TECHNISCHE
UNIVERSITÄT
WIEN
Vienna University of Technology

Diplomarbeit

Potential and Costs of Geothermal Energy

With particular Interest on District Heating

ausgeführt zum Zwecke der Erlangung des akademischen Grades eines

Diplom-Ingenieurs

unter der Leitung von

Univ.-Prof. Dipl.-Ing. Dr. Reinhard Haas
(E370-3 Institut für Energiesysteme und Elektrische Antriebe – Energy Economics Group)

Dipl.-Ing. Dr. Gustav Resch

(E370-3 Institut für Energiesysteme und Elektrische Antriebe - Energy Economics Group)

eingereicht an der Technischen Universität Wien

Fakultät für Elektrotechnik und Informationstechnik

von

Carlo Danese

1229311 (066 506)

Palermostraße 17

39100 Bozen, Italien

Wien, im September 2016

Carlo Danese

TECHNISCHE
UNIVERSITÄT
WIEN
Vienna University of Technology

Ich habe zur Kenntnis genommen, dass ich zur Drucklegung meiner Arbeit unter der Bezeichnung

Diplomarbeit

nur mit Bewilligung der Prüfungskommission berechtigt bin.

Ich erkläre weiters Eides statt, dass ich meine Diplomarbeit nach den anerkannten Grundsätzen für wissenschaftliche Abhandlungen selbstständig ausgeführt habe und alle verwendeten Hilfsmittel, insbesondere die zugrunde gelegte Literatur, genannt habe.

Weiters erkläre ich, dass ich dieses Diplomarbeitsthema bisher weder im In- noch Ausland (einer Beurteilerin/einem Beurteiler zur Begutachtung) in irgendeiner Form als Prüfungsarbeit vorgelegt habe und dass diese Arbeit mit der vom Begutachter beurteilten Arbeit übereinstimmt.

Wien, im September 2016

Carlo Danese

Questa tesi è dedicata a mia madre.
Non preoccuparti per noi,
ce la caveremo.

"Vale più un'acqua di Maggio e due d'Aprile che non questo tuo carro trionfale"	*"Tis' more valuable May's fall and twice in April than this triumphant chariot of yours"*
IL CARRO DI RE GUIDONE	THE CHARIOT OF KING GUIDONE

Abstract

The aim of this thesis is to provide a general overview of potential and costs of electricity and heat generation from geothermal energy in Europe, with particular interest on the potential of district heating.

The approach taken includes a literature survey, expert interviews and detailed complementary bottom-up modeling to accomplish data lacks identified throughout the literature survey.

This thesis provides a synthesis of different data and estimations from different specialized reports and researches concerning the potential for geothermal energy supply and use in Europe. Both district heating and electricity generation have been considered for a broad set of European countries, including the EU28 and focal countries outside the EU.

For what concerns the estimation of the district heating potential from geothermal energy in Europe, the existent (i.d. viewed) literature considers only a portion of the European countries. The evaluation has been expanded to the whole continent throughout a graphic and analytic process based on a temperature map provided by the GeoELEC Project.

The results and data have been compared in order to have a broader and more consistent view of the geothermal energy potential in Europe.

The analysis of the costs of a district heating system powered by geothermal energy has been made with the help of specific case-studies made in different countries.

The potential and the costs of the electricity generation from geothermal energy were, in the considered literature, already strictly related, and so they have been reported in this thesis.

The results, especially for the heat generation potential, are astonishing: almost every European country possesses a geothermal energy potential already at 1000m depth. The potential increases with deeper depths and with them, in general, the costs sink. In fact, in comparison to a resource at 60°C located at 1km depth, one just 20°C warmer located at 2km depth is more economically valuable. The total potential of the 30 analyzed territories accounts for 1428TWhth. The actual European heat generation from geothermal energy is around 14TWhth.

Considering only the electricity generation, the amount of electricity potential producible with power plants powered by geothermal energy is above 4000TWhe. If we think that the electricity demand of the EU28 in 2050 will be around 4300TWhe (countries like Turkey and Iceland aren’t included in the calculation), it becomes clear how the geothermal energy could play a key role in the future energetic paradigm.

Kurzfassung

Ziel dieser Arbeit ist die Erstellung einer allgemeinen Übersicht über Potenzial und Kosten der geothermischen Strom- und Wärmeerzeugung in Europa mit Schwerpunkt auf Fernwärme.

Als Methode wurde eine Recherche der Fachliteratur, Interviews mit Experten und ergänzende Bottom-Up Modellierung zur Potenzialabschätzung im Falle von Datenlücken.

Diese Diplomarbeit bietet folglich eine Synthese verschiedener Daten und Schätzungen aus diversen facheinschlägigen Berichten und Untersuchungen des Potenzials für geothermische Energieversorgung in Europa. Sowohl Fernwärme- und Stromerzeugung wurden für ein breites Spektrum an europäischen Ländern berücksichtigt, einschließlich den Mitgliedsstaaten der EU sowie Schwerpunktländern außerhalb der EU.

Hinsichtlich des geothermischen Fernwärmepotenzials innerhalb Europas war festzustellen, dass die die bestehende Literatur nur einen Teil der europäischen Länder abdeckt. Es wurde folglich eine ergänzende Modellierung unter Anwendung grafischer, statistischer und analytischer Verfahren entwickelt, wodurch auf Basis einer im Rahmen der GeoELEC Studie ermittelten geothermischen Temperaturkarte die Potenzialabschätzung auf den gesamten Kontinent erweitert werden konnte. Eingangsdaten und Ergebnisse wurden schließlich verglichen, um eine breitere und konsistente Sicht auf das geothermische Energiepotenzial in Europa zu haben.

Die Analyse der Kosten geothermischer Fernwärmebereitstellung wurde auf Basis spezifischer Fallstudien gemacht, wobei verschiedene Länder betrachtet wurden.

Das Potenzial und die Kosten der Stromerzeugung aus Geothermie waren in der betrachteten Literatur bereits gut erfasst, folglich erfolgte im Rahmen dieser Arbeit eine vergleichende Überblicksdarstellung bestehender Ergebnisse.

Die Ergebnisse, vor allem im Hinblick auf die mögliche Wärmeerzeugung, sind erstaunlich: Fast jedes europäische Land besitzt ein geothermisches Energiepotenzial bereits in 1000 m Tiefe. Das Potenzial steigt in der Regel mit zunehmender Tiefe während die spezifischen Kosten sinken. So zeigt der Vergleich einer geothermischen Wärmequelle von 60° C in 1km Tiefe mit einer um 20° C wärmeren in 2km Tiefe im Regelfall eine höhere Wirtschaftlichkeit für die tiefere bzw. wärmere Ressource. Das Gesamtpotenzial der 30 analysierten Länder beträgt 1428 TWhth, während die bestehende europäische Wärmeerzeugung aus Geothermie bei 14 TWhth liegt.

Wenn wir nur die Stromerzeugung berücksichtigen, liegt das Potenzial geothermischer Kraftwerke innerhalb der EU bei rund 4000 TWhe. Wenn wir dies mit der im Referenzfall erwarteten Stromnachfrage vergleichen, welche im Jahr 2050 bei in etwa 4300 TWhe liegen würde, wird deutlich, welche Schlüsselrolle die Geothermie in der Zukunft im energetischen Paradigma spielen könnte. Es sei abschließend erwähnt, dass Länder mit hohem geothermischen Potenzial, wie etwa die Türkei und Island, in diesem simplen Vergleich nicht berücksichtigt wurden.

Aknowledgments

This project would not have been possible without the support of many people. Here I want to thank my adviser Univ. Prof. Dipl. Ing. Dr. Reinhard Haas and my tutor Dipl. Ing. Dr. Gustav Resch, who helped make some sense of the confusion. A precious help has been gently offered me by the Head of Policy & Regulation of EGEC Luca Angelino and Prof. Francesco Rizzi of the University of Perugia. Also thanks to my class mates Mahfoud and Xavi, with whom I sailed from the very beginning of this journey.

A very special thanks goes to my closest and old friends in Italy and to the equally close but much newer friends in Vienna, for those the saying “at last but not least” has been coined. Both offered me an arm before I even asked for a nail. Their help will not be forgotten.

Nothing of this would have ever been thinkable without the help - material and spiritual - of my family, which understanding is far beyond my comprehension.

1 Introduction

The need of a warm place is an issue faced by the humanity since the dawn of the civilization. In the modern days in Europe 50% of the consumed energy is used in the residential and industrial heating sector and 80% of it exploits non-renewable resources (vs. 94% worldwide) – like gas, oil and derivates - emitting yearly X tons of greenhouse gasses (GHG). We may say heating is one of the leading concauses of global warming.

In the last decades the European population became aware of the consequences that the actual energy's paradigm might have in the near future, and in 2005 their governments reacted through the European Commission concurring a mutual energy policy apt to reduce GHG emissions in the coming years, promoting a faster insertion of renewable resources in the energy market and a more efficient use of fossil fuels.

Yet in the past decades and in particular after the oil crisis in the ‘70s, the need of a better controlled and efficient heating system led some European countries to begin developing a District Heating system (DH), distributing heat on a large scale by burning fossil fuels.

Along with District Heating, geothermal energy is a renewable resource particularly adapted – but not only - to provide hot water for Heating and Cooling (H&C) of residential and commercial spaces on a large scale, with very limited GHG emissions.

However, how many people could use geothermal DH? For what concerns the European Union, the existing literature provides an estimation of the population’s proportion suitable with geothermal District Heating only for a part of the member countries: objective of this thesis consists to extend these estimations to the whole European Union, including Iceland, Turkey and Norway, implementing a methodology similar to the one used in literature.

Furthermore, geothermal energy has in common with other renewable resources the question of the costs, generally higher than the traditional sources. Some case studies will be reported in this thesis in order to get a general idea of the geothermal heating costs.

Even though this thesis is focused on the heating and cooling sector, since the electricity generation represents an important part of the geothermal energy's panorama, the last chapter of this thesis has been saved for a brief overview on power plants.

1.1 Structure of this Thesis

The structure of this thesis tries to reflect the nature of the geothermal energy itself: beginning from the mere physical and geological proprieties of the earth's underground up to the electricity's costs in the energy market.

In the first chapter are explained the general characteristics of the geothermal reservoir, valid for every type of deep geothermal system. After that this thesis has been subdivided into two great chapter: *Geothermal District Heating* and *Geothermal Electricity Generation*, which are, from the commercial point of view, the two main sectors where the geothermal plants operate. The geothermal District Heating part is subdivided itself into two chapters: *Potential* and *Costs*. For the first one, this thesis provides an estimations of the amount of energy potentially producible in the future. The second one (Costs) consists in an investigation of different case-studies trying to give a consistent idea of which are the costs of a geothermal plant. For what concerns the power plants, the literature considered the potential in Europe bound to the price (i.e. cost) of the electricity produced. In other words, the study analyzed the amount of electricity producible within certain cost-range. Therefore potential and costs analysis have been reported at the same time in the same chapter.

Within the literature, some assumptions have been founded discordant: when possible all of them have been reported.

1.2 General Information on Geothermal Energy Use: Type of Resources, Factors and Technologies

The Earth's crust is a 4 to 50km thick rocky substrate surrounding the mantle. Particular geological conditions lead to have heat transferred from the deepest layers of the crust towards the Earth's surface. When these circumstances occur, we have an unusual hot substrate more or less close to the surface, causing a certain unusual high thermal gradient, which could be then exploited by a well taking the heat from the deep underground to the surface. Many factors affect the actual exploitability of a geothermal reservoir. The first one is the underground's geology (i.e. in what kind of material consists the reservoir/media): Geothermal energy can be stored as Hot Dry Rock (low permeability and little liquid's presence, the so called *conductive systems*), trapped in vapors or liquids (*convective systems* or - from now on - *Hydrothermal*) or in *Deep Aquifers* (which contains circulating fluids in porous media or fractured zones at depth typically greater than 3km).

In order to extract hot fluids from the underground, they must be allowed to flow throughout the underground and collect into the well. The underground should be then *permeable*. Another very important factor is the temperature of the reservoir: normally a resource is divided into three categories based on their temperature: Low, Medium and High Enthalpy. The Low Enthalpy goes from 50-60°C to 80°C, the Medium Enthalpy from 80°C to 150°C and the High Enthalpy from 150°C to 390°C. Resources with higher temperature (>390°C) are called Supercritical unconventional and there are limited to volcanic areas[1]. Typically, direct use[2] of geothermal energy needs Low and Medium Enthalpy resources, while power plants need Medium or High Enthalpy.

When both conditions, sufficient rock permeability and hot water/steam, naturally occur, we have an Hydrothermal, Sedimentary Resource or a Deep Aquifer, which are similar to the geological formation of oil and gas and also exploitable with similar well-known and experienced technologies. The traditional way to exploit geothermal energy wants these very aforementioned typologies of resources: once the well has been drilled (Figure shows a typical drill rig setup), the geo-pressured deep aquifer system floats throughout the well towards the surface without artificial lifts.

---

[1] EGEC, et al., *GeoELEC Report*, 2013, p.11, from now on cited as *GeoELEC*.

[2] With *direct* use of geothermal energy are implied all uses where the energy contained in hot water or steam is not transformed in other forms but heat. This means space heating, greenhouses, spa and baths.

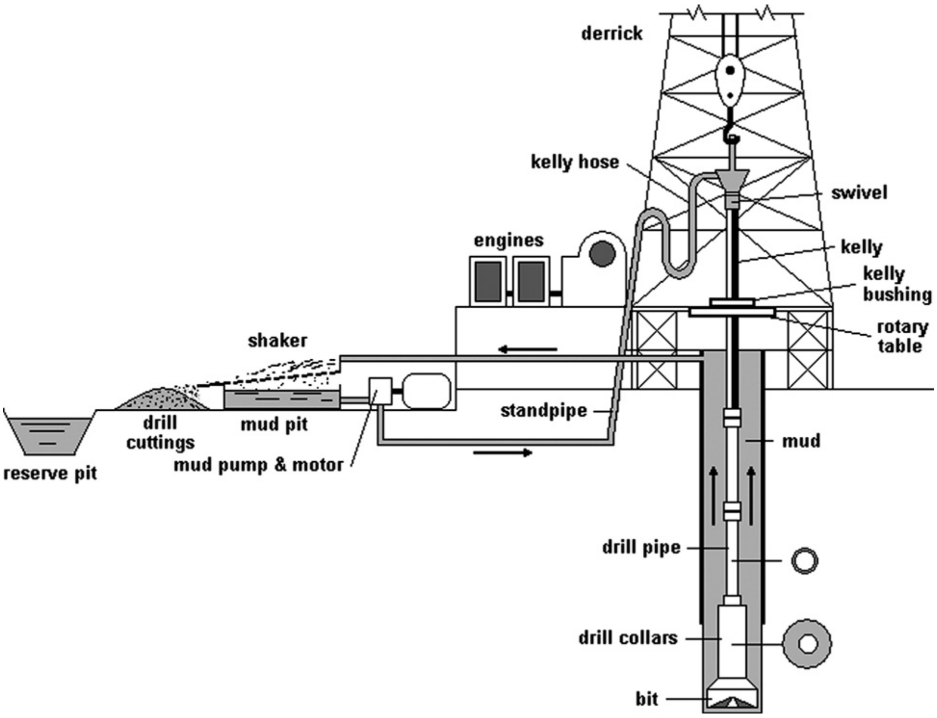


Figure 1 Typical drill rig setup. (source: OECD/IEA, Technology Roadmap: Geothermal Heat and Power, Paris 2011)

At this point it’s understandable how the natural presence of a geothermal fluid is essential to exploit geothermal energy. Therefore, if no fluid is available, the reservoir needs to be *enhanced*, becoming an *Enhanced Geothermal System* (EGS).

If the rock isn’t sufficient permeable or contains too little fractures, not enough water or steam can be contained and therefore the resource isn’t naturally exploitable (i.e. there is no fluid to extract, or the production is not high enough to be commercially affordable). This resource needs then particular measures in order to allow the extraction of the geothermal heat. The concept of EGS is simply explainable through the following points:

- The reservoir needs to have natural fractures
- Enlarging permeability through stimulation
- Installing a multi-well system
- Forcing water through the fractures

These characteristics can be particularly found in the Hot Dry Rock typology. Since Hot Dry Rock accounts for the majority of the geothermal energy resources all across the world[3], a technology capable to exploit it economically and with little environment's side effects would lead to an important step ahead in the geothermal energy sector.

This field is currently under research and a few different technologies are now in the development phase. The EGS is one of the most credited to become in the future the keystone of the geothermal panorama. The concept and it basically consists in a hydraulic stimulation of the rock that creates or widens fractures, increasing permeability, procedure that in certain circumstances can be similar to the *fracking* in the fossil fuel's field. A fluid will be injected into the soil by an injection well and then re-extracted by a second – or multiple - one (Figure 2).

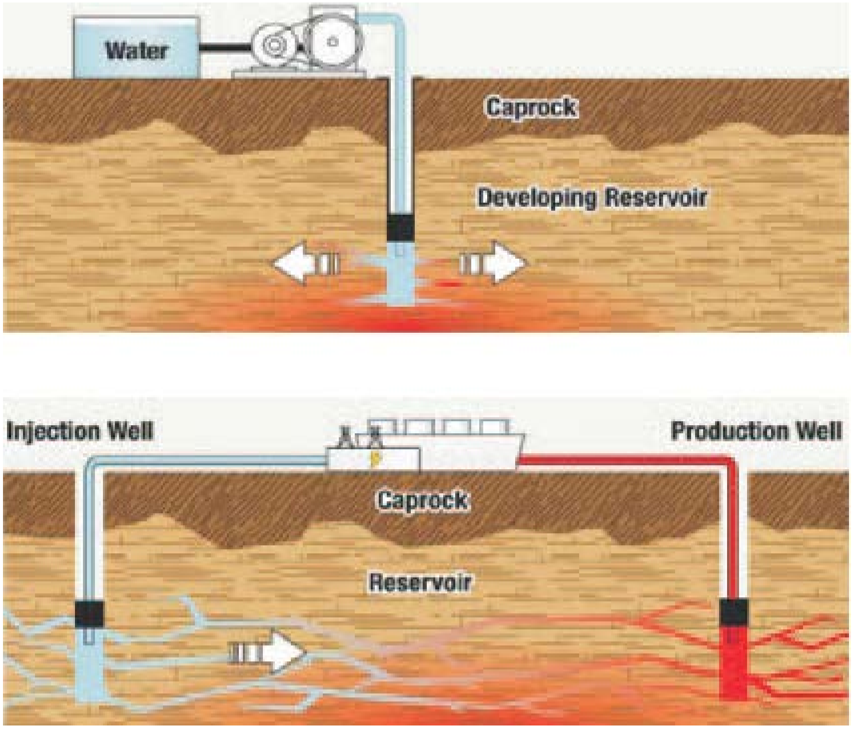


Figure 2 Two important steps in EGS. Above: hydraulic stimulation causes fractures in the rock. Under: Water is injected by the injection well and then extracted (warmer) by the production well (source: Office of Energy Efficiency and Renewable Energy (EERE), US Department of Energy)

---

[3] Goldstein, B., at. Al, "Geothermal Energy", *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* (O. Edenhofer et. Al), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2011, p. 408, quoting: "Stored thermal energy down to 3km depth on continents was estimated to be 42.67 10^6 EJ, consisting of 34.14 10^6EJ (80%) from hot dry rocks (or similar) and 8.53 10^6EJ (20%) from hydrothermal resources.

Underground's stimulation raises also some concerns due to the increasing risk of micro-seismic activity intense enough to be felt on the surface, even if the relation isn't yet completely proved and studied.

EGS has high investment costs, partially due to the fact that it's still in its initial phase[4], but also because the technology itself needs expensive infrastructures, peculiarity that will remain in the operational phase as well, compromising the application of it in those sectors, where a cheap exploitation is preferable, if not mandatory (DH is one of these). At the time there are no cases of EGS developed for DH plants, but even though the direct application of underground's stimulation seems unfeasible, an implementation of it in Cogeneration Heat and Power plants (CHP) could have better chances, exploiting basically heat that otherwise would be wasted[5]. About that the International Energy Agency[6] (IEA) says: "The feasibility of creating and building a combined heat and power EGS plant needs to be demonstrated, as this will also open up a promising market for replacing fossil-fuelled, district heating boiler plants with geothermal heating plants."

For what concerns the electricity generation, some small power plants using EGS are already built or under construction/investigation in France and Germany.

An important particular factor for geothermal DH is the location of heating and cooling demand: if power plants can be located nearly everywhere, generating electricity as cheap as possible and then put it into the grid even hundreds of kilometers far from the demand, heat plants must be placed near the costumers, because heat can't be transported for long distances without great amount of losses. This leads to the necessity to find a reservoir not only commercially and technically feasible, but also close to inhabited centers. This rises further problems, questions and factors, turning the estimation of DH into a much more tangled issue.

---

[4] Each new installation drops the investment costs by 20%

[5] According to Francesco Rizzi, Assistant Professor *by Scuola Superiore Sant'Anna di Pisa* (Sant'Anna School of Advanced Studies in Pisa, Italy). Rizzi has been interviewed on October 5th, 2015 in Pisa and after that via email.

[6] OECD/IEA, *Technology Roadmap: Geothermal Heat and Power*, Paris, 2011, p.27

2 Geothermal District Heating

2.1 What is District Heating?

District Heating (DH) is a heating system where the heat generator is located away from the consumer and the thermal vector is piped into a distribution grid. In this thesis is treated a specific type of DH: the heat generation exploiting geothermal energy; but these principles are applied to other resources as well, such as fossil fuels, biomasses and solar energy.

The other typical and more used heating system is the Individual Heating (IH), where every user has its own boiler located inside the building or house. Of course, there are benefits in both heating system, although since the oil crises in the ‘70s, many countries decided to invest more capitals in development of DH systems, driven by the necessity to increase the efficiency of their national heating systems and automatically decrease their energy-foreign-dependency-grade. Whatsoever the advantages of DH are not limited to energy efficiency: first of all the facilities operate on a large scale and in concentrated area, normally outside (even though close to) inhabited centers, limiting the air-pollution in highly populated areas and facilitating the installation and maintenance of pollution prevention equipment. There are also some more user-centered advantages such as the low maintenance needed (by costumers), the always available hot water (some boilers need a preheating), the absence of noise and vibration during operation and in particular an higher safety of the system because neither gas pipes nor burners are needed in the buildings, with a consequential reduction of insurance quotes.

2.2 State of the Play

Direct use of geothermal heat has various applications: agriculture, industry, balneology and space heating and cooling. Globally, in the field of space heating, geothermal energy is principally exploited by heat-pumps (49%), by spa and baths (25%) and by District Heating (12%). (OECD/IEA, 2011)

There are 247 (2014 data) geothermal DH plants (including co-generation systems) in the European continent. The total installed capacity amounts now to 4.5 GW_{th}, producing in 2012 13TWh[7]. 162 geothermal DH plants are located in European Union, with a total installed capacity of 1.3 GW_{th} and 4256 GWh (365ktoe) produced. Figure 3 shows the total installed capacity for DH in Europe.

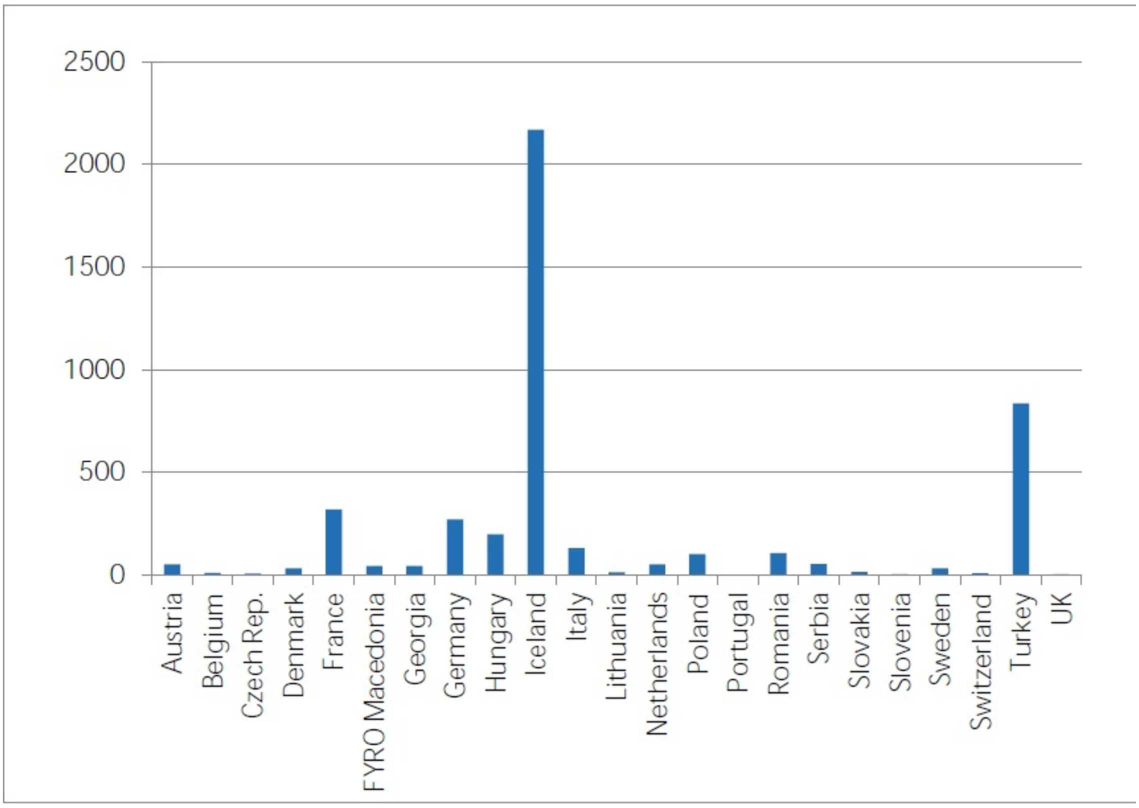


Figure 3 Geothermal DH capacity installed in Europe, per country in 2014 [$MWth_{th}$] (source: EGEC Market Report)

In Europe the geothermal DH situation changes strongly from country to country, due to a different morphology of the underground and past energy policies.

Geothermal temperature above 70°C can produce chilled water in sorption chillers, which can be piped through the same DH system used for heating purposes. And provide cooling instead of heating.

In 2013 the total installed capacity of direct use (all applications included) of geothermal heat in the European Union was 2865.7 MW_{th}, producing up to 7873GWh_{th} (677ktoe)[8]. This means that more than a half of the geothermal thermal energy in EU is used for District Heating.

---

[7] Angelino, L., P. Dumas, A. Latham, *EGEC Market Report 2013/2014*, 2013. From now on cited as *EGEC.*

[8] EurObserv'ER, *The State of Renewable Energies in Europe*, 2014

2.2 Geothermal District Heating – State of the Play

District Heating is the geothermal sector currently with the most dynamic development and the most interesting perspective in the coming years (Angelino, 2013). The direct use of geothermal energy and the geothermal energy for space heating and cooling (H&C) through a distribution network need reservoirs at a lower temperature compared to electricity generation purposes. The thermic energy's need for household could be further decreased by appropriate efficiency measures, such as better insulation and installation of floor heating, which allows the same heating power with lower temperature (thanks to the much bigger exchange surface). In case of medium/high temperature resource, the heat can be used also for "process purposes" such as biorefinery. This leads to the possibility to have a *cascade utilization* of the geothermal energy: under particular circumstances (appropriate enthalpy and demographic/economic conditions) the heat can be first used as source for electricity generation (at its higher temperature, typically above 150°C - 200°C), then for households' heating and cooling (60°C -70°C) and afterwards heating greenhouses, spa or baths (20°C -30°C).

Normally an underground's temperature of 60-100°C is enough in order to cover the household demand, however, as showed in Figure 4, at 2000m depth the potential is discontinuous and it's easy to note that, even if there is potential in every European country, only a portion of its population lives in areas that can be supplied by geothermal district heating (the green ones). Whatsoever, underground's temperature increases with depth (Figure 5).

The existing literature about the potential for geothermal district heating in Europe covers 14 European countries[9]. The main objective of this thesis is to combine the information provided basically by two different reports and extend this coverage to the whole European Union and relevant neighboring countries (Iceland, Turkey) with respect to geothermal energy.

---

[9] Here has been considered as source: Dumas, P., A. Bartosik, (EGEC), *GeoDH: Geothermal DH Potential in Europe*, November 2014. From now on cited as *GeoDH*.

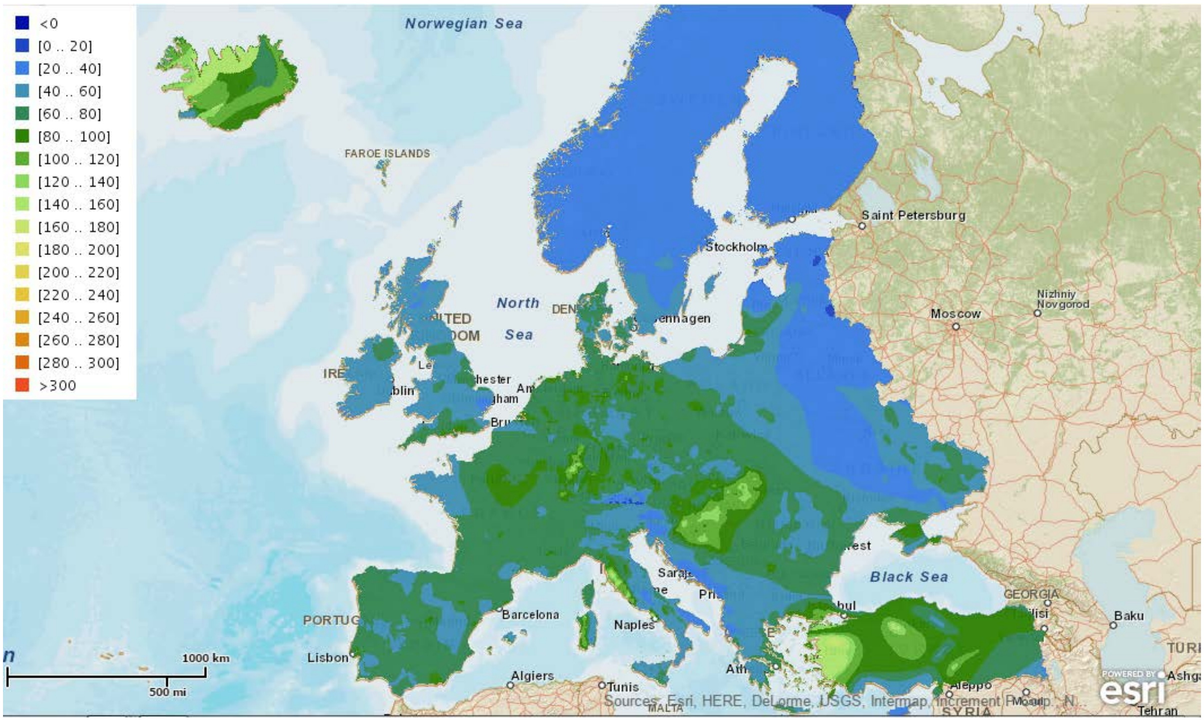


Figure 4 Model temperature at 2000 m depth (source: GEOELEC Viewer)

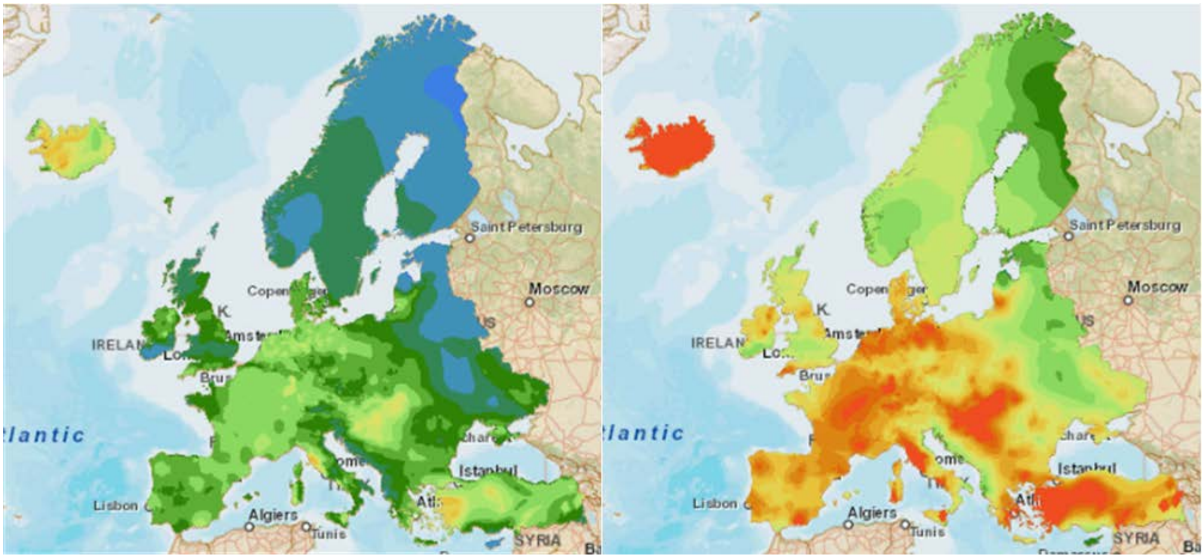


Figure 5 Model temperature at 4000 and 10.000 m depth (source: GEOELEC Viewer)

2.3 Methodology: Details on the Approach used for this Assessment

The assessment of geothermal potential of district heating in Europe is divided in two parts, according to two different methods:

1. According to GeoDH’s results

2. Own modeling, built on the combination of GeoELEC's results with other data, such as population density and NUTS3 regions

2.3.1 The GeoDH report

For what concerns the GeoDH report, it provides a percentage of a country's population which could be supplied by geothermal district heating. The assessment is calculated considering and combining the deep geothermal potential and the existing heating demand: a geothermal resource can be exploited for direct use purposes only if nearby an heat demand already exists. So if a huge amount of geothermal energy is available, but the heating demand of the considered region is low, the potential will be low as well.

