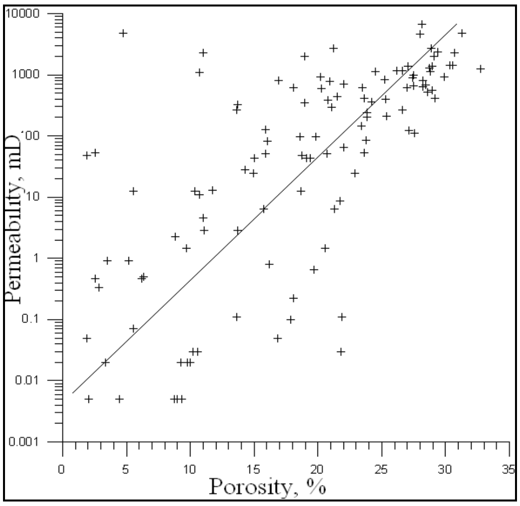


**Figure 7: Logging vs. lithology and well design of the injection wells KGDP 1I & 4I. Bold lines indicate boundaries of lithological packages. Yellow-sandstones, orange-siltstone, red-shale (after Seibt et al., 2008, unpublished report).**

### 2.3. HORIZONTAL JETTING

In November 2014, radial jetting technology was identified as a possible solution for enhancing the injectivity of the wells. With radial jet drilling, several open hole laterals of 100m maximum length and with a diameter of 1 to 2inch were jetted from the main well bore in order to enhance the connectivity of the well to the rock and thereby the well productivity or injectivity (Buset, et al., 2001, Ragab & Kamel, 2013, Peters, et al., 2016). The jet nozzle used for jetting the laterals has a number of forward and backward jets and is conveyed on mini coiled tubing. The forward-facing jets provide the required erosion of the rock surface and the backward facing jets cause the forward motion by pushing the nozzle forward. The laterals are created with a 90° or 45° angle from the main well bore and its azimuth can be controlled at the start. However, once the jet nozzle is in the formation, it is not steerable and relies on the stiffness of the jetting hose and the symmetry of the forward thrust generated by the backward facing jets to maintain inclination and azimuth. Experience with radial jetting comes mostly from the petroleum industry (Peters, et al., 2016) with limited applications in geothermal wells. The production increase resulting from using this technology is highly varied (Peters, et al., 2016) and there are still some clear questions regarding the technology, its performance in different geological settings and also in its long term (>5 year) performance.

At the Klaipeda site, well No.1I was selected for radial jetting. The original well No.1I was drilled in 1997. The well was vertical and plugged back at 1125m. In 2008/2009 the original backbone was abandoned and a new side track 1I(A2) was drilled with an inclination of 3° to 5° with respect to the vertical (S.Sliaupa, 2016) and azimuth around 180°. The side track was completed in December 2008. In this side track, 12 horizontal laterals of around 40m in length were planned in a number of highly permeable layers present in the aquifer. The planned laterals were set to kick off in the middle of the most productive reservoir intervals in three different productive layers (Fig. 8):

- **1st layer** (1037.5 - 1040.0m) start depth: 1039.0 ± 0.5 m
- **2nd layer** (1095.0 - 1097.5m) start depth: 1096.5 ± 0.5 m.
- **3rd layer** (1104.0 - 1107.5m) start depth: 1106.0 ± 0.5 m

For each layer four laterals with a length of 40 ± 0.5 m and a separation of 45° - 50° were planned.

