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WP6_Action_6.1: Identification of technologies with potential for AA

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Data: 18/03/2018	Data: 30/03/2018	Data: 30/03/2018

Document code: TSE0117IN002_v00

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1 Modifications

Data	Version	Clarifications
18/03/2018	V00	Final Report

2 Object

The purpose of this document is to identify geothermal technologies with potential for the implementation in the AA territories, taking into account the resources and potential as well as the existing energy infrastructure.

In addition to the description of the geothermal technologies with potential within the AA and that have not yet been introduced in the energy market, a small analysis of the current situation of geothermal energy in Europe and in the country of each project partner will be carried out.

3 Partner areas influence

The following table shows the partners participating in the project, indicating their origin countries:

	PARTNER	COUNTRY
1	Ourense City Council	Spain
2	EnergyLab (Centro Tecnológico de Eficiencia y Sostenibilidad Energética)	Spain
3	ITER (Instituto Tecnológico y de Energías Renovables)	Spain
4	AMCB (Associação de Municipios da Cova da Beira)	Portugal
5	Faculty of Engineering of University of Porto	Portugal
6	IET (Islay Energy Trust)	United Kingdom
7	ALI Energy (Argyll, Lomond and the Islands Energy)	United Kingdom
8	EDEN Proyect	United Kingdom
9	ALEC (Agence Locale de l'Energie et du Climat)	France
10	CIT (Cork Institute of Technology)	Ireland
11	EHPA (European Heat Pump Association)	EU (Brussels)
12	RNAE (Red Nacional Associação das Agências de Energia e Ambiente)	Portugal
13	EDA Renováveis (T.A.)	Portugal
14	DREn (Direçao Regional da Energía)	Portugal
15	CMRG (Câmara Municipal da Ribeira Grande)	Portugal
16	CMP (Câmara Municipal da Povoação)	Portugal

Table 1: Project partners.

Also includes a map with the location of each of the partners:

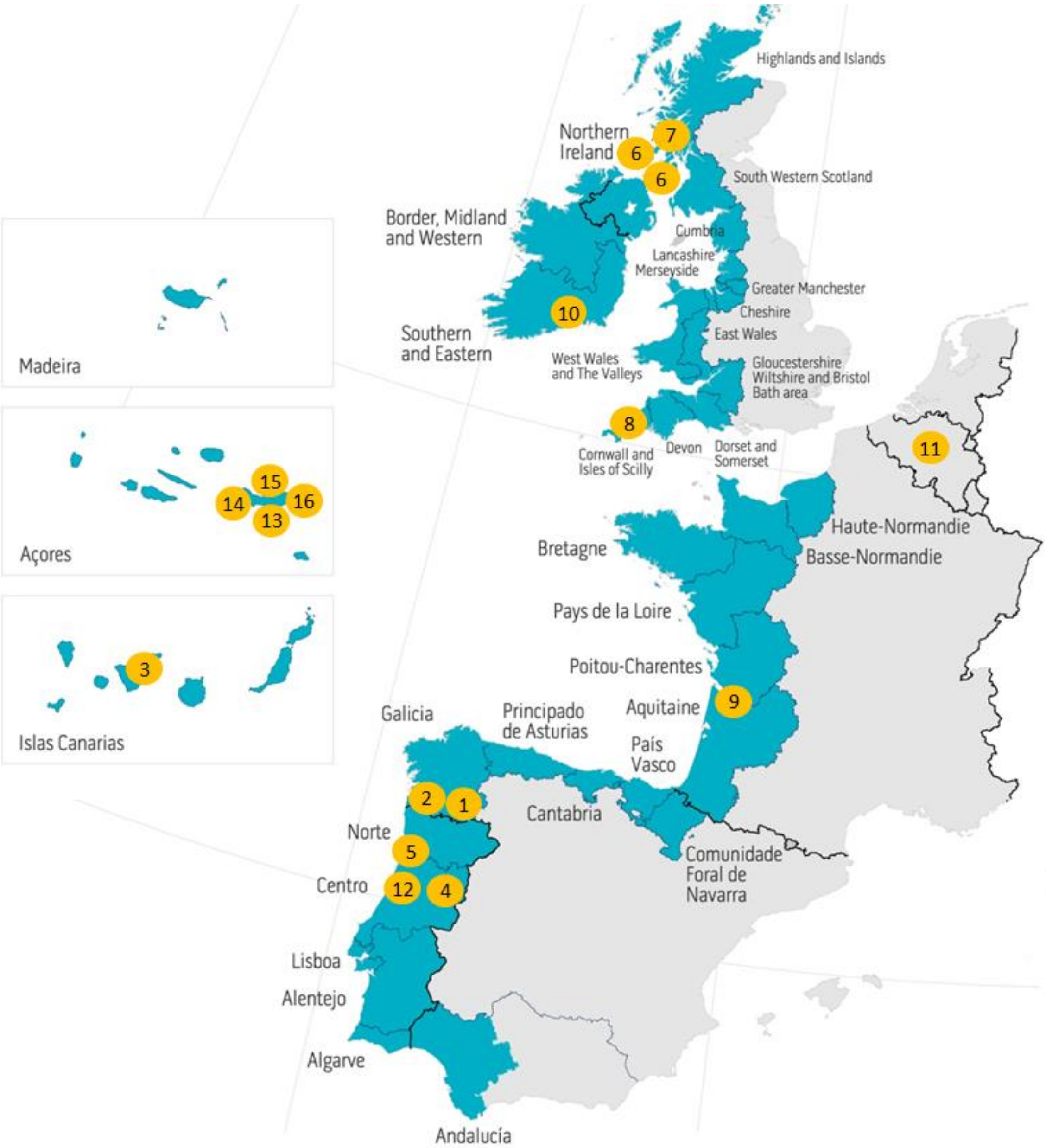


Illustration 1: Atlantic Area Programme 2014-2020.

4 World geothermal situation

The documentation shown in this section has been obtained from different associations specialized in geothermal energy, such as:

- International Renewable Energy Agency (IRENA).
- European Geothermal Energy Council (EGEC).
- Geothermal Energy Association (GEA).
- Intergovernmental Panel on Climate Change (IPCC).
- International Energy Agency (IEA).
- …

4.1. Introduction

Geothermal energy is a type of renewable energy which is generated within the earth and can be used directly for heating or transformed into electricity. An advantage of geothermal energy over some other renewable energy sources is that it is available year-long (whereas solar and wind energy present higher variability and intermittence) and can be found around the globe. However, for electricity generation, medium- to high-temperature resources, which are usually close to volcanically active regions, are needed.

Compared to fossil energy resources, geothermal power generation brings a number of benefits, such as: lower life-cycle greenhouse gas emissions; lower running costs; capability to supply baseload electricity, flexibility and ancillary services to a system; and higher capacity factors.

Global geothermal power capacity by the end of 2016 totaled 12.7 gigawatts (GW), with annual electricity generation reaching 80.9 terawatt-hours (TWh) in 2015 (most recent data), amounting to approximately 0.3% of global electricity generation. Geothermal electricity generation relies mainly on technologies that exploit conventional geothermal resources, such as: dry steam plants, flash plants (single, double and triple), binary plants, and combined-cycle or hybrid plants.

However, as high-quality conventional resources become harder to access, deeper resources may become accessible in the future through the development of enhanced geothermal systems (EGS).

4.2. Process and Technology Status

Geothermal energy is heat derived within the sub-surface of the earth. Water or steam carry the geothermal energy to the earth's surface. Depending on its characteristics, the geothermal energy can be used for heating and cooling purposes or can be harnessed to generate clean electricity. Geothermal power generation has higher capacity factors compared with some other renewable energy resources and is capable of supplying baseload electricity, as well as providing ancillary services for short and long-term flexibility in some cases. Furthermore, geothermal power generation has lower life-cycle greenhouse gas emissions than fossil fuel-based generation. Geothermal energy can be sourced from virtually everywhere. However, the vast majority of medium and high temperature geothermal systems, which are suitable for power generation, are located close to areas of volcanic activity for example, situated along plate boundaries (subduction zones, such as the majority of the Pacific "Ring of Fire"), mid-oceanic ridges (such as Iceland and the Azores) and rift valleys (such as the East African Rift) or near hot spots (such as in Hawaii).

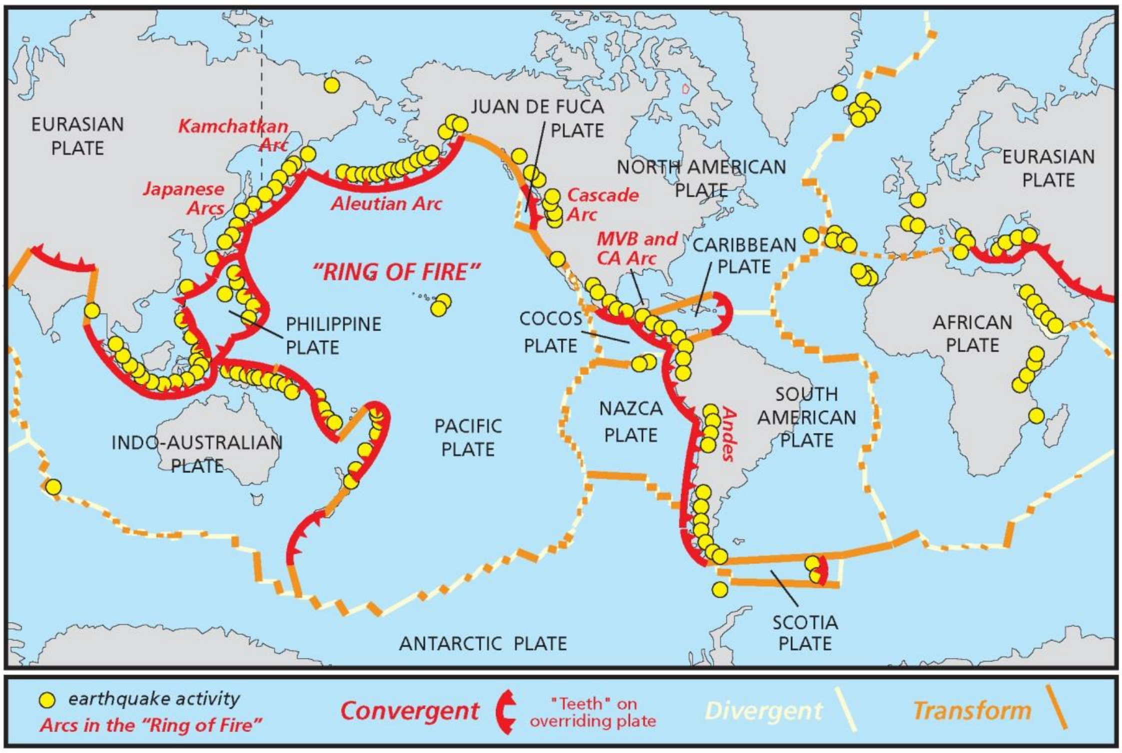
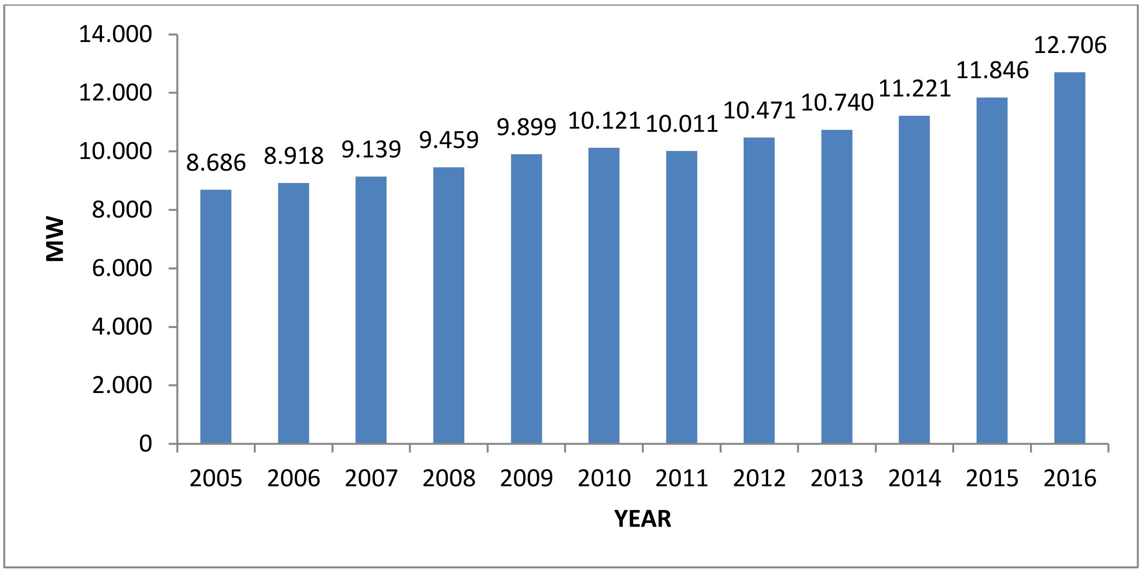


Illustration 1: Tectonic plates and global geological activity (Adapted form National Park Service (U.S).

In 2016, the global geothermal installed capacity was 12.7 GW.



Graphic 1: Global installed geothermal capacity (Source: IRENA, 2017a).

In 2015, geothermal power plants generated approximately 80.9 TWh, or approximately 0.3% of global electricity generation. As shown in the next table, the United States (2.5 GW), the Philippines (1.9 GW) and Indonesia (1.5 GW) lead in installed geothermal power capacity.

Country	Capacity (MW)
USA	2511
Philippines	1916
Indonesia	1534
Kenya	1116
New Zealand	986
Mexico	951
Italy	824
Turkey	821
Iceland	665
Japan	533
Costa Rica	207
El Salvador	204
Nicaragua	155
Russian Federation	78
Papua New Guinea	53

Table 2: Net installed geothermal power capacity by country in 2016 (Source: IRENA, 2017a).

Global installed capacity additions in 2016 amounted to 901 megawatts (MW), the highest number in 10 years, which were installed in Kenya (518 MW), Turkey (197

MW) and Indonesia (95 MW). With the growing momentum for utilising these geothermal resources, an increasing number of countries are showing interest in developing geothermal projects.

4.3. Geothermal Power Generation

The heat content of a geothermal field will define the power generation technology to be used. Power generation from geothermal resources requires a thermal resource with medium to high heat content. Geothermal power generation is currently based on the following four technology options:

4.3.1. Direct dry plants

In this case, the conversion device is a steam turbine designed to directly use the low-pressure, high-volume fluid produced in the steam field. Dry steam plants commonly use condensing turbines. The condensate is re-injected (closed cycle) or evaporated in wet cooling towers. This type of geothermal power plant uses steam of 150 degrees Celsius (°C) or higher, and, generally, the steam entering the turbine needs to be at least 99.995% dry to avoid scaling and/or erosion of the turbine or piping components. Direct dry steam plants range in size from 8 MW to 140 MW.

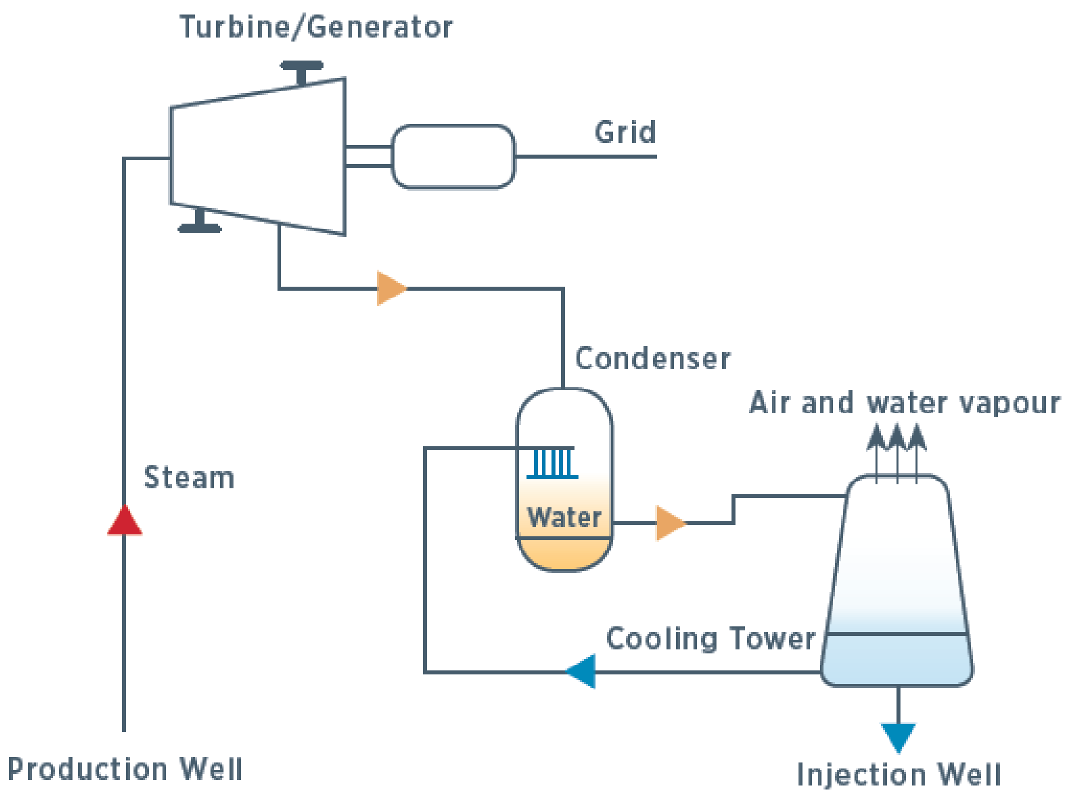


Illustration 2: Direct steam plant (Source: IRENA, 2017a).

4.3.2. Flash plants

These are the most common type of geothermal electricity plants in operation today. They are similar to dry steam plants; however, the steam is obtained from a separation process called flashing. The steam is then directed to the turbines, and the resulting condensate is sent for re-injection or further flashing at lower pressure. The temperature of the fluid drops if the pressure is lowered, so flash power plants work best with well temperatures greater than 180°C. The fluid fraction exiting the separators, as well as the steam condensate (except for condensate evaporated in a wet cooling system), are usually re-injected. Flash plants vary in size depending on whether they are single (0.2-80 MW), double (2-110 MW) or triple flash (60- 150 MW) plants.

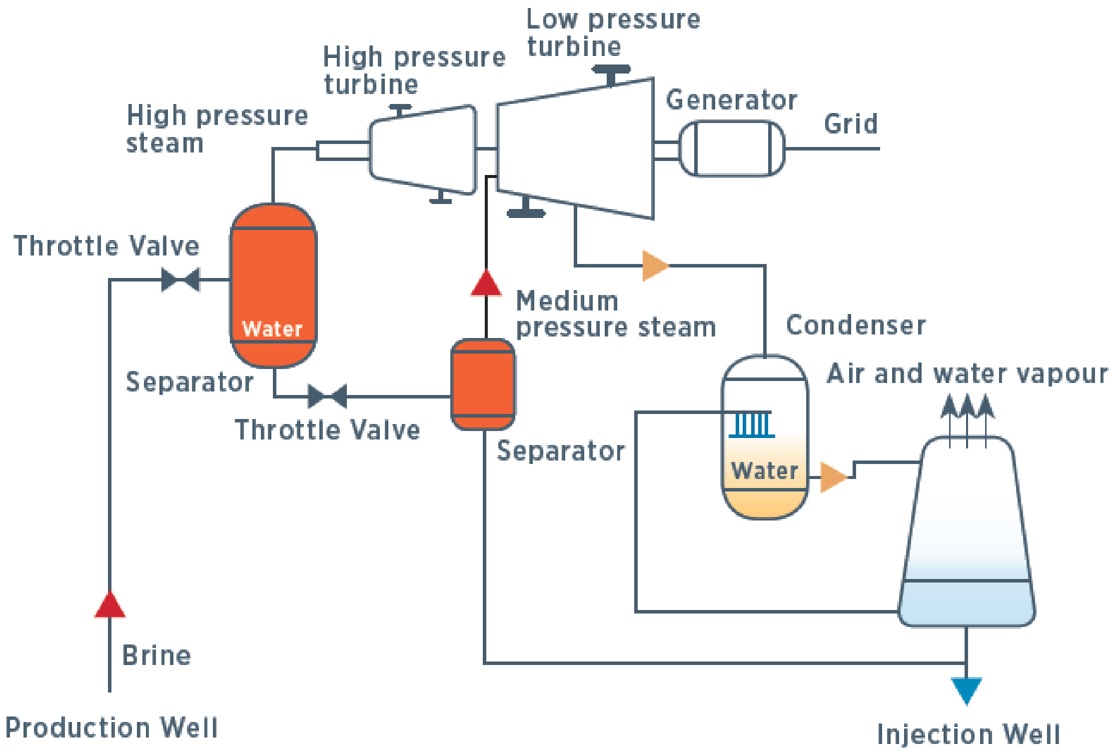


Illustration 3: Double flash plant (Source: IRENA, 2017a).

4.3.3. Binary plants

These plants are usually applied to low or medium enthalpy geothermal fields where the resource fluid is used, via heat exchangers, to heat a process fluid in a closed loop. The process fluid (e.g., ammonia/water mixtures used in Kalina cycles or hydrocarbons in organic Rankine cycles (ORC)) have boiling and condensation points that better match the geothermal resource temperature. Typically, binary plants are used for resource temperatures between 100°C and 170°C. Although it is possible to work with temperatures lower than 100°C, the efficiency of the electricity output decreases. Binary plants range in size from less than 1 MW to 50 MW.

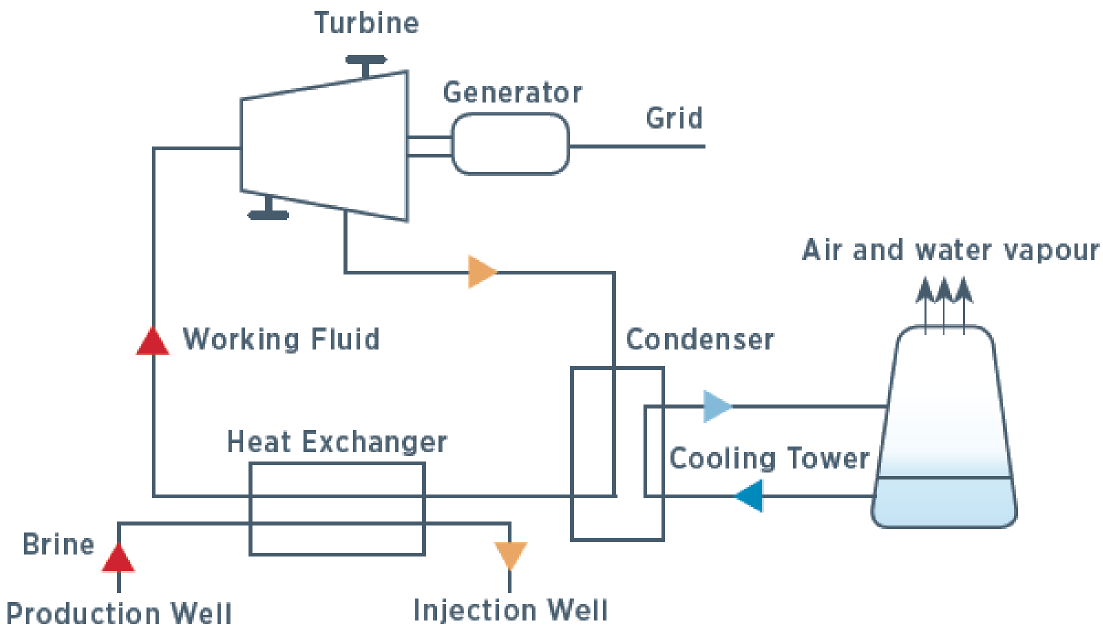


Illustration 4: Binary plant (Source: IRENA, 2017a).

4.3.4. Combined-cycle or hybrid plants

Some geothermal plants use a combined cycle which adds a traditional Rankine cycle to produce electricity from what otherwise would become waste heat from a binary cycle. Using two cycles provides relatively high electric efficiency. The typical size of combined-cycle plants ranges from a few MW to 10 MWe. Hybrid geothermal power plants use the same basics as a stand-alone geothermal power plant but combine a different heat source into the process; for example, heat from a concentrating solar power (CSP) plant. This heat is added to the geothermal brine, increasing the temperature and power output.

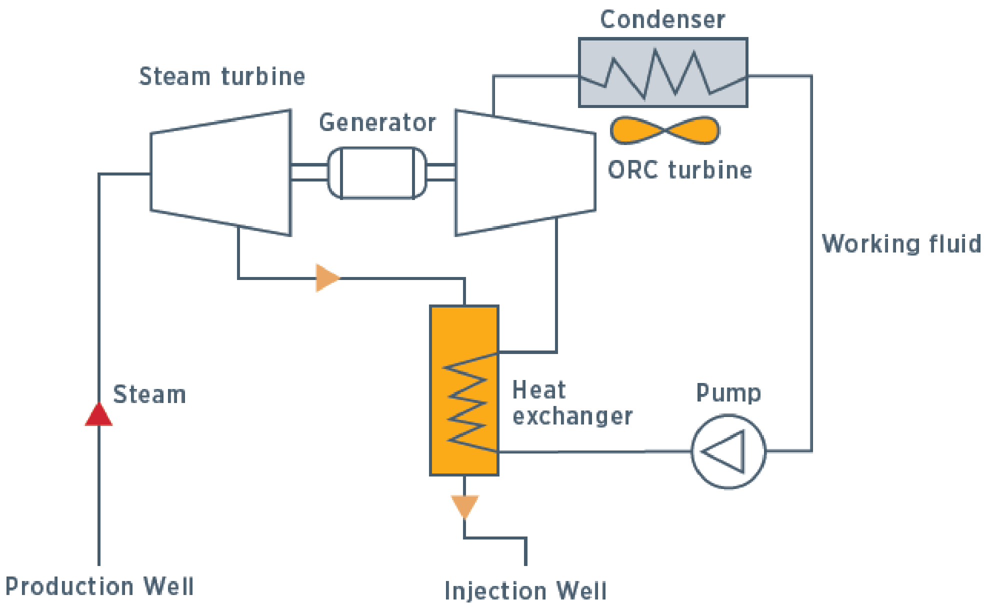
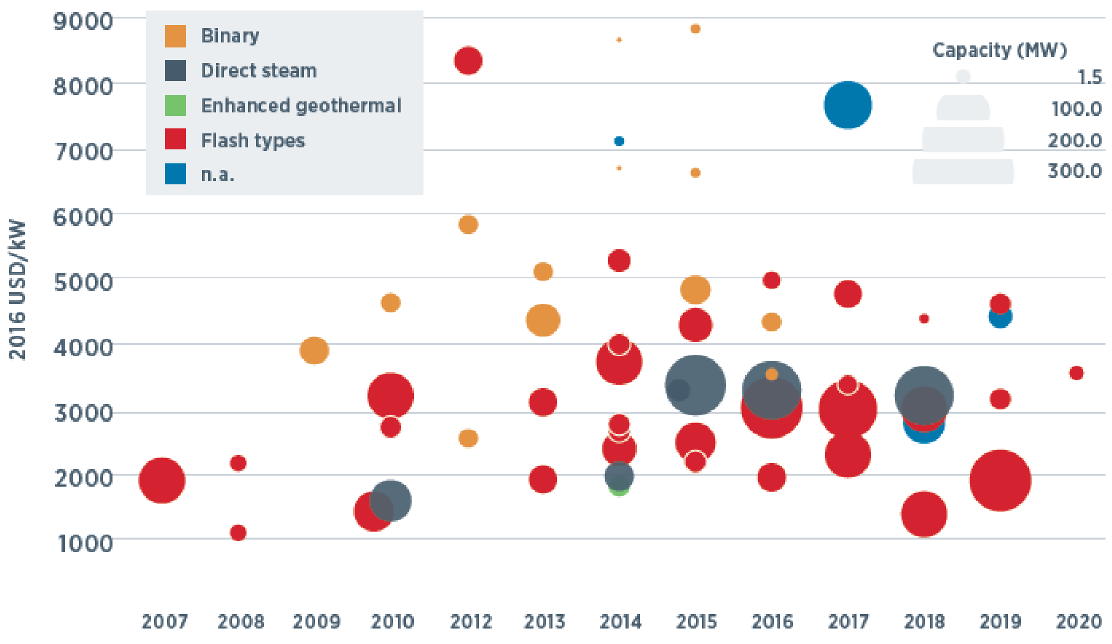


Illustration 5: Geothermal combined-cycle plant (Source: IRENA, 2017a).

4.4. Costs

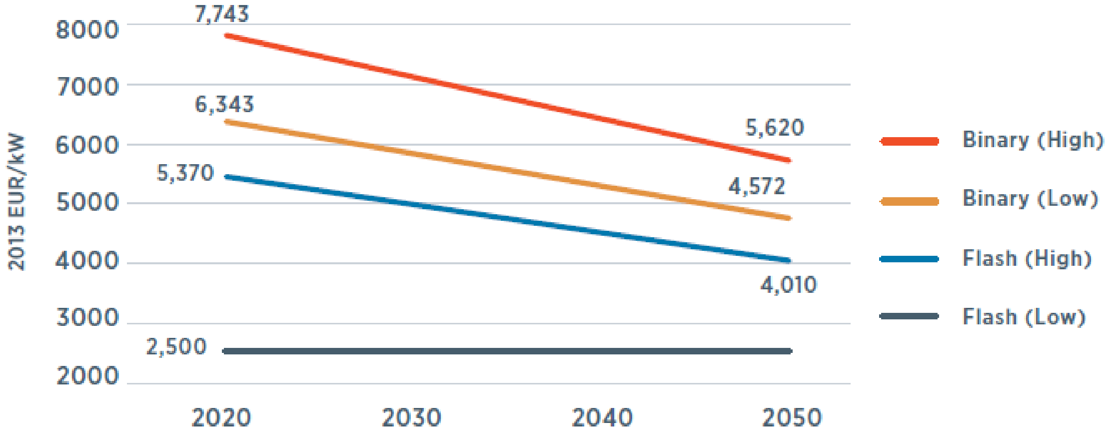
Geothermal power projects are capital intensive; however, they have very low and predictable operating costs. The total installed costs of a geothermal power plant cover the exploration and resource assessment, including: exploration drilling; drilling of production and injection wells; field infrastructure, geothermal fluid collection and disposal systems, and other surface installations; the power plant and its associated costs; project development costs; and grid connection costs. Furthermore, the cost ranges of geothermal power plants will depend largely on power plant type (flash or binary), well productivity (the number of wells) and other geothermal field characteristics.

The global total installed costs for geothermal power plants are typically between 1.870 USD to 5.050 per kilowatt (kW); however, costs are highly site-sensitive. For example, installing additional capacity at existing fields can be somewhat less expensive, while costs for projects with more challenging site conditions will be on the higher end of the range. Generally, costs for binary plants tend to be higher than those for direct steam and flash plants.



