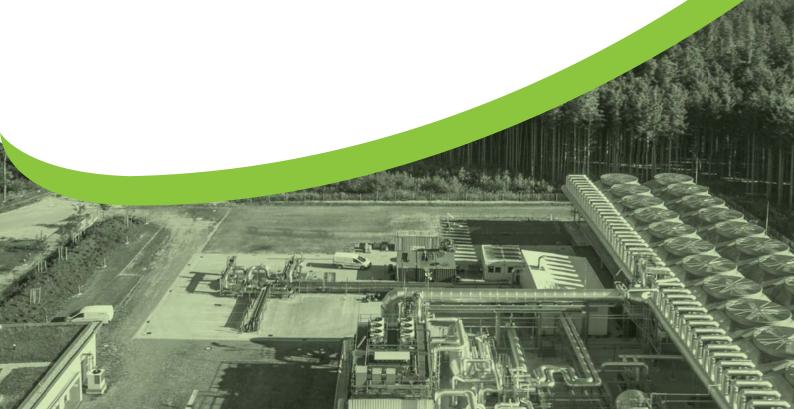


TOWARDS MORE GEOTHERMAL ELECTRICITY GENERATION IN EUROPE



TOWARDS MORE GEOTHERMAL ELECTRICITY GENERATION IN EUROPE

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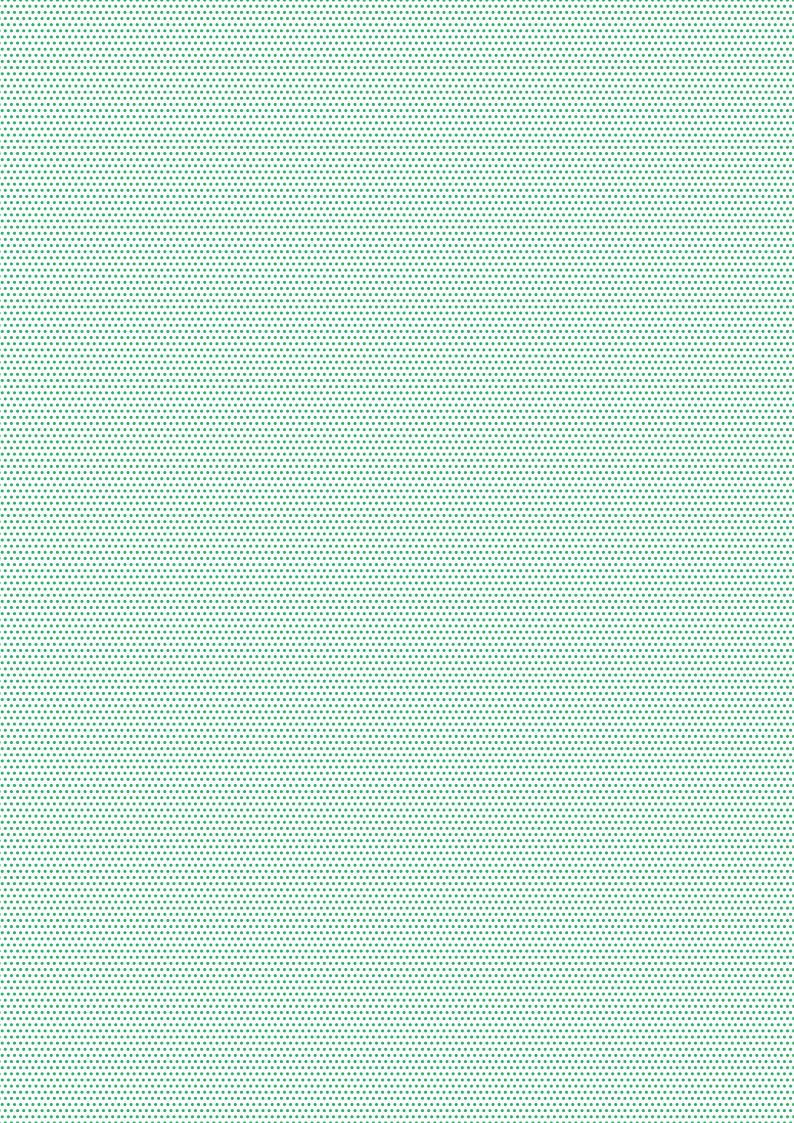
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LIST OF MAIN ABBREVIATIONS AND ACRONYMS USED

AND ACKONTMS USED		
AGEA	Australia Geothermal Energy Association	
CanGEA	Canadian Geothermal Energy Association	
CHP	Combined Heat and Power	
EIA	Environmental Impact Assessment	
EGEC	European Geothermal Energy Council	
EGRIF	European Geothermal Risk Insurance Fund	
EGS	Enhanced Geothermal Systems	
EU	European Union	
GHG	Greenhouse gas	
GIS	Geographical Information System	
HIP	Heat in Place	
HSA	Hot Sedimentary Aquifer	
LCoE	Levelised Cost of Energy	
NREAPs	National Renewable Energy Action Plans	
ORC	Organic Rankine Cycle	
PPA	Power Purchase Agreement	
RES	Renewable Energy Sources	
RES		
Directive	Directive 2009/28/EC on the promotion of the use of energy from renewable sources	
Rol	Return on Investment	
SPV	Special Purpose Vehicle	
TC	Theoretical Capacity	
TP	Technical Potential	
TPLCoE_p	Economic Technical Potential	

Water Framework Directive

WFD



Geothermal power generation has its roots in Europe, where the first test in 1904 and the real beginning of power generation in 1913 took place, both at the Larderello dry steam field in Italy. Since then, the development of geothermal technology has been continuous and the total installed capacity in Europe currently amounts to 1.8 GWe, generating approximately 11.5 TWh of electric power every year. For a decade, thanks to the optimisation of the new binary system technology, geothermal electricity can be produced using lower temperatures than previously. Moreover, with Enhanced Geothermal Systems (EGS), a breakthrough technology proven since 2007, geothermal power can in theory be produced anywhere in Europe.

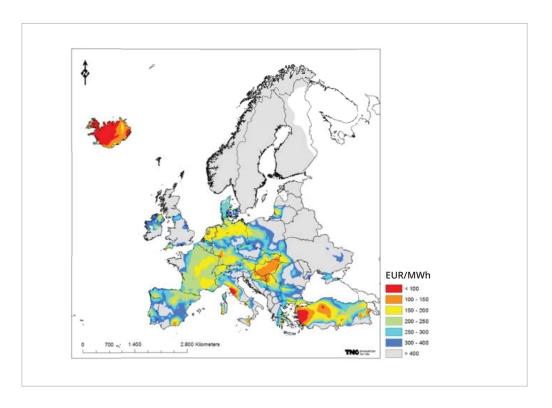
The main benefits of geothermal power plants are provision of base-load and flexible renewable energy, diversification of the energy mix, and protection against volatile and rising electricity prices. Using geothermal resources can provide economic development opportunities for countries in the form of taxes, royalties, technology export and jobs.

The potential of geothermal energy is recognised by some EU Member States in their National Renewable Energy Action Plans (NREAPs). However, the actual potential is significantly larger. In order to increase awareness, GEOELEC - an IEE project co-financed by the EU and running between 2010 and 2013- has assessed and presented for the first time the economic potential in Europe in 2020, 2030 and 2050. The figures are quite impressive, showing the large potential of geothermal and the important role it can play in the future electricity mix.

RESOURCE ASSESSMENT

The resource assessment is the product of the integration of existing data provided by the EU-28 countries and a newly defined methodology building on Canadian, Australian, and American methodology. The geological potential (heat in place) has been translated to an economical potential, using a Levelised Cost of Energy (LCoE) value of less than 150 EUR/MWh for the 2030 scenario and less than 100 EUR/MWh for the 2050 scenario:

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



Minimum LCoE in 2030 (in EUR/MWh)

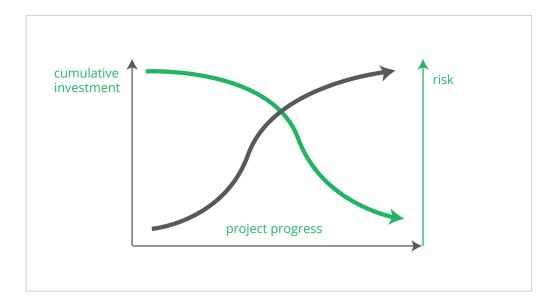
ECONOMICS AND FINANCE

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

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

- Support schemes are crucial tools of public policy for geothermal to compensate for market failures and to allow the technology to progress along its learning curve;
- Innovative financing mechanisms should be adapted to the specificities of geothermal technologies and according to the level of maturity of markets and technologies;

- A European Geothermal Risk Insurance Fund (EGRIF) is seen as an appealing public support measure for overcoming the geological risk;
- While designing a support scheme, policy-makers should seek a
 holistic approach, which exceeds the LCoE and includes system
 costs and all externalities. As an alternative, there is the chance to
 offer a bonus to geothermal energy for the benefits it provides to
 the overall electricity system, (e.g. balancing the grid).



In order to support the drafting of financial pre-feasibility studies for new projects, GEOELEC has built and now provides online free software for the first validation of geothermal power projects.

Furthermore, GEOELEC has studied issues relating to grid integration and has demonstrated how geothermal, being base load and flexible, can be integrated to the grid without technical problems and with negligible costs.

REGULATIONS AND PUBLIC ACCEPTANCE

The geothermal development promoted by the GEOELEC project must be done in a sustainable way. A regulatory framework for licensing procedures, ownership of the resources and competition for the use of the underground is necessary, but it must be streamlined. Regulatory barriers which can cause delays and increase costs for

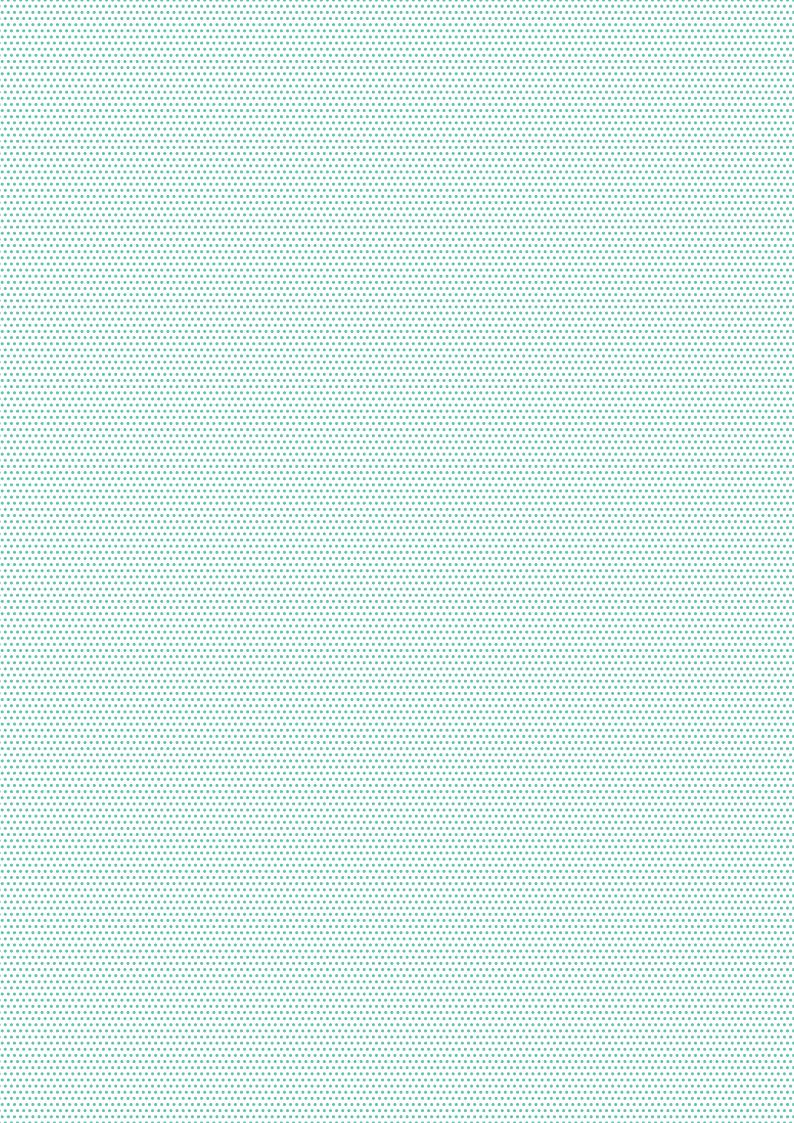
geothermal electricity projects still exist and have to be removed. The environmental impact of all infrastructure projects should be rightly considered, and environmental regulations are important tools for the development of geothermal electricity.

Such a sustainable development of the geothermal power sector would facilitate public acceptance. Lack of social acceptance can seriously damage the progression of geothermal developments and is an important issue to consider. Best practice shows that public acceptance is higher when project developers act openly and provide clear information which helps to create trust.

GEOTHERMAL ELECTRICITY ACTION PLAN FOR EUROPE

Based on the results of the project, the following recommendations are put forward:

- Create conditions to increase awareness about the advantages of this technology and its potential. National Committees on Geothermal promoting the technology to decision-makers and engaging the civil society to favour social acceptance should be established.
- Contribute to the economic competitiveness of Europe by providing affordable electricity. In order to progress along the learning curve and deploy at large-scale a reliable renewable technology, a European EGS flagship programme should be launched, including new demonstration plants and test laboratories: it should also look at new technologies, methods and concepts.
- Establish the economic and financial conditions for geothermal development:
 an EGRIF is an innovative option tailored to the specificities of geothermal to
 mitigate the cost of the geological risk and is a complementary tool to op erational support, still needed to compensate for the long-standing lack of a
 level-playing field.
- Enhance the education and training process, since multidisciplinary expertise
 and interaction of several disciplines are necessary. Create Networks for Geothermal Energy Education and Training involving industrial platforms, Universities and Research Centres developing a workforce for future geothermal
 development.
- Contribute to the development of the local economy. Create local jobs and establish a geothermal industry in Europe which will be able, by 2030, to employ more than 100,000 people (exploration, drilling, construction and manufacturing).





1 INTRODUCTION

Although geothermal energy has provided commercial base-load electricity around the world for more than a century, it is often ignored in national and European projections of energy supply. This could be a result of the widespread misperception that the total geothermal resource only relates to high-grade, hydrothermal systems that are too few and too limited in their distribution in Europe to make a long-term, major impact at a European/national level.

This perception has led to the undervaluing of the long-term potential of geothermal energy as the opportunity to develop technologies for sustainable heat extraction from large volumes of accessible hot rock anywhere in Europe has been missed. In fact, many attributes of the geothermal energy, namely its widespread distribution, availability 24 hours a day all year round, of having base-load ability without the need for storage and flexibility, small footprint, and practically zero greenhouse gas emissions, are desirable for reaching a sustainable energy future for the EU.

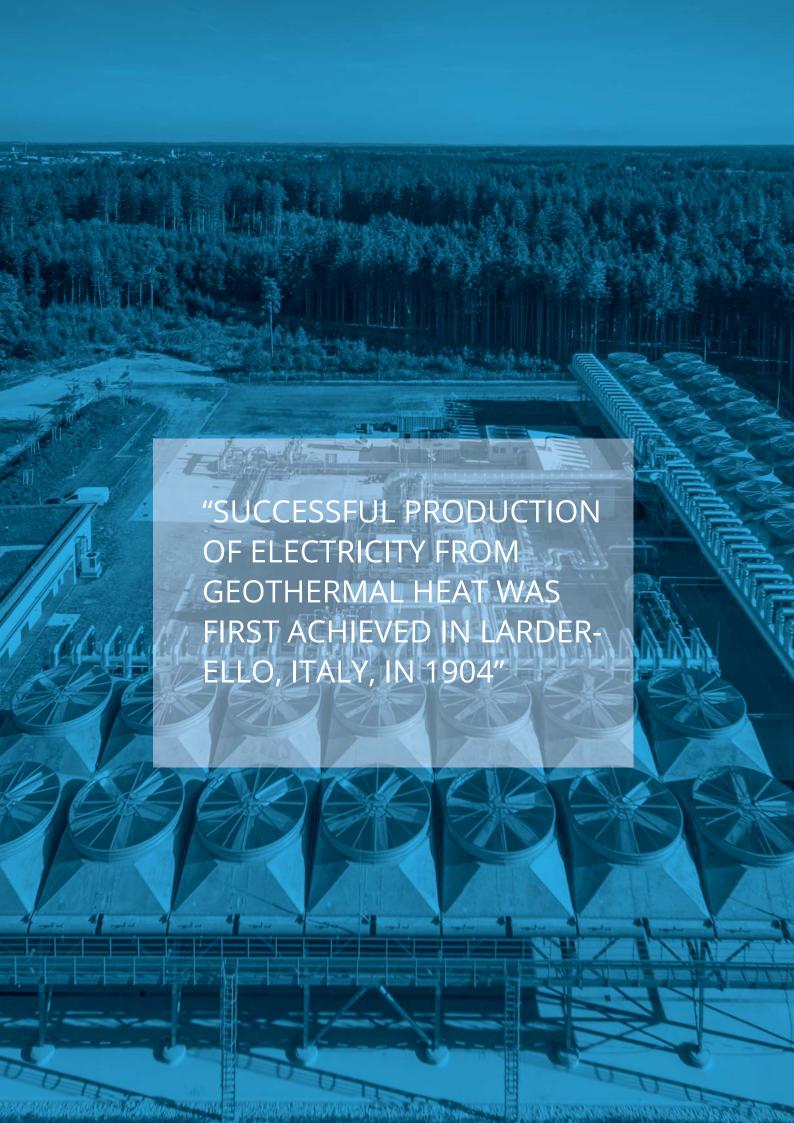
Realising the geothermal potential also requires an adequate regulatory framework and greater involvement of the private sector, however not all financial institutions and private investors are familiar with the complexity of geothermal technology, its challenges, and environmental and economic benefits.

The objective of GEOELEC, a project co-funded by the European Union through the Intelligent Energy Europe Programme, is therefore to inform decision-makers about the potential of geothermal electricity in Europe, to stimulate banks and investors in financing geothermal power installations and finally to attract key potential investors such as oil and gas companies and electrical utilities to invest in the sector.

The consortium (full list of the GEOELEC partners is provided in Annex II) covers 7 EU Member States, i.e. Belgium, France, Spain, Germany, The Netherlands, Italy, and Greece, and Iceland. However, the aim is to have an impact beyond the project countries.

This final report aims, among other things, to show the potential contribution of geothermal electricity in the entire EU and in some other countries such as Turkey, Iceland, and Switzerland for a short and mid-term perspective. Additionally, it presents all the other main results achieved during thirty months of work between 2011 and 2013 and puts forward recommendations for an action plan to remove financial, legal, social and environmental barriers, and to develop sufficient and adequate workforce. It thereby paves the way for the full realisation of the geothermal electricity potential in Europe.

2TECHNOLOGY: STATE OF PLAY AND DEVELOPMENTS



2.1 TECHNOLOGIES

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

Since then, the production of geothermal electricity has steadily increased, though has been concentrated in areas where hightemperature hydrothermal resources are available. The technological systems for geothermal electricity production can be subdivided in three broadcategories, which are linked to the temperature ranges:

Minimum production temperature: 80°C - 150°C (Medium Enthalpy resources): this range of temperature is appropriate for use with binary plants (Organic Rankine or Kalina cycle), with typical power in the range 0.1-10 MWe. These systems are also suitable for heat & power co-generation, typically for single edifice to small town heating;

Minimum production temperature: 150°C - 390°C (High Enthalpy resources): temperatures in this range can be exploited with dry steam, flash and hybrid plants, with typical power in the range 10-100 MWe. These systems also allow heat cogeneration for large towns' district heating. Above 200°C, these resources are generally limited to volcanic areas.

Minimum production temperature 390°C (Supercritical unconventional resources): temperatures in this range, limited to volcanic areas, generally involve superheated dry steam plants, with power per unit volume of fluid up to one order of magnitude larger than conventional resources.

Besides the temperature range, the methods of exploitation can be further subdivided in two categories: conventional (dry steam and flash steam turbines) and low temperature (binary) geothermal electricity.

CONVENTIONAL GEOTHERMAL ELECTRICITY: DRY STEAM AND FLASH STEAM TURBINES

Operating with large hydrothermal reservoirs at high temperature, i.e. above 150°C, such as those found in Tuscany (Italy) and Iceland, this technology has 100 years of history and is fully competitive today with a full cost of about 0.07 EUR/kWh including systems costs and externalities.

