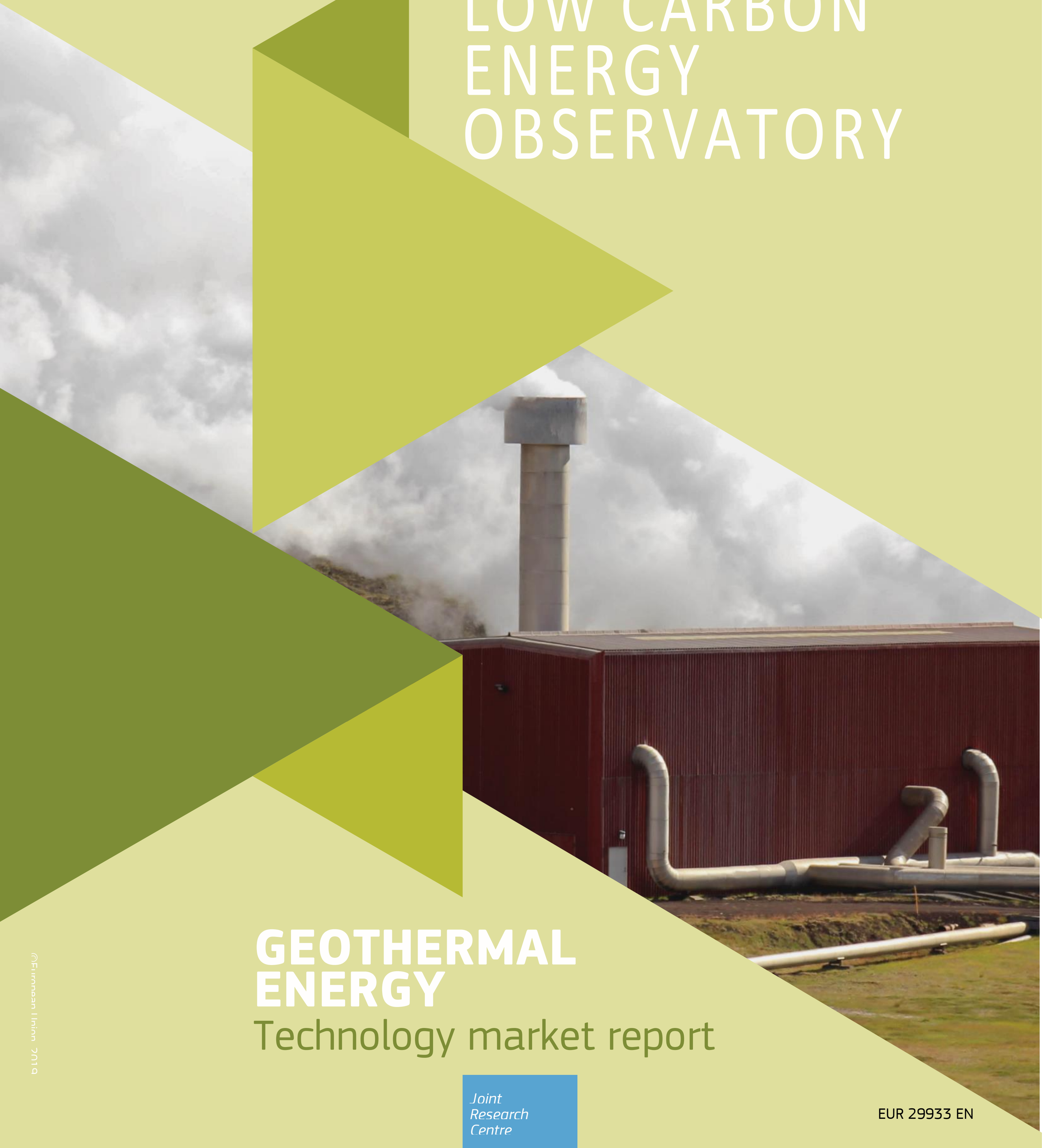
European Commission

LOW CARBON ENERGY OBSERVATORY



GEOTHERMAL ENERGY

Technology market report

Joint Research Centre

EUR 29933 EN

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Contents

Foreword on the Low Carbon Energy Observatory

The LCEO is an Administrative Arrangement being executed by DG-JRC for DG-RTD, to provide top-class data, analysis and intelligence on developments in low carbon energy supply technologies. Its reports give a neutral assessment on the state of the art, identification of development trends and market barriers, as well as best practices regarding use of private and public funds and policy measures. The LCEO started in April 2015 and runs to 2020.

Which technologies are covered?

- Wind Energy
- Photovoltaics
- Solar Thermal Electricity
- Solar Thermal Heating and Cooling
- Ocean Energy
- Geothermal Energy
- Hydropower
- Heat and Power from Biomass
- Carbon Capture, Utilisation and Storage
- Sustainable advanced biofuels
- Battery Storage
- Advanced Alternative Fuels

In addition, the LCEO monitors future emerging concepts relevant to these technologies.