Graphic 2: Geothermal project-level costs by technology (2007-2020) (Source: IRENA, 2017b).

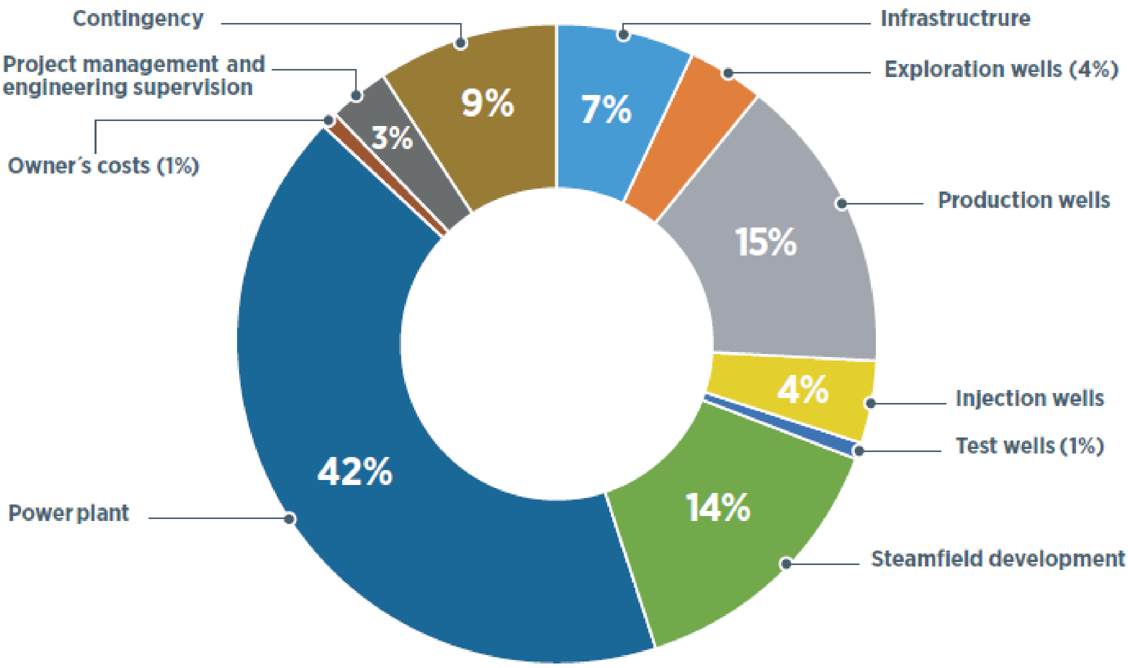
The European Commission (EC) forecasts the installed costs for both flash and binary plants to decrease through 2050.



Graphic 3: Forecast of capital expenditures (CAPEX) for geothermal power plant in the European Union (Source: Sigfusson and Uihlein, 2015).

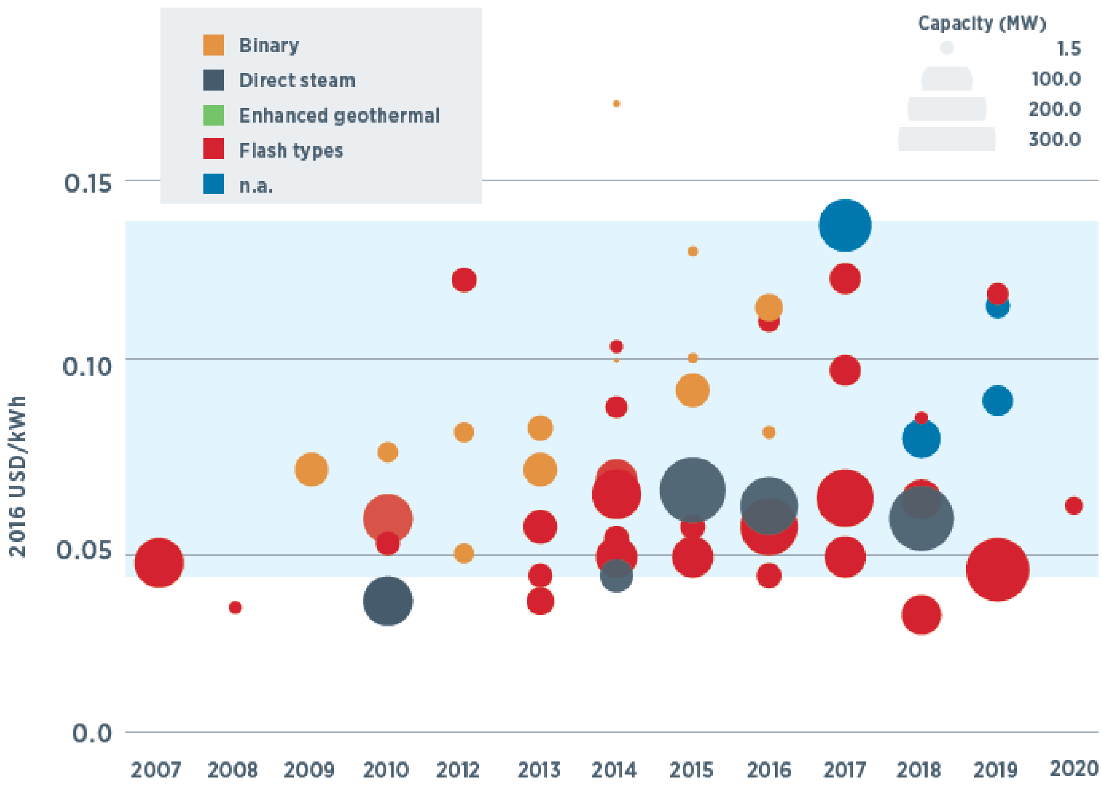
Next graphic presents the estimated cost breakdown for the development of two 110 MW flash geothermal power plants in Indonesia, with total installed costs of around

3.830 USD per kW. The power plant and infrastructure costs amount to 49% of the total installed costs; drilling exploration, production and injection wells account for around 24%; while the steam field development accounts for 14%. The energy costs performed a similar assessment for flash and binary plants and found that roughly 55% of total installed costs corresponds to the power plant and other infrastructure, while exploration, drilling and field development costs amount to 20% for flash plants and 35% for binary plants.



Graphic 4: Total installed cost breakdown for two proposed 110 MW geothermal plants in Indonesia (Source: IRENA, 2014)

The LCOE (levelised cost of electricity) from a geothermal power plant is generally calculated by using the installed costs, operations and maintenance (O&M) costs, economic lifetime, and weighted average cost of capital. Next graphic presents the LCOE for geothermal projects assuming a 25-year economic life, O&M costs of 110 USD per kW per year, capacity factors based on project plans (or national averages if data are not available), two sets of make-up and injection wells over the 25-year life and the capital costs outlined in Graphic 2: Geothermal project-level costs by technology (2007-2020). The observed LCOE of geothermal plants ranged from 0,04 USD per kWh for second-stage development of a field to 0,14 USD per kWh for a first of a kind greenfield development.



Graphic 5: Geothermal project-level LCOE by technology (2007-2020) (Source: IRENA, 2017b)

The economics of geothermal power plants may be improved by exploiting by-products such as heat, silica or carbon dioxide.

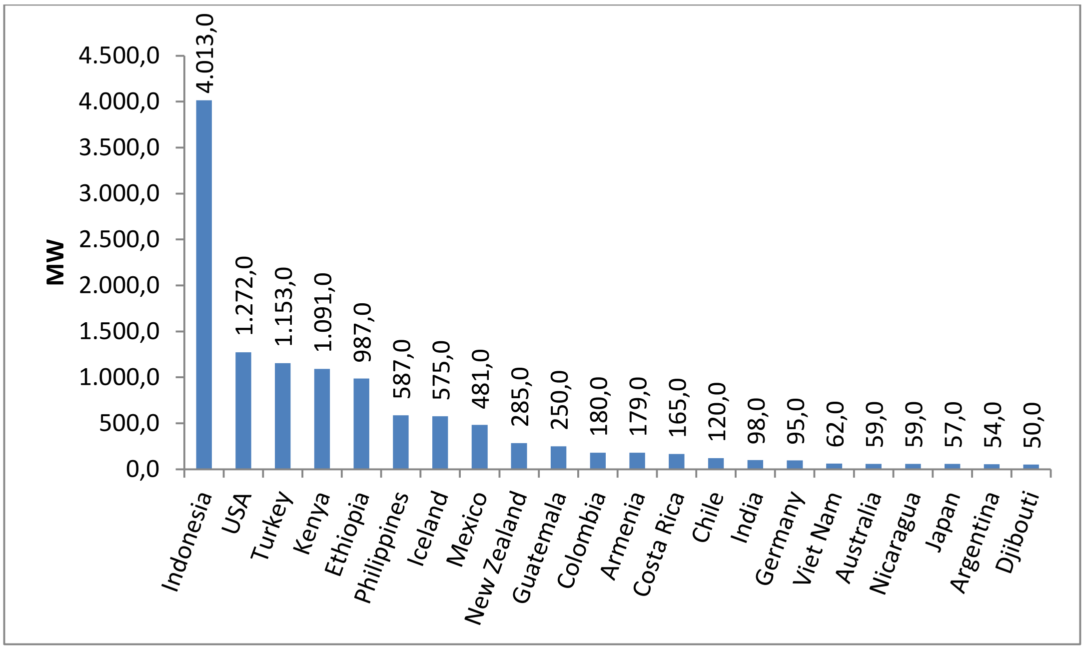
4.5. Potential

The global technical potential for electricity generation from hydrothermal resources is estimated to be 240 GW, with a lower limit of 50 GW and an upper limit between 1.000 GW and 2.000 GW, under the assumption that unidentified resources are likely five to ten times larger than currently identified resources. According to the Geothermal Energy Association, the global geothermal industry is expected to reach about 18,4 GW by 2021. Below are shown planned capacity additions in the medium term.

Country	2016	2025	>2025*
Australia	0,8	0,8	462,5
Chile	-	98,0	298,0
China	28,4	28,4	98,4
Costa Rica	213,5	368,5	368,5
Croatia	-	16,5	36,5
El Salvador	204,4	204,2	304,4

Country	2016	2025	>2025*
Ethiopia	8,5	178,5	278,5
Germany	13,2	13,2	66,1
Guatemala	54,2	54,2	134,2
Iceland	612,4	752,4	1.322,4
Indonesia	1.468,9	3.410,7	4.270,2
Italy	946,4	946.4	1.142,4
Japan	545,5	612,0	935,7
Kenya	617,2	932,2	1.247,2
Mexico	882,9	957,9	1.252,9
New Zealand	1.058,8	128,8	1.483,8
Nicaragua	133,2	190,2	412,2
Papua New Guinea	56,0	56,0	166,0
Philippines	1.943,4	2.104,4	2.834,4
Portugal	27,8	27,8	53,8
Russian Federation	95,2	95,2	150,2
Turkey	409,3	721,6	997,6
USA	3.490,3	3.874,3	5.425,3
*Capacity additions after 2025 correspond to planned and deferred projects without a completion date.			

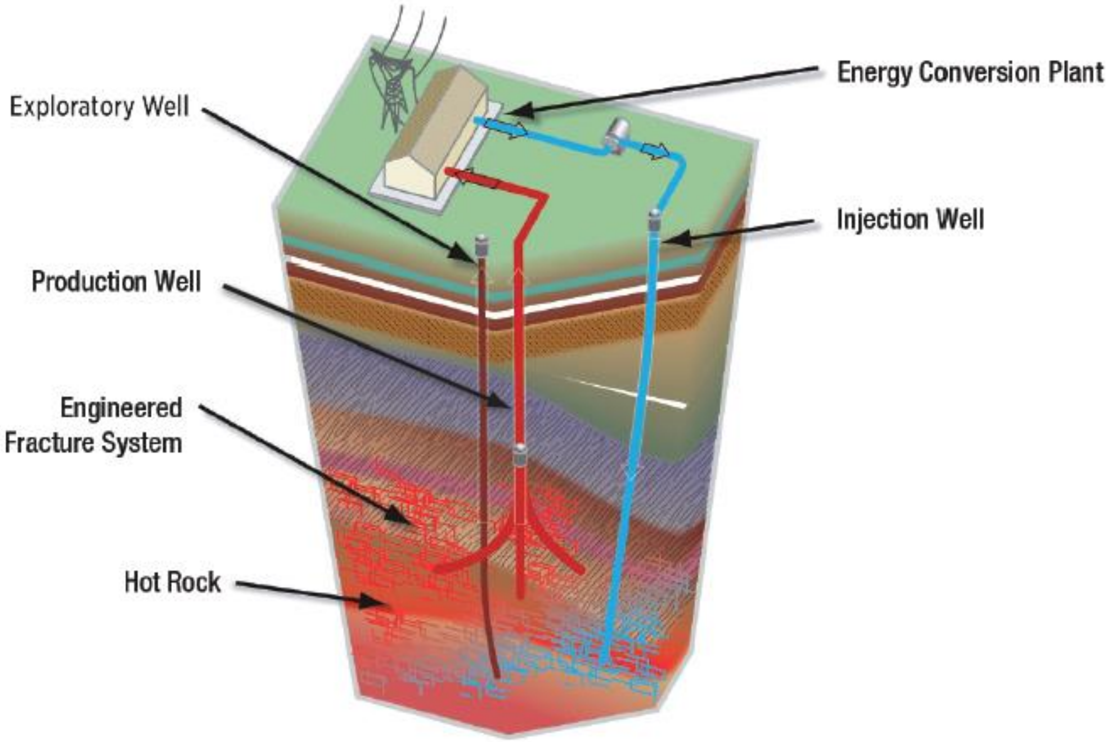
Table 3: Projected geothermal capacity (MW) (Source: S&P Global Platts, 2016).



Graphic 6: Planned capacity additions for geothermal power by country (Source: GEA, 2016).

4.5.1. Enhanced geothermal systems

A large part of the geothermal potential is heat stored at depths greater than commonly drilled. Standard hydrothermal technologies depend on permeable aquifers, which allow the flow of water through them, to produce hot water. However, at greater depths the ground becomes less porous and water flow is restricted. Research and demonstration projects are being developed to overcome this limitation. Instead, artificial fractures are created to connect production and injection wells by hydraulic or chemical stimulation. Stimulation is accomplished by injecting water and a small amount of chemicals at high pressure to create or reopen fractures in the deep rock.



Graphic 7: Enhanced geothermal system (Source: GTP, 2008).

To prevent these fractures from closing again when the injection pressure is reduced, special materials called proppants are added.

This approach, known as enhanced geothermal (EGS), uses binary plants to produce power from the hot brine. As there is no natural flow of water, all the brine has to be re-injected into the reservoir to keep the pressure and production stable. This helps prevent air emissions during the service life. Several pilot projects were performed in France, at Soultz-sous-Forêts and in Strasbourg, as well as in the US.

Exploiting untapped resources is not the only way to increase the geothermal installed capacity.

4.5.2. Low-temperature bottoming cycles

When dealing with high-enthalpy resources, it is common to use a flash plant configuration to exploit them. In a traditional flash plant, the steam exiting the turbine is re-injected into the ground, leaving it as waste heat. This steam, however, frequently exits the turbine at temperatures that are suitable for power generation through a binary cycle turbine. This would increase the overall efficiency of the plant by increasing the power output.

4.5.3. Co-generation

Geothermal energy has many potential uses besides power generation. The water collected after separating the steam for generation is normally re-injected into the ground because the temperature is too low for power generation. However, because it is frequently higher than 100ºC, by exchanging the heat with different water source before injection, this newly heated water can be used for various direct-use applications such as domestic hot water supply and space heating.

4.5.4. Co-produced resources

The use of geothermal fluids that are a by-product of other industrial processes also provides a great opportunity to produce electricity at low cost and with virtually no emissions. Hot geothermal fluids which are a by-product of oil and gas operations usually are considered a nuisance, given that they need to be disposed of at a cost. Power actually can be produced from these coproduced resources, and this already has been successfully tested in the US.

4.5.5. Supercritical geothermal systems

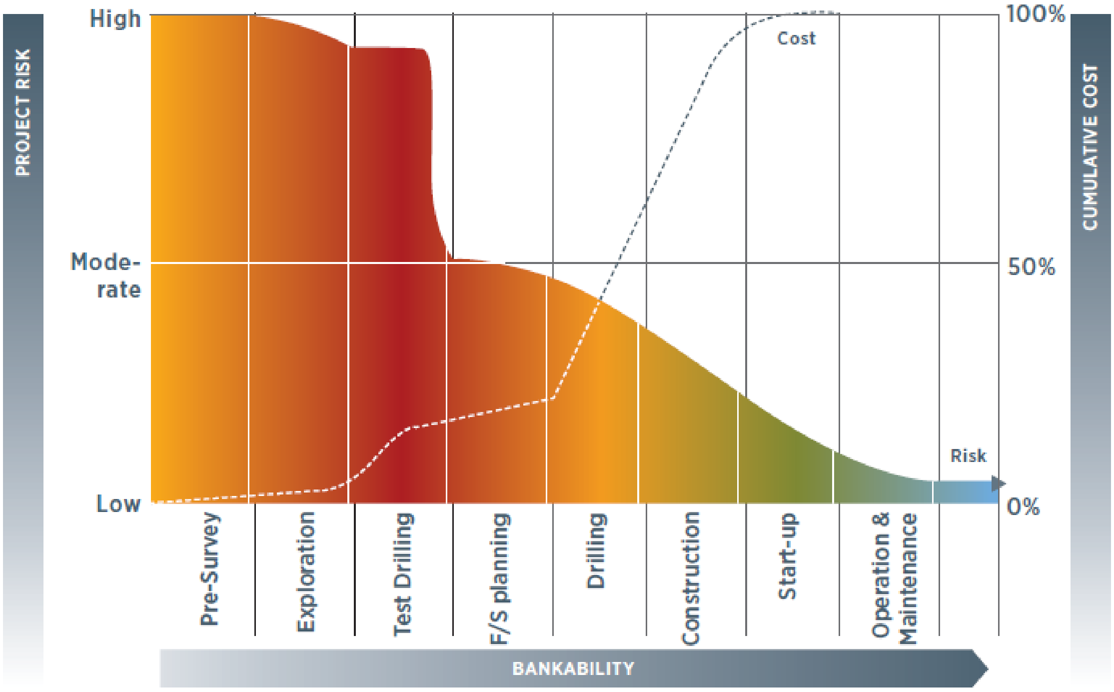
These are high-temperature systems located at depths where the reservoir fluid is in supercritical state, e.g., 374ºC and 221 bar for water. These systems are the subject of ongoing research and are not yet commercial; however, they are capable of attaining higher well productivities than conventional systems given their high temperatures. In 2009, the IDDP- 1 well in Iceland found magma and was capable of producing superheated steam at 450ºC, effectively creating the first magma-EGS system. The well, however, had to be shut down in 2012 due to a valve failure. While such a system could prove to be more economical by exploiting the steam directly from the well, the possibility of applying a reverse procedure also has been explored. This would mean using these types of wells for injection with the objective of enhancing the performance of existing conventional systems.

4.6. Barriers

The main barriers to geothermal development can be grouped into three broad categories: financial, environmental and administrative.

4.6.1. Financial barriers

Geothermal power plant development involves substantial capital requirements due to exploration drilling costs, for which it can be difficult to obtain bank loans. Since geothermal exploration is considered high risk, developers generally need to obtain some type of public financing. This risk is derived from the fact that capital is required before confirmation of resource presence or exploitability, and therefore before project profitability can be determined.



Graphic 8: Typical uncertainty and expenditure profiles for a geothermal project (Source: Gehringer and Loksha, 2012).

Governments can reduce this risk and the cost of capital for private developers in a number of ways. For instance, they can create public companies that exploit geothermal resources and provide private companies (that install power plants and supply electricity to their customers) with the steam. Other risk mitigation instruments include cost-sharing for drilling and public-private risk insurance schemes.

With sufficient resource information, including seismic events/fractures and deep drilling data (which national or local governments can make available to developers), and reliable conceptual models of the underlying geothermal system and groundwater resources, risks could be reduced and financial barriers could be further eased, thereby accelerating geothermal development.

4.6.2. Environmental and social barriers

National regulations differ among countries; however, an environmental and social impact assessment of some type is almost always mandatory. Furthermore, apart from the assessment process, sufficient discussion with local groups may be needed before development can commence.

These issues can delay or lead to the cancellation of the geothermal power project; however, if managed in a timely and efficient manner, they do not present an obstacle.

4.6.3. Administrative barriers

Administrative issues such as licensing, permitting and environmental assessments are technically not barriers. However, they need to be tackled carefully by project developers, as they might impact a geothermal project by causing unnecessary delays. On the other hand, governments should ensure that their regulations establish a transparent and straightforward process that will foster the deployment of new projects.

4.7. Summary

Technical performance	Typical current international values and ranges			
Energy input / output	Hydrothermal fluid / Electricity			
Well drilling technologies	**Heat gradient well**	**Slim well**	**Full-size well**	**Injection well**
Depth, metres	<300	1.000 -1.600	>1.600	Varying depth
Final diameter of well size, inches	<6	<6	>6	Varying size
Power plant technologies	**Dry steam**	**Flash steam**	**Binary cycle**	
Steam quality	Dry (>99.995%)	Wet	Dry/Wet	
Typical steam temperature, °C	>150	>180	100-150	
Typical plant size (capacity), MW	0.3-110	0.3-110	0.1-45	
Total cumulative capacity, GW	12.7			
Capacity factor, %	>80 (worldwide), >90 (some individual plants or units)			
CO_2 emissions, gCO_{2eq}/kWh	Lifecycle assessments of greenhouse gases: 6-79			
Forecast for cumulative capacity, GW	18			
Technical potential for hydrothermal resources, GW	>200			
Cost	**Typical current international values and ranges**			
Typical installed cost breakdown Indonesia/EU	**Flash steam power plant in Indonesia (110 MW – IRENA, 2014)**	**Flash stem power plant in EU (Sigfusson andUihlein, 2015)**	**Binary-cycle power plant in EU (Sigfusson and Uihlein, 2015)**	
Power plant, steam field development / Power plant and surface installations	56%	56%	55%	
Drilling wells / Exploration, drilling, stimulation	24%	21%	34%	
Infrastructure / Interconnection, heating process	7%	7%	1%	
Project management and engineering supervision / Planning, management, land	3%	12%	5%	
Others / Insurance	10%	4%	4%	
Typical total installed costs	**Flash steam power plant**	**Binary-cycle power plant**		
2016 USD/kW	1.870 – 5.050			
2015 USD/kW	1.900 – 3.800	2.250 – 5.500		
2014 USD/kW	2.851 (average cost for plants installed in 2013, >1 MW/plant)			
2013 USD/kW	2.500 – 5.930	6.470 – 7.470		
Forecast in US, 2015 USD/kW	2.687			
Forecast in EU, 2013 EUR/kW	2.500 – 5.370 (in 2020)	6.300 – 7.743 (in 2020)		
	2.500 – 4.870 (in 2030)	5.660 – 6.957 (in 2030)		
	2.500 – 4.420 (in 2040)	5.088 – 6.253 (in 2040)		
	2.500 – 4.010 (in 2050)	4.572 – 5.620 (in 2050)		
Levelised cost of electricity	**Geothermal power projects**			
Global LCOE, 2016 USD/kWh	0,04 – 0,14			
O&M cost, USD/kWh	0,01 – 0,03			
Forecast in US, 2015 USD/kWh	0,0423 (O&M: 0,0131, capacity factor 91%, in 2022) 0,0411 (O&M: 0,0152, capacity factor 93%, in 2040)			

Table 4: Key data for geothermal power.

4.8. Ground Source or Geothermal Heat Pump (GSHP or GHP)

For the harnessing of low enthalpy geothermal energy, there have been used geothermal heat pumps for many years, technology which is today still in continuous progress. Because geothermal utilization of low and very low enthalpy is feasible in almost any part of the earth's surface, geothermal heat pump technology plays a very important role. This is the reason why a section is devoted to this technology.

The documentation included in this section has been obtained from different associations specialized in geothermal energy, such as:

- International Ground Source Heat Pump Association.
- Ground Source Heat Pump Association.
- U.S. Department of Energy.
- European Heat Pump Association.
- …

4.8.1. Introduction

Geothermal (ground-source) heat pumps (GHP) are one of the fastest growing applications of renewable energy in the world, with annual increases in many countries. Its main advantage is that it uses normal ground or groundwater temperatures (between about 5 and 30ºC), which are available in all countries of the world. Most of this growth has occurred in the United States and Europe, though interest is developing in other countries such as Japan and Turkey.

4.8.2. Technology

GHPs use the relatively constant temperature of the earth to provide heating, cooling and domestic hot water for homes, schools, government and commercial buildings. A small amount of electricity input is required to run a compressor; however, the energy output is of the order of four times this input. These “machines” cause heat to flow “uphill” from a lower to higher temperature location really nothing more than a refrigeration unit that can be reversed.

“Pump” is used to described the work done, and the temperature difference is called the “lift” the greater the lift, the greater the energy input. The technology isn’t new, as Lord Kelvin developed the concept in 1852, which was then modified as a GHP by Robert Webber in the 1940s. They gained commercial popularity in the 1960s and 1970s.

The physics of GSHP is well-known. While heat (thermal energy) tends to flow naturally from high-temperature sources and bodies to low-temperature heat sinks, heat pumps can move heat from low-temperature to high-temperature heat sinks. The GSHP principle is based on the four phases of the reverse Carnot cycle[1]. Therefore, a GSHP can typically be used to extract heat from a refrigerator or an air-conditioner and provide heat for water or space-heating. The basic configuration of a GSHP consists of the evaporator (i.e. outdoor unit) where the process fluid evaporates, absorbing heat from the heat source (e.g. ground/water), a compressor to compress the fluid and increase its temperature, a condenser (i.e. indoor unit), which releases heat by condensing, and an expansion valve to reduce the pressure and temperature of the process fluid to below the level of outside air temperatures in order to restart the cycle. The energy for the process is provided by the electric energy to run the compressor and circulate the fluid.

Depending on GSHP applications, various process fluids have been used over time. While NH_3, CO_2 and ether were used in early heat pumps, freon-based gases (e.g. CFC, HCFC) have been widely used over the last decades of the 20th century because they are efficient, stable and safe. However, the regulations to protect the ozone layer have led to a phase-out of these gases since the Montreal Protocol in 1987. As an alternative, hydro-fluoro-carbon (HFC) gases have been developed and are currently used. Fluids with a lower global warming potential are now under development.

FLUID	TYPE	GWP[2]	COMMENT
R134A	Organic HFC	1430	Mainly commercial
R407C	Organic HFC blend	1774	Domestic/commercial
R410A	Organic HFC blend	2088	Domestic/commercial
R32	Organic HFC	675	Not yet widespread: flammability
R290	Organic HF	3,3	Mainly process: flammability
R717 (ammonia)	Inorganic	0	Toxicity
R744 (CO_2)	Inorganic	1	Low critical temperature

Table 5: Common working fluids compared.

[1] The Carnot cycle (Sadi Carnot, 1824) is a theoretical thermodynamic process to convert thermal energy into mechanical energy, using the thermodynamic transformations of an ideal fluid (i.e. perfect gas): a) the heat provided by a high temperature source (e.g. combustion) is first absorbed by the isothermal expansion of the fluid; b) the fluid then expands adiabatically (e.g. in a piston or a turbine) and generates mechanical energy, while reducing its temperature; c) the residual heat of the fluid is then released during an isothermal compression; d) finally, an adiabatic compression increases the fluid temperature to the initial level to restart the cycle. In common practice, the theoretical Carnot cycle translates into the Rankine cycle, using a phase-change fluid.

[2] Global warming potential: the global warming effect with reference to CO_2.

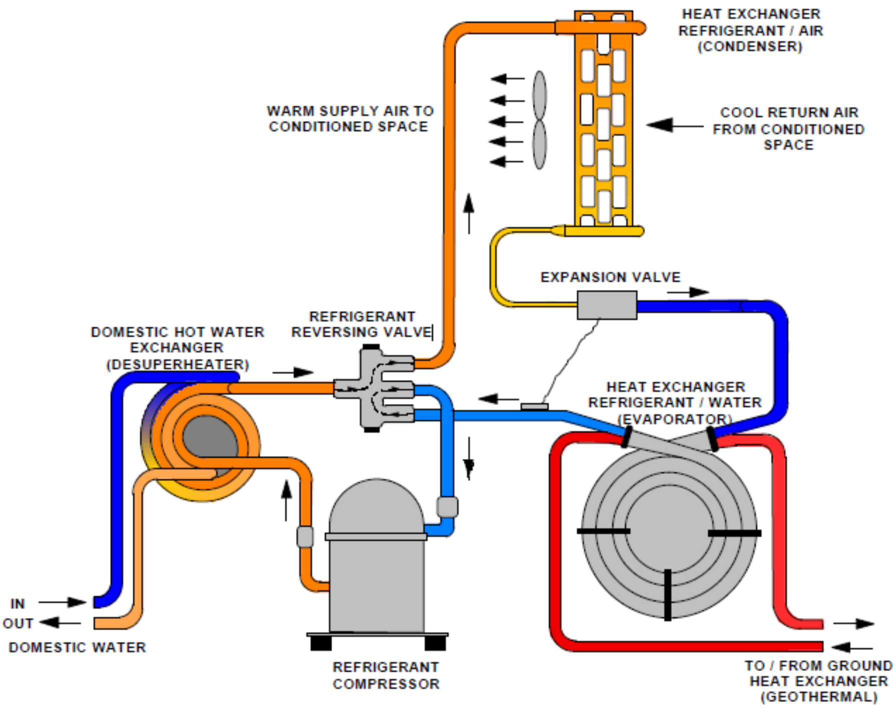


Illustration 6: GHP in the heating cycle (Source: Oklahoma State University).

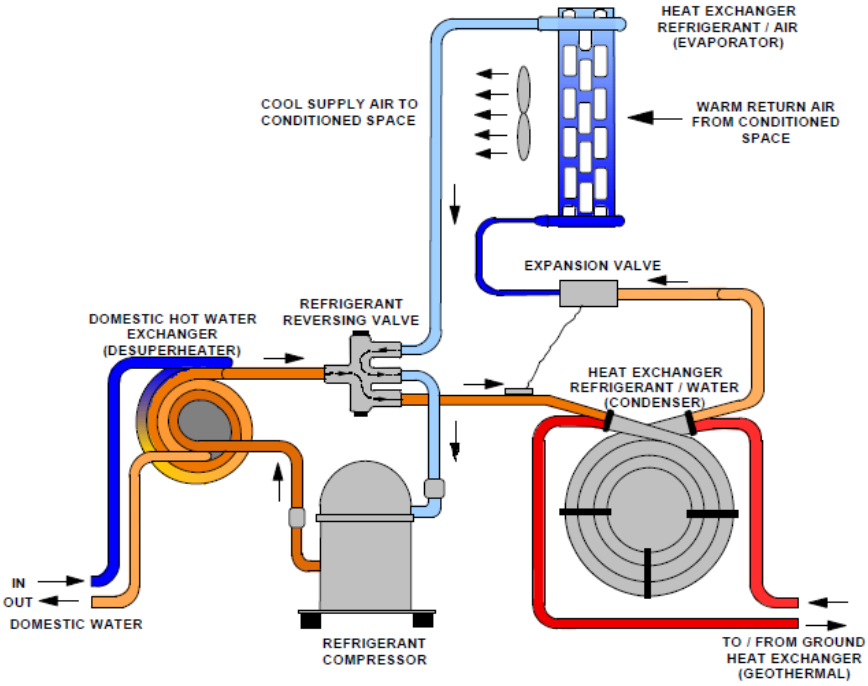


Illustration 7: GHP in the cooling cycle (Source: Oklahoma State University).