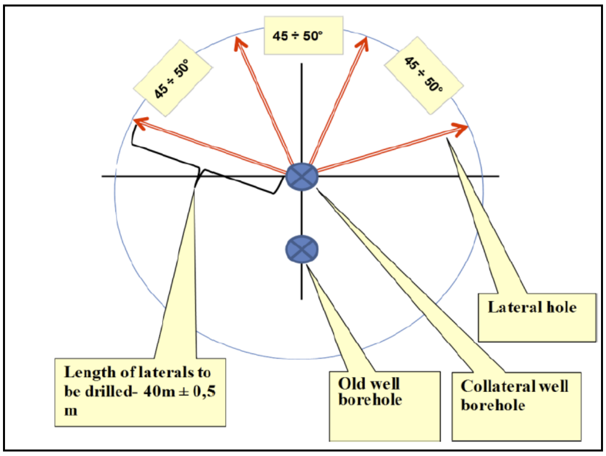


**Figure 8: Schematic of laterals to be jetted in Klaipeda Well 1I (Blöcher, et al., 2016).,**

In December 2014, the radial jetting job was carried out. In total 12 laterals were jetted, of which nine reached 40m, two reached 35m, and one reached 28m. In deviation from the workplan, five laterals were jetted at the intermediate depth and only three at the deepest kick-off point.

According to the project programme after radial jetting, back flashing was then done (1,040m³ were pumped out with pump with 50m³/h flow rate). Injection rate after final project completion for well No.1I was positive; the rate was increased by 4.5m³/h.

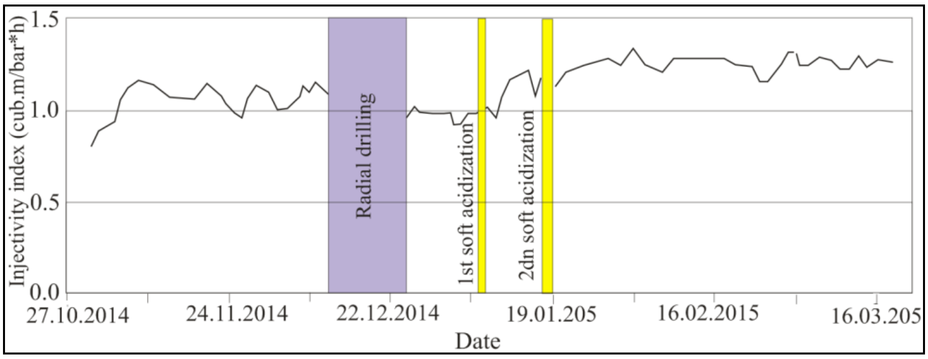


**Figure 9: Injectivity index before radial jetting / acidisation and after Klaipeda well 1I.**

Two types of soft acidizing campaigns were performed soon after the jetting. These soft acidizing procedures were often executed after electrical power supply breaks for injection pumps in order to regain previous injection rates in the wells.

**First soft acidisation**. Carried out 17 days after the jetting. The well No.1I was acidized with 1m³ of 18% HCl acid solution. Injection rate after final treatment of well No.1I was positive, and the injection rate was increased by 3.9m³/h.

**Second Soft acidisation**. 12 days after the first acidisation campaign, the second acidisation was performed. Well No.1I was acidized with 1m³ of 12% HCl and 6% HF acids mixture. Injection rate after final treatment of well No.1I carried a less significant result with the rate increase of just 2.2m³/h.

Production data after jetting suggests an improvement in injectivity of approximately 14%, in total, 30 % with acidisation.

## 3. GEOTHERMAL UTILIZATION

### 3.1. Klaipeda Geothermal Demonstration Plant (KGDP)

Usage of geothermal resources for district heating started in Klaipeda in 2000. The absorption heat pumps use lithium bromide (LiBr) solution. Low-temperature geothermal heat is extracted from geothermal water of the Devonian aquifer. Plant capacity is confirmed by the State Commission – 35MW$_t$ (geothermal part – 13.6MW$_t$). (In detail the operation of KGDP was described in papers (Zinevicius et al. 2003) and (Zinevicius and Sliaupa 2010)). KGDP was solving the difficulties of injection and at the same time was struggling in the market. As a result, operation was only during the heating season in the period from 2013 to 2017.

Due to an unfavourable economical environment and problems with injection of used geothermal water - the operation of Klaipeda geothermal plant was stopped in year 2017 (Fig. 10). We hope, that problems faced by this plant will be solved and this pioneering installation will serve for research and education purposes; essential for further activities aimed at geothermal energy development in Lithuania. During KGDP operation from year 2001 to 2017 – 88,000 tones of CO2 emission were saved.