How is the analysis done?

JRC experts use a broad range of sources to ensure a robust analysis. This includes data and results from EU-funded projects, from selected international, national and regional projects and from patents filings. External experts may also be contacted on specific topics. The project also uses the JRC-EU-TIMES energy system model to explore the impact of technology and market developments on future scenarios up to 2050.

What are the main deliverables?

The project produces the following generic reports:

- Technology Development Reports for each technology sector
- Technology Market Reports for each technology sector
- Report on Synergies for Clean Energy Technologies
- Annual Report on Future and Emerging Technologies (this information is also systematically updated and disseminated on the online FET Database).

Techno-economic modelling results are also made available via dedicated review reports of global energy scenarios and of EU deployment scenarios.

How to access the deliverables

Commission staff can access all reports on the Connected LCEO page. These are restricted to internal distribution as they may contain confidential information and/or assessments intended for in-house use only. Redacted versions also are distributed publicly on the SETIS website.

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Acronyms and Abbreviations

ASHP	Air Source Heat Pumps
ATES	Aquifer Thermal Energy Storage
BHE	Borehole heat exchangers
BTES	Borehole Thermal Energy Storage
CAPEX	Capital expenditure
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilisation and Storage
CPC	Cooperative Patent Classification
DOE	Department of Energy of the United States
EGRIF	European Geothermal Risk Insurance Fund
EGS	Enhanced Geothermal System
ETS	Emission Trading Scheme
EU	European Union
FIP	Feed-in-premium
FIT	Feed-in-tariff
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
LCOE	Levelised Cost of Electricity
MS	Member State
NDC	Nationally Determined Contribution
NREAP	National Renewable Energy Action Plans
OPEX	Operating expenditure
ORC	Organic Rankine Cycle
R&D	Research and Development
UTES	Underground Thermal Energy Storage

1 Introduction

The objective of this report is to highlight recent technology market trends and developments in the field of geothermal energy and to explore the medium and long-term perspective of the geothermal energy technology markets with a focus on Europe. The report highlights the relative competitive position of the EU geothermal industries.

This report builds on established JRC work [JRC 2015a, JRC 2015b, Magagna et al. 2017] in the area of geothermal energy and includes results from additional modelling work performed in the framework of the LCEO. It also provides an outlook for future deployment of geothermal energy through modelling and sensitivity analysis of both techno-economic and external drivers.

The report is structured as follows: section 2 addresses the technology status and trends, section 3 the current deployment situation and market, section 4 looks at the market outlook and section 5 provides conclusions and recommendations.

Total geothermal energy supply was about 1550 PJ in 2017 which was about 6.8 % of all energy supply from renewables [IEA 2018]. The installed capacity of global geothermal power plants reached 12.7 GW_{el} [Uihlein 2018] and heat production reached 44732 TJ in 2017 [IEA 2018]. Globally, geothermal represents not more than 0.2 % of the world final energy consumption but can reach high shares in specific regions or countries [Limberger et al. 2018].

The resource potential for geothermal heat & power is very large. The global annual recoverable geothermal energy is in the same order as the annual world final energy consumption of 363.5 EJ [Limberger et al. 2018]. The theoretical potential for geothermal power is very large and even exceeds the current electricity demand in many countries. For the EU, the economic potential for geothermal power was estimated at 34 TWh in 2030 and 2570 TWh in 2050 [van Wees et al. 2013].

The geothermal energy market can be divided in three sectors: power generation, direct use and ground source heat pumps (GSHP) [JRC 2015a]. In this chapter we provide an introduction to these three sectors, including the market readiness of the associated technologies and the shares of each in the global energy system. Underground Thermal Energy Storage (UTES) is also mentioned in the last section, since it partly overlaps with the relevant geothermal applications.

1.1 Power generation

There are two main types of geothermal resources: convective hydrothermal resources, where the earth’s heat is carried by natural hot water or steam to the surface; and hot dry rock resources, where there is no possibility of extraction using water or steam, and other methods must be developed. Geothermal areas are categorised as low- and high-temperature fields, where high-temperature fields have temperatures over 180° C and are found around tectonic plate boundaries where volcanic activity is high.

At the end of 2017, global installed geothermal power capacity reached around 12.7 GW_{el} of running capacity and 13.8 of GW_{el} nameplate capacity [Uihlein 2018].

Since many places in the world are not rich in hydrothermal sources, but still have vast untapped potential of geothermal heat, there is a need for the development of enhanced geothermal systems (EGS) technologies to tap into these resources on the large scale.