GHPs come in two basic configurations: ground-coupled (closed loop) and groundwater (open loop) systems, which are installed horizontally and vertically, or in wells and lakes. The type chosen depends upon the soil and rock type at the installation, the land available and/or if a water well can be drilled economically or is already on site.

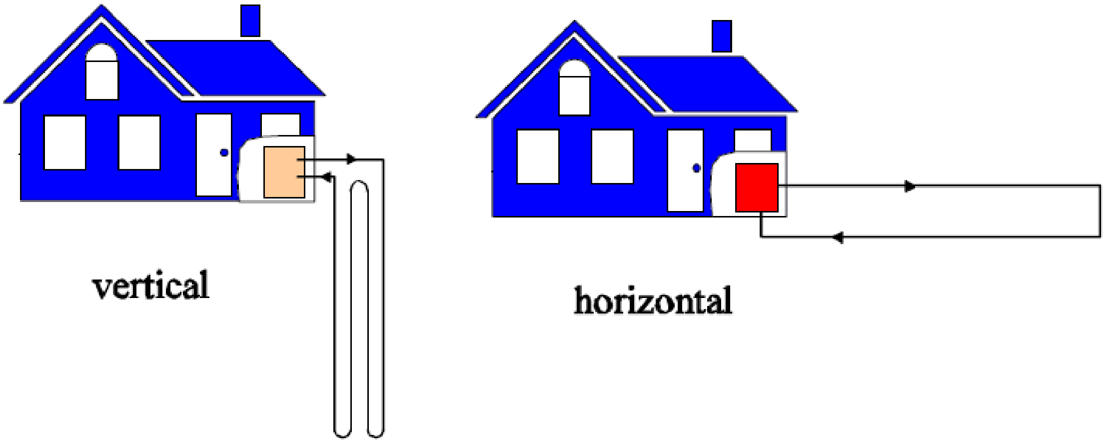


Illustration 8: Closed loop heat pump systems (Source: Geo-Heat Center).

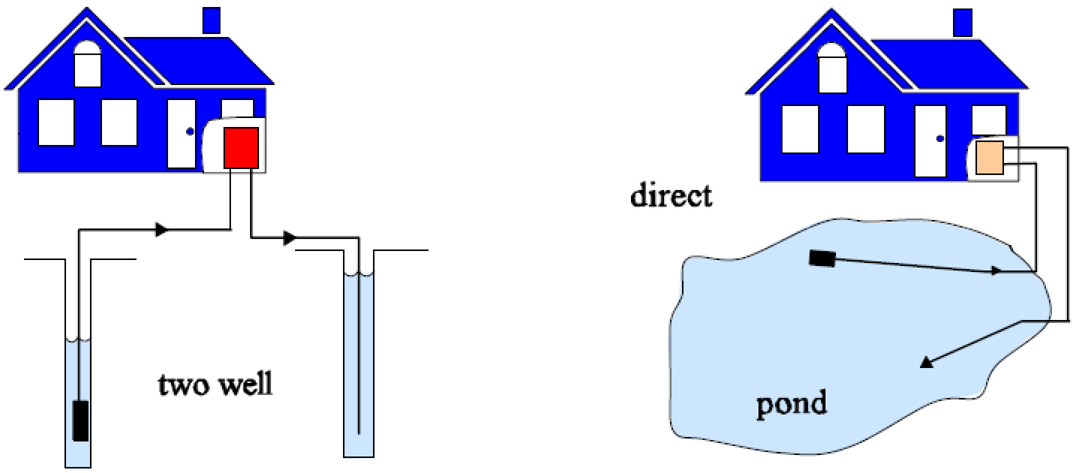


Illustration 9: Closed loop heat pump systems (Source: Geo-Heat Center).

In the ground-coupled system, a closed loop of pipe, placed either horizontally (1 to 5 m deep) or vertically (50 to 200 m deep), is placed in the ground and a water-antifreeze solution is circulated through the plastic pipes to either collect heat from the ground in the winter or reject heat to the ground in the summer. The open loop system uses groundwater or lake water directly in the heat exchanger and then discharges it into another well, into a stream or lake, or on the ground (say for irrigation), depending upon local laws.

The efficiency of GHP units are described by the Coefficient of Performance (COP) in the heating mode and the Energy Efficiency Ratio (EER) in the cooling mode (COP_h and COP_c, respectively in Europe) which is the ratio of the output energy divided by the input energy (electricity for the compressor) and varies from 3 to 6 with present equipment (the higher the number the better the efficiency). Thus, a COP of 4 would indicate that the unit produced four units of heating energy for every unit of electrical energy input. In comparison, an air-source heat pump has a COP of around 2 and is dependent upon backup electrical energy to meet peak heating and cooling requirements. In Europe, this ratio is sometimes referred to as the "Seasonal Performance Factor" and is the average COP over the heating and cooling season, respectively, and takes into account system properties.

While heat pumps are a mature technology, their efficiency is expected to increase by 2030 by 30-50% for heating and 20-40% for cooling, and by 2050 by 40-60% for heating and 30-50% for cooling. Cost reductions are expected as a consequence of technology improvements, market penetration and synergy with thermal storage systems.

	2030		2050	
	Heating	Cooling	Heating	Cooling
Cost reduction %	20-30	5-15	30-40	5-20
COP increase %	30-50	20-40	40-60	30-50
Delivered energy cost reduction %	20-30	10-20	30-40	15-25

Table 6: GSHP Cost and Performance Targets (Source: IEA-ETSAP and IRENA© Technology Brief E12 – January 2013).

4.8.3. Market

Of the approximately 16,000 MWt[3] global installed base of GSHPs, about 56 percent of this capacity is installed in the U.S., corresponding to about 65 percent of the GSHP unit installations. Europe follows, with about 39 percent of the installed capacity, and Asia has about 5%. In Europe, Sweden is the dominant player in the GSHP market, with approximately 3000 MWt.

In 2016, after several years of relative stagnation, the GSHP market pursued the recovery started in 2015, in particular the number of sales has increased by 1.6% between 2015 and 2016.

Country	2015	2016
Sweden	26.377	22.843
Germany	17.000	20.700
Finland	9.210	8.491
Poland	5.567	5.390

[3] MWt: Mega Thermal Watt.

Country	2015	2016
Austria	5.897	5.228
Netherlands	2.086	4.065
France	3.810	3.095
Denmark	1.885	2.248
United Kingdom	2.388	1.920
Slovakia	234	1.920
Estonia	1.750	1.750
Belgium	1.404	1.600
Czech Republic	1.570	1.521
Italy	952	860
Hungary	85	800
Lithuania	785	770
Slovenia	913	700
Ireland	337	371
Spain	72	77
Portugal	59	25
Bulgaria	532	0
Luxembourg	87	0
Total EU 28	**83.000**	**84.374**

Table 7: Market of geothermal (ground source) heat pumps in 2015 and 2016 (number of units sold) (Source: EuroObserver'ER 2017).

Country	2015	2016
Sweden	497.658	514.038
Germany	330.244	349.623
Finland	94.504	102.995
Poland	36.605	41.995
Austria	95.860	101.088
Netherlands	47.407	50.943
France	148.675	151.770
Denmark	56.023	60.691
United Kingdom	27.263	29.183
Slovakia	3073	4.993
Estonia	10.625	12.375
Belgium	7.774	9.374
Czech Republic	21.628	23.149
Italy	14.000	14.200
Hungary	510	1.310
Lithuania	3.693	4.463
Slovenia	9.350	10.050
Ireland	3.453	3.824
Spain	1216	1.293
Portugal	832	857
Bulgaria	4272	4.272
Luxembourg	420	420
Total EU 28	**1415085**	**1492906**

Table 8: Total number of heat pumps in operation in 2015 and 2016 (Source: EurObserv'ER 2017).

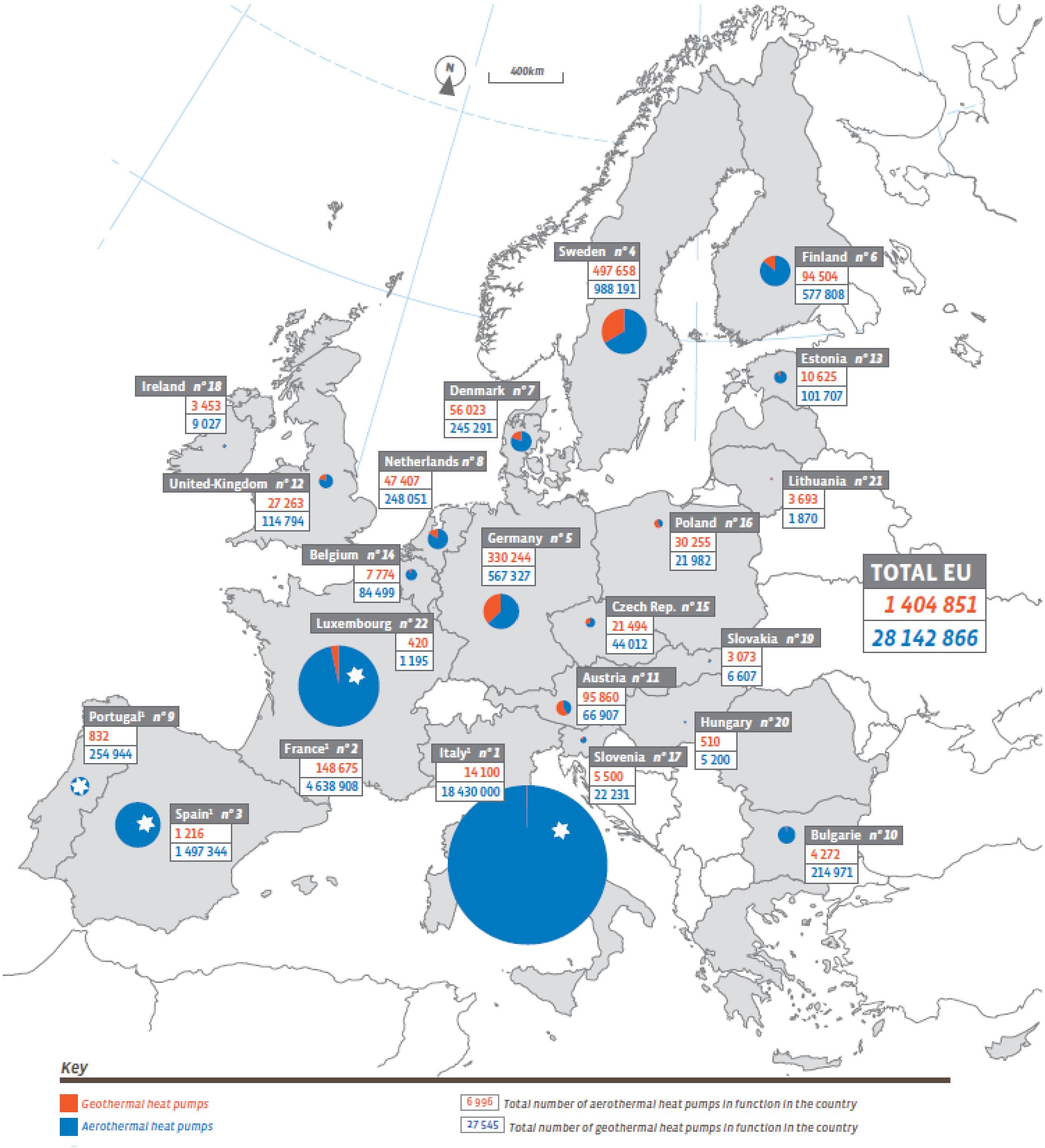


Illustration 10: Installed units of aerothermal and geothermal heat pump park in operation in European in 2015 (Source: EurObserv'ER 2016).

The lights have turned to green for the next few years. The sector should take off from a combination of favourable factors such as the improved price ratio between electricity and gas, the economic recovery that increases homeowners' investment capacities and the more stable construction market.

Development of the GHP market could also profit from the advent of the PV self-consumption market as the production of solar power is the perfect match to the cooling requirements of reversible GHP technologies. The unused surplus solar power could also be channelled to top up GHP's assigned to domestic hot water and heating production.

4.8.4. Main Barriers

The main barriers to increased use of GSHPs in EU are discussed below. This includes technological, market, institutional, regulatory, and other barriers.

4.8.4.1. Technological Barriers

There are several key technological barriers to widespread adoption of GSHPs, including:

- The need for a ground loop adds significant complexity, cost, and risk:
    - Adds site-specific design considerations, which are particularly significant for single-family residential applications. Geological conditions can vary significantly even within a given neighbourhood.
    - Site-evaluation costs can be high.
    - Creates risks and uncertainties in cost estimating. It is difficult for installers to provide quotes, unless prices are inflated to cover uncertainties/risks
- Generally requires installation-specific design and engineering of the ground loop.
- Pumping parasitics can be high if the system is not properly designed.
- Seasonal variations in ground temperature in the vicinity of ground loop keep temperature lifts higher than in theory, limiting efficiency gains.
- GSHPs can be difficult and costly to install in retrofit applications.
- Direct-exchange systems (refrigerant circuit in direct contact with the ground), while less popular today compared to secondary-loop alternatives, pose unique challenges, including:
    - May be difficult to ensure adequate refrigerant-oil return.
    - Increased difficulty in maintaining refrigeration-loop integrity and cleanliness.
    - High cost of copper or aluminum refrigeration tubing/piping.
    - High refrigerant cost.
    - System repair and maintenance challenges (i.e., more difficult to recover charge and re-charge system).
    - Detecting charge loss or repairing leaks can be problematic.

4.8.4.2. Market barriers

GSHPs also face several market challenges:

- High installation costs result in poor payback compared to Air Source Heat Pump (ASHPs), and limit energy savings compared to ultra-high-efficiency ASHPs, which costs less to install.
- Space constraints in many urban areas.

- Limited production volumes lead to higher costs.
- Operating cost is dependent upon electricity price.
- Advances in ASHPs are "raising the bar" (high-efficiency, cold climate).
- Longer project duration for installing a GSHP relative to an ASHP or furnace (which can be completed in less than one day), along with the excavation mess, is a disincentive for some customers.

4.8.4.3. Institutional, Regulatory, and Other Barriers

GSHPs face additional barriers, including:

- Environmental regulations in some regions restrict re-injection of ground water.
- Potential for glycol leaks can be a barrier.
- Low market awareness among consumers.
- Limited number of qualified, trained installers.
- Need codes to ensure proper design and installation of ground loop and pump selection (pump parasitic issue).

4.8.5. Initiatives to accelerate market adoption of GSHPs

The main initiative is to support advanced heat pump in general, rather than supporting only one type (such as GSHP). Bases on the las investigations, all types of heat pump (GSHP, ASHP, and possibly hybrid systems) can play important roles helping EU pursue its energy-efficiency objectives. Incentives such as federal tax credits or utility rebates can be based on energy efficiency achieved, rather than type of heat pump. R&D projects can be pursued based on the individual merit of each prospective project, rather than type of heat pump.

4.8.5.1. Additional Evaluations

Additional evaluations will help determine the likely impacts of R&D efforts to lower costs and to identify promotional projects that may be of interest to stakeholders.

4.8.5.1.1. Potential for GSHP Cost Reductions

Evaluate the potential for first-cost reductions for GSHPs, including potential economies of scale, alternative business models, and potential partnering relationships. Working with industry stakeholders, identify concepts to lower ground-loop installation costs then estimate their likely cost impacts. Potential concepts may include:

- Reducing the need for, and/or cost of, evaluating ground conditions (soil type/mix, thermal conductivity, water content/ground-water depth).
- For new construction, maximizing use of excavation required for the building foundation, including coupling ground loop to the foundation.
- Hybrid systems using air-cooled condensers or possibly cooling towers to reduce ground-loop size while still meeting peak cooling requirements.
- Additives to enhance soil conductivity in the vicinity of the ground loop.

- Heat-exchanger designs, or extended surfaces that then attach to ground loops that can be hammered into soil.
- Low-cost drilling/excavation equipment, including water-jet technology.

4.8.5.1.2. Detailed Performance and Energy-Benefits Modeling

It is advisable to detail the performance modelling to estimate the next impacts, which could significantly improve the economics of GSHPs:

- Potential improvements in economics due to using variable electricity rates, such as:
    - Commercial: Demand charges and time-of-use rates.
    - Residential: Current/upcoming time-dependent rate structures.
- Benefits of reducing peak electric demand. Understanding the peak demand reduction benefits of GSHPs is essential to justifying utility rebates that could substantially accelerate market adoption of GSHPs.

4.8.5.1.3. Promotional Programs with Stakeholders

Contact stakeholders to identify interest in a joint GeoAtlantic-Proyect promotional program. Arrange meetings with interested stakeholders to compare information, identify common interests, agree on priorities, and outline a joint collaboration effort, as appropriate. Stakeholders potentially interested in a GeoAtlantic-Proyect partnership to promote GSHPs may include:

- Electric utilities and the Consortium for Energy Efficiency (CEE).
- GSHP Manufacturers.
- European Council for an Energy Efficient Economy (ACEEE).
- Geothermal Heat Pump Consortium.
- International Energy Agency, Heat Pump Program.
- International Ground Source Heat Pump Association.
- Colleges.
- Leadership in Energy and Environmental Design.

4.8.5.2. Research and Development

After developing and evaluating various concepts for lowering ground-loop cost, develop prototype designs for the more promising concepts. Laboratory test or field test, as appropriate.

4.8.5.2.1. Ground-Loop Testing/Evaluation

Researchers have demonstrated that the ground loop has significant impacts on ground temperature in the vicinity of the ground loop. Also, soil characteristics vary dramatically, and have significant influence on ground-loop design and performance, and even the suitability of the site for a GSHP. Further, space constraints for some installations may not permit optimal sizing of the ground loop or spacing of bore holes.

4.8.5.2.2. Rigorous Performance Verification and Comparison to alternatives system

GeoAtlantic-Proyect will evaluate and document the energy-savings potential of GSHPs compared to alternatives through field testing and demonstrations. One option is to install both a GSHP and an alternative system in a test home and alternate use of each system. Adjust results for weather conditions and compare performance. Careful instrumentation of the ground loop is important to understand the impacts of seasonal ground-temperature variation (due to heat extraction in the winter and heat rejection in the summer).

4.8.5.2.3. Installations Codes

GeoAtlantic-Proyect recommends to work with state and local governments, manufacturers, and installers to develop model codes that state and local governments can utilize to ensure in-field performance is consistent with good design practice. The model codes should provide (or reference) appropriate ground-loop design and pump-selection guidelines for various installation conditions and ground-loop types. It should include functional performance testing requirements, if appropriate, to ensure that the system works as intended once installed.

4.8.5.2.4. Guidelines for Selecting/Designing Advanced Heat Pumps

There are many factors to consider when selecting the appropriate heat-pump technology for a given installation, including:

- Site conditions.
- Available space.
- Climate.
- Building type/construction.
- End-user economic criteria.
- End-user preferences.

Adequate tools are lacking for selecting the appropriate technology and designing the system to optimize cost and performance. GeoAtlantic-Proyect will work with interested stakeholders to develop, disseminate and support these tools.

4.8.5.2.5. Community-Based Systems

GSHPs, WSHPs, and even hybrid systems can offer significant cost and performance advantages when considered for communities. There are substantial opportunities for creative combinations with other types of community systems, such as:

- Combined Heat and Power (CHP) systems.
- District heating or cooling systems, including lake-water cooling systems.
- Heat recovery systems, including sources such as sewage, anaerobic digesters, or industrial waste-heat streams.

For example, WSHPs or hybrid systems installed at individual customer sites may be effective in reducing the capacity requirements for district heating and cooling systems, when a few, peak hours or days may otherwise dictate sizing requirements. Also, community-based systems provide a scale that may interest energy service companies or third-party owner/operators, helping to surmount the first-cost barrier.

4.8.5.2.6. Other promotional activities

Promotional activities should include:

- Support training for designers and installers (including drillers and excavators)
- Consider partnerships to create new business models to reduce drilling/trenching costs.
- Support regional information-dissemination programs.
- Work with local governments, utilities, developers, manufacturers and installers to consider community-based GSHP systems when constructing planned communities. These are especially attractive for communities that have access to lake, pond, or ocean water where, in many cases, direct cooling is possible for much or all of the cooling season.

5 Geothermal energy situation – partners regions/countries

Throughout this section, the geothermal technologies implemented in each of the regions / countries of the partners participating in the project are described, as well as the identification of geothermal systems in the development phase and which are not yet implemented in the market.

5.1. France

ALEC – Bordeaux (France)

5.1.1. Geothermal technologies currently used

5.1.1.1. Geothermy on aquifer

Main aquifer currently used for geothermy in Gironde (Aquitaine Basin - big sedimentary basin) for urban heating via heating networks or direct use (green houses, swimming pools, thermal facilities, aquaculture, drying, etc.

Some examples of the implementation of this technology are:

- **Eocene** (250 m / 24 ºC): the system consists of geothermal doublet with exchanger, heat pump that feed one or several buildings through a heating network or a moderate temperature water circuit.

- **Cenomanian** (900-1000 m / 50 ºC): the system consists of geothermal doublet with exchanger, heat pump single well (dating from the 1980s, fresh water not aggressive and not pollutant, exploitation rights currently being renewed) Moderate temperature water loop and heating pump at the foot of each building.

- **Limestone with filaments** (1600-2000 m / 70 ºC): ongoing prospection on Bordeaux in the frame of a heating network project. Geological risk covered by a guarantee fund at 90% (exceptionally because this is an experimental operation which should valid this deposit for other operations).

When the energy resource (geothermy on aquifer) exists, this technology is suitable to cover the heating needs of a heating district, achieving an economic balance in the area if there are public subsidies for the implementation of the system.

This type of geothermal systems allows to cover important needs such as urban heating networks, facilitating the energy transition strategy of large urban agglomerations, being its energy resource more limited than other sources of renewable energy such as biomass or solar energy.

On the other hand, investment in the implementation of the system is very high; it has an important geological risk and a complex and long structure (regulatory restriction, studies, etc.).

5.1.1.2. VERY LOW ENTHALPY

The low enthalpy geothermal resource is usually harnessed through geothermal heat pumps for the production of heating, HVAC and sanitary hot water.

Some of these geothermal systems are:

- **Heat pump on aquifer** (<200 m / 15-20 ºC): system used to meet the demands of heating, air conditioning and sanitary hot water in individual, collective and tertiary buildings.
  The main elements of the system are the geothermal doublet with heat exchanger and water/water heat pump. The probes are arranged vertically in a drilling diameter of 125 to 165 mm under a pattern of 2 U-tubes of 80 to 200 m depth. The perforation is filled with a mixture of cement and bentonite to guarantee the thermal exchange with the subsoil.
  This technology is capable of being used in all types of soil with a permeability that allows the flow of groundwater.
  This system is economically profitable for small, medium and large buildings, especially when it is required to cover the demands of heat and cold, and when public subsidies are available for their implementation.
  As an advantage we can highlight the high efficiency of the system, many times with a COP higher than 4. On the other hand, the reinjection is sometimes complicated and problems of obstructions and corrections can arise with the quality of the groundwater. Investments costs can be high if the aquifer is deep or contains water of poor quality.

Graphic 9: Open loop geothermal energy system.

- **Moderate loops:** system similar to the previous one, with temperatures of thermal exchange below 30 ºC.
  The main elements are the heating network of moderate temperature and heat pumps at the foot of each building (decentralized system).
  The geothermal capture system is usually made up of vertical geothermal probes.
  This type of system has low network losses and a better production yield due to the fact that the production adapts to the temperature level of each building. In addition, it is easy to insert other renewable energy systems.
  As a disadvantage, there are the higher costs of investment and exploitation linked to the various productions of the decentralized system.

- **Vertical closed loop**: The main elements of the system are vertical probes and heating circulation pumps.
  The material of the probes is usually synthetic (high density polyethylene), and its arrangement is vertical in drilling diameters from 125 to 165 mm under a pattern of 2 U-tubes or 4 U-tubes of 200 m depth.
  The perforations are filled with a mixture of cement and bentonite to guarantee the thermal exchange with the subsoil.

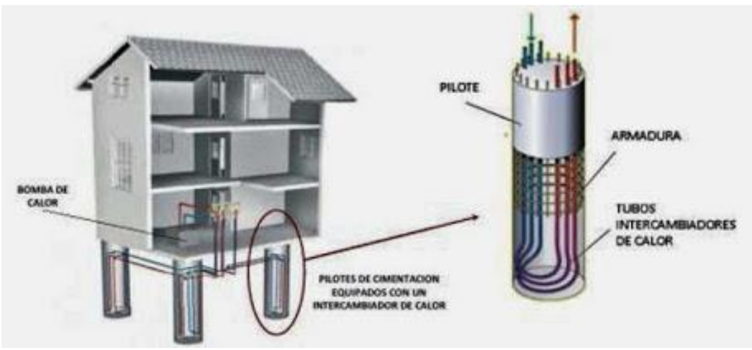
Graphic 10: Vertical closed loop.

- **Horizontal closed loop**: The main elements of the system are vertical probes and heating circulation pumps.
  This system is normally used for heating, air conditioning and sanitary hot water for individual buildings.

The main elements are the ground / water heat pump and the geothermal probes in horizontal closed disposition.
The probes used are made of synthetic materials (PE cross-linked polyethylene or HDPE high density crosslinked polyethylene), and they are installed horizontally in a trench on a certain surface, with a minimum pitch of 0,40 m.
This system is usually used in soft soils to meet the thermal demands of individual homes or small tertiary buildings. There are no subsidies for this type of system.
In some cases, the investment costs are not very high, but on the contrary, a higher surface area is necessary for installation than for the vertical probes system.
The performance of the installation will be conditioned by weather conditions (external temperature, solar radiation ...).

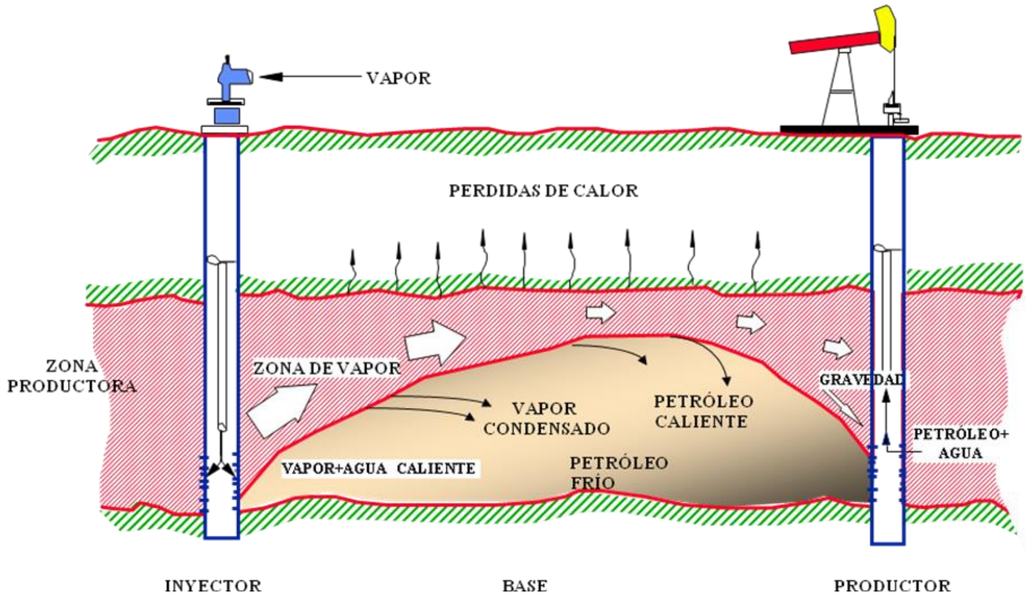
Graphic 11: Horizontal closed loop.

- **Geothermal piles or thermoactive foundations**: systems with very little use so far, and implemented exclusively in new buildings of new construction.
  The thermoactive foundation is a technology of energy use for the air conditioning of the building through the use of geothermal and the use of the elements of the reinforced concrete structure of the foundation, such as piles and screens, although in some cases you can use other structures.



Graphic 12: Thermoactive foundations.

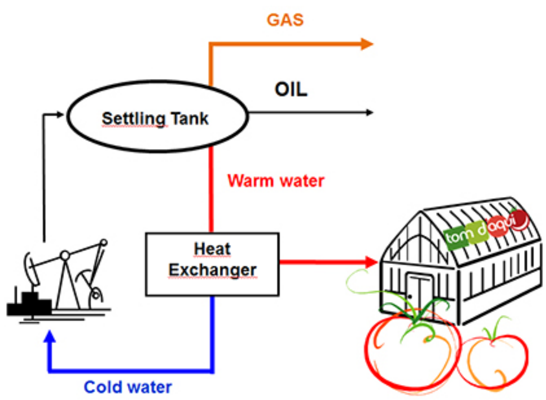
- **Waste heat from oil drilling**: although it is not the most common, in some cases geothermal systems are used to recover the waste heat from the oil extraction operation.



Graphic 13: Oil extraction process by steam injection.

Example of this, is the system of heat recovery through heat exchangers installed in the process of extraction of oil from the company Vermillion Energy, obtaining hot water at 60-70ºC which in turn is used for the production of tomatoes from Tom d'Aqui company:

1. Vermilion's petroleum extraction process in the Parentis field produces a mix of oil, gas and water, which is naturally heated to around 60°C.
2. After the oil and gas are separated out, the heated water enters a "closed loop" system where heat exchangers transfer its caloric energy to a second water system belonging to Tom d'Aqui (the two water systems never physically mix).
3. The second water system heats the Tom d'Aqui greenhouse next to the Parentis battery.
4. Vermilion reuses the produced water by pumping it back underground to maintain operating pressures and to enhance production.



Graphic 14: Scheme of exploitation of residual heat from oil extraction for the production of tomatoes.

5.1.1.3. GROUND SOURCE HEAT PUMPS

As indicated in previous sections, the geothermal heat pump is one of the most important elements in the use of low temperature geothermal energy.

Its use extends throughout the country as it allows the use of low and very low enthalpy available almost anywhere, for the production of heat, cold and hot water in residential, tertiary and industrial buildings.