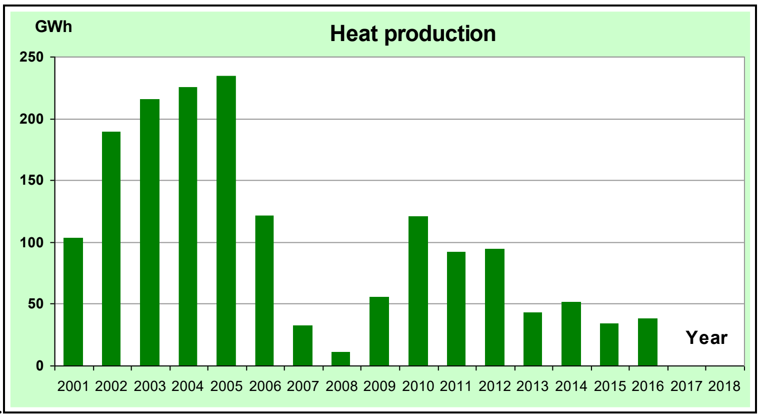


**Figure 10: Heat production of KGDP in the period from 2000 to 2018.**

### 3.2. Installation of Small-Scale Ground Source Heat Pumps (GSHP)

The number of small-scale ground source heat pump systems in Lithuania is growing. At present, there are nearly 7,700 installations thanks to such private enterprises as UAB Ekoklima, UAB “Naujos idejos”, UAB “Tenko Baltic”, UAB “EES”, UAB “Vilpra”, UAB “Ekokodas”, UAB “Steltronika”, UAB “Geoterminis sildymas”, UAB “Ardega”, UAB “Kauno hidrogeologija”. The Lithuanian Geothermal Association is proud of its legal bodies, like UAB “Donasta”. The total installed capacity is more than 110 MW (Fig. 11).


**Figure 11: Total capacity of installed small-scale GSHP systems.**

## 4. LEGAL BASIS

The main new legal act is:
**National Energy Independence Strategy of the Republic of Lithuania** (approved by the Seimas of the Republic of Lithuania on 21 June 2018)

***Executive summary - Energy for a competitive Lithuania***

**Item 1.4.4.2.** *Lithuania is a centre of information technology and cyber security solutions for energy, biomass and biofuel technology, solar and wind energy technology, **geothermal** technology, energy market development, improvement of electricity system operation, development of new electricity system management methods and implementation of energy projects*

***Chapter VI. Research and development demand and development of country's business***

**Item 69.** *As a result of completed significant strategic energy projects, the successful design and development of individual energy branches, Lithuanian energy companies, business enterprises and science and study institutions have accumulated exclusive competences in the field of solar energy, biomass, **geothermal energy**, LNG and other areas, which need to be maintained, further developed and strengthened. It is necessary to achieve that research and development in Lithuania and the resulting products acquire industrial production and become part of Lithuanian exports, thus contributing to the country's economic growth. This requires focusing on priority research directions and, at the same time, ensuring the practical use of the results of these studies and of existing and advanced competences*.

**Item 71.1**. *Increasing synergies among science and study institutions, energy companies and engineering companies by promoting various forms of cooperation through the use of investments from the EU research and innovation programme Horizon 2020, national and other programmes, developing digital energy innovations and improving technologies in Lithuanian energy sector, thus strengthening the ecosystem of **scientific research** and innovation in Lithuania.*

## 5. GOOD PRACTICE EXAMPLES

### 5. 1. First case study

Lithuania is a fast developing geothermal energy region. When the first deep geothermal plant in Lithuania came into operation, interest in this type of energy increased. Currently, most of the projects are ground source heat pumps, and the experience of high-capacity projects is high enough. Successful projects well managed and with short-term payback costs, often lead to continued cooperation with the same partners, wherever they are. A similar experience is with SANITEX, one of the largest wholesalers in the Baltic States. In 2014 after installing a logistics terminal in Kaunas, Lithuania (16,000m$^2$ floor heating, 200kW heat pump sub-station), the customer was convinced that geothermal could be a good and economical solution. An invitation from SANITEX Real estate development was received to install their logistics terminal in Riga, Latvia (Fig. 12). At that time, there was no significant experience of geothermal heat pump projects in Latvia, so the object was designed and installed by Lithuanian companies (DONASTA, STELTRONIKA, MR SISTEMOS). The key features of this were that the heating, ventilation and cooling needs of the building had been fully ensured by geothermal heat pumps only, while the waste heat of the ammonia chillers of the food chambers was also integrated.


