Co-funded by the Intelligent Energy Europe
Programme of the European Union

GEOELEC

Deliverable n° 2.5

Date : November 2013

# A prospective study on the geothermal potential in the EU

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## List of main abbreviations and acronyms used

| | |
|---|---|
| AGEA | Australia Geothermal Energy Association |
| CanGEA | Canadian Geothermal Energy Association |
| CHP | Combined Heat and Power |
| EGEC | European Geothermal Energy Council |
| EGRIF | European Geothermal Risk Insurance Fund |
| EGS | Enhanced Geothermal Systems |
| HIP | Heat in Place |
| HSA | Hot Sedimentary Aquifer |
| LCoE | Levelised Cost of Energy |
| NREAPs: | National Renewable Energy Action Plans |
| ORC | Organic Rankine Cycle |
| TC | Theoretical Capacity |
| TP | Technical Potential |
| TPLCoE_p | Economic Technical Potential |

# Executive summary

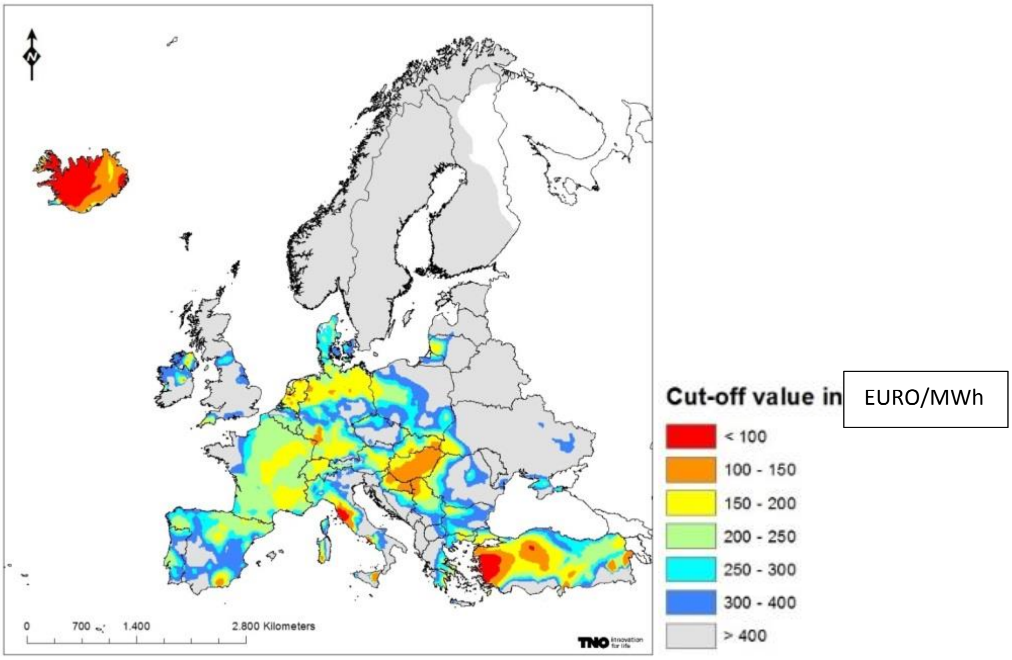
Geothermal power generation has its roots in Europe, where the first test in 1904 and the real beginning of power generation in 1913 took place in Italy. Since then, the development of geothermal technology has been slow but continuous.

Since a decade, thanks to the optimisation of the new binary system technology, geothermal electricity can be produced using lower temperatures. Moreover, with Enhanced Geothermal Systems (EGS), a breakthrough technology proven since 2007, geothermal power can in theory be produced anywhere in Europe.

According to the trajectories set out in the National Renewable Energy Action Plans (NREAPs) of the EU Member States, the capacity will grow from 0.9 GWe installed in 2013 to 1.4 GWe in 2020. The production of geothermal electricity in 2020 is planned to be 11 TWh.

These are very conservative targets as the actual potential is much larger. Indeed, information about geothermal potential is not always available (no geological data below 2-3 km from previous exploration campaign for oil, gas etc.) or it is scattered in different ministries, universities, national institutes, oil & gas companies and various private entities.

For this reason many policy-makers are simply not aware they stand on a frequently untapped source of local renewable energy. And this is also why geothermal power is not always taken sufficiently into consideration in some NREAPs and other strategic documents on the future electricity mix.



Minimum levelised costs of Energy in 2030 (in EUR/MWh)

The present GEOELEC study makes a first step to fill the existing gap. It provides an outlook of the potential by country; the resource assessment is the product of the integration and interpretation of existing data and a newly defined methodology building on Canadian, Australian, and American methodology.

The geological potential (heat in place) for geothermal power has been translated to an economical potential, using a Levelised Cost of Energy (LCoE) value of less than 150 EUR/MWh for the 2030 scenario and less than 100 EUR/MWh for the 2050 scenario:

- **The total geothermal electricity potential in the EU-28 is 21,2 TWh for the year 2020;**
- **In 2030 this amounts to 34 TWh or 1% of the projected total electricity production in the EU;**
- **Thanks to economies of scale, innovative drilling concepts and substantial cost reduction, the economic potential in the EU grows to approximately 2570 TWh in 2050 potentially covering as much as 50% of the projected electricity produced in the EU) and more than 4000 TWh including Iceland, Turkey and Switzerland.**

# Introduction

## *What is geothermal electricity?*

Until little over a century ago, the exploitation of geothermal resources was primarily for leisure purposes; hot springs and geothermal baths. It was at the beginning of the 20th century that the active development of geothermal resources for electricity supply began. Successful production of electricity from geothermal heat was first achieved in Larderello, Italy, in 1904.

Since then, the production of geothermal electricity has steadily increased. The methods by which hydrothermal resources are developed for electricity production can be divided in two categories: conventional (dry steam and flash steam turbines) and low temperature (binary) geothermal electricity.

### Conventional geothermal electricity: dry steam and flash steam turbines

Operating with large hydrothermal reservoirs at high temperature, i.e. above 150°C, such as those found in Tuscany (Italy) and Iceland, this technology has 100 years of history and is fully competitive today with a full cost of about 0.07 EUR/kWh including systems costs and externalities. Regrettably, it is very unlikely that new large geothermal reservoirs will be discovered in Europe. Therefore new projects need to be adapted to smaller and cooler resources.

### Low temperature, hydrothermal geothermal electricity: Binary: ORC and Kalina Cycle

Binary, known also as Organic Rankine Cycle (ORC) or Kalina Cycle, plants operate usually with waters in the 100°C to 180°C temperature range. Working fluid selection, in cooperation with beneficial conditions such as access to effective cooling, may allow power production from as low temperatures as 80°C.

In a binary system, the heat of water is transferred to a separate liquid with a lower boiling temperature. The separate liquid is called a ‘working fluid’. When the hot geothermal water is brought to surface from deep underground, it is run through a ‘heat exchanger’ which transfers the heat from the geothermal water to the liquid working fluid. Because the working fluid boils at a low temperature, it vaporises readily with less geothermal heat, and this vaporisation produces enough pressure to drive a turbine. What makes a binary system unique is that it operates a two closed-loops (hence, binary); neither the geothermal water nor the working fluid are exposed to the surface environment. All the water that is brought to surface has to be re-injected, and after vaporising, the working fluid is cooled to its liquid state, so it may repeat the process. There are no-emissions in the binary geothermal cycle.

### Beyond Hydrothermal: Enhanced Geothermal Systems – EGS

Geothermal energy has the potential to make a more significant contribution to the European electricity mix through the development of advanced technologies, especially the development of hot rock resources using EGS techniques that would enable thermal energy recovery from outside of traditionally favourable regions. An EGS is an underground reservoir that has been created or improved artificially.

The EGS concept is going to greatly increase geothermal potential as it allows for the production of geothermal electricity nearly anywhere in Europe with medium and low temperature.

This concept involves:

- Using the natural fracture systems in basement rocks
- Enlarging permeability through stimulation
- Installing a multi-well system
- Through pumping and lifting, forcing the water to migrate through the fracture system of enhanced permeability ("reservoir") and use the heat for power production.

## *Main benefits of geothermal electricity*

### A base load and flexible renewable energy source (no intermittency)…

Geothermal energy has many obvious qualities. A remarkable one is that it is not dependent on climate conditions as wind or solar energy may be. As a result, base load can be provided. This makes geothermal one of the most reliable amongst all renewable energies, as plants are able to operate up to 95 per cent of the time. Such a load factor makes some geothermal plants already competitive with fossil fuel and nuclear power plants. But geothermal electricity is also flexible as it can be ramped up or down on demand, thereby contributing to the stability of the grid.

### Ensuring price stability and increasing security of supply…

Developing and utilising geothermal resources for electricity can help to protect against volatile and rising electricity from fossil fuels. As a renewable and domestic resource, geothermal enables a diversification of the electricity mix. Making use of this local source of energy reduces the amount of fuel that countries have to import and thereby increases their security of supply.

### Providing Clean Electricity…

All human activity has an impact on nature, but compared to other energy sources, Geothermal has a negligible environmental footprint (see GEOLEC report "Environmental study on geothermal power"). Indeed, Geothermal power systems emit only a small amount of greenhouse gases; if one takes $CO_2$ as a benchmark, then geothermal closed-loop-binary plants emit 0 $CO_2$. Furthermore, Geothermal power plants produce only a small amount of air emissions compared to conventional fossil fuels, and unlike other renewable energies such as solar or biomass, have very small land-use footprint.

### Or Combined Heat and Power…

In a combined process the geothermal resources can be used to generate electricity and heat. Producing heat and electricity means optimising the efficiency factor of the energy production and upgrading cash flows.

### … And Supporting Local and Sustainable Economic Development

Using geothermal resources can provide economic opportunities for countries in the form of taxes, royalties, technology export and jobs. Because of specific geological conditions, these jobs require a thorough knowledge of the local conditions and cannot be exported. Therefore, investments in geothermal power can boost local economies and improve urban environment conditions alike.

## *Tackling the first barrier: Lack of awareness and data*

Geothermal energy can be a key source in helping EU Member States to achieve their 2020 targets for renewable energy as well as their long-term decarbonisation objectives. According to the trajectories set out in the National Renewable Energy Action Plans (NREAPs) of the EU Member States, the capacity will grow from 0.9 GWe installed in 2013 to 1.4 GWe in 2020. The production of geothermal electricity in 2020 is planned to increase from the current 6 TWh to 11 TWh. However, the actual potential is much larger.

Whilst some Member States acknowledge the possibility of developing geothermal power in their NREAPs, many others simply did not carry out any studies to assess the geothermal potential. Indeed, information is not always available, for example where there was no previous exploration campaign for oil, gas, etc. Where information for locating and estimating the geothermal resource does exist, it is scattered about in different ministries, universities, national institutes, oil & gas companies and various private entities. This has resulted in very conservative targets for geothermal power.

With this study the GEOELEC project aims to take the first step in filling the existing gap and providing an input for the national energy strategies of European countries, with a focus on the 2020, 2030, and 2050 horizons. The resource assessment is the product of the integration and interpretation of existing data provided by most of the EU-28 countries (data was not available for Cyprus, Finland, and Malta) plus Iceland, Switzerland and Turkey, and a newly defined methodology building on Canadian, Australian, and American methodology.

### *Structure of this report*

The first part of this report is dedicated to providing the reader with a quick overview of basic definitions and best practises for resource assessment (Chapter 1), and to present the methodology and assumptions used for the resource assessment in GEOELEC (Chapter 2).

The second part of the report presents the results of the GEOELEC resource assessment, both at an EU and national level. For each country covered, this report provides some background information on the geological conditions and on the market development. Looking at the 2020 horizon, it compares potential with national targets for 2020 as set out in the National Renewable Energy Action Plans (NREAPs). Where significant differences or gaps in terms of regulatory framework emerge, recommendations for the amendment of the NREAPs are put forward.

Each country outlook also analyses the longer-term economic potential, i.e. in 2030-2050 for the deployment of geothermal electricity and compare such a potential with the projected demand in each country. This can feed the current debate on the long-term energy strategies ongoing in many countries in Europe.

Finally, this Prospective Study puts forward a set of recommendations for policy-makers on how to establish favourable conditions so as to concretely realise the geothermal potential.

### *Sources and methodology*

Data and information in this report stem from different sources. To begin with the supply side, current information on geological conditions and market development are mainly extrapolated from the Country Update Reports submitted for the European Geothermal Congress 2013 and EUROSTAT. In addition, figures for the calculation of the economic potential for geothermal power in 2030-2050 are calculated according to the methodology laid down in Chapter 2 and entirely reported in Annexes, I, II, and III. Finally, national targets for geothermal electricity are taken from the NREAPs submitted to the European Commission[1].

As far as the total projected electricity production in 2050, the cumulative figures for the EU-27 are taken from the Current Policy Initiatives Scenario of the Energy Roadmap 2050. Regarding the projected electricity production per each EU-27 country, we have broken down at national level the average trend observed at EU level between 2010 and 2030 and between 2030 and 2050. It should be noted here that the projected electricity demand is not available for non-EU countries (Iceland, Switzerland, and Turkey) and for Croatia, which

[1] Available online: http://ec.europa.eu/energy/renewables/action_plan_en.htm .

was not yet a member of the EU in December 2011 (date of publication of the Energy Roadmap 2050).

# 1. Resource Assessment: Definitions and Best practises

This chapter gives a definition for resource assessment and is a basis for a pan-European map showing the resources which could be developed in 2020, 2030, and 2050. The GEOELEC resource assessment protocol is based on resource assessment concepts developed in the oil and gas industry, which have been adopted in an adjusted form for geothermal resource assessment and reporting. This protocol has been based on the following work:

- Beardsmore et al., 2010. A protocol for estimating and mapping the global EGS potential.
- AGEA, 2010. Australian code for reporting of exploration results, geothermal resources and geothermal reserves: the geothermal reporting code
- CanGEA, 2010. The Canadian geothermal code for public reporting

These documents describe a protocol to classify and estimate geothermal reserves and resources. Further, input from resource classification approaches developed in the oil and gas industry (Etherington et al., 2007) were used.

## *1.1 Basic definitions*

**McKelvey (Figure 1)** and **project approach:** Key to resource assessment and classification is the concept of the McKelvey diagram, and a project oriented approach in which resources develop progressively from being inferred at an early exploration stage towards becoming discovered after drilling and finally economically recoverable at the production stage. In the exploration the transition from an inferred (undiscovered) to a discovered resource is determined by drilling the reservoir, which is can prove the presence of the resource and to appraise the productivity.

**Plays, leads and prospects (Figure 2)**: In the geothermal exploration workflow prior to drilling, the identification of a prospective reservoir location starts off with a so-called play concept. A geothermal **play** is a geographically (and in depth) *delimited area* where *specific subsurface conditions* allow the obtaining of a sufficiently high flow rate of a sufficiently high temperature, with suitable pressure and chemical conditions. A **lead** is a *particular subsurface reservoir* which has been identified by surface exploration studies (e.g. MT). A **prospect** is a location which has been studied thoroughly by surface exploration and has been earmarked to be drilled.

**Conversion efficiency and power (Figure 3)**

$$Efficiency(\eta) = \frac{Tx - Ts}{Tx + Ts + 2*273.15K}\eta_c$$

Tx = production temperature [C]

Ts = average surface temperature [C]

$\eta_c$= relative efficiency compared to carnot efficiency [-]

$$Power\ (E) = \ Q\ \rho_{fluid}\ c_{fluid}(Tx - Tr)10^{-6}$$ (in MW)

Q = flow rate [m3/s]

Tr = re-injection temperature [C]

$\rho_{fluid=}$ fluid density [kg/m3]

$c_{fluid=}$ fluid specific heat [J/kg/K]

The first equation is based on Tester et al. (2006) and Di Pippo (2008). Their analysis shows that for a large variety of conversion designs covering a spectrum from using produced steam directly to drive turbines (flash) as well as binary systems, that $\eta_c$= 0.6 (Figure 4).

For binary systems Tr is about 8°C above average surface temperature (Beardsmore et al., 2010).

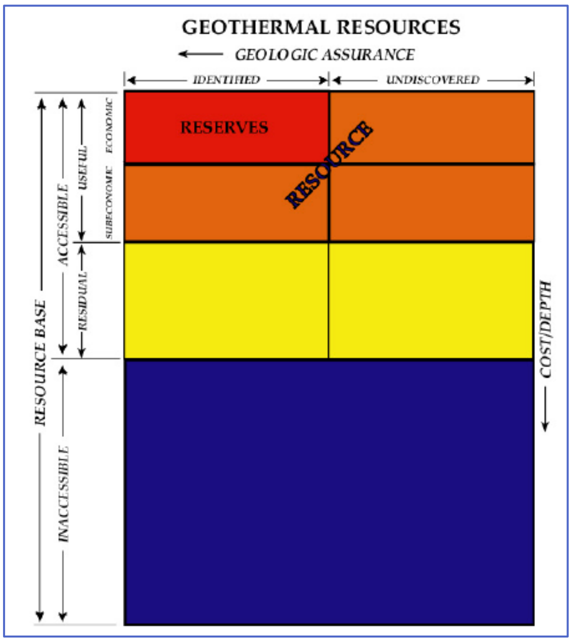



Figure 1: McKelvey diagram representing geothermal resource and reserve terminology in the context of geologic assurance and economic viability (from Williams et al., 2008)

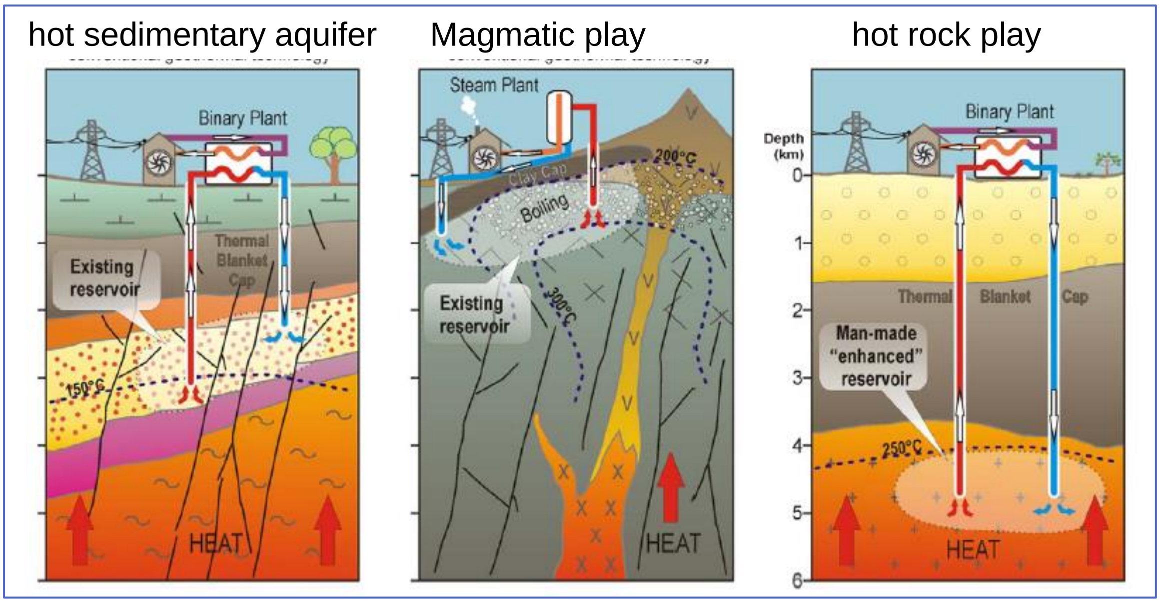



**Figure 2: Example of different play types for geothermal systems (modified from Hot Rock ltd). Hot sedimentary aquifers and magmatic plays can be mostly developed without enhancing the reservoir, relying on natural aquifer and fracture permeability. Magmatic plays can generally produce very high temperatures at shallow depth. Low permeable rock plays are located in regions of elevated temperatures (caused by radiogenic heat production, elevated tectonic heat flow, or vertical heat advection trough deep fault zones).**

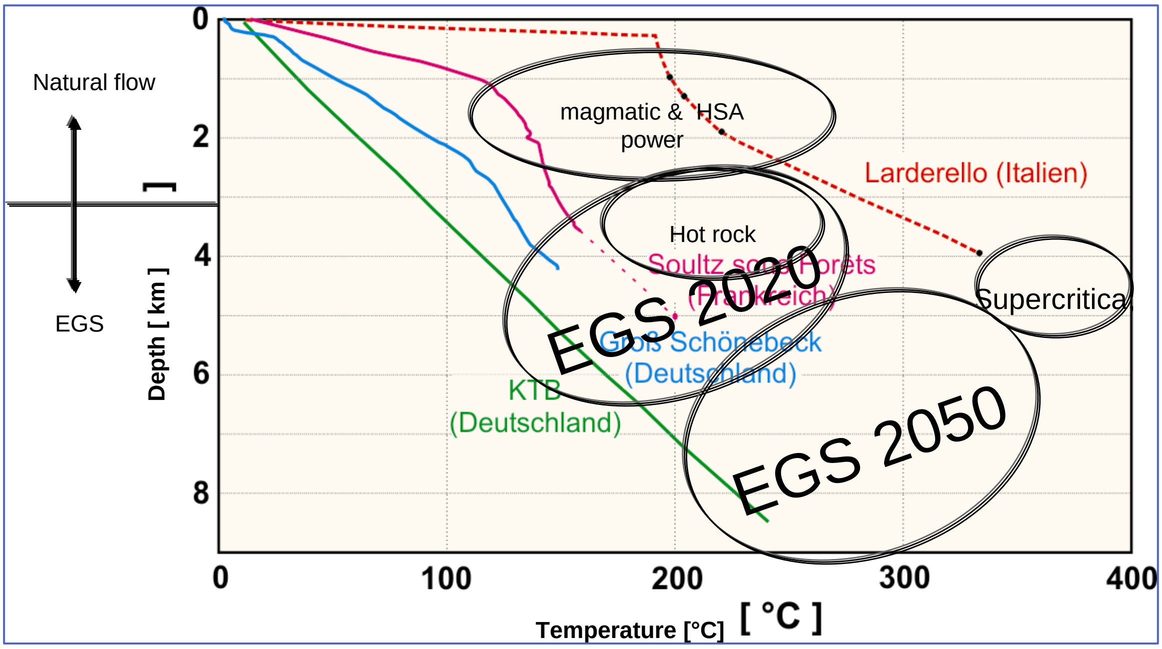



**Figure 3: Relative positioning in depth and temperature gradients of the different play types, and positioning of EGS development (hot rock/EGS correspond to low permeable rock. HSA to hot sedimentary aquifers (which can also be located deeper up to 4km).**

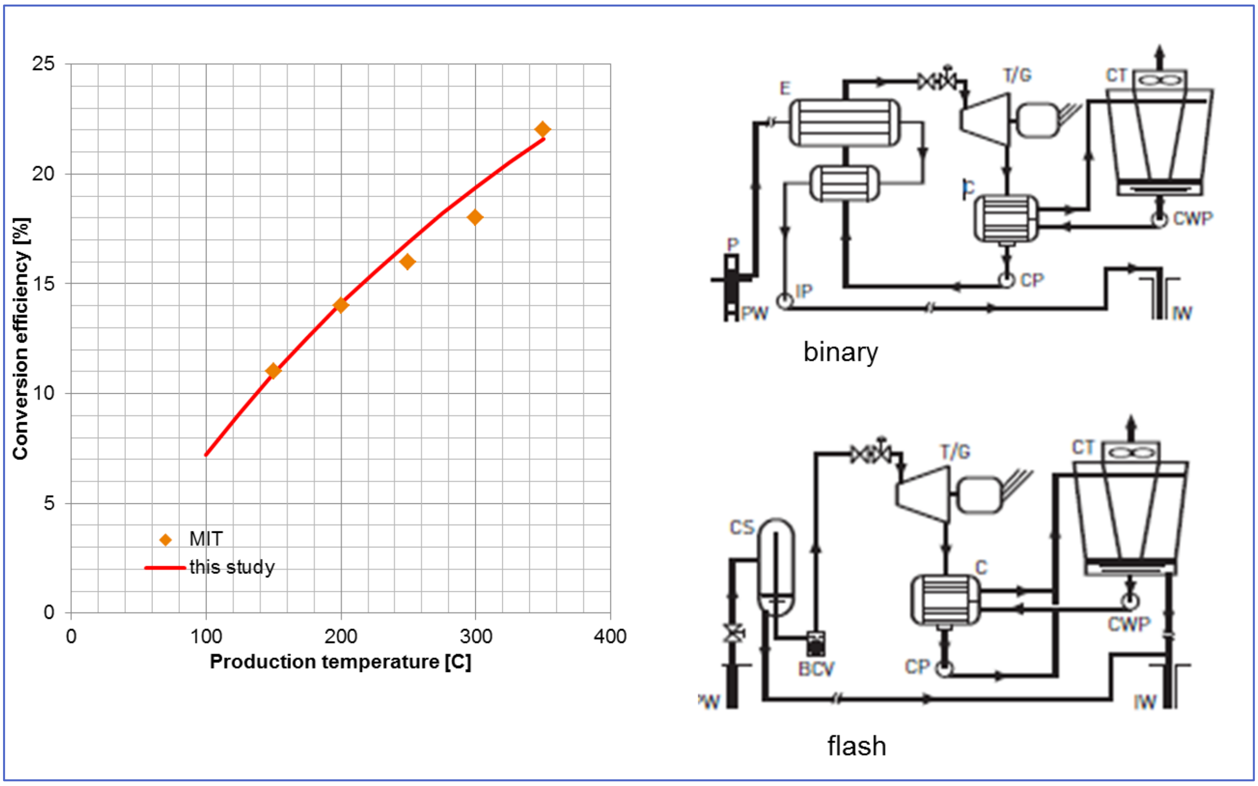



**Figure 4: Practically achieved conversion efficiencies of various geothermal production installations (left), including both binary and flash systems (right) (after Tester et al., 2006). The best fit curve fitting eq.1 for Ts =10C is achieved with η_c =0.6.**

### *1.2 The hydrocarbon best practice*

Resource classification in the hydrocarbon industry is very mature and serves as an excellent starting point for geothermal classification and reporting. The publication of Etherington and Ritter (2007; Figure 5) forms the latest extension of the Petroleum resource management system accepted by oil and gas industry. Here we summarise the main aspects of the classification scheme which can be useful for geothermal energy. It should be emphasised that geothermal resources in geothermal systems differ from both minerals and petroleum resources as they are renewable through recharge, albeit usually at a slower rate than that at which energy is extracted. The rate of this recharge can vary significantly from system to system, and can be stimulated to a varying degree by production.

***Prospective Resources*** are those quantities estimated to be commercially recoverable from yet unexplored accumulations assuming a discovery is confirmed. While there is always a grey area, a discovery is declared in the oil and gas industry when results of one or more exploratory wells support existence of a significant quantity of potentially moveable hydrocarbons. Geothermal resources are also confirmed through drilling. Discovered quantities should be initially classified as *Contingent Resources*. The portion of these quantities that can be recovered by a *defined commercial project* may then be reclassified as

*Reserves*. Commerciality requires that the project form part of an economic venture and an organization claiming commerciality has a firm intention to develop and produce these quantities. Firm intention implies that there is high confidence that any current constraining contingencies will be overcome and that development will be initiated within a reasonable time frame. A reasonable time frame for the initiation of development depends on the specific circumstances and varies according to the scope of the project. In oil and gas industry five years is recommended as a benchmark, however in geothermal development and especially EGS a longer time frame may be applied.

