Review of the geothermal energy potential in the Europe and Latvia

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Introduction

A large portion of the global energy supply is used for electricity generation and space heating, with the majority derived from fossil fuels. Fossil fuels are finite resources and their combustion is harmful to the environment, through the emission of greenhouse gases and contribute to climate change and other pollutants. Use of renewable energy sources leads to the reduction of the environmental pollution which is well described in similar study [1]. Demand for energy is increasing and future fossil fuel shortages are predicted [2]. A variety of different renewable energy sources are presented on the energy market and some of them really has a potential to substitute or partly replace fossil fuels, thus contributing energy independence for the countries which geographically deprived of fossil energy sources. Geothermal energy is worldwide the most extensively used renewable energy besides hydro-power. By the end of 2000, geothermal power plants amounted worldwide to an installed capacity of about 8,000 MWel. They produced electrical energy of roughly 50,000 GWh per year. Besides this about 52,000 GWh of geothermal energy per year were extracted worldwide for direct use for space heating, process heat, thermal spas or greenhouses. Compared to other renewable energies geothermal heat is advantageous since it is available all day and at all seasons. This and its great resource make geothermal energy an attractive option for a sustainable energy supply in the future.

Geothermal energy can be exploited with various technologies, although it generally, albeit not exclusively, involves drilling and pumping water from depth. It feeds a great diversity of applications, alone or in combination with other sources of energy. Geothermal energy is stored in the subsurface in certain concentrations and modes, which influence the type of application and extraction method that can be adopted.

Geothermal district heating

In the EU-27 countries there are 3550 DH systems providing heat for 2160 cities and towns over 5000 inhabitants, thus satisfying 12% of total heat demand of the population. The majority of the systems are fed by gas and only 1% by renewables (mostly biomass). Despite the favorable geothermal conditions in Europe, geothermal energy contributes only 0,001% of the district heating systems. In 2011 there were 212 Geo-DH systems operating in Europe with a total installed capacity of ~ 4700 MWt capacity. The major markets are in France, Iceland, Germany and Hungary, however most of the European countries foresee a significant growth by 2020, also in line with their NREAP (National Renewable Energy Action Plans) targets [3].

Over 25% of the EU population lives in areas directly suitable for Geothermal District Heating (GeoDH). There is a large potential in Central and Eastern Europe, with GeoDH systems in operation in 22 European countries including Hungary, Poland, Slovakia, Slovenia, the Czech Republic, and Romania, where existing heat networks are well developed. Leading countries by GeoDH capacity installed are Iceland, Hungary, France, Germany, and Italy. There are 237 Geothermal District Heating plants (including cogeneration systems) in Europe representing the total installed capacity of 4.3 GWth and production of some 12883 GWh or 1107 ktoe in 2012. Systems can be small (from 0.5 to 2 MWth), and larger with capacity of 50 MWth. There are some new District heating schemes that utilise shallow geothermal resources, assisted by large heat pumps. Additionally, the installation of GeoDH systems becomes more economic close to areas with higher urban density, as both resources and demand need to be geographically matched [4].

Additionally, it would be useful to mention, that development of geothermal energy potential within development of smart cities [5], where steps are being taken to improve the energy efficiency of residential sector by the renovation of multi-apartment buildings [6] and decrease the consumption of thermal energy, is promising and feasible measure for heating and hot water preparation.

Geothermal benefits and potential in Europe

Geothermal generation has its roots in Europe. In the EU, 180 geothermal district heating systems have a total installed capacity of 1.1 GWth, producing some 4256 GWh of thermal power, (i.e. 366 ktoe in 2012). The main benefits of geothermal heating and cooling are provision of local base load and flexible renewable energy, diversification of the energy mix and protection against volatile and rising fossil fuels prices. Using geothermal resources can provide economic development opportunities for countries in the form of taxes, royalties, technology export, and jobs. The geothermal potential is recognized by some EU Member States in their National Renewable Energy Action Plans. However, the actual potential is significantly larger. In order to increase awareness, GEODH, an IEE project co-financed by the EU - has assessed and presented for the first time the potential in Europe on an interactive maps:

– http://map.mfgi.hu/geo_DH/ [7];
– https://heatroadmap.eu/peta4/ [8].