Large scale EGS deployment will not be possible before high upfront costs such as drilling and resources assessment and elevated risk have been lowered. So far, EGS technology has only been demonstrated successfully in a handful of locations. Many countries are currently developing novel technologies to try to reduce EGS investment costs.

1.2 Direct use

Geothermal heat is currently mainly used for bathing, swimming and space heating, but also use in agriculture, especially for heating greenhouses, is significant in some countries. Data about direct use are very difficult to obtain and the most reliable information are country updates provided by IGA[1] every five years.

Global direct use, including heat pumps, as of 2015 was estimated at 70 GW_{th}. Excluding heat pumps, it has been estimated at around 20 GW_{th} [Lund & Boyd 2015].

1.3 Ground source heat pumps

Geothermal heat pumps can use geothermal energy at very low temperatures to heat or cool buildings of any size and allow the adjustment of the temperature to the building's needs. GSHPs are more efficient than Air Source Heat Pumps (ASHP) thanks to the thermal inertia of the ground, whose temperature is more constant than the air temperature over the year.

According to [Lund & Boyd 2015] the global installed heating capacity of GSHP systems is over 50 GW_{th} and the annual heating production is over 90 TWh/year. In the EU the production from installed heat pumps accounted for at least 23 TWh in 2016 [EGEC 2018].

UTES systems are another way to use underground conditions, this case to store energy seasonally. Large scale GSHP plants will typically use borehole heat exchangers (BHE) or aquifers to store energy.

[1] https://www.geothermal-energy.org/explore/our-databases/geothermal-power-database

2 Technology trends and prospects

Renewable energies are commonly recognised as fundamental players in carbon mitigation, and geothermal can also play a relevant role [Anderson & Rezaie 2019]. For now, only 6-7 % of the world's estimated geothermal potential is being harnessed [Matek 2016]. For geothermal power, pre-development risks remain high overall. Globally, the installed capacity of geothermal technologies required to avoid an increase of 2°C in global temperatures has not yet been attained [IEA 2017a].

2.1 Geothermal power

In 2016, global geothermal power generation stood at an estimated 84 TWh spread across 24 countries (about 12.7 GW_{el} of running capacity). Worldwide, power development is concentrated in ten countries, which account for 93 % of installed projects [Uihlein 2018]. Top countries include the United States, the Philippines, Indonesia, Turkey, Mexico, New Zealand, and Italy.

Because of low oil prices in the last few years, there has been less interest in the oil industry to develop new fields and that has created opportunities for geothermal outside of the USA, since international day rates for drilling rigs have fallen, allowing smaller developers to capitalise on this. However, overall – pre-development costs and risks are prohibitively high and research and development is needed to address this.

Based on current data, the global geothermal industry is expected to reach an installed capacity of about 18.4 GW_{el} by 2021 (about 120 TWh of power production) [Matek 2016]. If all countries fulfil their geothermal power development targets the global market could reach 32 GW_{el} by the early 2030s [Matek 2016], with the biggest capacity additions expected in Indonesia, Turkey, the Philippines and Mexico [IEA 2017b].

Demonstrating and reducing the cost of EGS plants and de-risking the environmental impact is a major R&D priority for the geothermal power sector. Outside the EU, countries supporting EGS research projects include the USA, Australia, Japan and El Salvador [Breede et al. 2013]. A review of EGS projects around the world is provided by [JRC 2015a]. More recently, the USA, which already has a number of EGS demonstration projects, has been very active in supporting EGS technologies through R&D funding.[2]

2.1.1 Developments in EGS

In 2017 the Lawrence Berkeley National Laboratory began a USD 9 million (EUR 8 million) project funded by the U.S. Department of Energy (DOE) aimed at removing technical barriers to commercialisation of EGS. As well as this, the Department of Energy's Geothermal Technologies Office launched the EGS Collab –where subsurface modelling and small-scale, in-situ experiments focused on rock fracture behaviour and permeability enhancement are carried out. The aim is to address critical barriers to EGS advancement by facilitating direct collaboration between the geothermal reservoir modelling community, experimentalists, and geophysicists in developing and implementing well-field characterisation and development, monitoring, and stimulation methods.

The results from the EGS Collab laboratory scale stimulation/rock mechanics studies will be used in the large field scale FORGE project, which was started in 2014. The FORGE subsurface laboratory (Frontier Observatory for Research in Geothermal Energy) initiative located near Milford (Utah) was launched as the first dedicated field site of its kind for testing targeted EGS R&D.

FORGE was set up for the development, testing and improvement of new technologies and techniques in an ideal EGS environment. The key mechanisms controlling EGS success, in particular how to initiate and sustain fracture networks in basement rock

[2] https://www.energy.gov/eere/geothermal/enhanced-geothermal-systems-demonstration-projects

using different stimulation technologies and technique are the main focus. With this knowledge it is hoped that large scale, economically sustainable EGS systems can be developed.