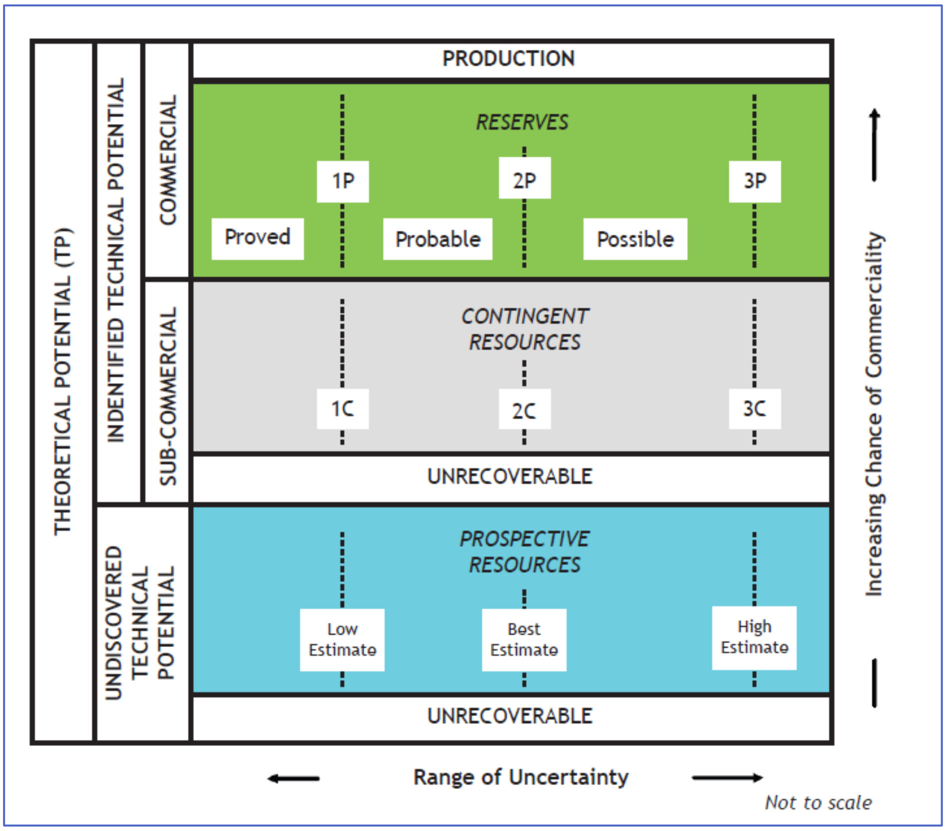



**Figure 5: uncertainty ranges for resource and reserves estimates, and commerciality axis of projects moving them up from prospective resources to contingent resources to reserves (from Etherington and Ritter, 2007). 1,2,3 relates to levels of uncertainty representing low, mid, and high estimates respectively.**

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- AGEA-AGEG, 2010. Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves, The Geothermal Reporting Code, Second Edition, 28 p.


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- Beardsmore, G.R., Rybach, L., Blackwell, D., and Baron, C., 2010. A protocol for estimating and mapping the global EGS potential, July 2010 edition, p. 11
- Etherington, J.R., and Ritter, J.E., 2007. The 2007 SPE/AAPG/WPC/SPEE Reserves and Resources Classification, Definitions, and Guidelines: Defining the Standard!, 2007 SPE Hydrocarbon Economics and Evaluation Symposium, Dallas, Texas, USA, 1-3 April 2007. SPE 107693, p. 9.

## 2. Resource assessment methodology in GEOELEC

In this chapter guidelines for estimating theoretical and technical potential (TP) for enhanced low permeability high enthalpy systems are defined in detail for different stages in the workflow (play, lead, prospect, contingent resources, and reserves) and for different play types. Resource assessment in GEOELEC is focused on prospective resources. Reporting can be subdivided in three levels (Figure 6):

- *Level 1: Global European prospective resource assessment for producing electricity*
- *Level 2: Prospective undiscovered resource assessment for different play types*
- *Level 3: Contingent (discovered) resources and reserves*

| | |
|---|---|
| 1. Global European prospective resource assessment for producing electricity | European wide assessment (cf. Beardsmore et al., 2010). Determine TP for different depth ranges for EGS, key input are base maps of temperature, and rock type to identify theoretical potential. Filter maps with information on natural reserve areas etc. Assume relatively low ultimate recovery in agreement with whole depth column (cf. IPCC, 2011). distinguish relative attractiveness, low, mid, high estimates according to drilling depth required to reach temperature |
| 2. Prospective undiscovered resource assessment for different play types | Identify delimited areas with a particular play type (e.g. Hot Sedimentary Aquifer (HSA), magmatic and low permeability). Include data relevant to exploration of particular play types and exploration outcomes (cf. AGEA-AGEC, 2010) for exploration data relevant to resources assessment |
| 3. Contingent (discovered) resources and reserves | From industry and government reporting obtain information on drilled prospects and producing reserves, play types, development type[2] |

**Figure 6: Representation of the various levels of resource categorisation progressing from global (level 1), to prospect based (level 2), to drilling and production (level 3).**

[2] However, it can be problematic to gather and disclose publically confidential information from private industry. A minimum period of non-public disclosure applies to the most recent or on-going geothermal projects. For each of these projects authorisation from several private organisations (owner, contractor, sub-contractor) will have to be requested. A regulatory framework on that matter will have to be developed, for instance by the International Geothermal Association, similar to what may already be in force in mining and hydrocarbon explorations.

In depth the resource assessment is limited to 5 or 6.5 km for present developments, but may increase in the future. The development of two timelines is therefore proposed, one based on 7 km for 2020 and 2030, one based on 10 km for 2050.

A global Level 1 was conducted by GEOELEC assessment. The information gathering for the assessment was accomplished through data workshops and a data request sheet. It was concluded that insufficient data was available for a level 2 or 3 assessment, none was conducted. The level 1 resource assessment has been performed on a regular 3D hexahedral grid with a horizontal resolution of 20 km and a vertical resolution of 250 m. The areas covered by this voxet cover the EU-28 countries including various other countries in Eastern Europe. The area is delineated in Figure below showing the temperature model.

For each sub volume theoretical to practical potential is calculated, schematically illustrated in Figure 7 of the schematic workflow going from theoretical potential to realistic TP. These calculations are performed for each sub volume of the grid. The calculations are detailed below.

**Heat in place (HIP):** The heat in place is calculated as the heat energy available in the subsurface. The calculation for a subvolume V:

$$HIP\ [PJ\ ] = V\ * \rho_{rock}\, c_{rock} * (Tx - Ts) * 10^{-15}$$

where

V=volume [m3] of the subsurface subvolume

$\rho_{rock}$ = Density = 2500 kg m-3

$C_{rock}$ = Specific heat = 1000 J kg-1 K-1

Tx = temperature at depth in the subvolume

Ts = temperature at surface

The map of HIP [PJ/km$^2$] is calculated as the vertical sum of the vertically stacked sub-volumes divided over the surface area of the grid cells in km$^2$.

**Theoretical capacity (TC):** the *theoretical capacity* [TC] is in agreement with the heat energy in place multiplied by an (electricity) conversion factor which depends on the application:

TC=H *η

Where

$$H = V\ * \rho rock * Cprock * (Tx - Tr) * 10^{-15}\ \text{(in PJ)}$$

The HIP (HIP) also takes into account the fact that not all energy can be utilised. A return temperature (Tr) is used, which equals the previously mentioned cut-off production temperature for the application. For electricity production, following Beardsmore et.al. (2010):

To obtain a Theoretical potential map the values in the 3D-grid are vertically summed.

For heat production Tr is significantly lower than for electricity production

**Technical potential:**

Technical potential (TP) denotes the expected recoverable geothermal energy [MW] (e.g. Williams et al., 2008). The TP assumes that the resource will be developed in a period of thirty years. The conversion from *Theoretical capacity* to *Technical potential* is therefore:

$TP\ [MW/km^2] = 1.057 * TC[PJ/km^2] * R.$

Where R is the recovery factor which is underlain by various steps, depending also on the delineation of the volume for the TC. For a global assessment, such as that performed for chapter 4 on geothermal energy of the IPCC (2011) and Beardsmore et al. (2010), TP considers HIP of all the sediments and crust beyond a threshold depth in agreement with a cut-off temperature for electricity production systems. In Beardsmore et al., 2010, the ultimate recovery (R) corresponds to:

$R=R_{av}\ R_f\ R_{TD}$,

and includes available land areas, limited technical ultimate recovery from the reservoir based on recovery of heat from a fracture network ($R_f$) and limitation of operations as an effect of temperature drawdown ($R_{TD}$). Globally this can result in a recovery of about 1% of the theoretical capacity (IPPC, 2011). The recovery factor of EGS as demonstrated by Beardsmore et al. (2010) does not delineate the reservoir in depth beyond the threshold temperature. For a volumetric delineation which is based on particular play levels, leads, and prospects (e.g. an aquifer), the recovery factor is generally much higher in the order of 10-50%, whereas the underlying TC involves a significantly lower amount of rock volume.

We propose to use three different levels of TP:

- TPtheory: this is the maximum possible (theoretical) technical potential (R=1.00)
- TPreal: realistic underground Technical Potential according to typical predictive reservoir engineering approaches and empirical practice. This is the equivalent of $R_f*R_{TD}$ in Beardsmore et al., 2012. According to Beardsmore $R_f$ is on average 0.14. $R_{TD}$ is estimated at 90%, resulting in R=0.125. For geothermal aquifers in the Netherlands R is estimated to be 33%

- TPbm: Technical Potential according to Beardsmore et al., 2010 (R=0.01)

**Economic technical potential:** The economic potential (TPLCoE_p) is calculated from the TPreal, accepting only those subvolumes where the levelized cost of energy (LCoE) is less than a given threshold. The LCoE depend on the application (*power, power and co-heat*). The economics input the expected flow rate takes as. In TPLCoE_p, p denotes the cumulative probability (0..100%) of exceeding the flow rate and temperatures used. The economic evaluation considers the achievable flow-rate as major technical uncertainty

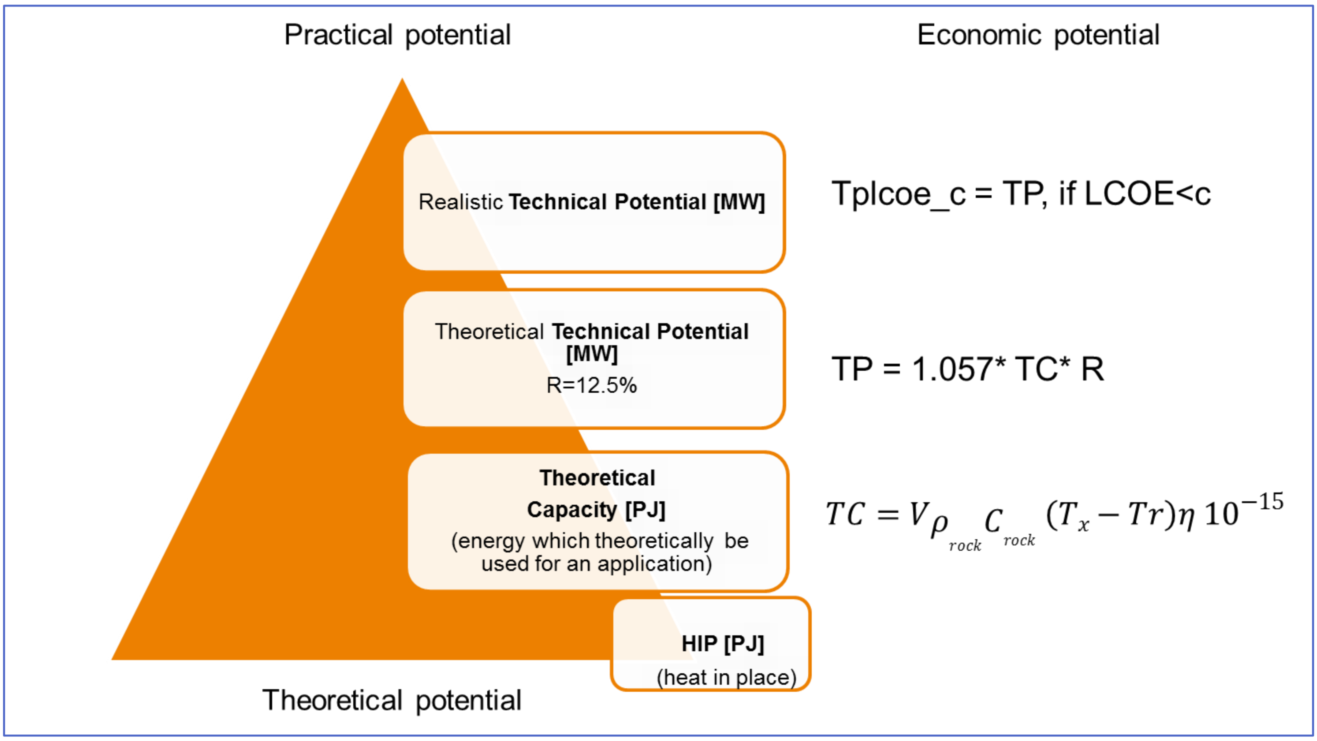


Figure 7: Schematic workflow to go from theoretical potential to realistic technical potential.

For the maps the sub volume results are vertically summed, and subsequently divided over the area of the grid cell in km$^2$. The following maps have been calculated

Table 1: Type of potential maps in the information system

| Map | Name | Unit |
|---|---|---|
| HIP | Heat in place | PJ/km$^2$ |
| TC | Theoretical capacity | PJ/km$^2$ |
| TPtheory | Theoretical Technical Potential (R=1) | MW/km$^2$ |
| TPbm | Technical Potential according to Beardsmore et al., 2010 (R=0.01) | MW/km$^2$ |
| TPreal | Technical Potential (R=0.125) | MW/km$^2$ |
| TPLCoE_c | Realistic Technical Potential (LCoE<c) adopting TPreal | MW/km$^2$ |

Table 2: Additional maps based on the 3D grid calculations

| Map | Name | Unit |
|---|---|---|
| LCoE | Minimum LCoE in a vertical stack of the 3D grid | EUR/MWh |
| LCoEDEPTH | Depth of the Minimum LCoE in a vertical stack of the 3D grid | km |

For the country outlooks it is assumed that 25% of the economic (realistic technical) potential in MWe can be installed on a country basis, due to restrictions in land use. For the conversion from installed capacity to TWh a load factor of 90% is adopted.

## LCoE analysis and sensitivities

For the economic analysis of the LCoE a cash flow calculation is performed. A dominant cost item in the analysis is the cost of drilling and stimulation. For the costs of drilling we assume three different scenarios for the 2020, 2030 and 2050 timelines, based on an exponential and linear well cost model. More detailed information on well, stimulation and plant costs and performance aspects is given in Chapter 3.3.

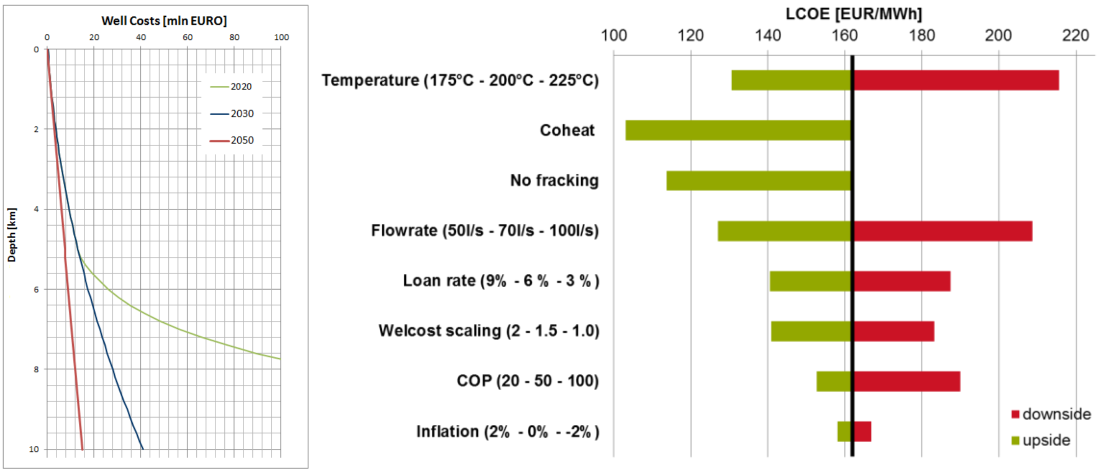


Figure 8: Well costs (for EGS 2 wells have been assumed) and sensitivities of predicted LCoE to input parameters for the 2030 scenario at a potential EGS location at 5 km depth with forecasted resource temperature of 200°C.

## Uncertainty and CHP

Within the 2030 scenario we considered the effect of uncertainty in flow rate and the effects of combined heat and power (CHP) on the resource base.

For uncertainty in flow rate we assumed a deviation of +-30% of the default flow rate and its effects. For CHP it has been assumed that heat sales are 9 EUR/GJ and account for the thermal power which can be generated from Tr to a reinjection temperature of 35°C. CHP can result in a reduction of the LCoE of about 50 EUR/MWh, whereas increase in flow rates (50l/s – 70 l/s – 100 l/s) can decrease LCoE typically by 10-50 EUR/MWh.

### Temperature maps

The potential calculations take as input a newly constructed model of subsurface temperatures up to 10 km depth. The methodology for constructing these temperatures has been described in Limberger and Van Wees (2013). The adopted model in GEOELEC corresponds to their model C.

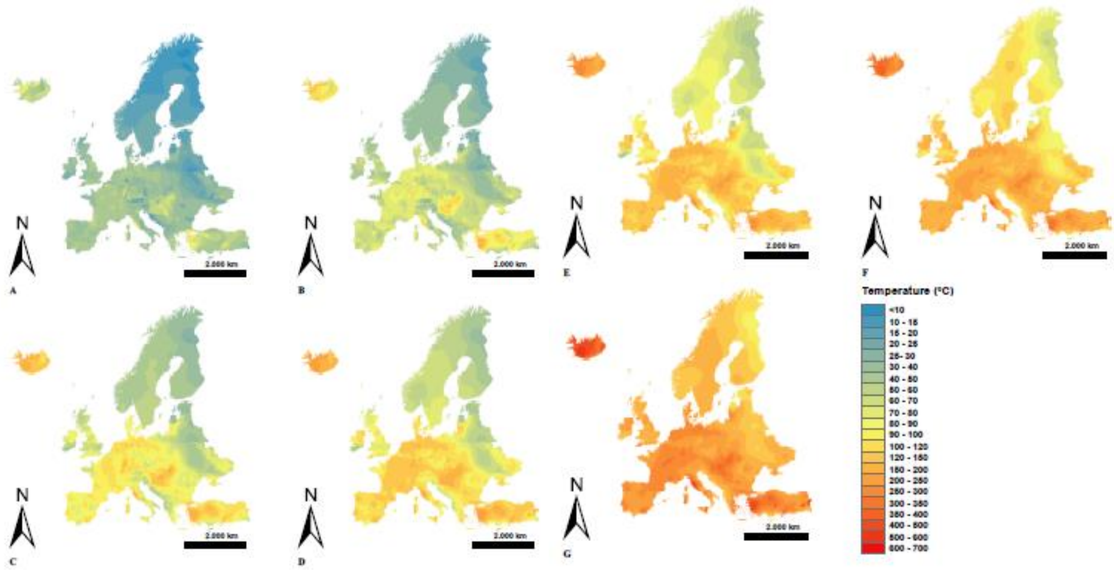

Figure 9: Modelled temperature at 1,2,3,4,5,7, 10km depth

To give a best representation of the prospects for geothermal electricity, it is essential to choose the proper scenarios. Adjusting the scenarios severely alter the outcome of the prospects. The most influential parameter for an economical prospect is the chosen cut-off value, e.g. feed-in tariff, price of electricity - including premiums. With a very high cut-off value, eventually all targets can be developed economically.

To get a best representation, the following scenarios are chosen. For the years 2020, 2030 and 2050 the cut-off value decreases. In other words, the feed-in tariffs decrease. For the near future (2020) we assume a cut-off of 200 EUR/MWh, which corresponds to 0.2 EUR/kWh. Ten years further in the future, we assume feed-in tariffs or premiums are less necessary in comparison to 2020. Here a cut-off of 150 EUR/MWh is chosen. Towards 2050 this decreases further down to 100 EUR/MWh.

These chosen cut-off values only represent the economic boundaries for the prospects. But also on the technical side of the scenarios developments are defined which favour the prospects. The assumptions are shown in the Table below. The maximum depth range increases, due to assumed improved drilling techniques, from 7 kilometres depth to 10 kilometres depth in 2050. Also the flow rates increase due to better stimulation techniques from 50 L/s to 100 L/s in 2050. As the effect of stimulation increases in flow rate, the costs for stimulation of a project remain the same: EUR 10 Mio. To reach the maximum drilling depths, improvements in drilling techniques lead to a different, more beneficial well cost model. Where the well cost model increases exponential with depth in 2020, it is assumed to be less depth dependent in 2050, resulting in a more linear relation. The efficiency in both the system and in conversion increases. The coefficient of performance increases from 30 in 2020 to 50 in 2030 and 1000 in 2050. The relative Carnot efficiency[3] increases from 60% in the near future to 70% in 2050. In addition the use of heat to convert to electricity is more efficient and the CHP outlet remains equal.

Table 3: Assumptions for the prospective study (COP = Coefficient of Performance | CHP = Combined Heat and Power)

| Parameter | Unit | 2020 | 2030 | 2050 |
|---|---|---|---|---|
| **Maximum Depth** | km | 7 | 7 | 10 |
| **Flow Rate** | L/s | 50 | 70 | 100 |
| **COP** | - | 30 | 50 | 1000 |
| **Well Cost Model** | - | Wellcost Scaling 1.5 + Exponential | Wellcost Scaling 1.5 | Linear 1500 EUR/m |
| **Stimulation Costs** | EUR Mio. | 10 | 10 | 10 |
| **Relative Carnot Efficiency** | - | 0.6 | 0.6 | 0.7 |
| **Tinc for Tr (Tr=Tsurface + Tinc)** | °C | 80 | 80 | 50 |
| **CHP outlet** | °C | 35 | 35 | 35 |

The cut-off values, e.g. feed-in tariffs, may change per country and be adapted to national circumstances and according to the maturity of the technology and/or the market. Therefore more than one cut-off value is represented. Also Table 3.4 displaying a range of cut-off values, stacking the gained potential with increasing cut-off values:

Table 4: Overview of cut-off values for the defined scenarios

| SCENARIO | Cut-off range | Steps |
|---|---|---|
| **2020** | Less than 100 EUR/MWh to a maximum of 300 EUR/MWh | 100 – 150 – 200 – 300 |
| **2030** & **2050** | Less than 50 EUR/MWh to a maximum of 200 EUR/MWh | 50 – 100 – 150 – 200 |

The cut-offs apply for power-only, and do not include CHP. Finally the economic geothermal potential for electricity production is presented as maps of the LCoE and at which these cut-off values can be reached. See below an overview of all available maps and scenarios:

[3] A theoretical thermodynamic cycle proposed by Nicolas Léonard Sadi Carnot in 1823. It can be shown that it is the most efficient cycle for converting a given amount of thermal energy into work. A relative carnot efficiency is a percentage compared to the carnot efficiency with around 150 °C

Table 5: Overview of available maps in the report (for all maps produced in this project, go to www.thermogis.nl/geoelec (TP = Technical Potential)

| Scenario | 2020 | 2030 | 2050 |
|---|---|---|---|
| **Maps** | LCoE | LCoE | LCoE |
| | LCoEDEPTH | LCoEDEPTH | LCoEDEPTH |
| | TP for cut-off lower than 300 EUR/MWh | TP for cut-off lower than 200 EUR/MWh | TP for cut-off lower than 150 EUR/MWh |
| | TP for cut-off lower than 200 EUR/MWh | TP for cut-off lower than 100 EUR/MWh | TP for cut-off lower than 100 EUR/MWh |
| | TP for cut-off lower than 100 EUR/MWh | TP for cut-off lower than 50 EUR/MWh | TP for cut-off lower than 50 EUR/MWh |

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- Williams, A.F., Lawless, J.V., Ward, M.A., Holgate, F.L., and Larking, A., 2010. A code for geothermal resources and reserves reporting, Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25-29 April 2010, 7 p.
- World Petroleum Council. Petroleum Resources Managment System, SPE-AAPG-WPC-SPEE, p.47

# 3. Overview of Geothermal electricity potential in Europe

At this point the scenarios are described and the maps of Europe presented. The question which logically may arise is what that means per country. In this and in the following sections we present the outlook per country. The table below shows the potential per country in TWh for the 2020, 2030 and 2050 scenarios. This is the economic potential based on the above mentioned assumptions and no application of co-heat (for the effects of the application of co-heat, see next chapter). For the chosen scenarios we assume an LCoE of less than 200 EUR/MWh for 2020, of less than 150 EUR/MWh for the 2030 scenario of less than 100 EUR/MWh and for 2050.

As the current and projected financial support may differ per country, below the economic geothermal potential is presented in stacked potential of all assessed cut-off values. The ranges are shown in Table 3.6. **A very low cut-off value results in a minimal economic potential, whereas very high cut-off values make more geothermal resources within economic reach.**

In the previous chapter you can find a sensitivity diagram showing the effects of different variables on the LCoE. The majority of the parameters have both a positive and negative effect; e.g. the required temperature can be both lower and higher. A higher required temperature means a well at greater depths, hence higher drilling costs resulting in a higher LCoE. Two elements can indisputably lower the LCoE: when no stimulation is needed or when co-heat is applied.

The application of co-heat involves a cascading system of first electricity generation using the high temperature geothermal source, followed by the use of lower temperature residual heat for the use of direct heat (spatial heating, greenhouses, etc.).

The sensitivity diagram shows in a best case scenario a lowering of the LCoE by EUR 50. In the diagram the LCoE drops from 160 EUR/MWh to approximately 110 EUR/MWh. This same principal can be applied to the country outlooks and the maps. Assuming a co-heat scenario may increase the potential in each country from the < 150 EUR/MWh scenario to a < 100 EUR/MWh scenario.

Table 6: Economic Potential per country (2020 = LCOE < 200 EUR/MWh; 2030 = LCOE < 150 EUR/MWh; 2050 = LCOE < 100 EUR/MWh)

| Country | Economic Potential (in TWh) | | |
|---|---|---|---|
| | **2020** | **2030** | **2050** |
| **AUSTRIA** | 0 | 0 | 67 |
| **BELGIUM** | 0 | 0 | 22 |
| **BULGARIA** | 0 | 0 | 72 |
| **CROATIA** | 1 | 3 | 50 |
| **CZECH REPUBLIC** | 0 | 0 | 31 |
| **DENMARK** | 0 | 0 | 29 |
| **ESTONIA** | 0 | 0 | 2 |
| **FRANCE** | 0 | 0 | 653 |
| **GERMANY** | 0 | 1 | 346 |
| **GREECE** | 0 | 0 | 81 |
| **HUNGARY** | 9 | 17 | 174 |
| **ICELAND** | 73 | 74 | 322 |
| **IRELAND** | 0 | 0 | 27 |
| **ITALY** | 11 | 12 | 226 |
| **LATVIA** | 0 | 0 | 3 |
| **LITHUANIA** | 0 | 0 | 19 |
| **LUXEMBOURG** | 0 | 0 | 3 |
| **POLAND** | 0 | 0 | 144 |
| **PORTUGAL** | 0 | 0 | 63 |
| **ROMANIA** | 0 | 0 | 105 |
| **SLOVAKIA** | 0 | 1 | 55 |
| **SLOVENIA** | 0 | 0 | 8 |
| **SPAIN** | 0 | 1 | 349 |
| **SWEDEN** | 0 | 0 | 1 |
| **SWITZERLAND** | 0 | 0 | 43 |
| **THE NETHERLANDS** | 0 | 0 | 52 |
| **TURKEY** | 50 | 62 | 966 |
| **UNITED KINGDOM** | 0 | 0 | 42 |

**GEOTHERMAL POTENTIAL IN EUROPE:**

- **The production of geothermal electricity in the EU in 2013 is 6 TWh**
- **The NREAPs forecast a production in the EU-28 of ca. 11 TWh in 2020**
- **The total European geothermal electricity potential in 2030 is 174 TWh**
- **The economic potential grows to more than 4000 TWh in 2050**

The resource assessment exercise produced maps of the geographical distribution and extent of the potential, which are shown in the next pages. For a full overview of all produced maps, go to www.thermogis.nl/geoelec.