According to Eurostat, about one third of the EU's total crude oil (34.5%) and natural gas (31.5%) imports in 2010 originated from Russia. Of this, 75% of the gas is used for heating (2/3 in households and 1/3 in the industry). Geothermal DH technology has the potential to replace a significant part of that fuel.

Geothermal resources are defined as that part of the geothermal energy which can be extracted economically and legally in the near future. In order to quantify these resources, it is necessary to define the amount of heat available in the rock (geothermal reservoir) and the characteristics of the reservoir with respect to the extraction of this heat. There are different methods and models that can be used to quantify geothermal resources. The assessment of geothermal resources is based on a volumetric heat content model for porous reservoirs assuming exploitation of geothermal energy by a doublet described in [9, 10].

Temperature distribution at depths of 1000 m (Figure 1) and 2000 m provide a large scale view of the thermal field, while maps depicting the cities of presently operating geothermal installations (red dots) and the areas for which more detailed resources assessment can be found in specific national contributions.

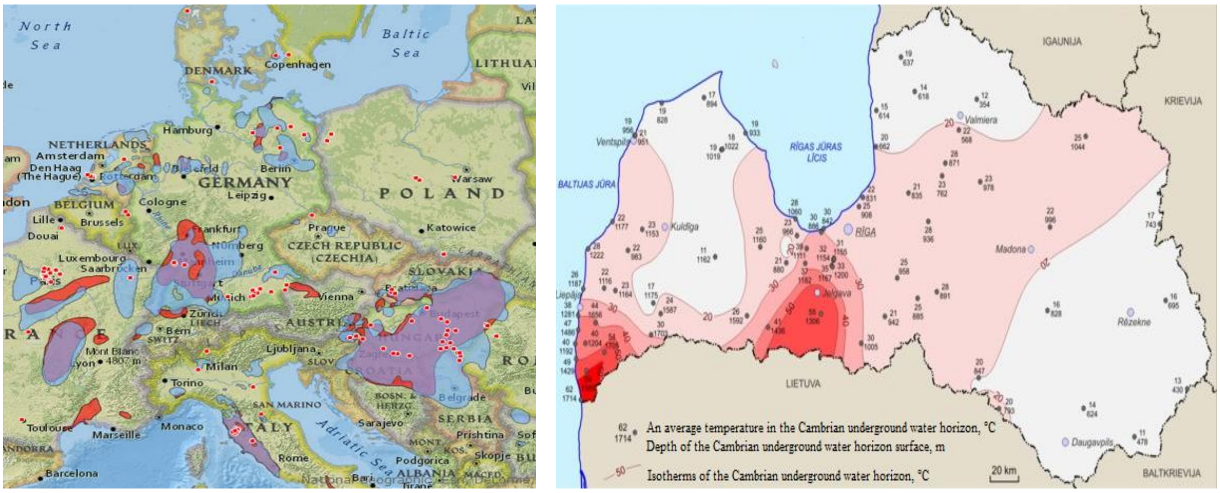

Figure 1 Temperature distribution at depths of 1000m T>50°C (blue polygons) and 2000m T>90° (red polygons), red dots – geothermal district heating [4] (left).
An average temperature map in the Cambrian underground water horizon, Latvia [11] (right).

The map is not a tool to determine drilling sites for geothermal installations. Rather, it should be employed in activities preceding the targeting of drilling for geothermal purposes. It serves as a guide to set priorities for future investments in local studies and auxiliaries in delineating target areas for these investments.

Geological Structure of Latvia's territory

The utilization of geothermal energy in the territory of Latvia can be classified in the following groups:

- Geothermal resources of low temperature <20°C; applicable for heating small objects and individual buildings and for preparing hot water with heat pumps;
- Geothermal resources of medium temperature 20°C - 30°C; applicable for heating buildings and for preparing hot water with heat pumps;
- Geothermal resources of high temperature >30°C; applicable for heating small residential areas and for preparing hot water with heat pumps, for direct heating as well as in combined electric power stations;
- Petro thermal energy resources >100°C; applicable for electricity production, heating and preparing hot water.