5.1.1.4. PROMOTION OF GEOTHERMAL ENERGY

Of the different programs that regulate the use of geothermal energy in France, the following stand out:

- **RAGE** (Art Rules Grenelle de l'Environnement 2012): this collective program funded through the EDF energy saving certificates and soon also from GDF-Suez, aims to help the construction sector achieve the objectives set by the Grenelle de l'environnement, both in the new ones as in the existing ones. To achieve this, it is a set of five actions, including the drafting of professional recommendations related to the design, sizing, implementation, maintenance and maintenance of techniques not covered by NF DTU. Companies can rely on these professional recommendations, recognized by insurers, both in construction and renovation.
- **PACTE** (action plan for the construction of quality and energy transition): this plan supports the development of the professional skills needed in the field of energy efficiency to strengthen the quality of construction and reduce damage.

5.1.2. Geothermal systems in the development phase

Throughout this section some geothermal systems that are currently being developed and/or have not yet been commercialized will be described.

5.1.2.1. GEOTHERMAL ENERGY BASKETS OR COMPACT HEAT EXCHANGER

The baskets of geothermal energy are systems of thermal sensors collection composed of polyethylene tubes wound in spiral and subjects with a metallic skeleton. Currently, its installation is not regulated.

Below are examples of the two types of existing geothermal energy baskets:

FEATURE	TYP_1CO	TYP_2CO	TYP_3CO
Diameter (a) (m)	2,4	2,4	2,4
Diameter (b) (m)	1,4	1,4	1,4
Length (c) (m)	1,2	2,0	2,7
Spatial volume of baskets (m^3)	3,5	6,1	8,1
Clearance between baskets – center to center (d) (m)	5,0	6,0	7,0
Capacity per basket (kW)	0,7 - 1,0	1,1 - 1,5	1,6 - 2,0

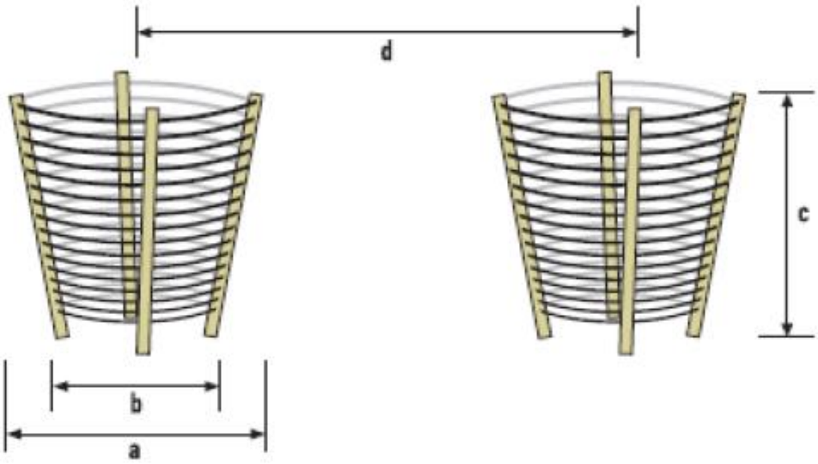


Table 9: Types and dimensions of conical geothermal energy baskets.

FEATURE	TYP_1CY	TYP_2CY
Diameter (a) (m)	1,8	1,8
Length (b) (m)	1,1	2,3
Capacity per basket (kW)	0,6 - 1,6	0,8 - 1,8

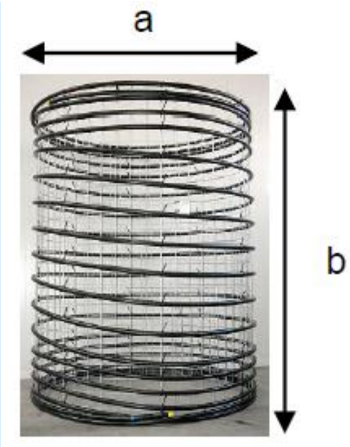


Table 10: Types and dimensions of cylindrical geothermal energy baskets.

The chosen dimensions of the baskets are dependent on the available space and the geological conditions of the soil. After having evaluated the size, the baskets are installed in 1-1,5 m soil depth and are connected with each other. The depth is chosen to 1-1,5 m because the baskets need to be installed below the frost line to prevent the baskets from freezing damage.

The tubes are filled with a liquid made of water and anti-freezing agents. This liquid is used to absorb the warmth of the soil. The absorbed warmth of the liquid is then passed down to a heat pump which is used as water heating system in the household.

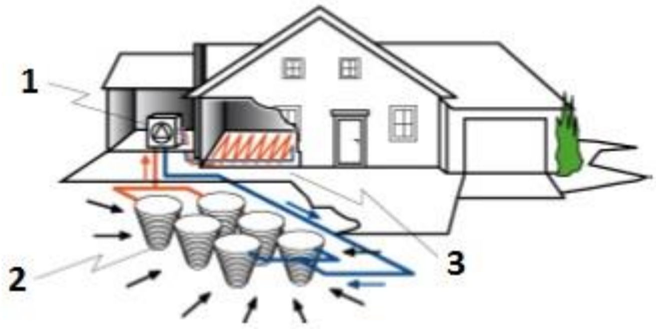


Illustration 11: Assembly of the needed infrastructure in order to use geothermal energy baskets. 1: heat pump 2: geothermal energy baskets 3: low temperature heating.

The main advantage of geothermal energy baskets is that the soil warmth in 1-1,5 m depth is approximately constant; the annual soil temperature fluctuates are within the range of 7°C to 13°C. Hence, geothermal energy baskets are an ideal energy source for heat pumps because heat pumps have a longer lifecycle if temperatures are similar over the whole year.

An innovative project is the one developed by Terrendis France, a subsidiary of RYB, in which it manufactures a new generation of grooved geothermal baskets.

For several years, RYB has participated in the MICRO-Geo project to develop a low enthalpy geothermal channel for the low-consumption individual housing market (heating, cooling and sanitary hot water for newly built houses).

Within the framework of this project, the CIAT group has developed a new low-power geothermal heat pump. For its part, Terrendis France has contributed its knowledge in the creation of an optimized geothermal basket (called TerraSpiral-NEO), where the internal grooves of the probe tube creates turbulence within the basket and it improves thermal exchange.

In fact, the basket has been resized (2,70 m in height, 1,20 m in diameter). It is folded and unfolded by a single person.

For the record, the basket goes between the horizontal sensors and the vertical probes. Therefore, it is interesting because the floor space is reduced, which allows the geothermal on small surfaces with an economic excavation.

Illustration 12: TERRA Spiral NEO – Inner spiral structure (Source: Terrendis).

5.1.2.2. HORIZONTAL SENSORS DOUBLE LAYER DISPOSED

RAGE simulation studies results: extraction thermal power <8W/ml of tub (interaction induced by the layering of tubes implies a more difficult regeneration of soils, 0,8 and 1,4 depth with a step of 0,6, staggered rows disposal is to prioritize with backfilling.

5.1.2.3. USE OF OIL WELL IN THE END OF LIFE

Ongoing study in the Bay of Arcachon by BRGM and ALEC.

In current energy outlook and oil price trends, oil companies are actively seeking more innovative ways to reduce operating costs and to extend the life of their ageing fields. Mature oil fields are characterized by a large amount of co-produced water, which must be treated continuously and could not be delivered to the environment. The waste heat recovery from the produced stream could be a quite interesting option while the wells are still producing hydrocarbons. When the oil field is depleted the field could be converted into a geothermal reservoir. This study proposes an unconventional lifecycle management.

5.1.2.4. ELECTRICITY PRODUCTION

In 2016, France had two power plants:

- ✓ One plant of 16 MW at Bouillante in Guadeloupe operated since more than 20 years.
- ✓ The plant of Soultz-sous-Forêts produced 12000 MWh per year, corresponding in electric consumption of around 2400 housings.
  Since 2002 wells are drilled at 5000 m depth in the center of a granitic massif. In 1997 after 10 years of tests and survey, a water circulation have been realized between 2 deep drillings during 4 months. With a flow rate of 25 K/s and a tª above 140°C, with neither water losses nor corrosion effect, and with a little pumping power. This world first has given the green light to follow up the programme: the implementation of a scientific pilot with the achievement of 3 drillings of 5000 m deep. In 2008, an electrical power plant with an output of 1,5 MW has been brought into service. This technology, in which pressurized water is injected into dry rocks, is called Enhanced Geothermal System (EGS).

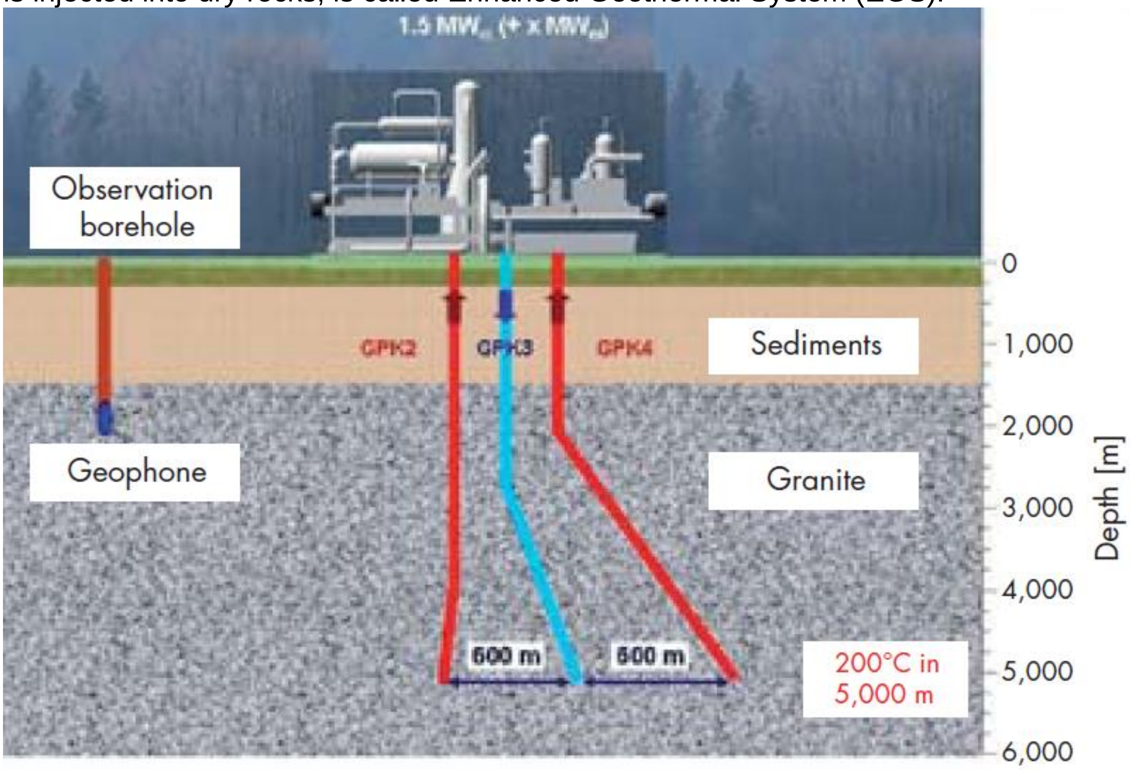


Illustration 13: Power Plant plant of Soultz-sous-Forêts (Source: BINE Information Service).

In metropolitan France, the potential is little operated at the moment. Several exclusive licenses for research have been allowed or are currently being considered expressing a real upcoming dynamic for this channel. Operating license areas for high temperature cover 8265 km^2. Ongoing demands are covering an additional area of 3823 km^2, Energy pluri-annual programmation (PPE) are 8 MW in metropolitan France for 2018.

Based on the same model than Power Plant plant of Soultz-sous-Forêts, a commercial installation is running in Landau (Germany), in Rhine Graben, and a project is ongoing in Australia in Copper Basin at Habareno. In parallel, 4 different projects are at mature stages in United States. A full control of the reservoir stimulation, joined to improvement in drilling technologies, binary fluid central efficiency, and reliability of immersed pumps would allow a reduction of production costs and extend this technology to large portion of continental area.

5.1.2.5. GEODENERGIES - PILOTS

GEODENERGIES, a scientific interest organization for the development of decarbonate energies and support by BRGM, with 12 enterprises, 6 others public research organizations and 2 competitiveness hub.

This organization aims to foster emergence of 3 channels dedicated in sustainable exploitation and management of ground resources:

- CO_2 storage.
- Energy storage.
- Geothermy.

GEODENERGIES aims to bring a part of the solution by developing the missing technological bricks.

Below there are some of the projects promoted by GEODENERGIES related to geothermal energy:

5.1.2.5.1. PILOTE CO_2 DISSOLVED

Demonstration pilot that aims to capture, inject and store locally the emitted CO_2 after being dissolved in brine extracted from a geothermal doublet.

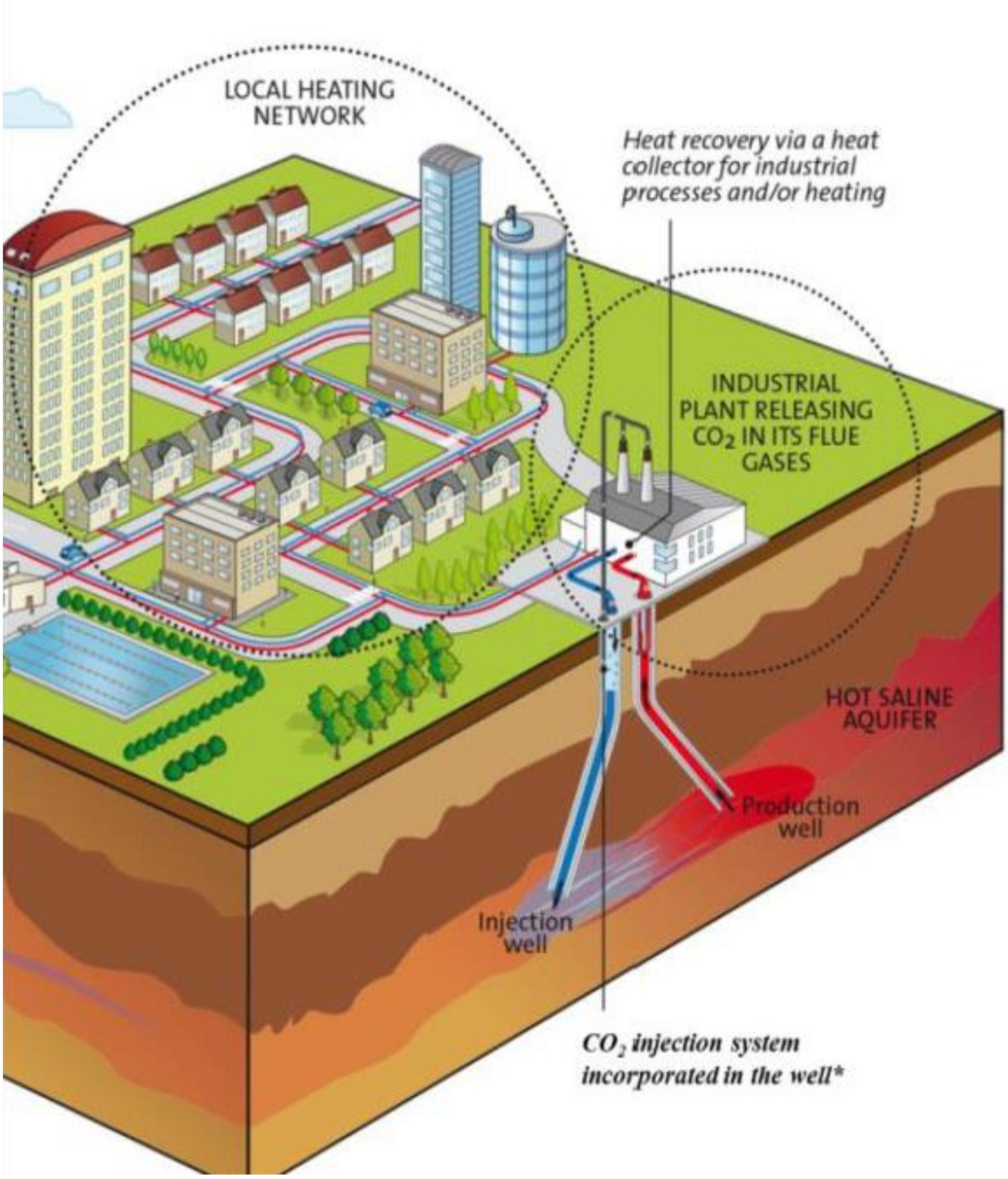


Illustration 14: PILOTE CO2 DISSOLVED (Source: Geodenergies).

Storing CO_2 underground while producing geothermal heat, this is the idea explored by ANR CO_2Dissolved project, Following successful results a second project « pilot CO2Dissolved » will develop a prototype at a reduce scale to valid the technology in the core process as well as preparing implementation of a pilot project on an industrial site. In case of success small CO emitter (<150tk/year) would be the main beneficiaries.

5.1.2.5.2. REFLET

REFLET aims to define a methodology to realize conceptual models of geothermal reservoir in a fault zone in graben context. The project relies on the development of successive conceptual models enhanced by the input of field data to establish a protocol helping geothermal operators. Those field data will come from three deep geothermal industrial projects carried out by Fonroche Géothermie and Electerre de France.

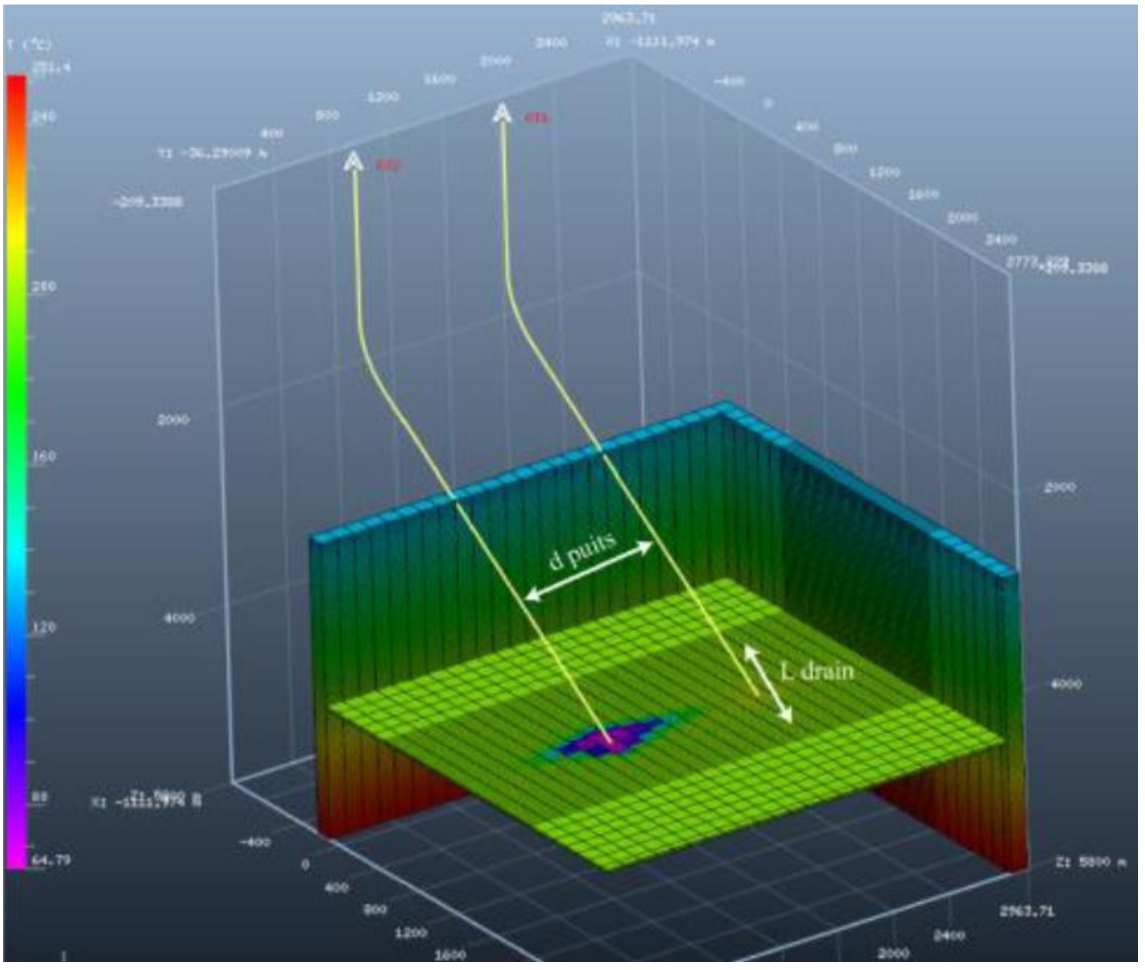


Illustration 15: Conceptual models of geothermal reservoir (Source: Geodenergies).

5.1.2.5.3. TEMPERER

Temperer project aims to develop passive seismic technics uses for the operational use, monitoring and survey of the dynamic behavior of a deep geothermal reservoir. Based on the record of micro seismic events of very low magnitude (<2, human perception threshold), this project will improve social acceptance of deep geothermal industrial projects. Record events are also a capital information resource for interpretation and characterization of geothermal reservoir.

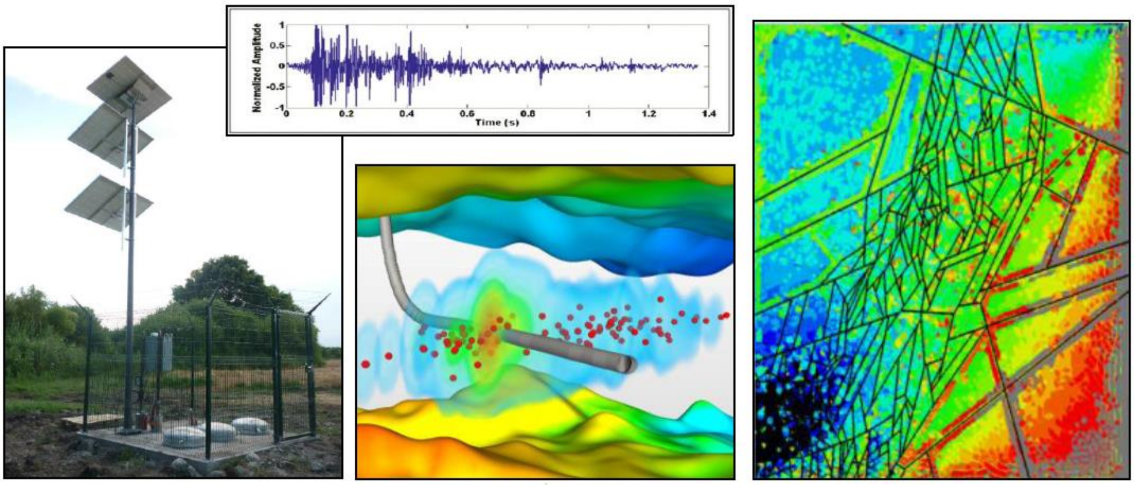


Illustration 16: 3D reservoir model with associated stresses system (Source: Geodenergies).

5.1.2.5.4. CARPHYMCHEAU

The CARPHYMCHEAU project aims to increase the understandings of the fouling and corrosion phenomena in geothermal applications. Lab scale experiments will be carried out in order to:

- Develop a state of the art deposits formation model allowing the assessment of the fouling according to the brine composition and the exploitation conditions;
- Study corrosion of different heat exchanger materials.

Those experiments and models will be validated against data from two dedicated pilot plant installations (in Alsace and in Massif Central).

Illustration 17: Inlays inside a pipe.

5.2. Scotland

ALI Energy – Oban (Scotland / United Kingdom)

5.2.1. Geothermal technologies currently used

5.2.1.1. Introduction

The Scottish Government has identified deep geothermal energy as an important emerging renewable energy technology that could have the potential to play a significant role in Scotland's future energy provision.

To date, the extent and location of the potential deep geothermal resources has not been well defined. In addition, potential commercial investment in development of deep geothermal energy requires greater certainty regarding the current administrative framework, including clarification of legal ownership of resources legal ownership, resource licensing, planning and permitting regimes, and financing.

The key points to carry forward the commercialization of deep geothermal energy in Scotland are the following:

- Assessment of the areas most likely to hold deep geothermal resource based on existing geological data sets.
- Identification of policy options and key actions that can be implemented by the Scottish Government to encourage commercial exploitation of the available geothermal resource. In considering the requirements for a future potential licensing regime for exploiting geothermal energy, the depth of the resources that it would apply to needs to be considered and a depth of 200 m has been recommended as the nominal division between generally shallower GSHP developments and deeper geothermal developments.

Geothermal energy is the natural heat that exists within our planet. In Scotland there is little direct evidence at the surface of the vast reservoir of stored heat below and geothermal energy has remained largely untapped. Technologies and concepts for exploiting geothermal energy are developing rapidly along two lines: low temperature resources, which exploit warm water in the relatively shallow subsurface to provide heat either directly (as warm water) or indirectly (via heat exchange systems); and high temperature resources, which yield hot water, usually from greater depths, that can be used to generate electricity.

The geothermal heat resource beneath Scotland can be considered in terms of three main settings:

- Abandoned mine workings (low temperature):

  Mine water in abandoned workings in Scotland's Midland Valley might form an important low enthalpy resource for space and domestic hot water heating, and related uses. Mining creates anthropogenically enhanced aquifers‖ (Banks, 1997) with additional permeability within strata that otherwise typically have significantly lower permeability. Mine waters are exploited using GSHP technology. Mine workings often spanned a significant depth range (up to several hundred metres), enabling water to be abstracted from one depth interval and returned to the ground at a different depth. This vertical separation can increase the time before the returned water, at lower temperature, starts to arrive at the point of abstraction (thermal breakthrough), which can improve the efficiency of a scheme. Mines can extend to relatively deep levels, so in some cases they can provide easy access (e.g. via remnant shafts) to higher temperature water. For example, a borehole at the Solsgirth Colliery in Clackmannanshire recorded at temperature of 21.5°C at a depth of 387 metres.

- Hot sedimentary aquifers (low and possibly relatively high temperature):

  In the Hot Sedimentary Aquifer (HSA) concept, the heat energy is contained in permeable, water-bearing sedimentary rocks (aquifers), and is recovered by simply sinking one or more boreholes into the resource and extracting the hot water. Although the aquifer water holds a substantial amount of heat, the main heat store resides in the host rocks, and water drawn into the aquifer to replace that drawn out via a borehole will absorb heat from the host rocks. The best HSA prospects will exist where a natural system of circulating groundwater yields a high and sustainable flow rate of heated water.

- Hot dry rocks / petrothermal sources (relatively high temperature):

  Much of the world's accessible high-enthalpy geothermal energy exists in crystalline (non-porous) rock at depths exceeding several kilometres. Such rocks are generally assumed to lack open fractures and consequently have very low permeability. They are therefore essentially dry, hence they are known as Hot Dry Rock (HDR) resources. The EGS concept for exploiting HDR resources relies on creating open fractures to hydraulically connect two or more boreholes drilled some distance apart into a hot rock zone. Cold water pumped down one or more injection wells flows through the fracture system, absorbing as it does the geothermal energy held in the enclosing rocks, and is recovered as hot water from one or more production wells. The thermal energy stored in the water can be converted into electricity at the surface in various ways.

Hydraulic fracturing (injecting water at high pressure through a borehole to open existing fractures and/or create new ones in deeply buried rock) is used to develop the system of open fractures a process usually referred to as stimulation. The fracture walls then act as heat exchange surfaces, and an engineered geothermal reservoir is created as cold water is pumped into the system. The position, shape and volume of the developing reservoir is monitored using micro-seismic survey techniques, which locate the origins of the seismicity induced as fractures open during hydraulic fracturing. In operational mode, water is pumped through the injection well under high pressure, which keeps the fractures open and forces the water to circulate through the system in a closed loop, arriving in the form of hot water (or steam) at a power plant on the surface.

The same water, relieved of its heat, can then be re-cycled back into the injection well.

In recent years, major projects in Australia, France and the US have demonstrated the considerable potential for generating electricity using EGS to exploit HDR resources. All of these projects have exploited the same particularly favourable geological setting, where a thick layer of sedimentary rocks overlies an intrusion of granite with elevated concentrations of radioactive elements. The sedimentary rocks act like a thermal blanket, trapping beneath them the heat generated in the granite, which builds up over millions of years into a substantial geothermal resource at a relatively shallow, and therefore accessible, depth (4–6 km).

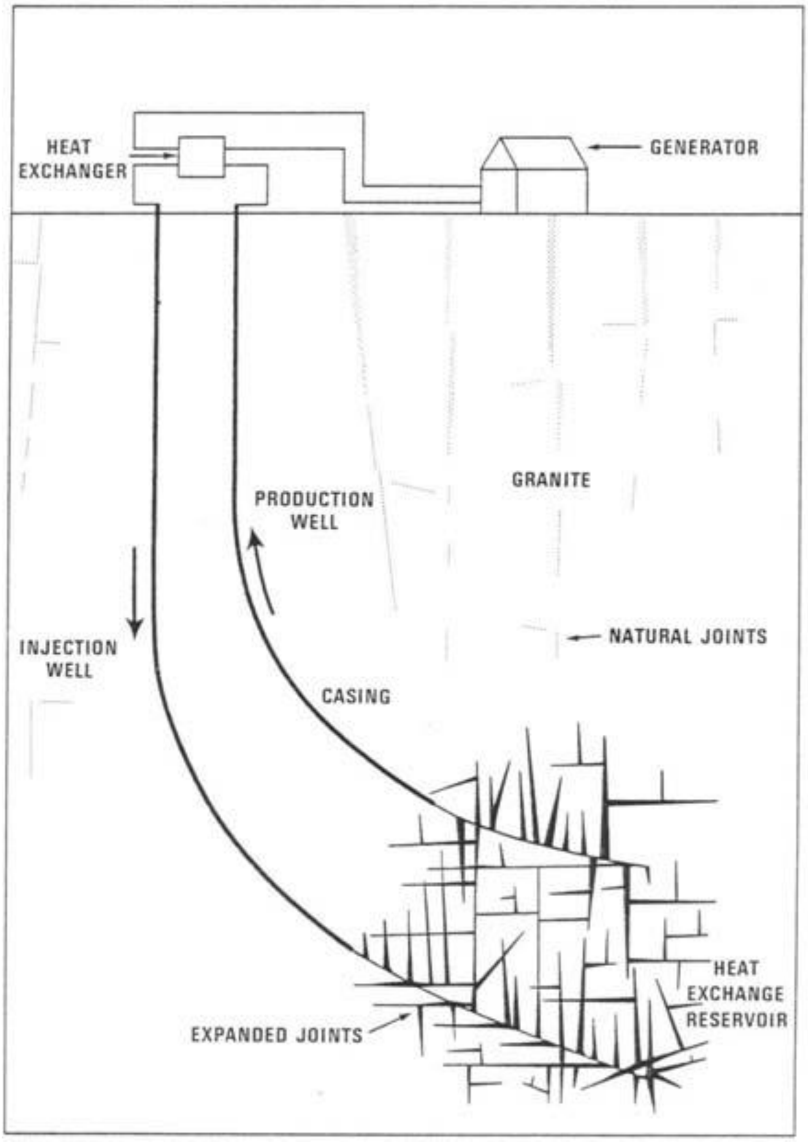


Illustration 18: Concept of a two-well hot dry rock system. Note that in this representation the HHP granite extends from the reservoir to the ground surface, i.e. it is not buried beneath a layer of low thermal conductivity rocks (Source: Scottish Goverment Project Number AEC/001/11).