2.1 TECHNOLOGIES

FLASH: The high temperature, water at high pressure is brought to surface, where it is enters a low pressure chamber and 'flashes' into steam. The pressure created by this steam is channelled through a turbine, which spins to generate electrical power. Once the steam has exited the turbine, it is either released into the atmosphere as water vapour, or it cools back into liquid water and is injected back underground.

DRY STEAM: dry steam power plants utilise straight-forwardly steam which is piped from production wells to the plant, then directed towards turbine blades. Conventional dry steam turbines require fluids of at least 150°C and are available with either atmospheric (backpressure) or condensing exhausts.

Regrettably, it is very unlikely that new large geothermal reservoirs will be discovered in Europe. Therefore new projects need to be adapted to smaller and cooler resources.

LOW TEMPERATURE, HYDROTHERMAL GEOTHERMAL ELECTRICITY: BINARY: ORC AND KALINA CYCLE

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

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

2.1 TECHNOLOGIES

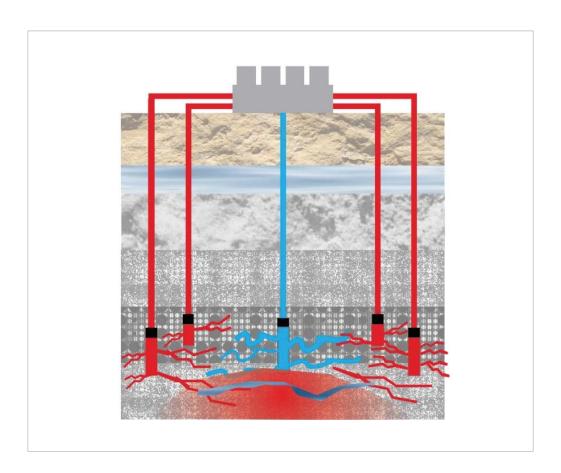
BEYOND HYDROTHERMAL: ENHANCED GEOTHERMAL SYSTEMS – EGS

Geothermal energy has the potential to make a more significant contribution to the European electricity mix through the development of advanced technologies, especially the development of hot rock resources using EGS techniques that would enable thermal energy recovery from outside of traditionally favourable regions.

An EGS is an underground reservoir that has been created or improved artificially. The EGS concept is going to greatly increase geothermal potential as it allows for the production of geothermal electricity nearly anywhere in Europe with medium and low temperature.

This concept involves:

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



An Enhanced Geothermal System (EGS)

2.2 BENEFITS OF GEOTHERMAL ELECTRICITY PRODUCTION

A BASE LOAD AND FLEXIBLE RENEWABLE ENERGY SOURCE (NO INTERMITTENCY)...

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

But geothermal electricity is also flexible as it can be ramped up or down on demand, thereby contributing to the stability of the grid. Furthermore, geothermal plants can be productive for many years. Typically they have a 30 to 50 year life span before the equipment wears out. Indeed the world's first geothermal power plant at Larderello, Italy was commissioned in 1913 and is still productive.

ENSURING PRICE STABILITY...

Developing and utilising geothermal resources for electricity can help to protect against volatile and rising electricity prices (Figure 2.1). The costs for fuels used to generate electricity influence the final price of the electricity produced. On the one hand, fossil fuels have traditionally been low price, but their costs are increasing. On the other hand, the costs of geothermal power mainly depend on capital costs, as the fuel is free of charge and operation and maintenance costs are very limited. Emerging geothermal technologies hold significant potential for cost reduction and will reach full competitiveness in 2030.

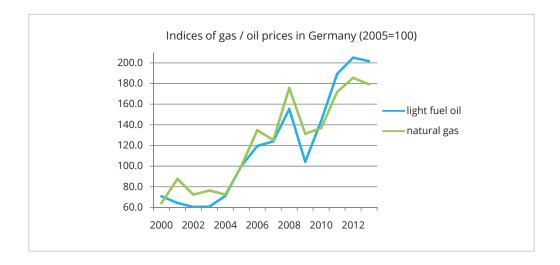


Figure 2.1: Development of energy prices in Germany
Source: Destatis

INCREASING SECURITY OF SUPPLY...

As a renewable and domestic resource, geothermal enables a diversification of the electricity mix. Making use of this local source of energy reduces the amount of fuel that countries have to import and thereby increases their security of supply.

2.2 BENEFITS OF GEOTHERMAL ELECTRICITY PRODUCTION

SCALABLE...

Geothermal power production is scalable. It is possible to have a very small geothermal project, for instance owned and run by a municipality, so it is necessary to have scale specific policies in place.

PROVIDING CLEAN ELECTRICITY...

All human activity has an impact on nature, but compared to other energy sources, Geothermal has a negligible environmental footprint (see GEOLEC report "Environmental study on geothermal power"). Indeed, Geothermal power systems involve no combustion. Therefore they emit only a small amount of greenhouse gases; if one takes ${\rm CO_2}$ as a benchmark, then geothermal closed-loop-binary plants emit 0 ${\rm CO_2}$. Furthermore, Geothermal power plants produce only a small amount of air emissions compared to conventional fossil fuels, and unlike other renewable energies such as solar or biomass, have very small land-use footprint.

OR COMBINED HEAT AND POWER...

In a combined process the geothermal resources can be used to generate electricity and heat. Producing heat and electricity means optimising the efficiency factor of the energy production and upgrading cash flows. There are many types of direct use applications for the geothermal heat: greenhouses, aquaculture, industrial processes, agricultural processes, baths and spas, and district heating and cooling.

... AND SUPPORTING LOCAL AND SUSTAINABLE ECONOMIC DEVELOPMENT

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

BENEFITS OF GEOTHERMAL ELECTRICITY

- A BASE LOAD AND FLEXIBLE RENEWABLE ENERGY SOURCE
- ENSURING PRICE STABILITY
- INCREASING SECURITY OF SUPPLY
- SCALABLE
- PROVIDING CLEAN ELECTRICTY
- OR COMBINED HEAT AND POWER
- AND SUPPORTING LOCAL AND SUSTAINABLE ECONOMIC DEVELOPMENT

2.3 MARKET DEVELOPMENT

Geothermal electricity in Europe is growing continuously, not only in traditional areas but also in areas with low-medium temperature resources through the utilisation of binary plants technologies. Indeed, after some years of slower paced development in Europe, the geothermal electricity market has seen a renewed momentum in the last 5 years.

Currently there are 68 geothermal power plants in 6 European countries (Italy, Iceland, Turkey, Portugal, France, Germany, and Austria) for a total installed capacity now amounting to around 1.8GWe, producing some 11terawatt-hours (TWh) of electric power every year (EGEC Market Report 2013/2014).

According to the EGEC Geothermal Market Report 2013 there are 74 projects currently under development in Europe, which would increase the total installed capacity to a total of 2.7GWe in 2017. In addition, 144 projects are now being explored. Figure 2.2 depicts the installed and projected geothermal power plants in Europe up to 2020.

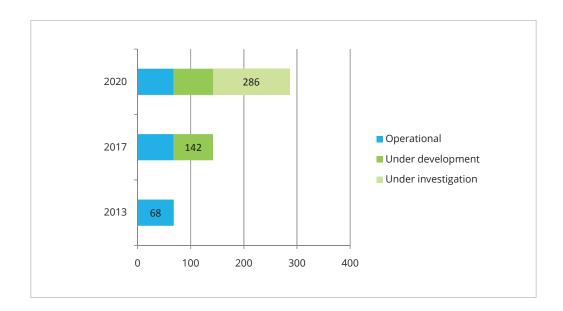


Figure 2.2: Number of geothermal power plants in Europe. Source: EGEC Geothermal Market report 2013/2014

Italy dominates the market with more than 50% of the European capacity, i.e. 875 MWe. After the liberalisation of the Italian geothermal market (legislative decree n. 22, 2010), more than 130 applications for research permits for geothermal exploitation and development have been submitted. Many new players are now operating in exploration activities, preparing for the future development of geothermal energy in the country. Iceland has installed 7 power plants representing a capacity of 662 MWe. Nearly 300 MWe are currently being developed with 5 new projects. In addition 5 more projects are being investigated, notably one, the Iceland deep drilling project, which could provide a very large amount of electricity if successful in exploiting supercritical resources.

In Turkey, the market is booming. According to the projects under development and investigation, the installed capacity should grow from 242 MWe today (10 plants) to triple by 2017and to reach 1GWe in 2020.

2.3 MARKET DEVELOPMENT

France (Guadeloupe) and **Portugal** (Açores) have been developing geothermal electricity power plants on Atlantic islands since the 1980s; this development is continuing with the GeothermieBouillante 3rd unit and the Pico Vermelho plant for 2016. France is the home of the first EGS pilot project (Soultz) which was inaugurated in 2008.At least 12 other EGS projects are being investigated with more and more permits for research and exploration being awarded by the government.Figure 2.3 shows a breakdown of the current and expected installed capacity in Europe by country.

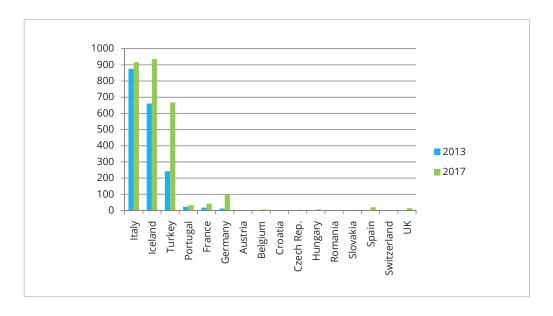


Figure 2.3: Breakdown of installed capacity in Europe by country (MWe). Source: EGEC Geothermal Market report 2013/2014

But what is worth highlighting is that geothermal electricity is developing beyond traditional geothermal countries. In Germany, with the inauguration of 3 new geothermal plants in 2013, there are now 8 plants in operation representing a capacity of 28 MWe. Several geothermal power projects are expected to be commissioned in the next years. A total of 15 projects are under development and 28 under investigation, most of which are concentrated in Bavaria and in the Upper Rhine Graben area. According to the EGEC Market report 2013/2014,in total geothermal power development in Germany can be estimated to reach about 180-190 MWe installed capacity by the end of 2020.

Greece is another important newcomer in the geothermal electricity market with 13 projects being investigated, mainly on the Greek islands. They are expected to become operational by 2019.

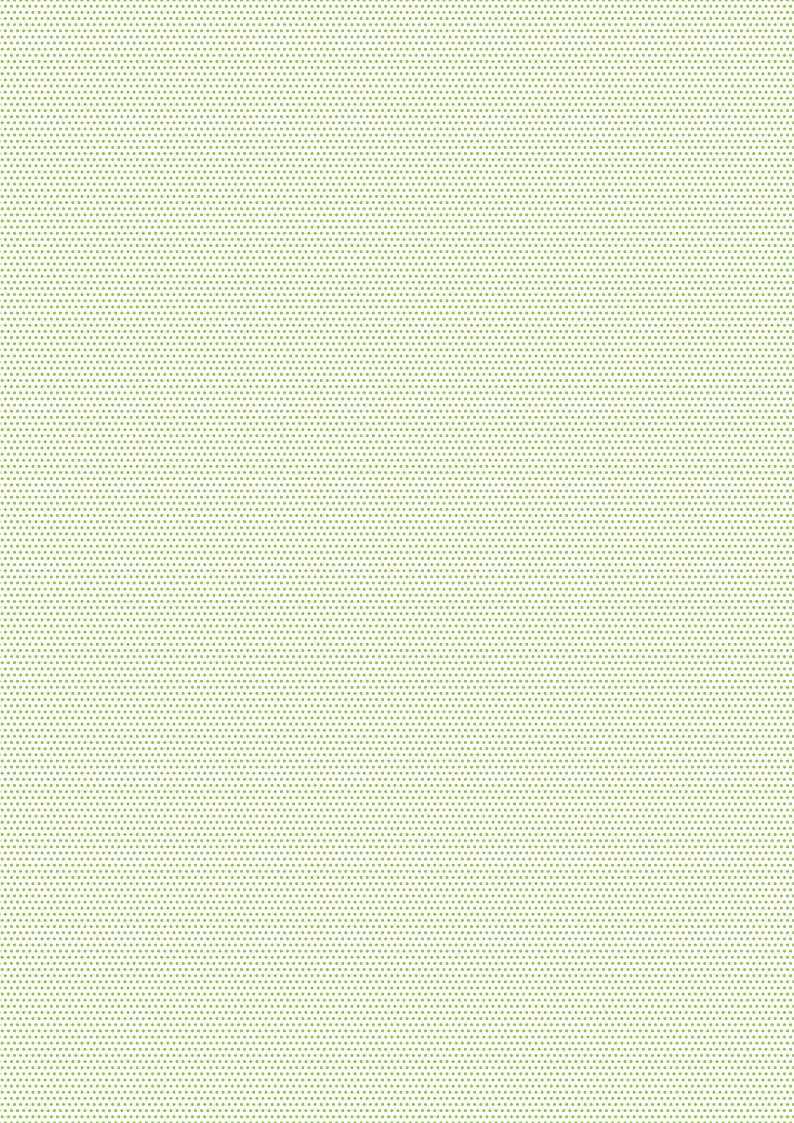
Finally, some 40 EGS projects are being developed or investigated in Belgium, Croatia, Czech Republic, France, Germany, Hungary, Latvia, Romania, Slovenia, Spain, Switzerland and the United Kingdom.

REFERENCES:

- EGEC Market Report 2012
- EGEC Market Report 2013/2014

GEOELEC Deliverables:

Investment Guide



3 GEOTHERMAL RESOURCE BASE ASSESSMENT IN EUROPE



cKelvey (Figure 3.1) and project approach: Key to resource assessment and classification is the concept of the McKelvey diagram, and a project oriented approach in which resources develop progressively from being inferred at an early exploration stage towards becoming discovered after drilling and finally economically recoverable at the production stage. In the exploration the transition from an inferred (undiscovered) to a discovered resource is determined by drilling the reservoir, which is can prove the presence of the resource and to appraise the productivity.

Plays, leads and prospects (Figure 3.2): In the geothermal exploration workflow prior to drilling, the identification of a prospective reservoir location starts off with a so-called play concept. A geothermal play is a geographically (and in depth) delimited area where specific subsurface conditions allow the obtaining of a sufficiently high flow rate of a sufficiently high temperature, with suitable pressure and chemical conditions. A lead is a particular subsurface reservoir which has been identified by surface exploration studies (e.g. MT). A prospect is a location which has been studied thoroughly by surface exploration and has been earmarked to be drilled.

Conversion efficiency and power (Figure 3.3)

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

Tx = production temperature [C]

Ts = average surface temperature [C]

 η_c = relative efficiency compared to carnot efficiency [-]

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

Q = flow rate [m3/s]

Tr = re-injection temperature [C]

 ρ_{fluid} = fluid density [kg/m3]

 c_{fluid} = fluid specificheat [J/kg/K]

The first equation is based on Tester et al. (2006) and Di Pippo (2008). Their analysis shows that for a large variety of conversion designs covering a spectrum from using produced steam directly to drive turbines (flash) as well as binary systems, that = 0.6 (Figure 3.4).

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

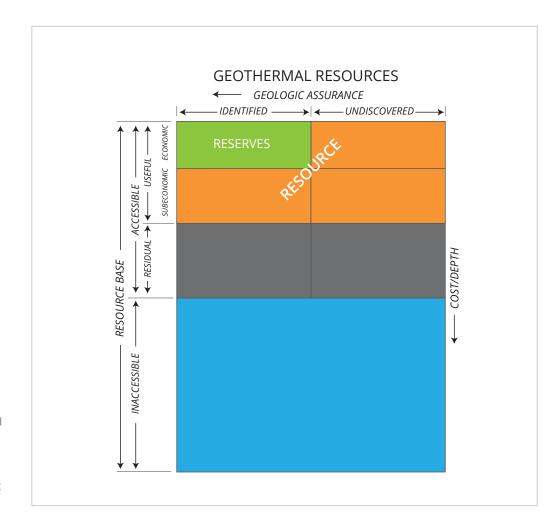
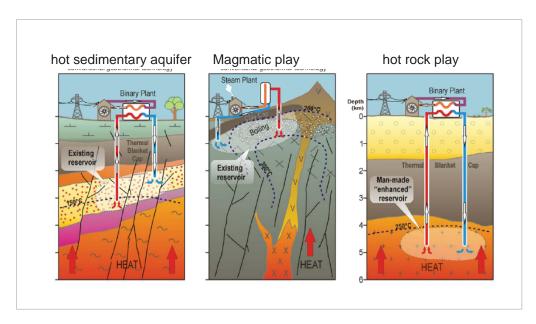


Figure 3.1: McKelvey diagram representing geothermal resource and reserve terminology in the context of geologic assurance and economic viability (from Williams et al., 2008)

Figure 3.2: Example of different play types for geothermal systems (modified from Hot Rock ltd). Hot sedimentary aquifers and magmatic plays can be mostly developed without enhancing the reservoir, relying on natural aquifer and fracture permeability. Magmatic plays can generally produce very high temperatures at shallow depth. Low permeable rock plays are located in regions of elevated temperatures (caused by radiogenic heat production, elevated tectonic heat flow, or vertical heat advection trough deep fault zones).



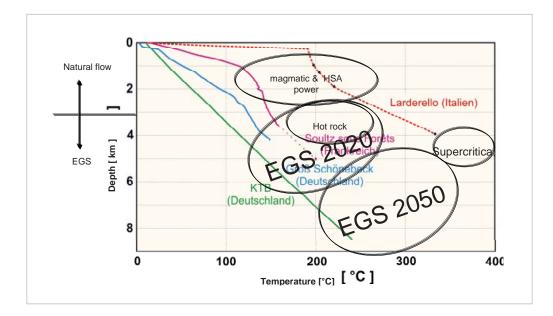


Figure 3.3: Relative positioning in depth and temperature gradients of the different play types, and positioning of EGS development (hot rock/EGS correspond to low permeable rock. HSA to hot sedimentary aquifers (which can also be located deeper up to 4km).

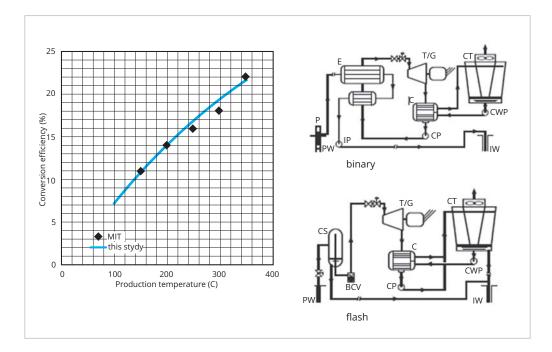


Figure 3.4: Practically achieved conversion efficiencies of various geothermal production installations (left), including both binary and flash systems (right) (after Tester et al., 2006). The best fit curve fitting eq.1 for Ts =10C is achieved with η_c =0.6.

THE HYDROCARBON BEST PRACTICE

Resource classification in the hydrocarbon industry is very mature and serves as an excellent starting point for geothermal classification and reporting. The publication of Etherington and Ritter (2007; Figure 3.5) forms the latest extension of the Petroleum resource management system accepted by oil and gas industry. Here we summarise the main aspects of the classification scheme which can be useful for geothermal en-

ergy. It should be emphasised that geothermal resources in geothermal systems differ from both minerals and petroleum resources as they are renewable through recharge, albeit usually at a slower rate than that at which energy is extracted. The rate of this recharge can vary significantly from system to system, and can be stimulated to a varying degree by production.

Prospective Resources are those quantities estimated to be commercially recoverable from yet unexplored accumulations assuming a discovery is confirmed. While there is always a grey area, a discovery is declared in the oil and gas industry when results of one or more exploratory wells support existence of a significant quantity of potentially moveable hydrocarbons. Geothermal resources are also confirmed through drilling. Discovered quantities should be initially classified as Contingent Resources. The portion of these quantities that can be recovered by a defined commercial project may then be reclassified as Reserves. Commerciality requires that the project form part of an economic venture and an organisation claiming commerciality has a firm intention to develop and produce these quantities. Firm intention implies that there is high confidence that any current constraining contingencies will be overcome and that development will be initiated within a reasonable time frame. A reasonable time frame for the initiation of development depends on the specific circumstances and varies according to the scope of the project. In oil and gas industry five years is recommended as a benchmark, however in geothermal development and especially EGS a longer time frame may be applied.