An average geothermal gradient varies within the interval of 0.8°C/100m – 1.9°C/100m in the north and east part of Latvia, but an average geothermal gradient reaches 3.5°C /100m in the central and southwest part of Latvia. The change of geothermal gradient in the cross section happens in the point where a blocking layer meets the water horizon. The graphs of rocks' temperature measurements carried out in the boreholes reflect it as the change of an angle between a vertical axle and a temperature graph. Three lithological stratigraphically structures with different geothermal gradients are apparent in the geological cross section of Latvia:

1. Devonian terrigenic Carboniferous rocks.
2. Silurian and Ordovician Carboniferous clay deposits.
3. Cambrian and Venda terrigennic rocks.

In the Cambrian and Venda cross section, gradients vary from 0.6°C/100m to 3.1°C/100m. The maximum value is reached in the southwest of Latvia. The analysis of the changes in an average temperature of Cambrian structure in the territory of Latvia is based on the observation data from measurements of temperature conditions in 72 boreholes that are scattered unevenly.

There are 2 geothermal zones in the Cambrian structure with an increased temperature:

1. The zone in the direction to the south, southeast of Liepaja, where the temperature in Cambrian deposits reaches 38°C – 62°C in the depth of 1,281 – 1,714m.
2. From the borders of Jurmala to the Lithuanian border (Eleja geothermal anomalous zone), where the water temperature of the Cambrian reservoir is 33°C – 55°C in the depth of 1,100 – 1,436m [12].

Evaluation of heat pump installation impact on final energy consumption

Considering before mentioned information, it can be concluded that shallow geothermal energy could have a potential for wide implementation. The most realistic application could be water – water heat pumps for single family houses or mid-scale detached houses. In scope of this chapter the theoretical impact of heat pump installation on primary energy consumption for single family houses was evaluated. For the simulations, IDA-ICE software was used.

Building's basic data is shown in Table 1. It is insulated according to low energy approach.

Table 1 Properties of external building elements

Building envelope	Area [m^2]	U [W/(m^2 K)]	U*A [W/K]	% of total
Walls above ground	71.61	0.11	7.84	14.15
Roof	74.42	0.08	6.09	10.98
Floor towards ground	77.55	0.15	11.72	21.15
Windows	19.03	0.90	17.12	30.89
Doors	2.10	1.09	2.28	4.12
Thermal bridges			10.37	18.71
Total	244.70	0.23	55.43	100.00
Wind driven infiltration airflow rate				69.676 l/s at 50.000 Pa

As a reference scenario a simple gas boiler was chosen. The system with bore hole and air to air heat pump was compared. The advanced model is shown in Figure 2.