5.2.1.2. Geothermal data for Scotland

Heat flow is the standard measure of the amount of heat travelling through Earth's crust. As such, heat flow measurements have been used as the basis for all previous assessments of geothermal energy potential in Scotland. Unfortunately, the heat flow dataset for Scotland is relatively small, and no new values have been reported since the 1980s. Furthermore, the values are subject to a range of factors that reduce the degree to which they can be assumed to provide an accurate indication of the size of the geothermal resource at depth. Making a significant step forward in our understanding of the deep geothermal energy potential in Scotland therefore requires either more heat flow data coupled with a better understanding of the factors that affect heat flow measurements, or an alternative means of assessing the size and distribution of the heat resource.

Temperatures measured directly in boreholes provide the best currently available alternative source of heat data. Available temperature data measured in onshore boreholes were collated and reported by Burley et al. (1984). The vast majority of the boreholes from which temperature data have been obtained were drilled for reasons other than geothermal energy assessment (usually oil/gas/coal exploration), and the data have not previously been evaluated in a geothermal energy context.

The heat flow and borehole temperature datasets for Scotland are reviewed in this section. Although this assessment of geothermal energy potential in Scotland is limited to onshore areas, temperature data obtained from offshore boreholes are included in the review because they increase the size of the dataset and extend the depth range of measured temperature data, thereby improving the confidence with which onshore data can be extrapolated to greater depths.

5.2.1.3. HEAT FLOW DATA

There are only thirty-five published heat flow values for Scotland, all of which derive from onshore boreholes. Thirty-four of them are collated in the BGS Catalogue of Geothermal Data for the UK (Burley et al., 1984). The heat flow values range from 29 to 82 mW m^{-2}; the mean is 56 mW m^{-2} and the median is 57 mW m^{-2}. The sparseness of the dataset is such that closed contours (indicating the location of apparent ‗hot spots') are formed in only two areas: in the central part of the Midland Valley, where a 60 mW m^{-2} contour encloses a cluster of values; and in the East Grampians region, where a 70 mW m^{-2} contour encloses a cluster of values derived from granite intrusions. The 50 mW m^{-2} contour in the East Grampians area has been extended tentatively to the west to intersect a cluster of values in Loch Ness. Most of the reported heat flow values derive from measurements made at depths of less than 400 metres below ground surface.

REGIÓN	BOREHOLE NAME	HEAT FLOW DENSITY (mW m^{-2})
Caithness	Altnabreac A	43
Caithness	Altnabreac B	53
Caithness	Achanarras	42
Caithness	Houstrie of Dunn	45
Caithness	Yarrows	52
Loch Ness	1	73
Loch Ness	2	64
Loch Ness	3	62
Loch Ness	4	57
Loch Ness	5	82
Loch Ness	6	67
Loch Ness	7	55

REGIÓN	BOREHOLE NAME	HEAT FLOW DENSITY (mW m^{-2})
Loch Ness	8	43
Loch Ness	9	43
East Grampians	Tilleydesk (Ellon)	29
East Grampians	Cairngorm	70
East Grampians	Bennachie	76
East Grampians	Mt Battock	59
East Grampians	Ballater	71
Argyll	Ballachulish	53
Argyll	Meall Mhor	57
East Midland Valley	Montrose	46
East Midland Valley	Balfour	37
East Midland Valley	Boreland	40
East Midland Valley	Glenrothes	56
East Midland Valley	Marshall Meadows	51
East Midland Valley	Livingston	62
West Midland Valley	Clachie Bridge	55
West Midland Valley	South Balgray	72
West Midland Valley	Blythswood	59
West Midland Valley	Kipperoch	54
West Midland Valley	Barnhill	60
West Midland Valley	Hurlet	60
West Midland Valley	Maryhill	63
Dumfries & Galloway	Castle Douglas	61

Table 11: Heat flow data for Scotland (Source: Scottish Goverment Project Number AEC/001/11).

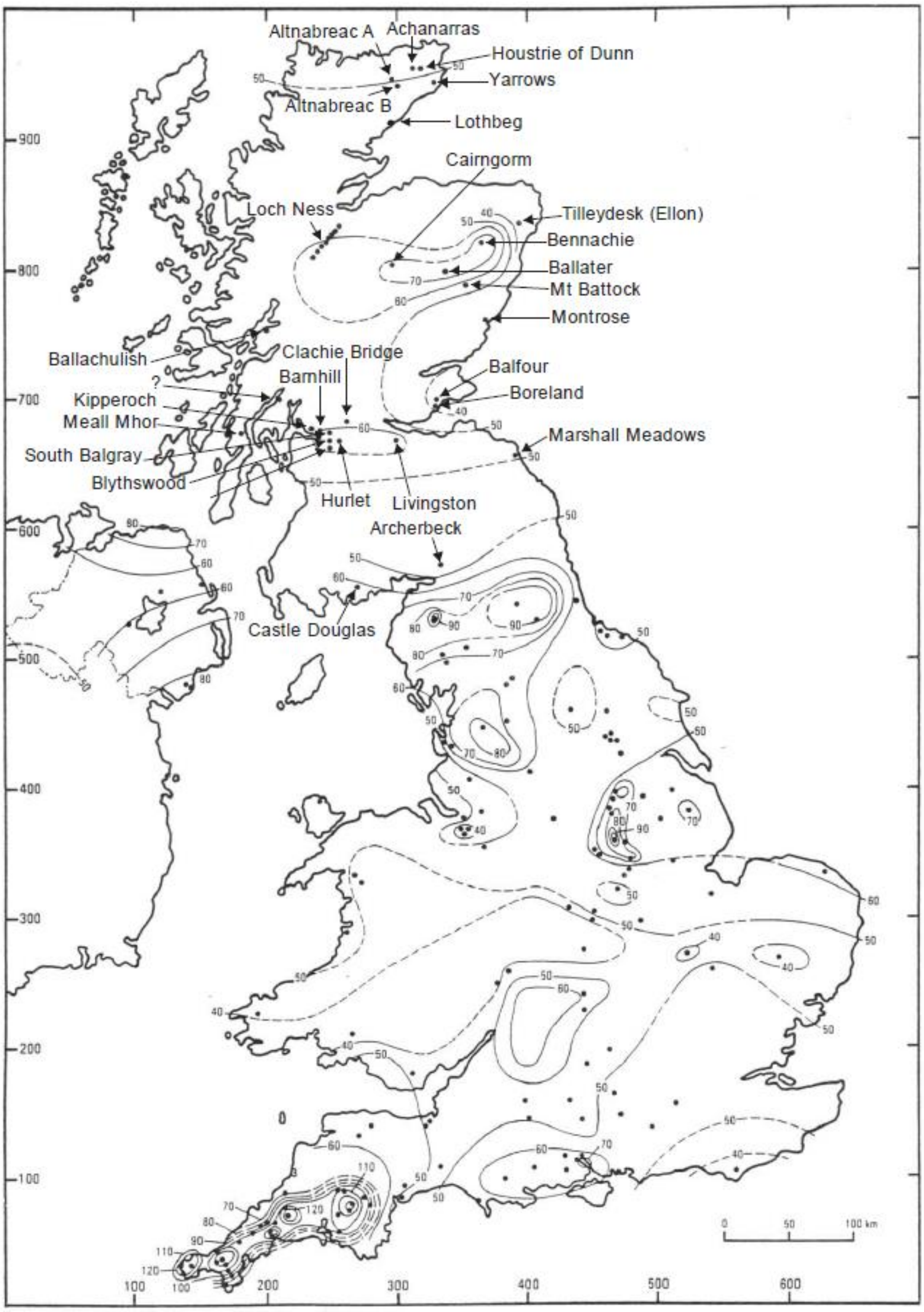


Illustration 19: Heat flow map of the UK (Source: Scottish Goverment Project Number AEC/001/11).

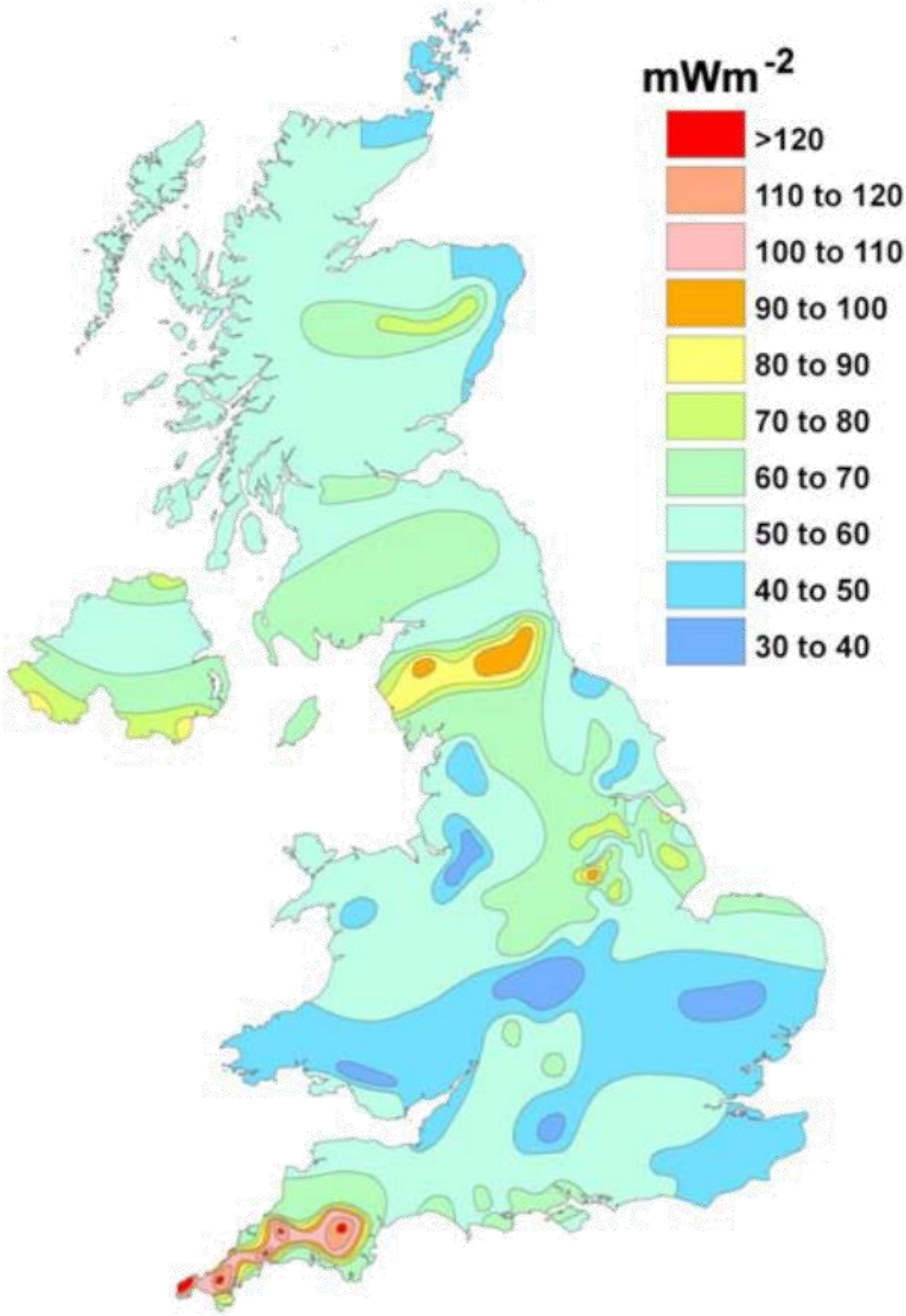
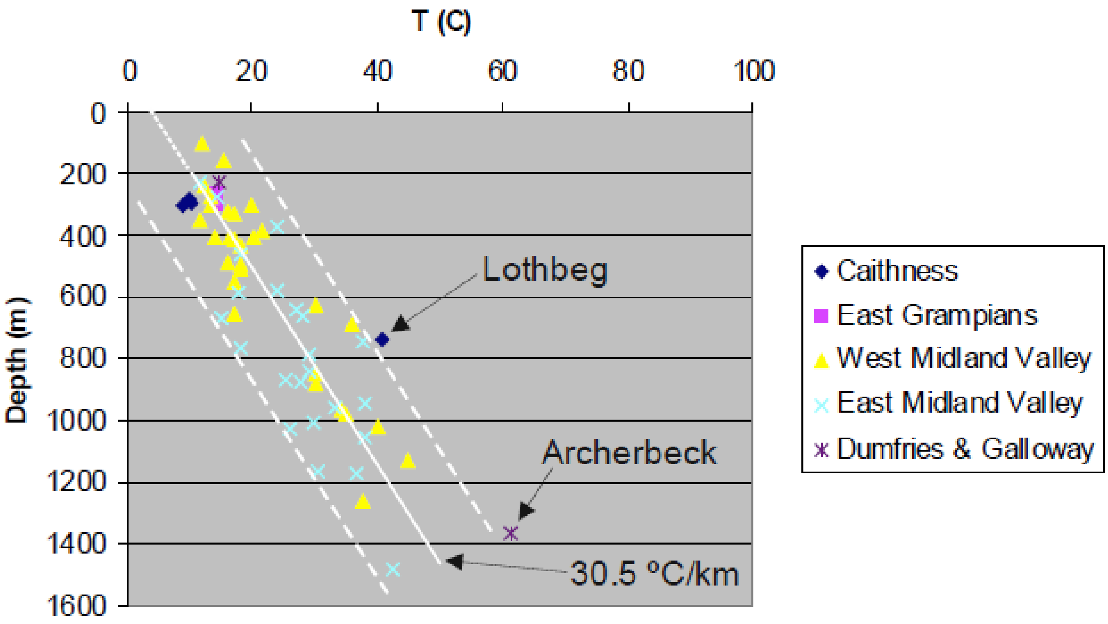


Illustration 20: Colour-contoured heat flow map of the UK (Source: Scottish Goverment Project Number AEC/001/11).

5.2.1.4. BOREHOLE TEMPERATURE DATA

5.2.1.4.1. TEMPERATURE DATA FROM ONSHORE BOREHOLES

The BGS Catalogue of Geothermal Data for the UK (Burley et al., 1984) includes a list of borehole temperature data for sixty-one boreholes in onshore parts of Scotland; these include many of the boreholes from which heat flow values have been calculated. In most cases, the temperature measurement has been made at, or near to, the bottom of the borehole. Whereas most of the available heat flow data come from depths of less than 400 metres below ground surface, the onshore borehole temperature data extend to a depth of around 1,300 metres. Unfortunately, they are clustered mainly in Caithness, the East Grampians region, and particularly in the Midland Valley, and so do not significantly extend the spatial coverage of onshore geothermal data beyond that provided by the heat flow dataset.



Graphic 15: Bottom-hole temperature vs depth (T-z) data for onshore boreholes in Scotland (Source: Scottish Goverment Project Number AEC/001/11).

Borehole name	Región	Grid reference	Source	Depth	Temp	T grad	Type
Altnabreac	Caithness	NC 9990 4528	BGS	299	10.3	7.4	LOG
Altnabreac	Caithness	NC 9939 4291	BGS	301	8.8	3.7	LOG
Altnabreac	Caithness	ND 0232 4167	BGS	282	10.1	7.1	LOG
Lothbeg No.1	Caithness	NC 946 095	PCO	736	40.6	42.9	BHT
Bennachie	East Grampians	NJ 6690 2110	BGS	294	14.0	20.1	BHT
Mt Battock	East Grampians	NO 543 905	BGS	263	14.0	22.1	BHT
Ballater	East Grampians	NO 4000 9850	BGS	296	14.0	19.6	BHT

Borehole name	Región	Grid reference	Source	Depth	Temp	T grad	Type
Rashiehill	West Midland Valley	NS 8386 7301	BGS	964	34.4	26.2	LOG
Clachie Bridge	West Midland Valley	NS 6447 8368	BGS	300	13.2	16.0	LOG
Salsburgh	West Midland Valley	NS 8166 6486	GAS	883	30.0	24.1	BHT
Hallside	West Midland Valley	NS 6694 5975	BGS	350	11.8	6.0	LOG
Grangemouth	West Midland Valley	NS 9513 8387	NCB	1134	45.0	30.9	BHT
South Balgray	West Midland Valley	NS 50 75	BEN	160	15.3	45.0	EQM
Blythswood	West Midland Valley	NS 5003 6823	BEN	105	12.0	37.1	EQM
Douglas Colliery	West Midland Valley	NS 830 300	NCB	239	12.2	14.2	MWT
Solsgirth Colliery	West Midland Valley	NS 9777 9329	NCB	387	21.5	31.0	MWT
Bogside Colliery	West Midland Valley	NS 9564 8778	NCB	334	17.0	22.2	MWT
Highhouse Colliery	West Midland Valley	NS 5321 7202	NCB	436	18.0	19.5	MWT
Barony Colliery	West Midland Valley	NS 5105 1971	NCB	411	17.0	19.0	MWT
Killoch Colliery	West Midland Valley	NS 4883 2130	NCB	655	17.0	11.9	MWT
Polkemmet Colliery	West Midland Valley	NS 91906278	NCB	549	17.0	15.5	MWT
Eggerton	West Midland Valley	NS 8504 3171	NCB	410	14.0	13.2	BHT
Tillicoultry	West Midland Valley	NS 9276 9653	NCB	510	18.0	15.9	BHT
Tullibody	West Midland Valley	NS 8601 9594	NCB	325	16.0	18.8	BHT
Cartlove	West Midland Valley	NS 9403 9267	NCB	404	16.6	16.3	BHT
Gartenkeir	West Midland Valley	NS 9267 9486	NCB	488	16.0	15.0	BHT
Shannock Hill	West Midland Valley	NS 9338 9512	NCB	497	18.0	19.9	BHT
Pipersink	West Midland Valley	NS 9307 8911	NCB	408	20.2	25.5	BHT
Glenochill	West Midland Valley	NS 8769 9617	NCB	628	30.0	32.0	BHT
Queenslie	West Midland Valley	NS 6466 6598	NCB	691	36.0	38.4	BHT
Slatehole	West Midland Valley	NS 4906 2342	NCB	1024	40.0	29.8	BHT
Gallowknowe	West Midland Valley	NS 8388 3118	NCB	1261	37.5	22.8	BHT
Stoneyknowes	West Midland Valley	NS 8817 3570	BGS	277	13.5	18.1	BHT
Craighead	West Midland Valley	NS 8267 6212	TAW	977	35.0	27.2	BHT
Maryhill	West Midland Valley	NS 5718 6856	IC6	303	20.0	34.0	EQM
Comrie	West Midland Valley	NS 9787 9501	NCB	850	30.0	24.1	VST

Table 12: Temperature-depth data for onshore boreholes in Scotland (Source: Scottish Goverment Project Number AEC/001/11).

5.2.1.4.2. Temperature data from offshore boreholes

Most of the boreholes in offshore parts of Scotland have been drilled by hydrocarbon exploration companies; such boreholes are typically referred to as wells. Bottom-hole temperature (BHT) data from seventy-two wells drilled into thirteen sectors on the North West Margin of the UK continental shelf.

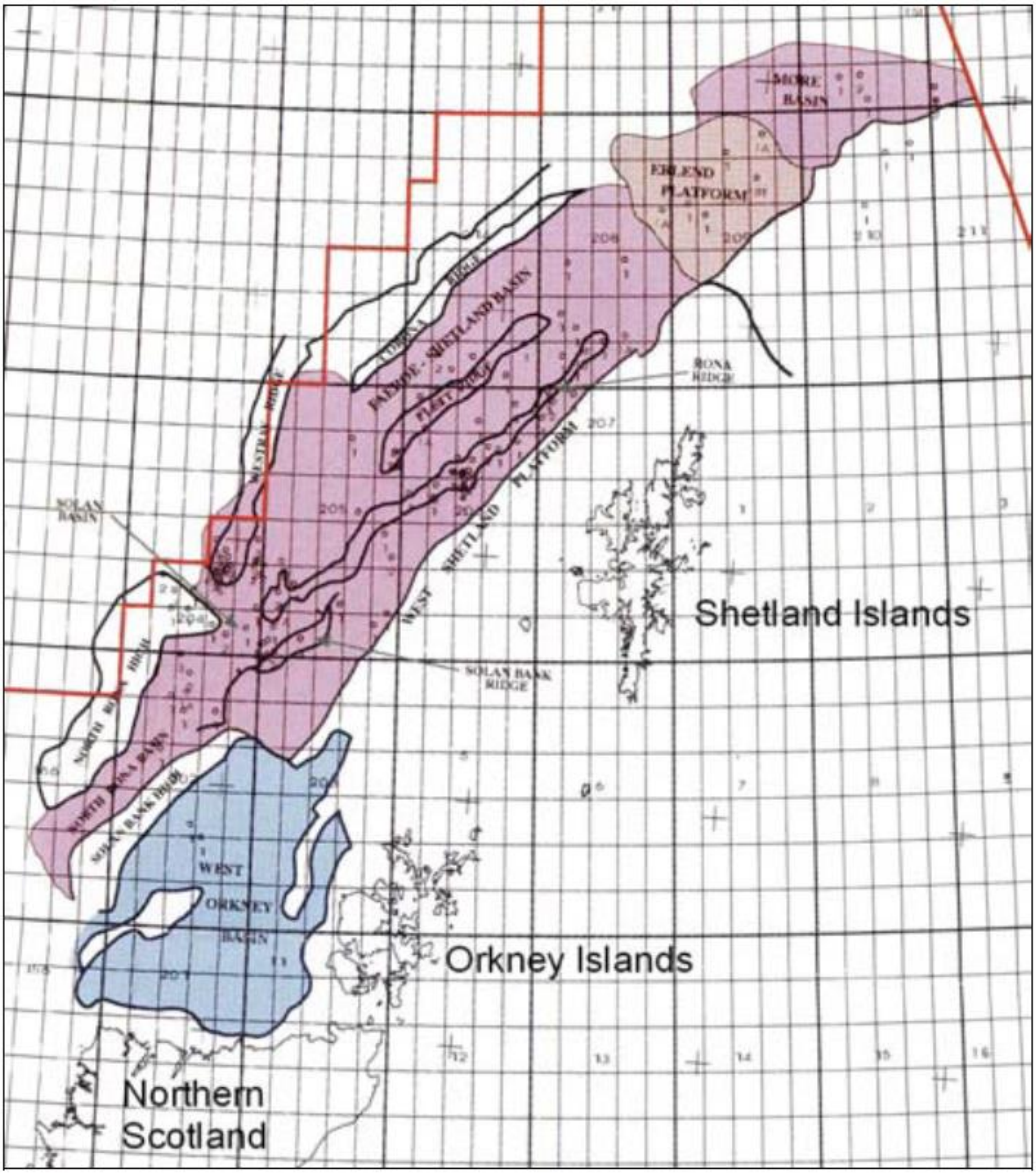
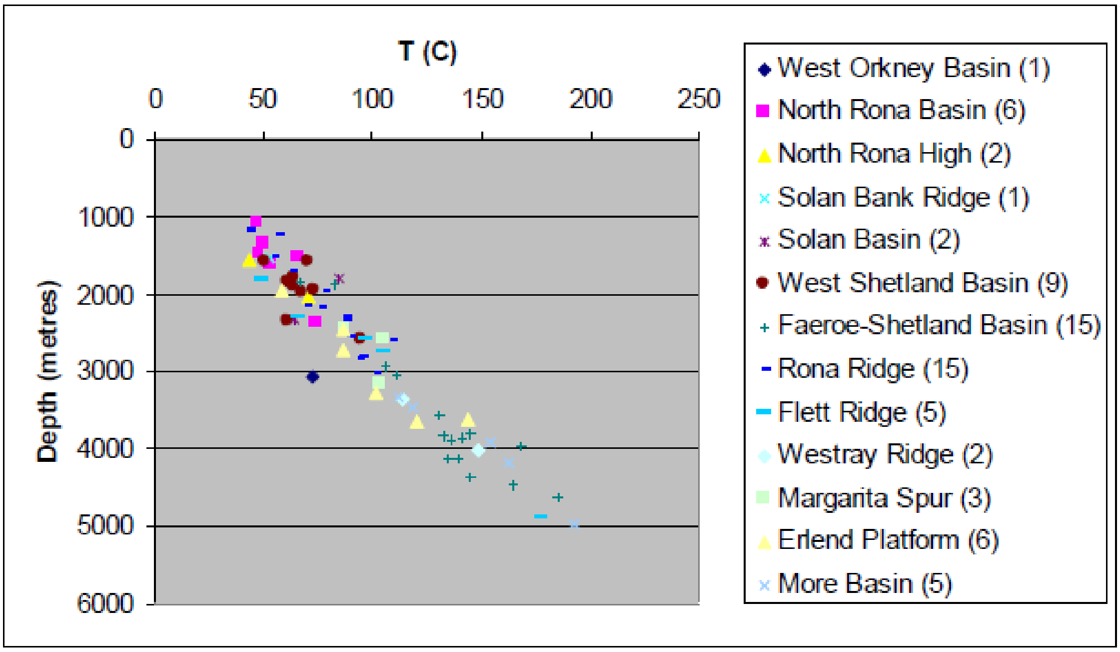
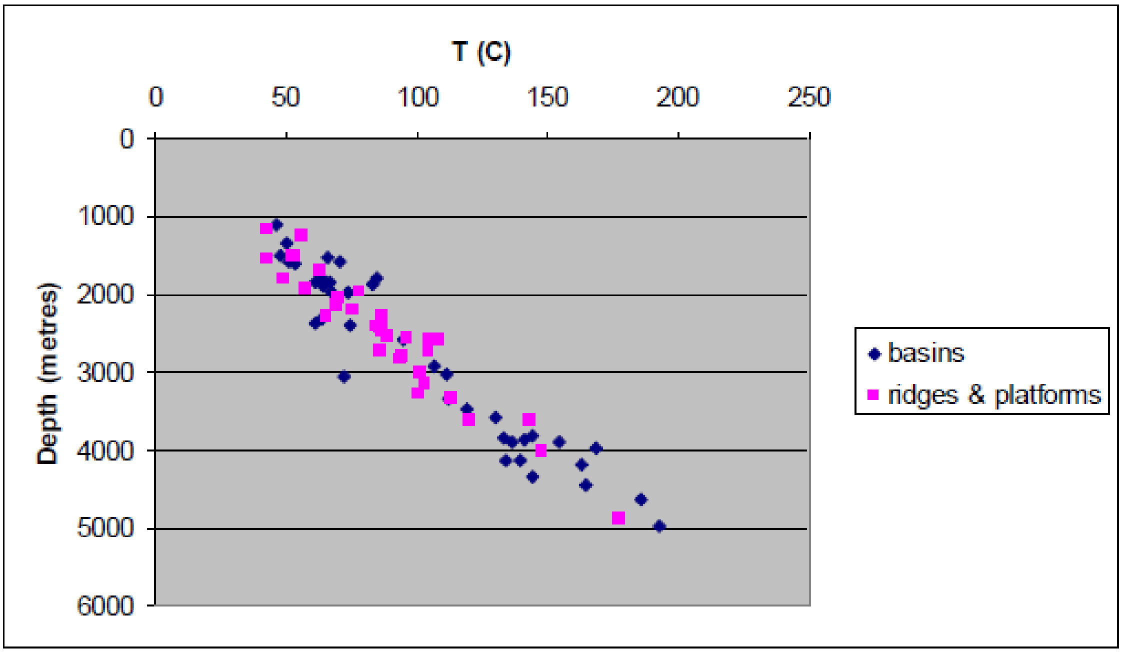


Illustration 21: Well and sector locations in the North West Margin (Source: Scottish Goverment Project Number AEC/001/11).



Graphic 16: Bottom-hole temperature versus depth (T-z) data for offshore wells in the North West Margin. (Data plotted according to sector) (Source: Scottish Goverment Project Number AEC/001/11).



Graphic 17: Bottom-hole temperature versus depth (T-z) data for offshore wells in the North West Margin. Data plotted according to structural setting (structurally low geological basins and structurally high ridges and platforms) (Source: Scottish Goverment Project Number AEC/001/11).

Sector	Well no.	T (°C)	Depth (m)	Seabed T (°C)	T grad (°C/km)
West Orkney Basin	202/19-1	72.1	3065	9	20.6
North Rona Basin	202/2-1	46.6	1094	9	34.4
	202/3-1A	53.2	1612	9	27.4
	202/3-2	49.9	1347	9	30.4
	202/3A-3	74.3	2384	9	27.4
	202/8-1	66.1	1538	9	37.1
	202/9-1	47.9	1493	9	26.1
	204/28-1	43.2	1565	8	22.5
North Rona High	204/29-1	70.7	2046	9	30.2
Solan Bank Ridge	205/27A-1	52.8	1538	9	28.5
Solan Basin	204/30-1	84.9	1801	9	42.1
	205/26A-2	63.7	2322	9	23.6
West Shetland Basin	205/20-1	63.7	1801	9	30.4
	205/23-1	94.8	2585	9	33.2
	205/25-1	61.3	2363	9	22.1
	205/30-1	67.2	1981	9	29.4
	206/13-1	51.2	1576	9	26.8
	207/1-2	70.4	1584	9	38.8
	207/2-1	64	1892	9	29.1
	208/23-1	61.5	1854	9	28.3
	208/24-1A	73.6	1962	9	32.9
Faeroe-Shetland Basin	205/16-1	168.5	3964	9	40.2
	206/1-2	136.6	3884	3	34.4
	206/2-1A	141.2	3872	3	35.7
	206/3-1	185.6	4626	9	38.2
	206/5-1	132.9	3838	9	32.3
	206/11-1	144.5	4354	9	31.1
	208/17-1	139.5	4123	3	33.1
	208/19-1	106.2	2928	9	33.2
	208/21-1	111.2	3038	8	34.0
	208/22-1	83	1878	9	39.4
	208/26-1A	130.3	3581	9	33.9
	214/27-1	144.5	3805	3	37.2
	214/27-2	66.7	1845	3	34.5
	214/28-1	164.3	4460	3	36.2
	214/29-1	134	4119	8	30.6
Rona Ridge	205/21-1A	42.9	1184	9	28.6
	205/22-1A	101.9	3027	9	30.7

Sector	Well no.	T (°C)	Depth (m)	Seabed T (°C)	T grad (°C/km)
	206/8-1A	69.5	2163	9	28.0
	206/8-2	63.1	1720	9	31.5
	206/8-3	84.8	2416	9	31.4
	206/8-4	94.4	2848	9	30.0
	206/8-5	78.4	1970	9	35.2
	206/8-6	89	2560	9	31.3
	206/8-7	76	2200	9	30.5
	206/9-1	109.2	2612	9	38.4
	206/9-2	87.3	2297	9	34.1
	206/10A-1	95	2826	9	30.4
	206/12-1	54.3	1537	9	29.5
	206/12-2	87.3	2364	9	33.1
	207/1-1	56.6	1251	9	38.0
	205/10-1A	49.1	1815	8	22.6
	205/10-2	177.9	4900	8	34.7
Flett Ridge	205/10-3	65.5	2294	8	25.1
	206/1-1A	96.7	2578	8	34.4
	214/30-1	105	2748	8	35.3
Westray Ridge	204/19-1	148.1	4023	3	36.1
	204/23-1	113.3	3349	8	31.4
Margarita Spur	210/4-1	87.1	2462	9	31.7
	210/5-1	105.2	2600	9	37.0
	210/13-1	103.2	3159	10	29.5
Erlend Platform	208/15-1A	86.2	2733	9	28.2
	209/3-1A	58.1	1953	9	25.1
	209/4-1A	120.5	3637	9	30.7
	209/6-1	143.6	3629	9	37.1
	209/9-1	86.2	2447	9	31.5
	209/12-1	101.3	3279	9	28.1
M0re Basin	219/20-1	162.8	4187	5	37.7
	219/27-1	112.1	3335	9	30.9
	219/28-2	118.8	3466	8	32.0
	220/26-1	193.1	4961	9	37.1
	220/26-2	154.3	3902	9	37.2

Table 13: Bottom-hole temperature and depth data for offshore wells in the North West Margin region. Data from Gatliff et al. (1996). Depths are measured from the sea bed (Source: Scottish Goverment Project Number AEC/001/11).