2.3.2 The GeoELEC report

The principles explained in the previous paragraph have been applied to a part of the results of the GeoELEC project.

The GeoELEC project has been thought for the assessment of the geothermal energy's potential focused on electricity generation only, however one of its outputs is an interactive map showing the course of the underground's temperature at multiple depths, without referring the geology of the basin. As done by GeoDH, objective of this research is to combine these geographical data with heating and cooling demand and calculate the potential of the remaining European countries.

The difficulty to obtain and directly analyze the original data behind the map elaborated by GeoELEC (i.e. metadata and GIS-data) led to a graphically less accurate analysis, but with equal weight when it comes to the necessity of getting an idea of the issue.

The graphic software used in this thesis allows a qualitative and quantitative investigation of an image or parts of it of any shapes through the analysis of its histogram[10].

---

[10] An histogram is a graphic representation of the distribution of numerical data, in this particular case colors of the temperature model comprehended within a region's borders.

The histogram's analysis permits the quantification in pixels of any color included in the specified NUTS3[11] region (and its proportion to the total). Since every color corresponds to a certain range of temperature, knowing the percentages of every color means knowing the territory's portion, that lays on a certain temperature.

This method calculates with good approximation (the resolution of the temperature model is 2km^2) the percentage of territory laying above a certain temperature. In reality there are some zones where the geothermal resource is practically impossible[12] to exploit and other zones that lay within the radius reachable with DH, even though they do not lay geographically on a geothermal resource. However, these errors partially compensate each other.

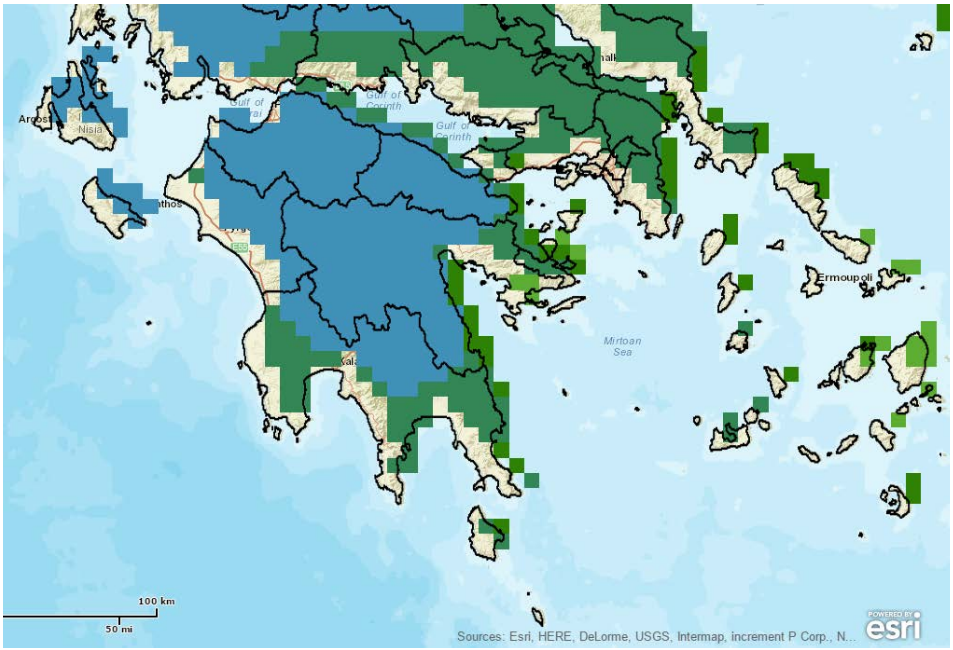
Another systematic error of this approach appears converting the area's percentage into a population's percentage: this would be theoretically valid only if the population was equally distributed on the territory's surface, condition that, of course, never shows up. Anyway, small regions (like those of Belgium, but it's a condition valid for the overwhelming majority of European regions) tend to comprehend a demographic sample more uniform than the larger ones, leading to smaller errors of this kind. Countries with large regions (like Iceland) have their estimations significantly deviated from reality.

Another issue encountered during this analysis' procedure, related partially with the temperature model's resolution and partially with imperfections of the GeoELEC model, is the not perfect overlap of the raster's layer and the temperature model's layer for countries with coastlines (Figure 6).

---

[11] *Nomenclature des Unités Territoriales Statistiques* or *Nomenclature of Territorial Units for Statistics*. Is an EU geocode standard for referencing the subdivisions of countries for statistical purposes. The average size of the NUTS3 regions shall lie within 150 and 800 thousand people.

[12] Not particularly for the reasons explained in Chapter *1.2 General Information on Geothermal Energy*, moreover if the resource is located under a very high residential area or in any place where the construction of a geothermal facility is impossible.



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., N...

Figure 6 Composition of NUTS3 raster and model temperature at 2km depth of Peloponnese, Greece (source: GeoE-LEC Viewer)

In this case the shape of the country and the perimeter of the model do not coincide. The presence within the country's borders of any colors apart the ones referred to the temperature model would affect the regions' histogram and therefore the calculations and potentials' estimations. In order to prevent that, the model has to be translated manually until it better fits its borders and then, if there are still zones with no temperature indications, the model has to be extended until it fills the whole territory (Figure 7 and 8), trying as much as possible to follow the trend of the model.

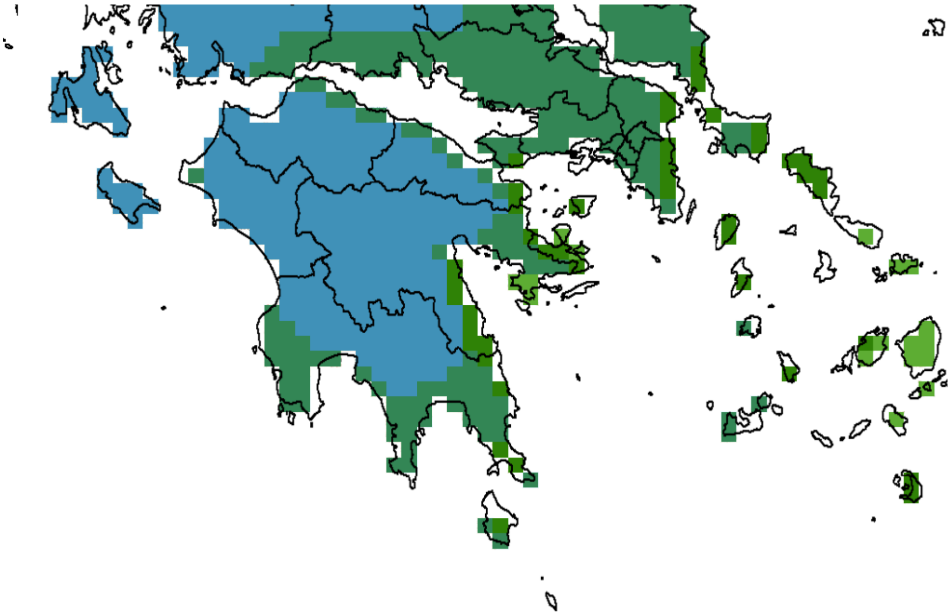


Figure 7 The temperature model has been translated in order to fit better its borders

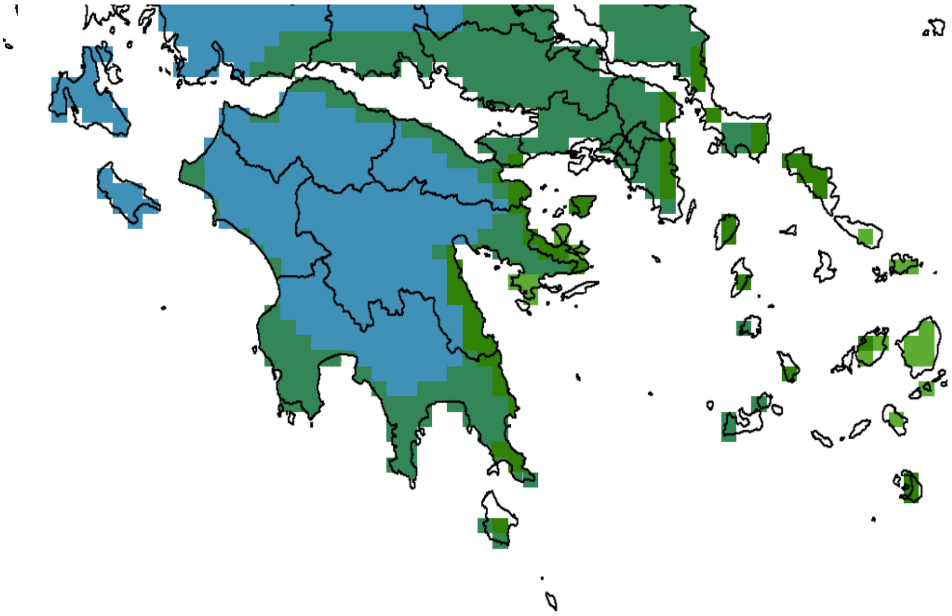


Figure 8 The model has been manually extended in order to fill its borders

2.3.3 Considerations about the expected results

Thus, the method used in this thesis considers as a geothermal reservoir all the fields with a temperature higher than 60°C at 1km and 2km depth and higher than 80°C at 2km depth, with no mention of the geology of the media, which could be more or less effectively exploitable with current or future technologies. On the contrary, the geology of the reservoir has been taken under consideration in the GeoDH's assessments, where only the geothermal energy in Hydrothermal or Deep Aquifers has been considered. The results of the aforementioned methods will then lead to different estimations if applied to the same country (as it can be seen in chapter 2.4 *Comparison between the Two Methods*), although it is not strictly necessary, considering that a country's reservoirs could be only (or by the overwhelming majority) Hydrothermal and/or Deep Aquifers. A good example of this case is represented by the Hungarian geological situation.

However, with the current technology the following results are unlikely and way above the actual amount of geothermal energy technically and economically exploitable. But if they aren't exploitable now, this doesn't mean they aren't exploitable in the future: IPCC SRREN provided a worldwide scenario which assumes that "hot rock technology becomes commercially viable soon after 2030. Under this assumed condition, the utilization of heat from deep rock formations should theoretically become possible wherever rock temperatures and the properties of the underground allow the economic sale of energy" (Goldstein, 2011)

Furthermore GeoDH used as source for Heating and Cooling demand a GIS-model, (its graphic representation is reported in Figure 9) and therefore it is not affected by the previously mentioned issues encountered and their consequential systematic errors.

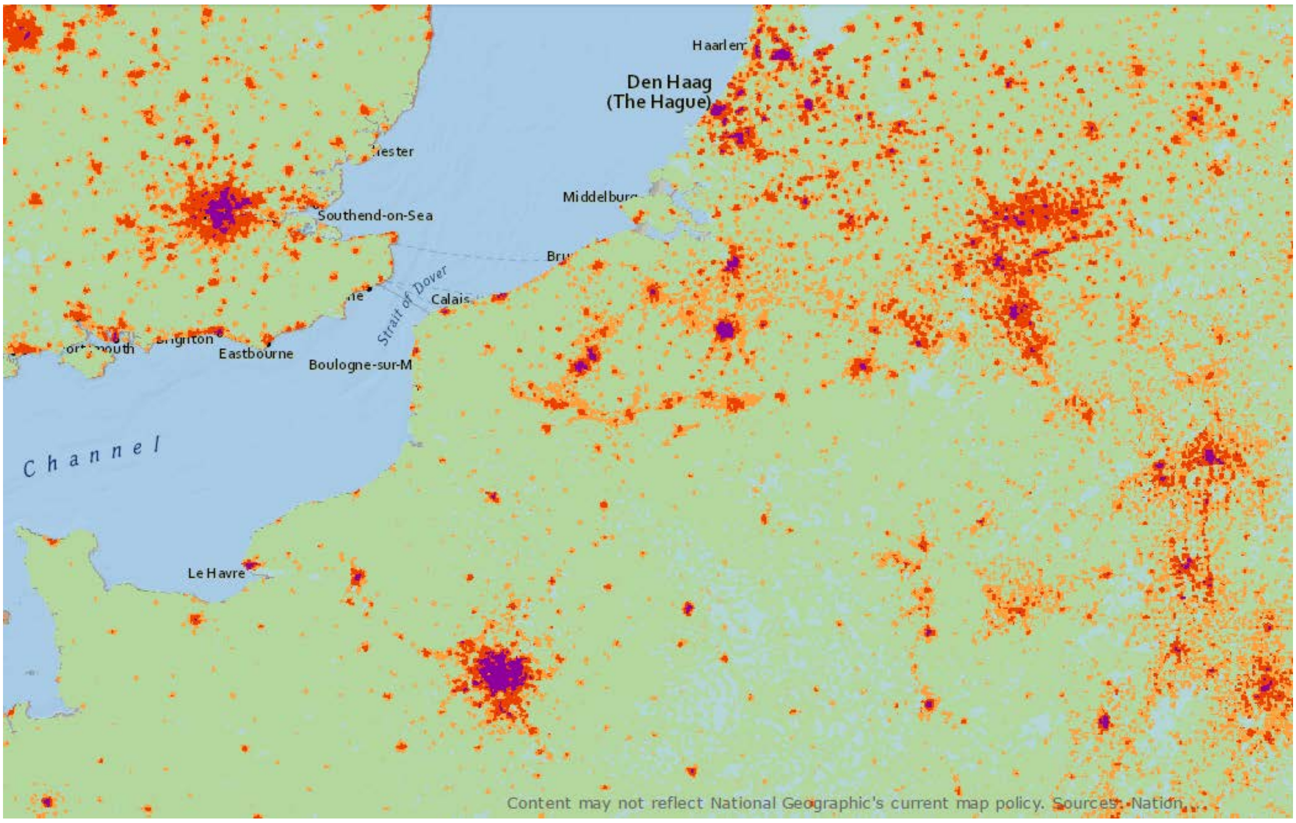


Figure 9 Graphic representation of H&C demand used by GeoDH. Here are viewable London, Paris, the Nederlands, Belgium and part of Germany.

2.3.4 Further Information

The total potential in GWh and ktoe[13] is calculated multiplying the population's potential percentage covered by geothermal district heating at different depths and the forecasted H&C demand in year 2050[14].

$$Potential = H\&C\ Demand\ \cdot \%\ of\ Population\ Covered$$

Needless to say, this kind of approach to assess the country's heating and cooling potential needs a further certain grade of approximation, not considering that the heating demand fluctuates within a country, depending on different factors such as altitude, latitude, proximity of seas, big lakes or mountains. Therefore the average temperature

---

[13] 1ktoe equals 11.63GWh.

[14] According to *Reference Scenario PRIMES 2013*. The relevant values are reported in annex.

and its consequent H&C demand is different in Milan and in Naples, even though in this thesis have been considered equal. Furthermore, the different typologies of the demand – the importance of this factor has been already mentioned – is *not* evaluated as well.

Aside from that is the situation of Iceland. Since it is not a member of the EU, is not mentioned in the reference scenario PRIMES 2013, although it provides its CPR and NREAP to the European Commission. The Heating and Cooling demand in year 2050 has been calculated starting off these documents.

According to the Icelandic NREAP, the gross H&C demand should constantly and linearly increase between 2005 (reference year) and 2020. A linear interpolation between 2005 and 2050 results in 1129ktoe of H&C demand.

According to Orkustofnun – the National Energy Authority - space heating demand in 2050 should increase by 50% respect to the year 2012, taking the heating demand up to 1131ktoe[15].

The H&C demand of Iceland in 2050 will be then considered of 1130ktoe.

Turkey is another important player in the field of geothermal energy, however, since it is not a member of the European Community, its data in terms of Heating and Cooling consumptions are not reported along the other member states. The Turkish economy is also in rapid growth and this could affect the following assumptions.

According to OeEB[16] the residential sector of Turkey demanded 1185PJ (329TWh) in 2008 and will demand 2000PJ (555TWh) in 2020. 75% of the residential consumption is reported to be for heating and cooling purposes. This would lead to 416TWh$_{th}$ of heating and cooling demand in 2020. Since no further study has been founded concerning the future scenario of the Turkey's heating and cooling demand, and the par-

---

[15] According to the Icelandic CPR 2013, the H&C sector is covered 96% by geothermal energy accounting for 724ktoe, which results in 754.2ktoe of gross H&C demand.

[16] Allplan GmbH for OeEB, Österreichischer Entwicklungsbank AG, *Energy Efficiency Finance,"Task 1 Energy Efficiency Potential, Country Report: Turkey"*, in cooperation with Frankfurt School and local partners, Vienna, November 2013.

ticularly growing economy, the reference year, instead of 2050 as for the other states, will be here 2020.

2.4 Comparison of the Two Methods

In order to see how the results of this approach are accurate and how much the two methods diverges, the method used in this thesis has been applied on two countries already partners of the GeoDH project. The two countries selected for this comparison are the Czech Republic and Slovenia.

According to GeoDH (for more details see respective chapters) 10% of the Czech population is suitable for district heating with temperature comprehended between 60°C and 100°C at a depth of 2000m. In Table 1 is shown the portion of area/population for each NUTS3 region estimated with this thesis' method. The results are that no population is suitable with a temperature of 60°C at 1000m depth, however the threshold of 60°C is founded 1km deeper, and a complete exploitation of this reservoir can cover 84% of the Czech population. 2.4% of the Czech people lives over geothermal resources hotter than 80°C at 2km depth.

Region	**Population**	**Potential @2km & T>80°**	**Potential @2km & T>60°C**	**Population Suitable @2km & T>80°**	**Population Suitable @2km & T>60°C**
	Thousand inhabt.	%	%	Thousand inhabt.	Thousand inhabt.
Moravskoslezský kraj	1232.7	2.93%	71.19%	36.12	877.56
Zlínský kraj	589.6	0%	91.57%	0	539.90
Olomoucký kraj	638.8	0%	72.94%	0	465.94
Jihomoravský kraj	1165	0%	84.71%	0	986.87
Kraj Vysocina	512.1		83.19%	0	426.02
Pardubický kraj	516.3		100%	0	516.3
Královéhradecký kraj	554.2	12.55%	100%	69.55	554.2

Liberecký kraj	438.3		100%	0	438.3
Ústecký kraj	828.2	14.06%	100%	116.44	828.2
Karlovarský kraj	303.5		87.68%	0	266.11
Plzenský kraj	571.5		66.65%	0	380.90
Jihocecký kraj	636		13.57%	0	86.30
Stredoceský kraj	1272.2	2.38%	94.83%	30.28	1206.43
Hlavní mesto Praha	1237.9		100%	0	1237.9
Total	10496.3			252.39	8810.93
Percentage of Population suitable				**2.4%**	**84%**

Table 1 Percentages of population suitable with DH at different depths and Temperatures in Czech Republic

For what concerns the second sample-country, Slovenia, according to GeoDH around 50% of its population is reachable with geothermal district heating with temperatures between 60°C and 100°C at 2km depth and a further 6.5% with temperature above 100°C. In Table 2 is shown the amount of population coverable with DH according to his method. The results say that 1.18% of the Slovenian population is suitable with temperature above 60°C yet at 1km depth, 28.72% at 2km depth and 9.9% with temperatures above 80°C at 2km depth.

Region	**Population**	**Potential @1km & T>60°C**	**Potential @ 2km & T>80°C**	**Potential @ 2km & T>60°C**	**Population Suitable @1km & T>60°C**	**Population Suitable @2km & T>80°C**	**Population Suitable @2km & T>60°C**
	Inhabt.	*%*	*%*	*%*	*Inhabt.*	*Inhabt.*	*Inhabt.*
Pomurska	118,988	9.34%	99.88%	100%	11,113.48	118,845.2	118,988
Podravska	323,534	4.08%	26.14%	99.74%	13,200.18	84,571.79	322,692.8
Koroska	72,364	0%	0%	33.97%	0	0	24,582.05
Savinjska	260,253	0%	3%	39.65%	0	0	103,190.3
Zasavska	43,926	0%	0%	0%	0	0	0
Spodnjeposavska	70,164	0%	0%	25.49%	0	0	17,884.8
Jugovzhodna Slovenija	142,680	0%	0%	2.06%	0	0	2,939.21
Notranjsko-	52,387	0%	0%	0.%	0	0	0

kraska							
Osrednjeslo-venska	536,484	0%	0%	0.%	0	0	0
Gorenjska	204,057	0%	0%	0.%	0	0	0
Goriska	119,236	0%	0%	0.%	0	0	0
Obalno-kraska	111,423	0%	0%	0.%	0	0	0
Total	2,055,496				24,314	203,417	590,277
Percentage of Population suitable					**1.18%**	**9.90%**	**28.72%**

Table 2 Percentages of population suitable with DH at different depths and Temperatures in Slovenia

Well considering the limits consciously imposed to this analysis, at this point the lack of more specific information about the other factors involved in the investigation of the potential of a geothermal reservoir leads to conjectures based only on a portion of what influences the estimation.

These results are not easily interpretable: if on one hand the influence of considering as a resource not only the Hydrothermal and Deep Aquifers, but also the Hot Dry Rock justifies the large overestimation of the Czech potential (80% vs. 10%), on the other hand it can not clarify the underestimation, even though less emphasize, of the Slovenia (29% vs. 56.5%), which is then to be attributed to other factors.

In Figures 10 and 11 are overlapped the temperature/resources estimations from both reports, GeoDH and GeoELEC. In this case the estimation reported by GeoDH and GeoELEC are simply different and therefore the two methodology have led to two different assessments. The green areas identify the zones with hot sedimentary reservoirs, while the red ones identify other potential reservoirs. Both of them (the green and red areas) recognize a geothermal potential, which is clearly bigger than the one estimated according to GeoELEC data, even though some temperature trend is similar in both assessments (the north-eastern region is the most favorable in both cases, while the potential decrease moving towards west).

These two examples could be considered as extreme cases, where the reservoirs' evaluations are either *geologically* wrong (no distinction between hot dry and sedimentary rock) or based on different data (geothermal fields present in a model and absent in the other). Between these two comparisons there is also cases where the GeoELEC evaluations fit the GeoDH results. Here is reported the example of Hungary.

Hungay lays completely on the *Pannonian Basin*, bed of an ancient sea which now presents an unusual quantity of deep aquifers. In Figure is viewable how the GeoELEC projections practically coincide with the GeoDH data. In particular, the two regions of Komàrom-Esztergom and Veszprém in the middle-west of the country are those with the less potential according to both sources. The profile of the 60°C range according to GeoELEC model quite coincides to the shape of the aquifers reservoir.

In the following Table 3 are reported the percentages of Hungarian population living over a geothermal potential. The population's proportion suitable with temperature above 60°C is 40% already at 1km depth and practically 100% at 2km depth. With temperature above 80°C at 2km depth the proportion decrease down to 91%.

Also if we do not consider the area on 60°C previously mentioned (in Figure is viewable as the grey-green region), the proportion slightly overtakes 90%.

According to the GeoDH estimations, 90% of the Hungarian population should be reachable with geothermal District Heating. Thus, the comparison in this case perfectly match.

Region	**Population**	**Potential @1km & T>60°C**	**Potential @2km & T>60°C**	**Potential @ 2km & T>80°C**	**Population Suitable @1km & T>60°C**	**Population Suitable @2km & T>60°C**	**Population Suitable @2km & T>80°C**
	inhabt.	*%*	*%*	*%*	*inhabt.*	*inhabt.*	*inhabt.*
Budapest	1,740,041	0.00%	100.00%	100.00%	0	1,740,041	1,740,041
Pest	1,245,048	29.19%	100.00%	91.07%	363,430	1,245,048	1,133,865
Komárom-Esztergom	310,200	0.00%	97.36%	15.73%	0	302,011	48,794
Veszprém	354,565	0.00%	98.82%	43.71%	0	350,381	154,980
Fejér	425,581	18.84%	100.00%	93.39%	80,179	425,581	397,450
Gyor-Moson-Sopron	451,827	0.00%	100.00%	66.11%	0	451,827	298,703
Vas	256,458	11.73%	100.00%	89.16%	30,083	256,458	228,658

Zala	285,154	34.31%	100.00%	100.00%	97,836	285,154	285,154
Baranya	388,907	60.77%	100.00%	100.00%	236,339	388,907	388,907
Somogy	315,850	41.69%	100.00%	100.00%	131,678	315,850	315,850
Tolna	229,116	98.78%	100.00%	100.00%	226,321	229,116	229,116
Borsod-Abaúj-Zemplén	678,261	82.34%	100.00%	95.00%	558,480	678,261	644,348
Heves	305,336	77.21%	100.00%	100.00%	235,750	305,336	305,336
Nógrád	198,933	6.01%	100.00%	80.71%	11,956	198,933	160,559
Hajdú-Bihar	538,037	81.73%	100.00%	100.00%	439,738	538,037	538,037
Jász-Nagykun-Szolnok	383,128	95.45%	100.00%	100.00%	365,696	383,128	383,128
Szabolcs-Szatmár-Bereg	551,871	93.86%	100.00%	100.00%	517,986	551,871	551,871
Bács-Kiskun	522,312	63.55%	100.00%	100.00%	331,929	522,312	522,312
Csongrád	419,366	19.89%	100.00%	100.00%	83,412	419,366	419,366
Békés	357,740	82.45%	100.00%	100.00%	294,957	357,740	357,740
Total	9,957,731				4,005,768	9,945,358	9,104,216
Percentage of Population suitable					40.23%	99.88%	91.43%

Table 3 Percentages of population suitable with DH at different depths and Temperatures in Hungary

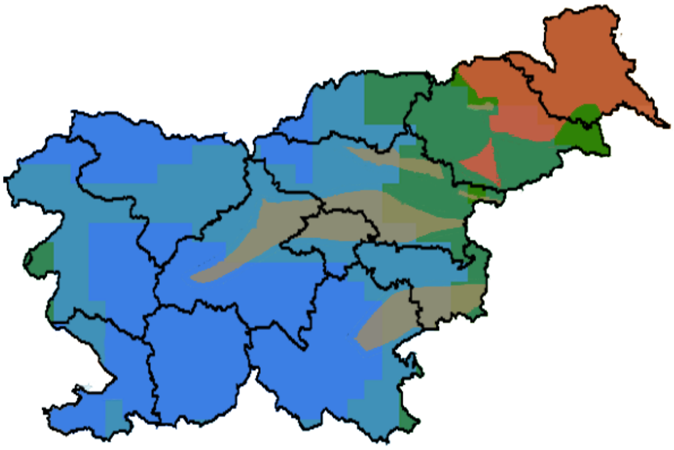


Figure 10 Overlap of GeoELEC and GeoDH models for Slovenia. Red and gray areas are deep aquifers according to GeoDH, the shades of green and blue are temperature ranges according to GeoELEC. An appropriate legend of GeoELEC color-references could be found in Chapter 2.6.1.

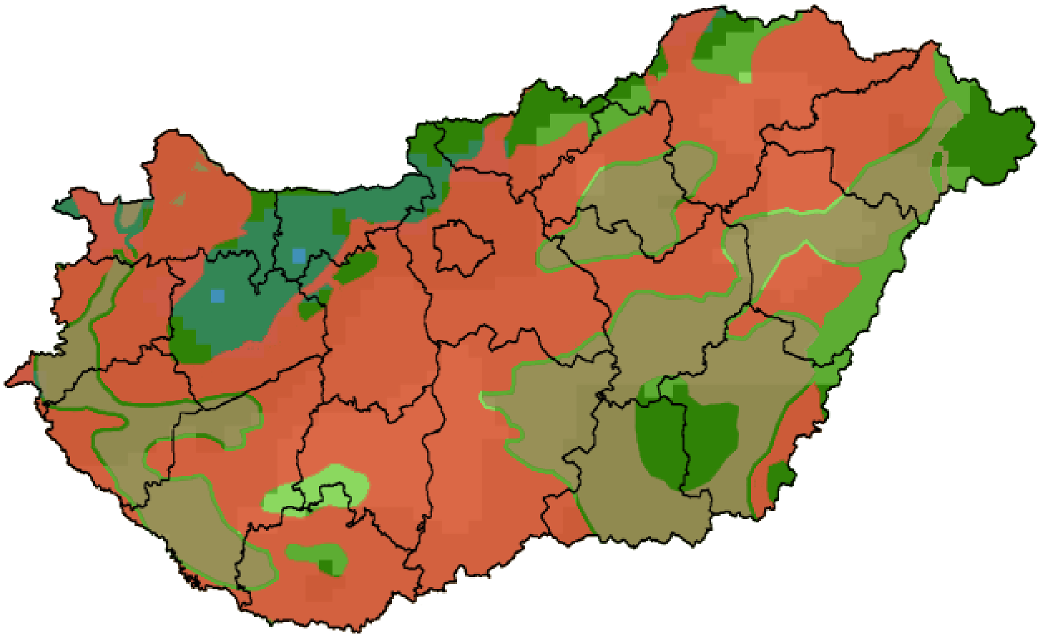


Figure 11 Overlap of GeoELEC and GeoDH models for Hungary. Red and gray areas are deep aquifers according to GeoDH, the shades of green and blue are temperature ranges according to GeoELEC. An appropriate legend of GeoELEC color-references could be found in Chapter 2.6.1.

2.5 Comparison CPR, EGEC and NREAP Data

The European Geothermal Energy Council's (EGEC) market report provides a full analysis of the current market of the geothermal sector of every project's members and makes some forecast for the future development. For what concerns the analysis of the geothermal DH, they have been taken under consideration only those plants where the heat has been actually sold through a distribution system to more than two customers and with an overall capacity higher than $0.5MW_{th}$.

Every EU-member were obligated to notify by 30 June 2010 a National Renewable Action Plan (NREAP) to the European Commission. The plan provides detailed road map of how the Member State expected to reach its legally binding 2020 target for the share of renewable energy in their total energy consumption. In the estimations of this action plan are considered in general only the deep geothermal energy, with no particular distinction for district heating[17].

---

[17] This means that beyond the heat sold through district heating, private and single uses are counted as well.

Every two years EU members report their progress in renewable energy sector towards their 2020 goals providing to the European Commission a Country Progress Report (CPR). Like NREAP's, the estimation considers only the deep geothermal energy in its whole and the DH portion is reported without distinction between the different renewable sources. In Figure 12 is shown a table extracted from the Italian CPR, showing the contribution of every renewable energy in the H&C sector.