In 2018, the U.S. DOE has announced that it will give the University of Utah up to USD 140 million (EUR 123 million) in funding for geothermal research and development over the next five years and the FORGE field laboratory will be the facility for the work,. These funds will be used to conduct site characterisation, drilling, reservoir stimulation and testing, seismic monitoring, and competitive R&D.

Furthermore, in June 2018, the U.S. DOE also announced up to USD 4.45 million (EUR 3.9 million) for early-stage development of EGS tools and technologies: the Zonal Isolation for Manmade Geothermal Reservoirs funding opportunity announcement. This seeks to improve the performance and economics of EGS systems by funding research in zonal isolation, since these technologies can greatly improve the performance and economics of EGS systems. They allow the targeting of specific zones for stimulation, reducing development costs and operational risks.

In China, the first EGS pilot project began in 2018 in the Hainan Province with the first well reaching to 4387 m and accessing temperatures of 185°C.[3]

In Australia, despite past success with the commercial 1 MW Habanero EGS plant, which came online in 2013, the only ongoing project related to geothermal energy is a study of geothermal reservoir characterisation led by the South Australian Centre for Geothermal Energy Research at the University of Adelaide. This project is partly funded by the Australian Renewable Energy Agency (ARENA).

The recent developments in EGS in the EU are presented in Section 2.1.4.

2.1.2 Flexible power generation

With the redesign of the European electricity market, flexibility, rather than base-load production will be required in the electricity grid. Turbines capable of ramping up or ramping down will hence be in higher demand [EGEC 2018]. Flexible delivery of power has been demonstrated by several US projects, such as the Puna Geothermal Venture plant in Hawaii. This 38 MW facility also has contracted 16 MW of flexible capacity. Thus, it provides ancillary services for grid support that are identical to those of the existing oil-fired peak generating resources on the Big Island. This geothermal plant is considered to be a first-of-its-kind. In the past, geothermal plants at the world's largest geothermal field – The Geysers, northern California – have operated in various modes, including traditional baseload, peaking, and load following. The flexible modes were offered as an appropriate response to the needs of one of the utilities purchasing geothermal power from The Geysers, but have since ceased [Matek 2015].

2.1.3 Hybridisation

Hybridisation also appears to be an emerging trend with a view to improve the performance of existing and future geothermal projects. Hybridisation can help to smooth load profiles*,* for instance. The Enel Green Power Stillwater project in Nevada is the first example of using hybridisation to overcome dips in generation during hot periods. This air-cooled binary 33 MW plant employs two additional sources of generation: 2 MW solar thermal and 26 MW solar PV. When high outside temperatures cause declines in plant output, the solar thermal system increases brine temperatures and hence plant performance and the solar PV also generate when geothermal output is lowest.

Battery hybrid plants may also smooth load profiles by storing energy in the evening for use during the day. This could be particularly useful for geothermal projects offering ancillary services. Sites considering hybrid designs include AltaRock project, which may

[3] http://www.ldocean.com.cn/En/NewsInfo566.aspx

use storage at Lake Bottle Rock Geothermal Plant (55 MW) and Ormat, which is interested in acquiring a battery storage business in order to participate in hybrid projects [BNEF 2016a].

2.1.4 EU geothermal power trends

The 55 operating geothermal power plants in the EU-28 account for about 1 GW_{el} capacity. In order to put this value in perspective, it is noted that the economic potential of geothermal power in the EU is estimated at 522 GW_{el} in 2050 [Limberger et al. 2014]. Currently, only 9 European countries have operating geothermal power plants, but 20 more have projects in development [EGEC 2018]. Over the last five years, the greater European market has had an annual growth rate of 10 %, most of which is attributable to capacity additions in Turkey.

Europe has been active in the development of EGS systems since their inception. The first project for using geothermal energy generated at great depths was proposed by scientists at Los Alamos, New Mexico in 1970. The initial stage of the project began in 1973 with the collaboration (in the form of funding and personnel) of Germany and Japan. The project was located 40 km west of Los Alamos. During the same period, preparations began for the first scientific EGS pilot plant in Bad Urach, Germany (Breede et al., 2013). Later, in 1987 a European benchmark project in Soultz-sous-Forêts, France began following the good results obtained at Los Alamos (Hot-Dry-Rock-Project). In this project, several other similar research projects joined together in a single European Programme, based at Soultz-sous-Forêts in the upper Rhine Valley in France [Olasolo et al. 2016].

To date, most geothermal energy in the EU is still produced from hydrothermal resources. Only four EGS plants exist within the EU. Three HSA EGS plants are in operation in Germany and large efforts have been put into ensuring connections of wells to the reservoir as well as lowering drilling costs and mitigating induced seismicity. One petrothermal EGS system is operating at Soultz-Sus-Forets plant in France (1.5 MW net), however it has experienced problems relating to fluid circulation and flow, induced seismicity and high costs of drilling.