The maps are sorted by scenario (2020 to 2050) and first display the distribution of the LCoE, followed by the corresponding minimum depths at which the LCoE can be obtained and concluded with the maps of the TP for a certain LCoE. The used cut-off values are in line with the values mentions in Table 3.6 and mentioned in the caption.

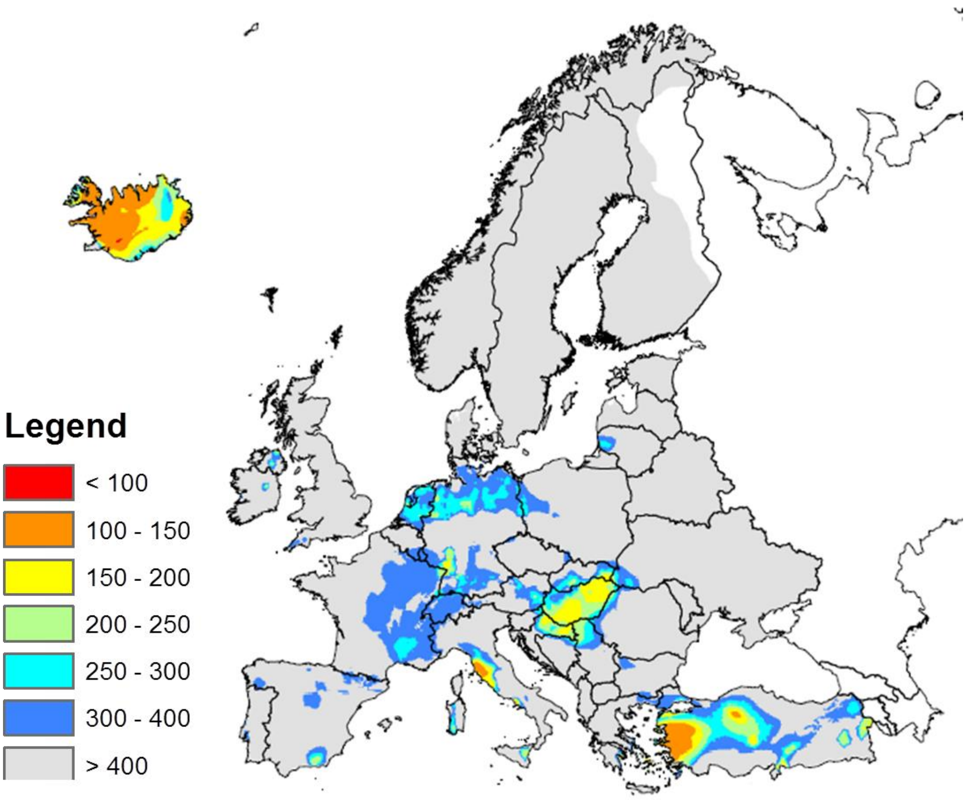



Figure 10: Minimum LCoE in 2020 (in EUR/MWh)

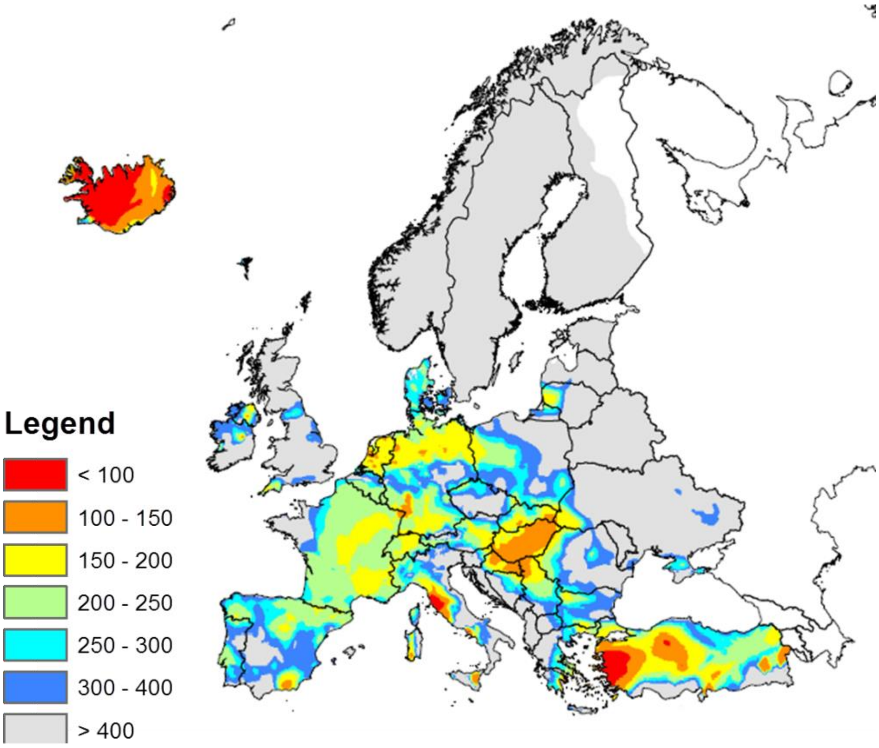



**Figure 11: Minimum LCoE in 2030 (in EUR/MWh)**

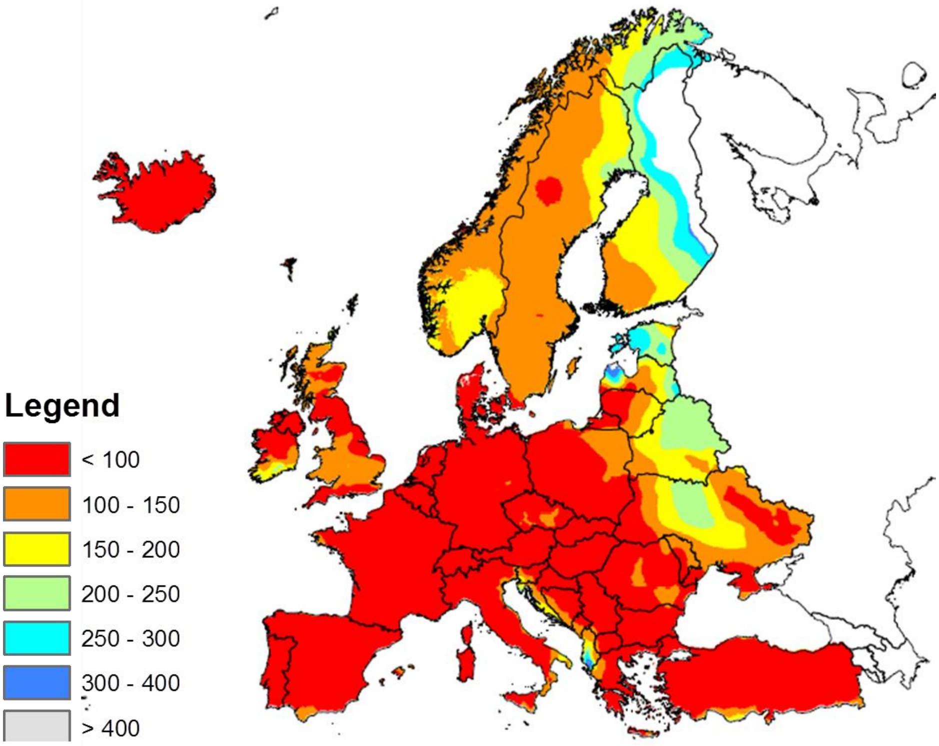



**Figure 12: Minimum LCoE in 2050 (in EUR/MWh)**

# Country Outlook

## Austria

### *Background*

Austria exhibits varying thermal conditions which are influenced by the Alpine Orogeny and by the neighbouring Pannonian Basin. Elevated geothermal conditions are found in the Eastern part of Austria, particularly in the south-eastern Styrian Basin, exhibiting heat flaw density values of more than 100 mW/m². These favourable conditions are related to a significant geothermal anomaly at the Pannonian Basin due to lowered lithospheric thickness.

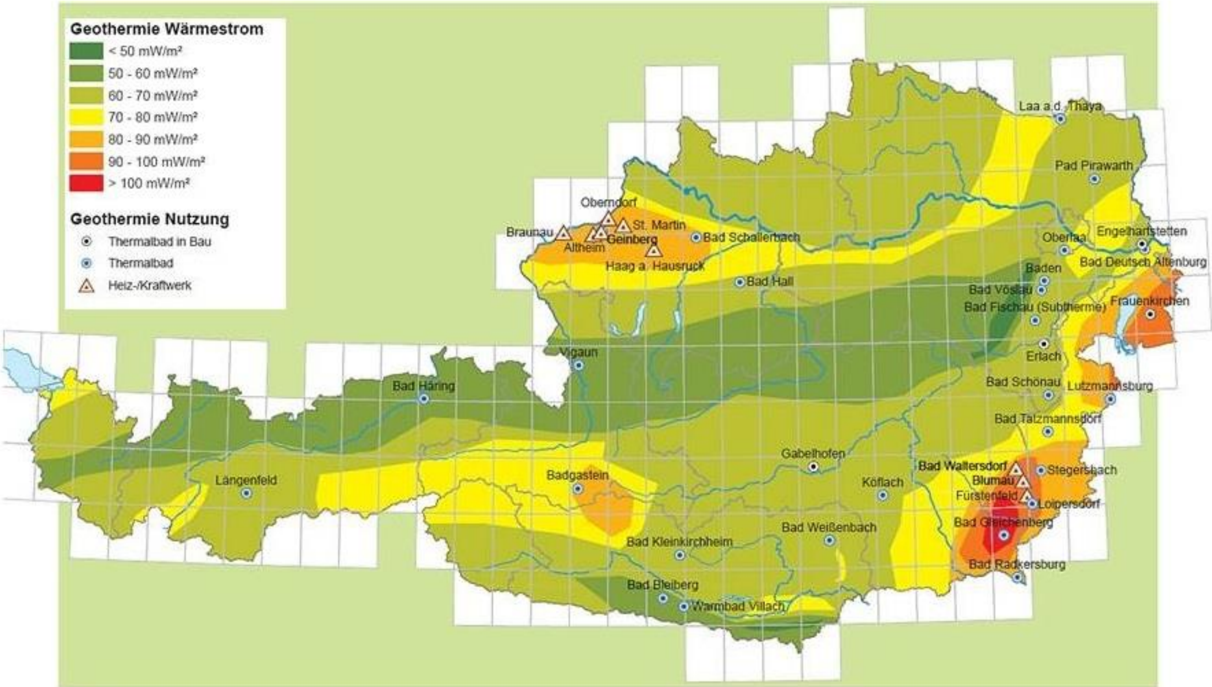



**Figure 13: Average Surface Heat Flow Density ~ 70 mW/m², Range: 45 to 130 mW/m². Source: Geological Survey of Austria, 2007 in Goldbrunner, J. and Goetzl, G.**

Recently executed joint modelling and interpretation of HFD data from Austria, Hungary, Slovakia and Slovenia within the Interreg IV project Transenergy showed, that the highest HFD values are located at the margin areas of the Western Pannonian Basin. The geothermal conditions at the Austrian parts of the Molasse Basin can be described as average to slightly elevated (70 - 80 mW/m²). Regions of enhanced terrestrial heatflow densities are associated to regional hydrothermal flow systems predominately located at basement reservoirs (Malmian limestones and Dogger sandstones). These local to regional scale anomalies can be found both in the western part of Austrian Molasse (Upper Austrian Molasse Basin) and the eastern margin of the Molasse Basin close to the transition zone to the Vienna Basin (Lower Austria). The geothermal conditions at the intra-mountainous regions of the Eastern Alps are quite heterogenic and not entirely investigated yet due to the lack of deep drillings.

### *Market Development*

Austria already has three geothermal cogeneration (combined heat and power) plants. However, the Austrian NREAP does not propose any target or dedicated measures to increase the share of geothermal electricity by 2020. A feed-in tariff of EUR 0.07 is in place, but is lower than for other technologies and does not appear to be adequate to trigger any investment.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Share of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | **2050** | | |
| 0.002 | 0.002 | 0.1 | 67.1 | 69% | 8 511 |

Assuming cost reduction and the full development of the EGS technology, the GEOELEC resource assessment shows that promoting the technology today can allow geothermal to be fully competitive in 2030. In 2050 geothermal power has the potential to provide plenty of clean, reliable and affordable electricity and cover up to 69% of the total electricity consumption projected in Austria (i.e. 67 TWh).

## REFERENCES


- Goldbrunner, J. and Goetzl, G.: Geothermal Energy Use, Country Update for Austria, Proceedings of the *European Geothermal Congress 2013,* Pisa, Italy,(2013), CUR-02, 1-7.
- European Geothermal Energy Council, EGEC Market Report 2012, Brussels, 2012.

## Belgium

### *Background*

The Geology of Belgium is dominated by partially metamorphosed, clastic to carbonate formations of Palaeozoic age related to the Caledonian Brabant Massif which are covered by clastic and carbonate rocks of Devonian to Triassic age. Dinantian anhydrite rocks in the Hainaut Basin (South of the country), Triassic sandstone and Dinantian limestone in the Campine and Liege Basin (North-Eastern and Eastern Belgium) contain aquifers which represent the highest potential for the exploitation of hydro-geothermal resources (European Commission, 1999).

VITO and the Geological Survey of Belgium recently completed surveys on deep geothermal resources assessment and new investigation campaigns (2D seismics, thermometry studies and 3D modelling) have been performed to assess the Belgian deep geothermal reservoirs (Hoes, H. and Petitclerc, E. and Declercq, P. Y. and Laenen, B., 2013).

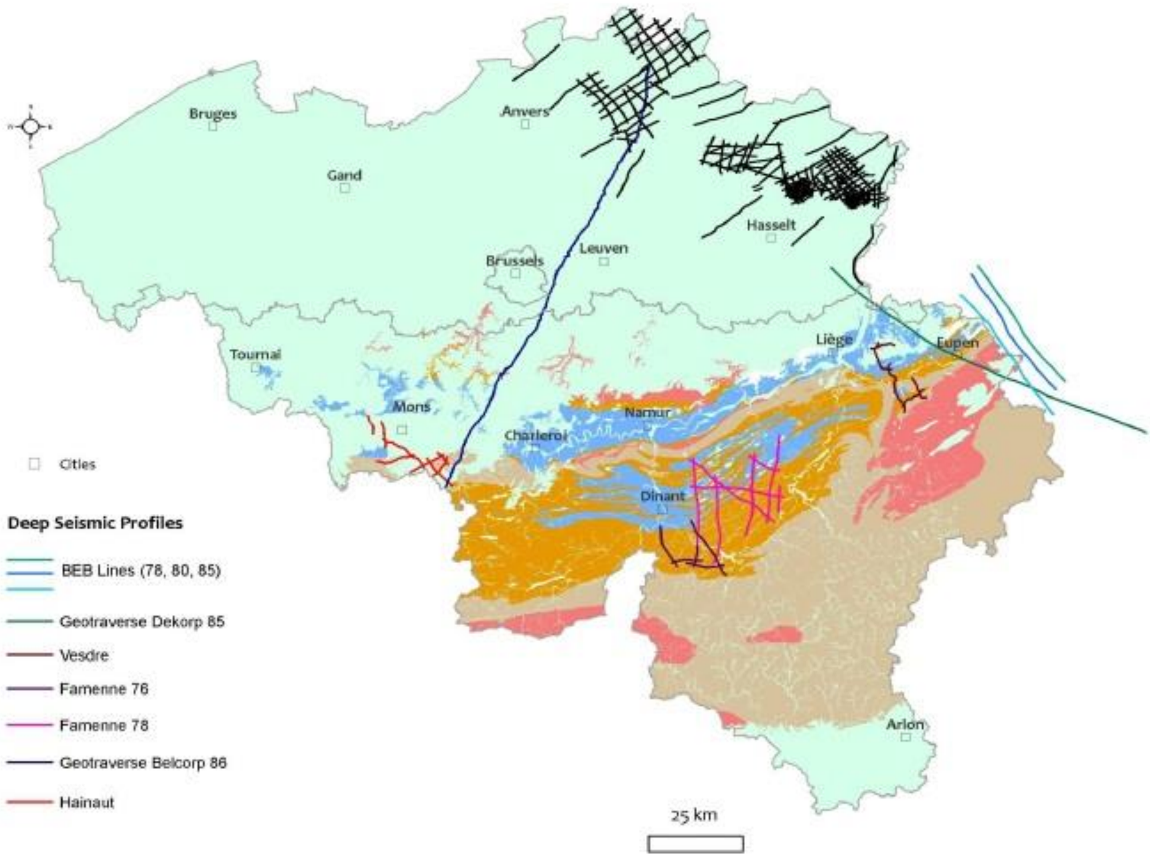



**Figure 14: Map of publicly available data at the Geological Survey of Belgium (GSB). Source: GSB.**

### *Market Development*

There is no geothermal power plant in Belgium. However, the recent investigations on deep geothermal potential have resulted in two projects currently under development in Balmatt (Flanders) and in the Mons basin (Wallonia).

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Share of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | **2050** | | |
| 0 | 0.002 | 0 | 22.28 | 17% | 2 826 |

The GEOELEC resource assessment, based on currently available data, clearly shows that geothermal electricity can potentially be developed at a competitive cost in Belgium. In 2050 nearly 3 GW can be installed in the country to provide some 22 TWh of electricity per year produced at ≤ 100 EUR/MWh. Geothermal power could cover up to 17% of projected electricity demand.

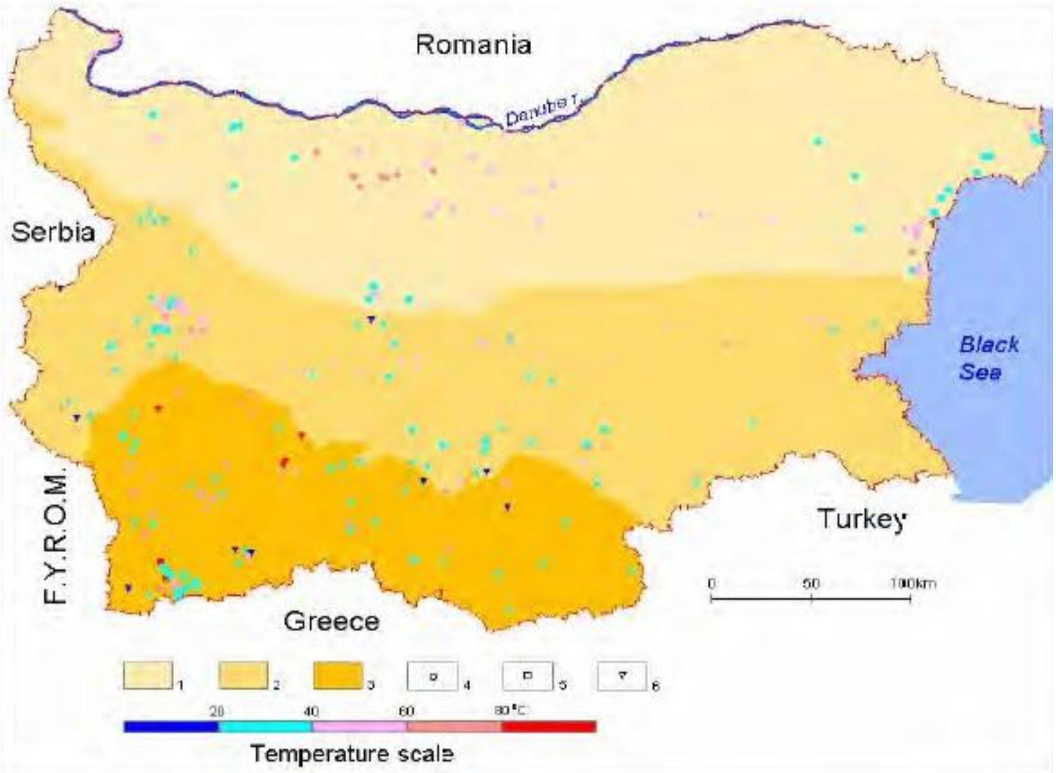
## REFERENCES


- European Commission: Blue Book on Geothermal Resources, *Luxembourg: Office for Official Publication of the European Communities*, Luxembourg, 1999
- Hoes, H. and Petitclerc, E. and Declercq, P. Y. and Laenen, B.: Geothermal Energy Use, Country Update for Belgium, *Proceedings of the European Geothermal Congress 2013*, Pisa, Italy,(2013), CUR-04, 1-7.

## Bulgaria

### *Background*

In Bulgaria today thermal waters with temperatures of up to 98·C have direct application, e.g. for heating of buildings and greenhouses, balneology, etc. Higher temperatures of about 150° C are expected to be found in the deeper seated sedimentary water bearing layers of Devonian and Triassic age in the Moesian plate, particularly in the Velingrad and Sapareva Banya geothermal fields (Bojadgieva, K. and Benderev, A. and Berova A. and Apostolova, I., 2013).




1. Moesian plate (stratified reservoirs)

2. Sredna goraSredna gora, incl.Balkan zone (secondary stratified reservoirs, fractured reservoirs)

3. Rila-Rhodopes massif (predominantly fractured reservoirs)

4. Major wells and groups of wells discovering stratified reservoirs in a plate region

5. Hydrothermal sources associated with waters from fractured reservoirs located in Southern Bulgaria.

6. Hydrothermal sources associated with waters from secondary stratified reservoirs located in Southern Bulgaria

**Figure 15: Map of hydrothermal deposit of Bulgaria. Source: Bojadgieva, K. and Hristov, H. and Hristov, V. and Benderev, A. and Toshev, V., 2005).**

### *Market Development*

No electricity is produced from geothermal resources in Bulgaria. This is due to a lack of data from drilling activities and to the relatively low temperature of geothermal waters discovered.

Bulgaria did not propose any target for geothermal electricity in its NREAP; although a feed-in tariff exists, this is not applicable in practice. Indeed the climate for developing geothermal and other renewable energy sources is not favourable. In 2012 the State Energy and Water Regulatory Commission implemented retroactive measures for producers of electricity from renewable sources, which will significantly hamper any further development. The grid connection of projects with preliminary contracts was postponed until 2016, while a moratorium on new projects was adopted.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Share of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | **2050** | | |
| 0 | 0 | 0.1 | 71.66 | 112% | 9 089 |

Although there is no geothermal power plant in operation or under investigation so far, Bulgaria has a huge potential for EGS. This opportunity however has never been studied in depth. According to the GEOELEC Resource Assessment, by 2030 it will be possible to produce electricity from geothermal resources at 100 EUR/MWh or less. Subsequently geothermal power could be widely developed. The geothermal economic potential for electricity generation, i.e. at ≤ 100 EUR/MWh, amounts to 71.7 TWh in 2050, which would even exceed the projected electricity demand in the country.

## REFERENCES


- Bojadgieva, K. and Benderev, A. and Berova A. and Apostolova, I.: Country Update for Bulgaria 2007-2012, *Proceedings of the European Geothermal Congress 2013*, Pisa, Italy,(2013), CUR-06, 1-8.

## Croatia

### *Background*

In Croatia there are two regions with a geothermal energy potential. The Southern area (the Dinarides) has lower geothermal energy potential. The Northern part, belonging to the *Pannonian* sedimentary basin, has an average geothermal gradient of 0.049°C/m. In this area several geothermal reservoirs, discovered during hydrocarbon exploration, have already been extensively tested (European Commission, 1999).

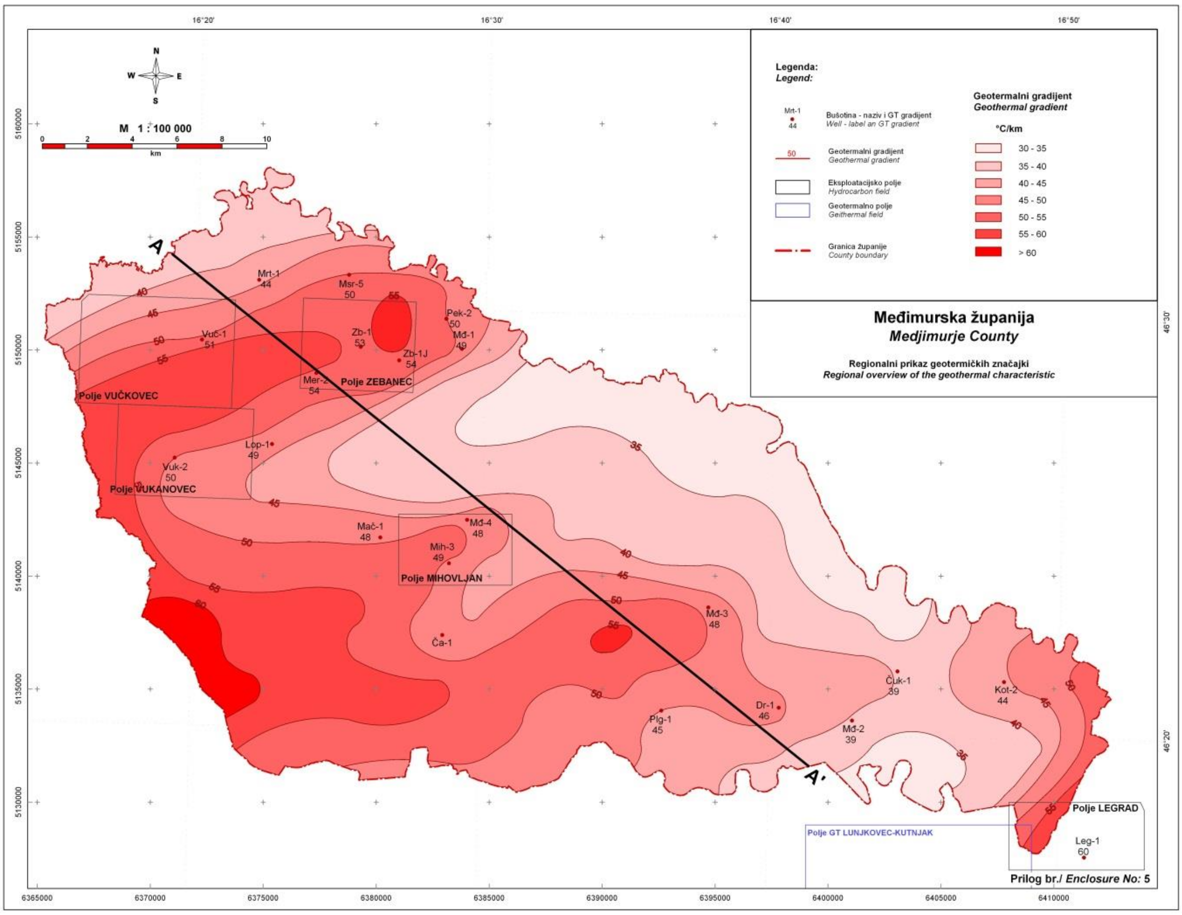



**Figure 16: Map of geothermal potential of Croatia. Source: ENER- SUPPLY project**

### *Market Development*

There are no existing geothermal power plants in Croatia, however, two projects are currently under development in the counties of Podravina and Bjelovar-Bilogora. At the time of writing, the Croatian Government has not yet submitted its NREAP to the European Commission. Therefore, it is not possible to evaluate the Croatian plans to promote geothermal power in order to achieve their 20% national target for renewable energy by 2020.