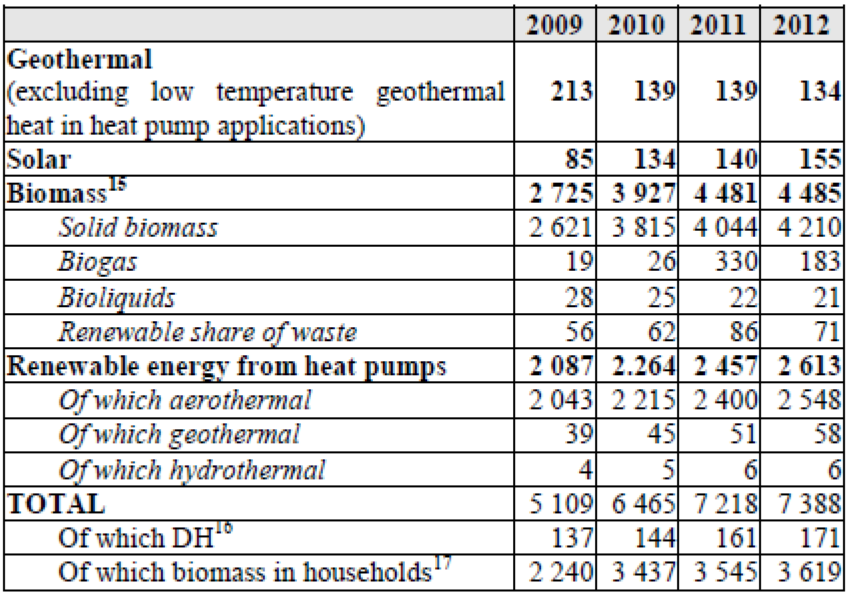
Country	**CPR '12**	**EGEC '12**	**NREAP '12**
	ktoe	*ktoe*	*ktoe*
Austria	22	13.66	23
Belgium[18]	1.43	1.54	3.9
Croatia	7.4	0	7.4
Denmark	3.4	6.87	0
Finland	0	0	0
France	94	107.05	195
Germany	25	29.98	114
Greece	13	0	21
Iceland*	724	696.21	722.7
Ireland	0	0	0
Italy	134	22.46	239
Luxemburg	0	0	0
Netherlands	12	85.05	75
Portugal	1.6	0	14
Spain	18	0	3.8
Sweden	0	23.21	0
UK	0.8	0	0.8
Cyprus	0	0	0

---

[18] CPR's and NREAP's values referred to year 2014.

Czech Rep.	0	2.15	0
Estonia	0	0	0
Latvia	0	0	0
Lithuania	2	8.07	3
Malta	0	0	
Hungary	107	60.30	120
Poland	15.8	13.72	29
Slovakia	6	0	3
Slovenia	31	0.54	18
Bulgaria	33	0	2.4
Romania	21.5	12.75	35

Table 4 Potential and population's percentage covered in 2050, 2012 stand and share of potential (2050) already exploited



	2009	2010	2011	2012
Geothermal (excluding low temperature geothermal heat in heat pump applications)	**213**	**139**	**139**	**134**
Solar	**85**	**134**	**140**	**155**
Biomass[15]	**2 725**	**3 927**	**4 481**	**4 485**
Solid biomass	2 621	3 815	4 044	4 210
Biogas	19	26	330	183
Bioliquids	28	25	22	21
Renewable share of waste	56	62	86	71
Renewable energy from heat pumps	**2 087**	**2.264**	**2 457**	**2 613**
Of which aerothermal	2 043	2 215	2 400	2 548
Of which geothermal	39	45	51	58
Of which hydrothermal	4	5	6	6
TOTAL	5 109	6 465	7 218	7 388
Of which DH[16]	137	144	161	171
Of which biomass in households[17]	2 240	3 437	3 545	3 619

Figure 12 Actual contribution from each renewable energy technology in Italy in H&C [ktoe] (source: EC, Italy's CPR)

In Table 4 are shown the values reported by the governments (CPR) and by EGEC, while under NREAP '12 can be founded the programmed amount of geothermal energy that should be produced in 2012 in order to follow the path towards the 2020 goals. The discrepancies between EGEC's data and those from CPR are principally caused by, as written before, the different characteristics considered. EGEC considers only the heat sold through a DH system, while CPR considers every typology of geothermal heat application. Matter of facts, the CPR's data should be then always higher or at least equal to the EGEC's, thing that doesn't happen for few countries, like the Netherlands, Sweden or France. This fact is attributed by Luca Angelino, Head of Policy and Regulation by EGEC, to communication's issue between producers and government.

Figure 13 shows the actual geothermal district heating production in European Union (and Iceland) according to CPR, EGEC and NREAP. Generally, with very few exceptions, NREAP expectations for 2012 are above the estimations of both CPR and EGEC. This means that, in order to accomplished the 2020 goals, every EU-Member should, in coming years, take more consistent measures in field of geothermal energy policy.

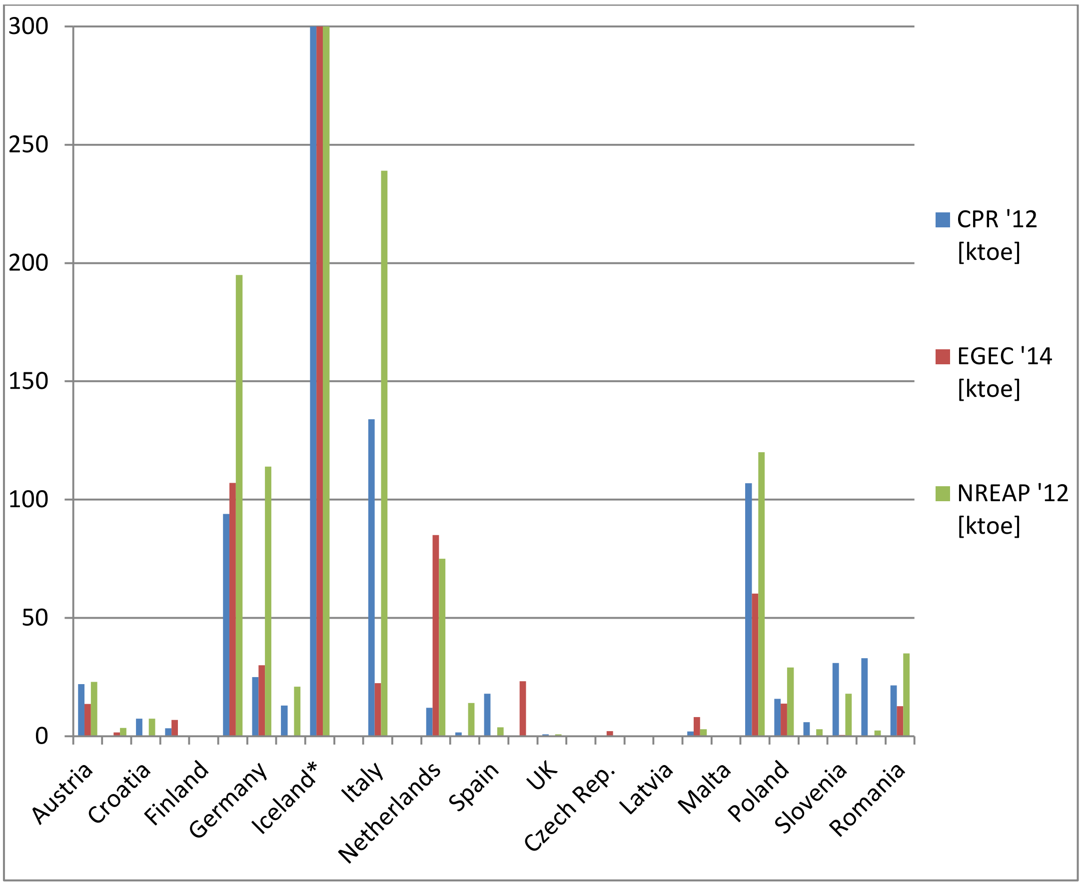


Figure 13 Actual geothermal DH production from different sources.

---

[*] For a better overview of the data, the Icelandic estimations have been taken out of bounds, being around 700ktoe.

2.6 Results

The assessments are here reported as a Table for a general and quick overview and then with more specific details country by country in the following pages, from Austria (2.6.1) down to the United Kingdom (2.6.26). To every country will be attached either a map extracted from the GeoDH report, or from GeoELEC, for the countries where the specific methodology of this thesis has been applied. In addition to that the detailed calculation for every NUTS3 region have been attached, with specified the potential at 1km and 2km depth and for temperature above 60°C and 80°C and correlated proportion of population suitable with specified temperature at given depth[19].

The following Table, as written just before, contains a brief overview of all the considered countries. The first six lines (excluding the first one: "*Country*") stay under the sub-group "*Percentage of Population Covered*" and report the values extracted from the GeoDH report and calculated through the GeoELEC model. Here the percentage coming from GeoDH are **cumulative**: This means that starting from 1km depth, every portion of population suitable at deeper depths is added to the total amount. Example: 38% of the German population live in areas with a geothermal DH potential. 1km deeper, a further percentage of 12% of the Germans can be reached as well. On the other side, the GeoELEC data are **non-cumulative**: in other words they all (i.e. the percentage at every depth) represent the absolute percentage of population coverable and they have to be considered separately. In the line "*Heating and cooling 2050*" are stated the forecasts of H&C according to the reference scenario PRIMES 2013. The coming lines – also highlighted in grey - report the potential calculations as combination of the first group's values and the forecasts. The first three lines state the potential according to GeoDH evaluations. As the percentage, these values are also cumulative as the GeoELEC values are not.

---

[19] The tables with NUTS3 regions and their population have been downloaded from "*http://knoema.com/ES_reg_dempoar_2013/population-and-area-1990-2012?geo=1000480-rheintal-bodenseegebiet&action=export*".

The total potential has been calculated for the GeoDH countries as the sum of the three potentials (at 1, 2 and 3km), and for the GeoELEC countries as the maximal value of them.

2.6 Geothermal District Heating –Results

COUNTRY		Austria	Belgium	Croatia	Denmark	Finland	France	Germany	Greece	Iceland*	Ireland*	Italy	Luxemburg	Netherlands	Portugal	Spain	Sweden	UK	Czech Rep.	Estonia	Latvia	Lithuania	Hungary	Poland	Slovakia	Slovenia	Bulgaria	Romania	Turkey
Percentage of Population Covered [%]	GeoDH @1000m						37%	38%			35%	50%		30%									90%				50%		
	GeoDH @2000m				75%		60%	12%				6%		33%				20%	10%					10%	70%	57%		30%	
	GeoDH @3000m																							50%					
	GeoELEC @ 1000m T>60°C	2.30%		29.90%					3.12%	15.67%																			37.15%
	GeoELEC @ 2000m T>60°C	74.90%	63.00%	65.20%					68.19%	78.95%					90.78%	85.80%					2.89%	22.42%							92.81%
	GeoELEC @ 2000m T>80°C	12.00%	1.34%	57.60%					6.88%	68.09%			100.00%		15.93%	3.50%						2.46%							68.52%
Heating and cooling (incl. cooking) 2050 [Gwh]		60,209.00	84,498.00	20,291.00	39,412.00	40,371.00	299,036.00	536,595.00	37,172.00	13,141.90	34,424.00	279,882.00	5,626.00	96,854.00	20,769.00	140,001.00	58,323.00	381,070.00	70,844.00	10,865.00	14,710.00	15,573.00	56,466.00	238,842.00	25,577.00	12,021.00	20,512.00	89,790.00	416,000.00
Estimation of the Potential in 2050 [GWh]	GeoDH Pot @1km	0.00	0.00	0.00	0.00	0.00	110,643.32	203,906.10	0.00	0.00	12,048.40	139,941.00	0.00	29,056.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50,819.40	0.00	0.00	0.00	10,256.00	0.00	0.00
	GeoDH Pot @2km	0.00	0.00	0.00	29,559.00	0.00	179,421.60	64,391.40	0.00	0.00	0.00	16,792.92	0.00	31,961.82	0.00	0.00	0.00	76,214.00	7,084.40	0.00	0.00	0.00	0.00	23,884.20	17,903.90	6,851.97	0.00	26,937.00	0.00
	GeoDH Pot @3km	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	119,421.00	0.00	0.00	0.00	0.00	0.00
	GeoELEC Pot @ 1000m T>60°C	1,384.81	0.00	6,067.01	0.00	0.00	0.00	0.00	1,159.77	2,059.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	154,544.00
	GeoELEC Pot @ 2000m T>60°C	45,096.54	53,233.74	13,229.73	0.00	0.00	0.00	0.00	25,347.59	10,375.53	0.00	0.00	5,626.00	0.00	18,854.10	120,120.86	0.00	0.00	0.00	0.00	425.12	3,491.47	0.00	0.00	0.00	0.00	0.00	0.00	386,089.60
	GeoELEC Pot @ 2000m T>80°C	7,225.08	1,132.27	11,687.62	0.00	0.00	0.00	0.00	2,557.43	8,948.32	0.00	0.00	0.00	0.00	3,308.50	4,900.04	0.00	0.00	0.00	0.00	0.00	383.10	0.00	0.00	0.00	0.00	0.00	0.00	285,043.20
	Total Potential [GWh]	45,096.54	53,233.74	13,229.73	29,559.00	0.00	290,064.92	268,297.50	25,347.59	10,375.53	12,048.40	156,733.92	5,626.00	61,018.02	18,854.10	120,120.86	0.00	76,214.00	7,084.40	0.00	425.12	3,491.47	50,819.40	143,305.20	17,903.90	6,851.97	10,256.00	26,937.00	386,089.60
	Total Potential [ktoe]	3,877.60	4,577.28	1,137.55	2,541.62	0.00	24,941.09	23,069.43	2,179.50	892.14	1,035.98	13,476.69	483.75	5,246.61	1,621.16	10,328.53	0.00	6,553.22	609.15	0.00	36.55	300.21	4,369.68	12,322.03	1,539.46	589.16	881.86	2,316.17	33,197.73

2.6.1 Austria

Austria is not a member country of the GeoDH project and it’s a quite recent exploiter of geothermal heat for district heating since all of its plants except ones were put in operations within the past 20 years. There are already 8 DH plants in operation with a total installed capacity of 51.5 MW_{th}, producing 13.66 ktoe in year 2012. Those DH plants are located in Altheim (2000), Bad Blumau (2001), Bad Waltersdorf (1979), Geinberg (2000), Haag (1996), Obernberg (2000), simbach-Braunau (2003) and St. Martin (2002).

One further plant in Ried im Innkreis is now under construction and its capacity is expected to be 25 MW_{th} extensible up to 55 MW_{th} (Ried im Innkreis 2) able to take the total installed capacity to 106.5 MW_{th}.

The DH heating plants are located either in the thermal zone at the border with Germany, in the region of Upper Austria, where the underground temperature at 2km depth is around 60°C to 80°C or close to the border with Hungary, next to Graz in Styria, where at 2km depth there are 80°C to 100°C (Visible in Figure 14 as the green zones).

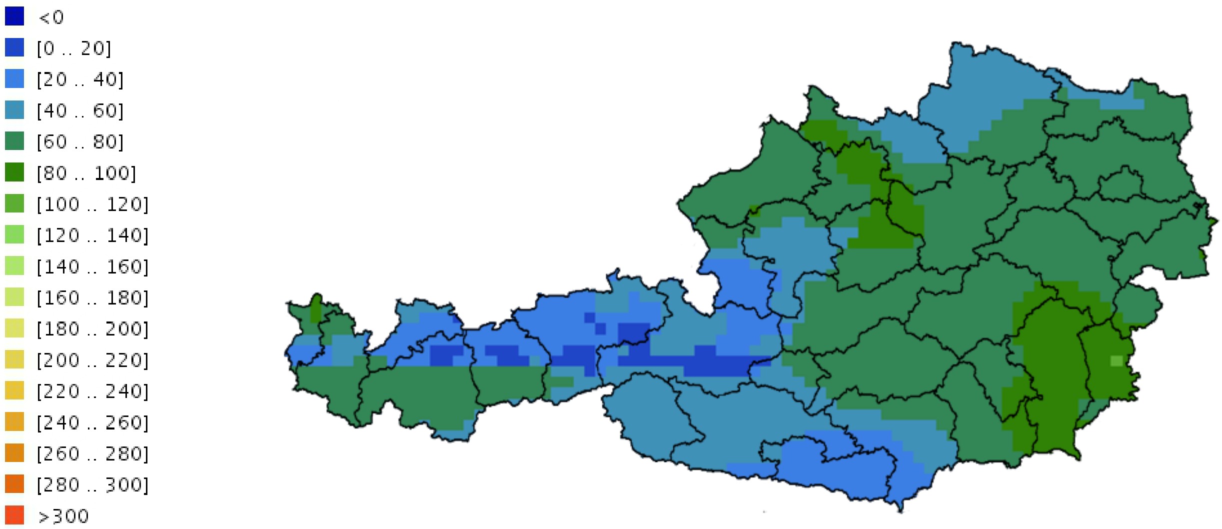


Figure 14 Model temperature at 2000 m depth (source: GeoELEC Viewer modified)

As said, since Austria isn't a member of the GeoDH project, its potential has been estimated through GeoELEC's data. Figure 14 shows the 3 zones above 80°C at 2km depth. The first in the eastern NUTS3 region of Rheintal-Bodenseegebiet, the second one comprehends parts of Styr and Burgenland and the third one is located in Oberösterreich. Figure 14 shows also the regions with temperatures above 60°C.

Figure 15 shows the model temperature at 1000m depth. The only zones with a temperature above 60°C are reported in green-blue color and they cover partially the region of Südburgenland, Graz and Oststeiermark.

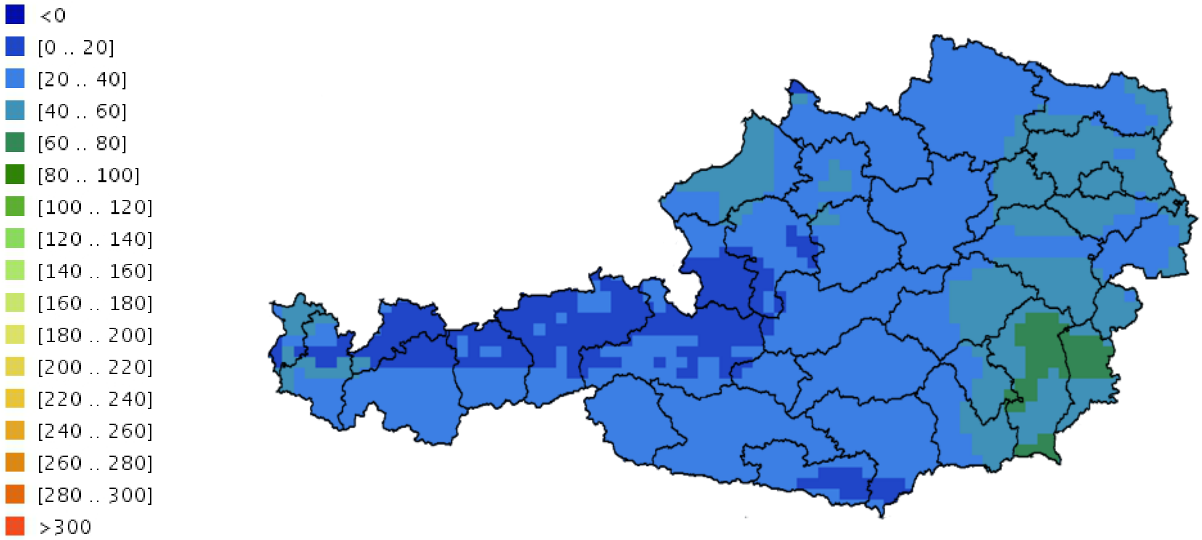


Figure 15 Model temperature at 1000m depth (source GeoELEC Viewer modified)

In Table 55 are reported the results of the analysis based on the GeoELEC maps. With an entire population of 8424000, the proportion of Austrian population suitable with temperature above 60°C already at 1km depth is 2.3%, corresponding to 1384.8GWh in the heating and cooling sector in 2050. The proportion of population suitable with temperature above 60°C at 2km depth is much higher: 74.9%, corresponding to 45086.2GWh in 2050. The population suitable with temperature above 80°C at 2km depth is 12%, corresponding to 7225.1GWh in 2050.

2.6 Geothermal District Heating –Results

Region	**Population**	**Potetial @1km & T>60°C**	**Potential @2km & T>60°C**	**Potential @2km & T>80°C**	**Population suitable @1km & T>60°C**	**Population suitable @2km & T>60°C**	**Population suitable @2km & T>80°C**
	thousand inhabt	*%*	*%*	*%*	*Thousand inhabt*	*Thousand inhabt.*	*Thousand inhabt.*
Mittelburgenland	38	0%	100.0%	19.8%	0.0	37.6	7.5
Nordburgenland	150	0%	100.0%	0%	0.0	150.2	0.0
Südburgenland	98	53.1%	100.0%	93.1%	51.9	97.8	91.0
Mostviertel-Eisenwurzen	241	0%	100.0%	15.7%	0.0	241.4	37.9
Niederösterreich-Süd	253	0%	100.0%	15.8%	0.0	253.3	40.0
Sankt Pölten	149	0%	100.0%	0%	0.0	148.6	0.0
Waldviertel	220	0%	34.2%	0%	0.0	75.0	0.0
Weinviertel	124	0%	78.8%	0%	0.0	97.4	0.0
Wiener Umland/Nordteil	308	0%	100.0%	0%	0.0	307.7	0.0
Wiener Umland/Südteil	320	0%	100.0%	0%	0.0	320.3	0.0
Wien	1723	0%	100.0%	0%	0.0	1722.7	0.0
Klagenfurt-Villach	277	0%	0.0%	0%	0.0	0.0	0.0
Oberkärnten	128	0%	0.0%	0%	0.0	0.0	0.0
Unterkärnten	153	0%	24.8%	0%	0.0	38.0	0.0
Graz	406	3.8%	100.0%	30.1%	15.2	406.4	122.5
Liezen	80	0%	87.3%	0%	0.0	69.5	0.0
Östliche Obersteiermark	165	0%	100.0%	15.0%	0.0	165.3	24.8
Oststeiermark	267	47.5%	100.0%	96.61%	126.8	266.9	257.9
West- und Südsteiermark	190	0%	99.2%	22.7%	0.0	188.7	43.3
Westliche Obersteiermark	103	0%	94.8%	0%	0.0	98.0	0.0
Innviertel	276	0%	99.3%	0.9%	0.0	273.9	2.5

Linz-Wels	552	0%	100.0%	45.7%	0.0	552.2	252.6
Mühlviertel	204	0%	62.6%	18.6%	0.0	127.9	38.0
Steyr-Kirchdorf	153	0%	89.8%	33.6%	0.0	137.1	51.3
Traunviertel	230	0%	19.5%	1.1%	0.0	44.8	2.5
Lungau	21	0%	30.9%	0%	0.0	6.4	0.0
Pinzgau-Pongau	163	0%	0.0%	0%	0.0	0.0	0.0
Salzburg und Umgebung	349	0%	22.3%	0%	0.0	77.6	0.0
Außerfern	32	0%	6.7%	0%	0.0	2.1	0.0
Innsbruck	287	0%	40.6%	0%	0.0	116.7	0.0
Osttirol	50	0%	0.0%	0%	0.0	0.0	0.0
Tiroler Oberland	102	0%	71.2%	0%	0.0	72.3	0.0
Tiroler Unterland	242	0%	2.3%	0%	0.0	5.5	0.0
Bludenz-Bregenzer Wald	88	0%	67.0%	0%	0.0	59.1	0.0
Rheintal-Bodenseegebiet	283	0%	52.2%	15.9%	0.0	147.5	44.9
Total	8424				193.9	6307.8	1016.5
Percentage of population suitable					**2.3%**	**74.9%**	**12.1%**

Table 5 Area and population of Austrian NUTS3 regions suitable with geothermal DH based on GeoELEC data

Considering the Austrian CPR 2012 and NREAP it appears that Austria is following its path quite well in order to accomplished the terms specified in 20-20-20 act.

2.6.2 Belgium

Like Austria, Belgium is another European country that is not a member of the GeoDH project. In its territory are now operating two geothermal DH plants, both built in 1985, one in Saint Ghislain with 6.1GW$_{th}$ and one in Douvrain with 4GW$_{th}$. Both combined produced in 2012 1.5ktoe. Five further plants are planned or under construction/investigation: Beerse, Charleroi-Tournai, Mol, Ghislain and Mons with a total installed capacity up to 45 additional MW$_{th}$.

Figure 16 shows an underground’s temperature (at 2000m depth) of 60°C to 80°C in almost the whole continental area of Belgium. The exploited or under construction geothermal plants are either south from Brussels or east from Antwerp. The regions partially covered with temperatures above 80°C at 2km depth are Arr. Antwerpen (11.59%) and Arr. Turnhout (6.93%). Figure 17 shows the temperature at 1km depth and how it doesn’t cross the threshold of 60°C in any region.

In Table 66 are reported are reported the results of the analysis based on GeoELEC maps. With a total population above 11 million, the proportion of it suitable with a temperature above 60°C at 2km depth is 63.3% corresponding to 53483.7GWh in 2050. The proportion of population suitable with temperature above 80°C at 2km depth is 1.34% corresponding to 1132.3GWh in 2050. No population is suitable with temperature above 60°C at 1km depth.

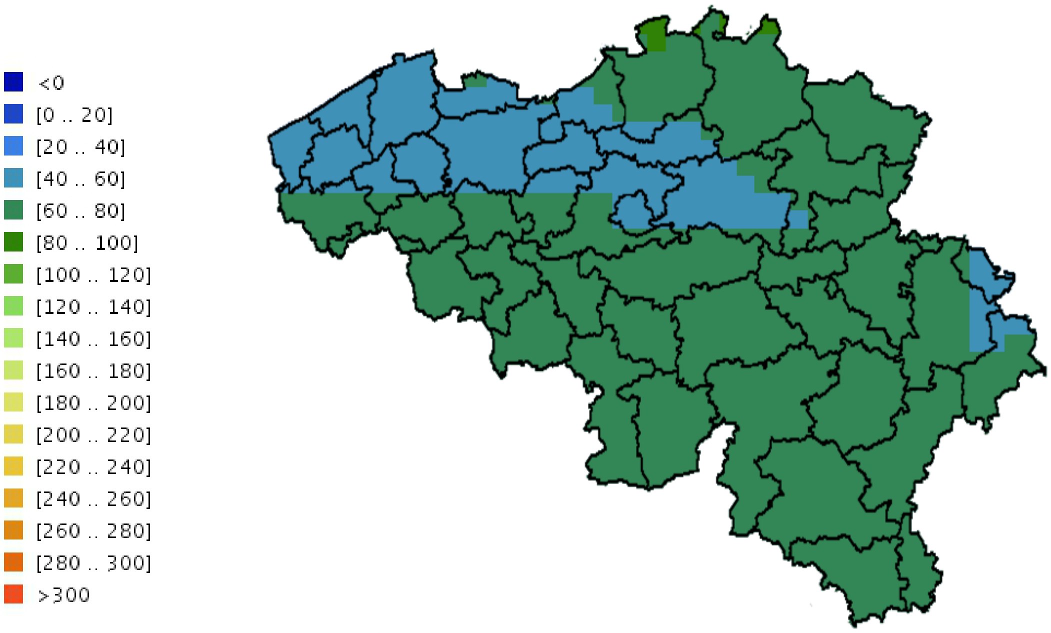


Figure 16 Belgium's model temperature at 2000m depth (source: GeoELEC Viewer, modified)

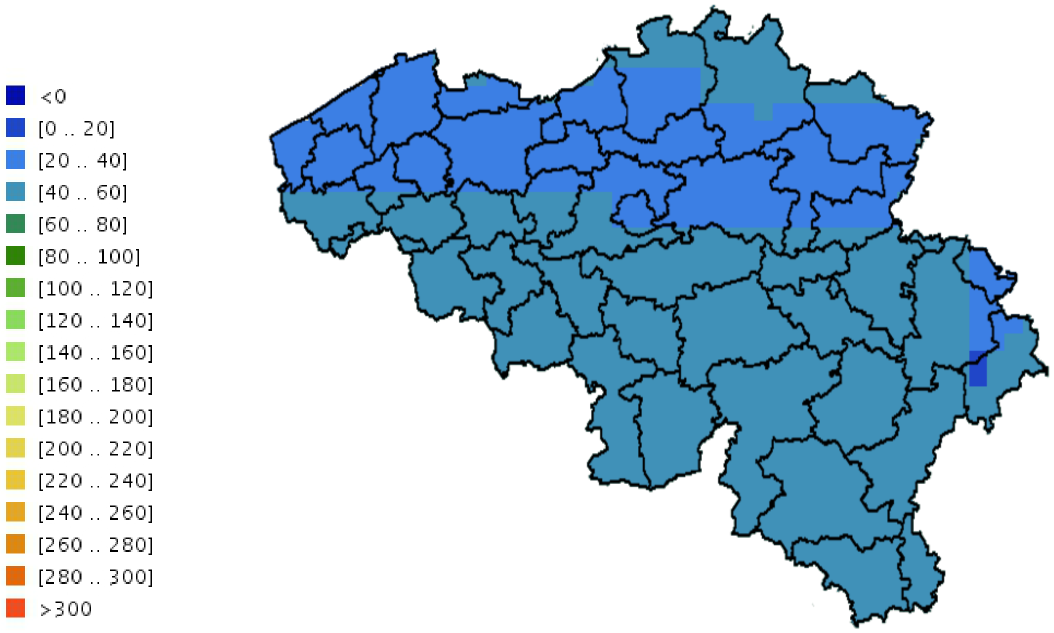


Figure 17 Model temperature of Belgium at 1000m depth (source GeoELEC Viewer modified)

Region	Population	Potential @2km & T>60°C	Potential @2km & T>80°C	Population suitable @2km & T>60°C	Population suitable @2km & T>80°C
	Inhabt.	*%*	*%*	*Inhabt.*	*Inhabt.*
Arr. de Bruxelles-Capitale / Arr. van Brussel-Hoofdstad	1,159,448	5.38%	0%	6,2378.3	
Arr. Antwerpen	1,016,926	92.38%	11.59%	939,436.2	117861.7
Arr. Mechelen	330,121	10.30%	0%	34,002.46	
Arr. Turnhout	443,977	99.69%	6.93%	442,600.7	30767.61
Arr. Hasselt	415,862	93.12%	0%	387,250.7	
Arr. Maaseik	235,834	100.00%	0%	235,834	
Arr. Tongeren	200,360	100.00%	0%	200,360	
Arr. Aalst	279,184	63.34%	0%	176,835.1	
Arr. Dendermonde	195,721	0	0%	0	
Arr. Eeklo	83,186	8.85%	0%	7,361.96	
Arr. Gent	537,364	0	0%	0	
Arr. Oudenaarde	121,412	91.67%	0%	111,298.4	

Arr. Sint-Niklaas	241,600	34.17%	0%	82,554.72
Arr. Halle-Vilvoorde	605,452	54.92%	0%	332,514.2
Arr. Leuven	491,758	19.37%	0%	95,253.52
Arr. Brugge	279,172	0%	0%	0
Arr. Diksmuide	50,334	0%	0%%	0
Arr. Ieper	106,819	86.25%	0%	92,131.39
Arr. Kortrijk	284,293	100.00%	0%	284,293
Arr. Oostende	153,630	0	0%	0
Arr. Roeselare	147,281	22.53%	0%	33,182.41
Arr. Tielt	91,393	0	0%	0
Arr. Veurne	60,896	0	0%	0
Arr. Nivelles	386,836	99.52%	0%	384,979.2
Arr. Ath	85,042	100%	0%	85,042
Arr. Charleroi	430,000	100%	0%	430,000
Arr. Mons	254,867	100%	0%	254,867
Arr. Mouscron	73,936	100%	0%	73,936
Arr. Soignies	185,457	100%	0%	185,457
Arr. Thuin	150,996	100%	0%	150,996
Arr. Tournai	146,088	100%	0%	146,088
Arr. Huy	110,085	100%	0%	110,085
Arr. Liège	616,817	100%	0%	61,6817
Arr. Waremme	77,422	100%	0%	77,422
Arr. Verviers - communes francophones	208,931	85.15%	0%	177,904.7
Bezirk Verviers - Deutschsprachige Gemeinschaft	76,788	67.90%	0%	52,139.05
Arr. Arlon	59,353	100%	0%	59,353
Arr. Bastogne	46,285	100%	0%	46,285
Arr. Marche-en-Famenne	56,236	100%	0%	56,236
Arr. Neufchâteau	61,344	100%	0%	61,344
Arr. Virton	52,936	100%	0%	52,936
Arr. Dinant	109,136	100%	0%	109,136
Arr. Namur	307,669	100%	0%	307,669
Arr. Philippeville	66,603	100%	0%	66,603

Total	11,094,850		7,022,582	148,629.3
Percentage of population suitable			**63.30%**	**1.34%**

Table 6 Area and population of Belgium suitable with DH

Belgium didn’t provide geothermal energy for H&C sector’s assessments in its 2013 CPR. However it did provide data in the CPR released in 2015: geothermal energy production decreased in the biennium 2013-2014, passing from 1.62ktoe in 2013 to 1.43ktoe in 2014, while in order to respect the NREP, the geothermal energy production in 2014 should have been of 3.9kote.