5.2.2. Geothermal systems in the development phase

The Scottish Government's Geothermal Energy Challenge Fund recently supported 4 feasibility studies exploring the capacity of Scotland's geothermal resource to meet the energy needs of local communities.

The reports are:

- Deep Geothermal Single Well (DGSW). Aberdeen Exhibition and Conference Centre (AECC).
- Guardbridge geothermal technology demonstrator project.
- Hill of Banchory Geothermal Energy Project.
- Fortissat Community Minewater Geothermal Energy District Heating Network.

The Scottish Government commissioned a synthesis report of these 4 feasibility study reports which was completed in March 17. Below is a technical summary of what each of these projects consists of:

5.2.2.1. Aberdeen Exhibition and Conference Centre Deep Geothermal Single Well

The DGSW technology is relatively straightforward. A single well will be drilled into the granite bedrock underlying the AECC site to a depth of 2.0 – 2.25 km. In this depth range it can be confidently predicted that the temperature at the bottom of the borehole will be 60 – 65°C. The well is lined over most of its depth with standard 7-inch diameter steel casing; the deepest 300 metres (m) are left unlined to maximise heat transfer from the hot rock; the upper 300 – 500 m are drilled to a larger diameter and lined with 10¾-inch casing. The well is fitted with a central polypropylene tube reaching nearly to the bottom. In the upper part of this tube (at 200 m depth) a submersible electric pump is fitted on the lower end of a flexible riser. This extracts water from the central tube causing a flow of hot water up through the central tube from the bottom of the well. The hot water is supplied to a heat exchanger on the surface with the returning, cooler flow fed to the top of the outer section of the well, where it returns down the well under gravity and pump-induced circulation.

The heat exchanger heats water in a secondary circulation loop, minimising the contact of geothermal waters (rich in dissolved salts) with surface plant. The secondary loop delivers water at 50°C to the heat demand, in this case maintaining the temperature in the anaerobic digestion plant. A control system is used to vary the speed of the DGSW circulation pump and the secondary loop pump, allowing temperatures in the two loops to be optimised. A supplementary gas-fired boiler can be included in the secondary circulation loop, either to boost the temperature or provide back-up during maintenance of the DGSW system. In the current project proposal, the temperature of the return flow in the secondary loop (30°C) is sufficient to provide heat to residential properties near the site. However, heat pumps are needed for each property to upgrade the heat sufficiently for domestic use.

The DGSW system is technology developed by Geothermal Engineering Ltd based on "closed loop" single geothermal wells. The system has been field trialled at a site in

Cornwall with similar granite bedrock to that beneath the AECC. Results from the trial and modelling suggest the AECC well may produce a peak heat output of 400 to 600 kilowatts (kW) with an input/output ratio of one unit of electricity for the pump to 40 – 50 units of thermal energy delivered at the surface. The trial established the system at a technology readiness level (TRL 6) meaning it is ready to be used in a commercial project.

The use of a single vertical borehole with no requirement for fluid flow through the rock surrounding it is a significant advantage of the DGSW technology over other geothermal heat recovery methods, such as doublet well systems or systems relying on groundwater flows from aquifers. There is no dependence on rock permeability in the DGSW system. Standard drilling techniques can be deployed using a mobile rig, meaning drilling costs can be controlled through a fixed-price engineering procurement contract. The DGSW design uses off-the-shelf materials; it is quick to install (two weeks following drilling completion) and easy to maintain. A monthly maintenance schedule is defined and an annual service downtime of six hours is required to remove, clean and reinstall the submersible pump.

Project delivery has been planned in some detail with five work packages based on prior experience from the field trial. The first four of these have been costed in detail for staff costs, drilling contract costs and materials costs. The final package will extend over three years of monitoring and costs will be borne internally by the operator. The project will be run and managed by Geothermal Engineering Ltd with ARUP and the University of St Andrews closely involved. Project personnel have been identified and have suitable experience; working relationships between partners are already established from previous projects. A project plan is outlined for the first four work packages, extending over 27 months with the drilling programme defined in greater detail. A detailed risk register has been compiled, including risk-mitigation actions. The highest risks, in terms of successful project delivery, are judged to be delayed or restricted funding and delays to equipment delivery.

5.2.2.2. Fortissat Community Minewater Geothermal Energy District Heating Network Project

The project will use heat pumps to concentrate the energy present in the minewater, which is at a temperature of approximately 17°C, and deliver it to residential properties via a low-temperature DHN (75°C flow, 45°C return). In this way, it is similar to other water source heat pump systems that concentrate energy from rivers, canals or lochs, except for the water body used as the energy source.

For this project, the geothermal energy resource consists of the waters in two flooded, interconnected mine systems lying 300 – 400 m beneath Hartwood Home Farm (owned by James Hutton Institute) and the surrounding areas, including the villages of Hartwood and Allanton. A production well will be drilled approximately 340 m into the deepest level of the mine systems. A submersible pump in the well will bring water to the surface, where a primary heat exchanger will transfer heat energy into a clean water loop, used to protect the heat pumps from the potentially corrosive and fouling effects of chemical-rich minewater. Handling of the minewater discharge from the heat exchanger depends on the site chosen for the production well and is outlined below.

The clean water loop runs to an energy centre housing the heat pump (or array of heat pumps), a thermal store (hot water tank), back-up gas boilers and circulation pumps. The heat pump transfers and concentrates the energy from the clean loop giving a flow temperature of 75°C in the network, which distributes heat to individual properties; water returns from the network at 45°C.

This flow temperature was chosen to allow the system overall to qualify for subsidy under the RHI. A higher flow temperature would require greater electrical input through the heat pumps and so would not qualify for the RHI, falling outside of the performance threshold. However, 75°C is lower than normal central heating flow temperatures and will require each customer property to be fitted with upgraded insulation and other measures to maintain the level of comfort. Different geographic extents of DHN have been studied, with three covering parts of Hartwood and Allanton selected for financial analysis and further assessment. These have total heat demands estimated at 3,860 megawatt hour per year (MWh/yr), 5,713 MWh/yr and 9,670 MWh/yr.

Two options for siting the production well were compared in detail. The preferred site is at the original colliery for the mine workings at Kingshill, south of Allanton. This would handle minewater return through a passive water treatment system (aeration cascade, settling ponds, reed beds) before discharge to a local watercourse. The alternative site is on Hartwood Home Farm and would use two reinjection wells to return minewater into upper levels of the mine system. The comparison of siting options is reasonably evenly balanced; the preference for the Kingshill option arises from the possibility that it may help alleviate existing issues affecting Allanton. Currently, minewater resurgence from the abandoned colliery causes periodic flooding in the village and there are water quality issues from regular minewater discharge, despite an existing passive treatment system. Renewal of the treatment system by the project and lowering of the water table through pumping for geothermal heat extraction may help to alleviate these issues.

The report notes that there is a “significant degree of uncertainty” on the total geothermal energy potential of the minewater systems studied in the project. The total energy available depends on the volume and temperature of the minewater, both of which are subject to wide uncertainty, and the efficiency with which it can be recovered. Available water volume is estimated in the range of 3.62 – 6.12 million cubic metres (Mm3). The water temperature is estimated to range between 13.2°C and 19.2°C. From these, with assumptions of recovery efficiency factors and other assumptions, a very wide range of total geothermal resource availability of 29 gigawatt hours (GWh) to 10,500 GWh is estimated. From this range, 1,420 GWh is used in the report to give example estimates of potential geothermal supply rate as 2.3 MW for 71 years or 0.63 MW for 258 years. Expressing this as a finite resource reflects uncertainties over the rate of reheating of minewater from geothermal input and the degree to which reinjecting cooled water (if this option is used) may cause cooling of the whole system over time.

An indicative project plan is given in the report, but only of the catalyst phase (in progress) and development phase (24 months from securing funding). Beyond that, construction is assumed to take 20 months. The programme is tentative due to the number of external influences on it, not least the need to engage with numerous stakeholders and get commitment to installing the DHN into both council and private properties as well as the upgrading of those properties.

5.2.2.3. Guardbridge Geothermal Technology Demonstrator Project

The study created a geological model for the region and identified four sandstone formations of interest. Significant uncertainty exists in the geological model due to sparse data. Two of the formations, present under much of Kinross-shire and eastern Fife, were identified as having potential for highly productive aquifers. Near Guardbridge, the depths of these strata are thought to be very different on either side of a major fault; different well options were investigated to target the aquifers at different depths.

The rock permeability (which controls groundwater flow) and the aquifer water temperature were estimated for the three main well options. Two were unlikely to produce the flow rates required and were ruled out. The third well modelled is predicted to supply 5 – 20 l/s of water at 23 – 27°C at the surface and was taken forward for evaluation. An electric submersible pump in the well would be used to raise the warm water to the surface.

To achieve these flows, the well would be drilled from the Guardbridge site with a deviated (curved) trajectory passing obliquely through the "damage zone" around the fault for about 460 m before entering the aquifers to the south of the fault at a depth of about 1,100 m. This long passage through the damage zone is considered key to achieving an adequate flow rate from the well, depending on the likely high degree of fracturing around the fault. However, the report discusses significant uncertainties in the location of the fault (even at the surface), the extent and nature of the damage zone and the permeability associated with it. The resulting uncertainty in potential flow rate is highlighted as the main challenge for the project. The temperature at depth is also uncertain, although better constrained by known geothermal gradients.

Hydrogeological modelling suggests that reinjection of water into the aquifer after heat extraction would be needed for output from the well to be sustainable in timescales beyond about 30 years, but the provision of a reinjection well was not included in the project design. Instead, options for discharging water to the Eden Estuary after treatment, or for recovery and re-use of water (which requires additional treatment), were evaluated. These options would have lower capital costs than a reinjection well.

Geothermal heat potential from the proposed well was estimated based on a temperature of 24°C and flow values of 5 l/s and 15 l/s, leading to potential heat outputs of 139 kW and 418 kW, respectively.

The project studied potential heat networks serving Guardbridge village and the larger nearby settlements of Leuchars and Bulmullo. However, the heat demands of these networks were greater than could be provided from the proposed well. Instead, the project focused on supplying heat to the developments planned within the Guardbridge Energy Centre, allowing a localised network close to the proposed well location on the site.

The project proposes using the geothermal supply with a heat pump to boost the temperature to that needed for supplying baseload heat to the Guardbridge site. This system would be linked through a heat exchanger to the Biomass Energy Centre (under construction), which would provide the additional capacity required. At the higher estimate of water flow from the well, the geothermal heat could supply half the heat demand of the proposed Guardbridge developments.

The drilling required for the deviated well design is outlined along with the type of equipment needed a conventional drilling rig with directional drilling capability. There are a number of risks and uncertainties associated with the well design and the need to drill obliquely through the fault damage zone. Some mitigation measures are identified.

The report provides initial definition of a second project phase, including geophysical surveys, environmental permitting, test well drilling and, assuming positive outcomes, full well and drilling programme design. This programme is required to progress well engineering definition to a point where a clear case for rig procurement and drilling is complete.

5.2.2.4. Hill of Banchory Geothermal Energy Proyect

The Hill of Fare granite is part of the Cairngorm Suite of granite intrusions in the north east of Scotland. Granite contains radioactive elements, which release heat as they decay, and is a relatively good conductor of heat from deep below ground, generally giving a more favourable opportunity for geothermal energy extraction than exists with sedimentary rocks. Based on new and existing data the thermal gradient at the Hill of Fare is estimated at between 21.1 and 29.0 °C/km, meaning that a temperature of 75°C is expected at a depth of between 2,200 m and 2,900 m.

The project considers a doublet borehole system that relies on water flow from one well to another; the rate of flow achievable depends on the rock permeability. Granite has inherently low permeability and flow is mainly through fracture networks, which are difficult to predict, making potential water flows uncertain. Data on fracturing and water flows from existing boreholes in granite is varied. Most cases have needed some degree of artificial stimulation, such as hydraulic fracturing (“fracking”), to achieve sufficient water flows for geothermal energy production. Low magnitude seismicity (not quantified in the report) is likely to be associated with the stimulation process.

Three flow-rate scenarios 5, 15 and 50 l/s were assumed on the basis of observations in similar granites and used for analysis of the potential of the scheme, although the report is careful not to present them as actual predictions of flow rates. Heat output from the system was estimated at 0.42 MW, 1.25 MW and 4.18 MW, respectively, assuming temperatures allowing direct integration to the existing heat network were achieved (see below).

Two boreholes into the Hill of Fare granite are proposed at a site to be determined 3 – 4 km from the Hill of Banchory Biomass Energy Centre. The boreholes would be typical of geothermal wells; each could act as the extraction or reinjection well allowing reversal of flow direction to avoid problems of clogging. Wells would take around six weeks to drill and complete. The wellheads would be linked to the heat network by a pair of insulated pipelines for the hot flow and cooler return.

The project proposes integrating extracted geothermal heat with the Hill of Banchory DHN. This is currently supplied by a 900 kW biomass boiler and two back-up gas boilers; a second 700 kW biomass boiler is planned. The system operates at a flow temperature of 85°C with return at 60–65°C. Two 50 m3 water tanks allow heat storage. When the planned network is complete, with more housing and businesses connected, biomass will supply 70% of the heat with gas providing the remaining 30%.

Geothermal heat supply may be integrated with the existing network and its planned expansion in three ways depending on the water temperature achieved. For temperatures >85°C direct heating of the network flow would be possible, but this temperature is unlikely to be achieved. For intermediate temperatures pre-heating of the network return could be used; this is likely to be feasible with the temperatures expected but may not be economic (see section below). For temperatures close to or below the network return temperature, a heat pump could be used to extract heat from the geothermal water; this option would have higher costs and was not considered further. Alternatively, an intermediate temperature that might be achieved by the geothermal system, such as 75°C, could be used with a new heat network, beyond current plans, designed to operate at lower temperature.

The project considered the forecasted developments around the Hill of Banchory area and estimated the resulting increases in heat demand in the period to 2020. It also examined the wider Banchory town area to identify further potential development of heat networks to supply public buildings and council and private housing areas, which could be designed for lower supply temperatures. Estimates were made of the heat demand and profile of six potential sub-networks, with indicators of CAPEX for the networks and likely sales price and revenues. Two sub-networks were identified as most favourable for initial development, one including a school, swimming pool and sports centre, the other a council housing area.

The project identifies a programme of next steps to build a robust business case (spanning 17 to 38 months), with the ultimate objective of developing a geothermal well doublet to deliver heat to network customers in Banchory.

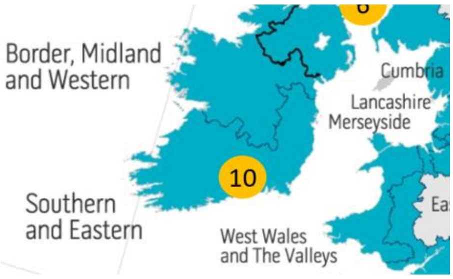
5.2.2.5. CONCLUSIONS

The feasibility studies summarised in this report propose four different technologies for extracting geothermal energy in Scotland: a single well recirculation system (AECC); a minewater extraction system (Fortissat); a single well extraction system (Guardbridge); and a doublet well extraction/reinjection circulation system (Hill of Banchory). Each of these has inherent challenges and opportunities, and the studies demonstrate feasibility to different degrees. All the projects would lead to savings in CO_2 emissions of similar scales and roughly proportionate to their displacement of fossil fuel usage.

Taken as a whole, the four studies indicate that geothermal heat can have a useful role in the energy mix in Scotland and there is a range of potentially viable options. The deployment of geothermal heat in Scotland will require site-specific assessment; feasibility studies such as these are a necessary first step. Demonstration projects would help to reduce uncertainty and encourage wider use of geothermal resource in Scotland.

5.3. Ireland

CIT – Cork Institute of Technology (Cork / Ireland)



5.3.1. Geothermal technologies currently used

Geothermal energy resources in Ireland are of low enthalpy in nature, with the main exploitation focussed on the use of ground source heat pumps.

The Energy White Paper 2015-2020 (DCENR, 2015) identifies geothermal energy, heat pumps and district heating as technologies for addressing the heat energy demand in Ireland and meeting renewable energy targets.

Ireland's intraplate geological setting is such that geothermal resources are classified as low enthalpy with lower average geothermal gradients of approximately 10°C/km recorded in the south to higher gradients in the north east and in Northern Ireland where values of up to 35°C/km are observed.

Shallow geothermal energy resources are favoured by the Irish climate that is dominated by warm and mild maritime conditions. Relatively consistent, year round soil temperatures and frequent rainfall keeping moisture in the ground maintains soil as an excellent conductor, allowing heat to move towards a thermal collector system. These conditions are particularly suited for horizontal closed loop systems.

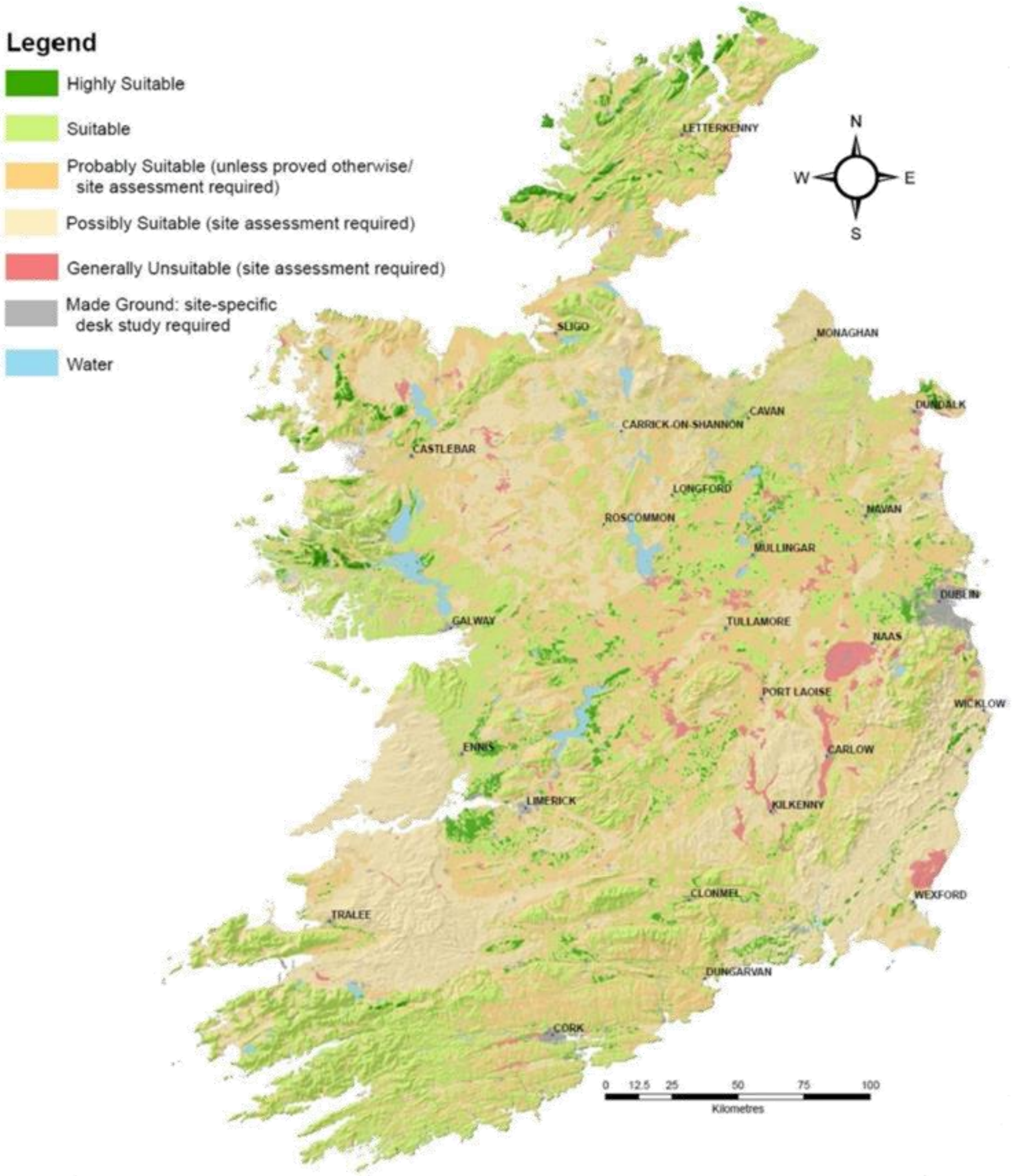


Illustration 22: Vertical Closed Loop Collector Suitability Map (Source: Geothermal Association of Ireland).

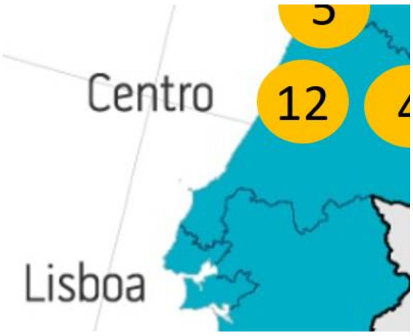
5.3.2. Geothermal systems in the development phase

The geothermal projects currently under development are briefly described.

- ✓ **IRETHERM project** has developed integrated models for different type of geothermal targets through a comprehensive program of geophysical field surveys, geochemistry, hydrochemistry and thermal property studies to identify those geological settings/localities that present the greatest opportunity for harnessing deep geothermal energy. Promising results from some of the study areas have shown that potential for delivering deep geothermal heat in both Ireland and Northern Ireland is present but further research and investigation is required. The validation of some of the model and work undertaken as part of the project should be achieved through the collection of additional base data for each area, the completion of further heat flow measurement studies and the completion of a deep demonstration borehole.

- ✓ **The Irish Ground Thermal Properties Project (IGTP)** is focussed on characterising the geothermal properties of Irish ground conditions and their suitability for deployment of closed loop collectors. This will be achieved by carrying out further site specific field tests on installed geothermal collectors where these are available. IGTP has obtained new data in different Irish ground conditions to facilitate design and sizing of geothermal collectors by installers and professionals through a public database. The compiled data has been used to develop ground loop sizing tables based on Irish conditions for use in small scale closed loop collector installations. The project helps to facilitate the understanding of the potential of shallow geothermal resources in a given areas and inform engineers of ground condition considerations at the design stage.
- ✓ The "CHeap and Efficient APplication of reliable Ground Source Heat exchangers and PumpS" **CHEAP-GSHPs project** kicked off in May 2015. (Cheap- GSHPs) project is funded by Horizon 2020, call LCE- 03-2014, under the technology-specific challenges in demonstrating of renewable electricity and heating/cooling technologies. This new project is adopting a practical demonstration approach to new technologies in ground source heat exchangers (GSHE). The project is focussed on the development of more efficient and safe shallow geothermal systems and the reduction of the installation costs. An existing, innovative vertical borehole installation technology of coaxial steel GSHE will be improved and a helix type GSHE with a new, innovative installation methodology will be developed. Decision support tools will also be developed to identify the best GSHE system to adopt based on climatic conditions and the building energy requirements. There will be a number of demonstration sites where the new technology will be tested. One of those sites will be in Ireland.
- ✓ The Geological Survey of Ireland has funded three geothermal energy projects as part of the Geoscience 2015 research funding:
  The Irish Soils Thermal properties **project** is developing a database of thermal properties of soils and sub soils based on existing classifications to facilitate in the charaterisation and design of horizontal collectors. Two deep geothermal projects are using the recently acquired Tellus midlands airborne magnetic and EM data to assess the potential for identifying deep geothermal targets. **The DeepGeo project** is using an integrated interpretation and modelling of Tellus aeromagnetic, gravity, radiometric and multispectral analysis of satellite imagery datasets for exploration and identification of deep geothermal target areas in the midland valley terrane.

5.4. Portugal

Faculty of Engineering of University of Porto	RNAE - Associação das Agências de Energia e Ambiente (Rede Nacional) (Vilanova de Gaia (Portugal)
	

5.4.1. Geothermal technologies currently used

The information shown below has been obtained from the report Geotermia - Energia Renovável em Portugal, DGEG - Direção Geral de Energia e Geologia, 1.ª edição, novembro 2017.

5.4.1.1. Mainland Portugal

The heat energy coming from warm waters occurring in Mainland Portugal was, during long time, used only for balneotherapy, practice already used since the times of occupation as previously mentioned.

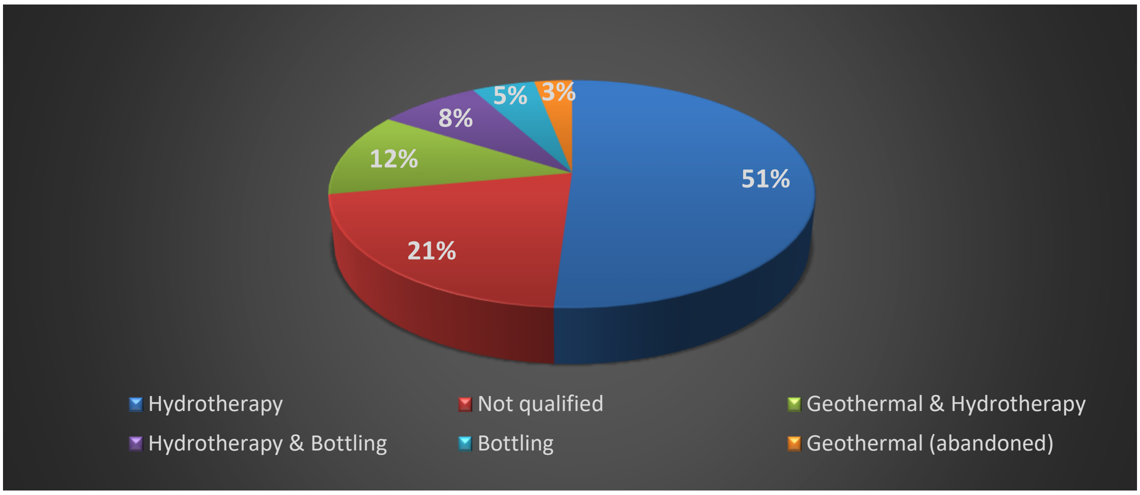
However, since about three decades, these waters began to have other uses, in particular in the use of heat for climatization. These actions mark, in Portugal, the emergence of the geothermal resource. In the last years, there has been a growing interest in the operators of these waters, in their usefor heating and cooling not only of the baths, but also of swimming pools, hotel units in support of thermal activity, in hot water production and, in some cases, also for heating greenhouses for the production of tropical fruits and fruits out of season. There is a growing interest in the development of new areas of exploration and research of this resource energy.

The energy crisis experienced at the beginning of the seventies, associated with the desire to use the resources of existing high enthalpy geothermal in the Archipelago of Azores, for essentially electricity production, , led to the consecution of the first regulation on geothermal energy.

The growing development around the world of low- enthalpy projects, and the finding that it was possible and desirable to exploit those existing resources in Mainland Portugal, determined the need to create a new regulatory framework appropriate for their exploitation.

Thanks to this regulation, geothermal resources are part of the public domain of the State. Their development and exploitation can only be performed within administrative contract with the state.

Of the 61 superficial geothermal manifestations studied in the DGEG publication[4], 45 are qualifying as natural mineral waters. Of these, some are used exclusively for bottling or hydrotherapy or have both uses. Only 7 of them (Alcafache, Carvalhal, Chaves, Longroiva, Monção, S. Pedro Sur and Vizela), have a double qualification as natural mineral water and geothermal resource.



Graphic 18: Percentage of use of superficial geothermal manifestations in Mainland Portugal (Source: Geotermia - Energia Renovável em Portugal, DGEG - Direção Geral de Energia e Geologia, 1.ª edição, novembro 2017).