In 2017, the European Commission released a call for funding under the Horizon 2020 program which included a EUR 10 million funding package (LCE-18-2017) for research on Enhanced Geothermal Systems in different geological conditions. The MEET project won the call, having as its aim to boost the market penetration of geothermal power in Europe. The MEET project's main goal is to demonstrate the viability and sustainability of EGS with electric and thermal power generation in all kinds of geological settings with four main types of rocks: granitic (igneous intrusive), volcanic, sedimentary and metamorphic with various degrees of tectonic overprint by faulting and folding.

Also in 2017, the Dutch Ministries of Economic Affairs and Infrastructure and the Environment, EBN, TNO and seven consortia of companies have signed the so-called Green Deal on Ultra Deep Geothermal Energy (UDG). The seven consortia each have the common target of developing a UDG project in a specific location in the Netherlands in the near future. In response to the UDG Green Deal, a consortium of Dutch, German and Belgian organisations has also been formed by the State Supervision of Mines to investigate the risks of Ultra Deep Geothermal Energy and EGS work in the Netherlands [Witteveen+Bos 2018].

In 2018, the Council of Cornwall in England, UK has announced a GBP 1.4 million grant (EUR 1.55 million) to Eden-EGS Energy near St Austell, Cornwall. This EGS project aims to drill to 4.5km depth and to produce 5-7 MW power.[4]

[4] https://www.edenproject.com/eden-story/behind-the-scenes/eden-deep-geothermal-energy-project

2.2 Direct use, heating and cooling

Data on direct use is very limited due to statistical gaps and the latest reliable information available represents the situation end of 2015 [Lund & Boyd 2015, Antics et al. 2016]. Direct use can be found in 82 countries, and is used for space heating, greenhouse heating, aquaculture pond heating, agricultural drying, industrial uses, bathing and swimming, cooling/snow melting and others. Geothermal heat pumps are also considered as a direct use, but they will be discussed in the next section, given that they comprise the largest share of the direct use applications.

2.2.1 Worldwide direct use trends

The most popular direct uses of geothermal heat globally are bathing and swimming (about 45 %), space and district heating (about 37 %), and the heating of greenhouses (9 %). Other direct uses such as agricultural drying or pond heating are less significant.

Figure 2 shows the development of geothermal direct uses annually. The total installed capacity for geothermal direct utilisation worldwide is 20.4 GW_{th} and the total energy production amounted to 263 PJ. The resulting capacity factor is about 40 % [Lund & Boyd 2015].

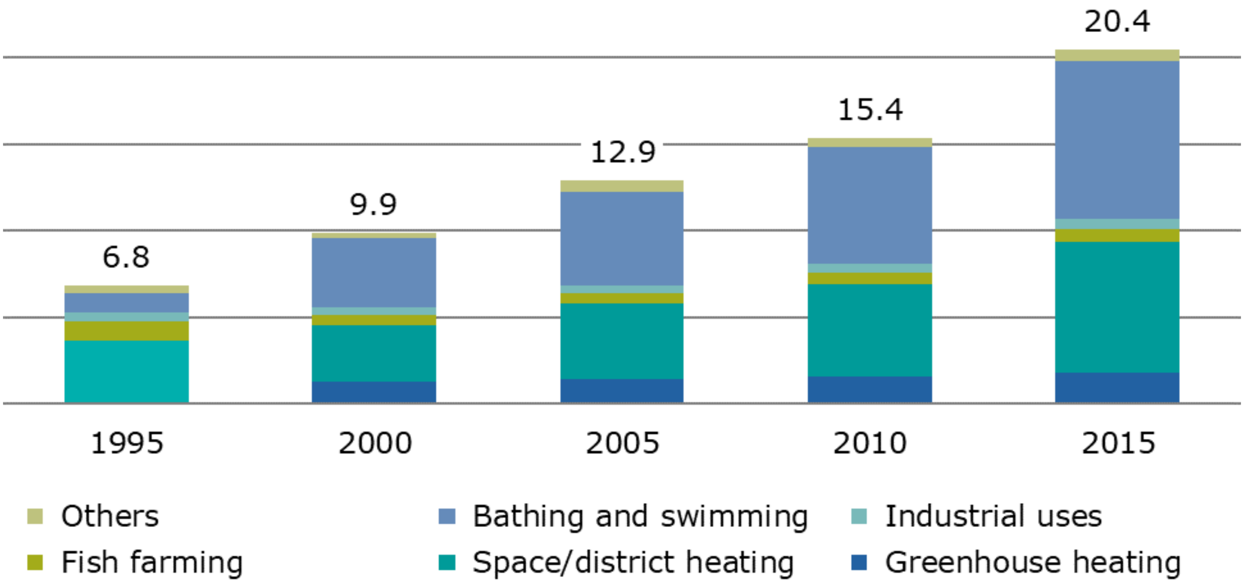


Figure 1. Installed capacity of geothermal direct use worldwide (1995 – 2015) in GW_{th}. Source: [Lund & Boyd 2015]

The countries with the largest utilisation (Figure 3) that together accounted for about 75 % of the global direct geothermal use in 2015 are China, Turkey, Iceland, Japan, Hungary, USA and New Zealand [Lund & Boyd 2015].