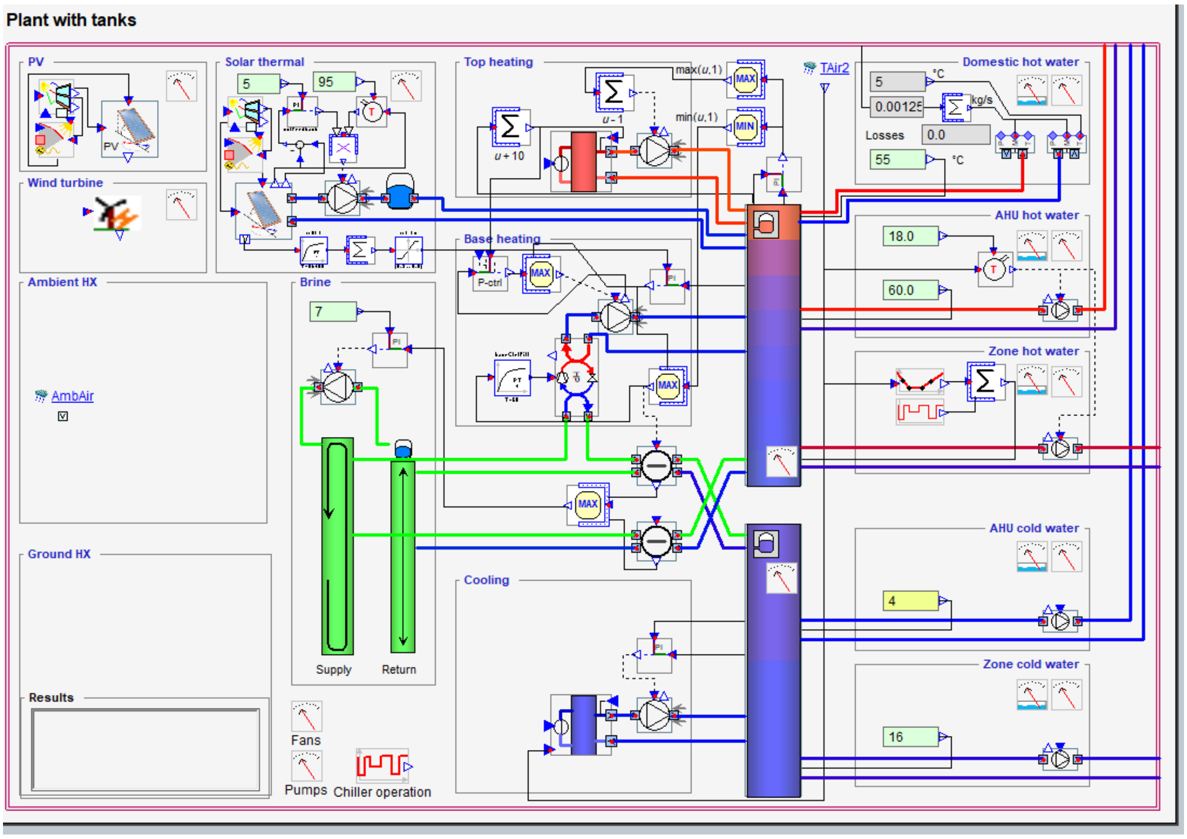

Figure 2 Advanced installation (with on-site solar energy)

Table 2 Energy consumption for different type of heat source

	Gas boiler (efficiency 85%)	Air to air heat pump	Brine to Brine heat pump
Delivered energy (fuel before combustion/ transformation), kWh/m^2	6910.0	1863.0	3448
Used energy, kWh/m^2	5 817,6	5 579,2	6 011,1
Primary energy, kWh/m^2	7 601	2 794,5	5 172

As it can be seen air to air heat pump is the most effect way for heating. However, in practice COP of such heat pump is not 100% predictable and depends on heating system operating temperature and outdoor air parameters. According to our measurements of COP for air to air heat pump is approximately 2 at real environment. It that case amount of delivered energy increases up to 2967 kWh. Further research on brine to brine heat pump model will be continued.

Evaluation of ground heat pump efficiency under real operation

The research will be carried out in two different ways-both data analyzing from the object and performing simulations in the modelling program. The system has been in operation since 2017. Characteristics of the private house: 2 floors, heating area: 1st floor 103.1 m2, 2nd floor 86.7 m2. House walls from indoor to outdoor consist of doubled plasterboard 24 mm, air gap 70mm, aerated concrete block 300mm, rockwool 100mm and decoration. The floor is insulated with Styrofoam 100 mm and the roof is insulated with rockwool 150mm. Only natural ventilation exists in the house. This is a temperate cold climatic zone with annual average temperature +6°C, area is not windy, but humidity is high, and average global solar radiation on horizontal plate is almost 1100 kWh/y. 8 pcs TS400 Thermosolar - flat vacuum type solar collectors are installed on the roof orientation 12°East South, and collector tilt angle 45°. Heat pump is power variable, nominated SEER=2.96 and electrical power consumption up to 13kW. Low temperature floor heating is used. Total heating area is almost 200 m2. Overall system scheme is shown in Figure 3.