**Figure 12: SANITEX Riga office and warehouse (general view).**

**Description:** Building total space - 40,000m$^2$, warehouse space - 24,800m$^2$, offices - 9,000m$^2$, cold room (+2..+4 °C ) - 6,200m$^2$;
Heat load: 988kW (space heating 695kW + ventilation 293kW);
Air condition load (offices): 500kW;
Freezer: Ammonia chiller

| Design temperature | winter | summer |
|---|---|---|
| outdoor | -20,7 °C | +27 °C |
| office temp | +21.5 °C | +24 °C |
| warehouse | +15 °C | not spec. |
| cold room | +4 °C | +4 °C |

Main heating source: heat pumps were used (10 x Stiebel Eltron WPF 66, B0/W35, total 670kW). The second heat source was the ammonium freezer in heat pump mode 346kW (285,4 + 60,7 compressor at B5W35. COP 5.71), available below 0° C outside temperature and 360kW direct electricity flanges in the buffer tanks.

As the heat source for heat pumps - geothermal probe heat exchanger was used (77 x 150m , total 11,550m and double U-type probe, 4xD32, PN16, length: 150m). The floor heating system was installed throughout the whole project space, and the cooling system was performed using fan coil and the floor space system. The ventilation system consisted of mechanical ventilation only for office space, with heat recovery. The two types of heat recovery units used were: plate and rotor-type.

Heat pump should provide:

- Space heating in winter,
- Heating for coils in ventilation system (295kW),
- DHW preparation all year,
- Passive cooling for office air conditioning and ventilation unit coils (300kW).

For the **regeneration** of geothermal heat exchanger it was planned to use waste heat from the heat of the office space in its passive cooling mode and ammonium chiller waste heat from freezer chambers system (condensing temperature in freezer + 35 °C).

The structural scheme can be seen at the building managing system BMS view:

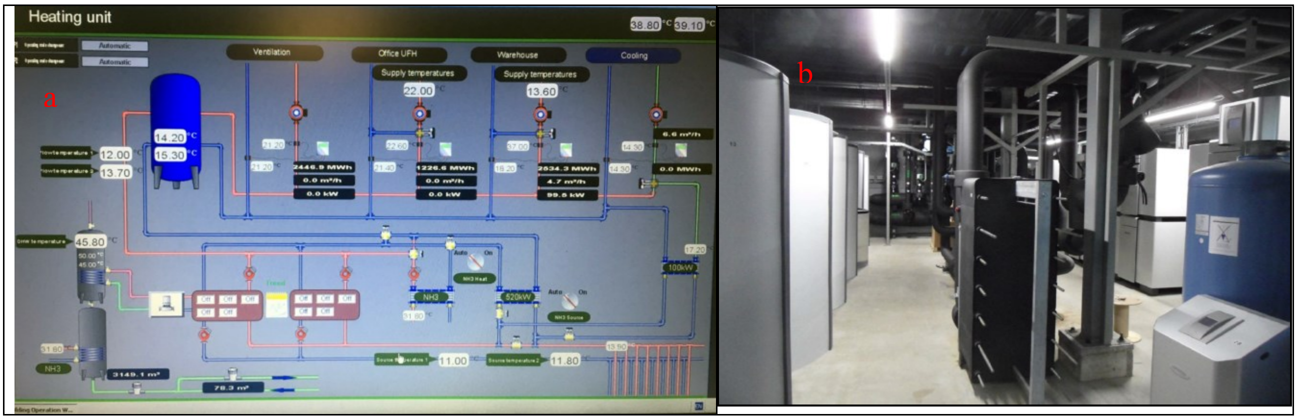


**Figure 13:View of the BMS: scheme (a) and heat supply sub-station with heat pumps (b) in SANITEX warehouse, Riga, Latvia.**

Geothermal field is designed with regard to the results of thermal response test (carried out by German partner HGC Hydro-Geo-Consulting GmbH), (Fig.14).