Nevertheless, a relatively stable feed-in tariff, amounting to HRK 1.20 (approx. €ct15.9 per kWh) is in force. Additionally, all plant operators are eligible for a bonus of up to an extra 15% on top of the tariff, based on the plant's contribution to the local economy and quality of life.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Share of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | **2050** | | |
| 0 | N.A | 3 | 49.97 | N.A. | 6 338 |

According to the GEOELEC resource assessment, there is significant economic potential for the development of geothermal electricity in Croatia. By 2030 3 TWh can be produced at the cost ≤ 150 EUR/MWh, which is in line with the current level of incentive.

The development of EGS, together with significant cost reduction in drilling activities can make geothermal even more competitive. By mid-century, more than 6 GWe can be installed in Croatia, providing up to about 50 TWh of sustainable electricity every year.

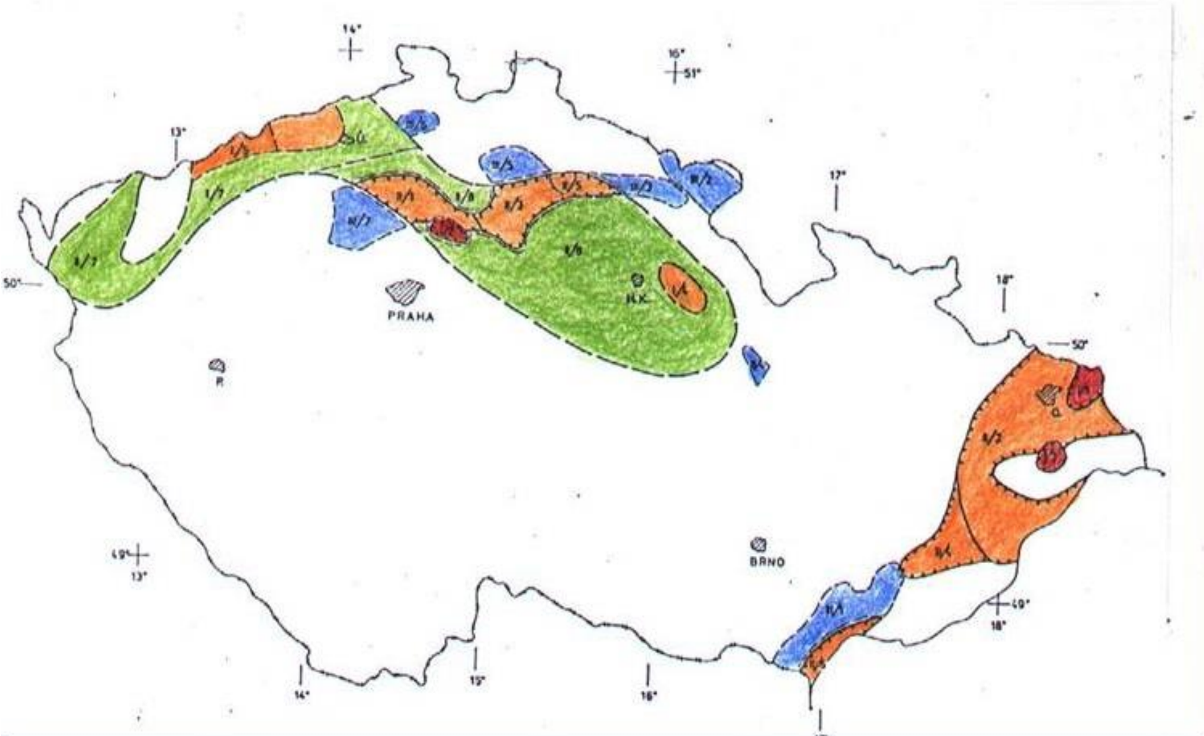
## REFERENCES


- European Commission: Blue Book on Geothermal Resources, *Luxembourg: Office for Official Publication of the European Communities*, Luxembourg, 1999

## Czech Republic

### *Background*

The Bohemian Massif and the Carpathian System are the two main tectonic units in the Czech territory. The Bohemian Massif is an old consolidated basement formed by Proterozoic and Paleozoic crystalline rocks which occupies most of the country. These rocks have been affected by the Variscan, Hercinian and Alpine orogenies, which caused extensive block faulting and folding (Hurter, S. and Haenel, R., 2002).



Red – Areas where isotherm 130°C is at depth 4 km
Orange – Less favourable geological conditions, 130°C at depth 4 to 5 km
Green – Marginal, less favourable areas and areas with protected mineral water and thermal water springs
Blue –Isotherm 130 °C at depth of 5 to 6 km

**Figure 17: Geothermal regions in the Czech Republic. Source: Czech Geological Survey**

In the South west of the country, the West Carpathians, part of the Alpine-Carpathian Orogeny, consist of nappes containing rocks of Precambrian - Tertiary age and can be divided into several elongate zones, one of which is of particular interest for geothermal energy: the Carpathian Foredeep.

### *Market Development*

An EGS research project for the combined production of electricity and heat is currently under development in Litomerice (North West of the country), while other two geothermal cogeneration projects are under investigation in the cities of Semily and Liberec in Northern Bohemia (European Geothermal Energy Council, 2013).

The Czech NREAP only takes into account the project under development in Litomerice, for which an installed capacity of 4.4 MWe and a production of only 18,4 GWh (availability: 4181 h/y) is assumed. Such a low level of electricity generation, however, does not however correspond to the reality of a geothermal power plant which is base load as it usually runs some 8700 hours a year.

In terms of incentive schemes, a hybrid feed-in tariff / feed-in premium system is in place guaranteeing CZK 4.50 per kWh (approx.€ct 18 per kWh) or a bonus of CZK 3.45 per kWh (approx. €ct 14 per kWh) on top of the electricity price. This scheme is likely to trigger the development of other projects.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Share of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | **2050** | | |
| 0 | 0.002 | 0.04 | 30.68 | 26% | 3 891 |

The Czech Republic has the potential to develop low temperature power and EGS plants. The GEOELEC Resource Assessment shows the economic potential of geothermal power in the country: by 2030 it will be possible to produce 40 GWh at ≤150 EUR/MWh, while nearly 4 GWe could be installed by mid-century, producing some 31 TWh and covering ¼ of the projected electricity production.

In order to achieve that, other measures should also be adopted, such as a clear geothermal regulatory framework, ensure security of rights for the licensee, and a risk insurance scheme to reduce the cost to manage the geological risk.

## REFERENCES


- Hurter, S. and Haenel, R. (ed.), Atlas of Geothermal Resources in Europe, *Office for Official Publications of the European Communities,* Luxembourg, (2002)
- European Geothermal Energy Council, EGEC Market Report 2013/14, Brussels, 2013

# Denmark

## *Background*

The deeper geothermal resources in Denmark are mainly related to two deep, low-enthalpy sedimentary basins, the Norwegian-Danish Basin and the North German Basin. Comprehensive research based on seismic and well data primarily from previous hydrocarbon exploration campaigns have shown that the fill of the Norwegian- Danish Basin contains several lithostratigraphical formations with sandstones of sufficient quality and temperature to serve as geothermal reservoirs (Mahler, A. and Røgen, B. and Ditlefsen, C. and Nielsen, L.H. and Vangkilde-Pedersen, T., 2013). Pronounced temperature anomalies are however absent in the country.

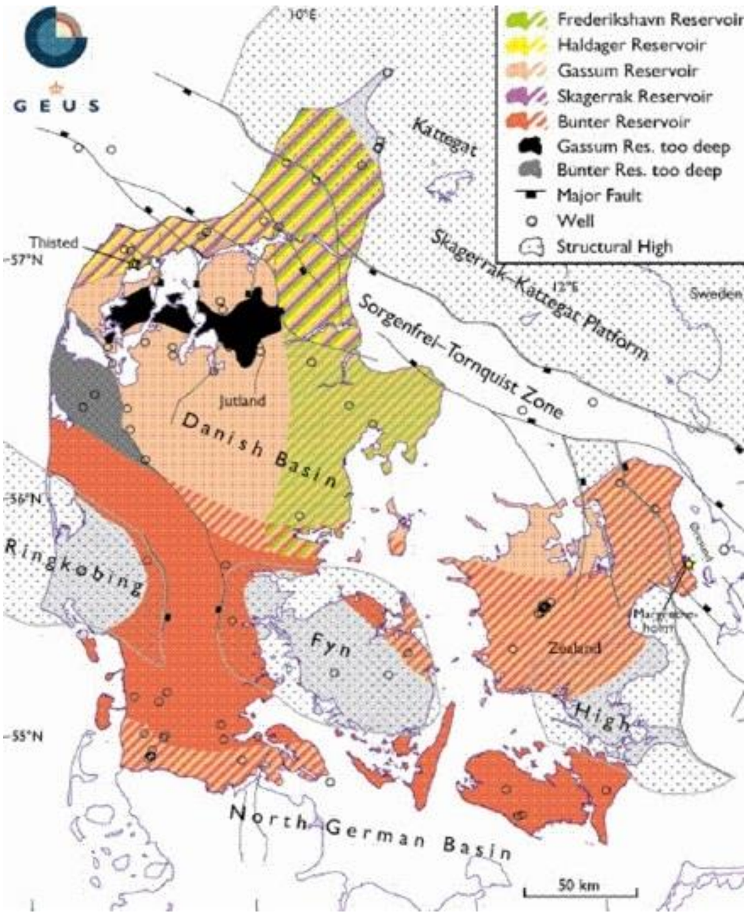



**Figure 18: Map of potential geothermal reservoirs in Denmark. Source: Mahler, A., et al. 2013**

### *Market Development*

Denmark presents moderate temperature gradients, but widespread geothermal aquifers around many towns that can be developed primarily for covering heat demand through district heating networks. Three geothermal heat plants are already in operation using absorption heat pumps, while 12 other plants are under investigation.

The Danish legal framework is in place and there is an increasing interest in geothermal energy among district heating companies and municipalities. Geothermal plants receive no funding, but high taxes on fuels and the focusing on $CO^2$ makes it attractive to substitute the burning of fossil fuels in CHP plants with wind turbine power and geothermal heat.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Share of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | **2050** | | |
| 0 | 0 | 0.03 | 29.43 | 55% | 3 732 |

To date Danish aquifers have not been found suitable for power production as sufficiently permeable layers are not sufficiently hot. With technological development and decreased costs, however, the GEOELEC Resource Assessment shows there is economic potential for geothermal electricity by 2030.

Thereafter, more than 3.5 GWe could be installed in the country. Geothermal power technologies have indeed the economic potential to cover more than half the power consumption projected in Denmark, which amounts to nearly 30 TWh every year.

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- European Geothermal Energy Council, EGEC Market Report 2013/14, Brussels, 2013

# Estonia

## *Background*

Estonia is situated on the Northern Slope of the Baltic Shield. The thickness of the Phanerozoic sedimentary rocks covering the Early Proterozoic basement increases from 150m in the north to 600- 700m in the south. The sedimentary cover is represented by Vendian, Cambrian, Ordovician, Silurian and Devonian sediments. The most interesting aquifers for geothermal development are in the Cambrian and Vendian sandstones and siltstones. Due to comparatively low heat flow from the Precambrian basement, and the small thickness of sedimentary rocks, the groundwater temperatures in the Phanerozoic aquifers are inadequate for geothermal electricity generation. However, these formations could well be used for producing geothermal energy for space heating and potential targets can be found in the basement for EGS applications (European Commission, 1999)

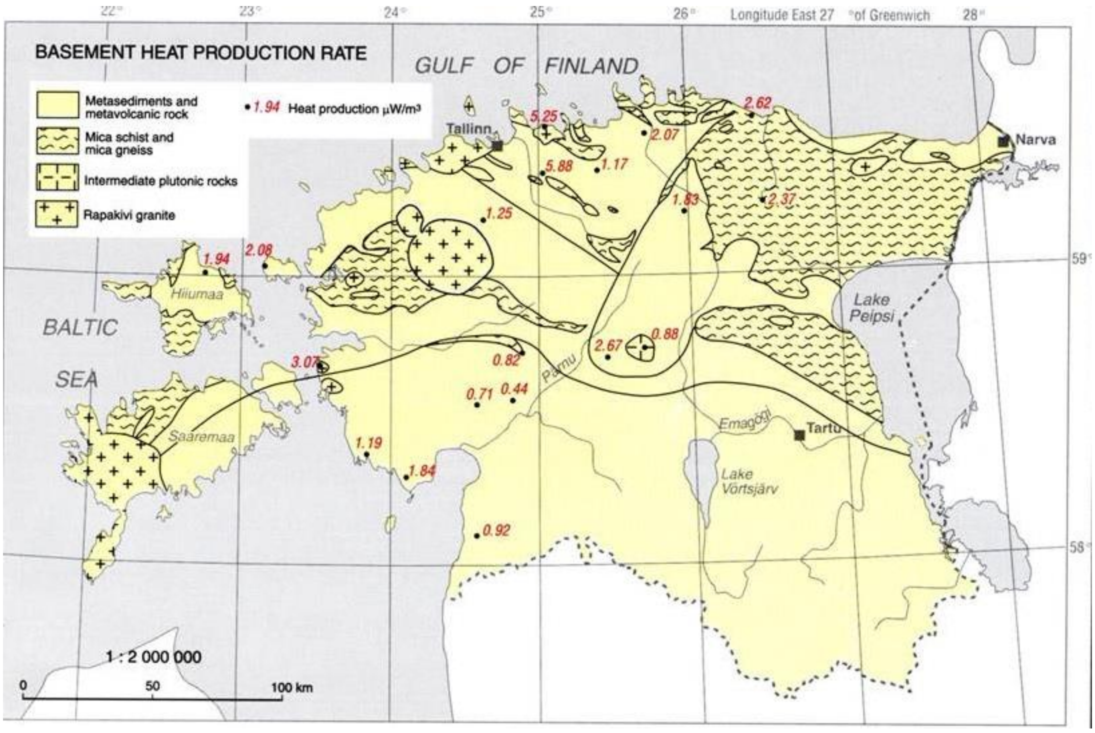


**Figure 19: Basement Heat Production Rate. Source: Estonian Geothermal Association, Jõeleht, 2002**

## *Market Development*

There are no deep geothermal installations in operation, but the first steps in creating a roadmap for further research and the analysis of the potential have been taken by the national geothermal association. Some of the actions taken are the geological study of the Estonian geothermal potential, mapping of potential structures, and creating a preliminary geothermal database.

It is also crucial to define geothermal energy in the Estonian legislation according to the definition set out in Article 2 of Directive 2009/28/EC as well as to work out economic stimulus packages for promoting the interest of the private sector (Soesoo, A. and Sukles, U., 2013).

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | **2050** | | |
| 0 | 0 | 0.04 | 1.67 | 9% | 212 |

The GEOELEC resource assessment shows that, thanks to the development of EGS technology, by 2030 geothermal electricity generation will be technically and economically feasible in Estonia. In the longer-tem at least 200 MWe could be installed, which would make up for 9% of the electricity generated in the country at a cost of ≤100 EUR/MWh.

## REFERENCES


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## France

### *Background*

France has been developing its geothermal resources for energy purposes since the two oil crises in the 1970s. Low-enthalpy resources, developed for thermal applications, are primarily located in the two major existing sedimentary basins: the Paris Basin and the Aquitaine Basin in southwest France.

The country also possesses high-enthalpy resources exploitable for electricity production. These are located essentially in its Overseas Departments (the volcanic islands of the Antilles - Guadeloupe and Martinique – and the Indian Ocean – La Réunion).

Several works have been conducted in the last years by BRGM (French Geological Survey), with the cooperation of ADEME (French Energy Agency) to update the assessment of French geothermal resources (Boissier et.al, 2010). Thanks to a new feed-in tariff put in place in 2010, a specific focus is now put on the geothermal potential of the mainland France for CHP, generally using EGS technologies, notably in the Alsace region, Massif Central, and in the Pyrenees region.

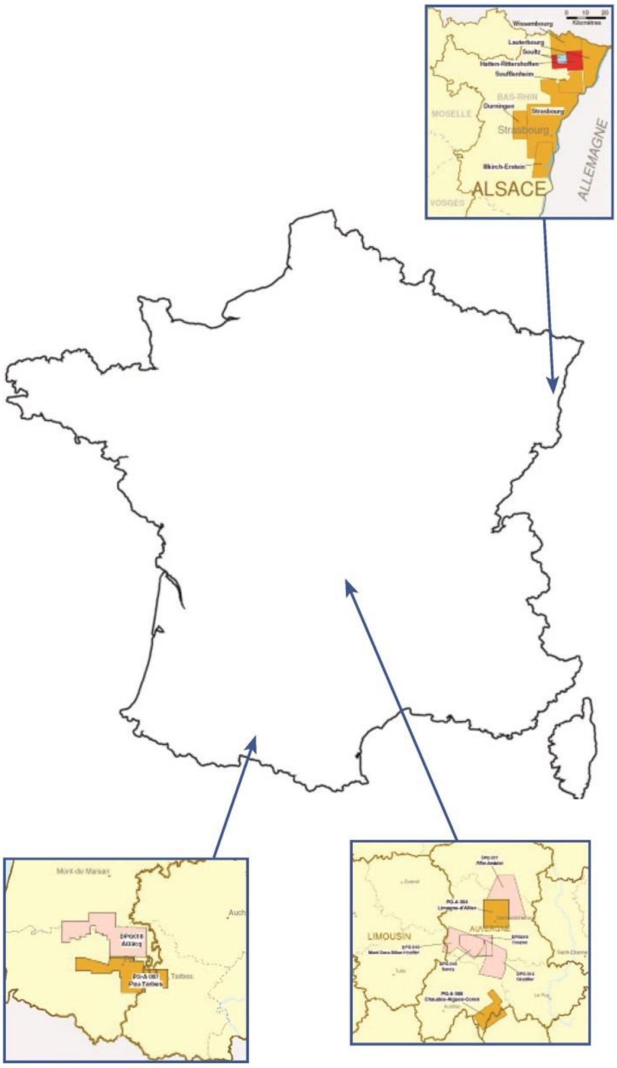


**Figure 20: Map of Geothermal leases in France. Source EGEC Market Report 2013/14 adaptation based on data from Ministère de l'écologie, du développement durable et de l'energie (Update 01/07/2013).**

### *Market Development*

Geothermal electricity has been produced in the country since 1986 at the Bouillante 1 plant in Guadeloupe. This plant has been extended with a second unit (Bouillante 2) inaugurated in 2005. Currently the total capacity amounts to 14.7 MWe, and a further extension is under development. France is indeed the new real hot market, with a particular focus on EGS. Most of the activities today are concentrated in Alsace, where the first ever EGS power plant in Soultz-Sous-Forêts was inaugurated in 2008 and connected to the grid in 2010. The development of EGS, however is at its early stage: 8 research permits have been awarded in the Alsace region, 2 in the Pyrenees region, while in the Massif Central, a region with old volcanoes, 2 research permits were given and 5 more are under consideration (European Geothermal Energy Council, 2013).

France has a fairly ambitious target in its NREAP, aiming to reach a capacity of 80 MW in 2020. All necessary conditions are present for increasing the production of geothermal power, including a fair regulatory framework, a risk insurance fund, and a stable feed-in tariff applying to the net power produced (20€ct /kWh, with an energy efficiency bonus of up to 8 €ct/kWh for mainland France and 13 €ct/kWh plus an efficiency premium of up to 3 €ct/kWh for energy on overseas departments and territories).

### *Economic Potential*

| | Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP / Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Geoth. Econ. Potent. (TWh) | Share of geothermal in gross electricity production | Geoth. Econ. Potent. Installed Capacity (MWe) |
|---|---|---|---|---|---|---|
| | **2010** | **2020** | **2030** | **2050** | | |
| **actual/ projected** | 0.153 | 0.475 | | | | |
| **≤300 EUR/MWh** | | 3 | | | | |
| **≤200 EUR/MWh** | | 0.01 | 7.53 | | | |
| **≤150 EUR/MWh** | | | 0.39 | | | |
| **≤100 EUR/MWh** | | | | 653.02 | 83% | 82 828 |

The GEOELEC resource assessment, based on currently available information over temperature and flaw rates, confirms the significant economic potential in France for geothermal power. By 2050 more than 82 GWe could be installed providing up to 653 TWh of clean power every year (90% load factor). This would amount to more than 80% of the projected electricity demand with ≤100 EUR/MWh all costs included.

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## Germany

### *Background*

The lack of appropriate high-enthalpy steam reservoirs in Germany implies that only binary power plants can be used for electrical power generation. The most important regions in Germany for electricity generation from hydrogeothermal resources are the Upper Rhine Graben and the South German Molasse Basin, and to a lesser extent the North German Basin. However, a successful development of hydraulic stimulation techniques (EGS) in crystalline but also in other rock types such as sandstone, would fundamentally change the situation in the country and make geothermal energy an option in regions without hydrogeothermal potential (Ganz, B. and Schellschmidt, R. and Schulz, R. and Sanner, B., 2013).


**Figure 21: Hydrogeothermal regions of Germany. Source: Ganz, B., et al. 2013**

### *Market Development*

Power production in Germany began in 2003 with a small turbine (ca. 200 kW) at the Neustadt-Glewe geothermal plant, which now is back to heat-only operation (turbine dismantled in 2012). With the inauguration of 3 new geothermal plants in 2013, there are 8 plants in operation today representing an installed capacity of 28 MWe and producing 65,4 GWh in 2012 (European Geothermal Energy Council, 2013). Two of these plants use some kind of EGS technology (Landau and Insheim) and are the only commercially developed EGS plants in operation world-wide.

Many other projects are either under development or under exploration. In total, geothermal power development in Germany can be estimated to reach about 80-90 MWe installed capacity by the end of 2017. Additionally, 28 geothermal power projects are under investigation, including 4 EGS plants (Krefeld, Bietigheim, Lohmen, Rülzheim), representing an additional capacity of more than 100 MWe.

The framework for developing projects appears to be favourable. Geological data on deep geothermal is available, although it is often not free of charge. The German Federal Mining Law (BBergG) includes geothermal use and is the pivotal law for the approval of geothermal projects. Moreover, § 28 of the EEG Law proposes a Feed-in Tariff of 25 €ct/kWh plus a bonus for the use of petrothermal technology (i.e. EGS) of 5 €ct/kWh, for a period of 20 years, applied to the produced gross power. However, the EEG Law is subject to changes in 2014; it is likely that this will involve the removal of the petrothermal bonus and thus a worsening of the investment climate.

### *Economic Potential*

| | Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP / Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Geoth. Econ. Potent. (TWh) | Share of geothermal in gross electricity production | Geoth. Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|---|
| | **2010** | **2020** | **2030** | **2050** | | |
| **actual/ projected** | 0.027 | 1.65 | | | | |
| **≤300 EUR/MWh** | | 9.91 | | | | |
| **≤200 EUR/MWh** | | 0.28 | 15.6 | | | |
| **≤150 EUR/MWh** | | | 1.37 | | | |
| **≤100 EUR/MWh** | | | | 345.59 | 40% | 43 834 |

According to its NREAP, Germany foresees an exponential growth in geothermal electricity generation up to 1.65 TWh in 2020, with an installed capacity of 298 MWe.

The GEOELEC resource assessment shows that the economic potential by 2020 would be only 0.28 TWh for electric power below 200 EUR/MWh, but 9.91 TWh at a cost below 300 EUR/MWh. This means that the German NREAP target of 1.65 TWh might be achieved at prices between 200-300 EUR/MWh. In 2030, 15.6 TWh can be produced from geothermal energy with less than 200 EUR/MWh, and 1.37 TWh below 150 EUR/MWh. With rapid cost reductions and technological developments geothermal power will fully be competitive thereafter. In 2050 geothermal electricity can provide 346 TWh per year from about 44 GWe of installed capacity, or 40% of the projected electricity demand at 100 EUR/MWh or less.

The geothermal industry in Germany is well developed in all relevant sectors, from geophysics through drilling to power plant construction. This is backed by R&D-work in several high-class research centres and universities (e.g. GFZ, LIAG, KIT). With experience from plants in operation, and in particular with experience on EGS, the German industry is well placed to work not only in the country, but also to take a decent share of the geothermal export to other countries.

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## Greece

### *Background*

Favourable conditions for the development of geothermal resources exist in Greece. The Quaternary volcanic spots and islands of the South Aegean volcanic arc *(Sousaki, Methana, Milos, Santorini, Nisyros, etc.*) are expected to have high-enthalpy geothermal resources, while low to medium enthalpy geothermal fields are widespread across the country (European Commission, 1999). Prospective areas for medium-temperature fluids of 120-160+ ºC, suitable for electricity generation with binary cycle plants, are the islands of Lesvos, Chios and Samothrace, as well as the Nestos Delta and Alexandroupolis basins (Andritsos, N. and Arvanitis, A. and Dalabakis, D. and Karytsas, C. and Mendrinos, D. and Papachristou, 2013, Mendrinos D., Choropanitis I., Polyzou O., Karytsas C., 2010).

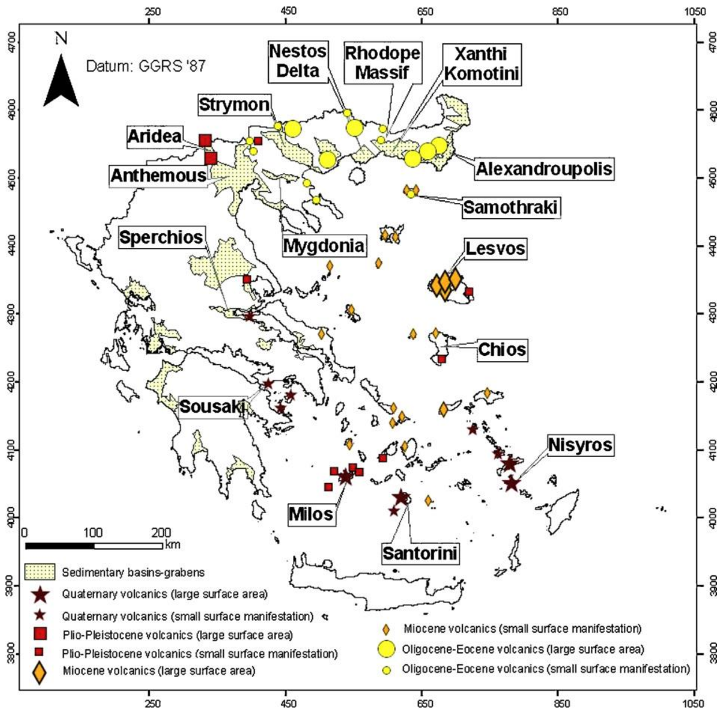


**Figure 22: Outcropping volcanic formations point to areas of geothermal interest for power generation in Greece. Source: Mendrinos, D., et al. 2010.**

### *Market Development*

Despite the significant potential, geothermal energy development in Greece is still limited to direct uses only. Geothermal exploration efforts started in Greece in the early 1970s and were focused on the high-enthalpy fields in the islands of Milos and Nisyros. Later in the same decade, several low-enthalpy fields in Northern Greece and on some Aegean Islands were studied. Drilling exploration highlighted elevated temperature conditions (300-325°C) at 1.0-1.5 km depth and very promising potential for electricity generation exceeding 250 MWe in Milos and Nisyros (Andritos, N., et al. 2013, Mendrinos, D., et al. 2010).

Greece is indeed expected to be an important newcomer in the geothermal electricity market with 13 projects being investigated and expected to become operational by the end of this decade.

In its NREAP the Greek authorities plan to have 120 MWe installed by 2020. This target is reasonable but much more could be done. For instance the feed-in tariff system adopted in 2010 for temperatures above 90°C amounts to 9.945 ct€/kWh plus an additional 20% (i.e. a total of 11,934 ct€/kWh) if the plant is not supported by other state or EU grants. At present, the tariff does not distinguish between temperatures above 90°C. A tariff of 15 ct€/kWh would boost geothermal development by making geothermal power plants economically attractive investments.