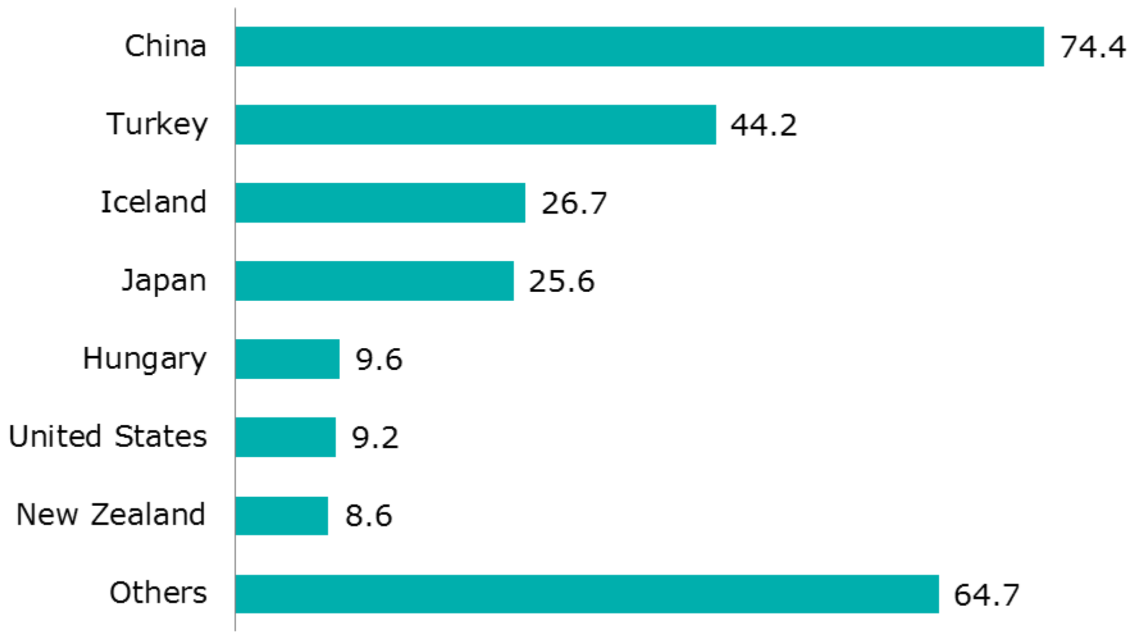


Figure 2. Top countries using the most direct geothermal heat in 2015 in PJ. Source: [Lund & Boyd 2015]

In total, about 1330 hectares of greenhouses are heated by geothermal energy. Turkey, Russia, Hungary, China and the Netherlands use geothermal the most for greenhouses [EGEC 2018]. In Turkey, agriculture accounts for 30 % of geothermal direct use. Aquaculture is a growing market, and the capacity increased by 6.7 % in the last five years. Top countries are USA, China, Iceland, Italy, Israel [EGEC 2018].

The installed capacity of geothermal space heating globally is 7.6 GW_{th}, of which 88 % (6.7 GW_{th}) is given by district heating. The leaders in district heating in terms of annual energy use are: China, Iceland, Turkey, France, and Germany. [Lund & Boyd 2015].

Over the next five years, the biggest growth is expected in China, with plans to more than triple the area covered by geothermal heating to 1.6 billion m^2 by 2020 to help tackle air pollution problems [IRENA 2017a]. A recent report by IRENA has suggested that a 24% renewable share in district heat generation by 2030 is feasible in China, split equally between geothermal, bioenergy and solar [IRENA 2017b].

Geothermal can play an important role in smart electricity and thermal grids since it can deliver both heating and cooling, and flexible electricity. Combined geothermal heat and power plants could serve as the base of smart thermal or smart grids. Several examples exist of the integration of both shallow and deep geothermal energy being integrated into smart thermal grids [EGEC 2018].

Whilst in the past geothermal district heating sites were located in high temperature geothermal areas, now medium and low temperature fields can be used economically in combination with heat pumps [EGEC 2018].

2.2.2 EU direct use trends

In the EU, geothermal district heating is the principal, and fastest growing, direct use application of geothermal energy (excluding geothermal heat pumps) [EGEC 2017]. Figure 3 shows the installed direct use capacity in Europe, and the share of district heating therein.