**Figure 14: Arrangement of geothermal probes for SANITEX warehouse, Riga, Latvia.**

**Table 1: Results of the Thermal Response Test.**

| Parameter | Symbol | Unit | Value |
|---|---|---|---|
| Evaluation period | | [min] | 1000…4436.5 |
| Vertical length of test inteval | **H** | [m] | 138.75 |
| Mean borehole radius | $r_b$ | [m] | 0.0589 |
| Minimum time validity criterion | $t_{min}$ | [h] | 178 |
| Heat flow | **Q** | [W] | 7469 |
| Average groud temperature at | $T_0$ | [°C] | 8.21 |
| **Thermal borehole resistance** | $R_0$ | **[K/(Wm)]** | **0.074** |
| **Effective thermal heat conductivity** | **λ*** | **[W/(mK)]** | **3.39** |

Today we can freely declare the real four year results of that project:
Total heating amount generated in four years is 4,562.5MWh; electricity consumption 920MWh (including circulation pumps, etc). The measured SPF (seasonal performance factor) is equal to 4.96 and at the electricity price 0.11 Eur/kWh the expenditure is 25,000 Eur/year (heating, cooling, ventilation losses with recovery included) - this result is more than three times less compared to the use of gas in Latvia. Pay-back of the project is calculated to be approximately five years.

### 5. 2. Second case study

Aquaculture could be one of the potential alternatives for western Lithuania geothermal resources utilization and this is one of the research topics of Klaipeda University (KU) Marine Research Institute. KU Marine Research Institute is working on innovative aquaculture solutions like marine re-circulating aquaculture technologies, probiotics applications and aquaponics. Innovative, blue biotechnology-based aquaculture is one of priorities within the 'Klaipeda Blue Economy Development Strategy 2030', so there is a solid background to develop innovative aquaculture.

One of the essential parameters determining fish growth and health, performance and efficiency of aquaculture systems is water temperature. Keeping fish at optimal rearing temperatures will give a much higher growth rate, which can be increased by 50 to 100%. The cost of reaching and maintaining the optimal water temperature all year round normally requires high demands of energy, therefore, the use of geothermal energy in aquaculture is increasing. The aim of geothermal aquaculture is to heat water to the optimum temperature for species in raceways, ponds and re-circulating aquaculture systems (RAS) (Ragnarsson, 2014; Van Nguyen et al., 2015)

Geothermal plant "Geoterma" in Klaipeda (which is using geothermal water from the 1,128m deep Devonian aquifer of 38°C temperature and 110g/l mineralization) together with Klaipeda Science and Technology Park were screening for different possibilities to diversify geothermal utilization. Along SPA and balneology, mineral mining and other options there was warm-water recirculating aquaculture. Based on several feasibility studies, the whiteleg shrimp (*Litopenaeus vannamei)* was identified as the best candidate to develop warm-water recirculating aquaculture in Klaipeda.

These whiteleg shrimp are the Pacific Ocean species, which live and have the highest feed intake rate in water of 28-32°C temperature (Wickins & Lee, 2002). Therefore geothermal water resources of Cambrian-Devonian aquifer perfectly fit to heat water to an optimal 30°C using heat exchanger technology.

Currently Klaipeda Science and Technology Park together with Klaipeda University is developing a recirculating aquaculture system (RAS) integrated with renewable energy sources for whiteleg shrimp production. This is a saltwater system of ca. 38m$^3$ total water volume, with eight tanks for 100 to 200kg production per cycle (Fig. 15). The goal of the experiment is to acquire shrimp cultivation knowledge and to optimize growth technology for local conditions. A successful prototype will open up for new business opportunities and models for innovative and energy smart aquaculture in the region (Initially it was planned to heat RAS by using geothermal energy from Klaipeda geothermal plant "Geoterma", but as it was closed by the Government, the project was developed in the premises of Klaipeda University Business Incubator). This work is being completed as part of a pilot infrastructure created as one of the innovative aquaculture development cases within the framework of the EU INTERREG South Baltic Programme funded project 'InnoAquaTech'.