Furthermore, in order to promote the technology, a concerted action to inform the local population and overcome public resistance is much needed. Indeed, geothermal energy has the potential to dramatically cut electricity generation costs by replacing diesel generators on the Greek islands and making remote areas energy independent.

### *Economic Potential*

| | Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP / Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Geoth. Econ. Potent. (TWh) | Share of geothermal in gross electricity production | Geoth. Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|---|
| | **2010** | **2020** | **2030** | **2050** | | |
| **actual/ projected** | 0 | 0.073 | | | | |
| **≤300 EUR/MWh** | | 9.43 | | | | |
| **≤200 EUR/MWh** | | 0.08 | 1.61 | | | |
| **≤150 EUR/MWh** | | | 0.47 | | | |
| **≤100 EUR/MWh** | | | | 81.30 | 103% | 10 312 |

The GEOELEC Resource Assessment confirms the enormous economic potential for geothermal electricity in Greece. In the long-term more than 10 GWe could be installed in the country, producing up to 81 TWh and potentially covering the entire power generation projected in the country in 2050.

# REFERENCES


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## Hungary

### *Background*

There are no geothermal power plants yet in operation in Hungary. However, the geothermal potential of the Pannonian basin is outstanding in Europe and promising developments are expected shortly.

The country lies on a characteristic positive geothermal anomaly, with heat flow density ranging from 50 to 130 mW/m$^2$ with a mean value of 90-100 mW/m$^2$ and geothermal gradient of about 45 °C/km. For geothermal power production especially the karstified Palaeozoic-Mesozoic carbonates, and fractured zones of the crystalline rocks in the basement are very promising with increased hydraulic conductivity.

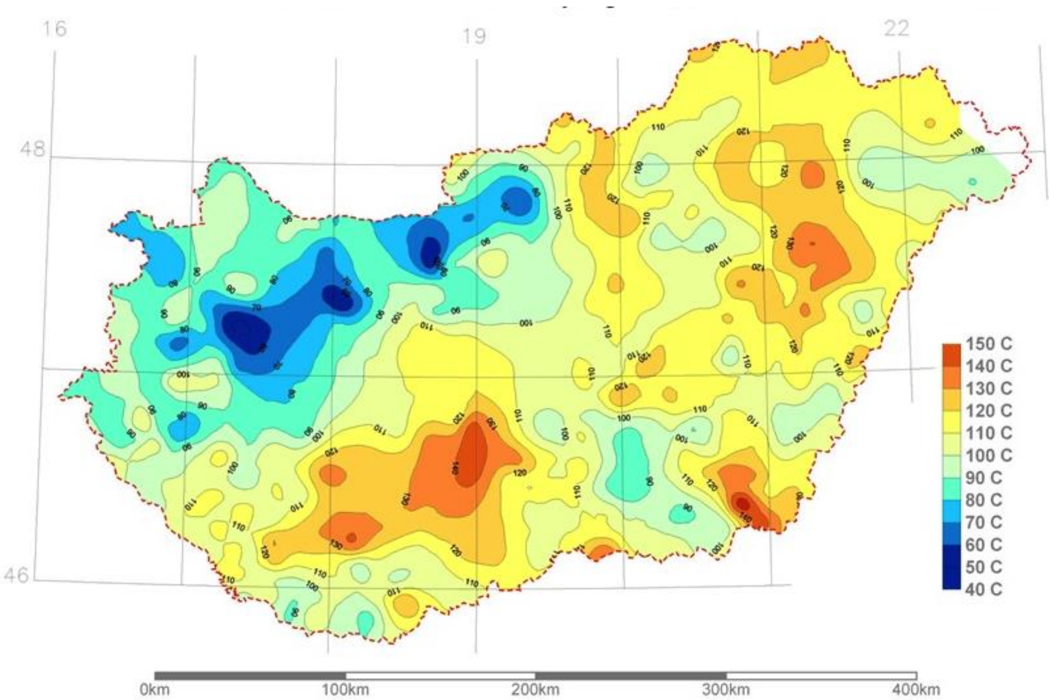


**Figure 23: Modelled temperature at a depth of 2000 metres. Source: Dövényi (1994)**

At the average depth of 2000 m or more temperatures can exceed 100-120 °C, and may provide favourable conditions for development of medium enthalpy geothermal systems (e.g. CHP plants). A high-enthalpy reservoir is also proven (pressure of 360 bars and 189 °C of the well-head) at a depth of 4200 m in Fábiánsebestyén (Nádor et al. 2013). In addition to these promising hydrogeothermal reservoirs, Hungary offers one of the best geological conditions for EGS plants (Dövényi et al. 2005). These are Palaeozoic granit bodies in the basement (especially at the S-SE-ern part of the country) at a depth of 2500-4000 m with temperatures around 150 °C.

### *Market Development*

Geothermal energy development in Hungary is still limited to direct uses only. In the mid 80's during hydrocarbon exploration drilling a high-enthalpy geopressured reservoir was observed in the area of Fábiánsebestyén. Since then studies of several areas in Hungary have indicated significant temperatures and yield, presumably suitable for electricity production. In the last thirty years numerous studies and plans have dealt with the further development of geothermal resources for electricity production. Although several tests have been made, and wells constructed, there is still no finalised well for geothermal electricity production.

Hungary is one of the few Member States planning to develop geothermal electricity to achieve its 2020 target for renewable energy. Its NREAP mentions support measures and the installation of 57 MWe and the production of 410 GWh by the end of this decade.

Several geothermal power plant models have been developed during the last few years show that it is feasible to fulfil the objectives of NREAP. There is already an EGS project under preparation in Hungary supported by the NER 300 scheme. If this would be a successful project, the power plant will be up and running before 2020.

The intention of State to support the geothermal industry is obvious, but somehow there are ambivalent results. However, there still three main barriers impeding investment in the country, namely:

a) The feed-in tariff system is under revision. The takeover price of the electricity produced from geothermal energy was about 10 €ct/kWh, but it is presently suspended;
b) The legal framework for geothermal energy use is rather complicated and needs to be simplified; the mining, energy, environmental protection and water management authorities share competences regarding regulations and licensing procedures. Legal contradictions and time-consuming licensing procedures are still in place.
c) According to a new regulation, exploration and exploitation of geothermal energy below -2500 m takes places in the frame of concessions. The first calls have been launched in the summer of 2013, but this requirement has hindered the progress of development of electricity production in the last couple of years.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| 2010 | 2020 | 2030 | 2050 | | |
| 0 | 0.41 | 17.06 | 173.69 | 338% | 22 031 |

The GEOELEC resource assessment shows the high economic potential for geothermal power in Hungary. By 2030 more than 17 TWh can be produced at ≤150 EUR/MWh. The electricity produced economically from geothermal could then increase by a factor of ten, up to 174 TWh. This could theoretically cover three times the projected electricity demand in the country in 2050.

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## Ireland

### *Background*

Ireland's geological setting is such that geothermal resources are classified as low enthalpy with lower average geothermal gradients of approximately 10°C/km recorded in the south to higher gradients in the north east and in Northern Ireland where values of up to 35°C/km are observed (Pasquali, R., and Jones, G. L. and Allen, A. and Burgess, J. and Wiliams, T. H., 2013). With the development of EGS, however, in the next decades geothermal power can significantly contribute to the Irish electricity mix.

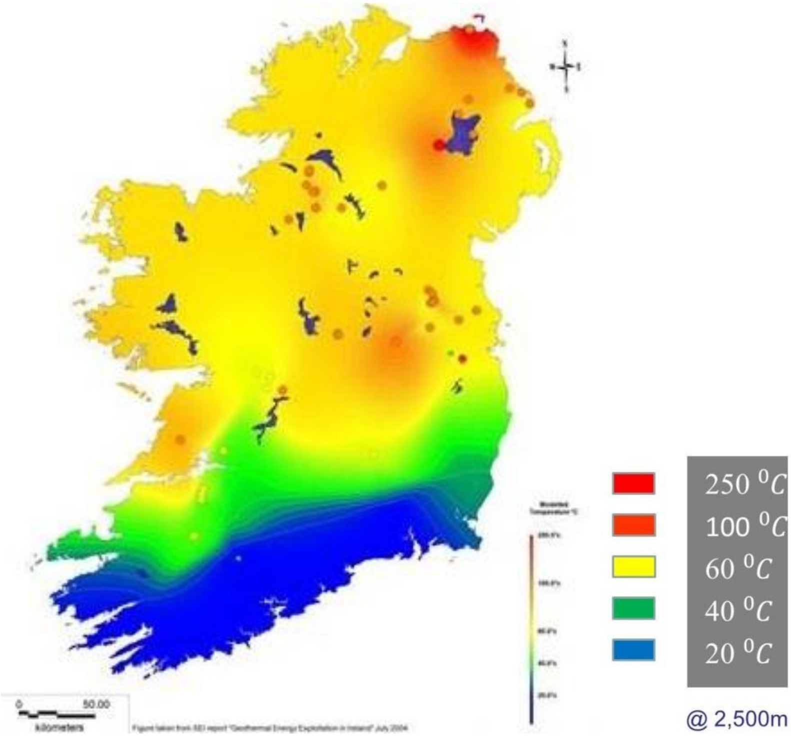


**Figure 24: Modelled Temperature at 2,500m (Goodman, R., and Jones, G.L. and Kelly, J. and Slowey, E. and O'Neill, N.: Geothermal Energy Resource Map of Ireland, Final Report. Sustainable Energy Ireland, Dublin, 2004)**

### *Market Development*

The Irish NREAP included a target for geothermal electricity, but only in the non-modelled scenario (where Ireland reaches its RES target before 2020 and exports RES production). Here, the proposal is to have 5 MWe installed in 2018 to produce 35 GWh (availability: 7000 h/y).

Extensive research aimed at better understanding the deep geothermal resources in different geological settings in Ireland is ongoing. Since the initial exploration drilling on the margin of the Dublin Basin, however, the deep geothermal energy sector has progressed very slowly. Despite encouraging results from 2D seismic surveys at the Newcastle project and planning permission for the first deep geothermal electricity plant being granted in late 2010, the lack of a feed-in tariff for geothermal electricity generation and the holdup in the implementation of a legislative framework for licensing deep geothermal resource exploration and development have stalled the sector (Pasquali, R., et al. 2013).

A first public-funded deep geothermal pilot project for electricity and / or heat production is highly recommended to kick-start the deployment of the technology in the country.

### *Economic Potential*

| | Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP / Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Geoth. Econ. Potent. (TWh) | Share of geothermal in gross electricity production | Geoth. Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|---|
| | **2010** | **2020** | **2030** | **2050** | | |
| **actual/ projected** | 0 | 0.035 | | | | |
| **≤300 EUR/MWh** | | 0.58 | | | | |
| **≤200 EUR/MWh** | | 0.06 | 0.59 | | | |
| **≤150 EUR/MWh** | | | 0.19 | | | |
| **≤100 EUR/MWh** | | | | 27.26 | 69% | 3 457 |

The GEOELEC resource assessment shows that electricity generation in Ireland is not only technically feasible, but it is economically viable in the next decades. The target set out in the NREAP can be achieved with a feed-in tariff of 200 EUR /MWh. In the longer term, with the significant cost reductions foreseen and the full development of EGS technology, more than 3 GWe could be installed for the production of 27 TWh per year, covering nearly 70% of the projected electricity consumption in the country.

## REFERENCES


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## Italy

### *Background*

Geothermal power generation has its roots in Italy, where the first test in 1904 and the real beginning of power generation in 1913 took place, both at the Larderello dry steam field in Tuscany. Thanks to its extraordinary high-enthalpy resources located in the central-southern Tyrrhenian belt, Italy represents more than 50% of the European capacity with around 875 MWe installed capacity today, all concentrated in Tuscany.

The geological structure of the country is extremely complex and the available geothermal information differs widely from region to region. During the Alpine orogeny (starting in the Cretaceous) period the collision between the African and European plates gave rise to the formation of the Alpine and Apennine chain. In the Late Miocene period the compressional front shifted east to the outer margin of the Apennine chain, resulting in the formation of foredeep basins along the Eastern margin of Italy. The inner West Apennines were affected by extension lasting up to the Pleistocene. This led to the opening of the Tyrrhenian basin, and to a significant crustal thinning associated with uplift of the mantle along most of the west Italian sector. Intensive intrusive and effusive magmatic activity occurred (Miocene - Quaternary) along the peri-Tyrrhenian area, in the Tyrrhenian Sea itself, in Ischia island, in Sicily (including the Aeolian and Pantelleria islands) and in Sardinia (Campidano graben) (Hurter, and Haenel, 2002).

Geothermal still has a large untapped potential in Italy, notably thanks to the development of new technologies such as binary cycles, which have opened up new areas to geothermal research targeting medium enthalpy fluids suitable for electricity production.

### *Market Development*

All of the thirty five geothermal power plants in Italy are owned and operated by Enel Green Power. However, a new Legislative Decree (n.22 of the 11th February 2010) has liberalised access to the geothermal market. As a result, more than one hundred and thirty requests for requests for geothermal exploration and exploitation have been presented over the last few years. Fifty research permits were already granted (until 2013), whilst the others were under evaluation. As depicted in the map overleaf, it is worth noting that for the first time there has been significant interest in areas outside Tuscany (European Geothermal Energy Council, 2013).

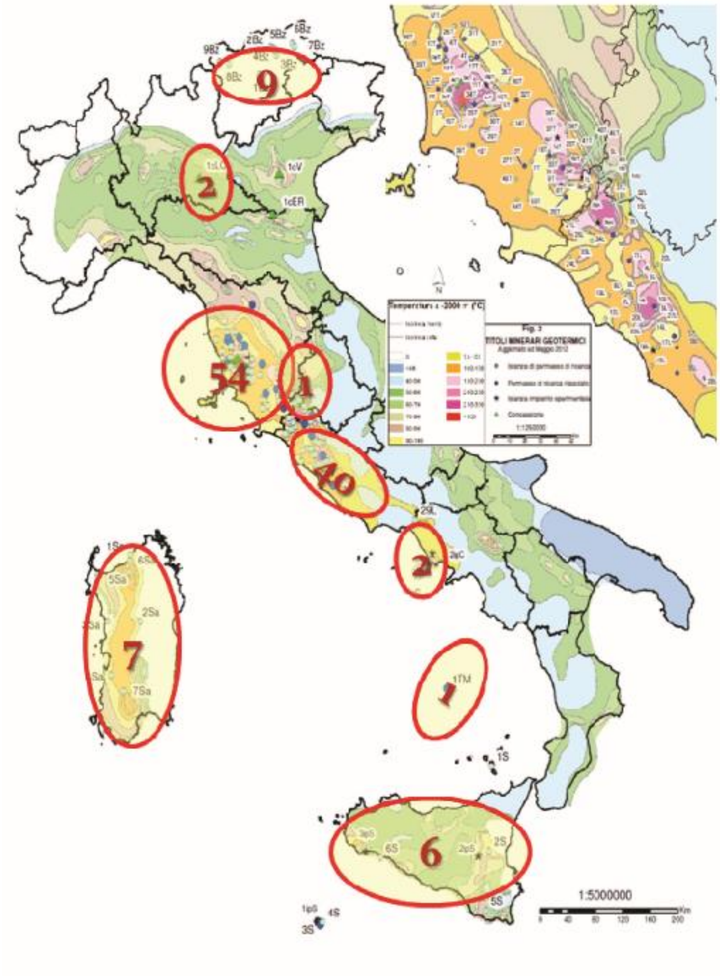


**Figure 25: Map of requests for research permits in Italy. Source: European Geothermal Energy Council, 2013.**

A support scheme (a hybrid Feed-in tariff /Feed-in premium and a Tender system) is in force until 2015. However, administrative procedures are extremely long. So much uncertainty is thus hindering both the climate for investment.

The process of putting the 2010 Legislative Decree into effect appears to be too slow, while Regions have been left with the responsibility of achieving the 2020 goals, but without tools, guidelines and often with no technical expertise required to assess and manage the permitting procedures. National guidelines for the exploration and production of geothermal resources are very much required.

The opportunities for the development of the geothermal sector in Italy are high. It is of the utmost importance that the relevant decision-makers take charge of the situation (regulatory and economical aspects, incentives, R&D) and start a dialogue with Regions, project-developers and civil society. The Government should start to consider the development of geothermal energy (which uses technology that it 90% Italian) as an opportunity to boost investments, the economy and to promote export.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | | **2050** | |
| 5.63 | 6.75 | 12.07 | 225.83 | 54% | 28 644 |

The GEOELEC resource assessment confirms the huge economic potential for geothermal power in Italy. By 2030 more than 1.5 GWe can be installed producing some 12 TWh, which is the double compared to the 2020 target in the Italian NREAP. By mid-century, with the full development of EGS and other technologies, more than 28 GWe could be installed, generating as much as 225 TWh per year and potentially covering more than half the projected electricity production in 2050.

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# Latvia

## *Background*

Geothermal aquifer zones of primary interest are located in the Middle Cambrian Deimena Formation (Cm2 dm) and in the Lower Devonian Kemeri Formation (Dikm). The Devonian aquifers lie in a depth of 400 - 1100m, the Cambrian aquifers lie at a depth between 960 - 2000m. In comparison with the Devonian aquifers the Cambrian aquifers have attracted more interest for geothermal energy use (European Commission, 1999).

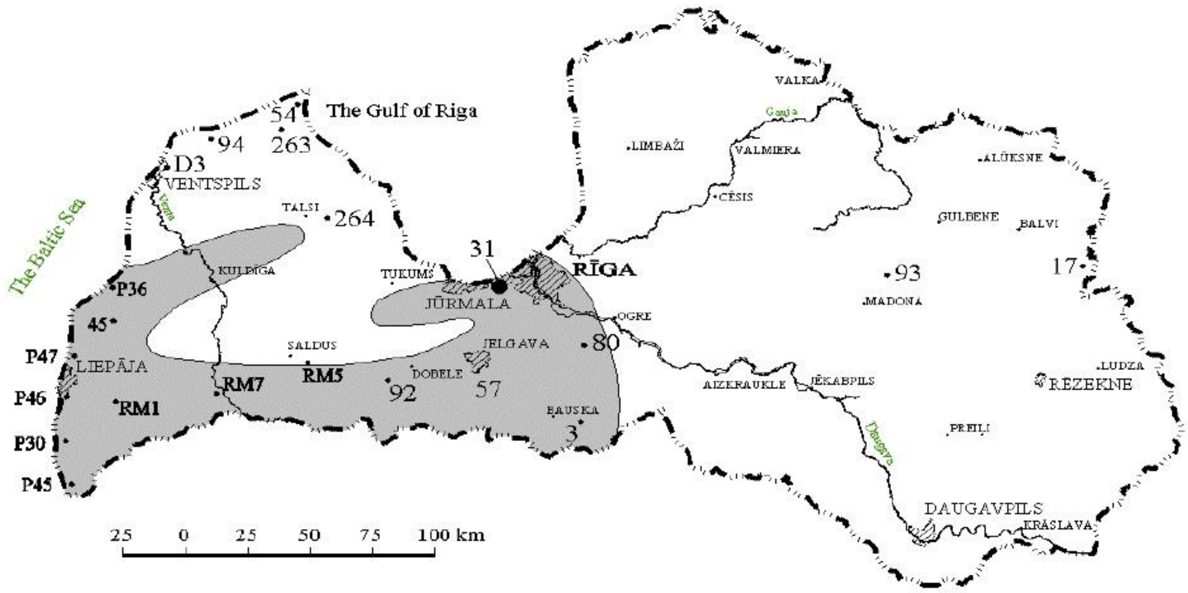


**Figure 26: Zones of Geothermal Anomalies. Source: Global Energy Network Institute.**

## *Market Development*

The city of Riga is planning on implementing the first EGS pilot project in the Baltic States, with electrical capacity of 3–4 MWe and heat capacity of 30–40 MWth. This project has been included in the Riga City Sustainable Energy Action Plan for 2010-2020, and approved by the Riga City Council on 6th July 2010 (Decision No.1644).

Nonetheless, the Latvian Government has not proposed any target for geothermal electricity. The potential for deep geothermal is briefly described, but there are no measures envisaged for geothermal electricity. A liaison should urgently be established between the Ministry and the Riga City Council as required by Article 5.4 of the Commission decision of 30.6.2009 establishing a template for National Renewable Energy Action Plans under Directive 2009/28/EC. Accordingly, the NREAP should be urgently amended to include the geothermal project and put forward a favourable regulatory framework for its implementation.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | **2050** | | |
| 0 | 0 | 0.01 | 2.84 | 31% | 360 |

The poor information available about the geothermal resources in Latvia has a negative influence on the results of the GEOELEC resource assessment. Nevertheless, it shows that on top of the above-mentioned pilot project in Riga, in the longer term up to 2.84 TWh per year could be harnessed through EGS in Latvia. In 2050 some 360 MWe could be installed to cover nearly one third of the projected electricity generation of the Baltic country.

## REFERENCES


- European Commission: Blue Book on Geothermal Resources, *Luxembourg: Office for Official Publication of the European Communities*, Luxembourg, 1999

## Lithuania

### *Background*

Lithuania is located in the eastern part of the Baltic sedimentary basin overlying the western margin of the East European Craton of the Early Precambrian consolidation. The heat flow systematically increases from 38 mW/m2 in the east to more than 90 mW/m2 in the west. Accordingly the most favourable conditions for the production of geothermal energy are related to the western part of the country.

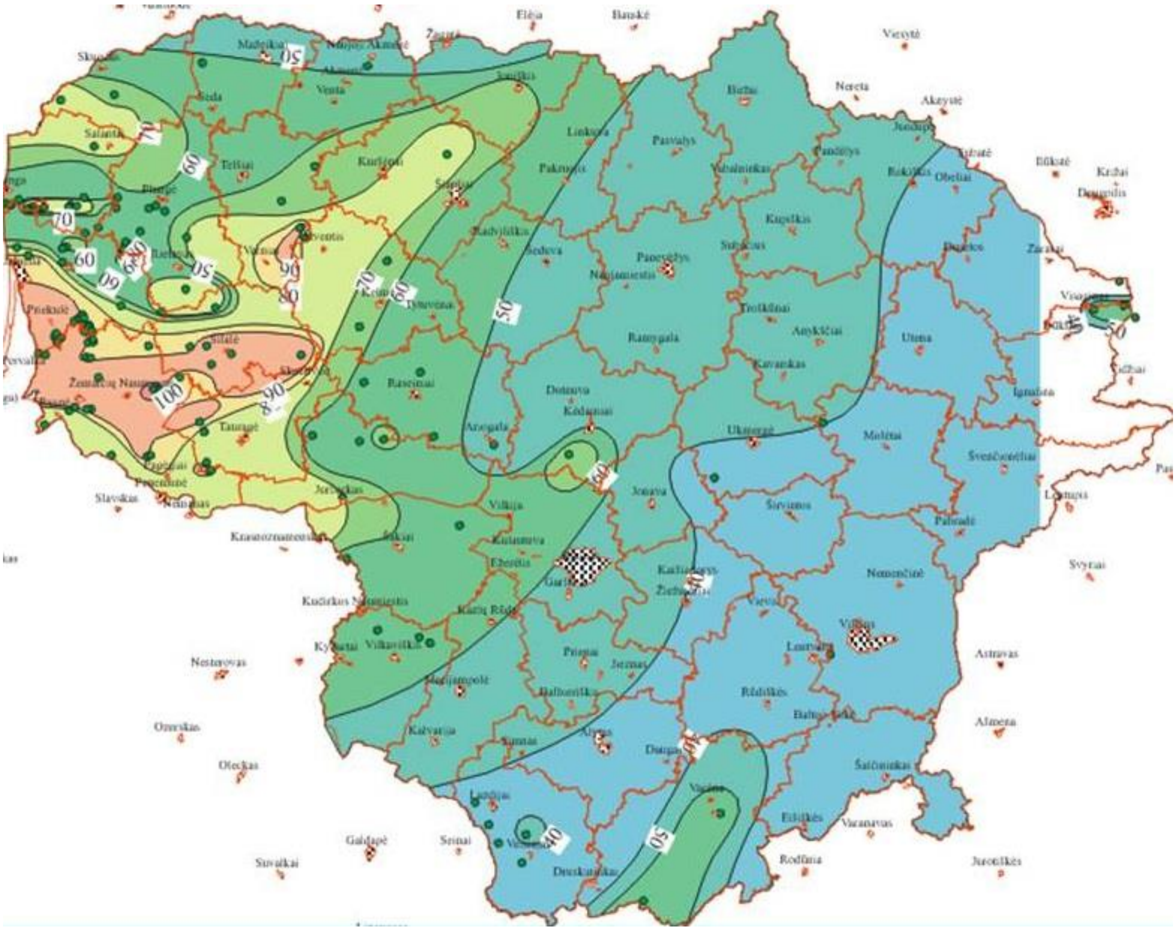

**Figure 27: Heat flow map of Lithuania (mW/m2). Source: Nature Research Center**

The basement is covered by 2 km thick sediments in the prospective area of West Lithuania. The temperatures do not exceed 100°C at the top of the crystalline basement; therefore the prospects for geothermal electricity generation are related to the deeper parts of the basement. In these areas, a number of Mesoproterozoic granitoid intrusions were identified. These are considered potential targets for EGS for the production of electricity combined with district heating (Zinevicius, F. and Sliaupa, S. and Aleksandravicius, T.A. and Mazintas, A., 2013).

### *Market Development*

Deep geothermal is not new in Lithuania. A geothermal heat plant has been operating in Klaipeda since 2004, while a first 3-MW geothermal power project is under evaluation in Silute.

Although the Lithuanian NREAP indicates the wish to promote electricity and heating production from geothermal energy utilising the potential of Western Lithuania, a target for geothermal electricity was not set out. The Lithuanian Geological Survey prepared a plan for 2011–2015 in order to determine the possibilities of using renewable and non-traditional resources of the earth's interior. It is part of the National strategy 2010-2015 yet, regrettably, is not reported in the NREAP.

The high exploration risk is considered as the main barrier for developing a geothermal project in Lithuania. In addition, while a feed-in tariff scheme is in force for RES, there is no dedicated tariff for geothermal.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | | **2050** | |
| 0 | 0 | 0.04 | 18.71 | 236% | 2 374 |

Geothermal electricity production in Lithuania can be economically viable after 2020. With the full deployment of the EGS technology, in the longer-term, geothermal can potentially provide more than twice the total projected electricity consumption in the country. More than 2 GWe could be installed producing some 18 TWh of renewable electricity per year by 2050.

## REFERENCES


- Zinevicius, F. and Sliaupa, S. and Aleksandravicius, T.A. and Mazintas, A.: Country Update Geothermal Energy Use, Country Update for Lithuania, *Proceedings of the European Geothermal Congress 2013*, Pisa, Italy,(2013), CUR-19, 1-12

## Luxemburg

### *Background*

Geothermal resources are not very well known in Luxembourg and any deep geothermal operations in the short to medium term are considered to be unlikely (European Comission, 1999). However, a successful development of EGS in the long-term could make geothermal energy an option even in a country like Luxembourg without hydrogeothermal potential.