The European district heating market as a whole has seen a 3 % annual growth rate in the last five years. In the EU, there are currently 198 geothermal district heating plants in operation, with a total capacity of 1.8 GW_{th}. The main markets for geothermal district heating are France, Germany and Hungary, but new markets are emerging in other countries in particular the Netherlands, Switzerland, Poland, and Denmark. It is expected that 190 new projects will come online in the coming years [EGEC 2018].

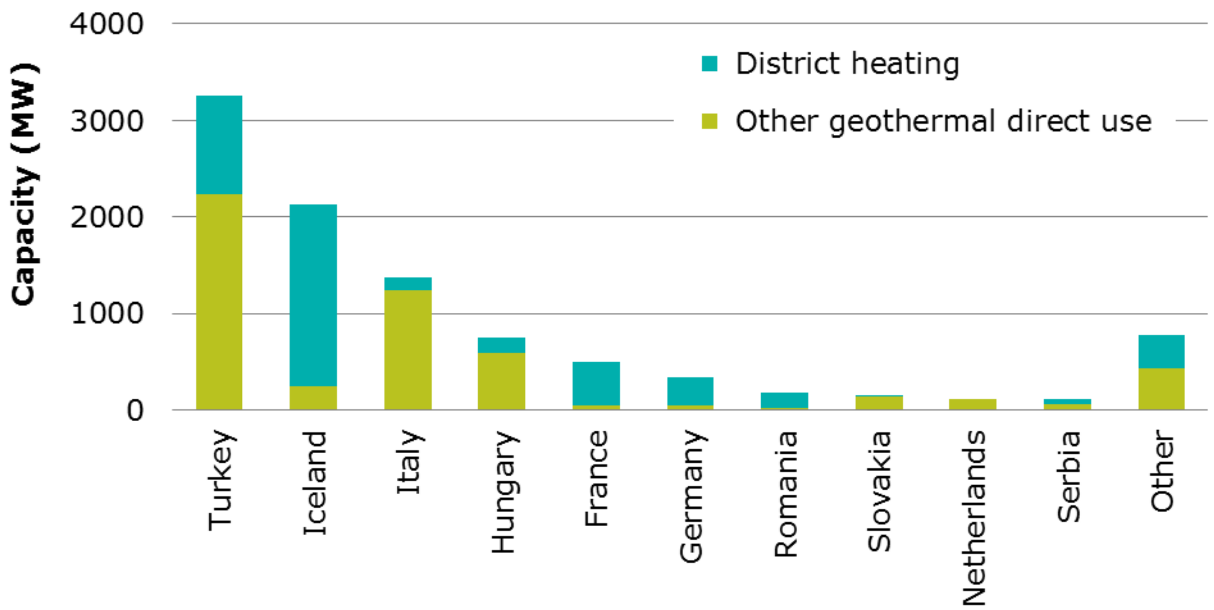


Figure 3. Installed capacity for geothermal direct use in Europe as of 2015, showing share of district heating for top ten countries. Source: [Antics et al. 2016]

Complete data is not available for all EU countries with regard to direct uses of geothermal. Figure 4 shows a break-down of direct use in selected EU countries. One can see that significant differences exist between countries. In Hungary around half of geothermal heat is used in agriculture and a third in balneological applications. In Italy and Slovenia, heat is used most for individual buildings and other applications, while district heating dominates the consumption in France and Germany. In Croatia, balneology is the largest use of geothermal heat.