2.6.3 Bulgaria

Bulgaria uses its geothermal resources, which consist in thermal water up to 90°C, heating buildings and greenhouses as well as in the balneology field. None of them are currently connected to a district heating grid, in fact, no geothermal DH system has been built in the country so far, and the Bulgarian DH market is not very dynamic (GeoDH, November 2014). As shown in Figure 18 the DH infrastructure is not well developed. Each dot represents a DH system, but none of them use geothermal energy as source of heating.

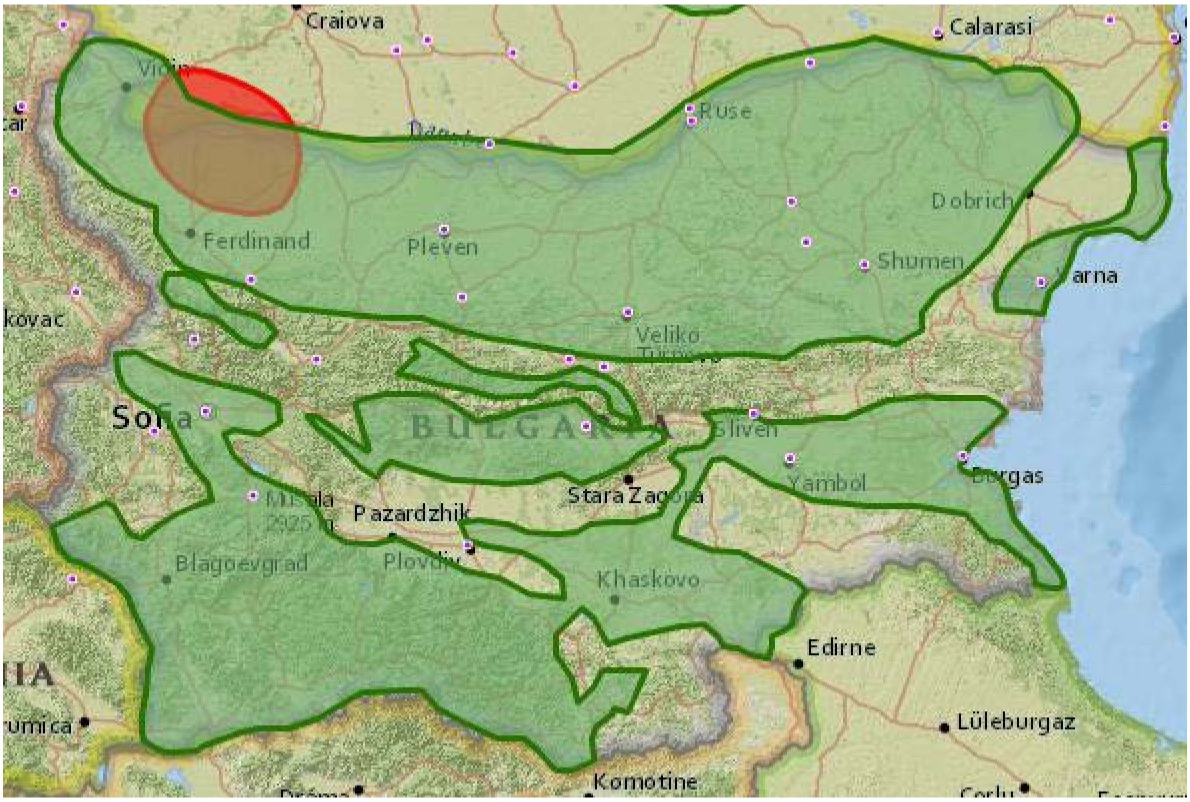


Figure 18 Map of geothermal potential in Bulgaria

The portion of Bulgarian population that can be reached with geothermal DH (with a geothermal heat at 1000m 60°C to 100°C) is around 50%. This leads an estimation of the Bulgaria geothermal potential in 2050 up to 881ktoe. This makes Bulgaria one of the potentially most suitable country in Europe for geothermal DH.

The high discrepancy between CPR, EGEC and NREAP data is probably due to a difficulty of communication between central data institution and local level production.

2.6.4 Croatia

Croatia has no geothermal district heating infrastructure yet, but it does have four planned plants, all of them near the border with Hungary, which is also the most suitable area (120°C up to 140°C at 2000m depth, visible in Figure 19 as light green). As said in chapter *Methodology* the presence of islands affects the accuracy of the analysis. However, the Croatian coastal zone (Dalmatia) presents no potential, so it doesn't compromise the calculation. As seen in Figure 19 and 20, the suitable regions are those in the continental part of Croatia for both depths (1 and 2km) and for both temperature-thresholds (60 and 80°C). In Table 7 are reported the results of the analysis. With a total population of 4405200, the proportion suitable with temperature above 60°C already at 1km depth is 29.9%, corresponding to 6067GWh in 2050. The percentage suitable with temperatures above 60°C at 2km depth is 65.2%, corresponding to 13229GWh in 2050, and with temperature above 80°C 57.6%, which makes Croatia one of the most interesting results of this thesis, and corresponding to 11687.6GWh in 2050.

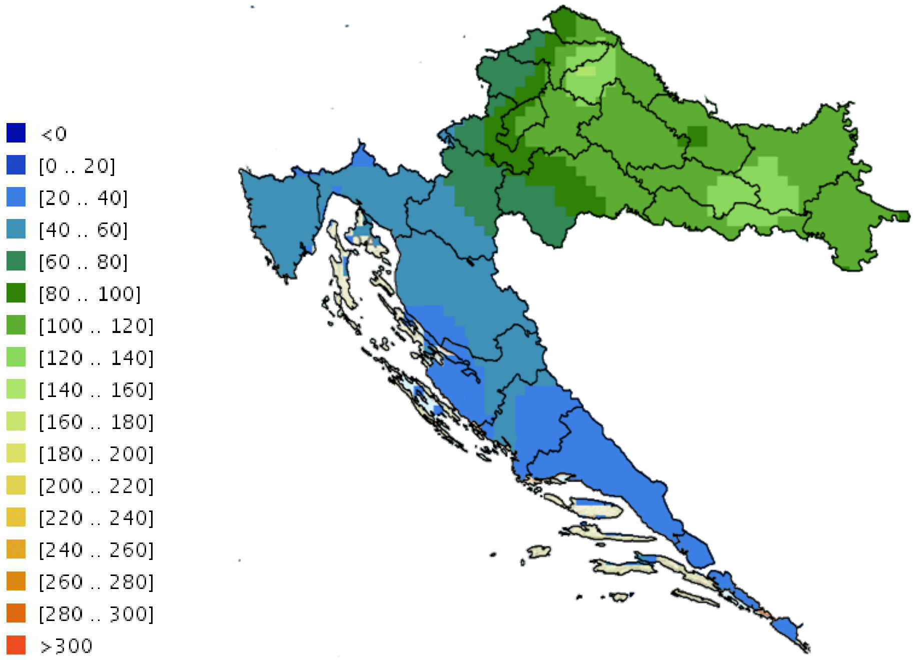


Figure 19 Model temperature of Croatia at 2000m depth. source(GeoELEC Viewer modified)

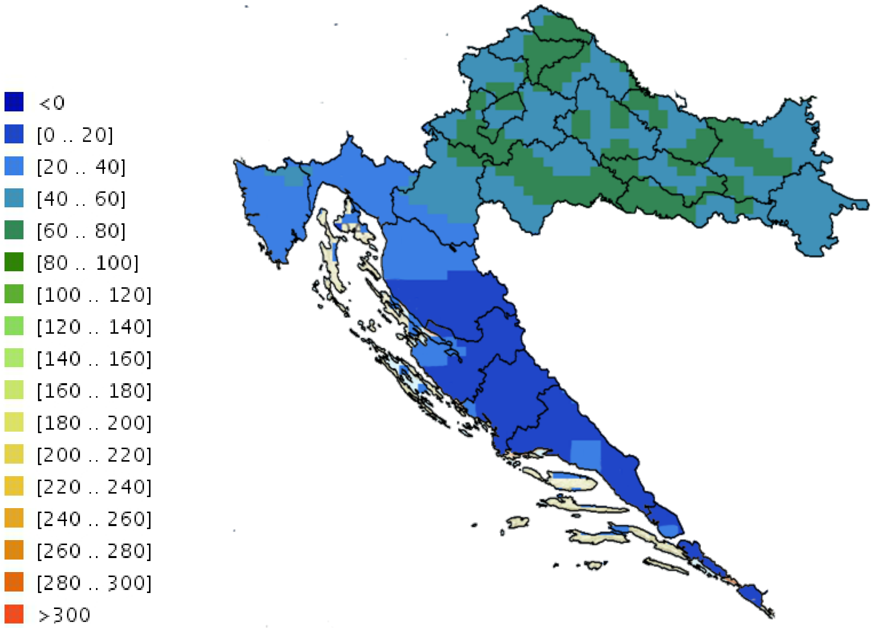


Figure 20 Model temperature of Croatia at 1000m depth (source: GeoELEC Viewer modified)

Region	Population	Potential @1km & T>60°C	Potential @2km & T>60°C	Potential @2km & T>80°C	Population suitable 1km & T>60°C	Population suitable @2km & T>60°C	Population suitable @2km & T>80°C
	Inhabt.	*%*	*%*	*%*	*Thousand inhabt.*	*Thousand inhabt.*	*Thousand inhabt.*
Primorsko-goranska zupanija	302,900	0%	0%	0%	0	0	0
Licko-senjska zupanija	48,300	0%	0%	0%	0	0	0
Sibensko-kninska zupanija	111,600	0%	0%	0%	0	0	0
Splitsko-dalmatinska zupanija	482,900	0%	0%	0%	0	0	0
Zadarska zupanija	177,200	0%	0%	0%	0	0	0
Istarska zupanija	214,600	0%	0%	0%	0	0	0
Dubrovacko-neretvanska zupanija	127,700	0%	0%	0%	0	0	0
Bjelovarsko-	122,300	35.1%	100.0%	100.0%	42.88	122.3	122.3

bilogorska zupanija							
Grad Zagreb	794,700	51.6%	100.0%	100.0%	409.74	794.7	794.7
Koprivnicko-krizevacka zupanija	118,400	44.5%	100.0%	100.0%	52.63	118.4	118.4
Krapinsko-zagorska zupanija	135,000	25.2%	100.0%	30.0%	34.05	135	40.4595
Medimurska zupanija	117,800	78.9%	100.0%	100.0%	92.98	117.8	117.8
Pozesko-slavonska zupanija	80,100	52.5%	100.0%	100.0%	42.01	80.1	80.1
Varazdinska zupanija	179,300	67.0%	100.0%	72.3%	120.04	179.3	129.56218
Viroviticko-podravska zupanija	85,700	55.7%	100.0%	100.0%	47.70	85.7	85.7
Zagrebacka zupanija	330,200	39.3%	98.8%	78.6%	129.80	326.14	259.3721
Brodsko-posavska zupanija	170,500	64.6%	100.0%	100.0%	110.21	170.5	170.5
Karlovacka zupanija	129,100	9.6%	50.5%	1.1%	12.35	65.18	1.45883
Vukovarsko-srijemska zupanija	193,800		100.0%	100.0%	0	193.8	193.8
Sisacko-moslavacka zupanija	167,000	52.5%	100.0%	65.3%	87.64	167	109.051
Osjecko-baranjska zupanija	316,100	43.4%	100.0%	100.0%	137.06	316.1	316.1
Total	4,405,200				1319.10	2872.02	2539.30361
Percentage of population suitable					**29.9%**	**65.2%**	**57.6%**

Table 7 Area and population of Croatia suitable with DH

For what concerns geothermal energy, Croatia’s CPR 2012 and NREAP suggest that Croatia is following its path in order to accomplished the terms specified in 20-20-20 act.

2.6.5 Czech Republic

There is a strong DH tradition in the Czech Republic. According to EHP[20], 37% of all households are already connected to a DH grid. A DH operates in every city with more than 50.000 inhabitants, reaching in urban-areas an astonishing share of 73%. However, only one of this DH systems uses geothermal energy, in facts, 67% of heat supplied is produced by coal and coal products, while natural gas accounted 26%. The only geothermal DH infrastructure is located in Decin (visible in Figure 21 as a red dot south-east from Dresden) and accounts 6.56MW_{th} with a total energy production in 2012 of 2.2ktoe. CPR and NREAP don't take under consideration this plant.

Another plant with an expected capacity of 50MW_{th} is planned in Litomerice, just a few kilometers southern from Decin.

As shown in Figure 21 the areas suitable with geothermal DH (at geothermal heat at 2000m 60°C to 100°C) are north-west, at the border with Germany and south-east, at the border with Slovakia. Those areas are now inhabited by 1 million people, which means 10% of Czech Republic's population and in 2050 an estimated heat coverage of 609ktoe.

---

[20] Bottio, I., Italy in District Heating and Cooling, Country by Country/ 2013 Survey, *Euroheat and Power*, Brussels, 2013.

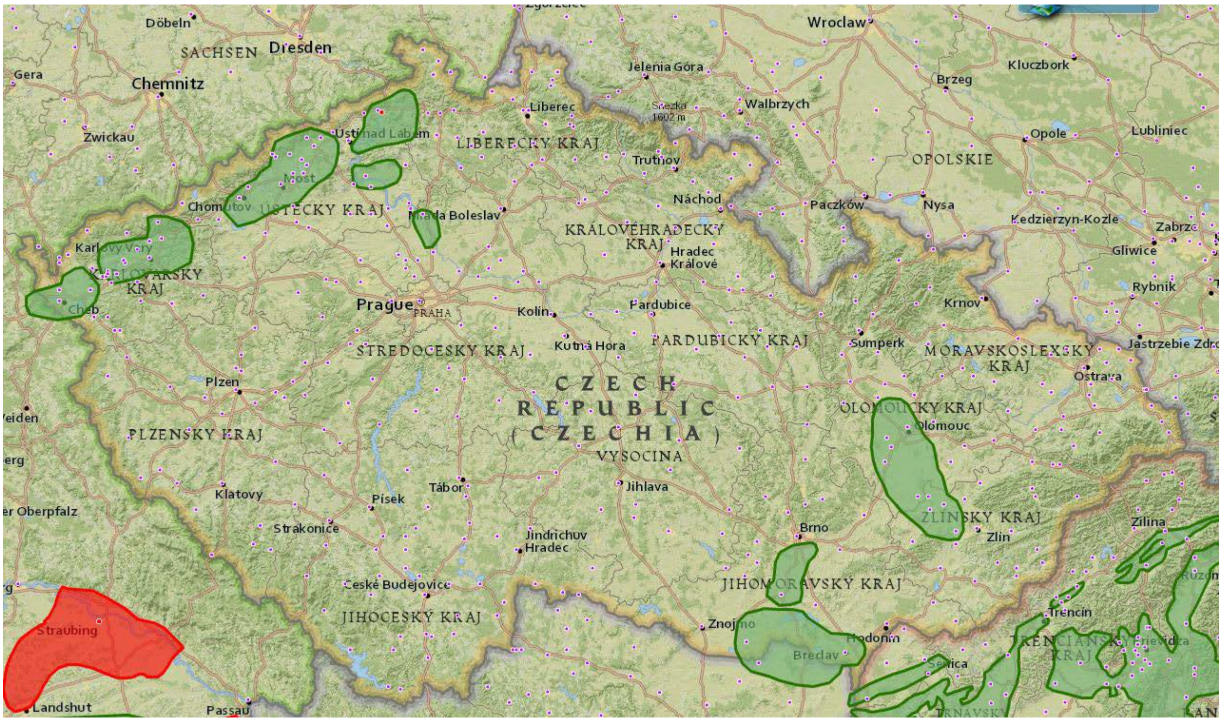


Figure 21 Map of geothermal potential of Czech Republic

Even though no geothermal energy exploitation was expected (CPR and NREAP in 2012 equal to 0), according to EGEC around 2ktoe have been produced in 2014 putting the Czech Republic ahead of its NREAP.

2.6.6 Denmark

The history of DH in Denmark has its roots, like other European countries, in the oil crisis in the winter of 1973. The need of an higher efficiency of the heating system brought Denmark to have 62.5% of the households connected to a DH grid and it keeps growing (4.1% between 2008 and 2012). Unlike Czech Republic, 40% of the energy consumed for DH comes from renewable resources. Coal accounts a share of 16.4% in 2011 (not considering CHP plants) and natural gas 32%.

There were around 400 district heating system installed in Denmark in 2011, three of them exploit their energy from geothermal resources: Copenhagen Margrethehoim (13.7MW$_{th}$), Sonderborg (12.5MW$_{th}$) and Thisted (7MW$_{th}$). Combined they produce 6.9ktoe. Ten additional plants are already planned or under construction. The additional capacity should be around 228MW$_{th}$

As shown in Figure 22 most of the Danish area is suitable for geothermal DH with temperatures between 60°C and 100°C at 2000m depth. Therefore 75% of the population could be supplied by geothermal DH, covering in 2050 2540ktoe of heating consumes.

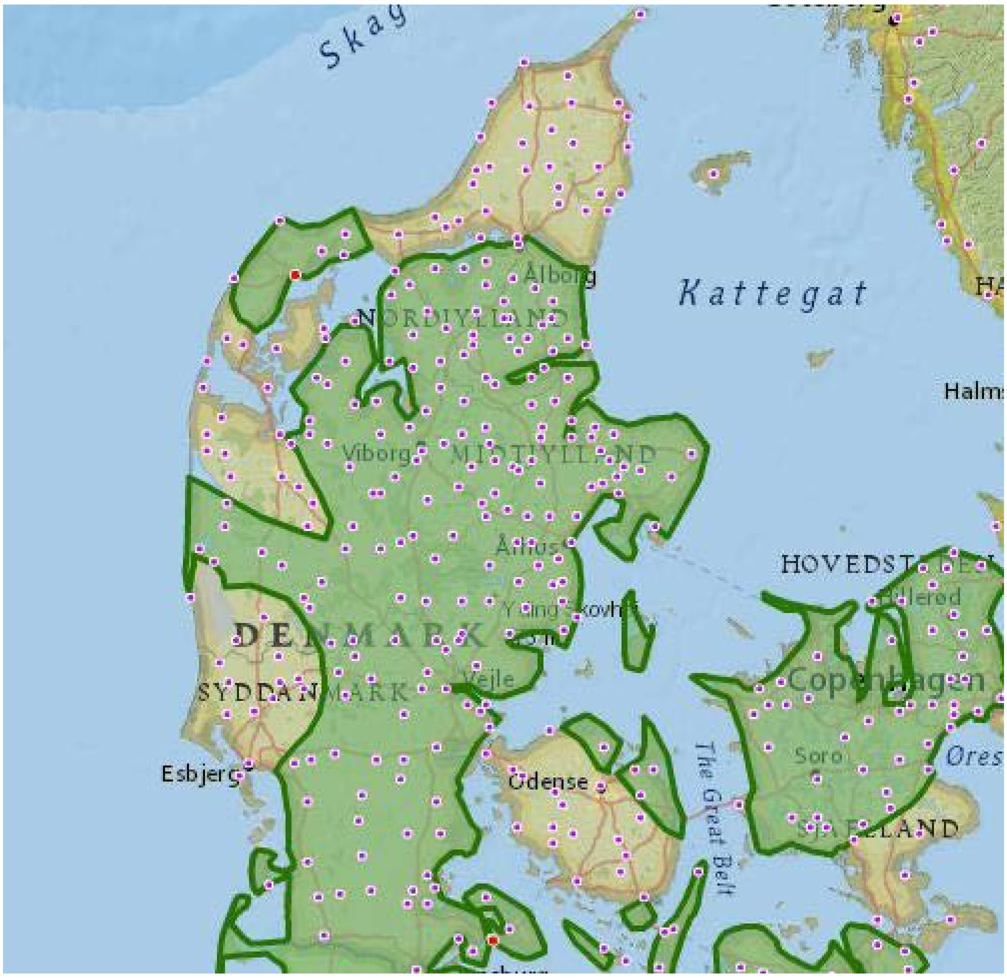


Figure 22 Map of geothermal potential in Denmark

Although three geothermal DH are running, 0ktoe are declared in the NREAP in year 2012. Data differ in CPR and EGEC reports and the reason is not clear: only one new DH system has been built since 2005 (in 2013) and its contribution was set on 0MWh$_{th}$ in 2014, so its production wasn’t counted in the 6.87ktoe reported.

2.6.7 France

In terms of geothermal DH, France is the second most developed country in Europe. Like Denmark, geothermal resources started to be developed since the oil crises in the ’70s.

Low enthalpy resources are primary located in two basins: the Paris Basin and the Aquitaine Basin in southwest France (see Figure 23). The Paris Basin has five large aquifers, including the Dogger which has the largest number of low-energy geothermal operations in the world(GeoDH, November 2014).

District heating is already partially developed, covering approximately 7% of the heating demand. The fuel used has been moving over the last decade from gas (the prominent resource) to more renewable resources such as waste (24%). Geothermal energy's share accounts 3.1%.

The French DH system's landscape is characterized by a high number of small or medium-size plants. According to EGEC report, there are in operation 45 DH systems, totalizing 319.5MW of installed capacity and producing 107ktoe in 2014. This means that the average installed capacity of a single plant is around 7MW.

Additional 45 plants are under construction or exploration. France together with Germany is one of the biggest investor of the EGS: 12 of the 45 new plants will exploit in facts Enhanced Geothermal System, contributing to the development of the technology which will play a key role in the future of geothermal energy in Europe and all over the World. According to GeoDH, geothermal heat production is expected to increase by a factor of 5 between 2006 and 2020.

Figure 23 shows the French morphology situation and as previously written, geothermal basins are located mostly in the Paris area and southwest, at the border with Spain. Luckily, these high-temperature areas include many big cities and metropolis like Paris, Toulouse, Lyon and Marseille. Of course, this increase the potential share of population which could be reached by a geothermal DH. 37% of the French population live in areas suitable with geothermal energy at a temperature from 60 to 100°C at 1000m depth. An additional share of 6.2% live in areas with underground temperature above 100°C at 2000m depth. The potential of geothermal energy DH in France is, in 2050, 11108ktoe.

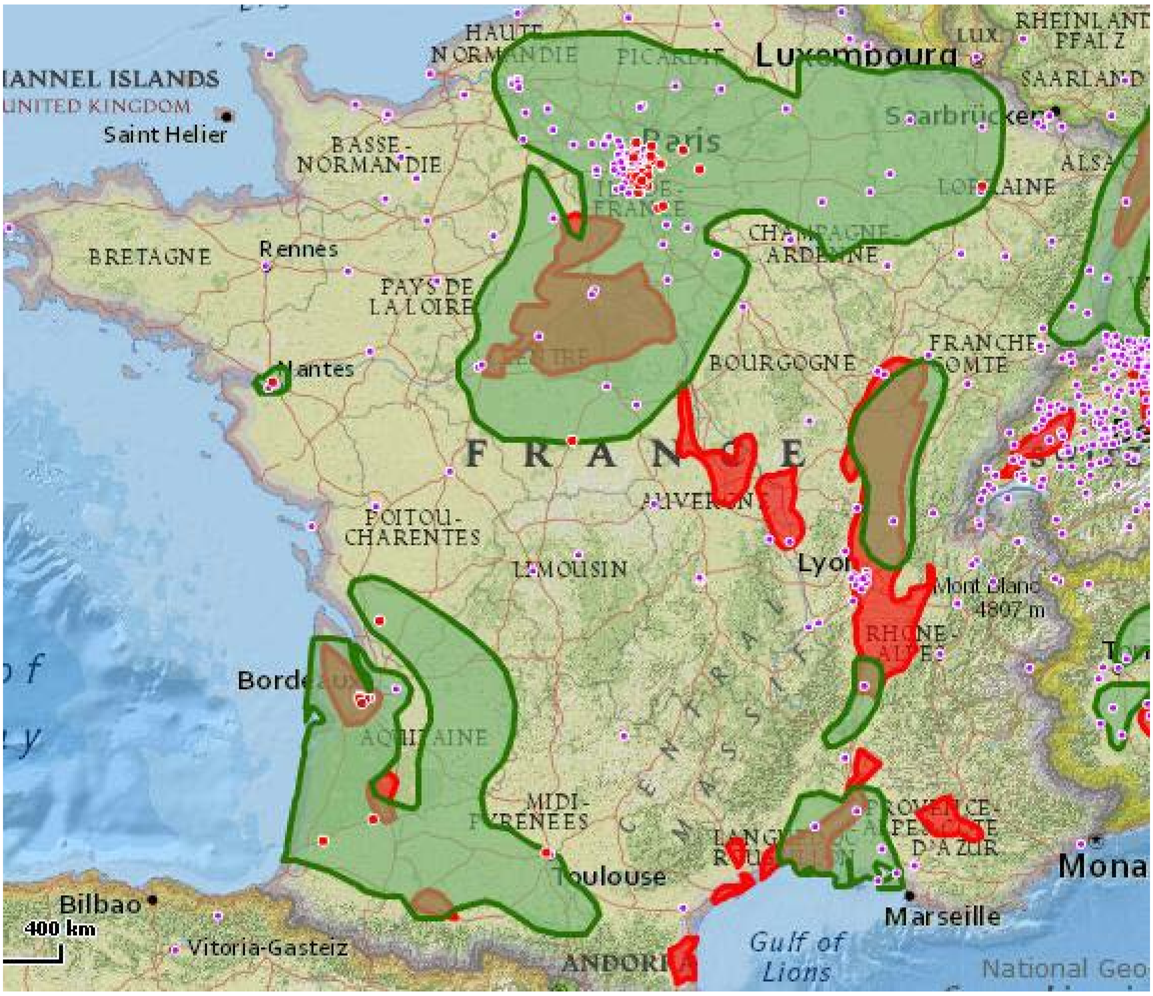


Figure 23 Map of geothermal potential in France

With 195ktoe in 2012 and 500ktoe by 2020, the French action plan is one of the most bold in Europe, second only to Iceland and Italy. However, the data show that the established targets have not been accomplished in 2012 even though the trend is positive and the geothermal DH share is increasing yearly.

2.6.8 Germany

Germany's geothermal resources are located in three different areas: Northern Germany, Southern Germany and the upper Rhine Graben. Both German particular history and morphology have contributed to the development of DH system. 31% of the population resident in the former East-Germany is connected to a DH, compared to around 8% in West-Germany.

In Germany there are 3390 DH plants, mainly powered by natural gas (44%) and coal or its derivatives (42%). The geothermal energy as resource for DH is used by 25 systems with a total installed capacity of 270.5MW$_{th}$ and accounting a production in 2014 of 29.97ktoe.

The landscape of geothermal energy exploitation in Germany is one of the most flourishing in Europe with 44 under construction or planned plants with an expected installed capacity of at least 600MW$_{th}$. Five of the 44 above mentioned planned plants will exploit EGS.

The potential of Germany in geothermal DH is huge. With more than 82 million inhabitants, Germany is the most populous country in Europe and nearly a half of them can be reached with a geothermal district heating system. With an expected heat demand in 2050 up to 536TWh, the potential of geothermal DH accounts for 23,096ktoe.

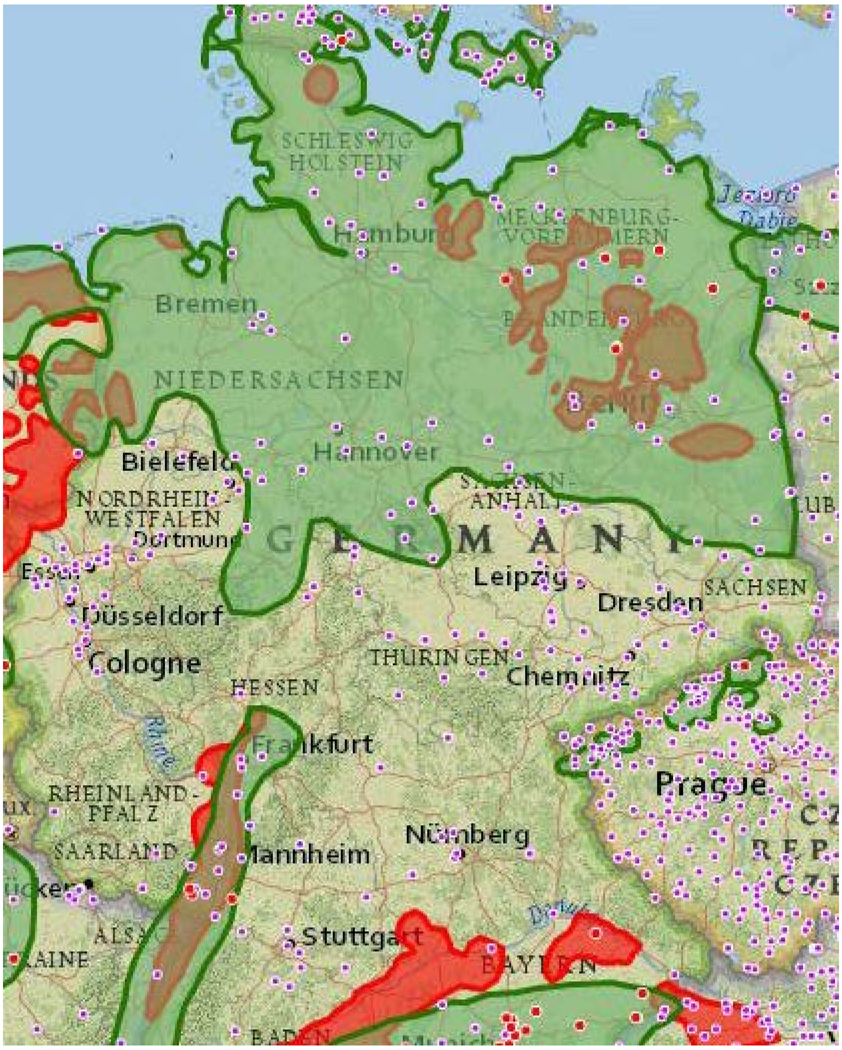


Figure 24 Map of geothermal potential in Germany

Both actual shares in heat consumption from geothermal resources published in CPR and EGEC reports are lower than in NREAP expected. The high 2020 target (set at

686ktoe) which would lead Germany to be the top of European countries for geothermal heat production needs the adoption of a larger action plan.

2.6.9 Greece

In Greece there is no District Heating system operating with renewable sources, including geothermal energy. The potential is concentrated in the Aegean Islands and in the far east regions (Evros, Xanthi, Rodopi and Kavala, on the right in Figure), close to the border with Turkey. A good part of the suitable area is formed by tiny islands, very touristic and with few inhabitants, which makes the realization of DH less appetible. Therefore the geothermal energy sector has developed in a more *single user* direction: according to the 2012 CPR, 13ktoe of deep geothermal energy has been extracted for heating and cooling purposes, more than other countries such as Croatia, Denmark, the United Kingdom and the Netherlands. Anyway, the first DH plant has been planned to be built in Polichnitos, Lesvos island, one of the most populated Greek islands and well known for its thermal facilities.