[4] Geotermia - Energia Renovável em Portugal, DGEG - Direção Geral de Energia e Geologia, 1.ª edição, novembro 2017

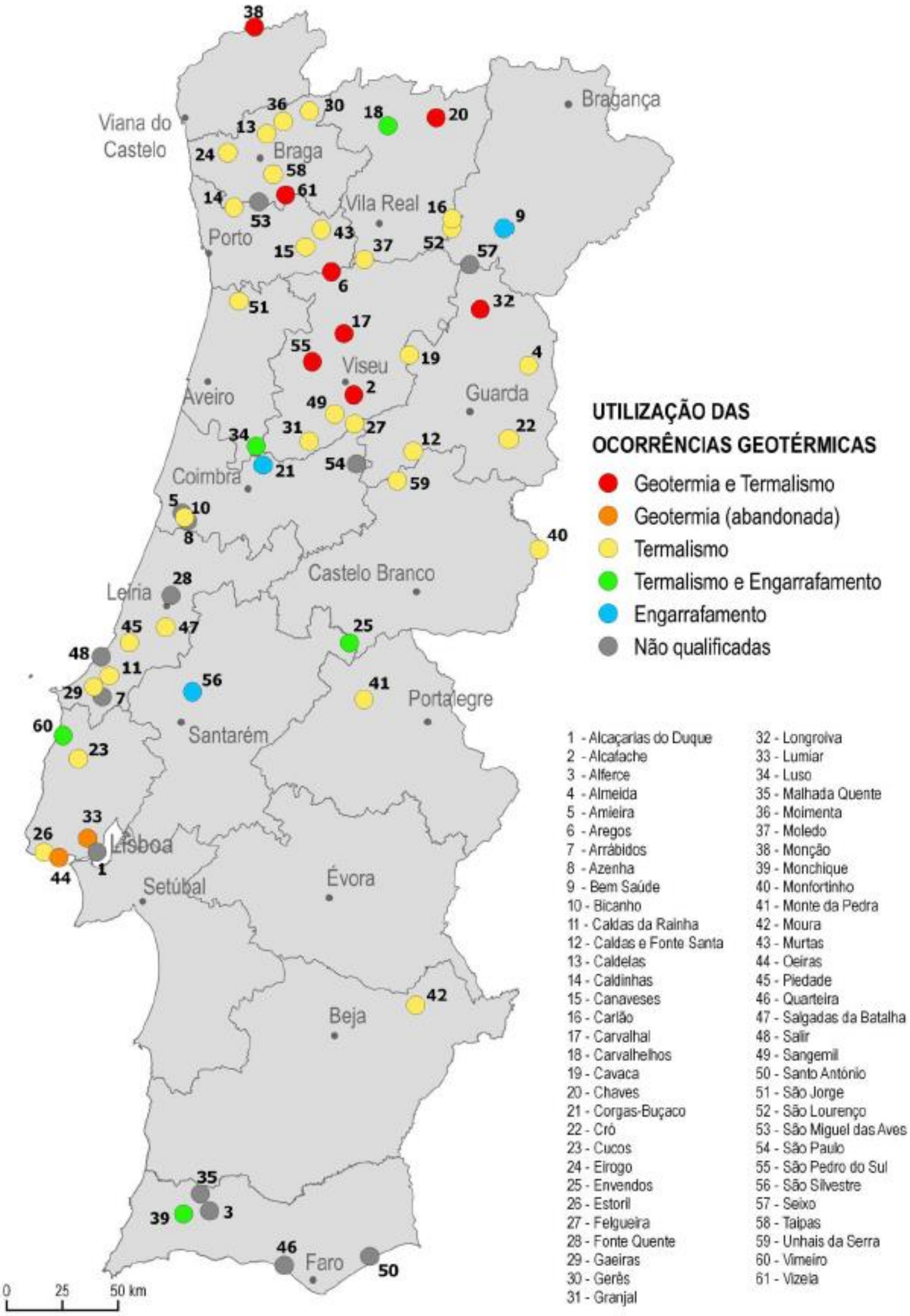


Illustration 23: Use of superficial geothermal manifestations in Mainland Portugal (Source: Geotermia - Energia Renovável em Portugal, DGEG - Direção Geral de Energia e Geologia, 1.ª edição, novembro 2017).

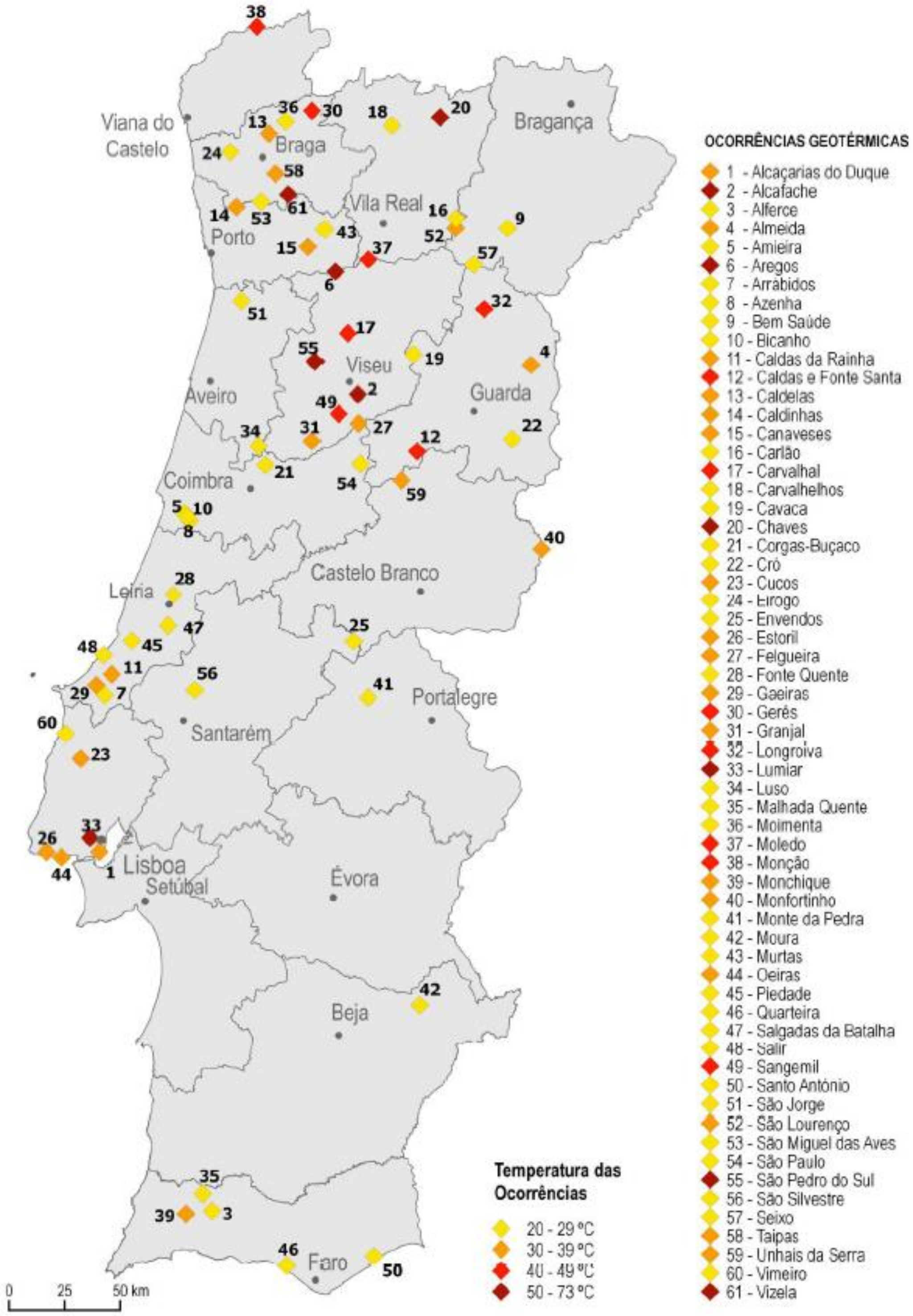


Illustration 24: Temperatures of superficial geothermal manifestations in Mainland Portugal (Source: Geotermia - Energia Renovável em Portugal, DGEG - Direção Geral de Energia e Geologia, 1.ª edição, novembro 2017).

5.4.1.2. AÇORES ISLANDS

The Archipelago of the Azores is composed of nine volcanic oceanic islands, located in the middle of the North Atlantic dispersed along a strip of about 600 km in length, located in the triple junction of the north plates American, Eurasian and African.

This location and situation of the archipelago of The Azores tcauses a seismic and volcanic activity including numerous demonstrations of secondary volcanism, such as fumaroles, degassing and springs, wells and holes with thermal waters. The volcanism of the archipelago of The Azores is generally characterized by 27 volcanic rocks systems and also by the existence of about 1750 monogenetic volcanoes, either on the flanks and inside of the subsidence boilers of polygenetic volcanoes, or integrating basaltic fissural systems These small volcanoes include, but are not limited to, basaltic slag, domes and trachytics coulees, cones and tuft rings, maars and eruptive fissures, which often define alignments volcano-tectonic

The geological nature, the intense associated fracturing, the tectonics and seismicity, potentiate the existence of geothermal reservoirs in several islands of the Azores (notably on the islands of S. Miguel, Terceira, Graciosa, Pico and Faial).

The field of Ribeira Grande should be highlighted on the island of São Miguel (with temperatures of water from the extraction from 142 °C to 203 °C) and the field geological survey of Pico Alto, Terceira (with water temperatures at outflow from 263 °C to 283 °C), and both currently in exploration.

In total there were identified in the Azores 48 low enthalpy geothermal manifestations (with temperatures between 22 and 98 °C), most of them (25 manifestations) in the called “Hydropolis of Furnas”, on the island of S. Miguel.

In the Autonomous Region of the Azores the following: are qualified as a geothermal resource

- The Geothermal Field of Ribeira Grande (island of S. Miguel), constituted by the formation of geological features and heat from the fluids captured in the wells CL1, CL2, CL3, CL5, CL6, CL7, PV2, PV3, PV4, PV7 and PV8, as well as by geological formations traversed by the wells reinjection CL4, CL4A, PV5, PV6, PV9, PV10 and PV11; these wells ensure the operation of the geothermal power stations in Ribeira Grande and Pico Vermelho, with a total installed capacity of 27.8 MW.
- The Geothermal Field of Pico Alto (Terceira Island), consisting of the geological formations and by the heat of the fluids captured in production wells PA2, PA3 and PA4, as well as by the formation geological features crossed by reinjection PA8; these wells ensure the operation of the geological center of Pico Alto, with total installed capacity of 4.0 MW.
- The geological formations and heat of fluids captured in the AC3 hole at the Ferraria (island of S. Miguel); this capture hole ensures the production of hot water for use in the spa thermal baths of Ferraria outdoor swimming pool; the

feature displays a temperature of 61 °C and a total mineralization of 20485 mg / L.
- The geological formations and the heat of fluids captured in the AC1 Carapacho (island Graciosa), previously addressed for recreational purposes but, currently unused.

Of the 48 geothermal low enthalpy superficial geothermal manifestations in the Azores, 18 are classified as natural mineral water and integrate the hydromineral concession called “Estancia Termal das Furnas”, demarcated by the General Directorate of Mining and Geological Services (Ministry of Economy). Currently, only the designated harvesting of "Quenturas - (or "Agua Férrea das Quenturas") is used in swimming pools of Furnas Boutique Hotel Thermal & Spa. Other manifestations of this concession have a traditional use in multiple strands (e.g. Bica da Água Santa, Poço, Padre José) or have been used in the development of new products (e.g. use of water “Terra Nostra” in dermocosmetics products and “Água Azeda” in the brine / ripening of cheese).

Similarly the water from the hole of PS2 capture, Carapacho (Ilha Graciosa), is classified as water natural mineral, fueling the thermal spa of Carapacho. It is a chlorinated water with a total average mineralization of 8200 mg / L.

The thermal water of Ladeira da Velha is still qualified as natural mineral water and integrates the known as “Água da Ladeira da Velha”..

5.4.2. Geothermal systems in the development phase

5.4.2.1. Mainland Portugal

The geothermal potential of Mainland Portugal is in the field of low and very low enthalpies, having, to date, been inventoried 61 manifestations of water with temperature above 20 °C:

- 34 superficial geothermal manifestations of very low enthalpy with a temperature between 20 °C and 29 ºC.
- 27 superficial geothermal manifestations of low enthalpy with a temperature between 30 °C and 73 °C.

The 61 known occurrences are divided into 2 types:

- 46 superficial geothermal manifestations qualified as natural mineral waters of which 7 are qualified as geothermal resources;
- 15 unrecognized superficial geothermal manifestations like natural mineral waters.

From the geological point of view, they correspond to circulating deep waters where they acquire high temperatures and rise to the surface because of the existence of tectonic and / or stratigraphic discontinuities, thus constituting, local geothermal anomalies that stands out from the regional values of geothermal gradient. They are distributed as follows:

- 38 occur in the whole of the Central-Iberian and from Galicia-Trás-os-Montes, essentially associated to granitic formations, but also quartzitic or xistenta and, often dependent of active failures.
- 1 in the Ossa-Morena Zone.
- 17 on the Meso-Cenozoic Associated with diaphric sediments or detrital sediments and carbonated structures.
- 3 in the South-Portuguese Zone associated with the sienítico massif Mesozoic of Monchique.
- 2 Orla Meso-Cenozoic of the Algarve.

The existing temperatures do not allow, in the current state of knowledge, the use of geothermal resources for production of electricity. However, the geothermal energy can be used in small to medium-sized direct application, with the use of cascade the most efficient way to use of the geothermal resource.

In the case of Mainland Portugal, geothermal applications are reduced to lower than 80 ºC temperatures, there are already some geothermal resource usage points in cascade, as is the case of Chaves, São Pedro do Sul, Vizela, Alcafache, Longroiva and Monção, where they exist, in addition to spa applications, small to medium-sized heating projects owned by thermal baths and hotels, for production of hot water and heating of swimming pools and greenhouses.

Projects linked to geothermal use in Mainland Portugal, with direct use from deep aquifers, are still small. However, there is a considerable margin for expansion and improvement of the results obtained, especially with the dynamism of the actual research and scientific studies.

Some studies of this type performed in some thermal spots indicate temperatures of reservoir significantly higher than those observed in thesurface. This has been confirmed in two granite geothermal manifestations from the Central-Iberian Zone:

In the occurrence of Carvalhal, where execution of a hole of 600 m depth, made it possible to increase in flow and temperature from 3 l/s to 44.4 °C for 6 l/s at 60 °C and in the Fonte Santa de Almeida, where a bore of 1000 m depth allowed a rise in temperature from 19 °C to 35 °C. It is then expected that the realization of this geological research would make it possible to obtain higher temperatures and, probably flows in the Central-Iberian Zone.

In the Meso-Cenozoic Sedimentary Edge there are waters with high temperature that evidence the existence of deep aquifers, whose potential geothermal is still unknown.

In Mainland Portugal, the average geothermal gradient is about 2 °C to 3 °C / 100 m, and it is estimated that, at depths in the order of 1500 m, temperature could be of 50 °C. These data is in line with the information provided by the oil companies, which also point for gradients of the same order. In the Lisbon area, the Lumiar geothermal system seems to be representative of these conditions, since it reached the temperature of 50 °C at the depth of 1500 m. At Peninsula of Setúbal, the prospections of the oil companies in the Barreiro area, revealed the same order of magnitude of the geothermal gradient, with a temperature of 75 ° C to 2800 m of depth.

Taking these data into account, there is a potential, extendable to all the country, for the development of geothermal depth use. This can be by the direct use from deep aquifers, as well as, in the absence of permeability, from the Enhanced Geothermal Systems Geothermal Systems (EGS).

There is also a potential in all the country to develop geothermal heat pumps for heating and cooling from aquifers or geological formations at normal temperature.

It can be considered that in Mainland Portugal, there is a high potential for the expansion of the use of geothermal resources of low and very low enthalpy, however, it is necessary to perform multidisciplinary studies for the quantitative evaluation of this potential. The dynamism of the use of this energy resource it is not just a question of availability of the resource, but also a problem of market, marketing and environmental awareness.

5.4.2.2. Açores Islands

Regarding to the high enthalpy geothermal energy, its use for the production of electric power began in 1980 in the Fogo Volcano, S. Miguel Island, with the Pico Vermelho pilot plant (with installed capacity of 3 MW). The industrial scale use began in 1994, with the Geothermal Plant of Ribeira Grande, with a capacity of 5.8 MW. Currently are running two fluid geothermal power stations on the island of S. Miguel (the Central Geothermal Plant of Ribeira Grande and Pico Geothermal Power Plant Red), with a total capacity installed capacity of 27.8 MW, a power of 23.2 MW and an energy output of 171.6 GWh (year of 2016), which corresponds to about 44% of the energy consumption the island.

The Geothermal Power Plant of Pico High on Terceira Island is in operation since August of 2017, with an installed capacity of 4.0 MW, producing 16% of the island´s consumption.

Regarding the direct use, there is an example with the greenhouses of INOVA-Institute of Technological Innovation of the Azores, financed under the the THERMIE Program and heated geothermically between 1997 and 2005, whose reactivation is under evaluation.

The foreseeable growth of electricity production in the future is limited by the demand and competition with other forms of renewable energy, as there are significant resources to allow an increase in production. The penetration of electric power produced by geothermal will depend on how the economy of S. Miguel Island and Terceira Island grow. In other islands there is room for the emergence of mini plants with binary fluids for the electric power from resources with temperatures in the range of 70-98 °C.

In Azores there are no surface geothermal operations (GSHP) but it is considered that there is a strong market for this technology in the field of heating and cooling (air conditioning, heating, cooling, dehumidification).

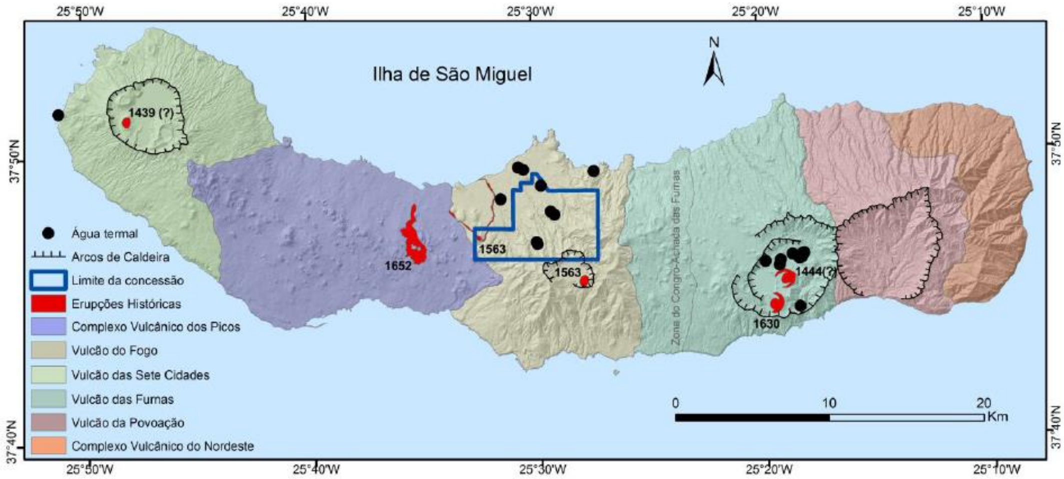


Illustration 25: Vulcan-stratigraphic framing of geothermal manifestation in Sao Miguel Island (Source: Geotermia - Energia Renovável em Portugal, DGEG - Direção Geral de Energia e Geologia, 1.ª edição, novembro 2017).

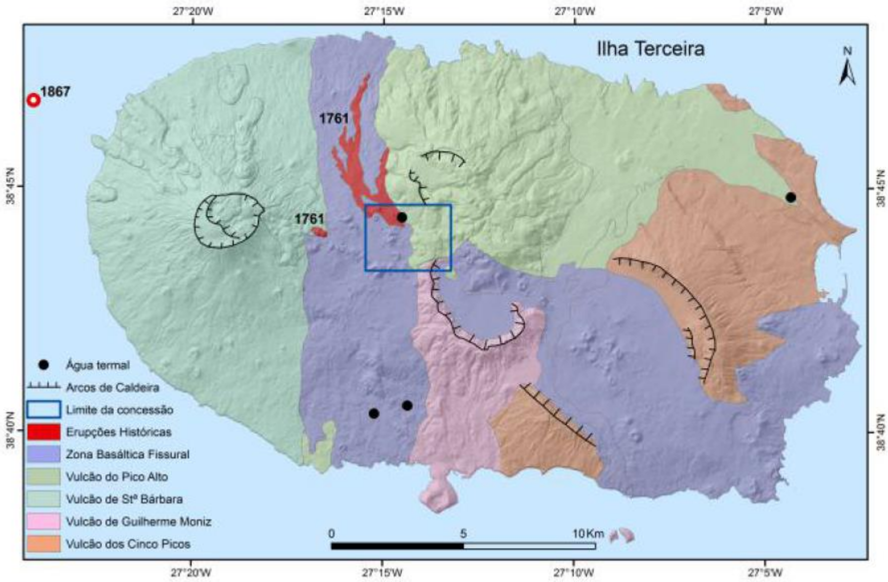


Illustration 26: Vulcan-stratigraphic framing of geothermal manifestation in Sao Miguel Island (Source: Geotermia - Energia Renovável em Portugal, DGEG - Direção Geral de Energia e Geologia, 1.ª edição, novembro 2017).

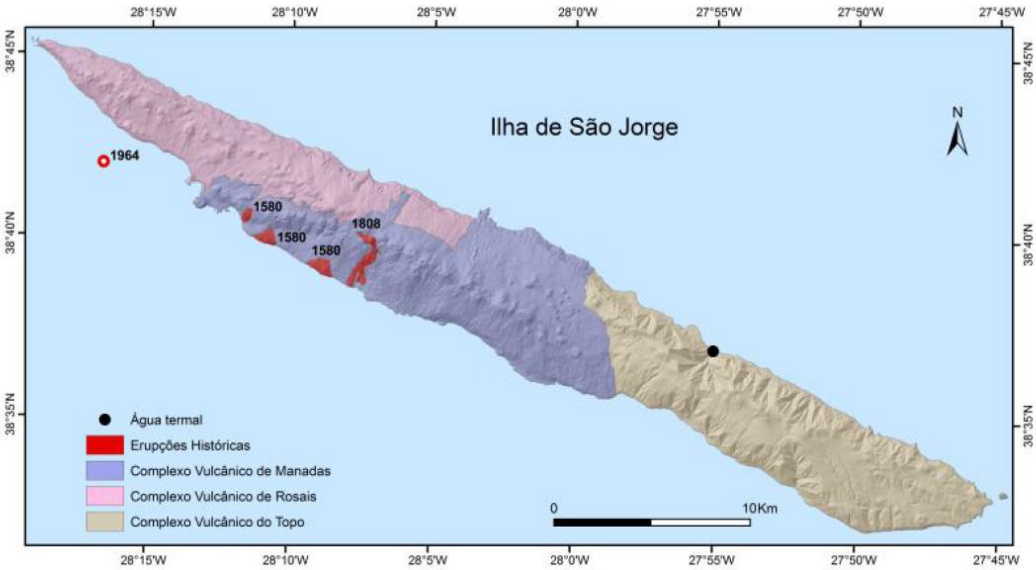


Illustration 27: Vulcan-stratigraphic framing of geothermal manifestation in Sao Jorge Island (Source: Geotermia - Energia Renovável em Portugal, DGEG - Direção Geral de Energia e Geologia, 1.ª edição, novembro 2017).

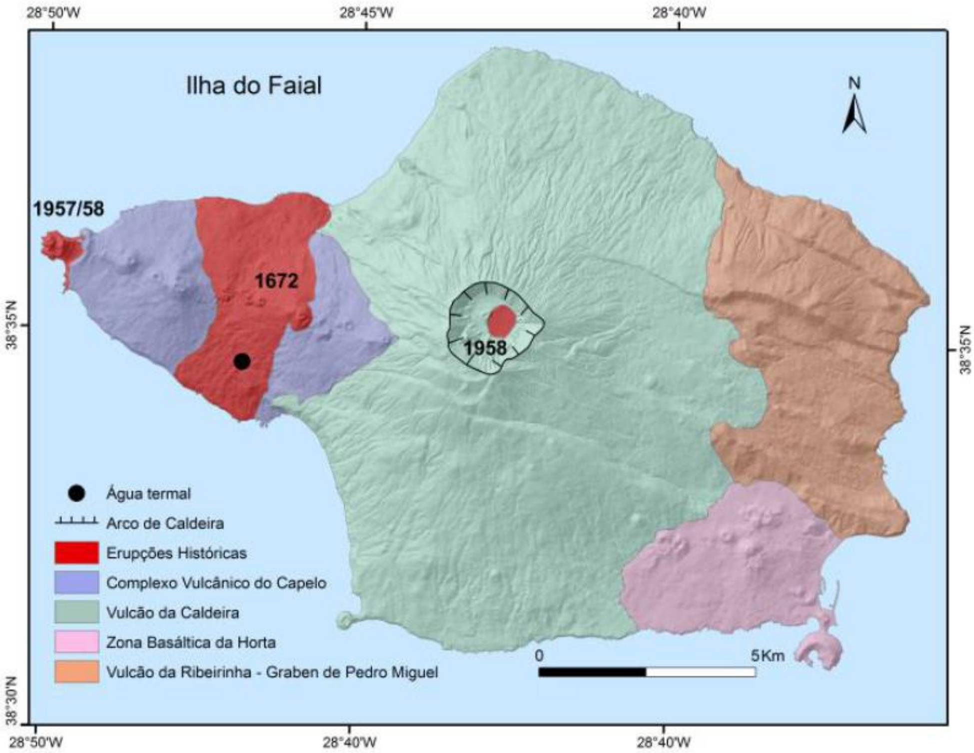


Illustration 28: Vulcan-stratigraphic framing of geothermal manifestation in Faial Island (Source: Geotermia - Energia Renovável em Portugal, DGEG - Direção Geral de Energia e Geologia, 1.ª edição, novembro 2017).

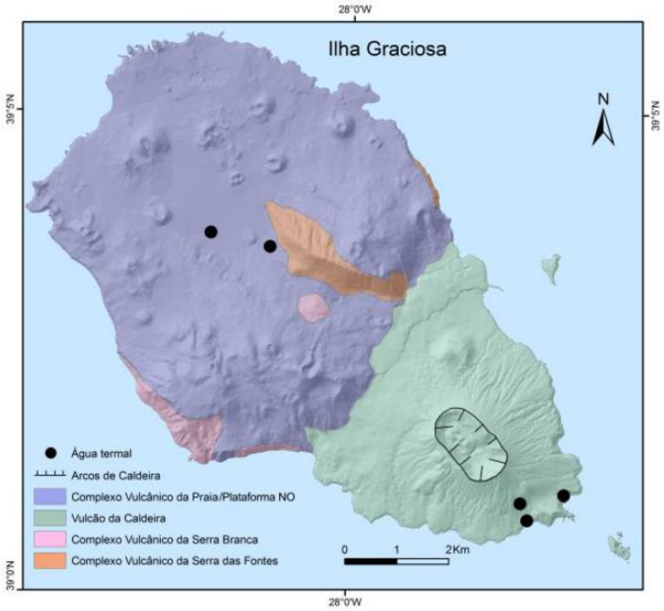


Illustration 29: Vulcan-stratigraphic framing of geothermal manifestation in Graciosa Island (Source: Geotermia - Energia Renovável em Portugal, DGEG - Direção Geral de Energia e Geologia, 1.ª edição, novembro 2017).

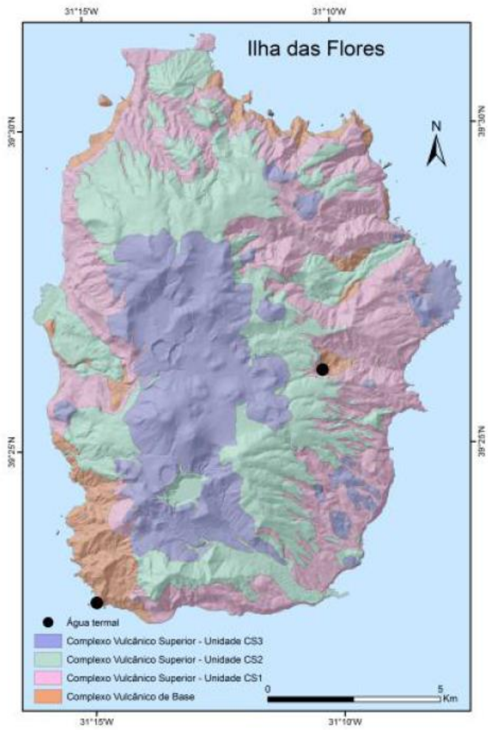


Illustration 30: Vulcan-stratigraphic framing of geothermal manifestation in Das Flores Island (Source: Geotermia - Energia Renovável em Portugal, DGEG - Direção Geral de Energia e Geologia, 1.ª edição, novembro 2017).

5.4.2.3. CONCLUSIONS AND TECHNOLOGICAL RECOMMENDATIONS

Technological developments, whether at the level of prospecting and research, drilling, or the use of geothermal resources, could lead to new applications of these resources. The technological evolution is in continuous development, since the use of geothermal resources for certain applications it is done at lower temperatures.

New drilling technologies could allow access to greater depths through any type of geological formation, enhancing access to hitherto inaccessible geothermal resources.

More efficient prospecting and research techniques in the development of geothermal projects may lead to a better knowledge of the subsoil, and reduced costs because of the reduced risk associated with the inherent uncertainty of in depth geology.

The integration of geothermal resources with other renewable technologies could also contribute to an increase in energy efficiency in buildings, industry, or the production of electricity, so the development of new solutions could also contribute to its development and improvement of performance.

The geothermal potential already revealed in Mainland Portugal is underexploited and there should be put in place lines of financial support for the development of projects with a view to encouraging the direct use of these resources.

Promoting the use of surface geothermal should be increased, as a way of using a renewable source of energy, for the heating/cooling of buildings through the utilization of heat pumps, and hot water production. For that is necessary its regulation, as a way to ensure its correct use, minimizing possible impacts that may exist, in particular with regard to interference with water resources and hydrogeological resources.

The use of geothermal energy is beneficial in terms of energy efficiency in buildings, as it is estimated that around 40% of European energy consumption is caused by buildings, contributing to the European achievement of the energy efficiency. To achieve this, it is worth highlighting the contribution of geothermal resources in the reduction of greenhouse gas emissions, which produce climatic alterations.

Faced with the geothermal potential of Mainland Portugal, and the current use of it, there is a need to formulate an action plan for its development, which should address, in a systematic way, the above topics, making geothermal energy a more attractive and with lower geological and financial risks, greater energy efficiency and lower environmental impacts.

5.5. Spain

Ourense City Council (Galicia / Spain)

EnergyLab (Galicia / Spain)

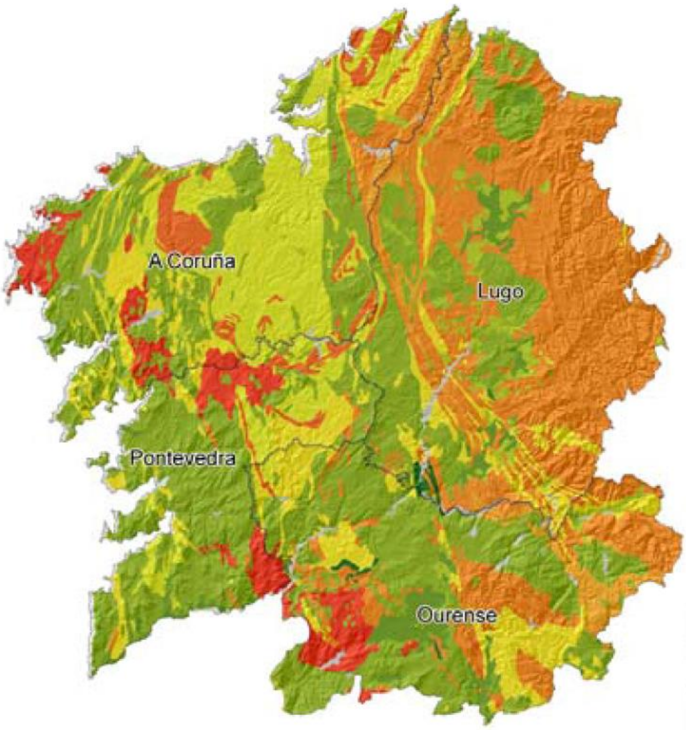
5.5.1. Geothermal technologies currently used

The use of geothermal systems in Galicia, focuses solely and exclusively on heating/cooling/hot water installation and thermal water, in a very similar way to its neighbour Mainland Portugal, using a low temperature geothermal resource.