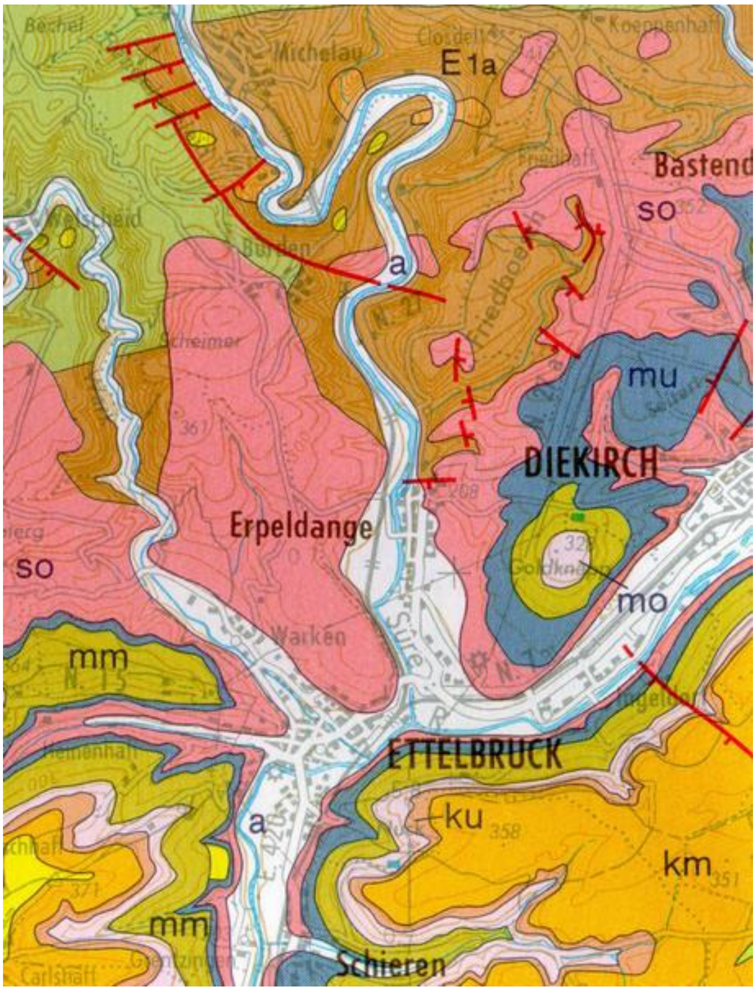


**Figure 28: General Geological Map of Luxembourg, Scale 1:100 000. Source: Service Geologique du Luxembourg (SGL)**

### *Market Development*

There are no deep geothermal projects in operation or under evaluation in Luxembourg.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | **2050** | | |
| 0 | 0 | 0 | 2.66 | 42% | 337 |

The GEOELEC resource assessment shows that, with the full development of EGS technology, after 2030 geothermal electricity generation will be technically and economically feasible in Luxembourg. By 2050 2.66 TWh of renewable power could be harnessed from geothermal resources. More than 300 MWe could potentially be installed to cover more than one third of the projected electricity production in the country.

## REFERENCES


- European Commission: Blue Book on Geothermal Resources, *Luxembourg: Office for Official Publication of the European Communities*, Luxembourg, 1999

## Poland

### Background

Poland extends over parts of three major tectonic provinces: the East European Platform in the North East, the Mid-European Platform in the South West and the Variscan fold belt in the West. The most important geothermal reservoirs lie in central and North Western Poland. The Polish Trough, extending over the central and northern Polish Lowlands, is filled with Permo-Mesozoic sediments.

In general, aquifers hosted in the Early Jurassic and Early Cretaceous section have the greatest geothermal potential in the Mesozoic cover. However, detailed investigations of other geological units may reveal additional potential (Hurter, S. and Haenel, R., 2002). With the development of EGS, however, geothermal resources in Poland can be developed for the production of electricity in several areas of the country.


Legend: 1. T-T zone, 2. Polish Trough, 3. Inter Cratonic boundary

**Figure 29: Major tectonic provinces in Poland**

### Market Development

Poland presents low-temperature hydro-geothermal resources connected mostly with Mesozoic sedimentary formations. In 2010-2012 twelve new geothermal wells were drilled. In the short-term, however, geothermal applications will be limited to space heating, balneotherapy, bathing and recreation. Meanwhile, some R&D work on prospects for geothermal binary power generation (based on at least 90-100ºC water) and on EGS prospects are ongoing (Kępińska, B., 2013).

The conditions for geothermal energy in Poland do not appear to be favorable. A solid regulatory framework is missing and no support mechanism is in place. Additionally, the NREAP does not include geothermal electricity generation (binary systems), even on a small scale (single devices with a capacity of tens-hundreds of kWe), as recommended by some experts (Kępińska, B., 2013).

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MW) |
|---|---|---|---|---|---|
| 2010 | 2020 | 2030 | 2050 | | |
| 0 | 0 | 0 | 143. 56 | 66% | 18 210 |

Thanks to technological developments giving access to resources available at deeper depths and at lower costs, the GEOELEC Resource Assessment shows the existence of economic potential for geothermal electricity in the long term.

Some 18 GWe could be installed in the country, producing up to 144 TWh at ≤100 EUR/MWh. Geothermal can not only supply more than 60% of the projected electricity demand, but has also the potential to contribute to local economic development, for instance by absorbing excess personnel from related sectors in decline such the coal mining sector.

In the next years it is recommended to establish a favourable legal framework and incentives to develop deep geothermal resources starting from thermal purposes, e.g. through district heating networks and low temperature power plants.

## REFERENCES


- Kępińska, B.: Geothermal Energy Use, Country Update for Poland, *Proceedings of the European Geothermal Congress 2013*, Pisa, Italy,(2013), CUR-23, 1-10
- Hurter, S. and Haenel, R. (ed.), Atlas of Geothermal Resources in Europe, *Office for Official Publications of the European Communities*, Luxembourg, (2002)

## Portugal

### *Background*

In Portugal, the presence of high temperature geothermal resources is limited to the volcanic islands of Azores Archipelago, which are associated with the triple junction of the North American, Eurasian and African (or Nubian) plates. Existing temperatures in mainland Portugal restrain the utilisation to direct uses only.

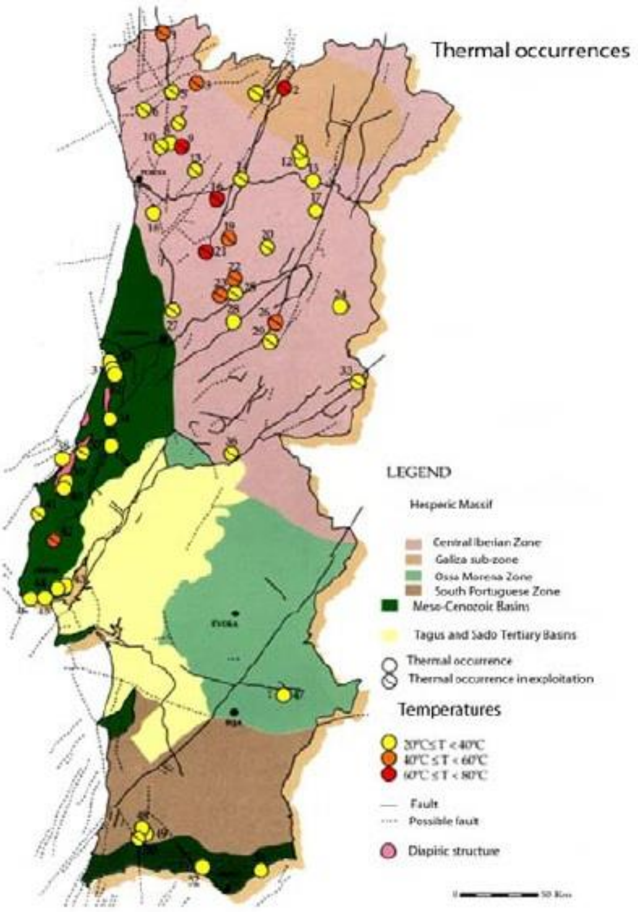


**Figure 30: Geological sketch of Portugal Mainland, with thermal occurrence. Source: Carvalho, J.M. and Coelho, L. and Nunes J.C. and Carvalho, M., 2013**

### *Market Development*

In the Azores islands, nearly 30 years after the beginning of the exploitation of geothermal resources for power generation at the Ribeira Grande field, the contribution of this energy source assumes an extremely relevant role. The installed capacity was expanded from 16 MW net to 23 MW net, with the new 10 MW net Pico Vermelho plant and the contribution of the geothermal source represents today 22% of the power generated in the Azores archipelago (Carvalho, J.M., et al. 2013).

In mainland Portugal, private investors obtained concession rights for exploration of geothermal resources for a total area of 2,655 km2 in 2008, aiming the future development of small scale power generation projects, but these EGS projects were not completed and technical and scientific results are unknown.

A 2020 target is proposed for geothermal electricity in the Portuguese NREAP. The increase planned is from 25 MWe (producing 163 GWh, availability: 6520 h/y) in 2010 to 75 MWe in 2020 (producing 488 GWh, availability: 6500 h/y). The projects allowing for this growth have already been identified (new 50 MWe in Açores are planned) and several EGS projects are examined (ca. 12 MWe).

### *Economic Potential*

| | Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP / Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Geoth. Econ. Potent. (TWh) | Share of geothermal in gross electricity production | Geoth. Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|---|
| | **2010** | **2020** | **2030** | **2050** | | |
| **actual/ projected** | 0.16 | 0.48 | | | | |
| **≤300 EUR/MWh** | | 0.45 | | | | |
| **≤200 EUR/MWh** | | 0.03 | 0.39 | | | |
| **≤150 EUR/MWh** | | | 0.16 | | | |
| **≤100 EUR/MWh** | | | | 63 | 85% | 8 000 |

Assuming cost reduction and the full development of the EGS technology, the GEOELEC resource assessment shows that geothermal electricity can not only be developed on the volcanic islands, but also in mainland Portugal. Without taking into account the constraints due to the peripheral location of some islands, in 2050 8 GWe could be installed in Portugal, corresponding to 63 TWh (load factor: 90%) of clean, reliable and renewable electricity.

## REFERENCES


- Carvalho, J.M. and Coelho, L. and Nunes J.C. and Carvalho, M.: Geothermal Energy Use, Country Update for Portugal, *Proceedings of the European Geothermal Congress 2013*, Pisa, Italy,(2013), CUR-24, 1-11

# Romania

## *Background*

Romania extends over a variety of tectonic units. The Pannonian Basin is bounded to the West by the Western Carpathians and to the South by the Southern Carpathians. The Transylvanian Basin is surrounded by the Western, Eastern and Southern Carpathians. In the South and East, the Getic and Pericarpathian Fordeeps separate the Southern and Eastern Carpathians from the Moesian and Moldavian platforms, respectively (Hurter, S. and Haenel, R., 2002)

The search for geothermal resources for energy purposes in the country began in the early 1960's based on a detailed geological programme for hydrocarbon resources. There are over 250 wells drilled at depths between 800 and 3,500 m, showing the existence of low enthalpy geothermal resources between 40 and 120°C (Rosca, M. and Bendea, C. and Cucueteanu, D., 2013). The map below shows how these are mainly found in the Western and Southern part of the country.  In addition, Romania presents an outstanding potential for EGS.


**Figure 30: Location of the main Romanian geothermal reservoirs. Source: Country Update Report**

### *Market Development*

Even though the Romanian NREAP does not mention any geothermal development and the target for geothermal electricity is set at zero, in 2012 the first ORC turbine became operational in Oradea.

The Romanian legal and financial frameworks relating to geothermal present other inconsistencies, which are hindering the development of the sector. Specific measures are established to support this technology, namely 2 green certificates (GC) per MWh, which means a minimum of EUR 54/MWh, within the national quota system. However, the new power plant in operation is not receiving GC for the electricity produced.

Additionally, a regulatory framework for geothermal energy is in place but the procedures for licensing must be simplified.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| 2010 | 2020 | 2030 | 2050 | | |
| 0 | 0 | 0.17 | 104.65 | 125% | 13 274 |

According to the GEOELEC resource assessment by 2030 170GWh of renewable power can be harnessed from geothermal resources at ≤150 EUR/MWh. After 2030 the electricity produced economically from geothermal could then increase up to 105 TWh per year. More than 13 GWe could be installed in the country by 2050, theoretically covering more than the entire projected electricity demand.

## REFERENCES


- Rosca, M. and Bendea, C. and Cucueteanu, D.: Geothermal Energy Use, Country Update for Romania, *Proceedings of the European Geothermal Congress 2013*, Pisa, Italy,(2013), CUR-25, 1-10

## Slovakia

### *Background*

The distribution of aquifers with geothermal waters and the thermal manifestation of geothermal fields in Slovakia have made it possible to define a significant number prospective areas and structures with potentially exploitable geothermal energy sources. These include mainly Tertiary and intramontane depressions situated in the Inner West Carpathians (south of the Klippen Belt).

The highest temperatures, geothermal gradient and heat flow density indicate that, with regard to the geothermal properties, the Eastern Slovakian basin is the most active region in Slovakia. Here medium- and high- temperature sources of geothermal energy suitable for electricity generation (25- 30M W C) can be captured. At a depth of 2500-3000m there are waters at 115-165°C. (European Commission, 1999)

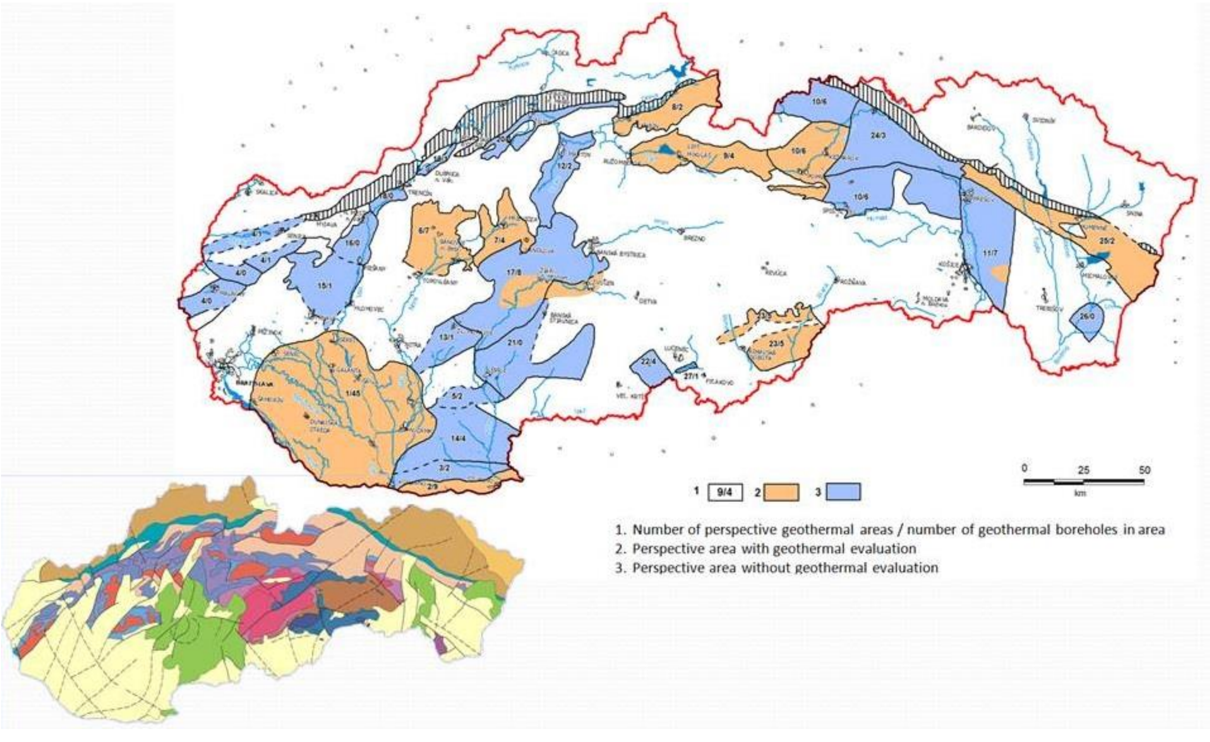


**Figure 32: Perspective geothermal areas. Source: State Geological Institute of Dionys Stur**

### *Market Development*

Slovakia has a long tradition in deep geothermal, with four geothermal heat plants already in operation. In terms of geothermal electricity, a project is under development and another under planning both in the Kosice region.

In its NREAP the Government only plans the installation of a 4-MWe plant but no more projects after that. The production would be 28 GWh (availability = 7 000 h/y), increasing to 29 GWh in 2019 and 30 GWh in 2020, with the same capacity of 4 MWe (availability improved to 7250 h/y and to 7500 h/y respectively).

This plan is rather peculiar because if the first plant is successful, many more projects will be developed: the NREAP should be amended accordingly.

Despite a Feed-in tariff is currently in place (amounting to 19.051 ct,EUR/kWh in 2012 and decreasing over time), the NREAP does not detail other specific support measures for geothermal in the next years; neither is there any indication about the much needed development of a simplified regulatory framework for deep geothermal.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | **2050** | | |
| 0 | 0.03 | 0.89 | 54.57 | 142% | 6 922 |

The GEOELEC resource assessment unveils more details on the geothermal electricity potential in Slovakia. By 2020, more than one project can be realised. Between 2020 and 2030 the installed capacity can increase further to produce up to 890 GWh in 2030 at less than EUR 150/MWh. By 2050 more than 50 TWh of renewable power could be harnessed from geothermal resources. Potentially, nearly 7 GWe could be installed, which could cover more than the entire projected electricity production in the country.

## REFERENCES


- European Commission: Blue Book on Geothermal Resources, *Luxembourg: Office for Official Publication of the European Communities*, Luxembourg, 1999

## Slovenia

### *Background*

Several tectonic units with different hydrogeological properties and geothermal conditions compose the territory below Slovenia. In the northeast, the Mura-Zala basin (the southwestern part of the Pannonian basin) and the Eastern Alps (incl. magmatic rock complex) are parts of the European plate. Predominately carbonate Southern Alps, External and Internal Dinarides and Adriatic foreland represent parts of the Adriatic microplate (Rajver, D. and Prestor, J. and Lapanje, A. and Rman, N., 2013).

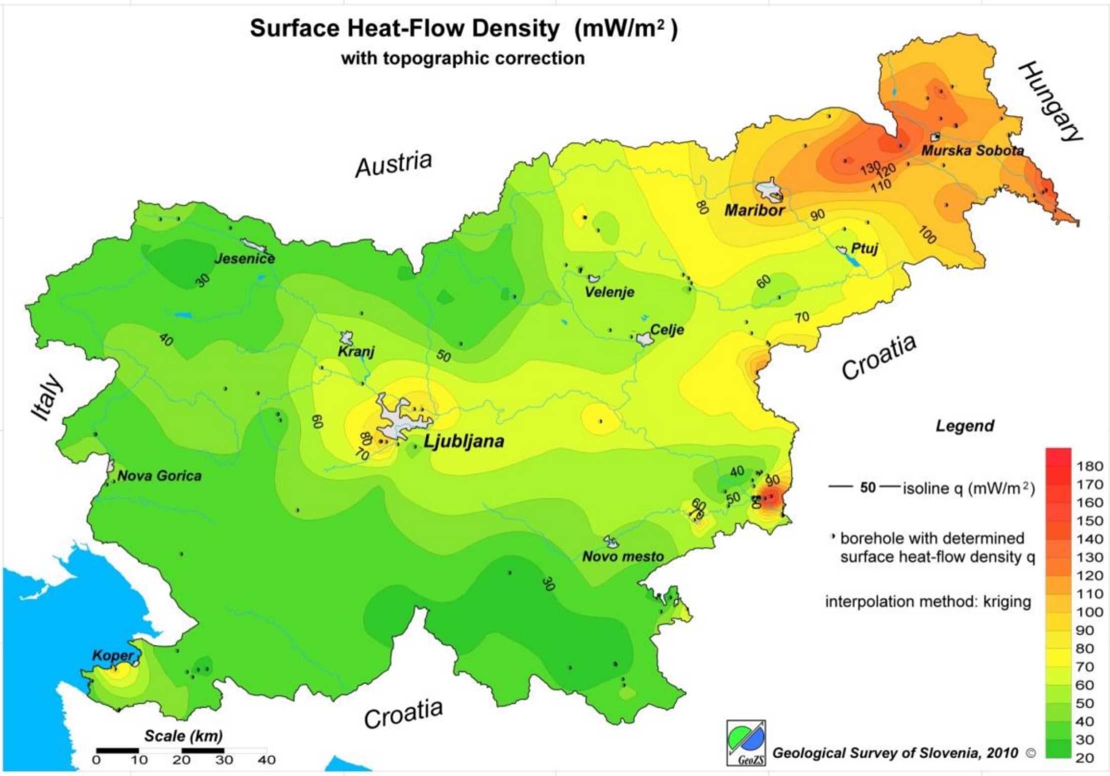


**Figure 33. Surface Heat-Flow Density in Slovenia with topographic correction. Source: Geological Survey of Slovenia**

The geothermal energy potential is concentrated in the eastern part of the country. The perspective geothermal reservoirs for electricity production are the following: (a) hydrothermal reservoirs in depths to 3 km and at temperature high above 80 °C: aquifers of the Lendava, Špilje and Haloze formations North East of Murska Sobota and in Lendava; (b) hydrothermal reservoirs in depths of 3 to 6 km and at temperature above 150 °C: carbonate rocks of the Pre-Neogene basement in the Radgona-Vas tectonic half-graben and on the Boč-Ormož antiform; (c) EGS at least 4 km deep in low permeable metamorphic or magmatic rocks: the Pohorje granodiorite massif and the Pre-Neogene basement of the Mura-Zala basin.

### *Market Development*

Geothermal in Slovenia is today limited to direct thermal water use for space heating, district heating, balneology and agriculture. Investigation potential for geothermal electric power production in the Pomurje region is ongoing.

The NREAP provides substantial information about measures for developing geothermal energy in Slovenia. For example, operators can choose either a guaranteed purchase price of 15.24 €ct./kWh or a bonus on top of the electricity price in the market of 10.36 €ct./kWh. However the plan does not forecast any production from geothermal electricity: 0 MWe and 0 GWh by 2020. Therefore, it is clear that other support measures are needed, such as increased awareness amongst decision-makers and the public, or a risk insurance scheme. A more detailed study of the potential will help to set appropriate targets.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | **2050** | | |
| 0 | 0 | 0.01 | 8.15 | 36% | 1 033 |

The GEOELEC Resource Assessment confirms the long-term economic potential for geothermal electricity in Slovenia. After 2020 a first geothermal power plant should be in operation, producing electricity at a cost in line with the current incentives. By mid-century, with significant cost reductions in EGS technology, more than 1 GWe could be installed in the country, producing some 8 TWh every year and potentially covering one third of the power generation projected in the country in 2050.

## REFERENCES


- Rajver, D. and Prestor, J. and Lapanje, A. and Rman, N.: Geothermal Energy Use, Country Update for Slovenia, *Proceedings of the European Geothermal Congress 2013*, Pisa, Italy,(2013), CUR-28, 1-16

- Hurter, S. and Haenel, R. (ed.), Atlas of Geothermal Resources in Europe, *Office for Official Publications of the European Communities*, Luxembourg, (2002)

## Spain

### *Background*

Spain's geothermal resource potential is very high. Nonetheless, geothermal energy in Spain still shows a very low penetration. The conditions that enable the existence of high temperature geothermal resources associated with active volcanism have been confirmed only in the Canary Islands. However, other geologic basins in Spain (e.g. the Cantabrian, Pre-Pyrenean, Tagus, Guadalquivir and Betic Range basins) normally host permeable formations at depths greater than 3,500 m, allowing for the existence of medium temperature geothermal resources suitable to be used in binary cycles.

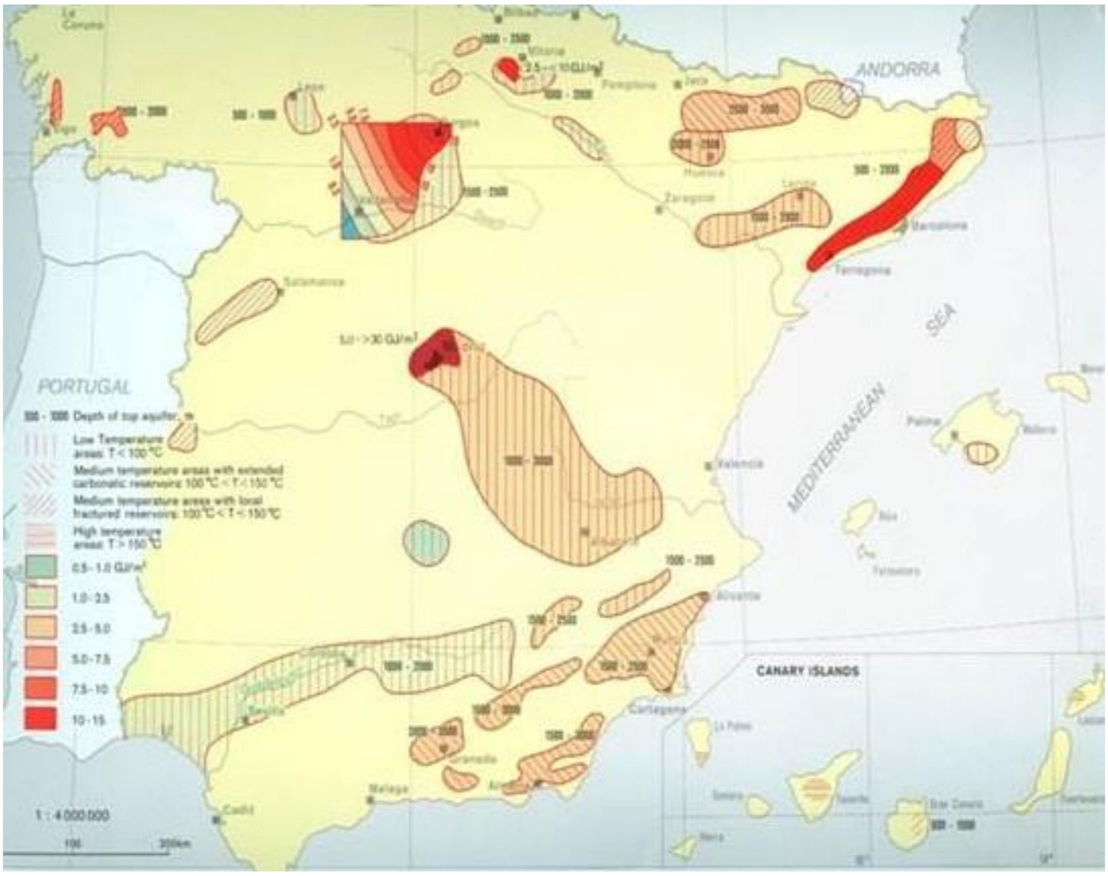


**Figure 34: Distribution of geothermal areas in Spain. Source: Haenel and Staroste, 1998**

A detailed review of the peninsular geology has also revealed a series of areas which, from a geological perspective, can allow the development of EGS, namely in the tectonic grabens of La Selva and Vallés in Cataluña, in areas of deep fracturing in Galicia, in the tectonic grabens in the South West of Salamanca, in fractured areas west of Cáceres, and in several areas of Andalucía where the granitic or Paleozoic bedrock are highly fractured (Arrizabalaga, I. and De Gregorio, M. and Garcia, C. and Hidalgo, R. and Urchueguía, J., 2013)

### *Market Development*

To date there are no power generation geothermal plants in Spain. However, the NREAP plans 50 MWe installed by 2020 which was rather conservative when considering the exploration in the Canaries. Also, the calculation of the production in GWh is incorrect: 300 GWh; this assumes an availability of 6000 h /y when it's typically 7800-8000 h/y for a geothermal power plant.

It is worth mentioning that the Spanish plan identified the geological risk as an important barrier, for which it is recommended to look at best practices from France and Germany and to support the creation of a European Geothermal Risk Insurance Scheme (EGRIF).[4] However, all of the business initiatives which emerged in Spain were abruptly slowed down by the indefinite moratorium decreed for all types of renewable energy, in addition to the 7% tax imposed on the value of electric energy production, including from renewables.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| 2010 | 2020 | 2030 | 2050 | | |
| 0 | 0.3 | 0.52 | 348.58 | 84% | 44 214 |

The GEOELEC resource assessment confirms the significant economic potential in Spain for geothermal power. By 2030 more than 500 GWh can be produced with ≤150 EUR/MWh. In the longer-term more than 40 GWe could be installed providing up to 349 TWh of renewable power every year. This would amount to more than 80% of the projected electricity demand in the country in 2050.