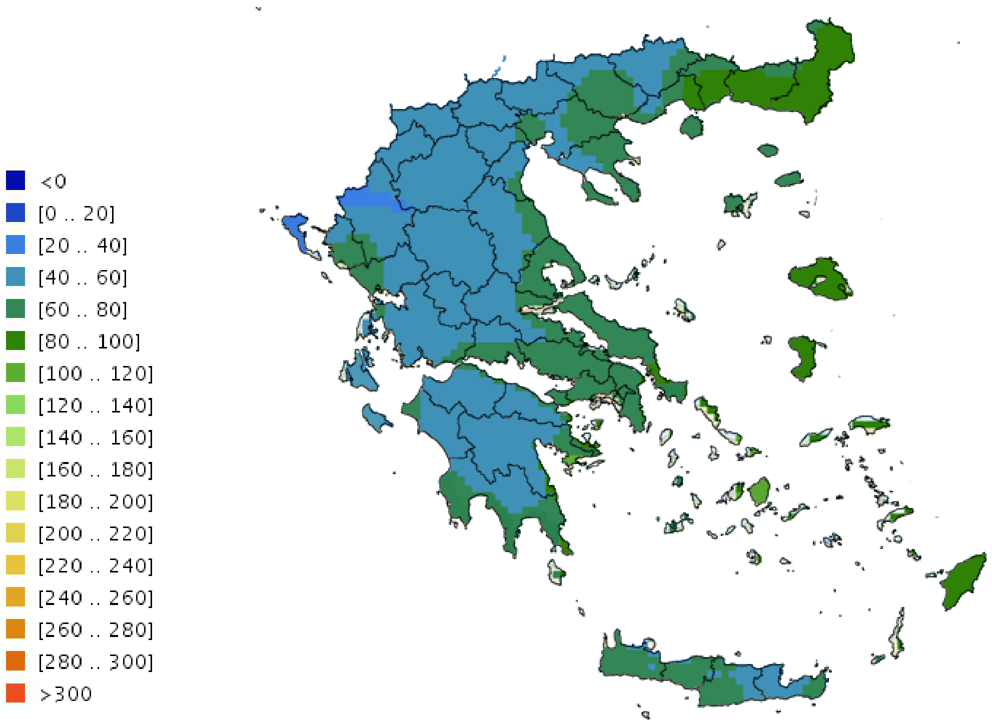


Figure 25 Model temperature at 2000m depth of Greece (source: GeoELEC Viewer modified)

6.88% of the Greek population lives above geothermal reservoirs with temperatures above 60°C at 1000km depth, corresponding to 2.56TWh in 2050. 68.19% of the population is suitable with temperature above 60°C at 2km depth, corresponding to 25.35TWh, and 3.12% with temperatures above 80°C, corresponding to 1.16TWh.

Region	Population	Potential @1km & T> 60°C	Potential @2km & T>60°C	Potential @2km & T>80°C	Population suitable @1km & T>60°C	Population suitable @2km & T>60°C	Population suitable @2km & T>80°C
	Inhabt.	*%*	*%*	*%*	*Inhabt.*	*Inhabt.*	*Inhabt.*
Evros	147,956	76.95%	100.00%	94.91%	113,852.1	147956	140425
Xanthi	108,569	53.65%	100.00%	62.72%	58,247.27	108569	68094.48
Rodopi	110,675	63.02%	100.00%	81.61%	69,747.39	110675	90321.87
Drama	98,916		28.99%		0	28675.75	0
Kavala	138,854	28.66%	84.71%	28.66%	39,795.56	117623.2	39795.56
Imathia	144,413		7.97%		0	11509.72	0
Thessaloniki	1,165,650		70.32%		0	819685.1	0
Kilkis	85,087		2.65%		0	2254.806	0
Pella	144,133		0.00%		0	0	0
Pieria	128,655		24.60%		0	31649.13	0
Serres	183,129		63.11%		0	115572.7	0
Chalkidiki	102,735		75.55%		0	77616.29	0
Grevena	30,592		0.00%		0	0	0
Kastoria	53,206		0.00%		0	0	0
Kozani	154,160		0.00%		0	0	0
Florina	53,773		0.00%		0	0	0
Karditsa	113,438		0.00%		0	0	0
Larisa	288,407	3.45%	21.53%		9,950.04	62094.03	0
Magnisia	203,779		97.86%		0	199418.1	0
Trikala	128,527	33.18%	0.00%		42,645.26	0	0
Arta	69,434		0.00%		0	0	0
Thesprotia	42,332	43.74%	61.89%		18,516.02	26199.27	0
Ioannina	184,023		11.42%		0	21015.43	0
Preveza	56,999		100.00%		0	56999	0

Zakynthos	40,597	0.00%		0	0	0
Kerkyra	133,556	0.00%		0	0	0
Lefkada	21,992	0.00%		0	0	0
Kefallinia	37,857	0.00%		0	0	0
Aitoloakarnania	216,395	11.38%		0	24625.75	0
Ileia	176,795	15.37%		0	27173.39	0
Achaia	348,816	7.86%		0	27,416.94	0
Evvoia	206,247	100.00%	5.98%	0	206,247	12333.57
Fokida	38,795	52.78%		0	20,476	0
Voiotia	124,857	98.53%		0	123,021.6	0
Evrytania	19,137	0.00%		0	0	0
Fthiotida	164,694	33.01%		0	54,365.49	0
Argolida	102,103	14.43%		0	14,733.46	0
Arkadia	86,520	14.43%	1.79%	0	12,484.84	1548.708
Korinthia	145,806	25.60%		0	37,326.34	0
Lakonia	91,000	57.17%		0	52,024.7	0
Messinia	162,183	57.17%		0	92,720.02	0
Attiki	4,109,074	100.00%		0	4,109,074	0
Lesvos	105,035	100.00%	82.28%	0	105,035	86422.8
Chios	51,704	100.00%	91.00%	0	51,704	47050.64
Samos	42,239	100.00%	100.00%	0	42,239	42239
Dodekanisos	198,499	100.00%	100.00%	0	198,499	198499
Kyklades	113,768	100.00%	44.16%	0	113,768	50239.95
Irakleio	305,380	66.84%		0	204,116	0
Lasithi	75,216	30.27%		0	22,767.88	0
Rethymni	82,210	95.96%		0	78,888.72	0
Chania	152,150	93.69%		0	142,549.3	0
Total	11,290,067			352,754	7,698,769	776,971
Percentage of Population suitable				**3.12%**	**68.19%**	**6.88%**

Table 8 Area and population of Greece suitable with DH

Even though not within a DH system, Greece produced 13ktoe of heat through geothermal energy in 2012. NREAP reports 21ktoe to be produced in the same year in order to accomplish the 2020 targets.

2.6.10 Hungary

95 DH system are already operating on the Hungarian territory (in 2011) supplying 655,000 households (15.2% of all households). Like other European countries, the majority of them is powered by non-renewable fuels: in 2009 natural gas accounts for 92.3% and only 2.8% of the heat supplied was produced from renewable resources (including geothermal). However the presence of an installed and developed heating grid helps the future integration of geothermal energy by keeping low the costs.

At the time (2014 data) Hungary has 21 plants for geothermal DH in operation producing 62.3ktoe in 2014 with a total installed capacity of 198.27MW$_{th}$. The majority of them are located between the capital city Budapest and the Romanian Border and nearby the border with Croatia. Additional 19 plants are planned, but the expected capacity is currently unknown.

Hungary lies on a positive geothermal anomaly which covers a large portion of the country. As shown in Figure 26, most of the Hungarian territory is suitable with geothermal DH reaching 90% of the Hungarian Population with temperature over 60°C at 1000 and 2000m depth. The expected heating demand in 2050 is 56,466GWh and it leads to a DH potential of 4,369ktoe.

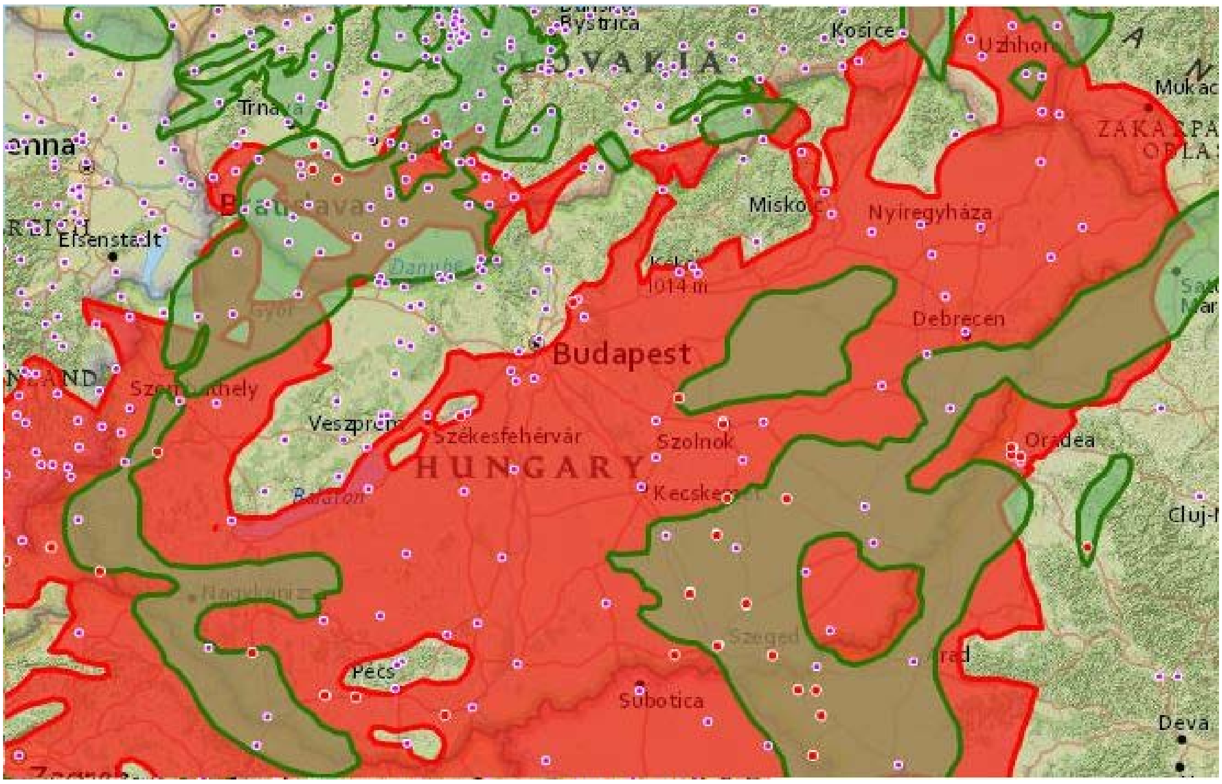


Figure 26 Map of geothermal potential in Hungary

The Hungarian NREAP gives targets only for deep geothermal, and within that does not differentiate between types of use.

Hungary has a target of 14.65% renewable resources by 2020 with a geothermal share of 9% to 17%. The share of RES in heating & cooling is expected to grow from 9% in 2010 to 18.9% in 2020 and the direct use of geothermal from 4.23 to 16.43 PJ (including a significant 20% of agricultural use).

2.6.11 Iceland

Iceland is well known for its huge geothermal potential. Like other European countries, Iceland began its geothermal exploitation after the oil crisis in the 1970s. Today, almost 90% of Iceland’s houses and buildings are heated by natural hot water. In 2013 32 heat plants were already operating in Iceland with an impressive total installed capacity of 2169MW_{th} producing 8027GWh. The largest heat plant is located in the Capital City of Reykjavik, it has been built in 1930 and its capacity is of an astonishing 1000MW_{th}. No other existing or projected heating plants outside Iceland is nearly comparable to it. As planned, the extension of Hellisheidi will increase the total installed capacity of further 267MW_{th}.

Therefore the Icelandic potential is surely underestimated: As said in chapter *Methodology*, the method treated in this thesis involves some approximations, which lead to a systematic error in the potential's calculations. This error is contained as long as the considered region has a population spread equally all around its territory. We approach this condition typically when the considered region is small (which is true for the majority of the European regions). The largest the region is, the lowest becomes the accuracy of this approach. The Icelandic case is in these terms the worst-case scenario: very low population density, concentrated in few villages which themselves are located only on the coast, leaving the whole inside practically uninhabited. The territory is divided into two regions, the first one containing the capital city Reykjavik (Hoefudborgarsvaedi) and the second one comprehend the rest of the country (Landsbyggd). Around 200000 people live in Hoefudborgarsvaedi, making the region relatively high populated, and only 100000 people live in the rest of the country, an area of 99258km^2 with a demographic density of 1.2inhabitant/km^2, one of the lowest in Europe.

The geothermal potential for DH calculated in this thesis reports that 15.67% of the population (although, as said, in this case the difference between area's percentage and population's is significant) is suitable with temperatures above 60°C at 1km depth (177.1ktoe). 78.95% of the Icelandic population is suitable with temperature above 60°C at 2km depth (892.1ktoe) and 68.09% with temperature above 80°C (769.4ktoe).

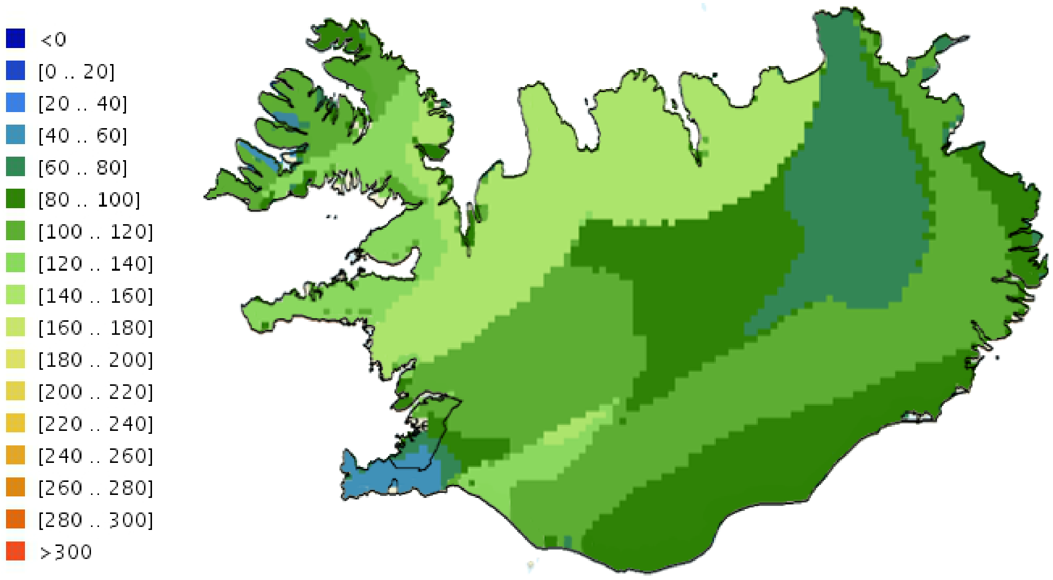


Figure 27 Model temperature of Iceland at 2000m depth (source: GeoELEC Viewer modified)

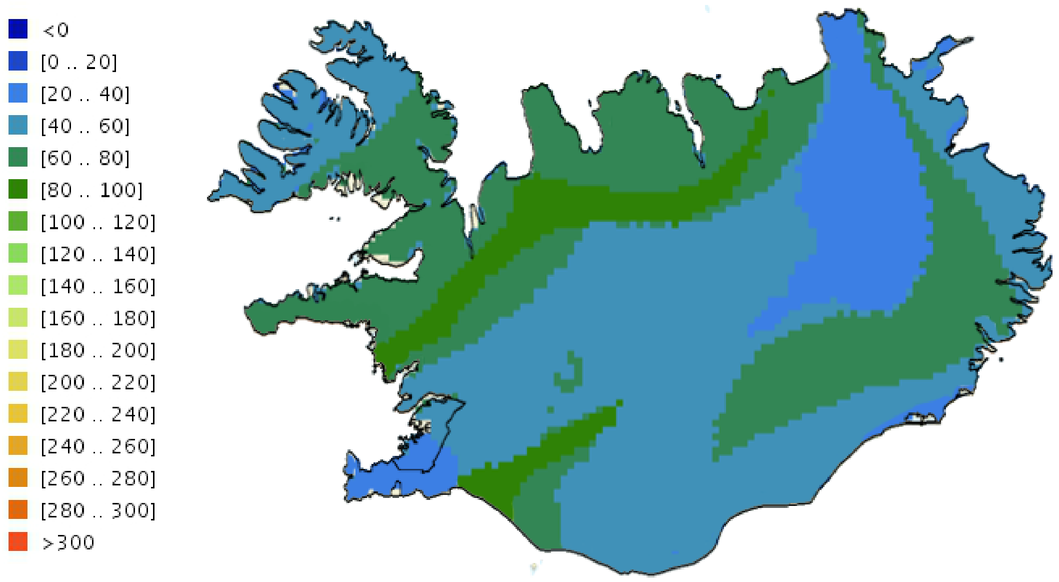


Figure 28 Model temperature of Iceland at 1000m depth (source: GeoELEC Viewer modified)

With 724ktoe produced in 2012 and 722.7 expected in the same year in its NREAP, Iceland is perfectly respecting the plans for 2020 targets.

2.6.12 Ireland

In Ireland is the geothermal energy only present in its low enthalpy form. The geothermal gradients go from 10°C/km in Southern Ireland up to 35°C/km in the north east. (GeoDH, November 2014)

Nowadays there are no geothermal district heating systems built or under construction in the island. (EGEC, 2013)

As shown in Figure 29 some portions of Ireland are suitable with geothermal DH. Around 35% of the population is suitable with temperatures between 60 and 100°C at 1000m depth. With an estimated heating and cooling demand of 34TWh in 2050, the potential of geothermal district heating in Ireland corresponds to 12TWh.

Figure 29 Map of geothermal potential in Ireland

No energy was expected to be produced in 2012 in Ireland and so has been. The Irish government didn’t focus on geothermal energy to reach the 2020 targets.

2.6.13 Italy

Even though the geothermal energy is pretty much developed as a source for electricity generation in the italic peninsula, it is not the same for heating purposes, as the district heating system of Italy has been discarded in favor of an extensive gas network. In 2011 DH served 133 cities covering 3.6% of total heating demand. 76% of the total supply was powered by natural gas, 13% by waste and only 1% by geothermal energy. (GeoDH, November 2014)

In 2013 19 district heating were operating in the Italian territory with a total installed capacity of 129.41MW$_{th}$ and they produced 261.3GWh. The largest one is located in Pomarance, Pisa, Tuscany with 21MW$_{th}$. Other 13 plants (included 3 extensions of existing plants) are under construction or investigation installing at least additional 117.5MW$_{th}$. (Angelino, 2013)

As shown in Figure 30 the majority of non-mountain territory is suitable with temperature between 60 and 100°C at 1000m depth, covering around 50% of the total population. As reported by GeoDH “The area that can be fully covered with geothermal installations includes NUTS3 regions of Cremona, Mantua, Monza and Brianza, Padua, Rovigo and cities such as Venice, Milan and Pisa.”

The additional percentage of population suitable with temperatures above 100°C at 2000m depth is around 6%, leading the total amount to 56%, corresponding to 156.7TWh in 2050.

Figure 30 Map of geothermal potential in Italy

According to the Italian NREAP, the production of geothermal heat in 2012 should have been second only to Iceland with 239ktoe. Only 134ktoe have been produced, consistently less than expectation: Italy will need stronger measures if it wants to accomplish its 2020 goals.

2.6.14 Latvia

Research into geothermal energy resources has been carried out in Latvia since the 1980’s. Between 1970 and 1990 23 boreholes were drilled in the western part of Latvia. District heating system with renewable fuels are increasing their share in the national heating market, nevertheless no geothermal DH system has been installed and none are planned to be in the future.

A part of the Lithuanian basin (see the next chapter) crosses the southern border of Latvia, making suitable two NUTS3 regions, Kurzeme and Zemgale, with temperature between 60 and 80°C at 2000m depth. The proportion of population suitable with district heating is 2.89%, corresponding to a potential in 2050 of 425.1MWh.

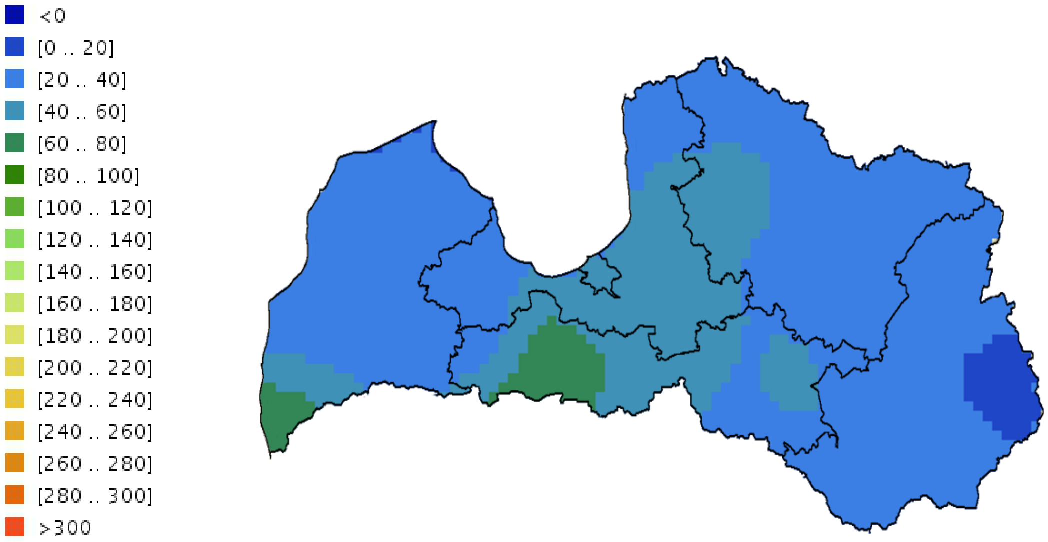


Figure 31 Model temperature at 2000m depth of Latvia (source: GeoELEC Viewer modified)

Region	Population	Potential @2km & T>60°C	Population suitable @2km & T>60°C
	Inhabt.	*%*	*Inhabt.*
Kurzeme	266,313	5.59%	14,886.9
Latgale	298,487	0%	0
Riga	650,478	0%	0
Pieriga	368,179	0%	0
Vidzeme	208,129	0%	0
Zemgale	250,177	17.66%	44,181.26
Total	2,041,763		59,068.15
Percentage of Population suitable			**2.89%**

Table 9 Area and population suitable with temperature above 60°C at 2km depth in every NUTS3 region of Latvia

The little geothermal potential of Latvia is reflected in its NREAP: no developments are expected in the geothermal field. Latvia will pursue its goals with other renewable energies.

2.6.15 Lithuania

Within the three Baltic Countries, Lithuania is the one with the most interesting geothermal situation. The only district heating system of the country is located in Klaipėda, it has a capacity of 13.6MW$_{th}$ and in 2012 it generated 93.9GWh. Another 9.5MW$_{th}$ are planned to be installed in Vilkaviskis. (Angelino, 2013)

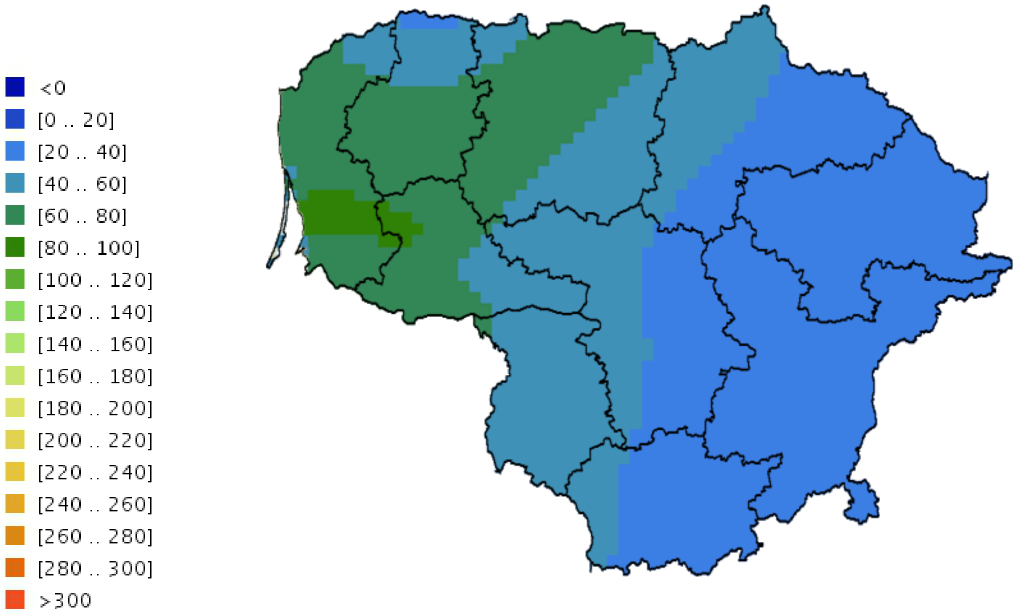


Figure 32 Model temperature at 2000m depth of Lithuania (source GeoELEC Viewer modified)

No potential is available over 2000m depth. At 2000m depth the regions of Klaipedos and Taurages are the only two suitable with temperature above 80°C. With temperature above 60°C are suitable other regions such as Siauliu and Telsiu and the potential of Klaipedos and Taurages increases respectively of +68.75% and +62.44% (Table 10).

With an heating and cooling demand in 2050 of 15573GWh, the geothermal DH potential with temperature above 80°C at 2km depth is around 383.1GWh and with temperatures between 60°C and 80°C is 3108GWh (other potential excluded).

Region	Population	Potential @2km & T>60°C	Potential @2km & T>80°C	Population suitable @2km & T>60°C	Population suitable @2km & T>80°C
	Inhabt.	*%*	*%*	*Inhabt.*	*Inhabt.*
Kauno apskritis	600,363	0%	0%	0	
Klaipedos apskritis	335,304	87.62%	18.87%	293,793.4	63,271.86
Marijampoles apskritis	159,447	1.17%	0%	1,865.53	0
Panevezio apskritis	246,591	0%	0%	0	0

Siauliu apskritis	296,305	56.22%	0%	166,582.7	0
Taurages apskritis	108,320	68.74%	6.30%	74,459.17	6,824.16
Telsiu apskritis	150,111	68.48%	0%	102,796	0
Utenos apskritis	149,179	0%	0%	0	
Vilniaus apskritis	806,935	0%	0%	0	
Total	2,852,555			639,497	70,096
Percentage of Population suitable				**22.42%**	**2.46%**

Table 10 Area and population suitable at different depths for every NUTS3 region of Lithuania

3ktoe expected in 2012 in its NREAP were maybe too few: even though the CPR reports only 2ktoe produced, more than 8ktoe have been sold through a DH system in 2014. For what concerns geothermal energy, Latvia is likely to pursue its goals if it keeps this trend.

2.6.16 Luxemburg

Luxemburg shows no particular interest in the exploitation of geothermal energy. The share of it in heating and in electricity generation sector is 0% and no installation of new facilities is planned within the next years, although there is the willingness to improve the DH system powered with biomasses (76.4ktoe in 2020 according to its NREAP).

The territory at 1000m depth of both countries lays entirely under the threshold temperature of 60°C, however the temperature at 2000m depth is above 60°C in the whole territory of Luxemburg. Therefore the geothermal district heating potential of accounts for 5626GWh in 2050.

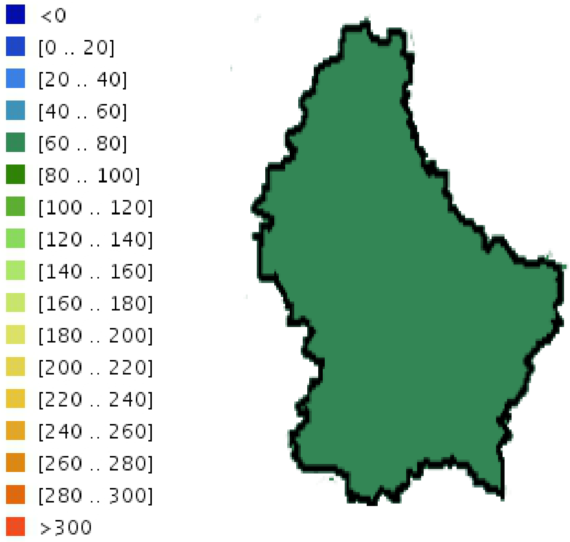


Figure 33 Model temperature maps of Luxemburg at 2000m depth (source: GeoELEC Viewer modified)

Geothermal energy doesn’t play an important role in the renewable energy’s panorama.

2.6.17 The Netherlands

Geologically, the Netherlands are subdivided into three basins (Figure 34): the Western Netherlands, the Central Netherlands and the Broad Fourteens Basin.

The DH system in the Netherlands is increasing, but is still low developed accounting a share of 4.4% of the demand and 92% of it is powered by natural gas (GeoDH, November 2014). Actually there are 8 heat plants exploiting geothermal energy with a total installed capacity of 51MW_{th} and producing 989.2GWh in 2012. Additional 4 are under construction with further 42.9MW_{th}. (EGEC, 2013)

30% of the population is suitable with temperature above 60°C at 1000m depth. An additional 33% is suitable with temperature above 90°C at 2000m depth, corresponding to 61TWh in 2050.

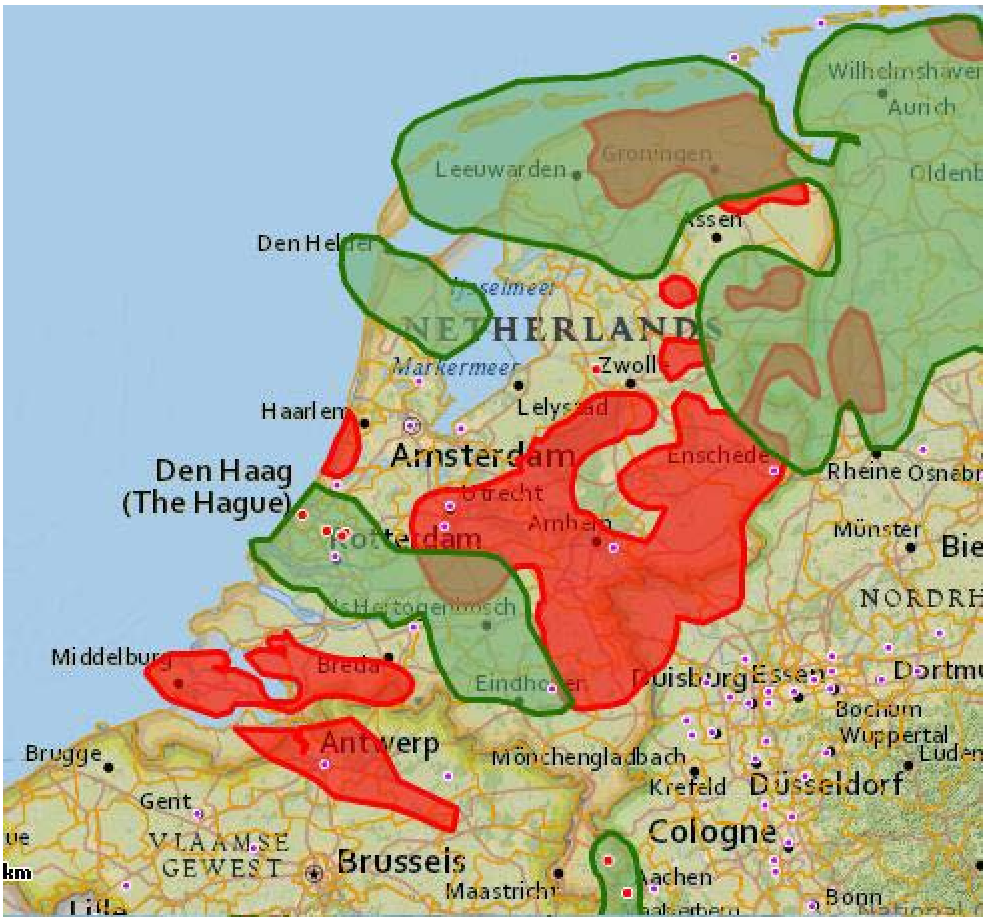


Figure 34 Map of geothermal potential in the Netherlands

Despite a very underestimated CPR (12ktoe in 2012) and a bold NREAP with 75ktoe expected in the same year, according to EGEC the NREAP has been overtaken with more than 85ktoe produced.

2.6.18 Poland

The heating system in Poland is strongly dependent to Coal, supplying 76% of total heat demand. Natural gas accounts for 6.77% and deep geothermal only 0.09%. In 2010 there were 6 heat plants with a total installed capacity of 101.9MW_{th} producing 159.6GWh. Two of them are planned to be extended in the next years (Uniejow's extension should be operating since December 2014) leading at least to further 8MW of capacity. (GeoELEC, 2013)

10% of the population is suitable with temperature above 60°C at 2000m depth, including important cities such as Szczecin and Lodz and NUTS3 regions such as Lodzki, Koninski, Szczecinski and Warszawski Zachodni. With a heating and cooling demand in 2050 of 238.88TWh, the potential of geothermal district heating in Poland accounts for 23.88TWh[21].