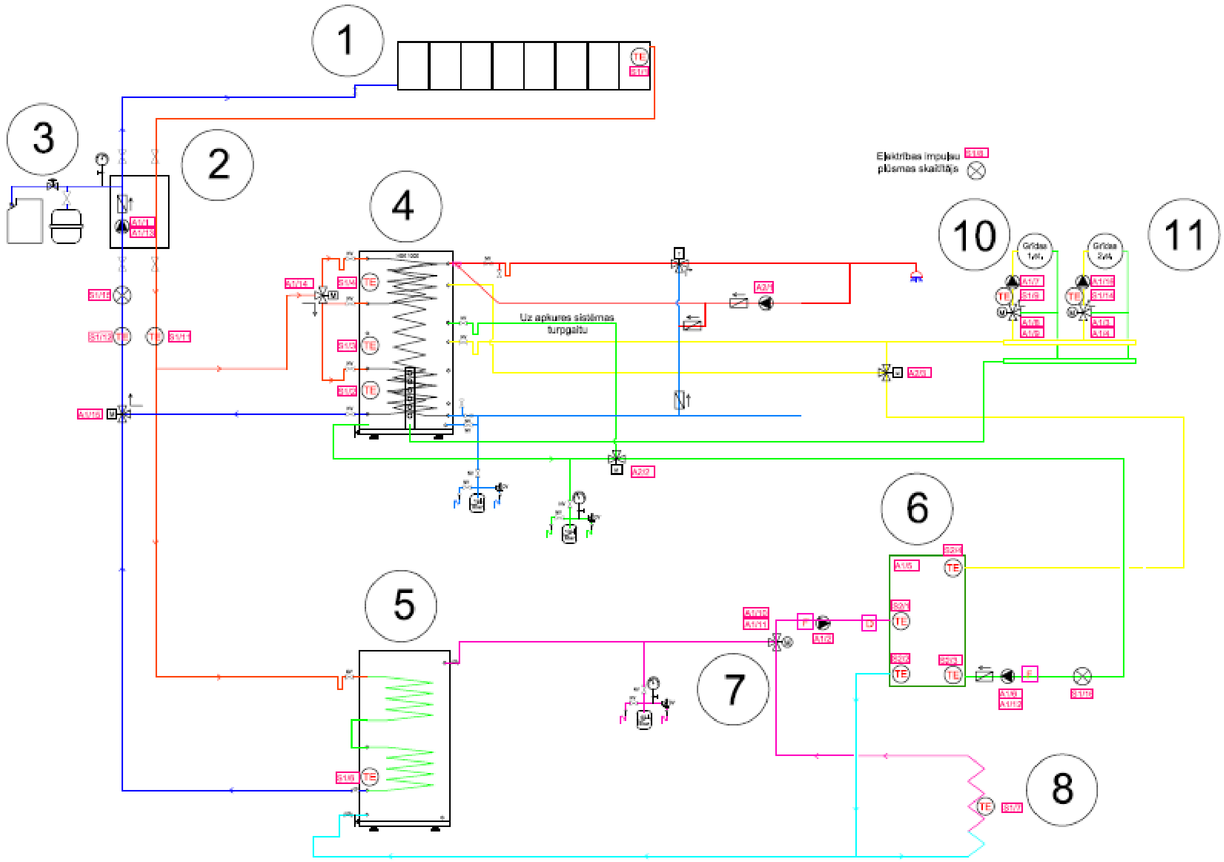

Figure 3 Heating system scheme

1. Vacuum flat plate solar collectors filled with krypton gas,

2. Solar collector loop circulation pump,
3. Expansion tank suitable for solar thermal energy,
4. DHW and heating combined tank 1000L for heating support,
5. Bioethanol storage tank 300 l,
6. Heat pump Qh – 13 kW,
7. Mixer for horizontal earth collector,
8. Horizontal heat pump ground collector 1 500 m,
9. DHW loop circulation pump,
10. 1st floor heating loop circulation pump,
11. 2nd floor heating loop circulation pump.

The combined heating system has 2 parts- ground heat pump with nominal load 13 kW, ground heat pump pipe system is built in 2m depth, and solar heating system that consists of 8 flat plate vacuum collectors. Solar collectors are connected due to copper pipes with solder connections. As a non-freezing heat carrier in system flows propylene glycol.

As a result, the max heat energy load in one-hour period from solar collector system was calculated and determined that at high solar irradiance Qsolar max = 14,58 kWh, but at low solar irradiance Qsolar min = 5,10 kWh. And therefore, the amount of heat energy to warm up accumulation tank till 55°C was calculated as 52 kWh.
Using modelling software based on the measurements, the relationship between outside temperature, hot water demand, and solar energy yield was established.