## REFERENCES


- Arrizabalaga, I. and De Gregorio, M. and Garcia, C. and Hidalgo, R. and Urchueguía, J.: Geothermal Energy Use, Country Update for Spain, *Proceedings of the European Geothermal Congress 2013*, Pisa, Italy,(2013), CUR-29, 1-10


[4] For further information see the GEOELEC report on risk insurance. Available on line at: http://www.geoelec.eu/wp-content/uploads/2011/09/D3.2.pdf

## The Netherlands

### *Background*

The geological structure of the Netherlands is characterised by three basins - the Western Netherlands, the Central Netherlands and the Broad Fourteens Basin which are limited in the south by the strongly folded Paleozoic of the Brabant massif.

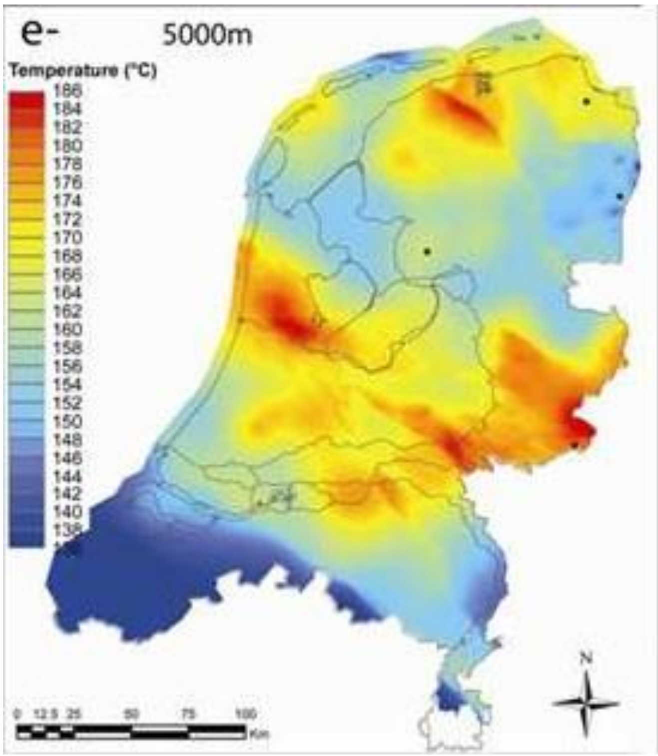


**Figure 35: EGS in NL. Source: TNO, 2012**

It is of interest an area around Amsterdam, where Createaceous sands suitable for geothermal utilisation exist. These are marine sandstones structured cyclically by alternating regressions and transgressions. They are characterised, partly, by outstanding reservoir properties and occur at a depth of about 2,000m with minimal deformation. The knowledge of individual reservoir horizons from wells differs. Because of hydrocarbon exploration, a significant number of wells have been drilled in the Slochteren formation, in the North of the Netherlands and around the Ijsselmeer. Contrariwise, in the Southern part of the country considerably less drilling has been done (European Commission, 1999).

### *Market Development*

There are no power plants in operation or under development in The Netherlands. However, the country presents a very dynamic market for geothermal heat and has high ambitions to further develop the deep geothermal sector in the future.

The Netherlands has the advantage of a Mining Act adapted for deep geothermal. It was mainly developed for the oil and gas industry, but the Mining Act also covers geothermal energy at depths of >500 meters. Several thousand deep boreholes have been drilled for oil and gas over the years, giving a lot of geological data for project developers.

During the last five years, several new projects have emerged, bringing the total number of deep geothermal installations to nine. Two new projects started drilling in March and April 2013 and more than 70 licences have been requested over the last 5 years. Two main reasons can explain this boom: The establishment of a governmental risk guarantee scheme to insure the geological risk of insufficient production volumes and the SDE+ system, a feed-in scheme, launched in 2012 (European Geothermal Energy Council, 2013).

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| 2010 | 2020 | 2030 | 2050 | | |
| 0 | 0 | 0.23 | 51.76 | 32% | 6 565 |

With the development of EGS and decreased costs, the GEOELEC Resource Assessment shows there is economic potential for geothermal electricity in the Netherlands by 2030.

By mid-century geothermal can become a relevant source in the country's electricity mix with more than 6 GWe potentially installed. Geothermal power technologies have indeed the economic potential to cover as much as 32% (i.e. more than 50 TWh) of the projected electricity consumption in 2050.

## REFERENCES


- European Commission: Blue Book on Geothermal Resources, *Luxembourg: Office for Official Publication of the European Communities*, Luxembourg, 1999
- European Geothermal Energy Council, EGEC Market Report 2013/14, Brussels, 2013

## United Kingdom

### *Background*

The geological and tectonic setting precludes the evolution of high enthalpy resources close to the surface and only low to moderate temperature fluids have been accessed by drilling in sedimentary basins in the south and northeast of England. Elevated temperature gradients and high heat flows have been measured in and above some granitic intrusions, particularly in southwest England. These granites were previously the site of the UK Hot Dry Rock programme in Cornwall. More recent work in northeast England also suggests higher than anticipated temperature gradients and hence increased focus on the possible application of geothermal heat in the region.

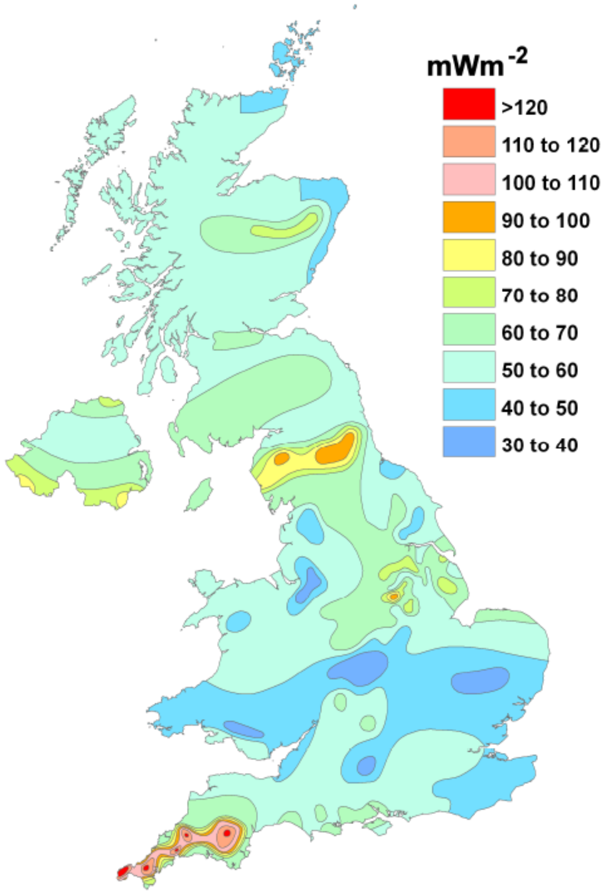


**Figure 36: Heat flow map of the UK (Busby, 2011)**

### *Market Development*

Despite two geothermal power projects are currently being developed (the Eden project and the United Downs Deep Geothermal project both in Cornwall) and three are under investigation, the NREAP does not set any target for 2020. For this reason it should be amended and include the establishment of adequate support measures. The same remarks apply to deep geothermal for heating and cooling.

Indeed legislation for deep geothermal development has been slow to catch up with the renewed level of interest in the sector. For instance there is still no official licensing scheme yet. Additionally, the Environment Agency, which regulates surface and aquifer water in the UK, has introduced a scheme to cover deep geothermal aquifer systems. This provides some degree of resource protection to developers but has not addressed the fundamental issue of resource ownership (Curtis et al, 2013).

In terms of financial support, in December 2013 the government announced a guaranteed price under the Contract for Difference (CfD up to £145 (approx. EUR 176.5) per MWh, which is however unlikely to be enough to stimulate substantial interest in the development of geothermal power generation.

### *Economic Potential*

| | Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP / Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Geoth. Econ. Potent. (TWh) | Share of geothermal in gross electricity production | Geoth. Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|---|
| | **2010** | **2020** | **2030** | **2050** | | |
| **actual/ projected** | 0 | 0 | | | | |
| **≤300 EUR/MWh** | | 0.28 | | | | |
| **≤200 EUR/MWh** | | | 0.43 | | | |
| **≤150 EUR/MWh** | | | 0.02 | | | |
| **≤100 EUR/MWh** | | | | 41.8 | 8% | 5 303 |

The GEOELEC resource assessment confirms the potential for geothermal power in UK. If the tariff were at the same level as in Germany, the project under development could be realised and 280 GWh could be produced every year by 2020. In the longer-term, with more underground information available and the full development of EGS more than 5 GWe could be installed providing as much as 42 TWh of renewable base-load power every year. This would amount to 8% of the projected electricity demand in the country in 2050.

## REFERENCES


- Busby, J.P and Dunbabin, P.: United Kingdom National Activities, in Annual Report 2011, *International Energy Agency Implementing Agreement for Cooperation in Geothermal Research & Technology*, (2011)

- Curtis, R. and Ledingham, P. and Law, R. and Bennett, T: Geothermal Energy Use, Country Update for United Kingdom, *Proceedings of the European Geothermal Congress 2013*, Pisa, Italy,(2013), CUR-33, 1-9

# Iceland

## *Background*

Iceland lies on the Mid-Atlantic ridge, one of earth's major rift zones, and is a geologically young country. The Mid-Atlantic ridge separates the North American and Eurasian tectonic plates. Iceland is created by a hot spot of unusually great volcanic productivity. In Iceland there are a large number of volcanoes and hot springs; more than 200 volcanoes are located within the active volcanic zone depicted in the figure below. At least thirty of the volcanoes have erupted in historical times and earthquakes are also frequent.

There are both high-temperature and low-temperature fields in Iceland as can be seen in figure below. The high-temperature areas are defined by temperature reaching 250°C within 1000m depth and the low-temperature areas are defined by temperature not being over 150°C in 1000m depth. Presently at least 20 high-temperature areas and about 250 low-temperature areas have been discovered in Iceland.

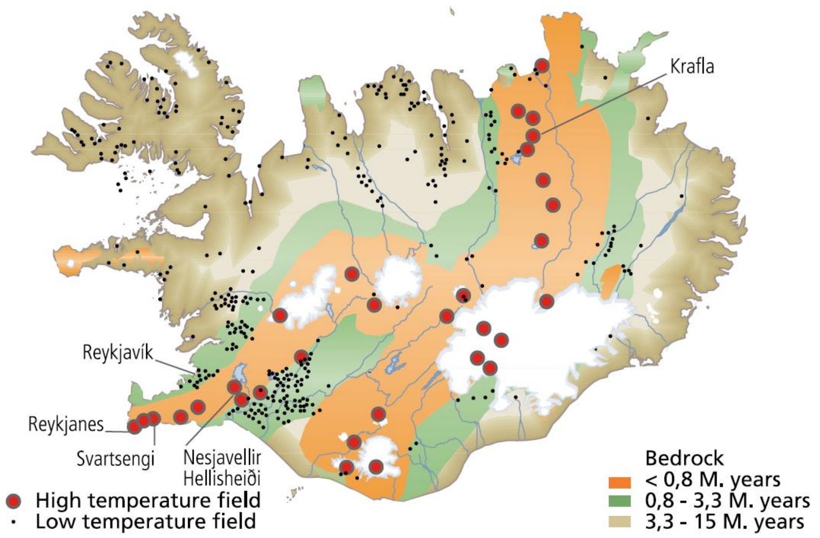


**Figure 37. High and low temperature geothermal fields in Iceland (Björnsson, 2005).**

## *Market Development*

During the course of the 20th century, Iceland went from being one of Europe's poorest countries, dependent upon imported coal for its energy, to a country with a high standard of living where practically all stationary energy, and roughly 72% of primary energy, is derived from indigenous renewable sources (54% geothermal, 18% hydropower). The rest of

Iceland’s energy sources come from imported fossil fuel used for fishing and transportation. Iceland’s energy use per capita is among the highest in the world and the proportion of this provided by renewable energy sources exceed that of most other countries.

Geothermal power production in Iceland began in 1969 at Bjarnarflag which is today a 3.2 MW power plant. The Svartsengi power plant came online in 1977 with few MWs, and has increased its production since then up to its current level of 72 MW. Electrical power production started at Krafla in 1977. Due to a volcanic eruption in the middle of power plant development power production was at first only on a small scale. The initially planned 60 MW came on line 1999. A power plant in Húsavík has an installed capacity of 2 MW (2000), Nesjavellir 120 MW (1998), Reykjanes 100 MW (2006) and Hellisheiði 303 MW (2006) bringing the total installed capacity in 2013 to 660.2 MW.

### Economic Potential

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|
| 2010 | 2020 | 2030 | 2050 | | |
| 4.5 | 5.8 | 73.7 | 321.89 | N/A | 40.829 |

The GEOELEC Resource Assessment shows there is still an enormous and untapped economic potential for geothermal electricity in Iceland. Indeed it could increase from 5.8 TWh in 2020 to some 74 TWh in 2030. With the development of new technologies some 41 GWe can potentially be installed in the long-term, producing up to 322 TWh every year in 2050.

## REFERENCES


- Björnsson, S.: Geothermal Development and Research in Iceland, *National Energy Authority and Ministries of Industry and Commerce, Reykjavlk, (2006)*
- Ketilsson, J.: Iceland National Activities, in Draft Annual Report 2012, *International Energy Agency Implementing Agreement for Cooperation in Geothermal Research & Technology*, (2012)
- Orkustofnun, The Resource, Retrieved on October 2013, Available on: http://www.nea.is/geothermal/the-resource/

## Switzerland

Switzerland is roughly divided into the Tabular and the Folded Jura in the West and North, the Swiss Molasse Basin and the alpine orogen in the central and southern parts. The Swiss basement consists of crystalline rocks containing troughs with permo-carboniferous sediments (Link, K., and Rybach, L. and Wyss, R., 2013). Possible targets of deep hydrothermal projects for heat and power production are potential Mesozoic Aquifers and fault zones, while EGS are in theory possible in the whole country. Currently, the crystalline basement north of the Alps is considered as target rock.

### *Background*

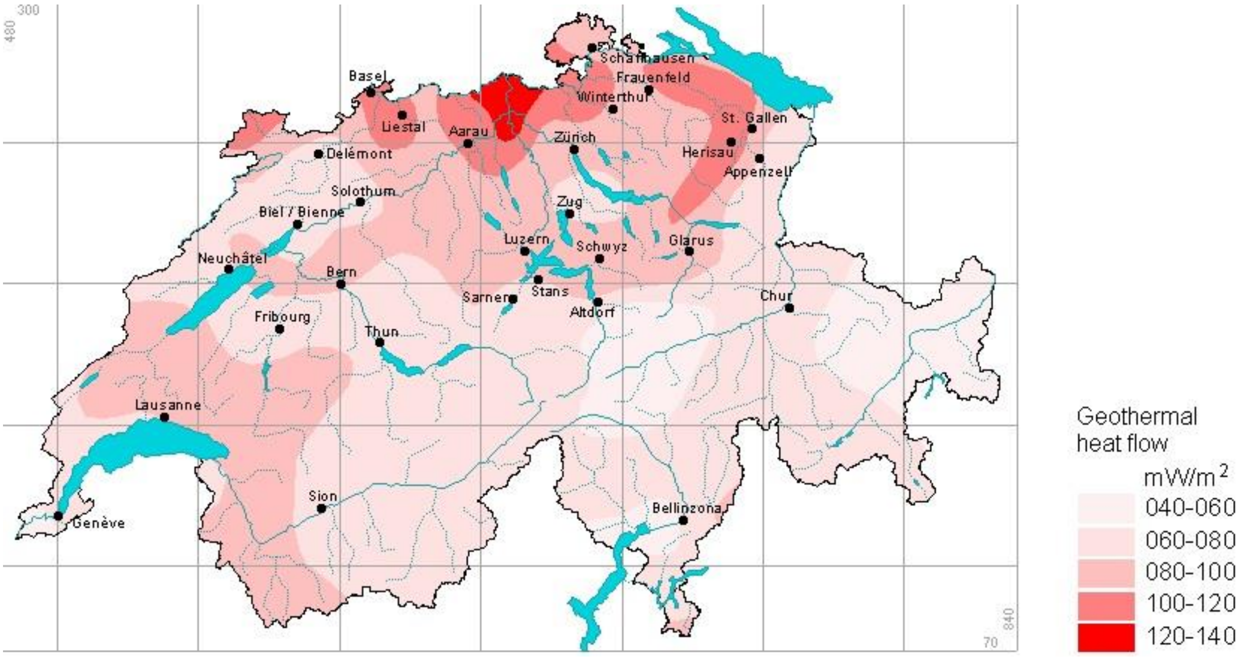


**Figure 38: Geothermal Energy in Switzerland. Source: 2004 Energie-Atlas GMbH, Switzerland according to Medici/Rybach Geothermal Map of Switzerland 1995)**

### *Market Development*

Swiss' energy policy took a major U turn in 2011. The Swiss Federal Assembly decided to phase-out the nuclear power programme and to substantially develop renewable energy. In the Swiss Energy Strategy 2050 developed by Swiss Federal Office of Energy deep geothermal energy plays a key role.

In the framework, a comprehensive package of measures is planned to stimulate the deep geothermal market and to achieve these objectives (Link, K., and Rybach, L. and Wyss, R., 2013). Indeed, a stable feed-in tariff for geothermal power is in place (Min. 18,89 ct€/kW for projects above 20 MW; Max. 33,3ct€/kW) as well as a risk insurance scheme covering up to 50 % of the costs for drilling and testing.

Despite the ambition in developing the deep geothermal sector, a major problem in the country is that the deep underground is not very well known yet. Indeed only 10 deep wells below 3,000 meters have been drilled and further investigation is much needed.

### *Economic Potential*

| | Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP / Economic Potential (TWh) | Geothermal Economic Potential (TWh) | Geoth. Econ. Potent. (TWh) | Share of geothermal in gross electricity production | Geoth. Economic Potential – Installed Capacity (MWe) |
|---|---|---|---|---|---|---|
| | **2010** | **2020** | **2030** | **2050** | | |
| **actual/ projected** | 0 | N/A | | | | |
| **≤300 EUR/MWh** | | 0.17 | | | | |
| **≤200 EUR/MWh** | | | 1.13 | | | |
| **≤150 EUR/MWh** | | | | | | |
| **≤100 EUR/MWh** | | | | 42.9 | N/A | 5 448 |

Despite the very little information currently available in Switzerland, the GEOELEC resource assessment confirms the large potential for geothermal power in the next decades. With the current support schemes 170 GWh of electricity could be harnessed from geothermal resources. With more information available, the full development of EGS technology and significant cost reduction, more than 5 GWe could be installed in the country by 2050, providing up to 43 TWh per year.

## REFERENCES


- Link, K., and Rybach, L. and Wyss, R: : Geothermal Energy Use, Country Update for Switzerland, *Proceedings of the European Geothermal Congress 2013*, Pisa, Italy,(2013), CUR-31, 1-8

## Turkey

### *Background*

In Turkey, recent volcanism and active faulting related to the Alpine tectonic Belt have created highly favourable conditions for the development of geothermal systems. More than 1000 hot springs are known and several of them are suitable for electricity generation. High enthalpy geothermal systems are mainly located in graben structures in Western Anatolia whereas low to intermediate temperature resources are disseminated in Middle and Eastern Anatolia, along fault zones (Northern Anatolian Fault) and in volcanic areas (European Commission, 1999).

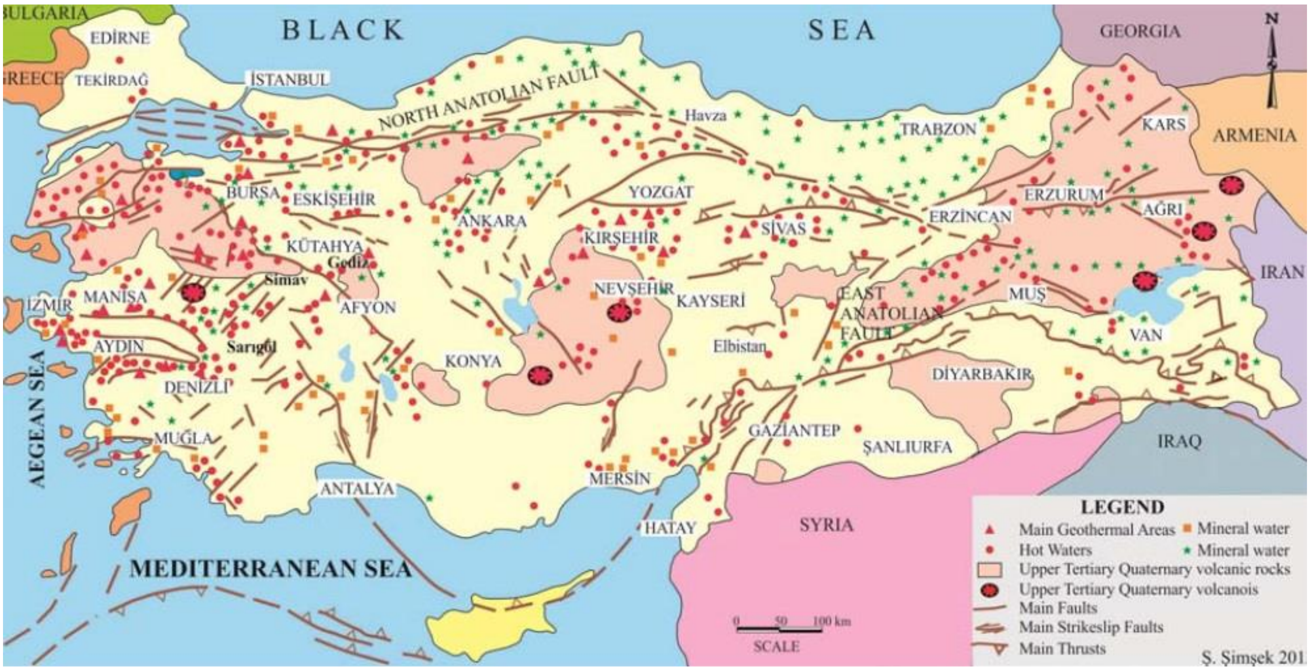


**Figure 39: Main neotectonic lines and hot spring distribution of Turkey. Source: Parlaktuna et al (2013)**

### *Market Development*

The Kizildere geothermal field was the first field utilised in 1974 for electricity production in Turkey. In that field new geothermal power plants have been installed since 2006 with a real boom between 2009 and 2013.

After the liberalisation of the Turkish electric market many players are now conducting in exploration activities, preparing the basis for the future development of geothermal energy in Turkey. Indeed the country is today one of the hottest markets for geothermal electricity in Europe, with a capacity of around 667MWe expected to be installed by 2017 (European Geothermal Energy Council, 2013).

Geothermal activities in Turkey is regulated by Law on Geothermal Resources and Natural Mineral Waters (No: 5686, Date: June 3, 2007) and its Implementation Regulation (No: 26727of December 2007). Along with a feed-in tariff, this well-developed regulatory framework provides stability and contributes to attract investments in the country.

### *Economic Potential*

| Gross Geothermal Electricity Generation (TWh) | Geothermal Electricity Target in the NREAP (TWh) | Geothermal Economic Potential (TWh) | Geothermal Economic Potential (TWh) | % of geothermal in gross electricity production | Geothermal Economic Potential – Installed Capacity (MW) |
|---|---|---|---|---|---|
| **2010** | **2020** | **2030** | **2050** | | |
| 0.7 | N/A | 62.31 | 965.9 | N/A | 122 515 |

The GEOELEC resource assessment confirms the very large economic potential for geothermal electricity. Indeed by mid-century more than 900 TWh/y of electricity could be harnessed from geothermal resources at 100 EUR/MWh or less and some120 GWe could be installed in the country.

## REFERENCES


- Parlaktuna, M. and Mertoglu, O. and Simsek, S. and Paksoy, H. and Basarir, N.: Geothermal Country Update Report of Turkey (2010-2013), *Proceedings of the European Geothermal Congress 2013*, Pisa, Italy,(2013), CUR-32, 1-9
- European Geothermal Energy Council, EGEC Market Report 2013/14, Brussels, 2013

## Recommendations for policy-makers: How to realise the geothermal electricity potential in Europe

The potential of geothermal energy is recognised by some EU Member States in their National Renewable Energy Action Plans (NREAPs). However, the actual potential is significantly larger. In order to increase awareness, GEOELEC has assessed and presented for the first time the economic potential in Europe in 2020, 2030 and 2050. The figures show the large potential of geothermal and the important role it can play in the future electricity mix.

Based on the project results, the GEOELEC consortium puts forward the following recommendations to realise the potential of geothermal electricity in Europe.

- **Create conditions to increase awareness about the advantages of this technology and its potential. National Committees on Geothermal promoting the technology to decision-makers and engaging the civil society to favour social acceptance should be established.**

The GEOELEC project has paved the way for the creation of national Geothermal committees across the EU.

Such committee should be established in each EU-28 Member State with the objective of increasing awareness about geothermal and to ensure public acceptance of the geothermal projects. This initiative builds on the French experience, where such a Committee has already been established in July 2010. There, the Energy Ministry launched a 'Comité National de la géothermie' to propose actions and recommendations for a geothermal development in France. It is composed by 35 members from 5 different sectors: State level, Local authorities, NGOs, Employers, and Workers. The first results of the *Comité National de la géothermie* in France can be presented through 3 key actions:

- Simplifying administrative procedure and quality
- Training professionals
- Disseminating information

- **In order to progress along the learning curve and deploy at large-scale a reliable renewable technology, a European EGS flagship programme should be launched, including new demonstration plants and test laboratories. It should also look at new technologies, methods and concepts.**

EGS is a technology for accessing the heat in hot but impermeable basement rock. Once fully developed, it will provide a major increase in the geothermal resource base, both for heat and electric power. In spite of its potential and although the basic concepts have been developed already in the 1980s EGS has not matured yet into a ready-to-implement technology.

An EGS Flagship program in the EU should be launched for making this technology competitive at the horizon 2020. Ultimately, this will establish EGS as a technology applicable almost everywhere for both heat and power production.

At each stage of the EGS development, proven methodologies can be applied and bottlenecks identified. From this state-of-the-art assessment, priorities encompassing five main areas have been defined for medium to long term research. The expected outcome will be geothermal energy in a form that can be widely deployed and competitively priced, underpinned with reduced capital, operational and maintenance costs. Swift progress (and continuous improvement) will be pooled with coordinated international R&D efforts, with a view to successful demonstration and implementation.

- Establish network of complementary 5-10 European EGS test laboratories;
- Develop Demonstration sites in different geological settings and upscale size of the power plants;
- Launch Training and education programs for new geothermal professionals specialized in EGS;
- Ensure Public acceptance on micro-seismicity, stimulation, environmental impact, emissions;
- Towards grid flexibility: Flexible and base load electricity production from EGS plants, with test on dispatchability, to develop regional flexible electricity systems.

- **A European Geothermal Risk Insurance Fund (EGRIF) is an innovative option tailored to the specificities of geothermal to mitigate the cost of the geological risk and is a complementary tool to operational support, still needed to compensate for the long-standing lack of a level-playing field.**

Financing a geothermal project includes two crucial elements in the initial phase of the project development: a high capital investment for drilling wells which can take up to 70% of the total project costs, and an insurance scheme to cover the geological risks.