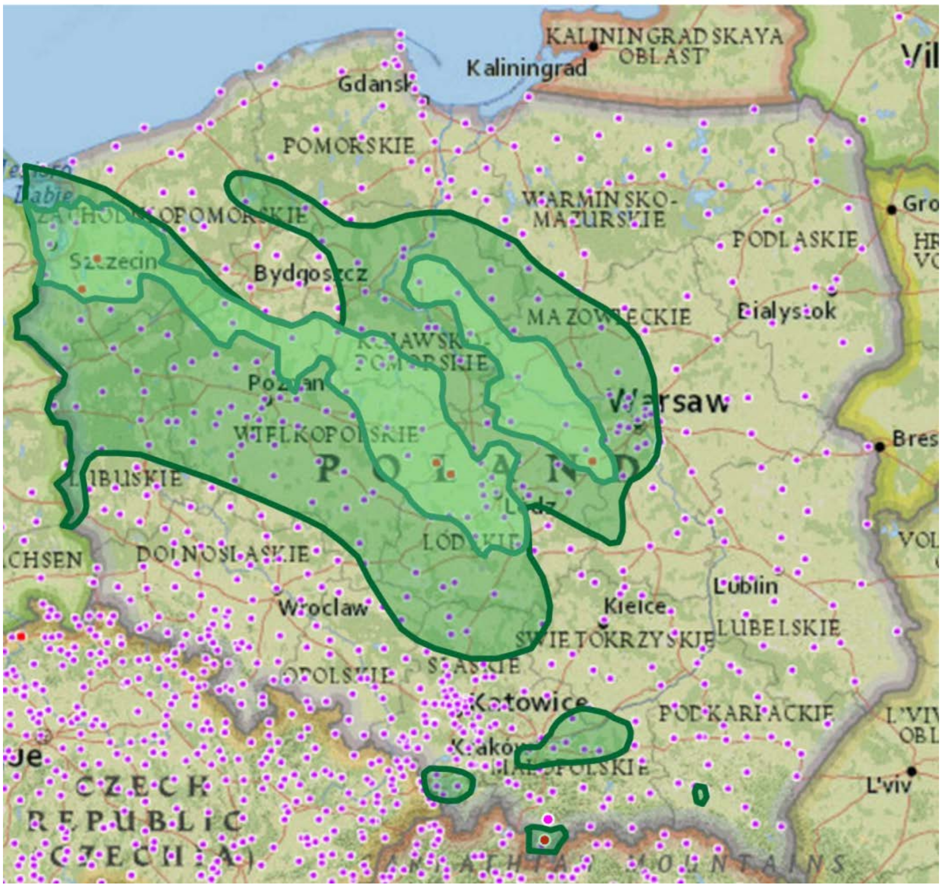


Figure 35 Map of geothermal potential in Poland

With 15.8ktoe produced in 2012, Poland hasn't accomplish its mid-term goals set at 29ktoe in the same year: stronger measures are needed in the coming years.

2.6.19 Portugal

Two DH systems are operating in the Portugal's territory with a total installed capacity of 1.5MW$_{th}$. No data are available regarding their heating production in 2012, as no data are available for a planned DH system in Lisbon. (EGEC, 2013)

Portugal lays like the rest of the Iberian Peninsula on a relatively inactive geothermal area. Its whole territory has a temperature under 60°C at 1000m depth. At 2000m

---

[21] GeoDH considers here also potential above 60°C at 3000m depth due to their connection with Early Jurassic reservoirs (op. cit. p. 42). No further reason has been given to explain the particular consideration of Poland's potential. Under these conditions an additional share of 50% of the population becomes suitable, taking the potential up to 143.3TWh in 2050.

depth the NUTS3 regions of Grande Lisboa and Peninsula de Setùbal are suitable with temperature above 80°C in more than a half of their territory (Figure 28).

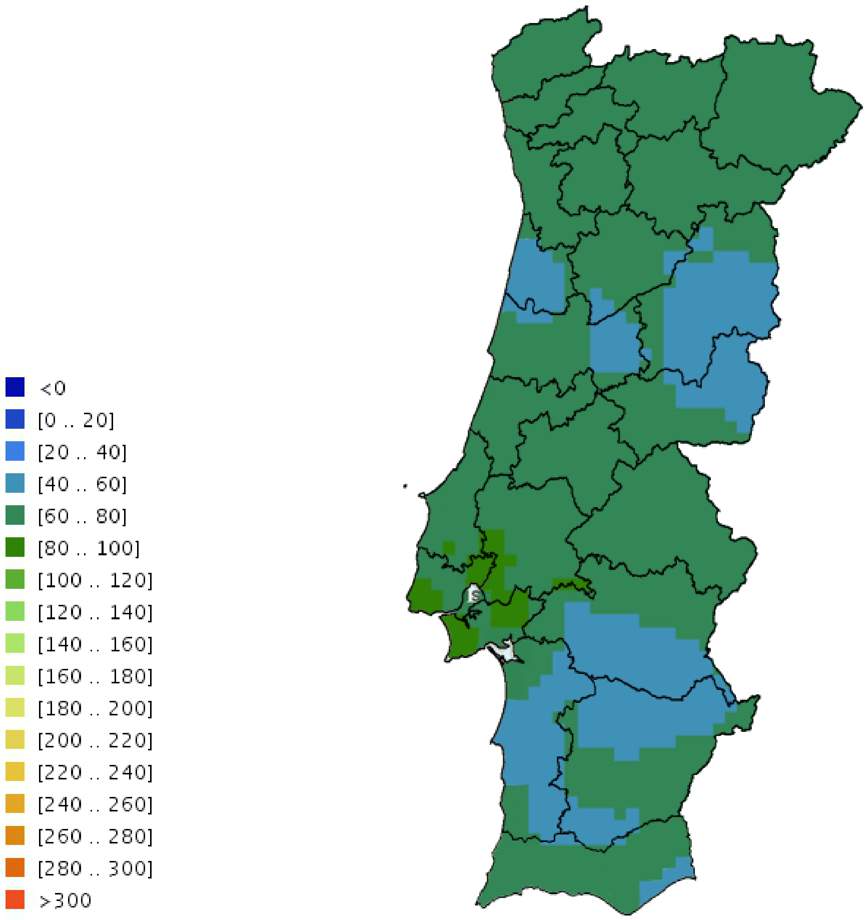


Figure 36 Model temperature of Portugal at 2000m depth (source: GeoELEC Viewer modified)

In 2050 the Portugal's heating and cooling demand should be around 20769GWh, which means that the geothermal potential for DH at 2km depth with temperature above 80°C will be 3.31TWh and above 60°C 18.85TWh.

Region	Popuation	Potential @2km & T>60°C	Potential @2km & T>80°C	Population suitable @2km & T>60°C	Population suitable @2km & T>80°C
	Inhabt.	*%*	*%*	*Inhabt.*	*Inhabt.*
Minho-Lima	243,286	100.00%	0.00%	243,286	0
Cávado	409,764	100.00%	0.00%	409,764	0

Ave	510,603	100.00%	0.00%	510,603	0
Grande Porto	1,284,967	99.87%	0.00%	1,283,296.54	0
Tâmega	549,426	100.00%	0.00%	54,9426	0
Entre Douro e Vouga	274,126	100.00%	0.00%	274,126	0
Alto Trás-os-Montes	202,701	100.00%	0.00%	202,701	0
Douro	204,543	100.00%	0.00%	204,543	0
Algarve	450,993	89.44%	0.00%	403,368.14	0
Baixo Vouga	389,979	23.19%	0.00%	90,436.13,	0
Baixo Mondego	331,681	70.05%	0.00%	232,342.54	0
Pinhal Litoral	260,728	100.00%	0.00%	260,728	0
Dão-Lafões	276,023	88.91%	0.00%	245,412.05	0
Pinhal Interior Norte	130,560	70.05%	0.00%	91,457.28	0
Pinhal Interior Sul	40,308	100.00%	0.00%	40,308	0
Serra da Estrela	43,391	33.00%	0.00%	14,319.03	0
Beira Interior Norte	103,651	33.00%	0.00%	34,204.83	0
Beira Interior Sul	74,469	54.78%	0.00%	40,794.12	0
Cova da Beira	87,362	33.00%	0.00%	28,829.46	0
Médio Tejo	219,742	100.00%	0.00%	219,742	0
Oeste	361,636	100.00%	6.00%	361,636	21,698.16
Grande Lisboa	2,044,636	100.00%	49.75%	2,044,636	1,017,206
Península de Setúbal	779,162	100.00%	65.85%	779,162	513,078.2
Alentejo Litoral	97,697	31.78%	0.00%	31,048.11	0
Alto Alentejo	117,571	100.00%	0.00%	117,571	0
Alentejo Central	166,383	49.16%	1.39%	81,793.88	2,312.72
Baixo Alentejo	125,951	48.98%	0.00%	61,690.80	0
Lezíria do Tejo	246,895	100.00%	17.35%	246,895	42,836.28
Total	10,028,234			9,104,120	1,597,132
Percentage of Population suitable				**90.78%**	**15.93%**

Table 11 Area and population suitable with DH at different depths in every NUTS3 region of Portugal

The geothermal panorama of Portugal hasn't develop as expected till 2012. NREAP estimations were set at 14ktoe in 2012, but according to CPR only 1.6ktoe were produced, none of them as DH system.

2.6.20 Romania

As shown in the Figure 37, the geothermal resources of Romania are principally divided in two large basins: one on the west side, across the border with Hungary and the second one in Southern Romania, southern of Bucharest. The main fuel used for DH is natural gas (71%) followed by coal and coal products (26%). Renewable energies account for 1.2% of the heat supplied through DH system. (GeoDH, November 2014)

In Romania there were 12 heat plants operating in 2012 producing 148.3GWh annually with a total installed capacity of 106.6MW_{th}. The largest one is located in Moara Vlasiei and it accounts for 29.9MW_{th}. 9 projects are under consideration for the future, with an estimated further capacity of more than 300MW_{th}(5 of them are extensions of already operating facilities). (GeoELEC, 2013)

The portion of population suitable with temperatures above 60°C at 2000m depth is around 20%. The Capital City of Bucharest is fully suitable with DH. Furthermore, the population suitable with temperature above 100°C at 2000m depth is around 10%. With a total heating and cooling demand in 2050 of 89790GWh, the potential of geothermal district heating in Romania at 2000m depth is around 26.94TWh.

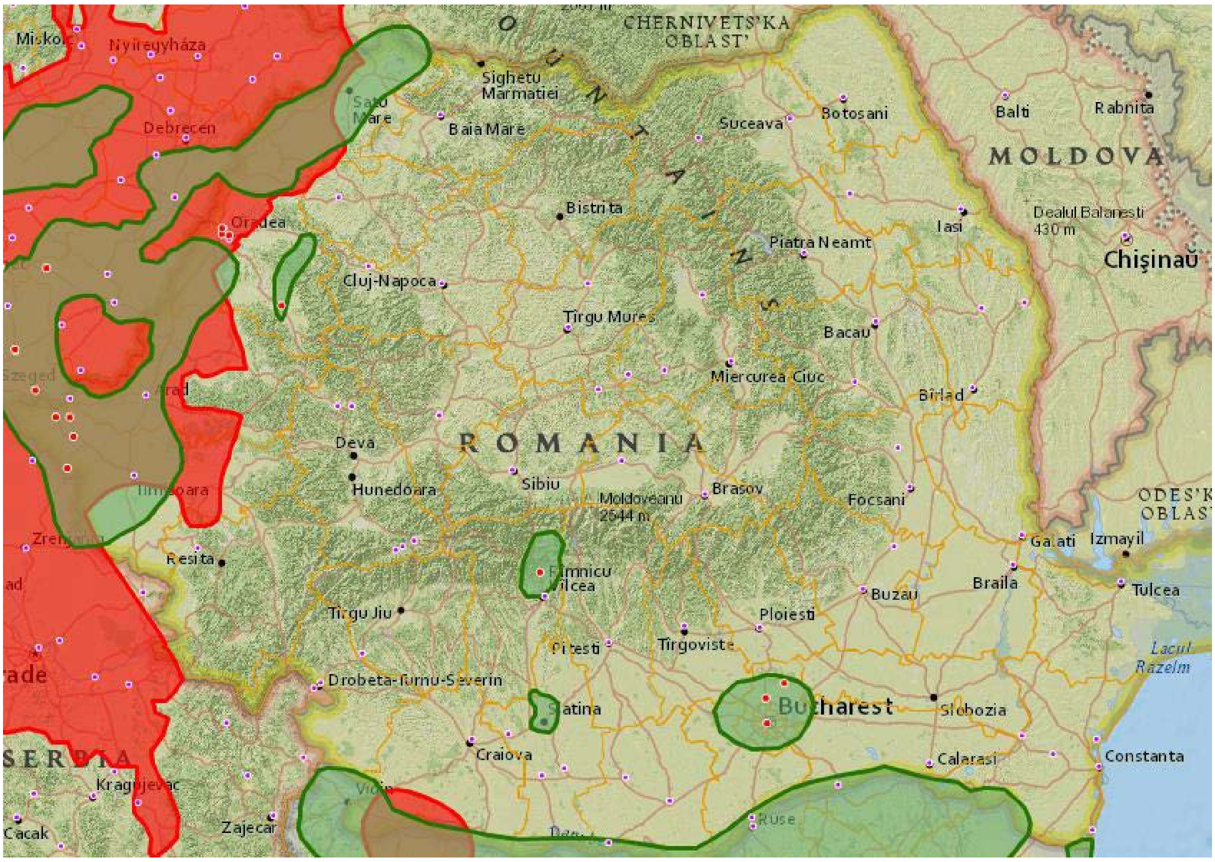


Figure 37 Map of geothermal potential in Romania

NREAP set the 2012 production at 35ktoe. Despite of that, only 21.5 were produced.

2.6.21 Scandinavia and Estonia

Due to the similar geothermal characteristics of the Scandinavian countries and Estonia, all of them have been considered and briefly discussed together in this chapter.

In all 4 countries geothermal resources are poorly exploitable and developable. The whole region has a mean temperature at 2000m depth of about 20 to 40°C and it also owns the coldest region of European continent: the Lapin, with an average temperature around 18°C.

The first technical interesting temperature is found at 4000m depth in the very south of the Finnish country, enclosing the Helsinki’s area, where, in facts, the first geothermal DH system is under exploration. Located in Espoo, Finland, it could reach a total capacity of 40MW. Despite of that, Finnish NREAP reports 0ktoe of geothermal energy production by 2020.

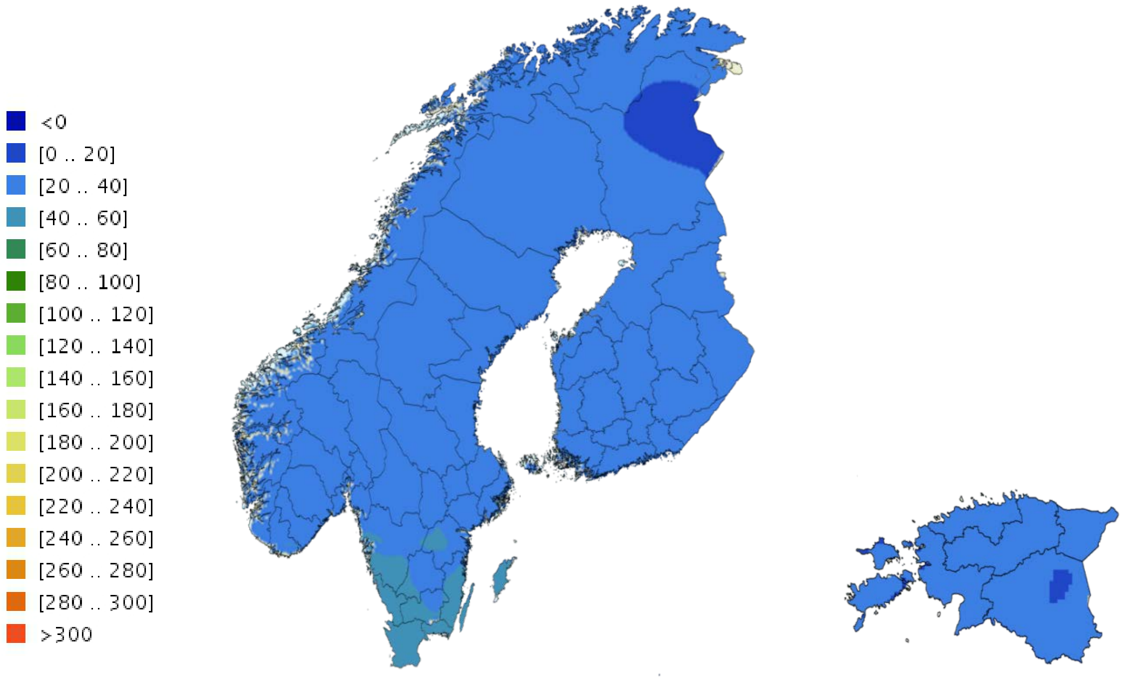


Figure 38 Map of temperature model of the Scandinavian peninsula and Estonia. Source: GeoELEC Viewer

Norway does not provide a CPR to the EC. Neither Sweden nor Finland nor Estonia report geothermal energy’s production in their CPR, even in the one published in 2015. EGEC report confirms the situation of Finland and Estonia, but according to it, a heat plant located in Lund, Sweden produced 270GWh (23.22ktoe) in 2012. In facts, according to the temperature model of GeoELEC, the area of Malmo (where Lund is located) is the only spot of the whole peninsula owning an underground temperature higher than 60°C (around 75°C in the proximity of Lund), but not before reaching 3000m depth.

2.6.22 Slovakia

The Slovakian geothermal landscape is defined by two large regions: the Carpathian Mountains and the Pannonian Basin. According to GeoDH: “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.”

The Eastern Slovakian Basin is the most active geothermal region in Slovakia and therefore the most suitable with geothermal DH. (European Commission, 1999)

In 2013 89% of the 2361 DH systems in Slovakia were powered using natural gas (61%), coal or its derivate (28%). The use of Biomasses is increasing and it accounts for 7%. 4 geothermal heating plants were operating with 14.2MW$_{th}$ of installed capacity, but no data has been collected regarding the energy production. 7 further plants were in the initial phase of construction or design. They should increase the installed capacity of at least 14MW$_{th}$.

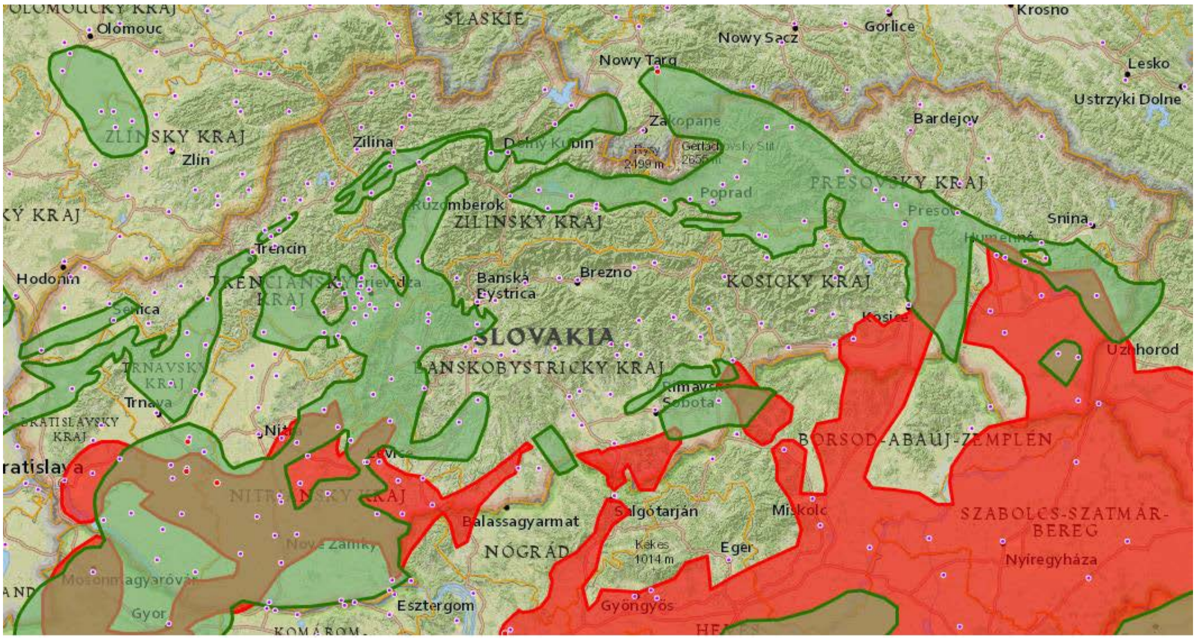


Figure 39 Map of geothermal potential in Slovakia

The share of Slovakian population suitable with temperature between 60°C and 100°C at 2000m depth is around 50% and above 100°C a further 20%. With a forecasted heating and cooling demand in 2050 of 25.5TWh, Slovakia’s geothermal district heating’s potential is around 17.9TWh.

Slovakia doubled its NREAP’s estimation producing in 2012 6ktoe while only 3ktoe were planned.

2.6.23 Slovenia

As shown in Figure 40, the geothermal potential of Slovenia is concentrated in the eastern and central side of the country.

The primary source of heat for DH in Slovenia are coal, coal products (71%), natural gas (13%) and renewable combustibles (11%). Out of the 54 DH operating in Slovenia, only 3 are based on geothermal energy, accounting for $3.72MW_{th}$ and 6.27GWh produced in 2012. Five further plants are planned for the coming years. The available data suggest an increase of $13MWh_{th}$.

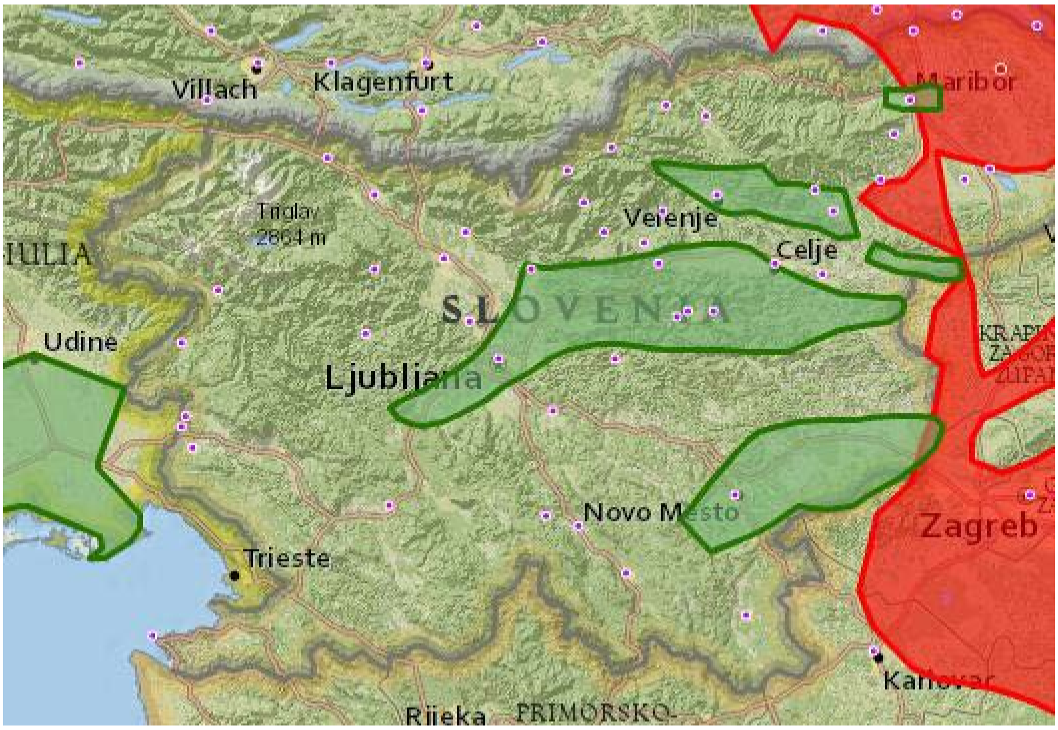


Figure 40 Map of geothermal potential in Slovenia

50% of the population is suitable with temperature between 60 and 100°C at 2000m depth. At the same depth, further 6.5% of population is suitable with temperature above 100°C. This last potential includes only Podravska region, which can be covered by 40% with geothermal installation.

Slovenia planned in its NREAP to produce 18ktoe in 2012. The target has been overtaken with 31ktoe in the same year, although less than 1ktoe was produced for DH system. Slovenia is pursuing very efficiently its 2020 goals.

2.6.24 Spain

Spain is one of the largest country in Europe, however, along with Portugal, the Iberian Peninsula doesn't have a significant tradition in geothermal energy in both DH and electricity generation. In the specific Spain has no district heating systems operating on its territory and no plants are planned to be built in the next years.

At 1000m depth, the whole Spaniard territory lays under the threshold of 60°C, leading to no geothermal potential at such depth. The Spaniard geothermal landscape changes radically in the next kilometer (shown in Figure 41 and Table 12): every NUTS 3 region is at least partially suitable with temperature above 60°C (18 regions are fully covered) and 8 of them have also temperature above 80°C.

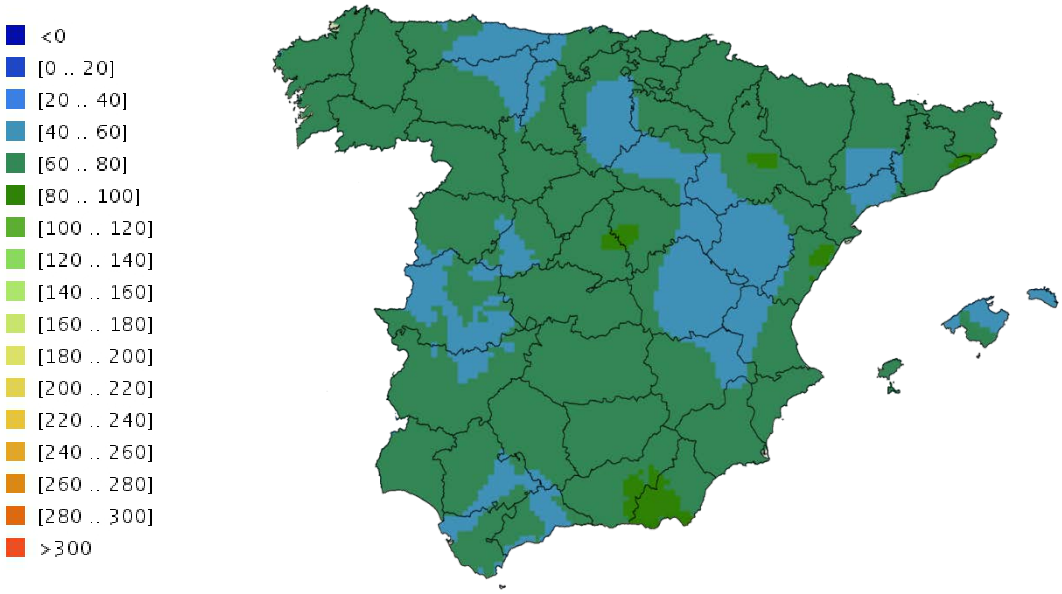


Figure 41 Model temperature of Spain at 2000m depth (source: GeoELEC Viewer modified)

With an estimated heating and cooling demand of 140TWh in 2050, the geothermal DH potential of Spain accounts for 4.9TWh with temperature above 80°C and 120.1TWh with temperature above 60°C (4.9TWh included).

Region	population	Potential @1km & T>60°C	Potential @2km & T>60°C	Potential @2km & T>80°C	Population suitable @2km & T>60°C	Population suitable @2km & T>80°C
	Inhabt.	%	%	%	Inhabt.	Inhabt.
A Coruña	1,123,724	0.0%	100.0%	0.0%	1,123,724	0
Lugo	337,266	0.0%	100.0%	0.0%	337,266	0
Ourense	321,228	0.0%	100.0%	0.0%	321,228	0
Pontevedra	946,688	0.0%	100.0%	0.0%	946,688	0
Asturias	1,052,711	0.0%	49.2%	0.0%	518,144.4	0

Cantabria	578,900	0.0%	74.3%	0.0%	430,064.8	0
Álava	310,080	0.0%	99.0%	0.0%	306,917.2	0
Guipúzcoa	688,083	0.0%	100.0%	0.0%	688,083	0
Vizcaya	1,130,234	0.0%	100.0%	0.0%	1,130,234	0
Navarra	624,607	0.0%	100.0%	0.0%	624,607	0
La Rioja	312,199	0.0%	92.0%	0.0%	287,316.7	0
Huesca	218,918	0.0%	100.0%	0.0%	218,918	0
Teruel	141,139	0.0%	24.5%	0.0%	34,607.28	0
Zaragoza	954,823	0.0%	77.5%	6.6%	740,274.3	63,113.80
Madrid	6387,824	0.0%	100.0%	8.8%	6,387,824	561,489.73
Ávila	166,302	0.0%	66.5%	0.0%	110,607.5	0
Burgos	359847	0.0%	43.7%	0.0%	157,109.2	0
León	477,390	0.0%	68.6%	0.0%	327,298.6	0
Palencia	167,050	0.0%	73.3%	0.0%	122,481.1	0
Salamanca	342,166	0.0%	90.8%	0.0%	310,823.6	0
Segovia	158,970	0.0%	100.0%	0.0%	158,970	0
Soria	92,054	0.0%	41.2%	0.0%	37,889.43	0
Valladolid	526,768	0.0%	98.0%	0.0%	516,180	0
Zamora	188,779	0.0%	100.0%	0.0%	188,779	0
Albacete	396,212	0.0%	73.8%	0.0%	292,404.5	0
Ciudad Real	519,049	0.0%	100.0%	0.0%	519,049	0
Cuenca	211,794	0.0%	21.8%	0.0%	46,107.55	0
Guadalajara	249,217	0.0%	72.6%	8.9%	180,831.9	22,080.62
Toledo	674,546	0.0%	99.6%	0.0%	671,982.7	0
Badajoz	679,107	0.0%	88.7%	0.0%	602,300	0
Cáceres	403,958	0.0%	46.2%	0.0%	186,467	0
Girona	729,557	0.0%	100.0%	3.5%	729,557	25,534.49
Barcelona	5,357,422	0.0%	92.8%	5.8%	4,972,759	312,337.70
Lleida	431,617	0.0%	75.8%	0.0%	326,993	0
Tarragona	799,917	0.0%	56.6%	0.0%	452,673	0
Alicante / Alacant	1,907,990	0.0%	100.0%	0.0%	1,907,990	0
Castellón / Castelló	590,635	0.0%	87.9%	18.7%	518,931.9	110,212.49
Valencia / Valèn-	2,512,922	0.0%	58.2%	0.0%	1,462,521	0

cia						
Almería	691,648	0.0%	100.0%	45.7%	691,648	315,875.64
Cádiz	1,229,926	0.0%	79.1%	0.0%	973,117.5	0
Córdoba	788,196	0.0%	96.2%	0.0%	758,402.2	0
Granada	913,399	0.0%	100.0%	16.3%	913,399	148,610.01
Huelva	509,990	0.0%	100.0%	0.0%	509,990	0
Jaén	651,698	0.0%	100.0%	0.0%	651,698	0
Málaga	1,614,059	0.0%	59.4%	0.0%	958,912.5	0
Sevilla	1,887,466	0.0%	75.1%	0.0%	1,417,864	0
Murcia	1,476,341	0.0%	97.0%	0.0%	1,432,051	0
Illes Balears	1,094,266	0.0%	43.7%	0.0%	478,303.7	0
Total	43,928,682				37,681,988	1,559,255
Percentage of Population suitable					**85.8%**	**3.5%**

Table 12 Area and population suitable with DH at different depth in Spain

Although no DH are now operating or planned in Spain, according to its CPR of 2012, 18ktoe were produced within the same year, while the by NREAP expected amount of geothermal heat produced accounted only for 3.8ktoe. As few other countries, Spain is brilliantly pursuing its 2020 targets.

2.6.25 Turkey

Along with Iceland, Turkey is one of the most promising country for what concerns the geothermal energy sector, already being one of the top country in the world in terms of installed capacity for both electricity and heating purposes.

20 heating plants are operating on Turkey’s soil, accounting 834.79MW$_{th}$ of installed capacity, in Europe second only to Iceland, but only one new facility is planned to be constructed in the future.

Two NUTS3 regions – Canakkale and Balikesir - are already suitable with temperature above 100°C yet at 1000m depth, others with temperature between 80°C and 90°C and between 60°C and 80°C (as shown in Figure). The proportion of population suitable within these conditions is 37.15%.

The yet favorable conditions become even more decisive at 2000m depth, where the overwhelming majority of Turkey’s NUTS3 regions are suitable with at least a temperature of 80°C (as shown in Figure 42) corresponding to 68.52% of the total population. Another 24.29% of the population is suitable with reservoir above 60°C at 2000m depth, leading the total amount of population to an astonishing 92.81%.

Therefore, in this thesis, Turkey presents itself as the country with the most flourishing future in the geothermal energy sector, with a matchless potential, which isn’t even comparable with many other European countries.