Shrimp RAS in Klaipeda was operated at 16g/l water salinity and 29.5 °C temperature, 7.7-8.2 pH, 70-85 % oxygen saturation, $NH_4$ concentration normally was <0.05 mg/l and $NO_3$ – 60-310 mg/l. The growth performance of cultivated shrimps was very good, reaching the market size (18-22g) in 120-130 days, while in 150 days of cultivation reaching 30.0±6.5 g (Fig. 16).

Preliminary operational costs per 1kg of production were evaluated for one 150 days production cycle. The energetic demand for heating of the process water constituted only fifth place in total operational costs. However, geothermal heating becomes a significant competitive advantage at commercial scale farms not only on Lithuanian ground but also on the regional scale.

Whiteleg shrimp lives in marine waters of high salinity (of 30g/l mineralization), therefore water was then produced locally from tap water and artificial sea salt. In order to keep operating costs low, as little salt as possible should be used. In comparison to other shrimp species, *L. vannamei* has a high physiological tolerance to a low salt content of the water (Wickins and Lee, 2002), therefore the tested growth technology was based on twice lower salinity (15-16 g/l). Despite this, the daily loss of salt with processed water was significant and in the Klaipeda pilot RAS, the routine water salination with artificial special salt constituted one of the highest operational costs (1 ton of salt price is €1,150Eur excl. VAT). The daily water loss through evaporation and technological processes was about 1-2 %, while it could increase up to 3-4 % with fully loaded system.

One of the shrimp cultivation technology development issues is the testing of the possibility to use geothermal water (110 g/l) for water salination. Calcium and magnesium in particular are necessary trace elements for shrimps (Wickins & Lee, 2002), and the geothermal water from 1,128m deep Devonian aquifer in western Lithuania is highly rich in natrium, calcium and magnesium. On the other hand, water quality and disease control need to be considered when using geothermal fluids in the aquaculture (Ragnarsson, 2014), therefore other trace elements (like strontium, zinc, barium, lithium and others, which were found in geothermal water) and physic-chemical parameters, which could have effect on the biological processes will be tested. Surveys on bioaccumulation, physiological status, growth and stress tolerance will be performed in the next steps of technology development.


**Figure 15: Pilot case for recirculating aquaculture system for shrimp cultivation in Klaipėda University Business Incubator: water preparation and filtration system (a) and shrimp growing tanks (b).**