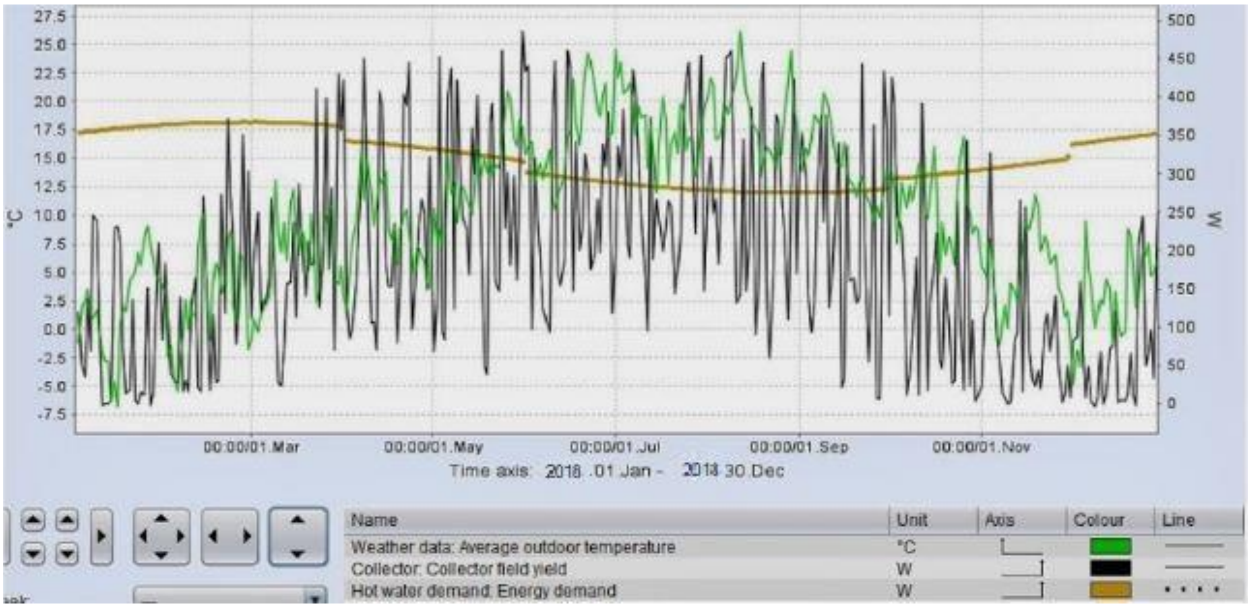

Figure 4 DHW, outside temperature, solar energy yield profile

Conclusions

1) Exploitation of geothermal resources is critically determined by the transmissivity of the aquifer, which constrains production rates. Transmissivity data and pumping test results are only available for specific areas. It would not be possible to obtain assessments for most of Europe based on such data. Furthermore, permeability may vary over several orders of magnitude within short distances, with almost unpredictable consequences for the exploitation.
2) With the increased interest in geothermal heat pumps, geothermal energy can now be developed anywhere, for both heating and cooling. Low-to-moderate temperature geothermal resources are also being used in cogeneration heating plants (CHP). CHP projects certainly maximize the use of the resources and improve the economics, as has been shown in Iceland, Austria and Germany.
3) Using low-to-moderate temperature geothermal resources in the direct heat applications, given the right conditions, is an economically feasible business, and can make a significant contribution to a country's or region's energy mix. As oil and gas supplies dwindle and increase in price, geothermal energy will become an even more economically viable alternative source of energy.
4) There are 2 geothermal zones in the Cambrian structure with an increased temperature:

The zone in the direction to the south, southeast of Liepaja and from the borders of Jurmala to the Lithuanian border (Eleja geothermal anomalous zone).