As pre-drill assessment of geothermal performance is subject to major uncertainty and EGS is in an embryonic development phase, the risk profile is high compared to alternative sources of renewable energy. In order to face these challenges the following financial incentives are required to facilitate growth of geothermal energy in Europe:

- Support schemes are crucial tools of public policy for geothermal to compensate for market failures and to allow the technology to progress along its learning curve;
- Innovative financing mechanisms should be adapted to the specificities of geothermal technologies and according to the level of maturity of markets and technologies;
- The EGRIF is seen as an appealing public support measure for overcoming the geological risk;
- While designing a support scheme, policy-makers should seek a holistic approach, which exceeds the LCoE and includes system costs and all externalities. As an alternative, there is the chance to offer a bonus to geothermal energy for the benefits it provides to the overall electricity system, balancing the grid.

- **Enhance the education and training process, since multidisciplinary expertise and interaction of several disciplines are necessary. Create Networks for Geothermal Energy Education and Training involving industrial platforms, Universities and Research Centres developing a workforce for future geothermal development.**

The acceleration in the development of geothermal energy utilisation and the increasing demand of skilled workforce from industry show the present need for a fast increase in highly qualified technicians, engineers and specialists. This transition requires the modification in the existing curricula in different fields of geothermal energy such as basic research in geothermics, reservoir, drilling, material, power plant, utilisation, economics and legal aspects:

- Enhancement of the educational and training process is the factor that can have the largest effect on the long-term needs regarding certain job specialities and skills. Ensuring the existence of necessary skills in the sector requires action at all levels of education and training, meaning technical and scientific education, training and continuous learning. In order to achieve the proper education reforms, cooperation between all organisations involved is required;
- Cooperation between education and training institutes and companies is also necessary to create a network allowing for a faster and more efficient satisfaction of the needs generated in the labour market, while students are provided with the appropriate skills and knowledge.

- **Establish a geothermal industry and align energy and industrial policies, complemented by corresponding social and educational policies.**

Geothermal can contribute to the development of the local economy and create local jobs.

In 2013, there were 2500-3000 jobs directly related to geothermal electricity in the EU-28, while the estimated total number amounts to 10,000 jobs. The industry could employ more than 100.000 people by 2030 (exploration, drilling, construction, and manufacturing), based on projects under development and under investigation.

Over the last few years little new installed capacity has caused a concentration of jobs mainly in O&M, traditionally requiring only a few workers. The development of a significant number of new projects will trigger a real boom in labour-intensive activities such as exploration, drilling, construction and manufacturing.

The potential of the geothermal power industry can be achieved only through the attraction, retention and renewal of the workforce. Companies and organisations need to team up to universities and research centres to shape and have access to the highly skilled workforce they need.

- Absorb workforce of declining industries: several opportunities exist in the geothermal sector for employing workers from sectors in decline such as the coal sector. Professions concerned are in geosciences, drilling and thermal power plants sectors. Regional and national governments should make use of EU funds available to facilitate the requalification of workers from declining industries and ought to align, to the largest extent possible, their active labour policies to energy and industrial strategies.
- Promote mobility of workers in Europe: the knowledge and expertise on deep geothermal is concentrated today. There is the need to create conditions for more cooperation and exchange between juvenile and more mature markets.
- Launch international cooperation especially on EGS: the EGS flagship programme could integrate an international dimension to exchange experiences and technologies and exploring export opportunities of the European know-how on EGS.

## ANNEX I: Modelling results - 2030

| country | area[km2] | area_real [km2] | old_power50 | old_power100 | old_power150 | old_power200 | area_ effective _factor | Potential at LCOE < 50 EUR/ MWh | Potential at LCOE < 100 EUR/ MWh | rel2power50 | Potential at LCOE < 150 EUR/ MWh | rel2power100 | Potential at LCOE < 200 EUR/ MWh | rel2power150 | LOADFACTOR | ECONOMIC POTENTIAL (TWh) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AUSTRIA** | 181200 | 83855 | 0 | 0 | 113.6336 | 1942.348 | 25.00% | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.22 | 0.21 | 90.00% | **0.10** |
| **BELARUS** | 580700 | 207560 | 0 | 0 | 16.07506 | 81.49559 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 90.00% | **0.01** |
| **BELGIUM** | 72000 | 30528 | 0 | 0 | 0 | 1.357289 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 90.00% | **0.00** |
| **BOSNIA AND HERZEGOVINA** | 96200 | 51129 | 0 | 0 | 22.72372 | 658.4464 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.08 | 90.00% | **0.02** |
| **BULGARIA** | 213100 | 110994 | 0 | 0 | 96.47601 | 546.2728 | 25.00% | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.07 | 0.06 | 90.00% | **0.10** |
| **CROATIA** | 101800 | 56594 | 0 | 0 | 2770.358 | 6561.068 | 25.00% | 0.00 | 0.00 | 0.00 | 0.39 | 0.39 | 0.91 | 0.53 | 90.00% | **3.00** |
| **CYPRUS** | 11700 | 9250 | 0 | 0 | 0 | 0 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 90.00% | **0.00** |
| **CZECH REPUBLIC** | 190100 | 78866 | 0 | 0 | 53.05592 | 176.1945 | 25.00% | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.01 | 90.00% | **0.04** |
| **DENMARK** | 122800 | 43094 | 0 | 0 | 49.50249 | 138.9533 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 90.00% | **0.03** |
| **ESTONIA** | 161500 | 45226 | 0 | 0 | 65.31903 | 163.3913 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 90.00% | **0.04** |
| **FINLAND** | 1815300 | 338424 | 0 | 0 | 0 | 0 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 90.00% | **0.00** |
| **FRANCE** | 1145300 | 674843 | 0 | 0 | 335.9231 | 6547.662 | 25.00% | 0.00 | 0.00 | 0.00 | 0.05 | 0.05 | 0.96 | 0.92 | 90.00% | **0.39** |
| **GERMANY** | 897900 | 357021 | 0 | 0 | 1761.038 | 20139.09 | 25.00% | 0.00 | 0.00 | 0.00 | 0.18 | 0.18 | 2.00 | 1.83 | 90.00% | **1.37** |
| **GREECE** | 198100 | 131940 | 0 | 0 | 364.3309 | 1242.252 | 25.00% | 0.00 | 0.00 | 0.00 | 0.06 | 0.06 | 0.21 | 0.15 | 90.00% | **0.47** |
| **HUNGARY** | 202000 | 93030 | 0 | 0 | 18991.45 | 34018.94 | 25.00% | 0.00 | 0.00 | 0.00 | 2.19 | 2.19 | 3.92 | 1.73 | 90.00% | **17.06** |
| **ICELAND** | 551300 | 103001 | 0 | 74512.77 | 202222.6 | 296559.7 | 25.00% | 0.00 | 3.48 | 3.48 | 9.45 | 5.97 | 13.85 | 7.89 | 90.00% | **73.70** |
| **IRELAND** | 187900 | 84421 | 0 | 0 | 214.8649 | 670.1218 | 25.00% | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.08 | 0.05 | 90.00% | **0.19** |
| **ITALY** | 539400 | 301230 | 0 | 2993.166 | 11082.01 | 20254.44 | 25.00% | 0.00 | 0.42 | 0.42 | 1.55 | 1.13 | 2.83 | 1.70 | 90.00% | **12.07** |
| **LATVIA** | 216300 | 64589 | 0 | 0 | 21.20503 | 122.1849 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 90.00% | **0.01** |
| **LITHUANIA** | 202500 | 65200 | 0 | 0 | 68.16508 | 873.6393 | 25.00% | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.07 | 0.06 | 90.00% | **0.04** |
| **LUXEMBOURG** | 5300 | 2586 | 0 | 0 | 0 | 0 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 90.00% | **0.00** |
| **NORWAY** | 1613100 | 385199 | 0 | 0 | 0 | 0 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 90.00% | **0.00** |
| **POLAND** | 819600 | 312679 | 0 | 0 | 0 | 1341.638 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.13 | 0.13 | 90.00% | **0.00** |
| **PORTUGAL** | 149800 | 91985 | 0 | 0 | 130.8764 | 326.2566 | 25.00% | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.05 | 0.03 | 90.00% | **0.16** |
| **ROMANIA** | 488000 | 238391 | 0 | 0 | 178.0375 | 1699.809 | 25.00% | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.21 | 0.19 | 90.00% | **0.17** |
| **SERBIA** | 166600 | 88361 | 0 | 0 | 1126.948 | 4819.632 | 25.00% | 0.00 | 0.00 | 0.00 | 0.15 | 0.15 | 0.64 | 0.49 | 90.00% | **1.17** |
| **SLOVAKIA** | 112000 | 49036 | 0 | 0 | 1037.524 | 4081.602 | 25.00% | 0.00 | 0.00 | 0.00 | 0.11 | 0.11 | 0.45 | 0.33 | 90.00% | **0.89** |
| **SLOVENIA** | 38800 | 20273 | 0 | 0 | 5.677826 | 297.0767 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.04 | 90.00% | **0.01** |
| **SPAIN** | 843700 | 505992 | 0 | 0 | 447.8075 | 2298.329 | 25.00% | 0.00 | 0.00 | 0.00 | 0.07 | 0.07 | 0.34 | 0.28 | 90.00% | **0.52** |
| **SWEDEN** | 2145000 | 449964 | 0 | 0 | 0 | 0 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 90.00% | **0.00** |
| **SWITZERLAND** | 87100 | 41285 | 0 | 0 | 1.887173 | 1217.136 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.14 | 0.14 | 90.00% | **0.00** |
| **THE NETHERLANDS** | 98700 | 41526 | 0 | 0 | 284.8184 | 4876.942 | 25.00% | 0.00 | 0.00 | 0.00 | 0.03 | 0.03 | 0.51 | 0.48 | 90.00% | **0.23** |
| **TURKEY** | 1270300 | 783562 | 0 | 10382.2 | 51782.71 | 101681.1 | 25.00% | 0.00 | 1.60 | 1.60 | 7.99 | 6.38 | 15.68 | 9.30 | 90.00% | **62.31** |
| **UKRAINE** | 1367200 | 603628 | 0 | 0 | 184.5544 | 1982.884 | 25.00% | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.22 | 0.20 | 90.00% | **0.16** |
| **UNITED KINGDOM** | 667500 | 243610 | 0 | 0 | 33.89548 | 607.8383 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.05 | 90.00% | **0.02** |
| **TOTAL** | | | | | | | | | 0.00 | | 0.00 | | 0.00 | | | 174.30 |
| | | | | | | | | | | | | | | | | *TWh @ cutoff 200 €/MWh* |

## ANNEX II: Modelling results - 2050

| Country | Area [km2] | area_real [km2] | old_power50 | old_power100 | old_power150 | old_power200 | area_ effective _factor | Potential at LCOE < 50 EUR/ Mwh | Potential at LCOE < 100 EUR/ Mwh | rel2power50 | Potential at LCOE < 150 EUR/ Mwh | rel2power100 | Potential at LCOE < 200 EUR/Mwh | rel2power150 | LOADFACTOR | ECONOMIC POTENTIAL (TWh) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AUSTRIA** | 181200 | 83855 | 116.0061 | 73564.48 | 89363.14 | 93136.32 | 25.00% | 0.01 | 8.51 | 8.50 | 10.34 | 1.84 | 10.78 | 8.93 | 90.00% | **67.10** |
| **BELARUS** | 580700 | 207560 | 26.98249 | 2753.079 | 8024.989 | 21254.06 | 25.00% | 0.00 | 0.25 | 0.24 | 0.72 | 0.47 | 1.90 | 1.43 | 90.00% | **1.94** |
| **BELGIUM** | 72000 | 30528 | 0 | 26662.12 | 33144.66 | 34700.86 | 25.00% | 0.00 | 2.83 | 2.83 | 3.51 | 0.69 | 3.68 | 2.99 | 90.00% | **22.28** |
| **BOSNIA AND HERZEGOVINA** | 96200 | 51129 | 0 | 23518.63 | 33407.27 | 36380.79 | 25.00% | 0.00 | 3.12 | 3.12 | 4.44 | 1.31 | 4.83 | 3.52 | 90.00% | **24.64** |
| **BULGARIA** | 213100 | 110994 | 88.94194 | 69798.19 | 90290.03 | 95421.92 | 25.00% | 0.01 | 9.09 | 9.08 | 11.76 | 2.68 | 12.43 | 9.75 | 90.00% | **71.66** |
| **CROATIA** | 101800 | 56594 | 275.7485 | 45601.54 | 51222.47 | 53769.25 | 25.00% | 0.04 | 6.34 | 6.30 | 7.12 | 0.82 | 7.47 | 6.65 | 90.00% | **49.97** |
| **CYPRUS** | 11700 | 9250 | 0 | 0 | 0 | 0 | 25.00% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 90.00% | **0.00** |
| **CZECH REPUBLIC** | 190100 | 78866 | 53.92516 | 37516.04 | 62095.69 | 68086.61 | 25.00% | 0.01 | 3.89 | 3.89 | 6.44 | 2.55 | 7.06 | 4.51 | 90.00% | **30.68** |
| **DENMARK** | 122800 | 43094 | 0 | 42543.78 | 53403.87 | 56069.38 | 25.00% | 0.00 | 3.73 | 3.73 | 4.69 | 0.95 | 4.92 | 3.97 | 90.00% | **29.43** |
| **ESTONIA** | 161500 | 45226 | 13.41011 | 3026.398 | 3691.18 | 4524.892 | 25.00% | 0.00 | 0.21 | 0.21 | 0.26 | 0.05 | 0.32 | 0.27 | 90.00% | **1.67** |
| **FINLAND** | 1815300 | 338424 | 0 | 0 | 8546.83 | 36929.64 | 25.00% | 0.00 | 0.00 | 0.00 | 0.40 | 0.40 | 1.72 | 1.32 | 90.00% | **0.00** |
| **FRANCE** | 1145300 | 674843 | 819.9914 | 562281.3 | 649408.8 | 670459.6 | 25.00% | 0.12 | 82.83 | 82.71 | 95.66 | 12.96 | 98.76 | 85.81 | 90.00% | **653.02** |
| **GERMANY** | 897900 | 357021 | 2106.504 | 440971 | 512249.8 | 529162.3 | 25.00% | 0.21 | 43.83 | 43.63 | 50.92 | 7.29 | 52.60 | 45.31 | 90.00% | **345.59** |
| **GREECE** | 198100 | 131940 | 2251.249 | 61932.86 | 78721.96 | 83661.92 | 25.00% | 0.37 | 10.31 | 9.94 | 13.11 | 3.17 | 13.93 | 10.76 | 90.00% | **81.30** |
| **HUNGARY** | 202000 | 93030 | 28300.14 | 191345 | 199772.8 | 201792.3 | 25.00% | 3.26 | 22.03 | 18.77 | 23.00 | 4.23 | 23.23 | 19.00 | 90.00% | **173.69** |
| **ICELAND** | 551300 | 103001 | 611267.9 | 874123.4 | 889761.3 | 892714.2 | 25.00% | 28.55 | 40.83 | 12.28 | 41.56 | 29.28 | 41.70 | 12.42 | 90.00% | **321.89** |
| **IRELAND** | 187900 | 84421 | 149.4088 | 30781.97 | 45965.09 | 50776.44 | 25.00% | 0.02 | 3.46 | 3.44 | 5.16 | 1.72 | 5.70 | 3.98 | 90.00% | **27.26** |
| **LATVIA** | 216300 | 64589 | 0 | 4827.627 | 11484.66 | 17352.05 | 25.00% | 0.00 | 0.36 | 0.36 | 0.86 | 0.50 | 1.30 | 0.80 | 90.00% | **2.84** |
| **LITHUANIA** | 202500 | 65200 | 94.89098 | 29487.52 | 43538.72 | 51319.63 | 25.00% | 0.01 | 2.37 | 2.37 | 3.50 | 1.14 | 4.13 | 2.99 | 90.00% | **18.71** |
| **LUXEMBOURG** | 5300 | 2586 | 0 | 2762.372 | 3095.718 | 3192.008 | 25.00% | 0.00 | 0.34 | 0.34 | 0.38 | 0.04 | 0.39 | 0.35 | 90.00% | **2.66** |
| **NORWAY** | 1613100 | 385199 | 0 | 244.3734 | 50946.2 | 118170.1 | 25.00% | 0.00 | 0.01 | 0.01 | 3.04 | 3.03 | 7.05 | 4.03 | 90.00% | **0.12** |
| **POLAND** | 819600 | 312679 | 0 | 190916.8 | 279107.8 | 304522.3 | 25.00% | 0.00 | 18.21 | 18.21 | 26.62 | 8.41 | 29.04 | 20.63 | 90.00% | **143.56** |
| **PORTUGAL** | 149800 | 91985 | 47.6143 | 52049.07 | 65024.23 | 68381.21 | 25.00% | 0.01 | 7.99 | 7.98 | 9.98 | 2.00 | 10.50 | 8.50 | 90.00% | **62.99** |
| **ROMANIA** | 488000 | 238391 | 0 | 108692.1 | 168037 | 182946.4 | 25.00% | 0.00 | 13.27 | 13.27 | 20.52 | 7.25 | 22.34 | 15.10 | 90.00% | **104.65** |
| **SERBIA** | 166600 | 88361 | 261.9264 | 87549.16 | 98980.18 | 101998.4 | 25.00% | 0.03 | 11.61 | 11.57 | 13.12 | 1.55 | 13.52 | 11.97 | 90.00% | **91.52** |
| **SLOVAKIA** | 112000 | 49036 | 1297.365 | 63240.29 | 70555.1 | 72364.16 | 25.00% | 0.14 | 6.92 | 6.78 | 7.72 | 0.94 | 7.92 | 6.98 | 90.00% | **54.57** |
| **SLOVENIA** | 38800 | 20273 | 0 | 7911.353 | 11333.35 | 12662.56 | 25.00% | 0.00 | 1.03 | 1.03 | 1.48 | 0.45 | 1.65 | 1.21 | 90.00% | **8.15** |
| **SPAIN** | 843700 | 505992 | 971.9594 | 294890.7 | 369698.3 | 388909.7 | 25.00% | 0.15 | 44.21 | 44.07 | 55.43 | 11.36 | 58.31 | 46.95 | 90.00% | **348.58** |
| **SWEDEN** | 2145000 | 449964 | 0 | 2491.01 | 167262 | 264041.5 | 25.00% | 0.00 | 0.13 | 0.13 | 8.77 | 8.64 | 13.85 | 5.21 | 90.00% | **1.03** |
| **SWITZERLAND** | 87100 | 41285 | 0 | 45975.58 | 51678.93 | 53075.35 | 25.00% | 0.00 | 5.45 | 5.45 | 6.12 | 0.68 | 6.29 | 5.61 | 90.00% | **42.95** |
| **THE NETHERLANDS** | 98700 | 41526 | 0 | 62416.94 | 67492.15 | 68876.97 | 25.00% | 0.00 | 6.57 | 6.57 | 7.10 | 0.53 | 7.24 | 6.71 | 90.00% | **51.76** |
| **TURKEY** | 1270300 | 783562 | 162606.6 | 794479.6 | 889518.1 | 914474 | 25.00% | 25.08 | 122.52 | 97.44 | 137.17 | 39.73 | 141.02 | 101.29 | 90.00% | **965.91** |
| **UKRAINE** | 1367200 | 603628 | 129.1373 | 81403.84 | 190831.9 | 243497.7 | 25.00% | 0.01 | 8.99 | 8.97 | 21.06 | 12.09 | 26.88 | 14.78 | 90.00% | **70.84** |
| **UNITED KINGDOM** | 667500 | 243610 | 6.7695 | 58120.63 | 132009.1 | 159117.9 | 25.00% | 0.00 | 5.30 | 5.30 | 12.04 | 6.74 | 14.52 | 7.78 | 90.00% | **41.81** |
| **TOTAL** | | | | | | | | **0.06** | **0.53** | | **0.65** | | **0.69** | | | **4140.59** |
| | | | | | | | | | *GWe* | | *GWe* | | *GWe* | | | *TWh @ cutoff 100 €/MWh* |

## ANNEX III: Geothermal potential and share in the electricity mix

| EU Country | Gross Electricity Generation (TWh) in 2010* | Projected Gross Electricity Generation (TWh) | | Gross Geothermal Electricity Generation (TWh)** | Geothermal Electricity Target in the NREAPs (TWh)** | Geothermal Economic Potential (TWh)**** | | | Potential % of geothermal in the electricity mix | | Installed capacity (GWe) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010* | 2030*** | 2050*** | 2010** | 2020 | 2020 ( ≤200€/ MWh) | 2030 ( ≤150€/ MWh) | 2050 ( ≤100€/ MWh) | 2030 | 2050 | 2030 | 2050 |
| Growth rate(%) | | **12.59%** | **37.61%** | | | | | | | | | |
| **Austria** | 71.13 | 80.09 | 97.88 | 0.002 | 0.002 | **0.04** | **0.10** | **67.10** | 0% | 69% | 0.013 | 8.511 |
| **Belgium** | 95.12 | 107.10 | 130.89 | 0 | 0.002 | **0.00** | **0.00** | **22.28** | 0% | 17% | 0 | 2.826 |
| **Bulgaria** | 46.65 | 52.52 | 64.20 | 0 | 0 | **0.04** | **0.10** | **71.66** | 0% | 112% | 0.012 | 9.089 |
| **Cyprus** | 5.35 | 6.02 | 7.36 | 0 | 0 | **0.00** | **0.00** | **0.00** | 0% | 0% | 0 | 0 |
| **Croatia** | 14.1 | N/A | N/A | 0 | N/A | **0.00** | **3.00** | **49.97** | N/A | N/A | 0.381 | 6.338 |
| **Czech Republic** | 85.91 | 96.73 | 118.22 | 0 | 0.002 | **0.01** | **0.04** | **30.68** | 0% | 26% | 0.005 | 3.891 |
| **Denmark** | 38.79 | 43.67 | 53.38 | 0 | 0 | **0.00** | **0.03** | **29.43** | 0% | 55% | 0.004 | 3.732 |
| **Estonia** | 12.96 | 14.59 | 17.83 | 0 | 0 | **0.00** | **0.04** | **1.67** | 0% | 9% | 0.005 | 0.212 |
| **Finland** | 80.67 | 90.83 | 111.01 | 0 | 0 | **0.00** | **0.00** | **0.00** | 0% | 0% | 0 | 0 |
| **France** | 569 | 640.64 | 783.00 | 0.153 | 0.475 | **0.01** | **0.39** | **653.02** | 0% | 83% | 0.049 | 82.828 |
| **Germany** | 627.92 | 706.97 | 864.08 | 0.027 | 1.654 | **0.28** | **1.37** | **345.59** | 0% | 40% | 0.173 | 43.834 |
| **Greece** | 57.39 | 64.62 | 78.97 | 0 | 0.073 | **0.08** | **0.47** | **81.30** | 1% | 103% | 0.060 | 10.312 |
| **Hungary** | 37.37 | 42.07 | 51.43 | 0 | 0.41 | **9.43** | **17.06** | **173.69** | 41% | 338% | 2.164 | 22.031 |
| **Ireland** | 28.61 | 32.21 | 39.37 | 0 | 0.035 | **0.06** | **0.19** | **27.26** | 1% | 69% | 0.024 | 3.457 |
| **Italy** | 302.06 | 340.09 | 415.67 | 5.632 | 6.75 | **10.86** | **12.07** | **225.83** | 4% | 54% | 1.531 | 28.644 |
| **Latvia** | 6.63 | 7.46 | 9.12 | 0 | 0 | **0.00** | **0.01** | **2.84** | 0% | 31% | 0.002 | 0.360 |
| **Lithuania** | 5.75 | 6.47 | 7.91 | 0 | 0 | **0.02** | **0.04** | **18.71** | 1% | 236% | 0.005 | 2.374 |
| **Luxembourg** | 4.59 | 5.17 | 6.32 | 0 | 0 | **0.00** | **0.00** | **2.66** | 0% | 42% | 0 | 0.337 |
| **Poland** | 157.66 | 177.51 | 216.96 | 0 | 0 | **0.00** | **0.00** | **143.56** | 0% | 66% | 0 | 18.209 |
| **Portugal** | 54.09 | 60.90 | 74.43 | 0.167 | 0.488 | **0.03** | **0.16** | **62.99** | 0% | 85% | 0.020 | 7.990 |
| **Romania** | 60.62 | 68.25 | 83.42 | 0 | 0 | **0.00** | **0.17** | **104.65** | 0% | 125% | 0.022 | 13.274 |
| **Slovakia** | 27.84 | 31.35 | 38.31 | 0 | 0.03 | **0.37** | **0.89** | **54.57** | 3% | 142% | 0.112 | 6.922 |
| **Slovenia** | 16.43 | 18.50 | 22.61 | 0 | 0 | **0.00** | **0.01** | **8.15** | 0% | 36% | 0.001 | 1.033 |
| **Spain** | 303.09 | 341.25 | 417.08 | 0 | 0.3 | **0.01** | **0.52** | **348.58** | 0% | 84% | 0.066 | 44.214 |
| **Sweden** | 148.61 | 167.32 | 204.50 | 0 | 0 | **0.00** | **0.00** | **1.03** | 0% | 1% | 0 | 0.131 |
| **The Netherlands** | 118.14 | 133.01 | 162.57 | 0 | 0 | **0.00** | **0.23** | **51.76** | 0% | 32% | 0.030 | 6.565 |
| **United Kingdom** | 381.13 | 429.11 | 524.47 | 0 | 0 | **0.00** | **0.02** | **41.81** | 0% | 8% | 0.003 | 5.303 |
| **Total EU-27 (Croatia)** | **3357.6** | **3780.33** | **4620.4** | **6.0** | **10.9** | **21.2** | **36.9** | **2620.8** | **1.0%** | **56.7%** | **4.683** | **332.418** |
| **Non-EU Country** | **Gross Electricity Generation (TWh)** | **Projected Gross Electricity Generation (TWh)** | | **Gross Geothermal Electricity Generation (TWh)** | **Geothermal Electricity Target in the NREAPs (TWh)**** | **Geothermal economic potential (TWh)** | | | **Potential % of geothermal in the electricity mix** | | **Installed capacity (GWe)** | |
| | **2010** | **2030** | **2050** | **2010** | **2020** | **2020** | **2030** | **2050** | **2030** | **2050** | **2030** | **2050** |
| **Iceland** | 17.1 | N/A | N/A | 4.5 | **5.820** | **73.00** | **73.70** | **321.89** | N/A | N/A | 9.348 | 40.829 |
| **Switzerland** | 67.82 | N/A | N/A | 0 | N/A | **0.00** | **0.00** | **42.95** | N/A | N/A | 0.0002 | 5.448 |
| **Turkey** | 229.39 | N/A | N/A | 0.7 | N/A | **14.07** | **62.31** | **965.91** | N/A | N/A | 7.903 | 122.515 |
| **Total Europe** | 3671.9 | N/A | N/A | 11.1 | N/A | N/A | 172.9 | 3951.5 | N/A | N/A | 21.9 | 501.2 |

*Source: Eurostat; **Source: National Renewable Energy Action Plans; ***Source: CPI Scenario of the Energy Roadmap 2050 for the EU-27; Breakdown at national level based on average trends observed at EU level;****Source: GEOELEC resource assessment

# ANNEX IV THE GEOELEC CONSORTIUM

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|---|
| European Geothermal Energy Council (EGEC – BE) |
| Bureau De Recherches Géologiques Et Minières (BRGM – FR) |
| Centre For Renewable Energy Sources And Saving (CRES – EL) |
| Consiglio Nazionale Delle Ricerche, Istituto Di Geoscienze e Georisorse (CNR-IGG – IT) |
| Asociacion De Productores De Energias Renovables (APPA - ES) |
| Gaßner, Groth, Siederer & Coll. (GGSC – DE) |
| EnBW Energie Baden-Württemberg (AG EnBW – DE) |
| Mannvit (IS) |
| Helmholtz Zentrum Postdam – Deutsches Geoforschungszentrum (GFZ – DE) |
| Nederlandse Organisatie Voor Toegepast Natuurwetenschappelijk Onderzoek (TNO – NL) |