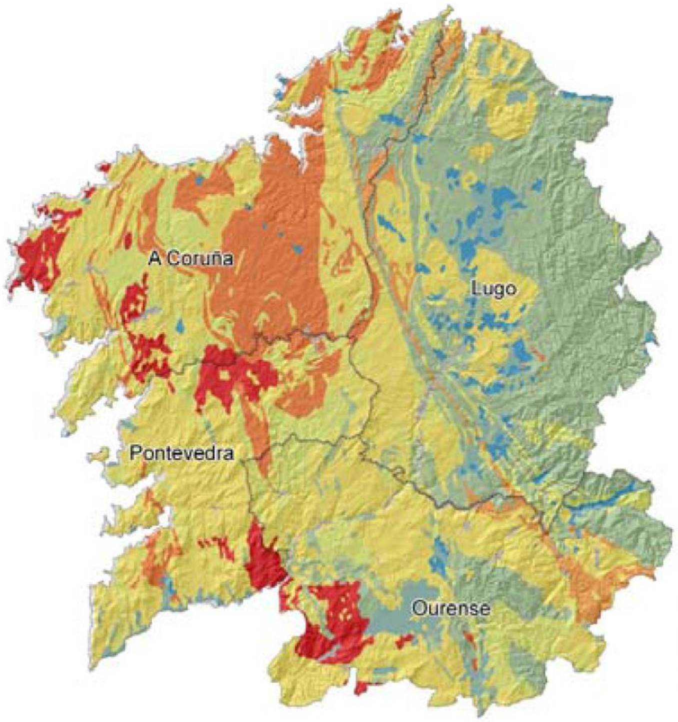
In terms of Geothermal Systems of low enthalpy (GSLH), used in the heating and cooling of buildings, they are based on the use of heat stored in the first 200 meters of the earth's crust through the use of exchangers introduced into the ground in combination with heat pumps. The fundamental difference with traditional systems that use a gas boiler, gas oil or other fuel, is that the former operate through a process of heat exchange from the ground to the building or vice versa, while the latter are based on a process of combustion with the consequent emission of greenhouse gases.

Geothermal energy of very low enthalpy, with temperatures of just a few degrees is available anywhere on our planet, but like any other mining resource its use depends on the geological conditions of the area where its use is intended. In the case of the Galician Autonomous Community, the existence of a subsoil with predominance of crystalline rocks of high thermal conductivity (granites), easily drivable and with a very shallow water table, makes that practically all of its territory is optimal for the implementation of the GSLH.

For the efficient use of the geothermal resource of very low temperature is fundamental to know as accurately as possible the thermal conditions of the place, both environmental and of the subsoil, as well as the definition of the use or energy contribution that this soil will make. That is why, below, the thermal conductivity and diffusivity of the Galician subsoil is shown:



Graphic 19: Thermal conductivity of the Galician subsoil (Source: INGEO).



Graphic 20: Thermal diffusivity of the Galician subsoil (Source: INGEO).

The sum of all these factors means that the energy efficiency and profitability of GSLH in Galicia are very high, as has been verified by EnergyLab after the monitoring of this type of facility. Consequence of this and the work of dissemination and promotion that has been carried out in recent years by the Ministry of Economy, Economy and Industry of the Xunta de Galicia, INEGA and the Cluster of Geothermal companies of Galicia (ACLUXEGA), the number of these facilities has multiplied without having attempted to quantify them until now. Due to this gap, and the limitations of not having all the information, it has been developed with the partnership of ACLUXEGA, an approximation to the number and power of these systems, analysing the situation of this technology from its introduction to the present.

For the elaboration of statistical analysis, we have had the historical data provided by the installation companies associated with the ACLUXEGA Cluster, making an estimate of the number of installations executed by companies not belonging to the Association in the same periods.

The Galician Autonomous Community ended 2016, with the figure of 1061 Geothermal Systems with heat pump. This figure implies a use of this technology of 0,39 units per thousand inhabitants. Although this figure is still far from the levels of introduction in other countries of the European Economic Community, they exceed the rest of the Spanish Communities and Regions, in the best case (Madrid, Barcelona, País Vasco) the ratio should be close 0,15 units per thousand inhabitants.

The distribution of the number of systems per province points to a greater implantation within the cities of La Coruña and Pontevedra, which account for 75% of them. The lower number of systems in Ourense and Lugo is partly due to the lower population density, partly due to a greater ignorance of this technology and also to the geological conditions not so exceptional as in the Atlantic Provinces where granite is more predominant.

The number of installations executed decreased dramatically in the years 2008-2014 as a consequence of the crisis in the construction sector. Data from recent years confirmed the recovery of levels and values close to those of 2007, which were the largest number in the historical series.

In terms of total thermal power it has reached by the end of 2016 in Galicia approximately 26 MW. This figure, although still modest, is not negligible and, to give an example, it could represent the equivalent of 6,5% of power in the combined cycle of the Sabón Thermal Power Plant (A Coruña). Although the source used by GEOPLAT (Spanish Technological Platform of Geothermal Energy) is unknown for its calculations, in some of its reports it is estimated that the total geothermal power installed in Spain reaches 168 MW. If this figure is true, Galicia, with only 6% of the country's population, owns 15,5% of the installed capacity.

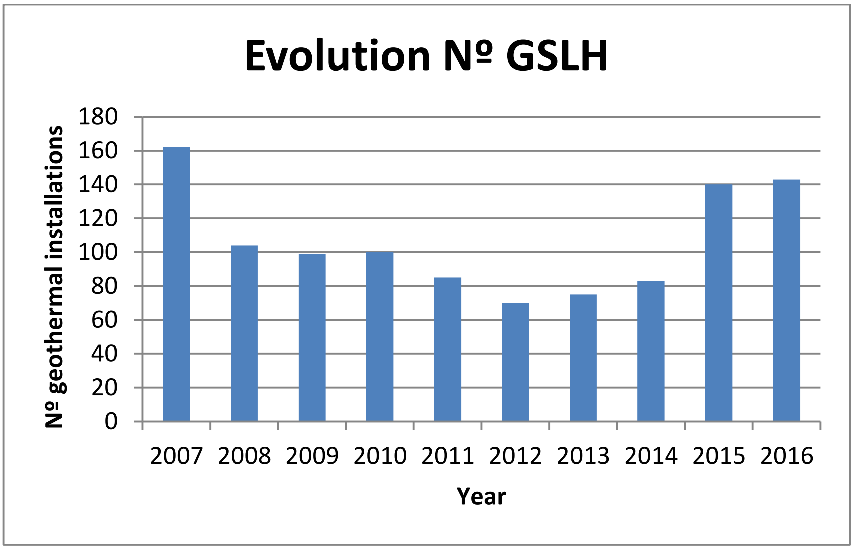
In recent years, a measure that popularizes these systems, there is a tendency to increase the number of GCS projects in large facilities. As a result, we must wait in the future and as the economic, operational, environmental and durability advantages of these systems become known within the business sector, the contribution of geothermal energy will grow exponentially.

YEAR	Nº INSTALATIONS	A CORUÑA	PONTEVEDRA	LUGO	OURENSE
2007	162	67	57	18	20
2008	104	43	37	11	13
2009	99	41	35	11	12
2010	100	41	35	12	12
2011	85	35	29	10	11
2012	70	29	24	8	9
2013	75	31	27	8	9
2014	83	35	29	9	10
2015	140	58	49	16	17
2016	143	60	49	16	18
TOTAL	**1061**	440	371	119	131
PERCENTAGE	100%	41,5%	35,0%	11,2%	12,3%

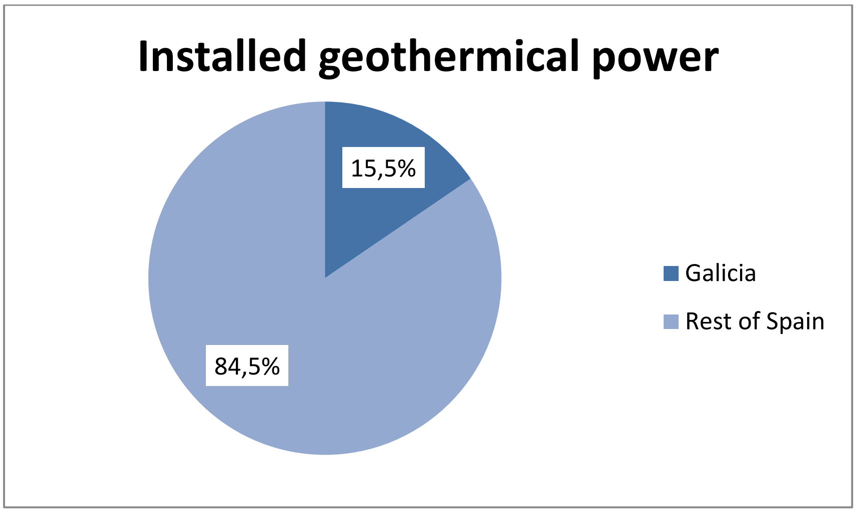
Table 14: Nº of GCS of low enthalpy in Galicia in each province (Source: ACLUXEGA).

YEAR	Nº TOTAL INSTALATIONS	10 kW	20 kW	125 kW	TOTAL INSTALLED POWER
		60%	30%	10%	
2007	162	97	49	16	3969
2008	104	62	31	10	2548
2009	99	59	30	10	2426
2010	100	60	30	10	2450
2011	85	51	26	9	2083
2012	70	42	21	7	1715
2013	75	45	23	8	1838
2014	83	50	25	8	2034
2015	140	84	42	14	3430
2016	143	86	43	14	3504
TOTAL	**1061**	636	320	106	**25997**

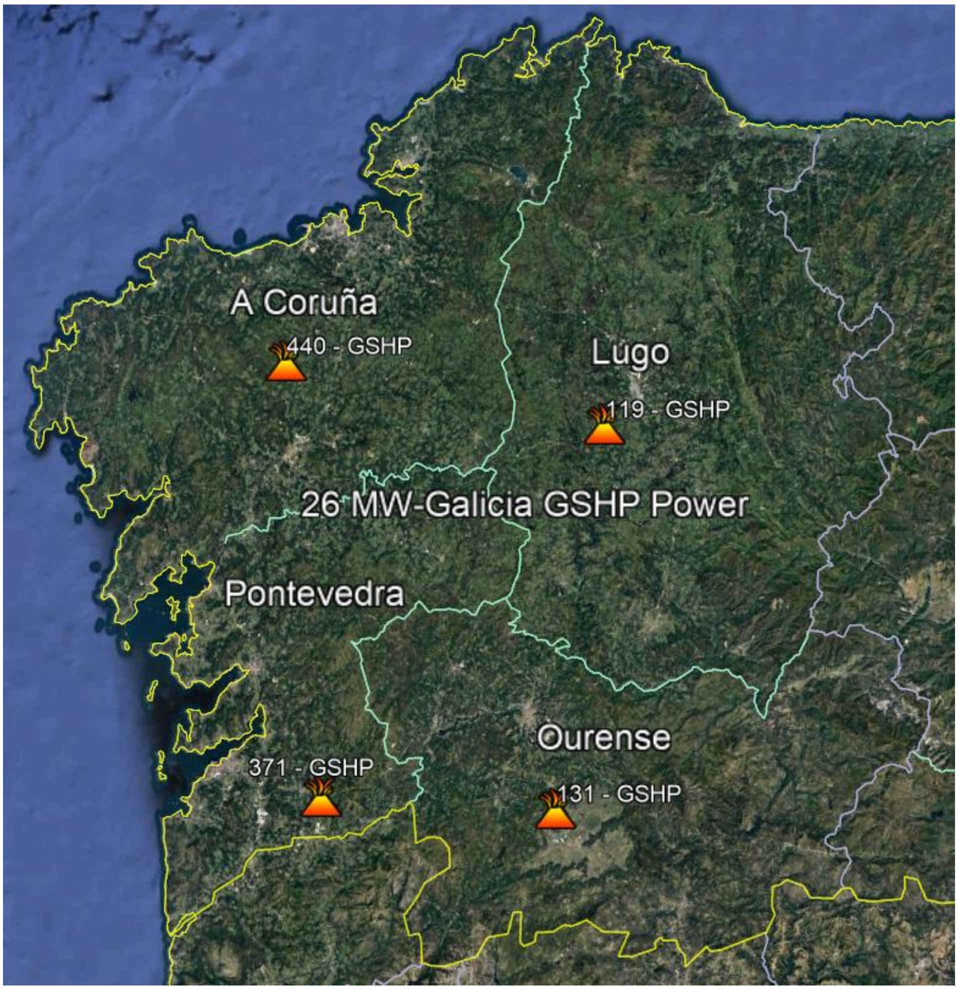
Table 15: Nº of GCS of low enthalpy in Galicia depending on the power (Source: ACLUXEGA).



Graphic 21: Evolution of geothermal installations in Galicia (Source: ACLUXEGA).



Graphic 22: Installed geothermal power: Galicia vs Spain (Source: ACLUXEGA).



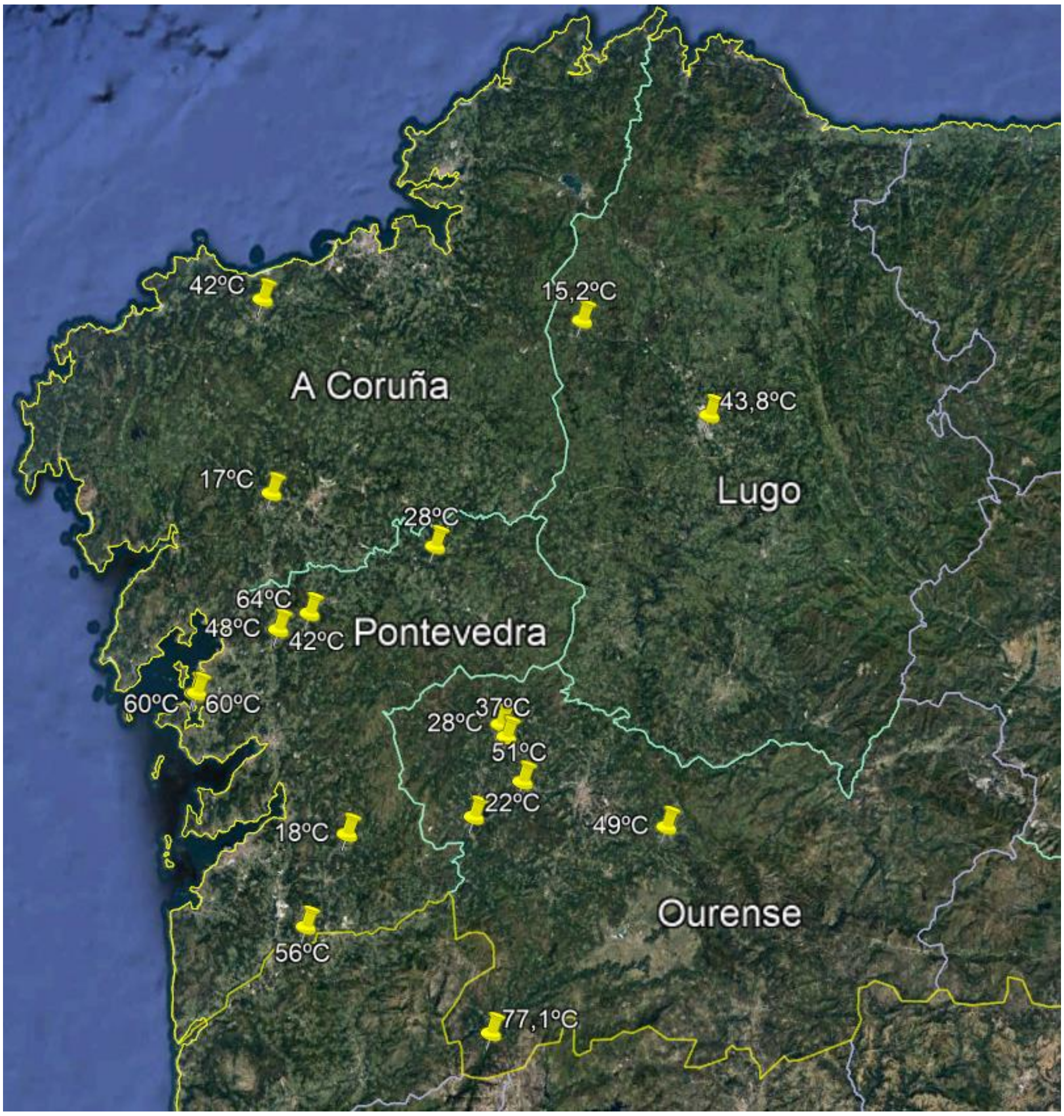
Graphic 23: Galician total GSHP power and number of GSHP per province (Source: EnergyLab).

On the other hand, there are several spas in Galicia located mainly in the provinces of Pontevedra and Ourense, where the geothermal resource is used in the form of hot springs.

SPA	WATER Tª (ºC)	ADRESS	WATER COMPOSITION
Arnoia Caldaria Hotel Balneario	22	Villa termal 1, 32417, Ourense, España.	Sulphurous waters - sodium, bicarbonate and magnesium.
Balneario Acuña	42	Rúa Ferreria 2, 36650, Pontevedra, España.	Chlorinated, silicate and bicarbonated chloride waters, thermal and sulfurous azoate, sodium - lithium and radioactive.
Balneario Baños da Brea	28	Lugar Paradela 4, 36583, Pontevedra, España.	Sulfuric, bicarbonated, alkaline and sodium chlorided waters.
Balneario Baños de Molgas	49	Rúa Samuel González Movilla 26, 32701, Ourense, España.	Radioactive, bicarbonated, sodium, silicate and

SPA	WATER Tª (ºC)	ADRESS	WATER COMPOSITION
			oligometallic waters.
Balneario Caldas de Partovia	37	Lugar Caldas 40, 32515, Ourense, España.	Waters are sulfated, sodium, chlorinated, bicarbonated and radioactive.
Balneario Davila	48	Avenida Pedro Mateo Sagasta 3, 36650, Pontevedra, España.	Chlorinated-sodium, radioactive, sulphurous and nitrogenous waters.
Balneario de Caldelas de Tui	56	Rúa Baños 65B, 36729, Pontevedra, España.	Chlorinated waters - sodium, sulfidic - azotylated and radioactive.
Balneario de Carballiño	28	Rúa de Astureses 42, 32500, Ourense, España.	Sulfur-sodium, alkaline, fluorine, lithium and radioactive waters.
Balneario de Carballo	42	Rúa Estrela 10, 15100, A Coruña, España.	Sulfur-bicarbonated sodium waters of weak mineralization.
Balneario de Compostela	17	Rúa de Vicente Ramos 7, 15280, A Coruña, España.	Cold sulphurous waters, sodium bicarbonated, silicate and fluorinated.
Balneario de Guitiriz	15,2	Avenida do Balneario 16, 27300, Lugo, España.	Sulphurous, fluorinated, sodium and radioactive waters.
Balneario de Lugo - Termas Romanas	43,8	27002, Lugo, España.	Sulfur-sodium, bicarbonated and hyperthermal waters.
Balneario de Mondariz	18	Avenida Enrique Peinador Vela 2, 36890, Pontevedra, España.	Carbogaseous, bicarbonated- calcium and ferruginous waters.
Gran Hotel La Toja	60	Rúa da Condesa 2 9, 36991, Pontevedra, España.	Chlorinated-sodium and fluoride, with high content of iron, lithium, magnesium, calcium and potassium along with other oligoelements.
Hotel Balneario Hesperia Isla de La Toja	60	Paseo do Mar, 36991, Pontevedra, España.	Chloride waters - sodium, brominated, ferruginous, fluorinated and lithic, rich in calcium, potassium and magnesium.
Laias Caldaria Hotel Balneario	51	Lugar Campo 8, 32459, Ourense, España.	Bicarbonated-sodium, alkaline, hyperthermal. Flow rate 8 liters / second.
Lobios Caldaria Hotel Balneario	77,1	OR-312 5, 32895, Orense, España.	Bicarbonate, sodium, chlorine, fluorine and silicates
Balneario Termas de Cuntis	64	Rúa do Balneario 1, 36670, Pontevedra, España.	Sulfur, sodium, fluoride, silicate and lithinic waters.

Table 16: Galician Spa's and rising water temperatures (Source: Aguas de Galicia).



Graphic 24: Insurgent water temperature of Galician spas (Source: EnergyLab).

5.5.2. Geothermal systems in the development phase

As indicated in the previous section, the use of geothermal energy in Galicia focuses solely and exclusively on resources of low and very low enthalpy for heating buildings and for thermal uses.

One of the objectives of this project is the implementation of a pilot project within the autonomous community that demonstrates new geothermal potentials in the region, taking advantage of geothermal resources of higher temperature than the one used so far.

As a starting point, the geothermal potential of the Iberian Peninsula corresponding to Spanish territory is analyzed below.

5.5.2.1. SPANISH GEOTHERMAL POTENTIAL

According to the studies carried out by the Geological and Mining Institute of Spain, Spanish territory has a propitious geological structure for the presence in the subsoil of geothermal resources. Different phenomena and geological facts thus attest:

- ✓ Abundant thermal manifestations, especially in the Mediterranean coastal strip.
- ✓ Persistent seismic activity.
- ✓ Formation of mountain ranges in recent eras and activity tectonics until today.
- ✓ Positive flow anomaly in the Levante and Southeast.
- ✓ Recent and current volcanism (Canary Islands, Olot, Southeast, Ciudad Real).

Throughout the studies carried out by the institute, the high interest of areas in Catalonia, Galicia, Ciudad Real, Cordillera Béticas, Canarias, Cuenca del Tajo, Cuenca del Duero, Pyrenees and the Ebro depression is highlighted.

As result of the investigations carried out, the following table of possibilities and expectations can be presented:

- **LOW TEMPERATURE WAREHOUSES (T <100 ºC)**

  The most promising areas are:

  - Tajo Basin: Madrid.
  - Eastern Area of the Duero Basin: Burgos and Valladolid.
  - Galicia: Areas of Ourense and Pontevedra.
  - Prebética and Iberian Area: Albacete and Cuenca.
  - Catalonia: Vallés, Penedés, La Selva, Ampurdán.
  - Internal Depressions of the Cordilleras Béticas: Granada, Guadix-Baza, Cartagena, Mula.

- **MEDIUM TEMPERATURE WAREHOUSES (100 ºC <T <150 ºC)**

  - Cordillera Béticas: Murcia, Almería and Granada (Lanjarón).
  - Catalonia: Vallés, Penedés, La Selva and Olot.
  - Galicia: areas of Orense and Pontevedra.
  - Central Pyrenees: Area of Jaca-Sabiñánigo.

- **TEMPERATURE AND DRY HOT ROCK STORAGE (T> 150 ºC)**

  - Canary Islands: Tenerife, Lanzarote, La Palma

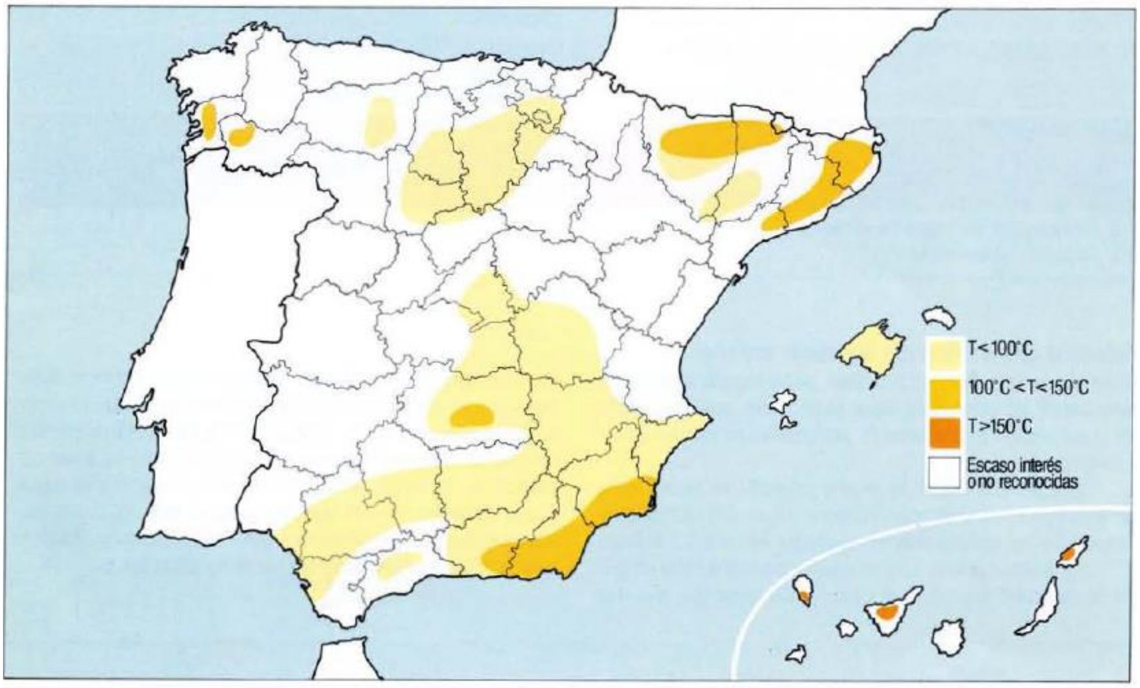


Illustration 31: Identification of geothermal energy stores in Spain based on their temperature (Source: Instituto Geológico y Minero de España).

Depending on the situation of the geothermal resources identified and the estimated storage temperature, possible geothermal uses are established in each of the areas of interest.

REGION	RESOURCE TYPE	APPLICATIONS
Galicia	Low-medium enthalpy T: 70·140 ºC D: 200 - 1.500 meters	Heating, Agriculture Electricity binary cycles Processes
Cuenca del Duero	Low enthalpy T: 60-90 ºC D: 1.500·2.500 meters	Heating Agriculture
Basin of the Ebro	Low enthalpy T: 60-90 ºC D: 1.400-2.000 meters	Heating Agriculture Industry
Catalonia	Law-medium enthalpy T: 70-140 ºC D: 300-2.500 meters	Heating Agriculture, processes Electricity binary cycles
Pirineo	Law-medium enthalpy T: 70-160 ºC P: 1.500-3.200 meters	Heating Processes Electricity binary cycles
Valley of the Ebro	Law enthalpy T: 60-75 ºC P: 1.300-1.800 meters	Heating Agriculture
Basin of tajo-La Mancha	Low enthalpy T: 60·90 ºC D: 1.500-2.500 meters	Heating Agriculture Processes

REGION	RESOURCE TYPE	APPLICATIONS
Betic mountain ranges	Law-medium enthalpy T: 60-140 ºC D: 400-2.500 meters	Agriculture Processes Electricity binary cycles
Canary Islands	Medium-high enthalpy Hot Dry Rock T: 150-300 ºC D: 20-2.000 meters	Electricity binary cycles Conventional electricity Desalination sea water
T = Estimate store temperature D = Estimated depth		

Table 17: Estimate of the Spanish geothermal resource vs possible applications (Source: Instituto Geológico y Minero de España).

6 Geothermal Technologies with potential for the AA

After what has been shown throughout this report, geothermal resources can be classified as follows:

Geothermal Resource	Temperature (ºC)	Technology	Applications
Very low enthalpy	5 - 25	GSHP[5]	Direct use Heating Cooling Hot water
Low enthalpy	25 - 50	GSHP	Direct use
	50 - 100		Direct use
Medium enthalpy	100 - 150	Binary cycles	Electricity Processes
High enthalpy	> 150	Binary cycles	Electricity
EGS[6] - HDR[7] (Not conventional)	> 150	Binary cycles	Electricity
Supercritical (Not conventional)	> 300		Electricity Hydrogen

Table 18: Types of geothermal resources as a function of temperature.

Taking into account the relationships listed in the previous table, the geothermal technologies used in each of the regions involved in this project are summarized below.

Region AA	Technology	Geothermal Resource	Tech situation
Bordeaux (France)	Geothermy on aquifer	VLE, LE	Market
	Heat pump on aquifer	VLE	Market
	Moderate loops	VLE	Market
	Vertical closed loop	VLE	Market
	Geothermal piles or thermoactive foundations	VLE	Market
	Waste heat from oil drilling	LE	Market
	Geothermal heat pumps	VLE, LE	Market
	Geothermal energy baskets	VLE	Development
	Horizontal sensors double	VLE	Development

[5] Ground Source Heat Pump

[6] Enhanced Geothermal System

[7] Hot Dry Rock

Region AA	Technology	Geothermal Resource	Tech situation
	layer disposed		
	Use of oil well in the end of life	LE, ME, HE	Development
	Power Plants - EGS	HE	Development
	CO_2 Dissolved	ME, HE	Development
	Geothermal simulations	VLE, LE, ME, HE	Development
	Micro seismic simulations	VLE, LE, ME, HE	Development
	Study of corrosion heat exchanges and brine composition in tubes	VLE, LE, ME, HE	Development
Scotland (UK)	Ground Source Heat Pump	VLE	Market
	Abandoned mine workings	VLE	Development
	Hot Sedimentary Aquifers	VLE	Development
	Hot Dry Rocks - EGS	LE	Development
Cork (Ireland)	Ground source heat pumps	VLE	Market
	Closed loop collector-Shallow geothermal resources	VLE	Development
	New ground source heat exchangers	VLE	Development
	Application to identify deep geothermal resources	ME, HE	Development
Mainland Portugal	Ground Source Heat Pump	VLE, LE	Market
	Spa	VLE, LE	Market
	Bottling		Market
	EGS	LE	Development
Açores - Portugal	Geothermal power Station	HE	Market
	Spa	LE	Market
	Cosmetic products	LE	Market
	Micro Binary Plants	LE, ME	Development
	Ground Source Heat Pump	VLE, LE	Development
Galicia (Spain)	Ground Source Heat Pump	VLE	Market
	Spa	VLE	Market
	Bottling		Market
	Low and medium temperature processes (District Heating, Agriculture, Electricity binary cycles, industrial processes)	LE, ME	Development

Region AA	Technology	Geothermal Resource	Tech situation

VLE: very low enthalpy
LE: low enthalpy
ME: medium enthalpy
HE: high enthalpy
Market: currently in the market
Development: technology still in development
EGS: Enhanced Geothermal System

Table 19: Technologies implemented and technologies under development in each of the GeoAtlantic Project partners.

With the provisions of this section, the technologies implemented and the technologies under development in each of the regions of the Atlantic Area linked to the GeoAtlantic Project are identified, thus fulfilling the main objective of task 6.1 of WP6.

7 Annexed 2 – References list

7.1. Tables index

7.2. Graphics index

7.3. Illustration index

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