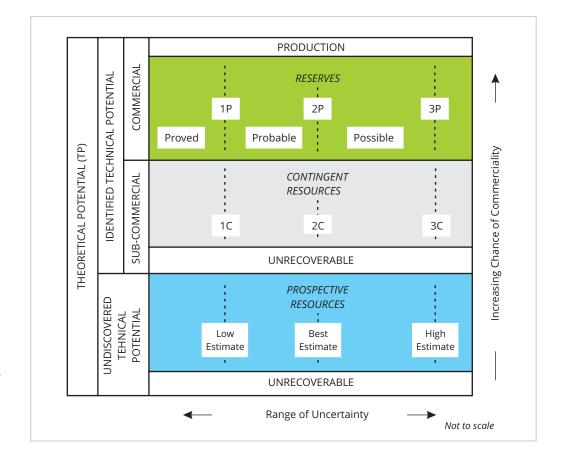


Figure 3.5: uncertainty ranges for resource and reserves estimates, and commerciality axis of projects moving them up from prospective resources to contingent resources to reserves (from Etherington and Ritter, 2007). 1,2,3 relates to levels of uncertainty representing low, mid, and high estimates respectively.

3.2 RESOURCE ASSESSMENT METHODOLOGY IN GEOELEC

Resource assessment in GEOELEC is focused on prospective resources. Reporting can be subdivided in three levels (Figure 3.6):

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

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

Figure 3.6: Representation of the various levels of resource categorisation progressing from global (level 1), to prospect based (level 2), to drilling and production (level 3).

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

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

¹ However, it can be problematic to gather and disclose publically confidential information from private industry. A minimum period of non-public disclosure applies to the most recent or ongoing geothermal projects. For each of these projects authorisation from several private organisations (owner, contractor, sub-contractor) will have to be requested. A regulatory framework on that matter will have to be developed, for instance by the International Geothermal Association, similar to what may already be in force in mining and hydrocarbon explorations.

3.2 RESOURCE ASSESSMENT METHODOLOGY IN GEOELEC

other countries in Eastern Europe. The area is delineated in Figure belowshowing the temperature model.

For each sub volume theoretical to practical potential is calculated, schematically illustrated in Figure 3.7 of the schematic workflow going from theoretical potential to realistic TP. These calculations are performed for each sub volume of the grid. The calculations are detailed below.

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

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

where

V = volume [m3] of the subsurface subvolume

 ρ_{rock} = Density = 2500 kg m-3

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

Tx = temperature at depth in the subvolume

Ts = temperature at surface

The map of HIP [PJ/km²] is calculated as the vertical sum of the vertically stacked subvolumes divided over the surface area of the grid cells in km².

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

TC=H * η

where

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

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

- To obtain a Theoretical potential map the values in the 3D-grid are vertically summed.
- For heat production Tr is significantly lower than for electricity production

Technical potential:

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

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

3.2 RESOURCE ASSESSMENT METHODOLOGY IN GEOELEC

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

$$R=R_{av}R_{f}R_{TD}$$

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

WE PROPOSE TO USE THREE DIFFERENT LEVELS OF TP:

- TPtheory: this is the maximum possible (theoretical) technical potential (R=1.00)
- TPreal: realistic underground Technical Potential according to typical predictive reservoir engineering approaches and empirical practice. This is the equivalent of R_f*R_{TD} in Beardsmore et al., 2012. According to BeardsmoreR $_f$ is on average 0.14. R_{TD} is estimated at 90%, resulting in R=0.125. For geothermal aquifers in the Netherlands R is estimated to be 33%
- TPbm: Technical Potential according to Beardsmore et al., 2010 (R=0.01)

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

3.2 RESOURCE ASSESSMENT METHODOLOGY IN GEOELEC

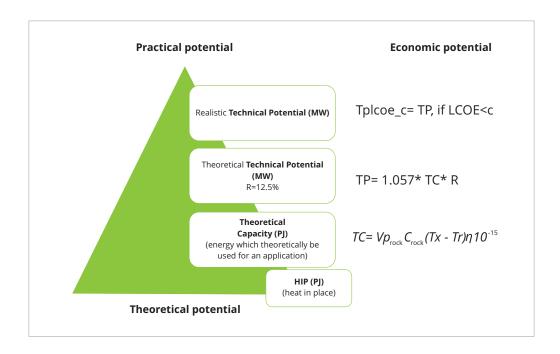


Figure 3.7: Schematic workflow to go from theoretical potential to realistic technical potential.

For the maps the sub volume results are vertically summed, and subsequently divided over the area of the grid cell in km². The following maps have been calculated

MAP	NAME	UNIT
HIP	Heat in place	PJ/km²
TC	Theoretical capacity	PJ/km²
TPtheory	Theoretical Technical Potential (R=1)	MW/km²
TPbm	Technical Potential according to Beardsmore et al., 2010 (R=0.01)	MW/km²
TPreal	Technical Potential (R=0.125)	MW/km²
TPLCoE_c	Realistic Technical Potential (LCoE <c) adopting="" td="" tpreal<=""><td>MW/km²</td></c)>	MW/km²

Table 3.1: Type of potential maps in the information system

MAP	NAME	UNIT
LCoE	Minimum LCoE in a vertical stack of the 3D grid	EUR/MWh
LCoEDEPTH	Depth of the Minimum LCoE in a vertical stack of the 3D grid	km

Table 3.2: Additional maps based on the 3D grid calculations

3.2 RESOURCE ASSESSMENT METHODOLOGY IN GEOELEC

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

LCOE ANALYSIS AND SENSITIVITIES

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

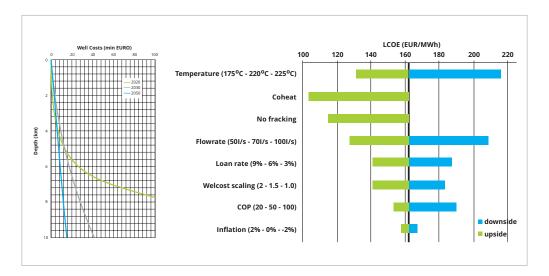


Figure 3.8: Well costs (for EGS 2 wells have been assumed) and sensitivities of predicted LCoE to input parameters for the 2030 scenario at a potential EGS location at 5 km depth with forecasted resource temperature of 200°C.

UNCERTAINTY AND CHP

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

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

TEMPERATURE MAPS

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

3.2 RESOURCE ASSESSMENT METHODOLOGY IN GEOELEC

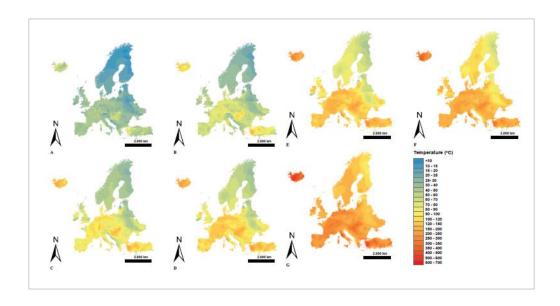


Figure 3.9: Modelled temperature at 1, 2, 3, 4, 5, 7, 10km depth

3.3 GEOTHERMAL POWER ECONOMIC POTENTIAL IN THE EU

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

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

These chosen cut-off values only represent the economic boundaries for the prospects. But also on the technical side of the scenarios developments are defined which favour the prospects. The assumptions are shown in the Table below. The maximum depth range increases, due to assumed improved drilling techniques, from 7 kilometres depth to 10 kilometres depth in 2050. Also the flow rates increase due to better stimulation techniques from 50 L/s to 100 L/s in 2050. As the effect of stimulation increases in flow rate, the costs for stimulation of a project remain the same: EUR10Mio. To reach the maximum drilling depths, improvements in drilling techniques lead to a different, more beneficial well cost model. Where the well cost model increases exponential with depth in 2020, it is assumed to be less depth dependent in 2050, resulting in a more linear relation. The efficiency in both the system and in conversion increases.

The coefficient of performance increases from 30 in 2020 to 50 in 2030 and 1000 in 2050. The relative Carnot efficiency² increases from 60% in the near future to 70% in 2050. In addition the use of heat to convert to electricity is more efficient and the CHP outlet remains equal.

PARAMETER	UNIT	2020	2030	2050
Maximum Depth	km	7	7	10
Flow Rate	L/s	50	70	100
COP	-	30	50	1000
Well Cost Model	-	Wellcost Scal- ing 1.5 + Expo- nential	Wellcost Scal- ing 1.5	Linear 1500 EUR/m
Stimulation Costs	EUR Mio.	10	10	10
Relative Carnot Efficiency	-	0.6	0.6	0.7
Tinc for Tr (Tr=Tsurface + Tinc)	оC	80	80	50
CHP outlet	٥C	35	35	35

² A theoretical thermodynamic cycle proposed by Nicolas Léonard Sadi Carnot in 1823. It can be shown that it is the most efficient cycle for converting a given amount of thermal energy into work. A relative carnot efficiency is a percentage compared to the carnot efficiency with around 150 °C

Table 3.3: Assumptions for the prospective study (COP = Coefficient of Performance | CHP = Combined Heat and Power)

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

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

Table 3.4: Overview of cut-off values for the defined scenarios

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

SCENARIO	2020	2030	2050		
	LCoE	LCoE	LCoE		
	LCoEDEPTH	LCoEDEPTH	LCoEDEPTH		
MAPS	TP for cut-off lower than 300EUR/MWh	TP for cut-off lower than 200EUR/MWh	TP for cut-off lower than 150EUR/MWh		
	TP for cut-off lower than 200EUR/MWh	TP for cut-off lower than 100EUR/MWh	TP for cut-off lower than 100EUR/MWh		
	TP for cut-off lower than 100EUR/MWh	TP for cut-off lower than 50EUR/MWh	TP for cut-off lower than 50EUR/MWh		

Table 3.5: Overview of available maps in the report (for all maps produced in this project, go to www.thermogis.nl/ geoelec (TP = Technical Potential)

COUNTRY OUTLOOKS

At this point the scenarios are described and the maps of Europe presented. The question which logically may arise is what that means per country. Hereby we present the outlook per country, both in a chart displaying the potential per country for 2020, 2030 and 2050.

The table below shows the potential per country in TWh for the 2020, 2030 and 2050 scenarios. Thisis the economic potential based on the above mentioned assumptions and no application of co-heat (for the effects of the application of co-heat, see next chapter). For the chosen scenarios we assume an LCoE of less than 200 EUR/MWh for 2020, of less than 150 EUR/MWh for the 2030 scenario of less than 100 EUR/MWhand for 2050.

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

COUNTRY	ECONOMIC POTE				
	2020	2030	2050		
ANDORRA	0	0	1		
AUSTRIA	0	0	67		
BELARUS	0	0	2		
BELGIUM	0	0	22		
BOSNIA AND HERZEGOVINA	0	0	25		
BULGARIA	0	0	72		
CROATIA	1	3	50		
CYPRUS	0	0	0		
CZECH REPUBLIC	0	0	31		
DENMARK	0	0	29		
ESTONIA	0	0	2		
FINLAND	0	0	0		
FRANCE	0	0	653		
GERMANY	0	1	346		
GREECE	0	0	81		
HUNGARY	9	17	174		
ICELAND	73	74	322		
IRELAND	0	0	27		
ITALY	11	12	226		
LATVIA	0	0	3		
LITHUANIA	0	0	19		
LUXEMBOURG	0	0	3		
MACEDONIA	0	0	10		
MOLDOVA	0	0	2		
MONTENEGRO	0	0	2		
NORWAY	0	0	0		
POLAND	0	0	144		
PORTUGAL	0	0	63		
ROMANIA	0	0	105		
SERBIA	0	1	92		
SLOVAKIA	0	1	55		
SLOVENIA	0	0	8		
SPAIN	0	1	349		
SWEDEN	0	0	1		
SWITZERLAND	0	0	43		
THE NETHERLANDS	0	0	52		
TURKEY	50	62	966		
UKRAINE	0	0	71		
UNITED KINGDOM	0	0	42		

Table 3.6: Economic
Potential per country
(2020 = LCOE < 200 EUR/
MWh; 2030 = LCOE < 150
EUR/MWh; 2050 = LCOE <
100 EUR/MWh). **Based on currently available data**

COMBINED HEAT & POWER (CHP)

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

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

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

MAPS

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

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

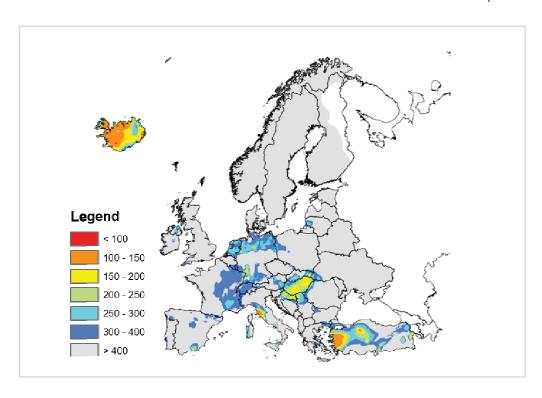


Figure 3.10: Minimum LCoE in 2020 (in EUR/MWh)

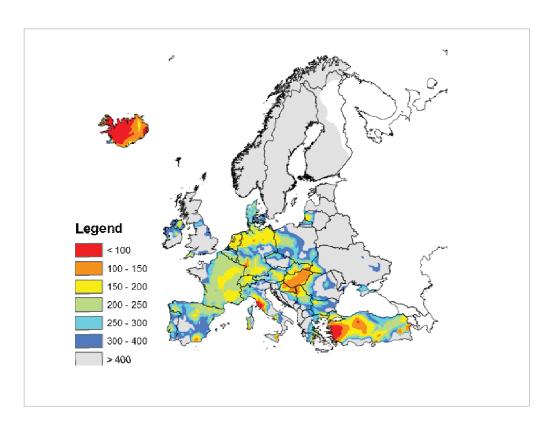


Figure 3.11: Minimum LCoE in 2030 (in EUR/ MWh)

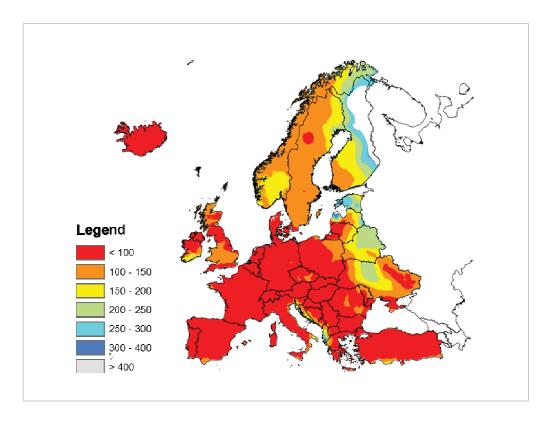


Figure 3.12: Minimum LCoE in 2050 (in EUR/ MWh)

3.4 WEBGIS

A smentioned in the previous chapter, all produced maps are available through the webGIS portal: www.thermogis.nl/geoelec. A preview of the viewer can be seen below, accompanied by instructions how the use the viewer.

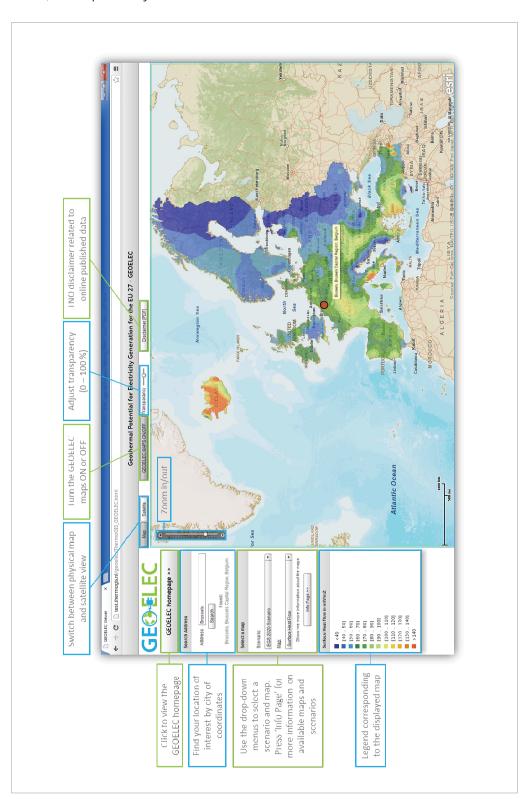


Figure 3.13: Preview and description of the GEOELEC online potential viewer

Whether or not there should be a specific European Geothermal Reporting Code is a question currently being discussed in the European geothermal industry. This section includes the history, basis and description of the existing Geothermal Reporting Codes, a discussion of the objectives, the pros and cons of having a specific European Geothermal Reporting Code and finally presents the GEOELEC recommendation for Europe.

CURRENT SITUATION AND DISCUSSION OF PROS AND CONS

The existing Australian and Canadian Geothermal Reporting Codes build upon the International Reporting Template from the Committee for Mineral Reserves International Reporting (CRIRSCO) that was first published in 2006. Key elements of the Australian Code were adopted and formed the basis of the Canadian Code.

A Geothermal Reporting Code can serve the following purposes:

- Facilitate understanding, confidence and reputation in the market place with investors, regulators and the public
- Provide a standardised reporting basis of geothermal energy information that is satisfactory to investors, shareholders and capital markets
- Be applicable for all geothermal plays on local and international market

ANY OF SUCH CODES SHOULD COMPLY WITH THE FOLLOWING PRINCIPLES::

TRANSPARENCY - the reader of any public report should be provided with sufficient information, clearly and unambiguously presented, to understand the report and not be misled.

MATERIALITY - This requires that a public report contains all the relevant information which investors and their professional advisers would reasonably require, and reasonably expect to find in the report, for the purpose of making a reasoned and balanced judgment regarding the material being reported.

COMPETENCE - This requires that the public report be based on work that is the responsibility of suitably qualified and experienced persons who are members of recognised, relevant professional organisations and subject to accountability and a professional Code of Ethics.

The Geothermal Reporting Code is a reporting code that covers the way geothermal exploration results, resource and reserve assessments are classified and publicly reported. It does not cover the way assessments are made.

In particular it covers:

 all forms of geothermal energy, for example, conventional volcanic based energy, hydrothermal aquifers and hot rocks (EGS)

- all uses of geothermal energy, including geothermal thermal energy for electricity generation, direct use in industrial processes or space heating, or as supplemental energy
- the minimum and mandatory set of requirements for public reporting of Exploration Results, Geothermal Resources and Geothermal Reserves

Reporting codes in the geothermal industry have a short history and their effect upon the market has not, to the authors' knowledge, been measured yet. In addition, there are no lists available of written code compliant reports so the exact amount of existing reports is not known and neither of the existing codes have been endorsed by any market nor regulator as of yet.

The GEOELEC consortium has assessed arguments for and against the development of a special geothermal reporting code for Europe.

THE ARGUMENTS AGAINST THE DEVELOPMENT OF SPECIFIC EUROPEAN CODE ARE THE FOLLOWING:

 The requirements by the EU market to a report template or reporting code are similar or the same as the international requirements and the two existing Geothermal Reporting Codes both state that they are applicable both locally and internationally.

The purpose of a Reporting Code is to have comparable reports for the different geothermal plays in the international market. Asthere is no international umbrella association, adding a third independent Reporting Code might undermine this comparison role.

 The existing geothermal reporting codes seem not to be regulated or supervised, all is down to the integrity of the Qualified Person, and no measurement of their effect is conducted.

Reports have been created which do not use code but still quote it. They do not state that the reports are code compliant but imply that the work is done in similar way. This can weaken the code and does not comply with standards. Nothing in the existing geothermal reporting codes prohibits this use.

 Only a handful of companies are expected to be listed in European stock exchanges for the next years. There are today 3 known listed companies and 2 believed to be in progress. So the users of a specific European Geothermal Reporting Code are few.

ARGUMENTS FOR DEVELOPING A SPECIAL GEOTHERMAL REPORTING CODE FOR EUROPE ARE LISTED BELOW:

 The existing reporting codes can serve as framework and principles to set a standardised international reporting format acceptable by investors, regulators and the general public. What is missing is the regulation authority and supervision of the usage of the code. If the code is used in ways that could diminish its trustworthiness there is no active supervision or instruments to fall back on for the solution. If there was

- a European Geothermal Reporting Code it could be arranged to have it regulated and supervised. This would require funding.
- By having an independent European Geothermal Reporting Code the European Geothermal Industry can enter the Geothermal Reporting Code discussion with more strength and push for creating an international umbrella association with comparable reporting code requirements and definitions of terminology.