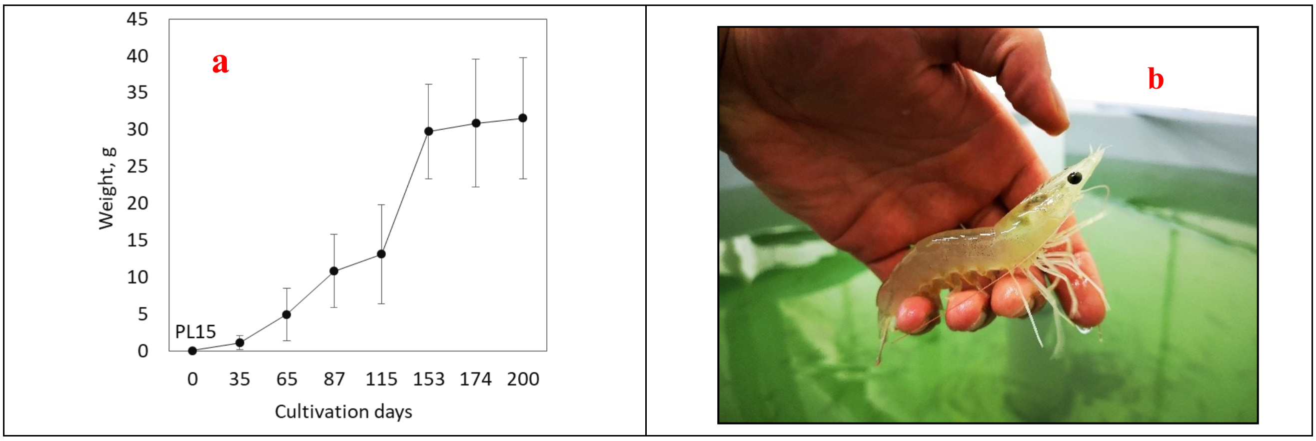


**Figure 16: Growth in weight (mean±SD) of *L. vannamei* from post-larvae (PL15, weight ~ 30mg) in Klaipeda experimental RAS (a); and individual of *L. vannamei* shrimp (b).**

## 6. CONCLUSIONS

1. The plant at Klaipeda is designed to be a low enthalpy geothermal conversion facility, relying on high injectivity and productivity to achieve the required energy capacity. The injectivity of the injection wells has deteriorated due to a variety of problems (scaling, fines mobilization, sanding etc.). Radial jet drilling was identified as a technology which could help improve injectivity and subsequently 12 laterals were jetted in well 1I in December 2014 that was soon followed by two soft acidisation campaigns. It resulted in a total injectivity increase for 30%.

2. Due to an unfavourable economical environment and problems with the injection of used geothermal water - the operation of Klaipeda geothermal plant was stopped in 2017. We hope that problems faced by this plant will be solved and this pioneering installation will once again start to serve as a site for research, education and production purposes, essential for further activities aimed at geothermal energy development in Lithuania.

3. Total capacity of the installed ground source heat pumps reached over 125MW$_t$.

4. Lithuanian companies successfully implemented a geothermal project in Latvia: The 700kW ground source heat pump system implemented in the SANITEX logistic centre. Pay back time is estimated to be approximately five years.

5. The first step was carried out to use geothermal resources in aquaculture development. Shrimp cultivation technology, using recirculating aquaculture system, was acquired. The second step: to test salt application and use heat from geothermal water.

## REFERENCES:

National Energy Independence Strategy of the Republic of Lithuania, Resolution No. XIII-1288 of the Seimas of the Republic of Lithuanian of 21 June 2018.

Suveizdis, P., Rasteniene V. and Zinevicius F: Geothermal Energy Possibilities in Lithuania. Proceedings of the World Geothermal Congress, Florence, Italy, (1995) Vol. 1, 227-232,.

Blöcher, G., Peters, E., Reinsch, T., & Petrauskas, S., (2016). *D3.2 Report on radial jet-drilling (RJD),* s.l.: Project SURE.

Buset, P., Riiber, M. & Arne, E.. Jet Drilling Tool: Cost-Effective Lateral Drilling Technology for Enhanced Oil Recovery (2001)

Peters, E., Veldkamp, J., Pluymaekers, M. & Wilschut, F. 2016. *Radial jet drilling for Dutch geothermal applications.* Strasbourg, France, EGC, 19 - 24 Sept 2016.

Ragab, A., Kamel A.. Improving well productivity in an Egyptian oil field using radial drilling technique. *Journal of Petroleum and Gas Engineering, (*2013) 103-117.

Sliaupa, S.. Reservoir characterisation of the Klaipeda geothermal plant (Lithuania), Vilnius, Lithuania: (2016) Nature Research Centre *report*.

Wolfgram M., Seibt P., Sliaupa S.. Investigations into the Injection Problems of the Klaipeda Geothermal Plant (Lithuania), (2008) (internal report).

Zinevicius, F., Rasteniene, V., and Bickus, A.: Geothermal Development in Lithuania, *Proceedings of the European Geothermal Conference* 2003, Szeged, Hungary, (2003), 1-9.

Zinevicius, F., and Sliaupa, S.: Lithuania - Geothermal Energy Country Update, *Proceedings of the World Geothermal Congress* (2010), Bali, Indonesia, (2010), paper # 0153, 1-8.

Ragnarsson, A, 2014. Geothermal energy in aquaculture. “Short Course VI on Utilization of Low- and Medium-Enthalpy Geothermal Resources and Financial Aspects of Utilization”, organized by UNU-GTP and LaGeo, in Santa Tecla, El Salvador, March 23-29, 2014.