5) Solar assisted ground coupled heat pump system is a good alternative source of heating, with a view to reducing the greenhouse effect and increasing the greening of the fighting environment. Transformation factor of solar assisted ground coupled heat pump system in Latvia is 3.98. Comparing the data obtained from the electricity demand shows a 40% of electricity savings, it can also be expressed as 2,08 [tCO2/year] carbon footprint reduction. In the system, solar collectors produced approximately 40% of the energy demand.

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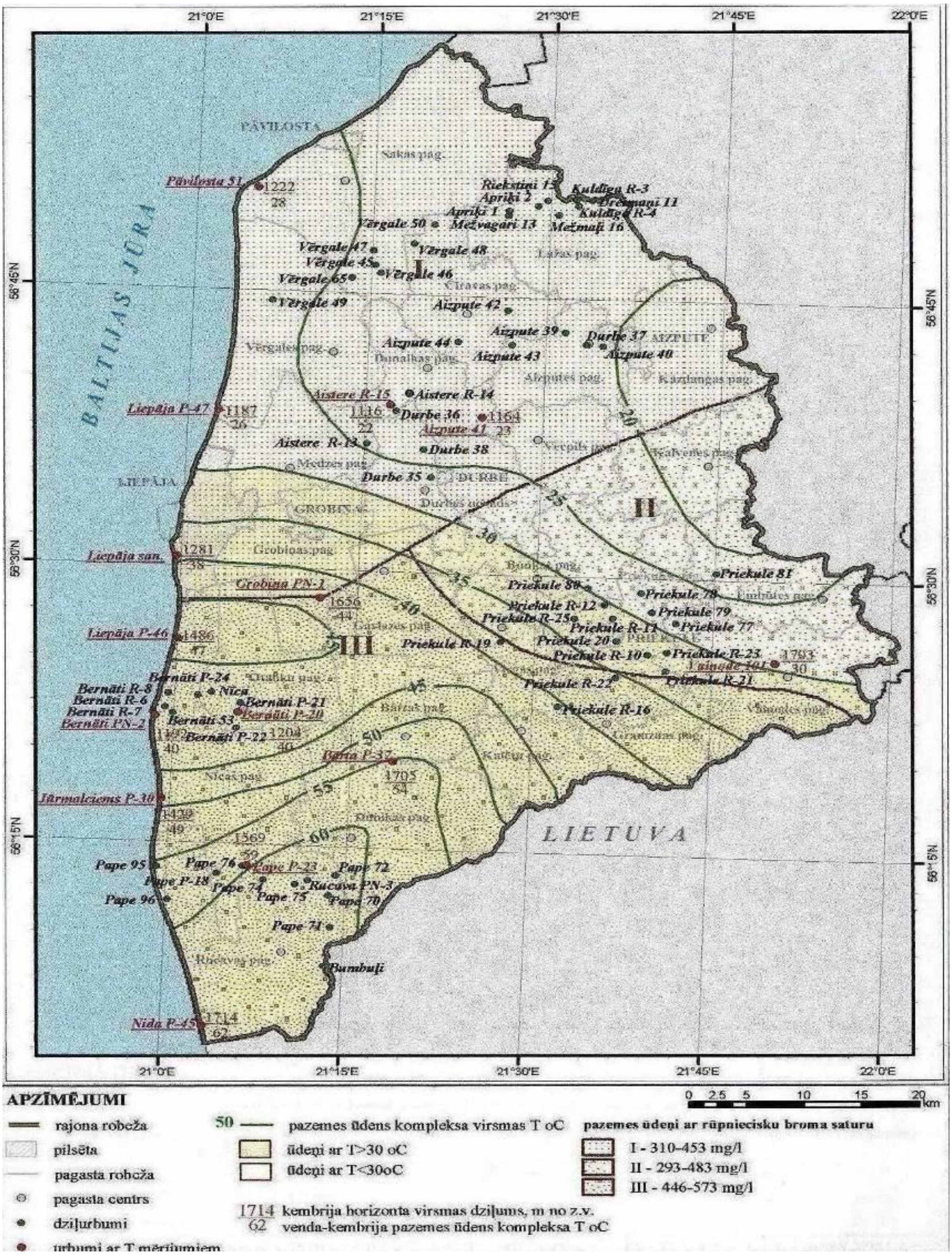
Annex 1