RECOMMENDATIONS

The Geothermal Reporting Code is believed to be of best use if it is international, regulated and supervised. This would ensure that the same principles are followed worldwide within the geothermal industry.

Publication, regulation and supervision of an international geothermal reporting code could be done in a similar way to what is done in the mineral reserves industry. For that a similar umbrella organisation as CRIRSCO is required for the geothermal industry. The Geothermal Reporting Code would then in all principles be the same, however tailored to the regions in similar fashion as in the mineral reserves industry. The Australian and Canadian Reporting Codes could then be seen as the pioneer documents within the international system.

It could be stated relevant and necessary to have an independent European Geothermal Reporting Code in order to join the international discussion to build up an international umbrella association bit by bit. This could speed up the process of having an international geothermal reporting code and bridge the gap until then by having an existing European Geothermal Reporting Code that can be regulated and supervised. For this funding is necessary to set up a body that can write the code, update it as necessary, participate in international discussion and most importantly regulate and supervise the use of the European Geothermal Reporting Code.

On the other hand it could be argued that for Europe it is not necessary to establish a special Geothermal Reporting Code until after this umbrella organisation has been agreed upon and established. That is primarily since the existing codes are international and can be used until then. Secondly, there are very few expected users of a specific European Geothermal Reporting Code and thirdly, to issue a third independent code in geothermal reporting would not serve the purpose of the reporting code which is establishing an environment that facilitates comparison.

It would take time for a European body to develop a geothermal reporting code for Europe. In the meantime a document similar to that published by the GEA or lexicons published as guidance with the existing Geothermal Reporting Codes could be of use for the geothermal industry. This document, guide or lexicon, should be specifically tailored to the European market. This could be done instead of creating one more unregulated Geothermal Reporting Code.

A document providing guidance in European specific situations could prove useful for professionals during assessment of European geothermal plays. This terminology and definitions should always be done in close cooperation with the international geother-

mal society. This means that at least both existing code committees should be consulted during the making of it. The reports could then be reported under an international reporting code such as the Australian or Canadian code if required to be code compliant. Such an option is believed to be acceptable for at least the next couple of years. The decision can then be revisited when more users have entered the market and there is a need for a specific European Geothermal Reporting Code.

Therefore, the GEOELEC consortium does not recommend the immediate investment in a European Geothermal Reporting Code but a wait and see strategy supported by lexicons and guidance until more potential users have entered the market.

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4FINANCING GEOTHERMAL PROJECTS

In spite of widely available geothermal resources, the European gross geothermal electricity production only reached ca.11.5TWh in 2012. This is only a small portion of the enormous economic potential. As shown in Chapter 3, with recently developed technologies harnessing Europe's geothermal resources for electricity generation has become viable from both the technical and the economic point of view.

Among all renewable energies, geothermal is the most reliable. With a load factor of more than 90%, the fact that it can produce a steady output around the clock makes geothermal power competitive with newly built conventional power plants, in areas where high-temperature hydrothermal resources are available.

However, it is a capital-intensive technology that needs 5-7 years to become operational from the start of the permitting process until commissioning. The significant upfront investment is related to the drilling and to the need to cover the geological risk at the beginning of the exploration. This is true for all deep geothermal projects.

Realising the geothermal potential will therefore require massive investment. Indeed, public support for geothermal energy, e.g. through a feed-in tariff, is available today to compensate for market failures and mobilise private financing. This will allow emerging geothermal technologies to progress along their learning curve and reach full competitiveness in the next few years.

Against this background, a greater involvement of the private financial sector is essential. Yet not all financial institutions and private investors are familiar with the complexity of geothermal technology, its challenges, and environmental and economic benefits. A different approach towards the sector is needed as that lack of capital, notably during the early project- stages, has commonly been a barrier hindering the growth of geothermal power. It should be added that the current capital crunch obstructs the necessary financing even further. It is clear that a pre-requisite to facilitate such a private financing mobilisation is a thorough understanding of how a geothermal project is planned and developed over several years, including the nature of its specific risks. Developers need to know their financing options while investors need to have basic knowledge of and confidence in these emerging technologies. Additionally, a mutual understanding between developers and investors is of the utmost importance, especially due to the initial investment required in a geothermal project.

Investors should be encouraged to take part in its promising development. In this respect, this report also puts forward a scheme for an EU Fund mitigating the risk associated with the geothermal resource and facilitating investments in geothermal electrical generation projects.

As explained in this Chapter, where knowledge of the geothermal resource is lacking, exploration is of crucial importance to collect relevant data before drilling. Beyond exploration, the bankability of a geothermal project is threatened by the geological risk. The geological risk includes the risk of not finding an adequate resource (short-term risk) and the risk that the resource naturally declines over time (the long-term risk).

Risk insurance Funds for the geological risk already exist in some European countries (France, Germany, Iceland, The Netherlands and Switzerland). The geological risk is a common issue all over Europe; collaboration between Member States to remove it will allow them to save money.

It is for this reason that the GEOELEC project calls for the establishment of a Geothermal Risk Insurance Fund at the EU level. This Fund could insure deep geothermal projects in the different EU countries.

4.1 GEOTHERMAL PROJECT DEVELOPMENT: PHASES AND EXPERTISE

The economic success of a geothermal project is influenced by a variety of factors. Although each project should be considered unique, there are elements common to all. This section will introduce the different phases of a geothermal project and the wide array of skills required for its successful implementation.

THE PHASES OF A GEOTHERMAL PROJECT AT A GLANCE

It is possible to divide a geothermal project into 4 key phases: exploration, resource development, construction, and commissioning, operation and maintenance.

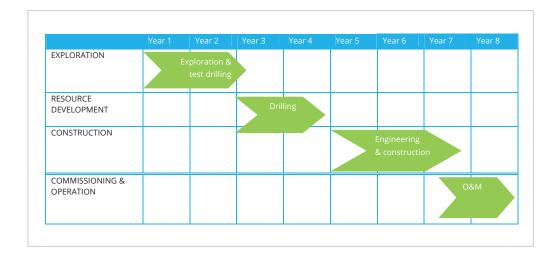


Figure 4.1: Phases of a geothermal project

Exploration Phase

Based on experience, it takes about 5-7 years to bring a geothermal power plant online.

In the 'Exploration phase' of a new project, (which is subject to an exploration permit usually granted by the mining authorities), available geological data is reprocessed and analysed.

Following a preliminary survey, detailed geophysical, geological and geochemical studies will be needed in order to identify drilling locations in the defined area and to estimate the geothermal potential. Exploration strategies should be designed for each site with the specific geological setting in mind but could involve the following (Bruhn et al. 2010):

- · Assessment of the geologic and geodynamic setting;
- Geochemistry including fluid and rock isotope chemistry;
- · Structural analysis of faults, fractures, and folds;
- · Determination of the regional stress field;

4.1 GEOTHERMAL PROJECT DEVELOPMENT: PHASES AND EXPERTISE

- · Potential methods, mainly gravity and magnetic surveys;
- · Electrical and electromagnetic methods;
- · Seismic methods, both active and passive.

Significant effort is put into exploration, attempting to minimise drilling uncertainties, combining magnetotelluric (MT) surveys. In Germany, there is a tendency to use of 3D seismic methods, even for projects of a few MW potential. Indeed, this is the best technology available today to identify fractured areas, but cheaper technology is necessary to bring the cost of geothermal development down, it is therefore important that 3D seismic studies are correlated with other technologies.

Another key step in the exploratory phase is the test drilling. At this stage a drilling programme is designed to develop a target to confirm the existence and potential of the resource. Within the geothermal industry there is a discussion on whether or not to use slim holes since a successful exploration well can turn into a production well. It should be answered on project basis taking into account the existing knowledge of the region and project economics. Aslim hole can for example reach up to 1.5 km depth with a diameter up to 15 cm., this requires lighter drilling rigs thereby limiting the costs.

Beside the geoscience and engineering, the legal and market framework conditions of the area also have to be studied and evaluated in a so-called 'feasibility study', the outcome of which will confirm the technical and economic viability of the project. The funding and the insurance concepts of the project will also stem from this phase. Hence, banks / investors / sponsors and also insurance companies have a role to play from the beginning.

Resource development

Based on the feasibility studies, project developers can take the decision to start the active phase of Resource development. This phase includes the drilling of the production and injection well(s) and the connection of the wells to the power plant. After the long-term flow test the potential of the geothermal resource is known.

Construction

Upon completion of the drilling activity and associated tests, the construction phase begins. At this point the power plant must be planned, constructed and connected to the electricity grid. A detailed design of the power plant can start with the knowledge of the long-term flow test. With lower efficiency factors, standardised plant modules can be ordered without completed flow-test. In this case, the financing of the power plant should be possible through equity capital. Currently, there is no known bank financing a power plant without the guarantee of the results of long-term flow tests.

4.1 GEOTHERMAL PROJECT DEVELOPMENT: PHASES AND EXPERTISE

Commissioning and Operation

Following the construction phase, the power plant is commissioned and initial tests are run. Once all tests have been completed successfully, the power plant is fully operational and can sell the electricity (and/or heat in the case of cogeneration plants) generated. Maintenance of both plant and geothermal resource will be needed throughout the lifecycle of the power plant.

Project team and interplay between disciplines

A number of different players are involved in a geothermal project over several years of project development and implementation (Figure 4.2).

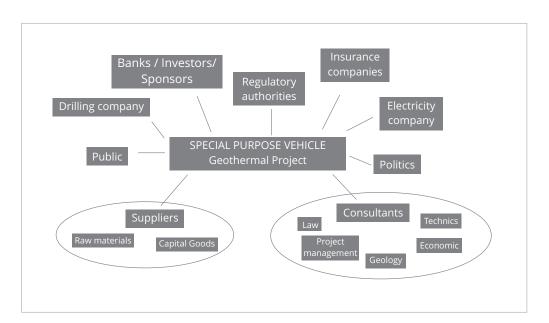


Figure 4.2: Players of a geothermal project development

The project manager plays a key role for the (economic) success of a project, especially in the early stage. She has to comply with the complex requirements related to structuring, developing and risk mitigation.

A team of consultants is needed to assist the project team. They need to have an enormous variety of skills, abilities and personality types. A team of financial experts, legal experts and technical experts, e.g. geoscientists, reservoir engineers, and drilling specialists, power plant engineers, environmental experts etc. must be established at an early phase. The challenge is to keep the complexity of the project under control and to reflect the technical aspects and the course of the project correctly in the cash flow. Also the interaction between individual disciplines, the definition of the interfaces and the on-going and active exchange of information must be perfectly organised.

Private financing in the geothermal market can be still considered in its early stage. Significant investment, higher level of risk, long project development cycle and long expectation for the return oninvestments (RoI) are the key challenges of a geothermal project. Every project has its individual financing requirements due to the specific project parameters related to geology, finance, politics and technique. The crucial factors for the economic success of a geothermal power project are shown in Figure 4.3 below.

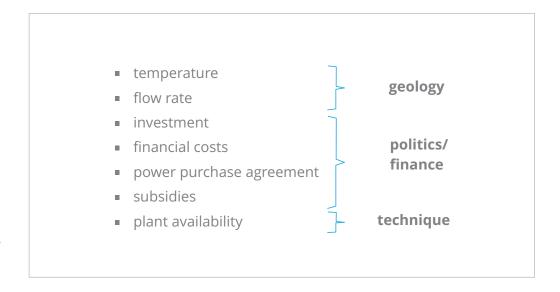


Figure 4.3: Crucial parameters for the economic success

Widespread development of geothermal energy will require high investment. The involvement of the private sector – banks, sponsors and investors is needed.

The financing of geothermal projects depends on the stage of the project. It has to be structured in two steps. Project investors are financially responsible for the geological risk, until debt financing by banks is possible following the completion of the long-term flow tests. From experience, a special purpose vehicle (SPV) for the geothermal project should be founded to develop the project finance and to define the project risks.

PROJECT FINANCE

Because of the varying level of risk implied, diverse financial tools are used to fund the different phases of a geothermal project. This is shown in Figure 9.

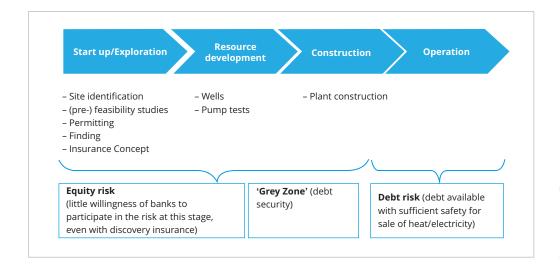


Figure 4.4: Financial instruments used to finance different phases of a geothermal project

Financing a geothermal project is indeed more difficult in the initial phase of project development as the geological risks during the exploration and drilling phases have to be taken by equity. If the construction phase begins before the results of the pumping-tests are available, the financing of the power plant is in a 'greyzone', in most cases debt financing cannot be constituted. With the completion of the long-term flow test project finance by banks is possible.

The basic idea of project finance is that the project should finance itself. The investors must have a credible perspective on an adequate equity yield rate and creditors need guarantee on the return of their credit capital. Cash flow-related lending, Risk-sharing and Off-Balance-Sheet financing are the central characteristics of project finance.

The SPV of the geothermal project should be established by the project initiators to have legal capacity and to be creditable. With it, the vehicle can obtain debt capital, whilst the sponsors can only participate as investors according to the amount of their deposits (Figure 4.5).

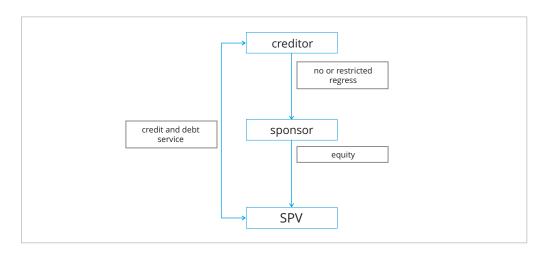


Figure 4.5: Project finance of a special purpose vehicle (SPV)

Project credits are allocated in the balance sheet of the geothermal SPV, whereas the annual accounts of the sponsors should not be affected (Off-Balance Sheet-financing).

The credit check is directly focused on the economic viability of the project because of the lack of economic history and the high specifics of each project. The cash-flow must be sufficient for the operation costs and the debt service. The orientation to the cash-flows by the credit check is called 'cash flow lending'. Only the two sources of collaterals - the assets acquired within the project and the expected cash-flows - are available.

The usual requirements of banks for geothermal projects are listed in Box 2.

REQUIREMENTS OF A BANK FOR FINANCING A GEOTHERMAL PROJECT

- COMPLETED FLOW-TEST
- SHARE OF EQUITY OF AT LEAST 30% OF THE BALANCE SHEET (AFTER SUCCESSFUL DISCOVERY)
- TERM: 15-20 YEARS DEPENDING ON THE TECHNICAL LIFETIME OF THE FACILITY
- SERVICE COVERAGE RATIO: >1,2
- · CAPITAL SURPLUS, e.g. for dry hole, pump replacement
- APPROPRIATE KNOW-HOW AND EXPERIENCE
- PROJECT STRUCTURE WITHOUT INTERFACE RISKS
- PROVEN TECHNOLOGY
- RISK MITIGATION
- INDEPENDENT FEASIBILITY STUDIES
- AVAILABILITY OF SUBSTITUTE MATERIALS
- FEED-IN TARIFF AGREEMENTS / SECURE SALE GUARANTEE

Another characteristic of project finance is risk-sharing. It assumes that the single risks are identified with their consequences and allocated to the project partners. This issue will be discussed in Chapter 4.3 of this Report.

RISK MANAGEMENT

A geothermal power project is based on the estimated geothermal power that can be generated from the reservoir and the estimation of costs and revenue streams related to each individual project. Estimating prospective costs and revenue streams involves uncertainties and risks.

Box 2: Requirements of a bank for financing a geothermal project

Financial backers are sensitive to project risks especially because of the Basel-II-principles and the lack of knowledge about geothermal projects. Therefore, solid project planning and risk management are essential elements of a developing project, and need to be implemented at the earliest stage. Risk management does not necessarily imply the elimination of risks, but rather their systematic management and mitigation (Figure 4.6).

Risks have to be identified and evaluated in terms of their probability and the (economic) consequences of their occurrence. Once these assessments have been made, strategies for risk management need to be developed. Sometimes, it will not be possible to avoid risks by means of appropriate and "affordable" measures.



Figure 4.6: The right risk strategy

Often, risk reduction is satisfactory. Some risks may be passed on to third parties, for example through insurance (Figure 4.7).

- business liability insurance
 - inkl. mining regulations
- constructors all risk insurance
 - damage-related costs for lost in hole of equipments, by-pass etc.
 - damage-related giving up of the borehole
- discovery insurance
 - coverage of the thermal capacity / energy potantial

necessary: agreement of insurance coverage

helpful: supporting throught experienced broker

Figure 4.7: Insurance coverage concept for deep geothermal projects

Lastly, there are risks that the company will categorise as (financially) acceptable and cover with equity capital directly.

Most of the investment falls into the high-risk phase of the geothermal project (Figure 4.8). While the project is being developed, the required budget changes successively. And with increasing effort in exploration, more and more knowledge about the resource is acquired and the risk of failure decreases accordingly.

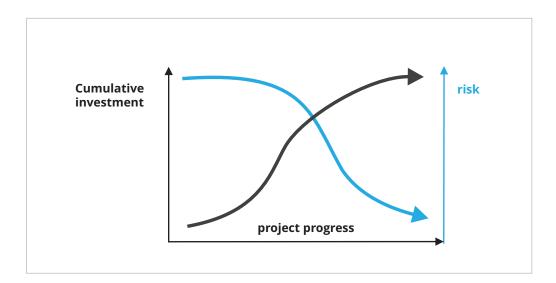


Figure 4.8: Risk and cumulative investment during the project progress

Finally, beyond exploration, the bankability of a geothermal project is threatened by the geological risk. Risk insurance funds for the geological risk already exist in some European countries (France, Germany, Iceland, The Netherlands and Switzerland). The geological risk is a common issue all over Europe. Collaboration between Member States is desirable; it can allow them to save money and trigger the uptake of a valuable technology alike.

For this reason the GEOELEC project has made proposals for a Geothermal Risk Insurance Fund at the EU level, which will be presented in the next section.

Although geothermal energy benefits from low operating costs, it involves high upfront investments. This substantially hinders the penetration of geothermal energy into the energy market. In addition to high upfront investments, geothermal developers face a specific risk associated with geothermal projects commonly known as the geological risk

THE GEOLOGICAL RISK INCLUDES:

- The short-term risk of not finding an economically sustainable geothermal resource after drilling;
- The long-term risk of the geothermal resource naturally depleting rendering its exploitation economically unprofitable.

Geological surveys help to find geothermal resources and give indications for their profitability but the only way to purge the geological risk and confirm the geothermal resource is to actually initiate the exploration and drilling work. This requires developers and investors to lay out significant amounts of cash beforehand without certainty as to the availability and adequacy of the geothermal resource and hence the bankability of the project.

GEOELEC endeavours to remove the risk associated with the geothermal resourcewhich is referred to as the 'resource risk'. A scheme for an European Fund mitigating the resource risk is therefore put forward, namely the EGRIF.

For now, the fairly small number of geothermal electricity operations in the EU does not provide a sufficient statistical basis to assess their probability of success. As a consequence, geothermal developers struggle to find insurance public or private schemes under affordable terms and conditions for the resource risk. In those circumstances, the EGRIF aims at alleviating the shortage of insurance policies for the resource risk and ease investments in geothermal electricity projects.

Principles of the EGRIF- The EGRIF is meant to work through the pooling of the resource risk among geothermal electricity projects taking place in the EU. The Fund does not challenge the EU principle of subsidiarity nor act as a competitor to existing national insurance policies. Figure 4.9 the phases of a geothermal electricity project where the resource risk may occur and the insurance from the EGRIF be released.

Until the first borehole has been drilled into the geothermal reservoir, developers cannot be sure about the exact parameters (temperature and flow rate) of the planned geothermal electricity project. Once drilling has taken place, in situ pump tests, temperature and hydrological measurements then reduce the resource risk and make it possible to attract external capital.