Van Nguyen, M., Arason, S., Gissurarson M. and Pálsson, P.G. 2015. Uses of geothermal energy in food and agriculture – Opportunities for developing countries. Rome, FAO

Wickins, J.F. & Lee D.O., 2002. Crustacean farming: Ranching and Culture, Second Edition. Blackwell Science. P. 446.

**Table 1. Present and Planned Production of Electricity**

| | Geothermal | | Fossil Fuels | | Hydro | | Other renewables | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Capacity, MWe | Gross Prod. GWh | Capacity, MWe | Gross Prod. GWh | Capacity, MWe | Gross Prod. GWh | Capacity, MWe | Gross Prod. GWh | Capacity, MWe | Gross Prod. GWh |
| In operation December 2018 | - | - | 1910 | 607 | 1028 (900 Kruonis HPS) | 947 (521 Kruonis HPS) | 521 wind<br>102 biomass<br>82 solar<br>22 waste<br>727 total | 1139 wind<br>376 biomass<br>80 solar<br>71 waste<br>1666 total | 3665 | 3220 |
| Under construction in December 2018 | - | - | - | - | - | - | 92<br>24 waste/ biomass | 400<br>170 | 116 | 570 |
| Funds committed, but not yet under construction in Dec. 2018 | - | - | - | - | - | - | 350 mln.EUR<br>140 mln.EUR | - | - | - |
| Estimated total projected use by 2020 | - | - | n.a. | n.a. | n.a. | n.a. | 1224 | 3000 | n.a. | n.a. |

**Note:** nuclear power plant Ignalina is closed in 2009.

**Table 5. Summary table of geothermal direct heat uses as of 31 December 2018**

| Use | Installed capacity[1)], (MWt) | Annual Energy Use[2)] | Capacity Factor[3)] |
|---|---|---|---|
| **Subtotal** | | | |
| Geothermal Heat Pumps:<br>- Small scale (total)<br>- Big (in Klaipeda Geothermal Demonstration Plant) | <br>125.5<br>18 | <br>1044<br>Closed in 2017 | <br>0.264 |
| **TOTAL** | 125.5 | 1044 | 0.264 |

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (ºC) - outlet temp. (ºC)] x 0.004184
2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (ºC) - outlet temp. (ºC)] x 0.1319
3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171

**Table 7. Allocation Of Profesional Personnel To Geothermal Activities (Restricted to personnel with University degrees)**

| Year | Professional Person-years of Effort | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| 2015 | 3 | 21 | 6 | | 3 | 30 |
| 2016 | 3 | 21 | 6 | | 3 | 30 |
| 2017 | 3 | 1 | 6 | | 2 | 30 |
| 2018 | 3 | 1 | 6 | | 2 | 30 |
| 2019 | 3 | 0 | 6 | 2 | 1 | 30 |
| Total | 15 | 44 | 30 | 2 | 11 | 150 |

(1) – Government; (2) – Public utilities; (3) – Universities; (4) – Paid Foreign consultants;
(5) – Contributed Through Foreign Aid Program; (6) – Private Industry.

**Table 8. Total investments in Geothermal in (2019), US$**

| Period | Research & Development incl. Surface Explor. & Exploration Drilling, mln. USD | Field Development incl. Production Drilling & Surface Equipment, mln. USD | Utilization | | Funding Type | |
|---|---|---|---|---|---|---|
| | | | Direct, mln. USD | Electrical, mln. USD | Private, % | Public, % |
| 1995-1999 | 0.035 | 8.51 | 15.4 | - | 0.4 | 99.6 |
| 2000-2004 | | 1.03 | 2.97 | - | 45.6 | 54.4 |
| 2005-2009 | 0.144 | 35.22 | 5.27 | - | 86.67 | 13.33 |
| 2010-2014 | 0.08 | 0.3 | 42.2 | - | 98.6 | 1.42 |
| 2015-2019 | 0.07 | - | 48.9 | - | 99.85 | 0.15 |