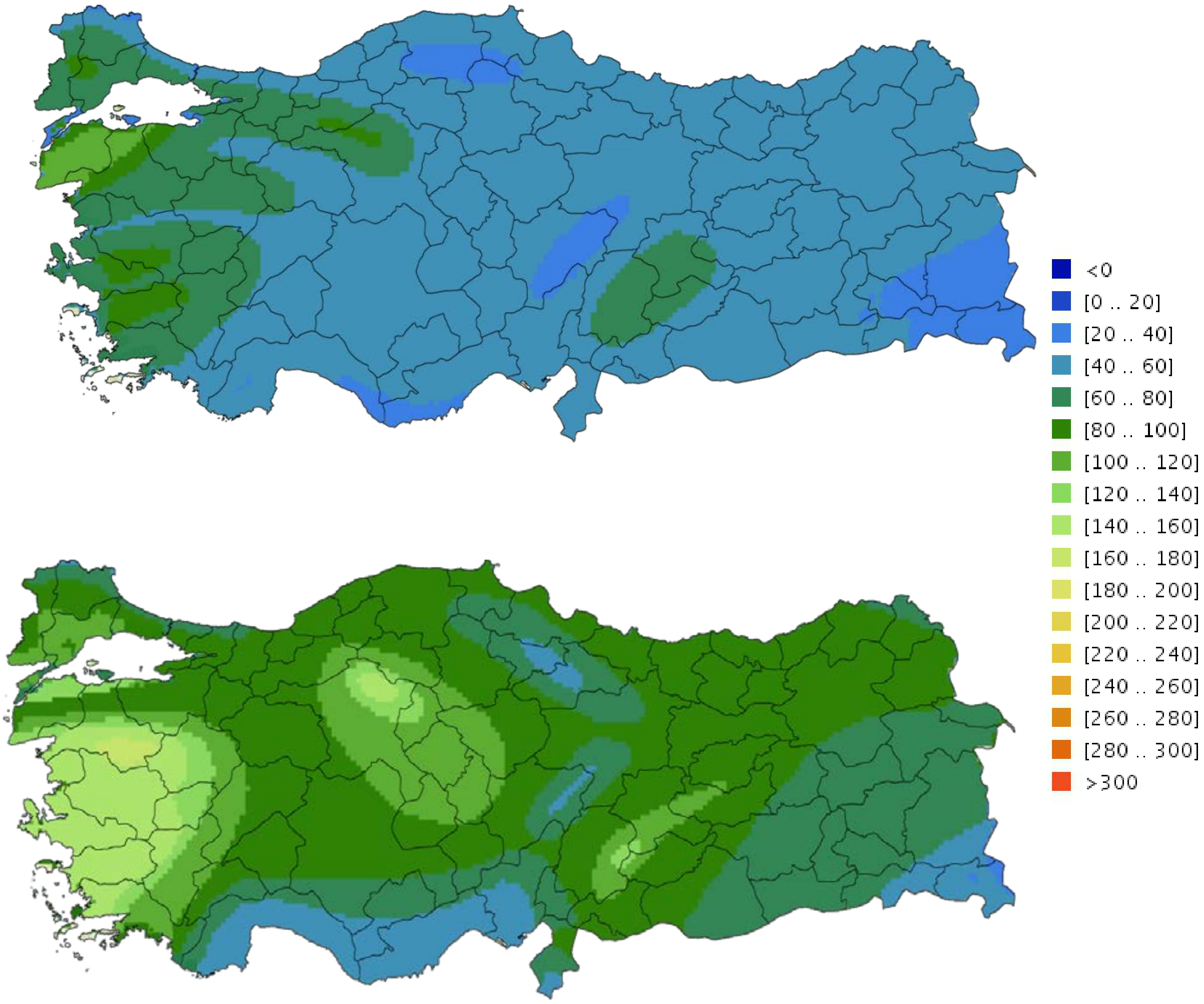


Figure 42 Temperature model of Turkey at 1000m (above) and 2000m depth. (source: GeoELEC modified)

2.6 Geothermal District Heating –Results

Region	Population	Potential @1km & T>60°C	Potential @2km & T>60°C	Potential @2km & T>80°C	Population suitable @1km & T>60°C	Population suitable @2km & T>60°C	Population suitable @2km & T>80°C
Istanbul	13,255,685	51.26%	100.00%	63.74%	6,794,864	13,255,685	8,449,174
Tekirdag	798,109	97.09%	100.00%	97.16%	774,884	798,109	775,442.7
Edirne	390,428	82.45%	100.00%	85.67%	321,907.9	390,428	334,479.7
Kirklareli	332,791	50.71%	97.26%	57.71%	168,758.3	323,672.5	192,053.7
Balikesir	1,152,323	100.00%	100.00%	100.00%	1,152,323	1,152,323	1,152,323
Çanakkale	490,397	100.00%	100.00%	100.00%	490,397	490,397	490,397
Izmir	3,948,848	100.00%	100.00%	100.00%	3,948,848	3,948,848	3,948,848
Aydin	989,862	100.00%	100.00%	100.00%	989,862	989,862	989,862
Denizli	931,823	86.96%	100.00%	100.00%	810,313.3	931,823	931,823
Mugla	817,503	64.26%	100.00%	89.10%	525,327.4	817,503	728,395.2
Manisa	1,379,484	87.04%	100.00%	100.00%	1200,703	1,379,484	1,379,484
Afyonkarahisar	697,559	27.16%	100.00%	100.00%	189,457	697,559	697,559
Kütahya	590,496	81.58%	100.00%	100.00%	481,726.6	590,496	590,496
Usak	338,019	99.58%	100.00%	100.00%	336,599.3	338,019	338,019
Bursa	2,605,495	93.21%	100.00%	100.00%	2,428,582	2,605,495	2,605,495
Eskisehir	764,584	30.90%	100.00%	100.00%	236,256.5	764,584	764,584
Bilecik	225,381	54.86%	100.00%	100.00%	123,644	225,381	225,381
Kocaeli	1,560,138	79.85%	100.00%	82.15%	1,245,770	1,560,138	1,281,653
Düzce	338,188	39.07%	100.00%	100.00%	132,130.1	338,188	338,188
Bolu	271,208	72.41%	100.00%	100.00%	196,381.7	271,208	271,208
Yalova	203,741	73.99%	100.00%	100.00%	150,748	203,741	203,741
Sakarya	872,872	70.48%	100.00%	89.74%	615,200.2	872,872	783,315.3
Ankara	4,771,716	48.89%	100.00%	100.00%	2,332,892	4,771,716	4,771,716
Konya	2,013,845	0.00%	97.58%	77.36%	0	1,965,110	1,557,910
Karaman	232,633	0.00%	68.64%	0.00%	0	159,679.3	0
Antalya	1,978,333	0.00%	27.31%	0.00%	0	540,282.7	0
Isparta	448,298	0.00%	100.00%	90.59%	0	448,298	406,113.2
Burdur	258,868	5.76%	100.00%	71.20%	14,910.8	258,868	184,314
Adana	2,085,225	0.00%	56.30%	11.38%	0	1,173,982	237,298.6
Mersin	1,647,899	0.00%	4.98%	0.00%	0	82,065.37	0
Hatay	1,480,571	0.00%	83.04%	25.42%	0	1,229,466	376,361.1
Kahramanmaras	1,044,816	71.15%	100.00%	97.06%	743,386.6	1,044,816	1,014,098
Osmaniye	479,221	4.44%	100.00%	11.76%	21,277.41	479,221	56,356.39

Kirikkale	276,647	0.00%	100.00%	100.00%	0	276,647	276,647
Aksaray	377,505	0.00%	100.00%	100.00%	0	377,505	377,505
Nigde	337,931	0.00%	100.00%	72.86%	0	337,931	246,216.5
Nevsehir	282,337	0.00%	100.00%	100.00%	0	282,337	282,337
Kirsehir	221,876	0.00%	100.00%	100.00%	0	221,876	221,876
Kayseri	1,234,651	0.00%	94.29%	57.88%	0	1,164,152	714,616
Sivas	642,224	0.00%	99.59%	61.57%	0	639,590.9	395,417.3
Yozgat	476,096	0.00%	100.00%	100.00%	0	476,096	476,096
Zonguldak	619,703	0.00%	100.00%	100.00%	0	619,703	619,703
Karabük	227,610	0.00%	100.00%	100.00%	0	227,,610	227,610
Bartin	187,758	0.00%	100.00%	100.00%	0	18,758	187,758
Kastamonu	361,222	0.00%	100.00%	96.68%	0	361,222	349,229.4
Çankiri	179,067	0.00%	100.00%	100.00%	0	179,067	179,067
Sinop	202,740	0.00%	100.00%	56.22%	0	202,740	113,980.4
Samsun	1,252,693	0.00%	97.73%	43.85%	0	1,224,257	549,305.9
Tokat	617,802	0.00%	85.14%	24.13%	0	525,996.6	149,075.6
Çorum	535,405	0.00%	100.00%	82.05%	0	535,405	439,299.8
Amasya	334,786	0.00%	69.13%	7.87%	0	231,437.6	26,347.66
Trabzon	763,714	0.00%	100.00%	100.00%	0	763,714	763,714
Ordu	719,183	0.00%	100.00%	100.00%	0	719,183	719,183
Giresun	419,256	0.00%	100.00%	100.00%	0	419,256	419,256
Rize	319,637	0.00%	100.00%	100.00%	0	319,637	319,637
Artvin	164,759	0.00%	100.00%	91.04%	0	164,759	149,996.6
Gümüshane	129,618	0.00%	100.00%	100.00%	0	129,618	129,618
Erzurum	769,085	0.00%	100.00%	77.74%	0	769,085	597,886.7
Erzincan	224,949	0.00%	100.00%	100.00%	0	224,949	224,949
Bayburt	74,412	0.00%	100.00%	100.00%	0	74,412	74,412
Agri	542,022	0.00%	100.00%	0.00%	0	542,022	0
Kars	301,766	0.00%	100.00%	100.00%	0	301,766	301,766
Igdir	184,418	0.00%	100.00%	10.33%	0	184,418	19,050.38
Ardahan	105,454	0.00%	100.00%	61.26%	0	105,454	64,601.12
Malatya	740,643	63.02%	100.00%	100.00%	466,753.2	740,643	740,643
Bingöl	255,170	0.00%	100.00%	44.06%	0	255,170	112,427.9
Elazig	552,646	11.30%	100.00%	100.00%	6,2449	552,646	552,646
Tunceli	76,699	0.00%	100.00%	100.00%	0	76,699	76,699
Van	1,035,418	0.00%	77.38%	0.00%	0	801,206.4	0
Mus	406,886	0.00%	100.00%	0.00%	0	406,886	0

Bitlis	328,767	0.00%	100.00%	0.00%	0	328,767	0
Hakkari	251,302	0.00%	0.00%	0.00%	0	0	0
Gaziantep	1,700,763	8.49%	100.00%	100.00%	144,394.8	1,700,763	1,700,763
Adiyaman	590,935	49.19%	100.00%	100.00%	290,680.9	590,935	590,935
Kilis	123,135	0.00%	100.00%	100.00%	0	123,135	123,135
Sanliurfa	1,663,371	0.00%	100.00%	41.73%	0	1,663,371	694,124.7
Diyarbakir	1,528,958	0.00%	100.00%	14.92%	0	1,528,958	228,120.5
Mardin	744,606	0.00%	100.00%	0.00%	0	744,606	0
Sirnak	430,109	0.00%	49.25%	0.00%	0	211,828.7	0
Batman	510,200	0.00%	100.00%	0.00%	0	510,200	0
Siirt	300,695	0.00%	99.23%	0.00%	0	298,379.6	0
Total	73,722,988				27,391,428	68,423,118	50,511,741
Percentage of Population suitable					**37.15%**	**92.81%**	**68.52%**

Table 13 Area and population suitable with DH at different depth in Turkey

2.6.26 The United Kingdom

Only low enthalpy geothermal energy is available in Great Britain due to its particular geological and tectonic setting. As shown in Figure 43 the south west, Yorkshire and the Humber are particularly suitable to geothermal district heating.

UK didn’t invest very much on district heating infrastructures on its territory in the past and therefore only 4% of houses and buildings is connected to a heating grid, covering between 1 and 2% of UK’s heating demand. Only one geothermal heating plant is operating with a capacity of 2.8MW$_{th}$ in Southampton and other 6 are planned to be installed in the future, two of them will exploit EGS, helping the development of the technology. The planned total installed new capacity should be around 70MW$_{th}$.

20% of the UK’s population in suitable with temperatures between 60°C and 100°C at 2000m depth, including NUTS3 regions like Clackmannanshire and Fife, Falkirk and West Lothian that could be fully covered by geothermal district heating.

The geothermal heat situation in the UK is stationary, since the 2015 CPR confirmed the same quantity of heat generated as in 2012: 0.8ktoe; it coincides with the NREAP estimations given for 2005. The UK doesn’t focuses on geothermal energy for the accomplishment of its 2020 goals.

Figure 43 Map of geothermal potential in the United Kingdom

2.7 Costs

From the electricity market's point of view, geothermal energy is much similar to hydroelectric energy: production costs are deeply influenced by the investment costs, in a minor part from O&M and they are independent from the quantity of "fuel" – hot water/steam – utilized, in other words: it has low marginal costs. The load factor (or capacity factor, CF) could be also high up to 90%, even though heat plants have normally CF around 30% and it can produce a quantity almost constant during the year. This puts the geothermal energy to cover the *base load* in the electricity market. These characteristics are partially reflected in the heating sector as well, where the feasibility of a DH system depends in the first place to the presence of a heating and cooling demand - the more constant within the year, the better – high enough to exploit the heat capacity as much as possible and therefore limiting dead times and with that the unit energy cost. The implementation of a cooling system next to the heating (the so called absorption refrigerator) can also increase the load factor of the system, leading to further lower unit energy costs.

Moreover it has to be considered the investment cost of the distribution system – the pipelines – which plays a very important role in the feasibility of the plant itself. Many countries – particularly those of the Eastern Europe – as reported in the previous chapter, have developed since the '70s a district heating grid providing heat to a consistent portion of their population, even though powered by fossil fuels or waste. These plants already existing on the territory can be converted to geothermal District Heating, where possible, partially excluding from the investment costs those parts of the costs related to the construction of a new distribution system. Countries like Denmark, Poland, former East-Germany, Hungary and Czech Republic having already a District Heating operating on their territories will be facilitated in the future development of their geothermal resources.

Generally the investment costs account up to 50% of the entire energy cost and – at global level – they range between 20-25% in different countries (subsides and incentives not included) due to different energy policies and knowledge of the underground. Countries with experiences in fossil fuels' extraction's sector will have a higher knowledge of the underground compared to who didn’t conduced researches in the field.

As previously written, geothermal energy is not a monotonous entity: the fact that in the majority of the cases is not directly viewable, like wind or an hydro basin, raises the first difficulties: Drilling the first exploration well is reported to have a success rate of 25% and for production and injection wells it raises up to 60-90%[22]. The exploration of a supposed reservoir represents another factor in the energy cost’s estimation and the financial risks that derive concern investors and affect the appeal of the sector. The unexpected reach, for example, of a cavity during the perforation can compromise the cementification of the well and the geothermal fluid, before reaching the surface, could fill the cavity, losing energy and pressure. A too high and quick loss of pressure can cause the *flashing* of the liquid and its consequential explosion. Case apart are the so called thermal zones, where the geothermal fluid comes naturally on the surface, like in Larderello in Italy or the geysers in Iceland, and the reservoir results therefore easy to be located and exploited. Not accidentally those places were the first locations where the geothermal energy has been spotted and extracted.

As explained in the chapter *Type of Resources* the quality of a reservoir doesn’t depend only to the temperature of the underground, but also to the geological typology of the media. To every geological media corresponds a different heat production’s capacity: the more the underground is permeable and the fluid part available, the more productive will be the well and cheaper the plant. Other Hydrothermal or Deep Aquifers with less favorable characteristics will be exploitable as well, but with higher costs.

All these variables influence in a more or less deep way the final energy cost and it is impossible to hypothesize a credible general cost range valid in every cases or even only in the majority of them. Therefore in this thesis will be reported only data referring to specific studies (case-study analysis).

---

[22] Hance, C.N., *Factors Affecting Costs of Geothermal Power Development*, Geothermal Energy Association, U.S. Department of Energy, Washington, D.C., U.S.A., 2005

A separate discussion needs to be done for Hot Dry Rock reservoirs, for which, as written before, is now under development a technology with a high potential in the future: the EGS. Although there are no commercial EGS plants in operation and their costs are subjected to higher uncertainties, it's estimated that every new plant built with this technology – in Germany and France – has reduced and will reduce the investment costs by 20%. The actual possibility to apply EGS to heat plants, even for CHP, remains uncertain: scenario IPCC SREN (Goldstein, 2011) assumes that EGS (or similar technologies) will become economic feasibly soon after 2030, while (OECD/IEA, 2011) says that EGS implementation to heating system needs to be demonstrated.

2.7.1 The IPCC SREN Scenario

Data reported on IPCC SREN Scenario are referred to Hydrothermal and Deep Aquifers resources' exploitation in the United States, however the costs range – therefore quite wide – is similar to every developed country[23]. Investment costs are reported as in the following Table 14:

Typical size of the facility	**Investment cost**	**O&M costs**	**Capacity Factor (CF)**	**Lifetime**
MW_{th}	*EUR/kW_{th}*	*EUR/MWh*	*%*	*years*
3.8 - 35	505.3 - 1347	16.90 – 22.49	25-30%	25

Table 14 Input data of the costs' analysis[24]

The costs have been calculated considering three different interest rates: 3%, 7% and 10%. The resulting costs are reported as *EUR/MWh*[25] in the following Table 15:

---

[23] Lund, J.W. and T.L. Boyd, "Geothermal utilization on the Oregon Institute of Technology campus, Klamath Falls, Oregon", *Proceedings of the 34th Workshop on Geothermal Reservoir Engineering*, Stanford University, Stanford, CA, USA, 9-11 February, 2009

[24] IPCC, op. cit., Annex III

[25] The costs were originally reported as USD in 2005 value. The values are here reported as EUR_{2010}. The exchange calculations have been made according to *statista.com* for the exchange rate ($1.33USD_{2010}=1EUR_{2010}$)

3%	7%	10%
36.38 – 72.76	42.44 – 93.98	45.47 – 115.2

Table 15 Energy costs according to IPCC for different interest rates

2.7.2 The Geothermal Roadmap

A similar analysis has been reported in the Geothermal Roadmap (OECD/IEA, 2011) based on the IPCC SREN Scenario. The input data are shown in the following Table 16:

Investment costs	O&M costs	Capacity Factor	Lifetime	Interest Rate
EUR/kW$_{th}$	*%*	*%*	*years*	*%*
480.8 – 1319	2% of the Investment	50%	25	10%

Table 16 Input data for the costs' analysis according to the Geothermal Roadmap

The resulting production costs are estimated to be in a range between 37.89 and 71.58EUR/MWh.

2.7.3 Heat's Price in Iceland

According to Orkustofnun[26] (Figure 44) geothermal DH heat's price is divided into three categories: *expensive*, *Reykjavik* and *low-priced*. The prices are reported in following Table as (EUR/MWh)[27].

Expensive	Reykjavik	Low-priced
30.2	18.12	12.08

---

and the US *Government CPI (Consumer Price Index) Data* published on May 17, 2016 for what concerns US inflation rates (1USD$_{2005}$=1.12USD$_{2010}$).

[26] Orkustofnun, Icelandic National Energy Authority, *Energy Statistics in Iceland 2014*, Reykjavik, Iceland, April 2015

[27] Values were originally reported as ISK 2014. Conversion has been made according to *x-rates.com* for ISK-EUR exchange rate in 2014 (1ISK=0.006462EUR) and to *Istat (Italian National Institute for Statistics)* for the inflation rates of Euro (1EUR$_{2010}$=1.07EUR$_{2014}$).

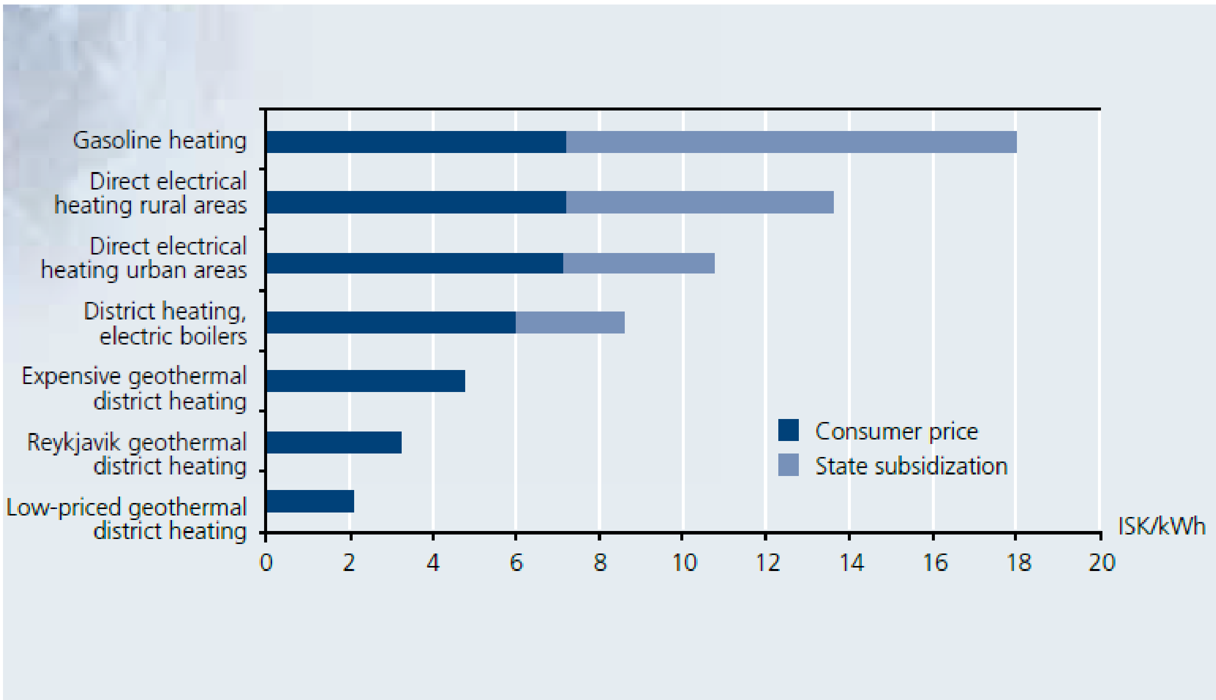


Figure 44 Comparison of energy prices for residential heating mid-year 2014 (source: Orkustofnun, 2015)

2.7.4 Politecnico di Milano's Case Study

The *Politecnico di Milano* (Milan Institute of Technology) provided a case study[28] considering two different geothermal power plants with different installed capacity: one of 20MW operating with a dry-steam system and located in Italy and the second one of 5MW with a binary system in Germany. Both power plants exploit a Hydro-thermal resource (no EGS).

The report refers then only to the costs of a geothermal power plant, but even though the electricity production is not the core-topic of this chapter, some parameters can be interesting as a comparison argument for heat plants.

The drilling costs in Europe are set between 1600 and 2400€/m, depending on the typology of the rock to be drilled and the depth of the well itself (the ratio is not linear, as can also be seen in Chapter 3.3.1 and particularly in Table 15).

A quick overview of the proportion of the different items shows that the exploration and validation costs are nearly always a half of the drilling costs of the actual well.

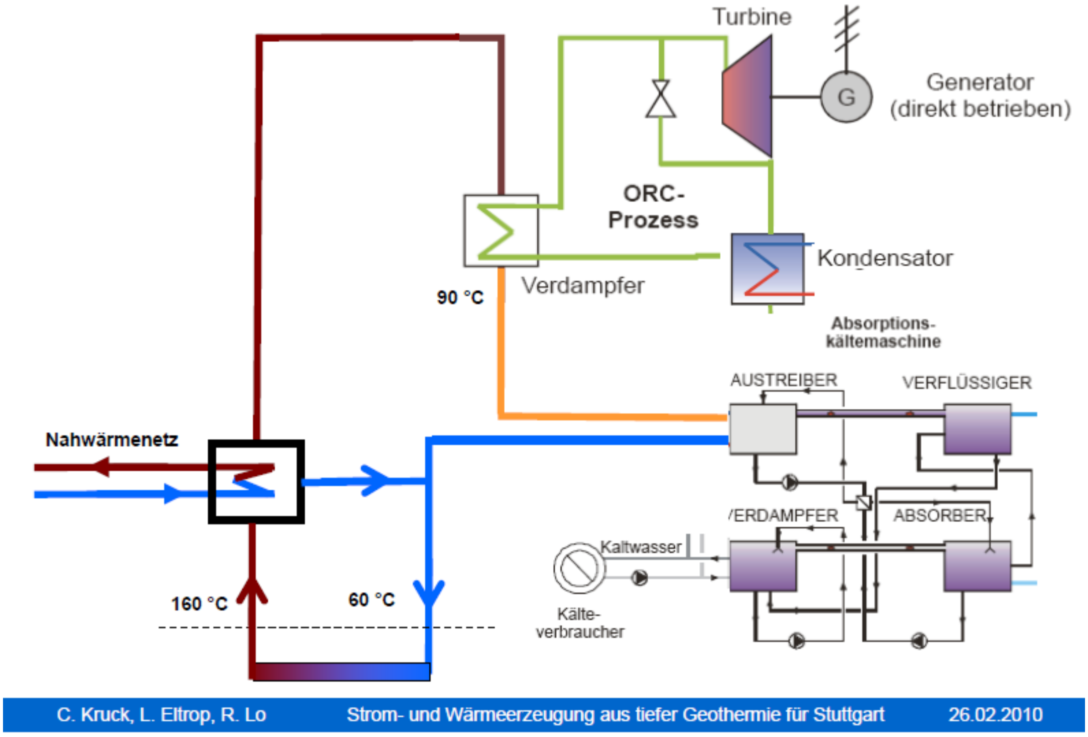
---

[28] Bombarda, P., M. Astolfi, P. Silva, *Estimating cost of the geothermal power technologies*, Energy Department, Gecos Group, Politecnico di Milano

Further information of the report are useless for the purposes of this thesis, therefore it didn’t have been mentioned.

2.7.5 Universität Stuttgart’s Case Study

Universität Stuttgart (University of Stuttgart) made a case study[29] about a CHP plant based on a resource developed with an EGS at a temperature of 160°. The plant is structured as in the Figure 45 below with an ORC process for the electricity generation, an absorber refrigerator for the cooling system and the heat exchanger for the heating system. The installed capacity accounts 13.9MW$_{th}$ for heat, 3.07MW$_{th}$ for cold and 1.23MW$_e$ for electricity. The resource is located 5km underneath the surface and the drilling costs for a dublette well amounted to 30m€, resulting 3000€/m each well.



C. Kruck, L. Eltrop, R. Lo Strom- und Wärmeerzeugung aus tiefer Geothermie für Stuttgart 26.02.2010

Figure 45 Structure of the by University of Stuttgart considered CHP plant

---

[29] Kruck, C., L. Eltrop, R. Lo, *Strom- und Wärmeerzeugung aus tiefer Geothermie für Stuttgart (electricity and heat production from deep geothermal energy in Stuttgart)*, IER, University of Stuttgart, 2010

The total investment costs results in about 40m€. The costs related to the EGS are not specified and only a voice related to the development of the resource - *Base Engineering* - accounts for 500k€. However in 3 out of 4 analyzed plants, the heat production costs range between 40 and 120€/MWh$_{th}$. The fourth plant named "Krankenhaus Bad Cannstatt" produces heat with costs range between 100 and 450€/MWh$_{th}$.

2.7.6 LCOE according to van Wees's study

A study made by Jan-Diederik van Wees[30] provides an Excel table[31] considering a multitude of variables which estimates the *levelized cost of energy* (LCOE) through a cash flow methodology. Since many of the considered variables weren't seen in this thesis (though they can be found in the *Annex I*), they have been left at their standard value. Some example are: Flowrate of the geothermal fluid (here 70l/s), number of wells (2) and Coefficient of Performance (COP, here set at 50%). Other factors were discussed in this thesis and by varying them into interesting combinations, the mutual dependency of the plant characteristics have been highlighted.

To be considered here is that the study of van Wees allows the calculation of LCOE for different types of plants: only power, only heat or CHP plants. The results reported in the following Table are concerning an heat plant with no power generation.

Depth [m]	**Temp [°C]**	**Load Hours**	**O&M**	**Interest Rate**	**Life Time [years]**	**LCOE [€/MWh$_{th}$]**
1000	60	30% (2628h)	1%	6%	30	***121.5***
2000	60	30%	1%	6%	30	***140.2***
2000	80	30%	1%	6%	30	***83.6***
1000	60	30%	2%	6%	30	***130.7***

---

[30] Van Wees, J.D., *A Methodology for Resource assessment and application to core countries*, TNO Innovation for Life, is the study upon which the entire report *GeoELEC* is based.

[31] The original file can be found at: *http://www.geoelec.eu/wp-content/uploads/2013/07/Geothermal_power_heat_LCOE_geoeleclSOULTZ2020.xlsx* (link checked May 2016).

2000	60	30%	2%	6%	30	***150.8***
2000	80	30%	2%	6%	30	***94.2***
2000	60	35%	2%	6%	30	***129.6***

Table 17 Sensitivity analysis of Levelized Cost of Energy (LCOE) according to van Wees

It's not clear if the distribution system's costs are included into some parameter, like *direct heat plant investments cost* nor if the *Stimulation and other Cost* is representative only for EGSs or if it considers some kind of stimulation for traditional reservoirs as well.

In any case, the first consideration that comes up from this study is that the temperature of the resource is more important than its depth, confirming what said by Rizzi[32]: a temperature of 60°C leads to at least an LCOE of 121.5€/MWh$_{th}$ at 1000m, while 1km deeper, with the same assumptions, but a resource 20°C warmer leads to a LCOE of 83.6€MWh$_{th}$. So a warmer resource not only compensates the drilling costs of a one kilometer deeper well, but it makes even the heat cost 30% cheaper. Further factors have, in comparison to the depth, minor influences: a doubled O&M cost leads to little increase of LCOE (7%-12% more) and a 16.7% growth in terms of load hours (from 30% to 35%) led to an 16% decrease of LCOE (from 150.8 to 129.6€/MWh$_{th}$).

If the *Stimulation and other cost* parameter is taken down to 10% of its standard value (from 10 to 1mln€/well), the LCOE decrease to 36€/MWh$_{th}$.

---

[32] Interview cited in page 7.

3 Geothermal Electricity Generation

3.1 Introduction

The geothermal energy as resource for power plants and electrical generation has its deep roots in Europe. In 4th July 1904 in Larderello, a little village in Tuscany, Italy, the first five bulbs in history were lighted thanks to the geothermal energy. 100 years later geothermal power plants have been spread through the continents and Enel now manages in Tuscany one of the largest geothermal complex in the world, producing alone 10% of geothermal energy worldwide: 34 plants with 796 MW installed capacity, able to cover 26% of the regional electricity demand.

Larderello is located in the middle of the so-called *Valle del Diavolo* (Devil's valley). The unusual name comes from the particularity of the area: the presence of several white fumaroles, which also inspired in XIV century Dante Alighieri and the landscape of his *Inferno*.