EXISTING NATIONAL INSURANCE SYSTEMS IN EUROPE: IDENTIFICATION OF RELEVANT PARAMETERS

There is a heterogeneous approach towards the resource risk in Europe and worldwide. In some countries outside Europe, geothermal developers are willing to internalise the resource risk among other costs. This willingness is rooted in either a risk culture developed in relation to mining and oil activities or a highexpected return on investment in the light of abundant geothermal resources. This allows geothermal to be economically attractive through support schemes, without need for insurance policies covering the resource risk. In other countries, the resource risk may not be internalised and remains a financial barrier to geothermal development. Regardless of support schemes, any geothermal expansion in all European countries is heavily dependent on insurance.

The Table below (Table 4.1) shows the current state of the resource risk insurance in each EU country, plus Iceland and Switzerland. Details of the existing insurance systems can be found in Deliverable 3.2. For each country, the chart specifies:

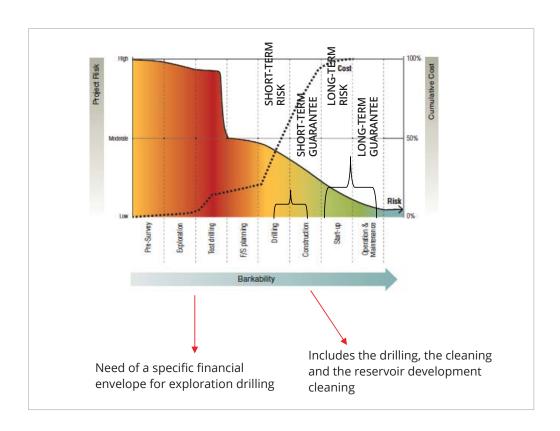


Figure 4.9: Geothermal Project Risk and Cumulative Investment Cost

- · Whether insurance for the resource risk exists;
- Whether the insurance covers heat or electricity production;
- Whether the insurance process is handled by public authorities or private entities;

- Whether the insurance mechanism is purely insurance-related or serves as a financial support as well;
- Whether the insurance is made available on the national stage only or in foreign countries as well;

	Insur	ance	Е	nergy	Gove	rnance	Type of	insurance	Loc	ation
Country	Yes	No	Heat	Electricity	Public	Private sector	Purely in- surance- related	Insurance mixed with financing	National	Foreign countries
Austria		Χ								
Belgium		Χ								
Bulgaria		Χ								
Cyprus		Χ								
Czech Republic		Χ								
Denmark		Χ								
Estonia		Χ								
Finland		Χ								
France	Χ		Χ		Χ		Χ		Χ	
Cormany	Χ		Χ	X	Χ	Χ		Χ	Χ	
Germany	X		Χ	Х		Х	Х	Х	Х	Х
Greece		Χ								
Hungary		Χ								
Iceland	Χ		Χ		Χ			Χ	Χ	
Ireland		Χ								
Italy		Χ								
Latvia		Χ								
Lithuania		Χ								
Luxembourg		Х								
Malta		Х								
The Netherlands	Х		Х		Х		Х		Х	
Poland		Χ								
Portugal		Х								

Table 4.1: Snapshot description of the national insurance systems in Europe

	Insurance		Energy		Governance		Type of insurance		Location	
Country	Yes	No	Heat	Electricity	Public	Private sector	Purely in- surance- related	Insurance mixed with financing	National	Foreign countries
Romania		Χ								
Slovakia		Х								
Slovenia		Χ								
Spain		Χ								
Sweden		Χ								
Switzerland	Χ		Χ	Χ	Х	Х	Χ		Х	
United Kingdom		Х								

KEY PARAMETERS FOR A EUROPEAN GEOTHERMAL RISK INSURANCE FUND

For the EGRIF:

- 1. The insurance mechanism could take several forms:
 - A post-damage guarantee
 - · a guaranteed loan
 - a complementary mechanism to insurance made available on the national stage, whether from insurance companies or from national insurance Funds
- 2. Governance: it could apply to all European countries or some of them only. With that in mind, the EGRIF may rely on:
 - an exclusive management by an EU institution
 - a shared management between an EU institution on the one hand and national insurance Funds/companies on the other hand
 - a shared management between an EU institution and national authorities;
 - an exclusive management by national authorities
- 3. Risks insured: three phases of the geothermal project may be concerned:
 - Some financing could be provided in relation to exploration
 - The Fund should insure the short-term risk, i.e. one or several drillings for production and injection wells. It may apply a revolving mechanism in this respect
 - The Fund could also insure the long-term risk, i.e. the quality and quantity of the geothermal resource over a certain time period; but with conditions.

- 4. Capital and financial structure: the seed capital could be filled with funding from:
 - The European Union
 - · the Member States
 - the regional level authorities of the Member States
 - insurance companies and brokers
 - private and public financial institutions
 - · other reliable stakeholders

Feedback shows that governance issues may arise when the distribution of the seed capital is not made transparent. This should be avoided in relation to the EG-RIF. The arrangement of its seed capital should constantly be made known publicly.

Once the Fund is launched with a seed capital, it may rely on several sources of income. There are various incomes the existing insurance systems rely on: premiums, fees, proceeds of investments made with the treasury, taxes on the electricity transmission, and public funding.

Feedback shows that the more diversified the incomes are, the more stable the Fund is. Some insurance systems, which relied on a unique source of revenue, were eventually compromised when this source dried up (e.g. GeoFund, ARGeo).

The Fund can either be balanced over time when the incomes allow it. It may also run out and be filled periodically.

As with any consistent insurance Fund, the EGRIF may call on reinsurance to a third body. Part of the resource risk would be transferred to the reinsurer, giving the Fund some financial relief. It could therefore issue more policies than its own incomes may allow and keep covering geothermal electricity projects while at the same time facing exceptional losses.

- 5. The insurance process:
 - Could rely on independent expertise
 - Could allow applications to be submitted continuously or on a tendering basis
 - Should systematically lead to the conclusion of a reference contract between the developer and the Fund
 - · Should include some reporting obligations
 - Should apply one or several languages, which should be clearly chosen
 - Should be clear, transparent and lead to public and reasoned decisions
- 6. Type of insurance and risks insured within the EGRIF:

As explained in the first part, where knowledge of the geothermal resource is lacking, exploration is of crucial importance to collect relevant data before drilling. Beyond exploration, two risks threaten the bankability of a geothermal

project: the risk not to find an adequate resource (short-term risk) and the risk that the resource naturally declines over time (the long-term risk).

As for geothermal electricity generation in Europe, EGRIF shall be concerned with the exploration phase, the short-term risk and the long-term risk.

THE EXPLORATION PHASE

Here again, exploration aims at acquiring some data about the geothermal resource. This may be achieved through surface studies and/or exploration drilling. The exploration drilling is not necessarily a production drilling, but is focused on data collection. However, if exploration proves favourable, the exploration well may be used as a production or injection well. As exploration drilling is largely an information gathering exercise, there are no clear success and failure criteria- success is determined on an individual basis. This makes any insurance irrelevant in relation to exploration. Instead, exploration is usually supported by public financing. Considering the importance of exploration for geothermal electricity generation in Europe, The EGRIF shall provide some financial envelope to support exploration. This financial envelope shall take the form of a repayable advance; this would allow for some financing of exploration, without depleting the Fund as the advance would be reimbursed. The amount of the repayable advance shall be set contractually and It shall cover the costs of exploration drilling and tests. Exploration costs specific to EGS shall also be considered (GEOELEC Geothermal Investment guide D3.4 § 'eligible costs and coverage ratio').

The advance would have to be reimbursed in case of production. In such a case, the amount to be repaid to the Fund shall be enhanced. A classical interest rate as well as a discount factor shall be applied; these shall be set contractually and modulated according to the estimated exploration risk (see D3.4 § 'eligible costs and coverage ratio').

The short-term risk

With regard to the short-term risk, the insurance shall aim at covering the costs of one or several drillings in case of a geothermal resource being economically flawed (see D3.4 § 'eligible costs and coverage ratio'). Two types of insurance may apply: a post-damage guarantee or a guaranteed loan. A guaranteed loan has the main advantage of serving as a source of financing while at the same time providing some insurance, as the loan is fore given when the resource risk materialises. However, it requires an immediate disbursement of funds which severely limits the financial flexibility of the Fund. The post-damage guarantee does not serve as a source of financing for geothermal projects; nevertheless, it proved to be an effective insurance design in EU Member States that provide it, as it allows geothermal developers to attract external capital. From an accounting point of view, the funds are frozen when the guarantee

is granted but only released when the risk occurs. As such, it allows some financial relief to the Fund and this flexibility ensures that many projects can be covered at the same time.

With regard to the aforementioned considerations, a post-damage guarantee shall be favoured in relation to the European Geothermal Risk Mitigation Fund.

The long-term risk

With regard to the long-term risk, the insurance shall aim at covering the remaining depreciable value of the wells and the geothermal loop as well as the loss of geothermal resource (see D3.4 § 'eligible costs and coverage ratio'). The coverage of the 'long term' risk should take into account some specific elements. Natural depletion is a standard technical risk that operators can deal with using properreservoir management; an unintended consequence of insurance provision could be unsustainable reservoir management, however this will be avoided with effective pre-defined and established systems. As previously explained, the EGRIF shall provide a post-damage guarantee rather than a guaranteed loan, given the noted advantages of the former.

Guideline

The European Geothermal Risk Insurance Fund shall provide a repayable advance in relation to exploration and a post-damage guarantee where the short-term risk and/ or the long-term risk materialise. In particular, these mechanisms shall apply, whether geothermal heat or electricity is generated conventionally or through EGS.

4.4 COST ANALYSIS

The total costs of a geothermal project are dominated by the capital costs at the beginning of the project. The range of the main capital costs are depicted in Figures 14&15, though the actual investment for specific projects can differ from these ranges.

RESERVOIR EXPLORATION AND DEVELOPMENT

The investment for the exploration and development of the reservoir (i.e. drilling) makes up the largest part of the whole investment. A general assessment of these costs is difficult because of varying geological conditions that influence the drilling, the completion, and the reservoir stimulation in the case of EGS. Investment estimations of the reservoir at an early stage of a geothermal project are usually based on existing data from other drilled and completed wells. Detailed cost calculations use geological site information. Such calculations should also consider an additional values for unforeseen problems - typically between 10% and higher in unknown geological areas.



Figure 4.10: Breakdown of capital costs in a 5 MWe EGS projects in Germany (see case study in the Financial guide GEOELEC)

Cost Category	Approximate percentage of CAPEX
Preparation & drilling	54%
Turbine-generator & auxiliary systems	13%
Steam supply system	10%
Design & supervision	11%
Buildings & ancillary systems	7%
Roads & camps	3%
Electrical, control & protection systems	2%

Figure 4.11: Example from a 5MWe low enthalpy binary Power Plant in Central-Europe

4.4 COST ANALYSIS

RESERVOIR ENGINEERING COSTS FOR EGS

EGS allows the development of low temperature areas by increasing the permeability of rocks nearly anywhere. Stimulation techniques based on high pressure water injection have the objective of generating a high permeability to extract as much mass flow as possible. Depending on the site specifications and the estimated power stimulations costs between 4 and 8EUR Mio. must be considered.

SURFACE INSTALLATIONS

The investment costs for the surface part of a geothermal project include the costs of the geothermal fluid supply system and the costs of the power plant unit and, if applicable, the extra costs for a heat plant unit.

The investments for the geothermal fluid supply system contain the costs for the equipment such as pumps, pipes, valves, separators (where it applies) and filters. The costs depend on the flow rate of the geothermal fluid, temperature and pressure in the gathering system. Further parameters affecting cost are chemical compositions, gas content and topography of the steam field.

The investment for a power plant generally depends on the installed capacity. The specific investments decrease with larger capacity. The main items are the turbine and generator unit, the heat exchangers and the cooling unit.

OTHER COSTS

From past experience, project planning including design can take up to approximately 10% of the overall capital costs. In addition, the costs for consulting (legal and economic, project management) and for the licensing procedure must be budgeted. Further investment costs are, for example, e.g. noise protection, office, clerical equipment, infrastructure, outside area. Insurances covering the geological risk, business liability insurance or constructors all risk insurance are further cost factors which must be considered.

OPERATIONAL & MAINTENANCE COSTS

The annual operating costs during the operating phase of a geothermal electricity plant include mainly the costs for personnel, consumption material, overhaul and maintenance. Costs for the consumption of the auxiliary power demand need to be considered if the required power is not provided by the power plant itself. Unlike for fossil fuels and biomass, at this point no costs for fuels are to be included.

4.5 REVENUES

SUPPORT SCHEMES FOR GEOTHERMAL ELECTRICITY

A critical element in the project development is to guarantee stable revenues through the sale of the electricity produced. Especially for an independent producer, (i.e. not a utility) negotiating a convenient power purchase agreement (PPA) is key. A PPA is a long-term contract (between 5 and 20 years) with a third party, usually a utility, to sell the electricity generated by a power plant. It is essential to secure a long-term stream of revenues.

In the EU, Directive 2009/28/EC (RES Directive) has set the target of 20% renewable energy in gross final consumption of energy for 2020. This general target was broken down into binding national targets. To facilitate the achievement of these targets Article 3 of the RES Directive allows Member States to make use of national mechanisms of support for the promotion of energy from renewable sources provided they are compatible with the State aid guidelines for environmental protection.

A wide range of public policy mechanisms are currently in place These can be distinguished between investment support (capital grants, tax exemptions or deductions on the purchase of goods) and operating support (regulated prices, renewable energy obligations with green certificates, tender schemes and tax reductions on the production of electricity).

The most widely used incentive in EU countries is the feed-in-tariff, which guarantees a fixed price per kWh electricity. These payments are mostly guaranteed to the electricity producer for 10-20 years thereby geothermal power producers the problem for negotiating and signing a PPA. This investment security and the guarantee of cash-flows allows them debt financing at more convenient conditions; this is essential for the financing of capital intensive projects like geothermal power projects.

Figure 16 provides an overview of the feed-in tariff systems in place in 11 European countries (EGEC, 2012). However, they differ in terms of length and other conditions. For more detailed information, the competent national authorities should be contacted.

4.5 REVENUES

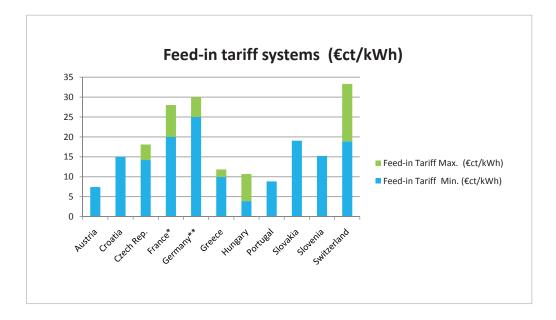


Figure 4.12: Feed-in tariff systems in Europe. Source: EGEC Geothermal Market Report 2012

- * Applies to the produced net power
- **Applies to the produced gross power

An alternative, more market-oriented, incentive is a system called feed-in premium, which gives the electricity producer a fixed financial payment per unit of electricity produced from renewable energy sources for the green value. On top of that the producer receives the market price for physical energy. Four countries promote geothermal power generation through feed-in premium mechanisms.

Lastly, Flanders (a region of Belgium), Romania, and the UK promote geothermal electricity by means of quota/certificate systems.

THE ADDED VALUE OF COGENERATION

CHP projects improve their economics by selling heat at market prices in competitions with other heat sources (Figure 4.13).

Since the drilling for geothermal fluid is a high risk and costly phase, the results should be utilised to generate as many income streams as possible to create a beneficial project. Geothermal CHP is nothing new. A low temperature (81°C) geothermal resource has been used since the late 1960's, at Paratunka, Kamchatka, Russia, combining power generation and direct uses of the waste heat for soil and greenhouse heating purposes. Heat maybe regarded as a by-product of geothermal power production in terms of either waste heat released by the generating units or excess heat from the geothermal source.

In Germany there are regulations and laws which privilege the utilisation of renewable energy heat (e.g. EEWärmeG).

4.5 REVENUES

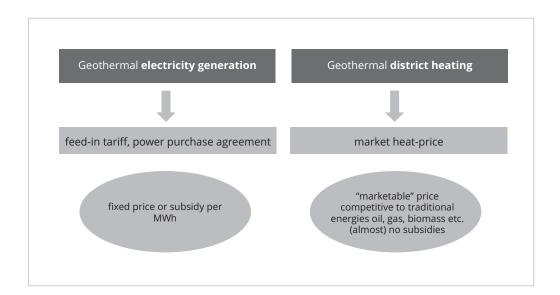


Figure 4.13: Revenues of a geothermal project – heat and electricity

In the case of a CHP power project, the revenues earned by heat are determined by the heating capacity provided to the network. The expansion of usual district heating networks, including subsequent increased density of coverage, usually takes 15 to 20 years; only then is the final level of sales achieved. A natural limit is imposed on the price by the competing sources of energy oil, gas, wood chips, etc. And the heat tariff must be designed so as to give consumers an incentive to switch.

4.6 SOFTWARE TO PRE-EVALUATE FINANCIAL FEASIBILITY

n order to support the drafting of financial pre-feasibility studies for new projects, GEOELEC has built and now provides online free software for the first validation of geothermal power projects.

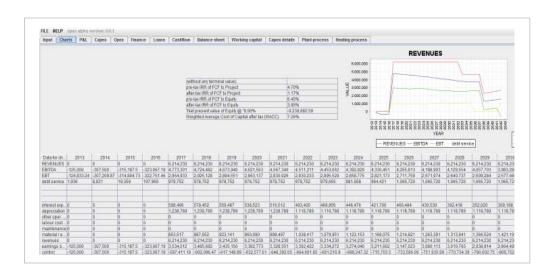
ABOUT THE SOFTWARE

In order to increase confidence and investigations into new projects, this software has been designed for project developers and public authorities that are investigating the potential of new geothermal power plants. Project costs, the financing model and business plan can now be pre-checked and validated using the new tool.

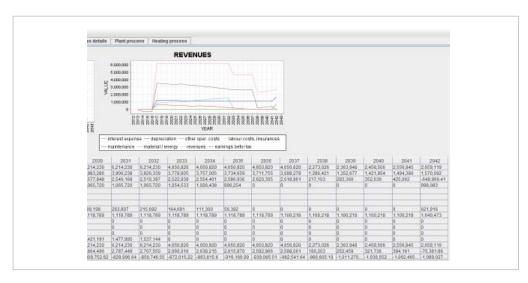
Specifically, users can check:

- · Internal Rate of Return (IRR)
- Net Present Value (NPV)
- · pay back time
- levelised cost of electricity production
- · profit and Loss
- balance sheet
- · cash flow

This software can be used with all three geothermal electricity technologies: conventional geothermal (hydrothermal, high temperature) with dry steam and flash steam turbines, low temperature hydrothermal geothermal with binary turbines (ORC and Kalina Cycle), and Enhanced Geothermal Systems (EGS)



4.6 SOFTWARE TO PRE-EVALUATE FINANCIAL FEASIBILITY



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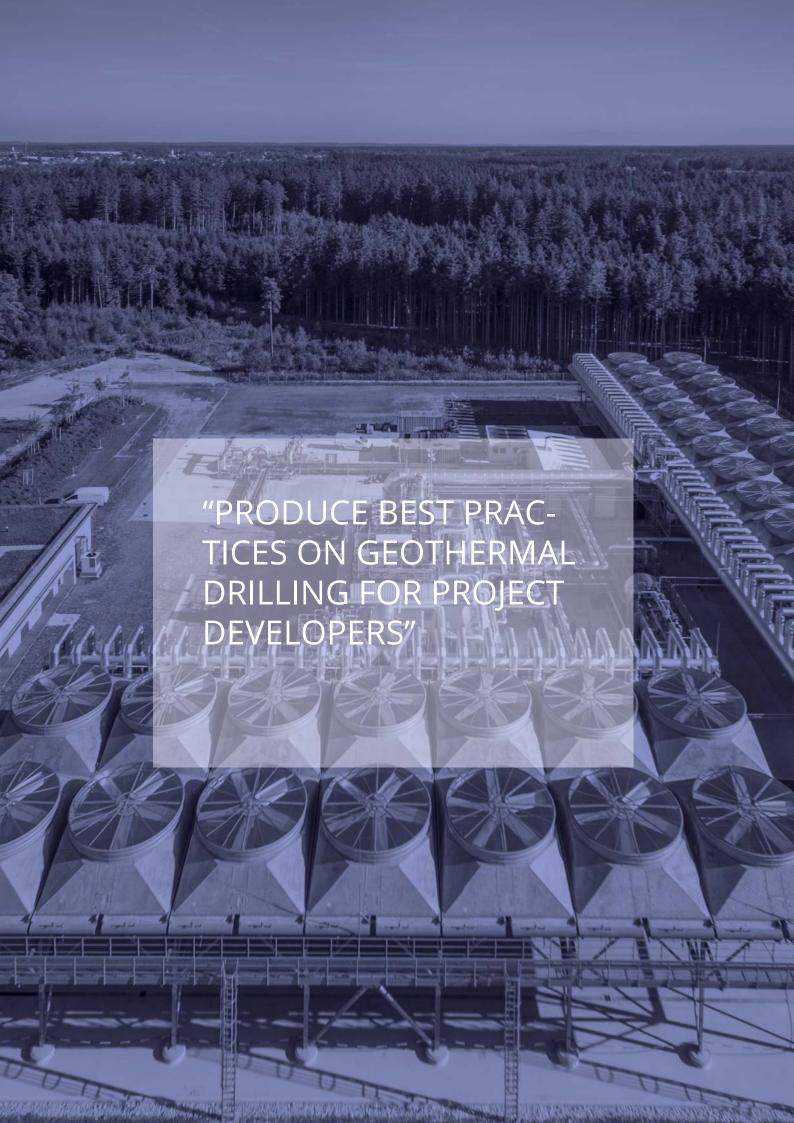
GEOELEC Deliverables

- Factsheet on Market Development
- Factsheet on Finance and Economics
- Report on risk insurance
- Investment guide
- · Software for financial pre-feasibility studies

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5 DRILLING TECHNOLOGY AND MARKET



5.1 ANALYSIS OF DEEP GEOTHERMAL DRILLING MARKET IN EUROPE

Drilling costs represent from 30% to 50% of the cost of a hydrothermal geothermal electricity project and up to 70% of the total cost of EGS. This Chapter aims to present proposals to overcome this substantial financial barrier.