Geothermal energy potential in Liepaja region[1]

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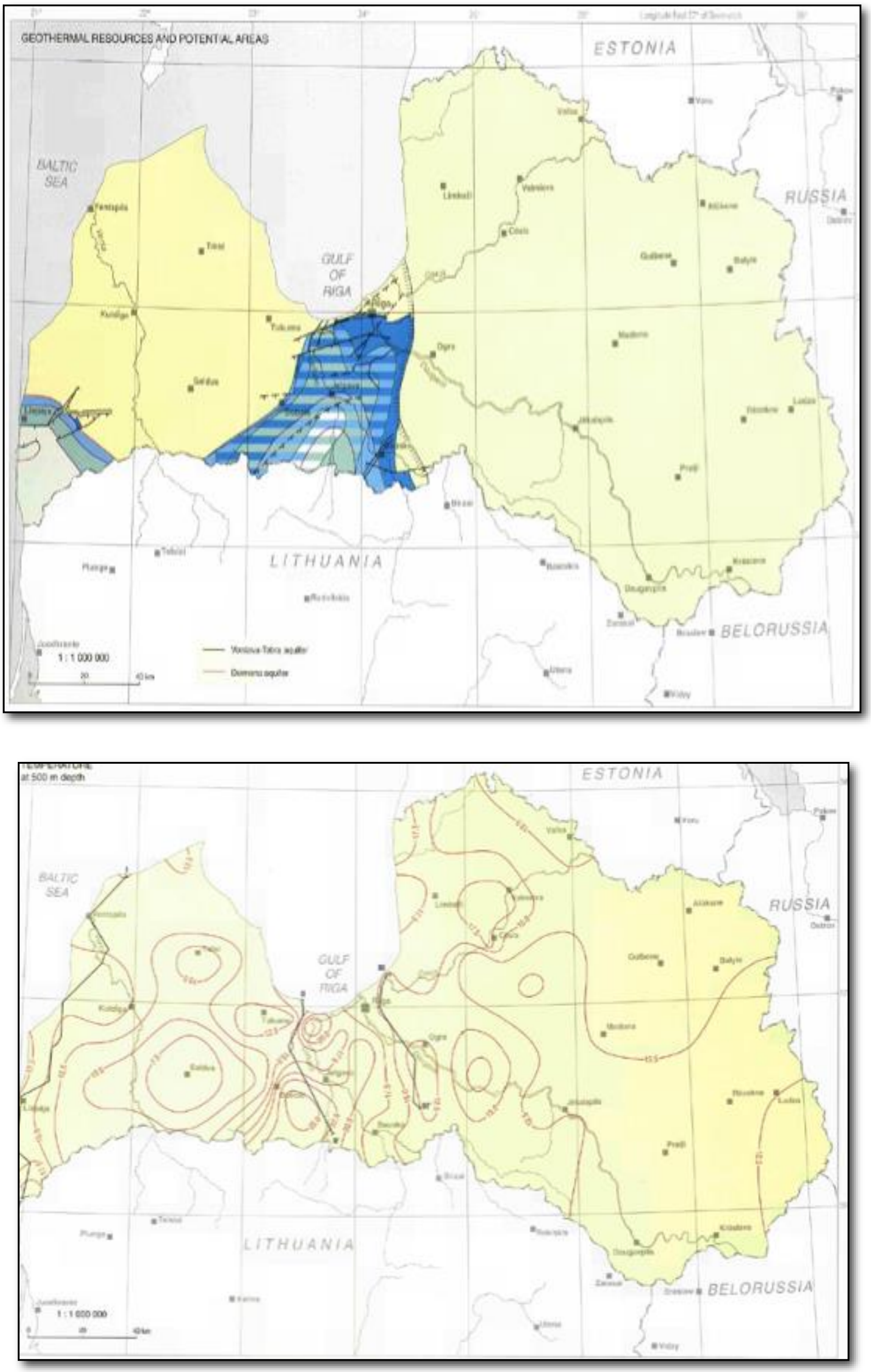
Annex 2



Geothermal energy territory (temperature varies 7 – 25oC at 500 m depth)[2]

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