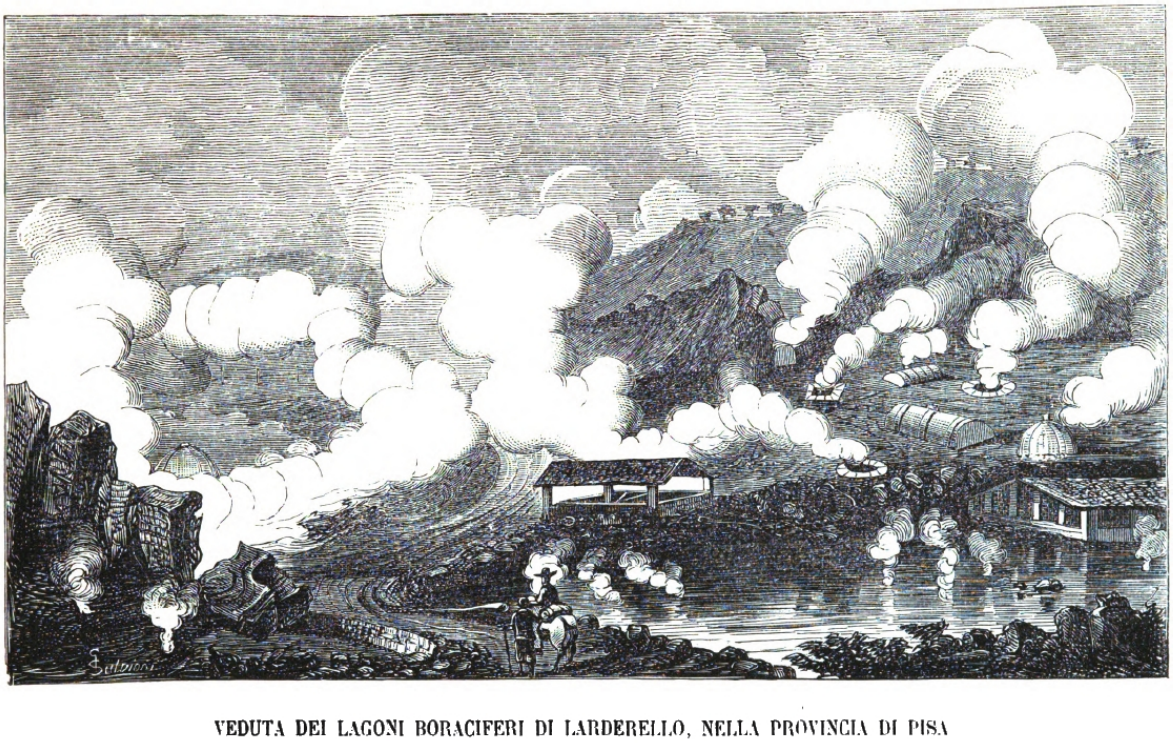


Figure 46 Ancient painting of a view of the fumaroles in Larderello, in the province of Pisa, Italy.

After Larderello, geothermal energy steady increased in Europe and worldwide, reaching in 2009 10.7GW_e of installed capacity and generating around 67.2TWh_e/yr of electricity (OECD/IEA, 2011). The first deep geothermal power producer are the United States with more than 16TWh$_e$ generated in 2009.

Geothermal energy provides a commercial base load electricity with very high load time (about 90%), which identifies geothermal energy as a high reliable resource suitable to become a relevant factor in future energy's panorama.

3.2 The Technologies involved

Conventional geothermal power plants use steam to generate electricity. While other conventional power plants' typologies use fossil fuel to produce steam, geothermal energy power plants *flashes* (i.e. reduces the pressure of) the geothermal fluid. They can operate with resources from medium enthaply (80°C – 150°C) up to supercritical unconventional typology (390°C) and with geothermal fluid as vapor, liquid + vapor or liquid only. These characteristics strictly depend on the nature of the reservoir.

There are three main types of plant: flash steam, dry steam and binary. The choice of which type of power plant needs to be used on a given reservoir depends on the nature of the reservoir itself.

Binary plants are appropriate for the medium enthalpy resources. They use an organic Rankine cycle (ORC) or a Kalina cycle. The principle is to produce vapor by transferring the heat from the geothermal fluid to an organic fluid with a low (i.e. lower than the geothermal fluid's) boiling point. Normally the lower-temperature geothermal fluid, after being exploited, is re-injected into the reservoir, promoting a sustainable resource exploitation. Binary plants accounts for 11% of global installed capacity[33].

The most common reservoir typology consists in a mixture of liquid and vapor. The specified technology for this type of resource is the Flash Steam. Flash Steam plants account for two third of total installed capacity around the world and are used when water-dominant reservoirs have temperature above 180°C (high enthalpy resource). In these reservoirs the geothermal fluid becomes suddenly steam as its pressure drops. Separated steam is piped through a turbine generating electricity and the remaining water can be re-flashed one more (double flash) or two more times (triple flash) at

---

[33] Bertani, R., *Geothermal Power Generation in the World 2005-2010 Update Report*, proceedings at World Geothermal Congress 2010, Bali, Indonesia, 25-29 April 2010.

lower temperature and pressure. The cooled brine will be then re-injected through injection wells into the reservoir.

A quarter of the installed capacity is represented by the Dry Steam plants, where the reservoir’s fluid consists only in vapor and the portion of liquid water is negligible. Here the steam coming from the production well is directly piped into the plant and then through the turbine. After the exploitation, the condensate steam is re-injected into the reservoir.

As written in chapter *Introduction*, in case of an absence of liquid in the underground, typical case is represented by Hot Dry Rock, the reservoir needs to be *enhanced* through the development of an EGS.

3.3 Overview on the Potential and Costs

3.3.1 Methodology

The report written by GeoELEC provides a very specific view of the potential of geothermal energy in electricity generation. In this chapter will be described the methodology used by GeoELEC to build up the scenarios.

The study is based on the hydrocarbon reserve’s classification made by McKelvey (Figure 47), which assumes that a resource to be commercially exploited needs to be identified, accessible, useful and economic. Therefore only a portion of the resource base is actually exploitable.

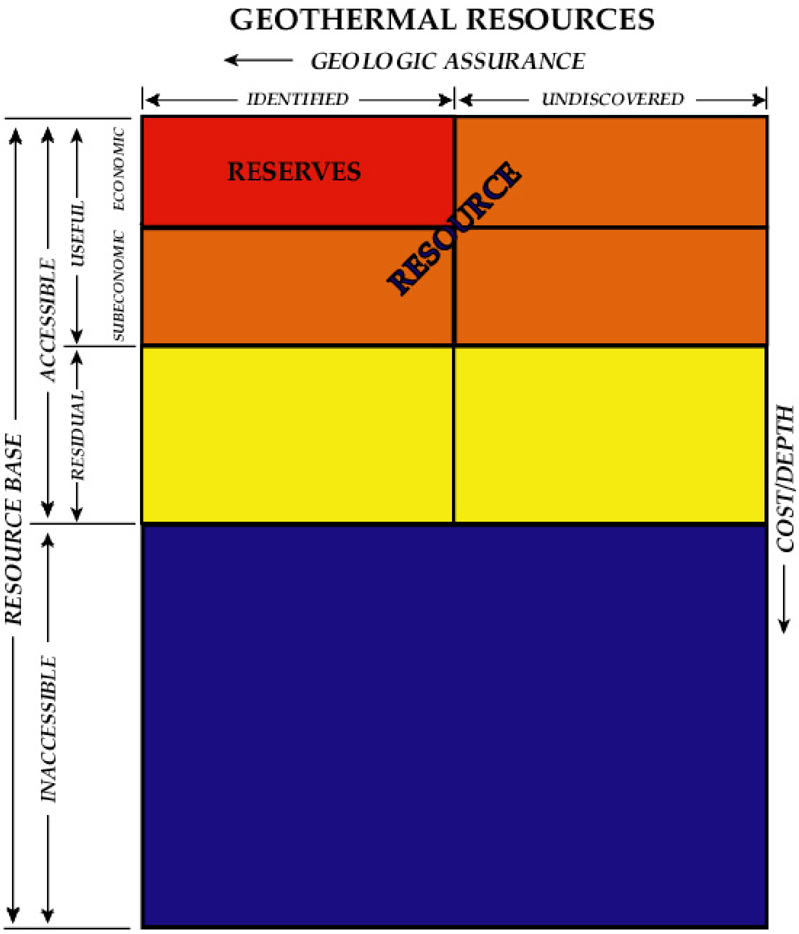


Figure 47 McKelvey Diagram (from http://tex.stackexchange.com)

This portion of resource, in McKelvey diagram identified as *reserves*, is named in the GeoELEC report *Heat in Place* (HIP) and it's calculated as the heat energy available in the subsurface. It's a function of:

- Volume of the subsurface subvolume v
- Density of the rock ρ
- Specific heat of the rock c
- Temperature at depth in the subvolume T_X
- Temperature at surface T_S

$$HIP\ [PJ] = v \cdot \rho \cdot c \cdot (T_X - T_S) \cdot 10^{-15}$$

The *Theoretical Capacity* (TC) considers the *Return Temperature* T_R and an electricity conversion factor η.

$$TC = \eta \cdot v \cdot \rho \cdot c \cdot (T_X - T_R) \cdot 10^{-15}$$

The *Technical Potential* (TP) considers the expected recoverable geothermal energy[34]. The TP will be then calculated as

$$TP\ [MW/km^2] = 1.057 \cdot TC \cdot R$$

Where *R* is the recovery factor, which includes available land areas, recoverable heat from fracture network and temperature drawdown. This factor can be more or less realistic.

The prospective study is based on three different years: 2020, 2030 and 2050. For every year have been chosen different assumptions, trying to estimate the ongoing of the technology in the near future.

The potential has been calculated as the amount of energy producible within certain costs' thresholds (cut-off range). Therefore the economic potential in the EU strictly depends on the LCoE in the considered year. In 2020 the cut-off range goes between less than 100€/MWh to a maximum of 300€/MWh and in 2030 and 2050 between less than 50€/MWh up to maximum 200€/MWh. Here is considered only power generation, with no CHP installed.

In Table 18 are reported the specific assumptions of this analysis.

Parameter		2020	2030	2050
Depth	*km*	7	7	10
Flow Rate	*l/s*	50	70	100

---

[34] Williams, Colin F., Marshall J. Reed, Robert H. Mariner, Jacob DeAngelo, and S. Peter Galanis, *Assessment of Moderate- and High-Temperature Geothermal Resources of the United States*, U.S. Geological Survey, 2008.

COP		30	50	1000
Well Cost Model		Scaling 1.5 + exp.	Scaling 1.5	Linear 1500 €/m
Stimulation Costs	*Mio€*	10	10	10
Relative Carnot Efficency		0.6	0.6	0.7
T_{INC} for T_R	*°C*	80	80	50

Table 18 Assumption for the study (source: GeoELEC)

3.3.2 Results

Country	2012 EGEC	2020	2030	2050
	TWh_e	*TWh_e*	*TWh_e*	*TWh_e*
Andorra	0	0	0	1
Austria	0	0	0	67
Belarus	0	0	0	2
Belgium	0	0	0	22
Bosnia and Herzegovina	0	0	0	25
Bulgaria	0	0	0	72
Croatia	0	1	3	50
Cyprus	0	0	0	0
Czech Republic	0	0	0	31
Denmark	0	0	0	29
Estonia	0	0	0	2
Finland	0	0	0	0
France	0	0	0	653
Germany	0	0	1	346
Greece	0	0	0	81
Hungary	0	9	17	174
Iceland	5	73	74	322
Ireland	0	0	0	27
Italy	5	11	12	226
Latvia	0	0	0	3
Lithuania	0	0	0	19
Luxembourg	0	0	0	3

Macedonia	0	0	0	10
Moldova	0	0	0	2
Montenegro	0	0	0	2
Norway	0	0	0	0
Poland	0	0	0	144
Portugal	0	0	0	63
Romania	0	0	0	105
Serbia	0	0	1	92
Slovakia	0	0	1	55
Slovenia	0	0	0	8
Spain	0	0	1	349
Sweden	0	0	0	1
Switzerland	0	0	0	43
The Netherlands	0	0	0	52
Turkey	0.4	50	62	966
Ukraine	0	0	0	71
The United Kingdom	0	0	0	42

Table 19 Economic potential per country and actual electricity production in 2012, TWh.

4 Conclusions

Even though geothermal energy is very difficult to analyze merely analytically, certain results are surely interesting and could in some way help understand the dimension of this particular energy resource. Considering all its aspects, as shown in this thesis, it is clear how geothermal energy could be an important partner in the future energy scenario.

4.1 Geothermal District Heating

The data and the results coming from the graphical analysis of the European temperature map don't always correspond and sometimes the difference is consistent[35]. However, after proper consideration, the results provided by this thesis are helpful to clarify the situation of geothermal energy in Europe in general, as well as at country level.

According to the results of this thesis, and strictly treating the considered countries (the "non-GeoDH" countries: Austria, Belgium, Croatia, etc.), 32% (271TWh$_{th}$) of their H&C consumptions are coverable with geothermal District Heating with temperature above 80°C at 2000m depth. 16% (133TWh$_{th}$) is coverable with temperature above 60°C at 1000m depth and 70% (596TWh$_{th}$) with temperature above 60°C at 2000m depth. Along with that, if we consider the costs of heating according to van Wees, with the actual technologies it is clear that a temperature of 60°C, particularly at 2000m depth, would be in general commercially difficult to exploit for DH purposes: the best-case is a temperature above 80°C at 2000m depth.

According to GeoDH, 25% of the EU population is suitable with geothermal District Heating. It is not clear how this percentage has been calculated for the states not taken in consideration in the study (the so-called *non-GeoDH*: Austria, Belgium, Croatia, etc.).

---

[35] This aspect is examined in depth in chapter 2.4: *Comparison of the Two Methods.*

Considering the different H&C demands of the different EU states, the total potential of geothermal DH in the GeoDH-countries accounts for over 1150TWh$_{th}$, equal to 53% of total H&C demand.

If we now cross the borders of the European Union and take a look at the whole European Continent (this means including countries such as Iceland and Turkey), and in particular the population suitable with temperature above 80°C at 2km depth, the actual total potential could cover up to 48% of the H&C demand (1428TWh$_{th}$). The actual amount of heat produced in 2013 in Europe accounts for 14TWh, almost 1% of the estimated potential.

If we consider the demand coverable with temperature above 60°C also at 2000m depth, the proportion of demand that could be provided by geothermal energy rises up to 60%.

Now, just to clarify the amount of energy represented here, according to EGEC the actual average installed capacity of a single DH-plant in Europe is around 18MW$_{th}$. Considering that normally a heat-plant has a load factor around 30% (2628 h/y), a heat plant with 18MW$_{th}$ installed produces yearly 47GWh$_{th}$. This means that in order to cover the whole potential reported in this thesis, 30,000 new heat plants would need to be constructed in the next decades.

Since this analysis, as written, considers a limited number of factors, a further study comprehending other parameters, such as heat demand, density or geographical restrictions, could be very interesting in order to have a more realistic evaluation of the potential. The implementation of a model representing the deep aquifers' location around Europe and its overlap with the data here considered could be an exciting next step as well. Furthermore, a potential's assessment calculated with an GIS analysis, instead of a graphical evaluation as done here, is surely the most natural continuation of this work.

4.2 Geothermal Electricity Generation

The technical and realistic potential of geothermal energy in Europe as assessed in the GeoELEC project is huge. Thinking that in 2050 the expected electricity generation in the EU28 accounts for 4300TWh[36], with a total potential (comprehending the contribute of other non-EU countries) above 4000TWh, geothermal power plants could provide a large piece of it, and in any case way larger than nowadays. In fact, according to these results, the actual exploited share of geothermal energy for electricity generation is narrowly above 0,003%.

In Figure 48 are represented the electricity potentials compared to the heat potentials in the European countries. France, Germany and Turkey are clearly the states with the highest potential overall. Countries like Iceland, with a high availability of geothermal energy, are anyhow restricted to a low heating potential, due to their low number of inhabitants. In general we might say that the countries with an high potential in electricity generation are also very suitable for deep geothermal heating. This is surely interesting if we think about the energy production that could be achieved by CHP plants, generating at the same time electricity and heat for nearby cities.

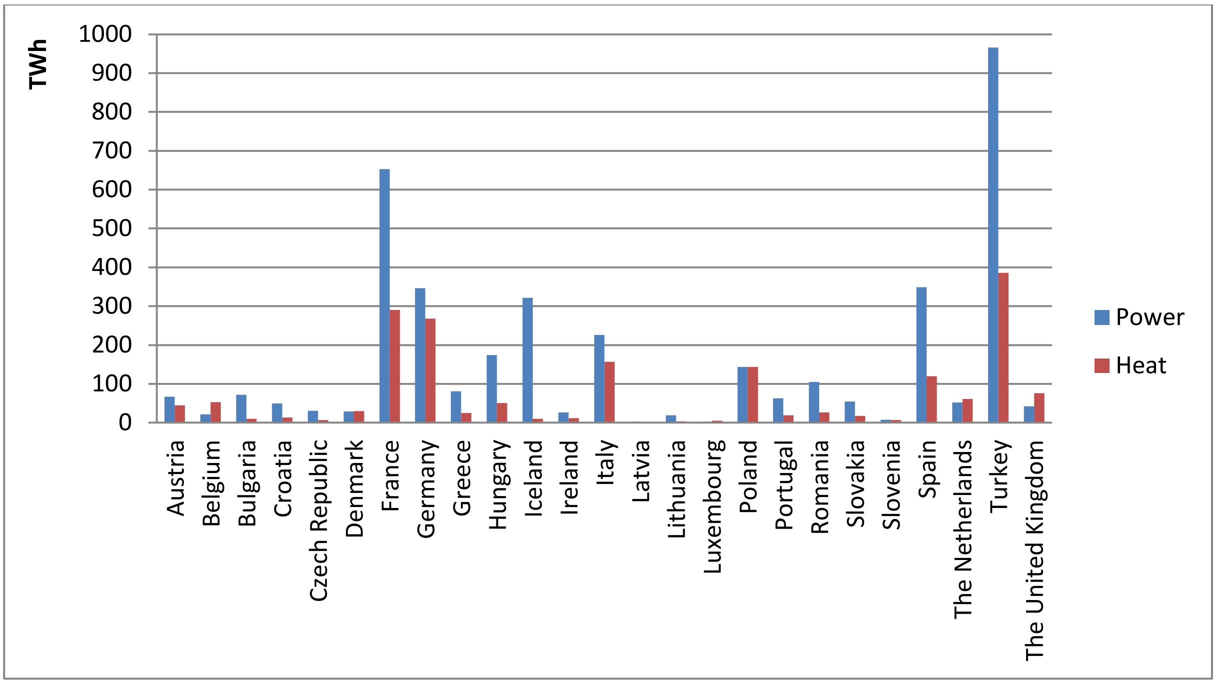
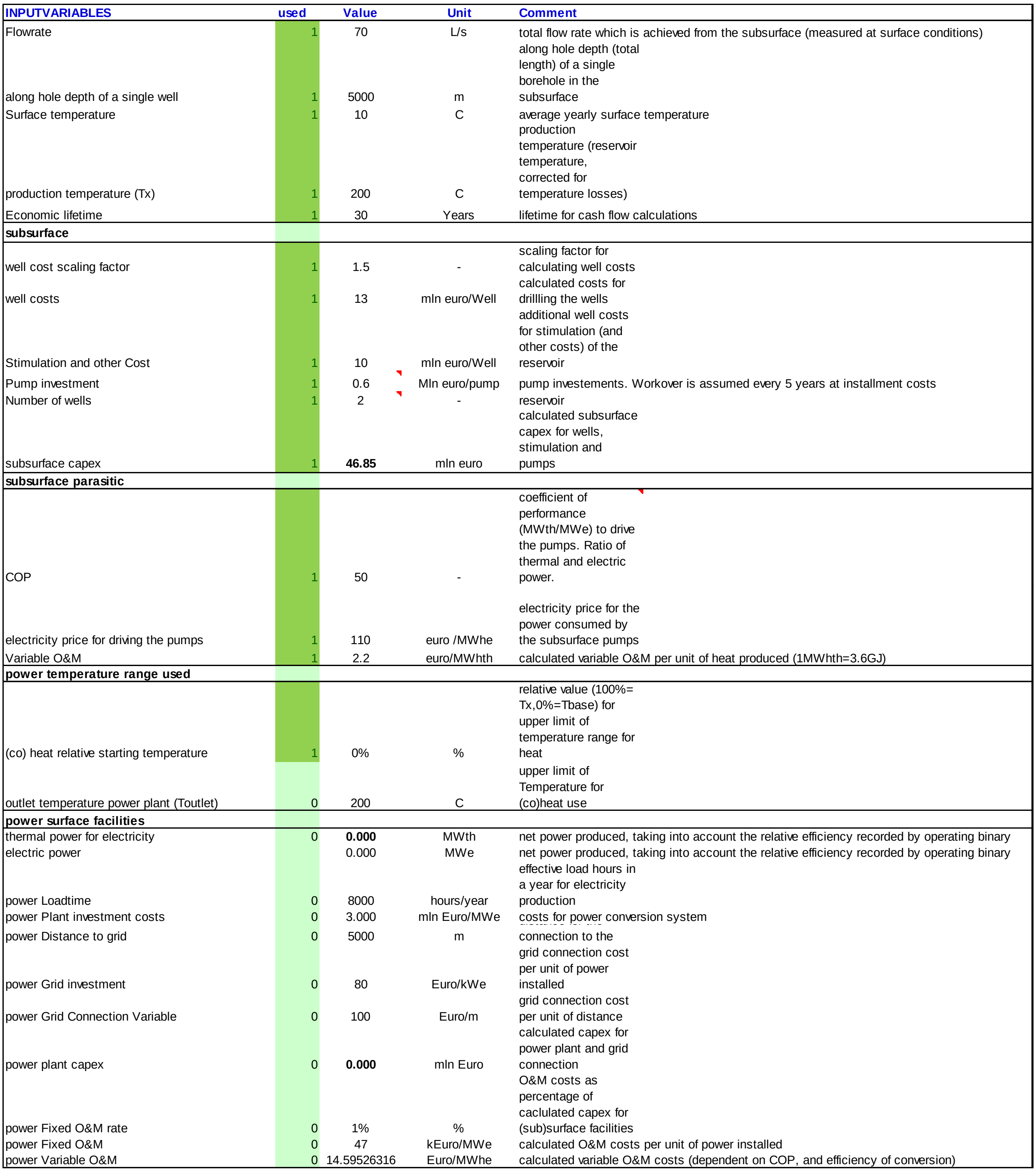


Figure 48 Comparison of the potential of Power and Heat production in the European countries in 2050

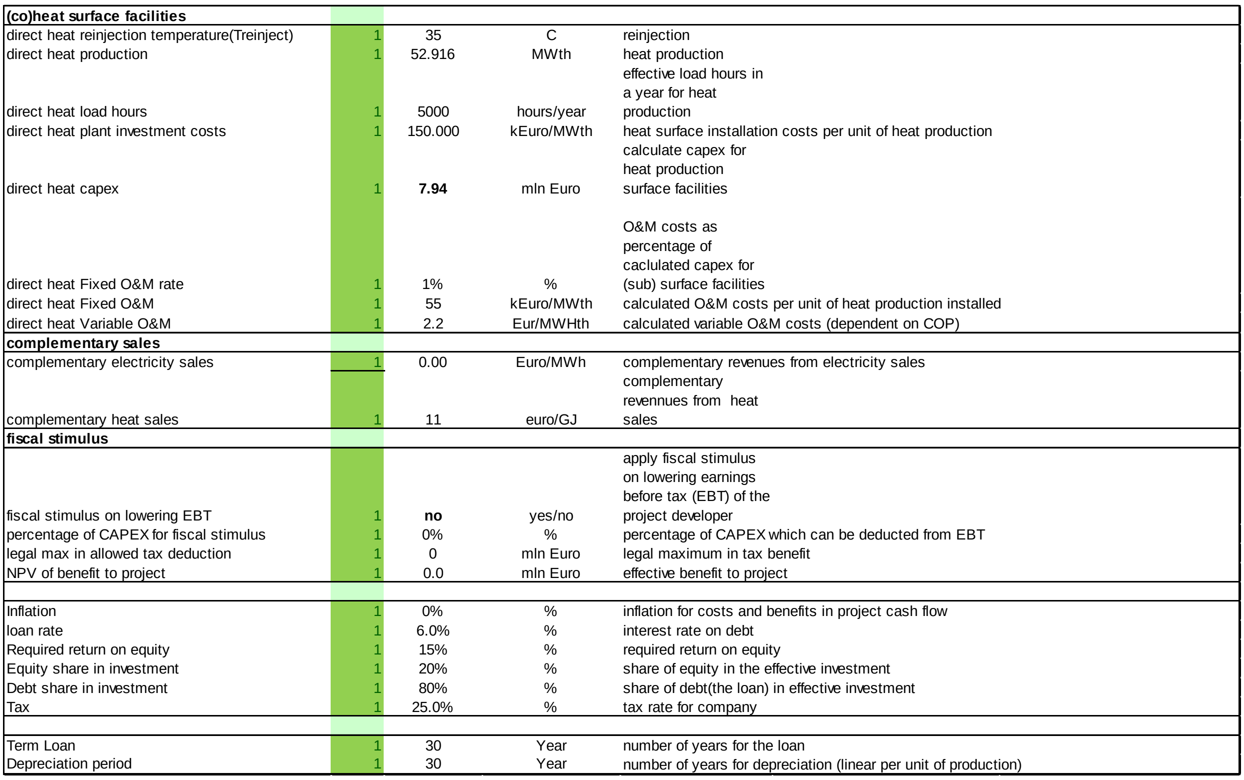
---

[36] According to *PRIMES 2013 Reference Scenario.*

Annex I



INPUTVARIABLES	used	Value	Unit	Comment
Flowrate	1	70	L/s	total flow rate which is achieved from the subsurface (measured at surface conditions)
along hole depth of a single well	1	5000	m	along hole depth (total length) of a single borehole in the subsurface
Surface temperature	1	10	C	average yearly surface temperature
production temperature (Tx)	1	200	C	production temperature (reservoir temperature, corrected for temperature losses)
Economic lifetime	1	30	Years	lifetime for cash flow calculations
subsurface				
well cost scaling factor	1	1.5	-	scaling factor for calculating well costs
well costs	1	13	mln euro/Well	calculated costs for drillling the wells
Stimulation and other Cost	1	10	mln euro/Well	additional well costs for stimulation (and other costs) of the reservoir
Pump investment	1	0.6	Mln euro/pump	pump investements. Workover is assumed every 5 years at installment costs
Number of wells	1	2	-	reservoir
subsurface capex	1	**46.85**	mln euro	calculated subsurface capex for wells, stimulation and pumps
subsurface parasitic				
COP	1	50	-	coefficient of performance (MWth/MWe) to drive the pumps. Ratio of thermal and electric power.
electricity price for driving the pumps	1	110	euro /MWhe	electricity price for the power consumed by the subsurface pumps
Variable O&M	1	2.2	euro/MWhth	calculated variable O&M per unit of heat produced (1MWhth=3.6GJ)
power temperature range used				
(co) heat relative starting temperature	1	0%	%	relative value (100%= Tx,0%=Tbase) for upper limit of temperature range for heat
outlet temperature power plant (Toutlet)	0	200	C	upper limit of Temperature for (co)heat use
power surface facilities				
thermal power for electricity	0	**0.000**	MWth	net power produced, taking into account the relative efficiency recorded by operating binary
electric power		0.000	MWe	net power produced, taking into account the relative efficiency recorded by operating binary
power Loadtime	0	8000	hours/year	effective load hours in a year for electricity production
power Plant investment costs	0	3.000	mln Euro/MWe	costs for power conversion system
power Distance to grid	0	5000	m	connection to the
power Grid investment	0	80	Euro/kWe	grid connection cost per unit of power installed
power Grid Connection Variable	0	100	Euro/m	grid connection cost per unit of distance
power plant capex	0	**0.000**	mln Euro	calculated capex for power plant and grid connection
power Fixed O&M rate	0	1%	%	O&M costs as percentage of caclulated capex for (sub)surface facilities
power Fixed O&M	0	47	kEuro/MWe	calculated O&M costs per unit of power installed
power Variable O&M	0	14.59526316	Euro/MWhe	calculated variable O&M costs (dependent on COP, and efficiency of conversion)



(co)heat surface facilities				
direct heat reinjection temperature(Treinject)	1	35	C	reinjection
direct heat production	1	52.916	MWth	heat production
direct heat load hours	1	5000	hours/year	effective load hours in a year for heat production
direct heat plant investment costs	1	150.000	kEuro/MWth	heat surface installation costs per unit of heat production
direct heat capex	1	**7.94**	mln Euro	calculate capex for heat production surface facilities
direct heat Fixed O&M rate	1	1%	%	O&M costs as percentage of caclulated capex for (sub) surface facilities
direct heat Fixed O&M	1	55	kEuro/MWth	calculated O&M costs per unit of heat production installed
direct heat Variable O&M	1	2.2	Eur/MWHth	calculated variable O&M costs (dependent on COP)
complementary sales				
complementary electricity sales	1	0.00	Euro/MWh	complementary revenues from electricity sales
complementary heat sales	1	11	euro/GJ	complementary revennues from heat sales
fiscal stimulus				
fiscal stimulus on lowering EBT	1	**no**	yes/no	apply fiscal stimulus on lowering earnings before tax (EBT) of the project developer
percentage of CAPEX for fiscal stimulus	1	0%	%	percentage of CAPEX which can be deducted from EBT
legal max in allowed tax deduction	1	0	mln Euro	legal maximum in tax benefit
NPV of benefit to project	1	0.0	mln Euro	effective benefit to project
Inflation	1	0%	%	inflation for costs and benefits in project cash flow
loan rate	1	6.0%	%	interest rate on debt
Required return on equity	1	15%	%	required return on equity
Equity share in investment	1	20%	%	share of equity in the effective investment
Debt share in investment	1	80%	%	share of debt(the loan) in effective investment
Tax	1	25.0%	%	tax rate for company
Term Loan	1	30	Year	number of years for the loan
Depreciation period	1	30	Year	number of years for depreciation (linear per unit of production)

Figure 49 Complete list of variable with relative value used in the Jan-Diederik - Van Wees analysis

Bibliography

Aldred, J. 22 April 2008. Iceland's energy answer comes naturally. *The Guardian.* 22 April 2008.

Allplan GmbH for OeEB, Österreichischer Entwicklungsbank AG, in cooperation with Frankfurt School and Local Partners. November 2013. *Energy Efficiency Finance, "Task 1 Energy Efficiency Potential, Country Report Turkey".* Vienna : s.n., November 2013.

Angelino, L., P. Dumas, A. Latham. 2013. *EGEC Market Report 2013/2014.* Brussels : s.n., 2013.

Bertani, R. 25-29 April 2010. *Geothermal Power Generation in the World 2005-2010 Update Report.* Bali, Indonesia : proceedings at World Geothermal Congress 2010, 25-29 April 2010.

Bombarda, P., M. Astolfi, P. Silva. *Estimating cost of the geothermal power technologies.* Milano : Energy Department, Gecos Group, Politecnico di Milano.

Bottio, I. 2013. *Italy in district Heating and Cooling, Country by Country/ 2013 Survey, Euroheat and Power.* Brussels : s.n., 2013.

Chamorro, C.R., J.L. Garcìa-Cuesta, M.E. Mondéjar, A. Pérez-Madrazo. 2013. *Enhanced geothermal systems in Europe: An estimation and comparison of the technical and sustainible potential.* Valladolid, Spain : Universidad de Valladolid, 2013.

DiPippo, R. 2012. *Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact.* 2012.

Dumas, P., A. Bartosik, (EGEC). November 2014. *GeoDH: Geothermal DH Potential in Europe.* November 2014.

EGEC, et al. 2013. *GeoELEC Report.* 2013.

EurObserv'ER. 2014. *The State of Renewable Energies in Europe.* 2014.

Goldstein, B. 2011. *"Geothermal Energy", IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation.* Cambridge, United Kingdom and New York, NY, USA : Cambridge University Press, 2011.

Hance, C.N. 2005. *Factors Affecting Cost of Geothermal Power Development.* Washington, DC, USA : Geothermal Energy Association, for the U.S. Department of Energy, 2005.

Hurter, S., R. Schellschmidt. 2003. *Atlas of geothermal resources in Europe.* Potsdam-Hannover, Germanyy : s.n., 2003.

Kruck, C., L. Eltrop, R. Lo. 2010. *Strom- und Wärmeerzeugung aus tiefer Geothermie für Stuttgart (Electricity and Heat Production from deep geothermal energy in Stuttgart).* Stuttgart : IER, Universität Stuttgart, 2010.

Lund, J.W. and T.L. Boyd. 2009. *"Geothermal utilization on the Oregon Institute of Technology campus, Klamath Falls, Oregon", Proceedings of the 34th Workshop on Geothermal Reservoir Engineering.* Stanford, CA, USA : Standford University, 2009.

OECD/IEA. 2011. *Technology Roadmap: Geothermal Heat and Power.* Paris : s.n., 2011.

Van Wees, J.D. *A Methodology for Resource assessment and application to core countries.* s.l. : TNO Innovation for Life.

William, C.F., M.J. Reed, R.H. Mariner, J. DeAngelo and S.P. Galanis. 2008. *Assessment of Moderate and High Temperature Geothermal Resources of the United States.* Washington, D.C. : U.S. Geological Survey, 2008.