Research and Development (R&D) can improve geothermal drilling technologies in order to reduce its costs, but the challenge today is also to improve market conditions for geothermal deep drilling. However, the deep geothermal drilling market has still not been thoroughly assessed- access to available geothermal drilling cost data is very limited. Moreover, the interaction between project developers and drilling contractors could be improved in order to stimulate both the market and the competition, the GEOELEC project tried to:

- · provide information, when available, on drilling costs in some EU countries
- create an European database listing drilling companies in order to pave the way for a dynamic and regularly updatedtool to be published online
- produce best practices on geothermal drilling for project developers

Geothermal drilling often uses the same technology as the oil and gas industries, particularly in low enthalpy sedimentary settings, although geothermal drilling does have several distinctive attributes. In short, sustainable geothermal exploitation requires deep seated, large diameter boreholes and long lasting well integrities.

Geothermal drilling costs follow the general oil and gas industry trend depicted in figure 1 which exemplifies a total dependence to (somewhat escalating) crude oil prices. This situation is likely to persist as long as the geothermal drilling sector does not build-up a strong market share of its own.

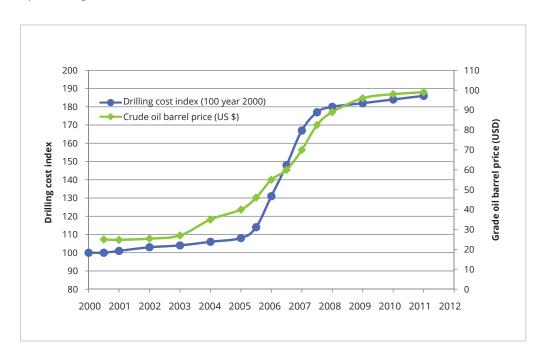


Figure 5.1: Drilling cost vs. crude oil prices

5.1 ANALYSIS OF DEEP GEOTHERMAL DRILLING MARKET IN EUROPE

It is of utmost importance that new technologies be implemented in order to maximise drilling cost effectiveness. Consequently one should contemplate two strategic issues:

- the transfer of the achievements of recently developed drilling technologies and equipment to EGS, and
- the potential application of novel technologies like spallation drilling, projectile drilling, chemical drilling and others, presently in the early R&D stage.

The support for any new drilling technology is recommended to be benchmarked by their demonstrated geothermal profitability-critical criteria:

Excavation productivity (m³/hr), excavation energy efficiency (KWh/m³) and specific borehole cost potential (ϵ /m_{borehole}&cm_{final diameter}).

Actual average cost for drilling in Europe is 1,000 EUR/m.

Drilling costs can be decreased by:

- R&D of current technology (more information available in the Strategic Research Agenda for Geothermal Electricity) and of developing novel technologies.
- Improvement of market conditions to develop competition

Firstly, drilling cost reduction concerns the costs decrease of equipment /methods:

- Drilling rigs
- · drilling services: drilling mud and directional drilling
- drilling tools such as high performance drill bits, novel drilling technologies
- directional drilling: side tracks, horizontal, multilaterals
- drilling/completion concept: exploration wells, slim hole drilling, sustainable well completion

Secondly, risk mitigation is also an issue for rendering the geothermal drilling costs more competitive with both the technical drilling risk (Lost in Hole) and the Mining Risk (Seismic Prediction While Drilling (SPWD).

The geothermal sector will develop in the next 10 years and drill new wells in both the electricity sector (1-5 km depth) and the district heating sector/direct uses (500 m - 2 km depth). Assuming an average number of 2 wells per plant per heating application, 5 MW per production well for electricity and an equivalent number of reinjection, the total number of geothermal wells in Europe in the next decade can be estimated to around 1300.

Against this background, one of the main problems encountered by geothermal developers today is related to drilling financing and regulatory barriers.

5.1 ANALYSIS OF DEEP GEOTHERMAL DRILLING MARKET IN EUROPE

The main problems of the drilling market in Europe can be summarised as follows:

- Manufacturing of a rig requires 1 year and costs circa EUR 20 Mio.
- There is a lack of experienced and skilled drillers: it takes 3-4 years to train a specialist.
- There is an insufficient number of supervisors for geothermal projects.
- There are no continuous business streams in the geothermal markets.
- Stop-and-go legislations to support geothermal are a barrier for long-term investment in new rigs and crew.

Regulatory aspects are quite different in each European country and regulations should be homogenised as much as possible.

5.2 DATABASE OF DEEP DRILLING COMPANIES

nformation regarding drilling market operators in Europe and rig equipment specifications is spread and often not easily available to project developers.

The GEOELEC online database includes a list of European drillers, drilling equipment manufacturers and providers, and drilling services companies. Such a list represents a first step towards a dynamic and regularly updated database available online at www.geoelec.eu. The database also contains information about the general features of the rigs available, e.g. operating climate conditions, draw works capacities, hook load capacities, drilling depth capacities.

5.3 BEST PRACTICE HANDBOOK

The formation and reservoir conditions that characterise geothermal systems require the adoption of drilling practices that differ from those utilised in conventional oil, gas, and water well drilling operations. Temperature, Geology, and Geochemistry are the principal areas of difference.

The elevated temperatures encountered; the often highly fractured, faulted, and permeable volcanic and sedimentary rocks which must be drilled; and the geothermal fluids which may contain varying concentrations of dissolved solids and gases have required the introduction of specialised drilling practices and techniques.

KEY FACTORS TAKE INTO ACCOUNT IN THIS REPORT ARE:

Temperature: the temperature of the earth's crust increases gradually with depth with a thermal gradient that usually ranges from 5°C to 70°C per kilometre. In anomalous regions, the local heat flux and geothermal gradients may be significantly higher than these average figures. Such anomalous zones are typically associated with edges of the continental plates where weakness in the earth's crust allow magma to approach the surface, and are associated with geologically recent volcanism and earthquakes. It is in such settings that the majority of geothermal resources are found and that the majority of geothermal wells have been drilled.

Geology: Geothermal fields occur in a wide variety of geological environments and rock types. The hot water geothermal fields about the Pacific basin are predominantly rhyolitic or andesitic volcanism, whereas the widespread hydrothermal activity in Iceland occurs in extensively fractured and predominantly basaltic rocks. In contrast the Larderello steam fields in Italy are in a region of metamorphic rocks, and the Geysers steamfield in California is largely in fractured greywacke. The one common denominator of all of these fields is the highly permeable, fractured and faulted nature of the formations in which the reservoirs reside. This high permeability is one of the fundamental and requisite components for any geothermal system to exist.

Geochemistry: Geothermal fluids contain varying concentrations of dissolved solids and gases. The dissolved solids and gases often provide highly acidic and corrosive fluids and may induce scaling during well operations. Dissolved gases are normally dominated by CO_2 but can also contain significant quantities of H_2S , both of which can provide a high risk to personnel and induce failure in drilling tools, casings and wellhead equipment. The presence of these dissolved solids and gases in the formation and reservoir fluids imposes specific design constraints on casing materials, wellhead equipment and casing cement slurry designs.

Drilling practices: the downhole conditions experienced in geothermal systems require some significantly different practices to be adopted. Some of these differences are outlined below.

Well design: The thermal efficiency of converting geothermal steam/water to electricity is not particularly high (±20%), therefore large mass flows and therefore volume flowrates are required, particularly in vapour dominated systems. These large volume flowrate requirements necessitate large diameter production casings and liners. Typically a 'standard' sized well will utilise standard API

5.3 BEST PRACTICE HANDBOOK

9 5/8" diameter casing as production casing and either 7" or 7 5/8" diameter slotted liner in an 8½" diameter open hole section. A 'Large' diameter well will typically utilise standard API 133/8" diameter casing as the production casing, with either 95/8" or 10¾" diameter slotted liner in a 12¼" diameter open hole. Casing sizes utilised for the Anchor, Intermediate, Surface and Conductor casings will be determined by geological and thermal conditions.

Casing depths. The depths of all cemented casing strings and liners is determined such that the casings can safely contain all well conditions resulting from surface operations and from the characteristics of the formations and fluids encountered as drilling proceeds.

Casing shoe depths are determined by analysis of data from adjacent wells which will include rock characteristics, temperatures, fluid types and compositions, pressures and particular fracture gradient data. At any time the depth of open hole below a particular casing shoe should be limited to avoid exposure of the formations immediately below the casing to pressures which could exceed the fracture gradient at that depth and hence lead to a blowout. It is usual to assume worst case scenario's such as exposing the previous casing shoe to the saturation steam pressure at the total drilled depth of that section.

Casing diameters: Casing diameters will be dictated by the desired open hole production diameter – typically either 8½" or 12¾". Slotted or perforated liners run into these open hole sections should be the largest diameter that will allow clear running – there is an obvious advantage to utilise 'extreme line' casing connections from a diameter point of view, however this is often offset by reduced connection strength of this type of casing connection.

Casing internal diameters should not be less than 50 mm larger than the outside diameter of connection collars and accessories, to allow satisfactory cementing.

Casing materials: Steel casing selected from the petroleum industry standard API Spec. 5CT or 5L. In general the lowest tensile strength steel grades are utilised to minimise the possibilities of failure by hydrogen embrittlement or by sulphide stress corrosion. The preferred API steels are: Spec 5CT Grades H-40, J-55 and K-55, C-75 and L-80; Spec 5L grades A, B and X42. In cases where special conditions are encountered, such as severely corrosive fluids, use of other specialised materials may be warranted.

Casing connections: The compressive stress imposed on a casing strings undergoing heating after well completion is extreme. Axial strength is critical and it is therefore important that the casing connection exhibits a compressive (and tensile) strength at least equivalent to that of the casing body.

Cementation of casings: The high thermal stresses imposed on the casings demand uniform cementation over the full casing length, such that the stress is distributed over the length of the casing as uniformly as is possible and such that stress concentration is avoided.

5.3 BEST PRACTICE HANDBOOK

The objective of any casing cementing programme is to ensure that the total length of annulus (both casing to open hole annulus, and casing to casing annulus) is completely filled with sound cement that can withstand long term exposure to geothermal fluids and temperatures. Many approaches are given by authors of report to solve this kind of problems.

Perforated and slotted liner: liner is usually perforated or slotted, typically, with the perforation or slots making up around 6% of the pipe surface area. As it is extremely difficult to determine exactly where the permeable zones within the production section lie, it is usual that the entire liner is made up of perforated pipe.

Drilling rig and associated equipment: The drilling rig and associated equipment are typically the same as is utilised for oil and gas well drilling, however a few special provision are required and are indicated in the Report.

Drilling fluids: The upper sections of a well are usually drilled with simple water based betonies mud treated with caustic soda to maintain pH. As drilling proceeds and temperatures increase, the viscosity of the mud is controlled with the addition of simple dispersants. If permeability is encountered above the production casing shoe depth, attempts will be made to seal these losses with 'Loss of Circulation Materials' (LCM), and cement plugs. If the losses cannot be controlled easily, then the drilling fluid is switched to either water 'blind' – that is drilling with water with no circulation back to the surface, or to aerated water. Further important remarks are given in the Report.

Well control: A geothermal well has the potential of being filled with a column of water at boiling point – even the slightest reduction in pressure on that column can cause part of, or the entire column to boil and flash to steam. This process can occur almost instantaneously. The potential for 'steam kick' is always there and requires special drilling crew training and attention.

In the final part of the report are described typical well design for geothermal heating and cooling of a district. Current low to medium enthalpy geothermal drilling/completion technology will be illustrated through selected examples focused on (i) deep district heating and cooling wells drilled in carbonate and sandstone reservoirs, (ii) design of injection wells in fine grained clastic alternating sand, clay, sandstone depositional sequences, (iii) medium depth dual completion wells exploiting tepid aquifers in conjunction with water/water heat pumps, and, last but not least, (iv) an anticorrosion well concept combining steel casings and fiberglass liners.

GEOELEC Deliverables:

- Report on Geothermal drilling
- Software on financial viability
- Database of deep drilling companies

6 REGULATIONS: STATE OF PLAY AND RECOM-MENDATIONS



6.1 OVERVIEW OF GEOTHERMAL REGULATORY FRAMEWORK IN EUROPE

Geothermal developers overtly abhor opaque, complex and lengthy licensing procedures. Deficient licensing rules can undoubtedly cramp investment in the geothermal electricity sector in Europe. Licensing rules for geothermal projects are no exception to the European diversity. They may be significantly different from one country to another and have uneven degrees of achievement all over Europe.

The initial assumption here is that, no matter the diversity and progress of the national geothermal licensing rules in Europe, they all remain to be perfected if geothermal electricity developers are to be guaranteed legal certainty. In order to kick-start the development geothermal electricity deserves at European stage, policy makers should remain aware of the need to further tighten national regulations so as to provide effective, reasoned and pragmatic licensing rules for geothermal. In this respect, the GEO-ELEC project here provides some yardsticks and recommendations for such effective and pragmatic geothermal licensing to be enforced.

By overviewing the geothermal regulatory frameworks in Europe, the main areas of legal problems and legal barriers can be defined. Regulations refer to the licensing process for exploration, drilling and mining and the environmental issues.

The terminology legal issue has been solved by the Directive on Renewable energy sources (2009/28/EC), with a binding definition of Geothermal Energy in the Article 2, which is defined as energy stored in the form of heat beneath the surface of solid earth. Talking about terminology, it should be underlined that 'exploitation' might not be the best word for a renewable energy such as geothermal; the energy extraction should be seen more a use or development of the resource. One area of legal problems and regulatory barriers is the resource ownership and protection definition. Regarding the ownership of the resources, two situations can be found within the European countries where plants are operational: a) by adoption of mining law or mineral resources law mentioning that the State / the crown gives a concession to project developer for exploiting the resource. It is a good option if licensing is regulated properly but it creates difficulties if it is included in water legislation; b) the underground resource ownership is given to the owner of the surface. It creates difficult situation in larger project where multiple owners are concerned, and for deep geothermal project this is very time consuming.

In juvenile markets there are no specifications about ownership. Traditionally, a first come - first served approach is in place; with the exception of states where a priority is given by law to a specific resources: water, energy etc.

Licenses allow the protection of an area and to avoid competitors using the same underground resources. Moreover, a licensing regime defines the frame for dispute solutions: the mining authorities and the responsible court of justice. However, licensing regulations can be another barrier to the development, due to their lengthy and complex procedures.

With state ownership, the following items are crucial for geothermal development:

- Who can apply for a license (non-discriminatory process)
- · One- or two-step-process (exploration, exploitation)
- Time period for which a license can be obtained, possible prolongations

6.1 OVERVIEW OF GEOTHERMAL REGULATORY FRAMEWORK IN EUROPE

- Royalties (based upon what parameter? Fixed or as a percentage of production?)
- Time for obtaining a license

Typically, exploration permission is firstly given for a period (4-6 years) and for a specific area. Afterwards an exploitation authorisation is attributed for 30 years or more, with in each case possibility of extension.

The length period of the permits should be enough long to allow for exploration and proper production, but should prevent speculations and fake exploratory projects.

The protection of the resource against other uses/users is crucial. No licenses should be given for other uses/users that would jeopardise the resource; and certain distance (or other protection) must be kept for other uses. The public entities involved to cover geological, water, energy aspects can be numerous: Mining authorities (national, regional), environmental agencies, local authorities etc. Each step can be time consuming.

Regulatory barriers can also result in cost barriers: These financial burdens include:

- Cost for legal fees, license fees
- Cost for royalties: in particular problematic if fixed and not related to production!
- Cost for environmental studies, public hearings, etc.

Taxes for the exploration permit (x EUR/km² of annual lease), for the mining lease and for the electrical production should neither be too high, and so preventing any investigation, nor too low and so creating speculation on permits.

The acquisition of geological data can also be a barrier when the data purchase is too expensive and when the confidentiality blocks the communication of the data. In the case of publicly funded projects, data protection is rather short but for private developers the confidentiality can remain for several years, with copy to the geological surveys.

Another main area of legal problems and regulatory barriers is the environmental regulation. The list of barriers resulting from environmental regulations can be rather long. There will, of course, be cases where environmental issues make a project impossible. However, this is limited to few cases and should be known as early in the project as possible. The rules protecting the environment in geothermal regulatory frameworks cover principally water protection, control of emissions, impact assessment and landscape assessment.

Groundwater protection is usually regulated in the different countries by water laws, but not always specific needs of geothermal projects are contemplated. For example pressure issues, soil protection as well as a protocol on micro-seismicity and surface issues. Regarding the protection of waters, Article 11 of Directive 2000/60/EC (Water Framework Directive) gives Member States the option to authorise the reinjection into the same aquifer of water used for geothermal purposes. It is therefore within the competence of the national governments to decide whether reinjection of the geothermal fluids is required.

Regarding emissions, all geothermal plants have to meet various national and local environmental standards and regulations, although emissions are not routinely measured below a certain threshold, and emissions from geothermal plants typically fall below this threshold. The pollution control regulations provided for EGS systems are no major obstacles for permit granting. Only noise limits may be of relevance, with regard to the cementation of the pipes and the hydraulic test work.

6.1 OVERVIEW OF GEOTHERMAL REGULATORY FRAMEWORK IN EUROPE

A major obstacle for geothermal projects is the environmental impact assessments (EIA). The National Planning Authority is responsible for monitoring the implementation and management of the EIA and has the power to decide which projects require an EIA. Since the contractor has the costs of implementation of an EIA, clear guidelines, which establish the conditions for EIA should be established.

6.2 PROPOSALS FOR IMPROVING THE REGULATORY FRAMEWORK

 $\mathsf{G}^\mathsf{EOELEC}$ project provides 12 key recommendations for improving the regulatory framework for geothermal electricity.

Legal certainty and transparency for geothermal licensing rely on ten key conditions that are shown in Figures 6.1 and 6.2 recommendations to meet these key conditions are reviewed in turn.



Figure 6.1: GEOELEC Key conditions to reach effective geothermal licensing rules

6.2 PROPOSALS FOR IMPROVING THE REGULATORY FRAMEWORK

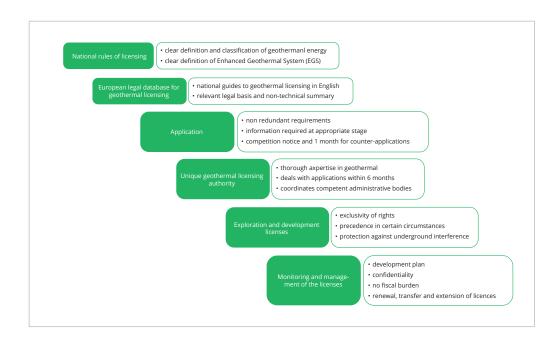


Figure 6.2: GEOELEC Description of the advised licensing process

Non-technical barriers against geothermal power plants and related to legal issues can result from:

- Uncertainty with regard to resource ownership and the difficult and lengthy
 procedures for obtaining exploitation rights. Best practice examples can be
 taken by the countries that solved satisfactory this issue.
- Environmental regulations, which are often unclear and difficult. They require a wise approach, protecting the environment but not killing projects, wherever possible.
- Unsecured grid access. As for other RES, grid access is a must for geothermal power. As already happens in some countries, a proper legislation may solve this issue.
- Transparent, reliable and coherent legal framework conditions of geothermal power development and implementation secure the long-term investments in the sector. A reduction of legal barriers may be obtained by implementing clear/standard administrative procedures to obtain concessions.

GEOELEC Deliverables:

- Report on legal grid access.
- Report on Geothermal Regulations.
- Overview of national Rules of Licensing for Geothermal.

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- European Union, Directive 2000/60/EC of the European Parliament and of the Council of 23
 October 2000 establishing a framework for Community action in the field of water policy.

7 ENVIRONMENTAL BENEFITS / IMPACT AND SOCIAL ACCEPTANCE



7.1 OVERVIEW OF ENVIRONMENTAL IMPACTS AND MITIGATION MEASURES

eothermal is fully recognised to be a safe, reliable, environmentally benign renewable energy source. However, all man-kind activities have somehow an impact on nature, including the construction of a geothermal power plant. GEOELEC has analysed the impacts to be considered in each of the phases of a geothermal project and put forward clear recommendations about possible mitigation measures. The Table 7.1 below summarises the result of this work.

	DEVELOPMENT PHASES	IMPACTS TO BE CONSIDERED	POSSIBLE MITIGATION MEASURES		
	Access roads, pipe laying	Main anticipated impacts are caused by surface disturbance, disposal of waste and visual impact.	Any permanent damage as such can be minimised with proper care, such as avoiding ecologically sensitive areas, locations of historical value and natural beauty.		
		Except for the visual impact, these effects are mostly tem- porary since they largely disap- pear once this construction phase is finished.	To minimise visual impact of the wellheads, it is recommended that each wellhead should be enclosed in a small building of a design that falls well in with the surroundings.		
	Well repair, well stimulation, well drilling and testing phase		Important to select only contractor(s) that have good environmental record. State in contract requirements on special waste ponds.		
		The predominant environ- mental concerns encoun- tered during this work phase are liquid and liquid carried pollutant release, noise and	With regard to noise impact, workers will need to apply hearing protections. Noise barriers will need to be erected if residential areas are being affected.		
		vibration, induced seismicity, solid waste, surface release of geothermal fluid, surface disturbance and visual impact.	Surface disturbance and visual impact can be minimised if care is taken during construction and careful land-scaping once the work is finished. Also important to avoid ecologically sensitive areas where possible.		
			Prior to EGS activities, the Project Owner will need to implement the		

Table 7.1: Summary of the possible impact of geothermal projects with regard to different development phases

Protocol for Induced Seismicity As-

sociated with Geothermal Systems.

7.1 OVERVIEW OF ENVIRONMENTAL IMPACTS AND MITIGATION MEASURES

DEVELOPMENT PHASES	IMPACTS TO BE CONSIDERED	POSSIBLE MITIGATION MEASURES	
Plant construction and equipment	The predominant environmental concerns encountered during this work phase are surface disturbance, noise, visual impact and disposal of waste.	The impact can be minimised through careful siting of the plant, avoiding ecologically and historically sensitive areas.	
installation		To minimise visual impact it is important to apply good architectural principles in the design and layout of facilities.	
Power plant com- missioning and operation		To minimise the number of hazardous substances in the geothermal fluid return stream it is recommended to consider thermodynamic scaling control rather than inhibitors where possible.	
	The predominant environmental concerns encountered during this work phase are emission and injection of geothermal fluids , gases and noise . Air emission from binary plants is minimal but flash plants for conventional use, emit some amount of hydrogen sulfide (H ₂ S) and carbon dioxide (CO ₂).	The geothermal plant should be designed avoiding any steam releases to the atmosphere. Non condensable gases should be either treated or diluted with large air quantities at the cooling tower.	
		For mitigation of emission of H ₂ S from flash geothermal power plants it is important to monitor the release and apply appropriate measures if emission numbers are above environmental limits.	
		Ventilation should be applied to avoid gases in confined spaces.	
		In terms of mitigation for noise, adequate ear protectors should always be made available to the staff.	
		Additional sound barriers, like trees being planted at strategic locations etc., could be required where permanent domiciles (farms, businesses, etc.) are located in the vicinity.	
Decommissioning of facilities	The predominant environmental concerns encountered during the decommissioning phase are chemical pollution and disposal of hazardous and other waste and surface disruption.	In general proper care should be taken when disposing of chemicals, during cleaning up of equipment and in landscaping during this project phase.	

7.2 POTENTIAL FOR CO₂ MITIGATION

The European Union is committed to decarbonising its economy while at the same time ensuring security of supply and preserving industrial competitiveness¹. This objective implies the reduction of greenhouse gas (GHG) emissions by 80-95% in 2050 compared to 1990 levels. As regards to the energy sector, this means some 85% GHG emission reductions by mid-century.

The development of geothermal energy for electricity production and particularly the use of EGS are promising options in this context. EGS are supposed to make a large contribution to a sustainable energy mix, in the future.

GEOELEC has analysed the potential of geothermal electricity regarding ${\rm CO_2}$ mitigation, considering ${\rm CO_2}$ -emissions of different energy sources and particularly of the different geothermal power plants on-line today and in the future. The resource assessment study developed within the framework of the GEOELEC Project and presented in Chapter 2 of this report is the basis for the ${\rm CO_2}$ -mitigation potential in the EU.

1 "[...] in the context of necessary reductions according to the IPCC by developed countries as a group". European Council, Presidency Conclusions, October 2009, p.3.

CO₂ EMISSION BY ELECTRICITY GENERATION FROM GEOTHERMAL POWER PLANTS

Emission rates associated with geothermal power plants are much lower than emissions from coal or gas-fired power plants. However, to quantify CO_2 mitigation by deployment of geothermal energy utilisation it is necessary to quantify the CO_2 emissions from geothermal power plants itself. Also here it is valid that one has to distinguish between CO_2 emissions occurring during the power production process and CO_2 emissions occurring during the whole lifecycle process, furthermore geothermal/volcanic systems emit gases naturally. Zero emissions can only occur when the power production process is considered solely but never when the whole lifecycle is included.

In the following pages the recent results concerning CO_2 emissions related to geothermal electricity production are examined, considering the aforementioned aspects and differentiating between (1) geothermal power plants using an open system (2) new geothermal power plants using a close system and (3) EGS geothermal power plants using a close system.

NATURAL EMISSIONS FROM GEOTHERMAL RESERVOIRS

In high-enthalpy or high-temperature geothermal reservoirs gasses emit naturally. The gases naturally vent to the atmosphere through diffusive gas discharges from areas of natural leakage, including hot springs, fumaroles, geysers, hot pools, and mud pots. CO_2 is the most widely emitted gas, but geothermal fluids can, depending on the site, contain a variety of other minor gases, such as hydrogen sulphide (H_2S), hydrogen (H_2), methane (CH_4), ammonia (NH_3) and nitrogen (N_2). Mercury, arsenic, radon and boron may be present (Goldstein et al., 2011). Thus to what extend gases emit to

7.2 POTENTIAL FOR CO₂ MITIGATION

the atmosphere depends on the geological, hydrological and thermodynamic conditions of the geothermal field. The question was raised if in such systems emissions of geothermal power production are negligible in comparison to natural emissions. Bertani and Thain (2002) analysed this question considering data from the Larderello geothermal field (Italy) and they concluded that all gas discharge resulting from power production is balanced by a reduction in natural emissions. However, the study conducted by Ármannsson et al. (2005) showed different results. The analysis of ${\rm CO_2}$ emission from the three major geothermal power plants in the country was 1.6·108 g in 2002, which is essentially equal to the natural ${\rm CO_2}$ discharge from Grímsvötn, the most active volcano in Iceland.

Natural emissions are restricted to geothermal/volcanic systems; this problem is not a matter of consequences for the deployment of EGS.

GEOTHERMAL POWER PLANTS IN OPERATION USING AN OPEN SYSTEM

In dry and flash steam plants, non-condensable gases are separated from the steam turbine exhaust in the plant condenser and are either discharged to the atmosphere or removed by an abatement system. Abatement systems so far prevent the release of hydrogen sulfide and elementary mercury; however, also CO_2 discharge can be prohibited by recovering liquid carbon dioxide (Nolasco, 2010). Several studies deal with the quantification of CO_2 emissions during the power production process through geothermal power plants using an open system. Ármannsson et al. (2005) analysed CO_2 emissions from Icelandic geothermal power plants. They evaluated data of three dry steam geothermal power plants and received CO_2 emissions between 26–181 g/kWh.

Bertani and Thain (2002) obtained CO_2 emission data from 85 geothermal power plants operating at this time in 11 countries around the world. The collected data show a wide spread in the overall CO_2 emission rate from the plants. The authors report a range of 4 g/kWh to 740 g/kWh with the weighted average being 122 g/kWh. From the collected data, the average CO_2 content in the non-condensable gas is 90.5%.

GEOTHERMAL POWER PLANTS IN OPERATION USING A CLOSE SYSTEM

Binary power plants retain non-condensable gases in a closed loop system; the thermal water is re-injected after utilising its heat at the heat exchanger. The result is near-zero emissions during the power production process as the non-condensable gases are never released to the atmosphere (Holm et al., 2012). However, if gas separation occurs within the circulation loop, some minor gas extraction and emission is likely (Goldstein et al., 2011).

7.2 POTENTIAL FOR CO₂ MITIGATION

EGS GEOTHERMAL POWER PLANTS IN OPERATION

For the generation of power from such systems closed-loop cycles are used and gaseous pollutants are not emitted during plant operation similar to binary power plants. Hence, EGS binary power plants can be assumed to be in most cases free of CO_2 emissions considering only the production process and further also natural emissions of gases do generally not occur in these reservoirs.

CO2-MITIGATION POTENTIAL OF GEOTHERMAL POWER PLANTS IN THE EU

Bertani and Thain (2002) calculated CO_2 mitigation based on the results of CO_2 -emission rates of the data they obtained from dry and flash steam geothermal power plants worldwide. They report that replacing a combined cycle natural gas fired plant with a geothermal power plant having a CO_2 -emission rate of 55 g/kWh would give a net saving of 260 g/kWh of generation. Similarly, if a fuel oil plant is replaced the net saving would be 705 g/kWh, and for a coal-fired plant the saving would be 860 g/kWh.

	PRODUCTION (TWh)	ADDITIONAL NET PRODUCTION (KWh)	CO, SAVING POTÊNTIAL BY SUBSTITUTING COAL-FIRED POWER PLANTS (TON, EQ/Y)	CO, SAVING POTÊNTIAL BY SUBSTITUTING GAS-FIRED POWER PLANTS (TON, EQ/Y)
EU-28 in 2012	5,6			
EU-28 in 2030 (GEOELEC)	34	28400000000	24.424.000	7.384.000
EU-28 in 2050 (GEOELEC)	2570	2.564.400.000.000	2.205.384.000	666.744.000

Table 7.2: Geothermal power net CO2 saving potential in the European Union compared to coal and gas

If we apply these results to the economic potential of geothermal power in the EU stemming from the GEOELEC resource assessment analysis and assuming that the economic potential in 2030, (i.e 34 TWh), is fully realised to replace ageing coal-fired power plants, the net CO₂ savings would amount to 24.4 Mt. As already mentioned, however, it should be highlighted that CO₂-emission rates for geothermal in Bertani and Thain (2012) are obtained from dry and flash steam geother-

mal power plants, while most of the new build (binary systems) will be carbon neutral.

Most importantly, if we consider the 2050 geothermal potential in the EU, i.e. 2570 TWh, the theoretical CO₂ mitigation potential amounts to 2205 Mt CO₂ compared to coal, and 666 Mt CO₂ compared to gas (Table7.2), which is more than sufficient to stamp out current emissions and avoid the construction of new fossil fuel power stations.

Social acceptance is an important factor in site selection due to environmental issues, missing involvement issues, financial issues (in case of e.g. municipal grants), NIMBY (Not In My Back Yard) acceptance issues, and local energy production.

GEOELEC has analysed a number of case-study to identify best-practice to favour public acceptance. The main results are summarised below.

PUBLIC ACCEPTANCE IN THE ENERGY AND IN THE GEOTHERMAL SECTOR

Public or social acceptance was defined by (Wüstenhagen, Wolsink and Bürer 2007) as a combination of three categories, socio-political acceptance, market acceptance and community acceptance. Figure 7.1 shows the so called "Triangle of social acceptance".

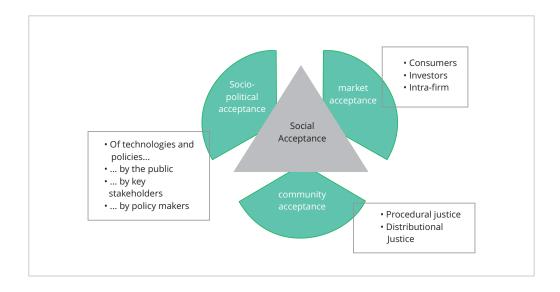


Figure 7.1: The triangle of social acceptance of renewable energy innovation (Wüstenhagen, Wolsink and Bürer 2007)

Energy issues are clearly perceived as very politicised at the moment (Pellizzone, et al. 2013). Environmental questions, land management, greenhouse gas emissions and economic impacts of energy policy make European citizens very sensitive to energy issues. However ethics is often seen as an obstacle to economic growth and the development of new technologies, but it can also operate as a driving force for innovation. In the case of renewable energies (e.g. geothermal, solar and wind), the reduction of anthropic impact on environment, the creation of new jobs, the allocation of funds in research and innovation and the political question related to the energetic independence from other countries are considered as drivers for research and advance of green technologies.

Nevertheless, social acceptance of green technologies has often been underestimated. Medium to large renewable energy plants necessarily relate to land management and local communities need. Surveys conducted in European countries show that views on geothermal energy are less formed amongst citizens than views on technologies that exploit and harness solar and wind energy. In certain areas, so far, European citizens show little knowledge on geothermal technologies and often different types of heat exploitation, i.e. high-low enthalpy, are not differentiated. Information on landscape impact, seismicity, emissions, economic and social impact of geothermal power plants are strongly required by citizens.

Ethical issues opened by geothermal technologies development could cause both positive reaction due to the exploitation of a renewable resource and negative reaction due to impacts unknown by the majority of citizens. An information campaign about this technology, its environmental, economic and social impacts is therefore strongly needed.

Surveys on citizens' expectations, concerns and needs are also essential to launch a participation program in the early stages of new plants and geothermal technology development. For a qualitative growth of research and innovation and a profitable dialogue between all stakeholders of energy policies, Research and Responsible Innovation is strongly recommended also in the geothermal project development.

The integration of the public and thus social acceptance cantherefore be reached through three steps (Hauff, et al. 2011):

- Communication and information
- · Integration and involvement
- Balance of interests and conflict resolution

If conflicts occur, the project developer should try to find a dialogue without predefined results.

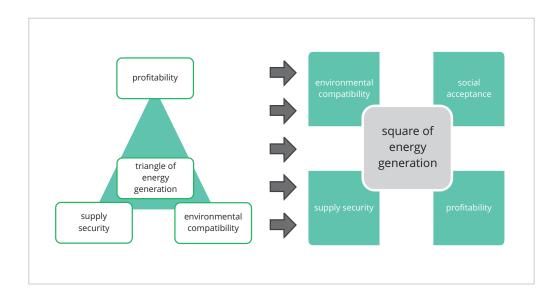


Figure 7.2: Square/ Triangle of energy generation

RECOMMENDATIONS

The goal of theGEOELEC project was not to write another guideline for social acceptance in renewable energy development. The consortium has rather raised awareness for the topic of social acceptance within geothermal energy development. Guidelines for social acceptance of geothermal power are currently developed e.g. in the research project "Project for evaluation and improvement of public relations for geothermal projects". In addition, general guidelines for social acceptance of renewable energies are for example published by (Haug and Mono 2012) or (Arndt, et al. 2013).

FOUR FACTORS WHICH ARE CRUCIAL FOR SOCIAL ACCEPTANCE

- OPEN AND TRUSTWORTHY COMMUNICATION
- A SURPLUS FOR THE STAKEHOLDERS
- ECONOMIC AND ECOLOGICAL MEANINGFULNESS
- FINANCIAL SECURITY FOR STAKEHOLDERS IN CASE OF AN ACCIDENT;
 PROJECT DEVELOPERS THAT ARE ABLE TO COMPENSATE FOR POSSIBLE DAMAGES

From the theoretical and practical examination of social acceptance issues in GEOELEC one can learn that information, participation, cooperation and consolidation are the backbones of a successful social acceptance initiative. In the following graph, the ideal implementation of a project is shown. Figure 7.3 below therefore shows the different steps of project implementation and the actions that should be taken in social acceptance issues.

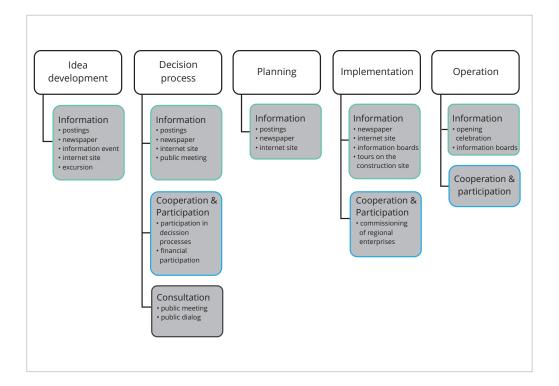


Figure 7.3: Implementation of renewable energies (Own illustration based on (Arndt, et al. 2013)

Right from the beginning the project should be offensively communicated to the public. The public should have access to several information channels like information events or the internet. In a second step the affected citizens should be integrated into the decision process; therefore the implementation process should be explained. Affected citizens can contribute their ideas, and fears can be relativised within an objective discussion. Additionally the community is informed about participation possibilities (e.g. financial participation; direct heat applications). Throughout a location analysis the public is fully informed about the current development. For the final decision, affected citizens and the project developers come together and discuss possible consequences of the power plant. During the planning phase the public is informed on a regular basis. The construction phase is also marked by a steady, unrequested information stream from the developers. By contracting local enterprises, added value stays within the community. After the completion of the power plant a ceremonial opening is organised, and citizens can visit the power plant (Arndt, et al. 2013).

As a conclusion a profit oriented project can only be realised with the consensus of the local community. This consensus can only be gained by "acting in consonance with the dynamic conditions of the environment, and in the respect of the people's health, welfare, and culture" (Cataldi 2001).

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April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance).

GEOELEC Deliverables

- Environmental study on geothermal power.
- Geothermal potential for CO₂ mitigation.
- Report on Public acceptance.

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8 SKILLS GAP
AND ACTION
PLAN FOR
ESTABLISHING
AN EDUCATIONAL
SYSTEM AND
CREATING JOBS
ON GEOTHERMAL
POWER



8.1 EXISTING EDUCATION SCHEME FOR GEOTHERMAL IN EUROPE

ost jobs in the industry require a university degree. Existing university courses in fields such as engineering, bio-sciences, earth sciences, business administration and finance can provide the ground for working professionally in the industry. Many universities already develop their courses and curricula to address the growing interest in renewable energy generally and geothermal energy more specifically. Many universities also offer postgraduate studies specialised in these topics.

The education at universities can be found in two different formats:

- Geothermal specialisation block courses integrated in university programmes of Geosciences/Geo-resources, Civil Engineering, Process and Environmental Engineering, Mechanical Engineering, Sustainable Energy. They are usually short-time courses covering basic skills, and often on voluntary basis.
- only few European universities hold chairs in geothermal energy and offer specific degree courses

Education at national (research) institutes exists also. These other academic institutions offer graduate and postgraduate education courses and PhD programs in close cooperation with universities. One of the main problems of the drilling market in Europe is the lack of experienced and skilled drillers. Some immediate actions are need there as it takes 3-4 years to train a specialist. Moreover, we can see an insufficient number of supervisors for geothermal projects. Here it is more complicate to overcome as some years of practical experience are required. It should be investigated to recruit in other sectors such as oil & gas.

Training geothermal power staff notably on EGS is an important issue today. The present situation shows that:

- The limited available higher education in specialisations related to geothermal energy exploration, exploitation and utilisation, is inadequate to supply the high skilled personnel needed in the geothermal power industry, as important geothermal topics are not presented in existing graduate courses.
- Basic training on geothermal technologies is rarely available in EU member states.
- The same applies to post-graduate specialisation in geothermal energy, as most geothermal courses around the world stopped or reduced activity due to lack of financial support.

As geothermal power projects need specialists in many fields of geology and engineering, on-the-job in-company training is still absolutely necessary. The closest fields in terms of available technical expertise are the oil, gas and coal sectors, but even these workers need to be re-qualified in order to operate in the geothermal sector, where technology has to cater for the high temperatures and the chemistry of the fluids concerned.

So geothermal training is expected to grow together with the growing of the geothermal sector.

8.2 GEOELEC TRAINING ACTIVITIES

raining activities must be developed now to support the development of geothermal power. The GEOELEC project tried to contribute to this activity.

The first step was to prepare a curriculum for each profile describing the minimum competence required. The different profiles were detailed during the project to determine the more pertinent ones from the following groups: resource assessment, exploration, drilling, production, surface systems, and non-technical issues.

Secondly, training materials have been produced. Existing materials in related fields (deep geothermal) have been integrated into GEOELEC training materials. The goal was to complete these existing documents by updating them with the latest technologies and development notably on EGS. Training materials developed consisted in power-point presentations and a manual of 50 pages.

Finally, GEOELEC organised 3 training courses in France (Strasbourg-November 2012), Germany (Postdam-April 2013) and Italy (Pisa-October 2013). These training courses lasted 4-5 days including a site visit.

During the GEOELEC training courses, attention was paid for a special "reconversion session" for people working today in industrial sectors in crisis and workers from oil and gas sector, presenting job opportunities in the geothermal sector. In particular, big efforts should be done in Central and Eastern European countries (Hungary, Romania, Italy) and in the emerging geothermal countries (Spain and Portugal) to recover the deep drilling experienced companies and make the existing national drilling industry capable for the deep geothermal drilling.

The target groups of the GEOELEC courses were the following:

- · Oil & gas sector,
- · Deep drilling industry,
- · Utilities,
- Developers and operators
- Geological surveys, national energy agencies
- · Professionals of the geothermal power sector
- · Educational facilities and associations,

8.3 RECOMMENDATIONS ON GEOTHERMAL POWER TRAINING AND EDUCATION

A) ENHANCE THE EDUCATION AND TRAINING PROCESS, SINCE MULTIDISCIPLINARY EXPERTISE AND INTERACTION OF SEVERAL DISCIPLINES ARE NECESSARY.

Enhancement of the educational and training process is the factor that can have the largest effect on the long-term needs regarding certain job specialties and skills. Ensuring the existence of necessary skills in the sector requires action at all levels of education and training, meaning technical and scientific education, training and continuous learning. In order to achieve proper education reforms, cooperation between all organisations involved is required. Cooperation between companies, universities, polytechnic schools, training organisations, employment agencies and certification institutions is needed.

Educational programmes often cover basic skills, while they are not able to meet more specialised requirements. Developing the content of a course may require time, effort and expertise, factors that can limit the educational institutes. This may result in an unattractive educational or training programme. This is why there must be cooperation, so that governments and geothermal power companies assist education suppliers to develop appropriate educational programs. Also, this cooperation will contribute to ensure a frequent updating of the content of educational and training programs, so that the skills and knowledge of graduates are always updated.

Financial support of both students and educational institutes is also a factor that can assist the whole process. In case the difficulty is in attracting young people, rather than the willingness of the industry to train them, then financial measures should aim more at the students. Financial incentives can be provided through covering the training cost of the students and by subsidising educational and training programs.

B) CREATE NETWORKS FOR GEOTHERMAL ENERGY EDUCATION AND TRAINING INVOLVING INDUSTRIAL PLATFORMS, UNIVERSITIES AND RESEARCH CENTRES DEVELOPING A WORKFORCE FOR FUTURE GEOTHERMAL DEVELOPMENT.

Cooperation between education and training institutes and companies is necessary, so that the number of graduates fits the requirements of the labour market, while students are provided with the appropriate skills and knowledge. Linkage between universities and companies can also create a network which may allow a faster and more efficient treatment of the needs that are generated.

The skill and workforce gap issue must be recognised and addressed, not individually, but comprehensively by all countries. International and intergovernmental organisa-

8.3 RECOMMENDATIONS ON GEOTHERMAL POWER TRAINING AND EDUCATION

tions should work in order to promote cooperation between countries. This may include cooperation and measures to increase the mobility between educational and training suppliers, researchers and apprentices which are involved in the education and training process and in the development procedures of standards regarding skill qualifications in different countries.

Education and training programs targeting on the sector should focus on skills that can be transferred between different fields. Employment in the development, manufacture and installation can be unstable, even if attempts are made to obtain an approximate smooth transition. In occupations associated with the operation and maintenance, there may also be periods where the intention to recruit new trained workers will be limited. Education and training programs should therefore be developed around a core specialty which will be suitable for a wider range of sectors.

Needs by 2030:

EDUCATION AND TRAINING NEEDS – European Union Member States and Associated Countries					
Qualification	European Workforce 2012	Estimated Education & Training Needs 2012-2020	Estimated Education & Training Needs 2020-2030		
		(new positions + replacements)	(new positions + replacements)		
GEOTHERMAL ENERGY					
TOTAL	2500	21 000 + 1000	35000 + 1450		
Researchers	500	5000 +200	5000 + 250		
Engineers	1100	8000 +400	15000 + 600		
Technicians	900	8000 + 400	15000 + 600		

The needs in education and training concern deep geothermal energy, only, with a strong focus on electricity production (SET Plan on Education & Training Initiatives Assessment Report for Geothermal energy, E. Schill, February 2013)

8.4 GEOTHERMAL EMPLOYMENT IN EUROPE

n 2013, there were 2500-3000 jobs directly related to geothermal electricity in the EU-28. Geothermal energy jobs can be broken down into different types, from engineers, drillers and workers in equipment factories to project managers. Geothermal power also generates indirect jobs, for example with suppliers of raw materials and induced jobs. The estimated total number of geothermal power jobs in 2013 is 10.000 jobs.

The geothermal energy sector builds upon various segments, essential for the core functions of the industry, i.e. resource exploration and geothermal energy production.

These segments involve equipment suppliers, service providers (e.g. technical/ financial/legal consultants), or final energy off-takers (consumers). Another key segment for the development of the geothermal industry is the underlying research and development as well as relating training and educational activities.

Geothermal development is closely intertwined with other activities such as governmental services (e.g. for obtaining exploration permits), regulatory affairs (upon which market regulation hinges) etc.

There are also industries that are related to geothermal in that they employ similar technics or specialists with identical core skills. With sectors such as mining, oil & gas, carbon capture and storage, the geothermal industry could engage in cooperation and technology crossover. Also, the geothermal sector (being on the rise) could attract workers or subcontractors from related sectors in decline, e.g. the mining sector in Europe.

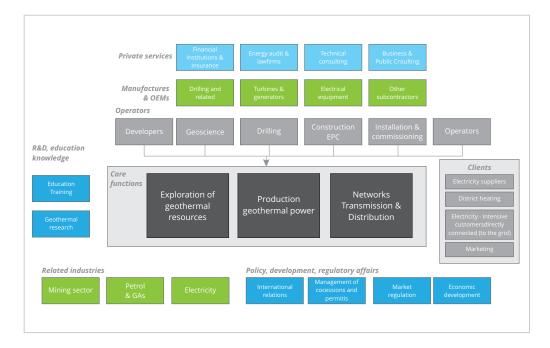


Figure 8.1: Geothermal industry overview. Source: GEOELEC, adapted from Capgemini Consulting and CanmetEnergy

8.5 RECOMMENDATIONS FOR JOBS CREATION IN EUROPE

Contribute to the development of the local economy. Create local jobs and establish a geothermal industry in Europe which will be able, by 2030, to directly employ more than 100,000 people (exploration, drilling, construction and manufacturing).

Based on the projects under development and under investigation as well as new installed capacity, job creation is expected by 2020 in Italy, Hungary, Greece, Portugal, France, Germany, Spain, UK, Iceland, Turkey, Belgium, Slovakia and Switzerland. By 2030, more than 100,000 people should be employed in the sector.

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

Job opportunities are provided for people with different types and levels of skills. Scientists and engineers are needed to explore new geothermal fields, and skilled technicians are required for construction and operation of the new geothermal power plants.

As the transition towards RES is progressing, it seems inevitable that significant reductions will occur in fossil fuel employment. Like every industry that is negatively touched by regional, national or European policies, it will be important to plan a fair transition for the workforce that has been affected. This implies that the general transition must occur with a stable pace, and not at once. It also implies that the workforce that has been affected has the opportunity to acquire new skill through retraining, so that they can get employed in the geothermal sector. To this end, there is a range of EU funds (e.g. European Social Fund, European Globalisation Adjustment Fund available to national and regional authorities that can be used in order to effectively manage employment restructuring.

Stimulating mobility of highly skilled employees between countries can contribute to the reduction of skill and workforce shortages. Regarding the mobility of employees within the EU members, movement is free as one of the fundamental freedoms of the Internal Market. On the other hand, the immigration of individuals from third-countries (countries outside the EU) remains in the national policy context of each individual EU member.

Some of the main areas in which the geothermal power industry can have an impact regarding economic activity and job creation are:

- Suppliers of mechanical equipment and raw material;
- Consultants and contractors searching for geothermal resources;
- Drilling and well service firms;
- Environmental services managing permits and sample testing;

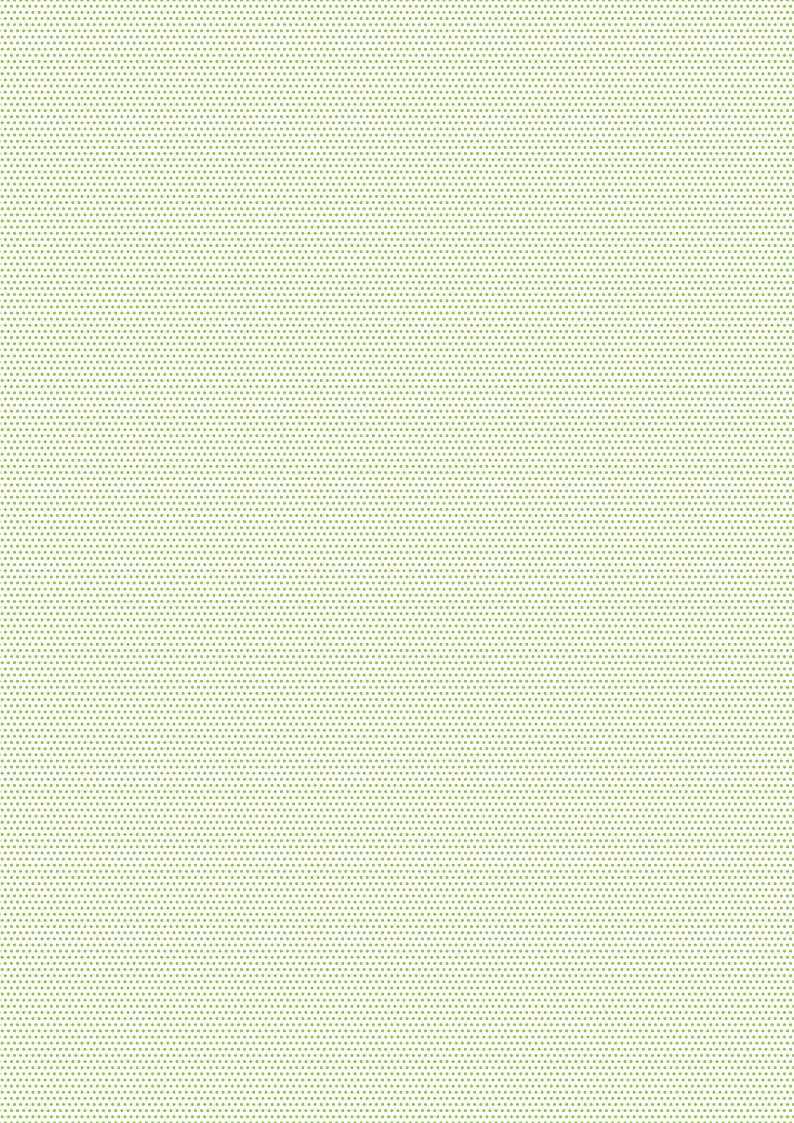
8.5 RECOMMENDATIONS FOR JOBS CREATION IN EUROPE

- Geothermal developers, regarding project development, construction, security etc.;
- Power plant operators and maintenance staff;
- Scientists for ongoing research and development.

As geothermal technologies are site specific (the geology is different all over Europe and knowledge of the local conditions is essential) and capital-intensive, the needs regarding exploration, resource development, construction and O&M are covered by the local workforce. Manufacturing jobs may be created internationally, depending on where the industries manufacturing the particular equipment are located.

Overall, it is estimated that 85% of the geothermal value chain in Europe is European. In the future, this is unlikely to change as most of the geothermal-related jobs cannot be relocated.

Employment in the geothermal power industry is expected to increase while skill gaps and labour shortages may occur. For this reason relevant public policy measures need to be consistent with energy policy (triggering change in employment needs) and industrial policy, and complemented by corresponding social and educational policies.



CONCLUSIONS: A GEOTHERMAL ELECTRICITY ACTION PLAN FOR EUROPE

CONCLUSIONS: A GEOTHERMAL ELECTRICITY ACTION PLAN FOR FUROPE

Based on the project results, the GEOELEC consortium suggests the following action plan to develop geothermal electricity in Europe.

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

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

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

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

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

Contribute to the economic competitiveness of Europe by providing affordable electricity. In order to progress along the learning curve and deploy at large-scale a reliable renewable technology, a European EGS flagship programme should be launched, including new demonstration plants and test laboratories. It should also look at new technologies, methods and concepts.

CONCLUSIONS: A GEOTHERMAL ELECTRICITY ACTION PLAN FOR FUROPE

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

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

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

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

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

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

As pre-drill assessment of geothermal performance is subject to major uncertainty and EGS is in an embryonic development phase, the risk profile is high compared to alter-

CONCLUSIONS: A GEOTHERMAL ELECTRICITY ACTION PLAN FOR EUROPE

native sources of renewable energy. In order to face these challenges the following financial incentives are required to facilitate growth of geothermal energy in Europe:

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

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

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

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

CONCLUSIONS: A GEOTHERMAL ELECTRICITY ACTION PLAN FOR FUROPE

Contribute to the development of the local economy. Create local jobs and establish a geothermal industry in Europe which will be able, by 2030, to employ more than 100,000 people (exploration, drilling, construction and manufacturing).

In 2013, there were 2500-3000 jobs directly related to geothermal electricity in the EU-28, while the estimated total number amounts to 10,000 jobs.

Additionally, based on the projects under development and under investigation, more than 100,000 people should be employed in the sector.

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

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

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

ANNEX I: GEOELEC PUBLICATIONS

RESOURCE ASSESSMENT	A Methodology for Resource assessment
	 Web-service Database on Resource Assessment
	 Factsheet on Geothermal Potential
	 Prospective Study on the Geothermal Electricity Potential in the EU
	Factsheet on Market Development
	 Factsheet on Finance and Economics
	Report on Risk Insurance
FINANCE	 Report on Geothermal drilling
	 Database of Deep Drilling Companies
	Investment Guide
	 Software for Financial pre-feasibility studies
	 Factsheet on Regulation and Public Acceptance
	 Technical Report on Grid Access
	 Environmental Study on Geothermal Power
REGULATIONS	Report on Legal Grid Access
	 Report on Geothermal Regulations
	 Overview of National Rules of Licensing for Geothermal
	Geothermal Reporting Code Review
	 Geothermal Potential for CO₂ Mitigation
-	Fact Sheet on Employment and Training
	 Training Manual (Postdam)
	 Presentations from Training Courses
TRAINING & EMPLOYMENT	 Action Plan for Promoting Workers' Mobility and an Education System
	 List of European Universities Offering Training and Education
	Employment Study
COMMUNICATION	Report on Public acceptance

ANNEX II: THE GEOELEC CONSORTIUM

EUROPEAN GEOTHERMAL ENERGY COUNCIL (EGEC – BE)





Gaßner, Groth, Siederer & Coll.

BUREAU DE RECHERCHES GÉOLOGIQUES ET MINIÈRES (BRGM – FR)

ENBW ENERGIE BADEN-WÜRTTEMBERG (AG ENBW- DE)





CENTRE FOR RENEWABLE ENERGY SOURCES AND SAVING (CRES – EL)

MANNVIT (IS)





CONSIGLIO NAZIONALE DELLE RICERCHE, ISTITUTO DI GEOSCIENZE E GEORISORSE (CNR-IGG – IT) HELMHOTZ ZENTRUM POSTDAM – DEUTSCHES GEOFORSCHUNGSZENTRUM (GFZ – DE)



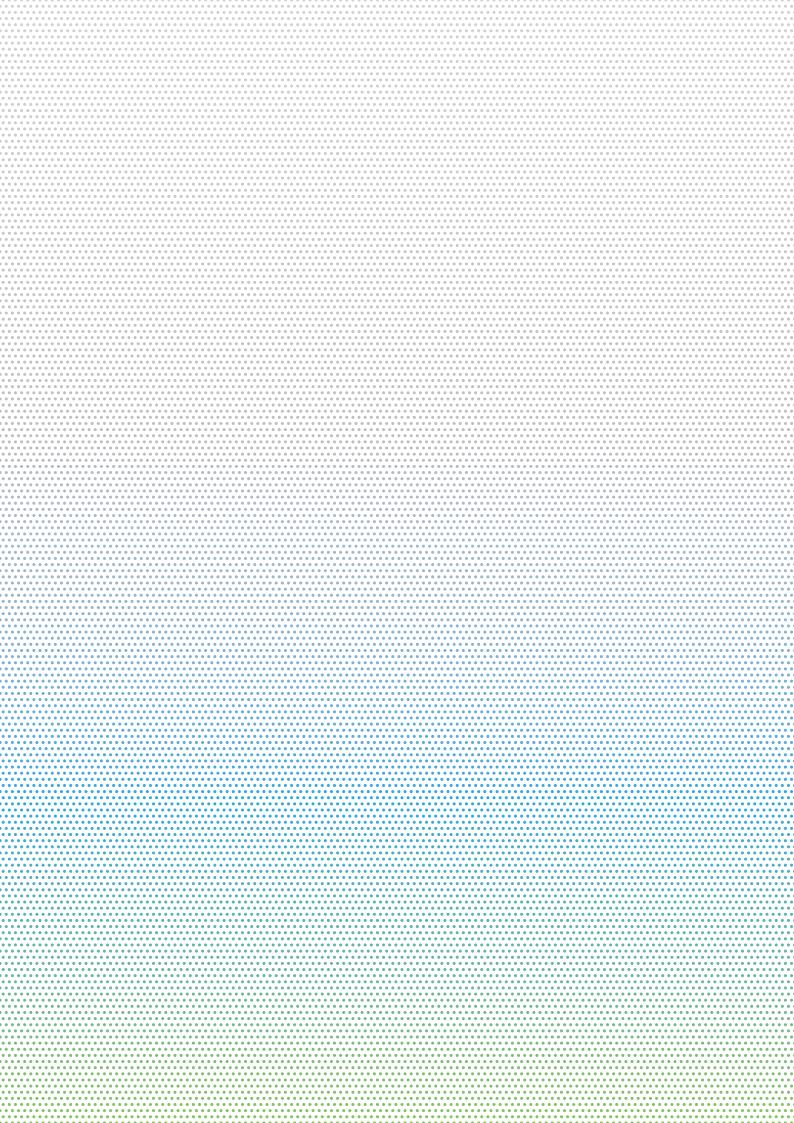


ASOCIACION DE PRODUCTORES DE ENERGIASRENOVABLES (APPA - ES)

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