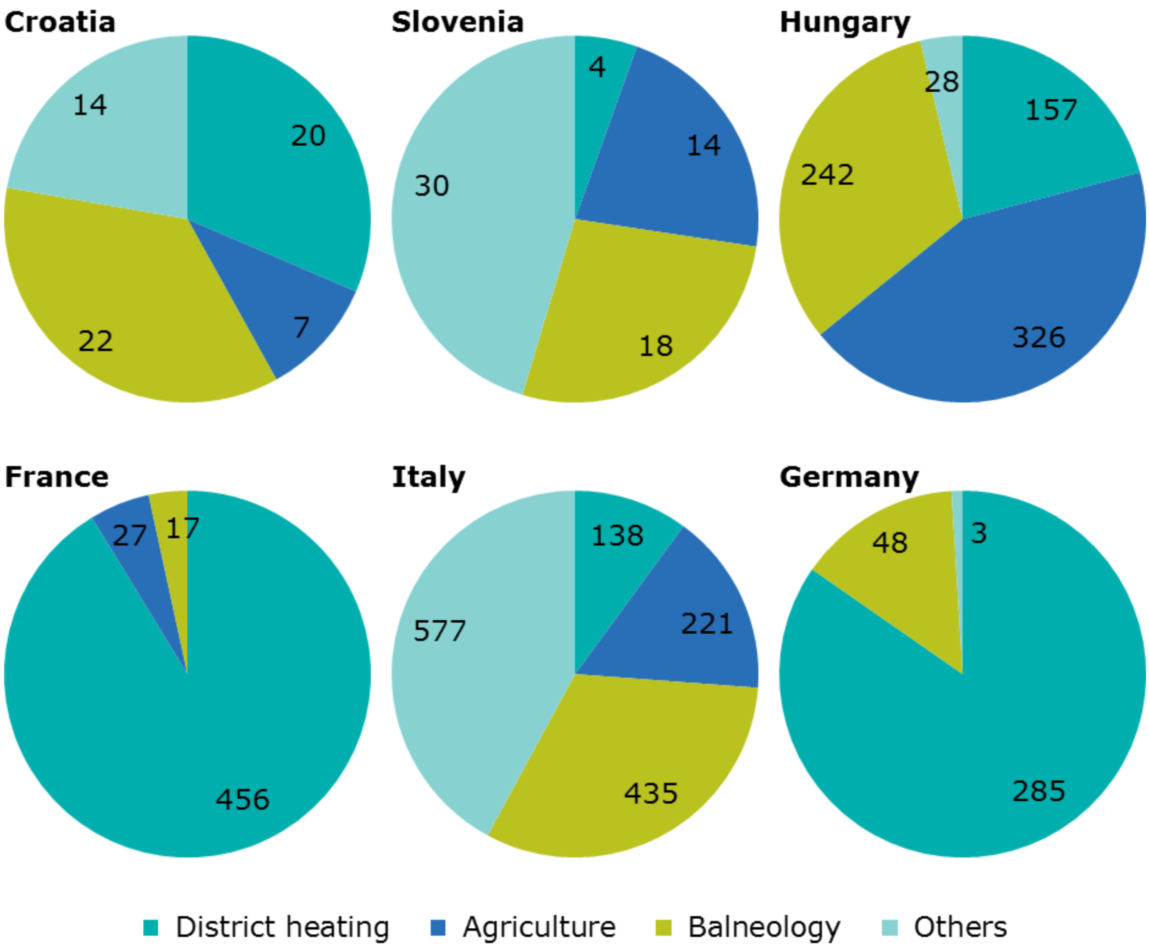


Figure 4. Direct use of geothermal heat in selected EU countries (MW_{th} installed capacity). Source: [Antics et al. 2016]

2.3 Ground source heat pumps

Geothermal (ground-source) heat pumps represent the largest direct-use of geothermal energy worldwide, accounting for 71 % of the installed capacity [Lund & Boyd 2015]. The size of individual units ranges from 5.5 kW for residential use to large units of over 150 kW for commercial and institutional installations.

The global leaders in installed units are the United States, China, Sweden, Germany and France [Lund & Boyd 2015].

Key factors driving demand include the rising global energy consumption, volatile oil prices and rising electricity prices. Furthermore, geothermal heat pumps offer benefits compared to conventional systems, such as lower operating costs, better efficiency, energy savings, ease of maintenance and longer life expectancies. The building sector represents almost 35 % of global energy consumption. The construction sector for residential buildings is recovering, which drives demand for geothermal heat pumps. In Europe, this growth, along with easy credit facilities and changing consumer preferences has added momentum to the geothermal heat pump market in the region. This is bolstered by the increasing policy emphasis on energy efficiency and reducing carbon emissions, and the potential of GSHP to ensure greater savings when compared with conventional HVAC units [Technavio 2017].

The non-residential building sector is the second largest global construction market and the sector is likely to grow, given increasing demand for retail and office space. Countries such as China and India are undergoing rapid and sustained economic growth, particularly in exported commercial services. This subsequent need for offices and extra commercial space should increase the demand for geothermal heat pumps [Technavio 2017].

Desuperheater components can recover the heat wasted from pumps' cooling. This recovered heat is then used to heat water for household purposes. A heat pump equipped with a desuperheater has the capability to heat water two to three times more efficiently than a conventional electric water heater [Technavio 2017].

2.3.1 EU GSHP market trends

Geothermal heat pumps are the most common form of geothermal energy use in the EU, with around 1.5 million systems installed. Installations are concentrated in Germany, France and Scandinavia. Sweden has the highest number of GSHP installed (0.5 million). The production from these plants accounts for at least 23 TWh (2016) in the EU [EGEC 2018].

The heat pump market for hydronic systems (i.e. GSHP and air-water heat pumps) has increased sharply due to the revival of the new build home construction sector in a number of countries, where most of the sales are concentrated and where new energy efficiency promotion policies are in force such as Germany. In 2017, the overall sales amounted to 383 157, with a 14 % growth with respect to 2016. Indeed, this growth was entirely related to air-to-water heat pumps (from 254 310 to 300 756 units sold), while sales of geothermal heat pumps remained constant (from 82 898 to 82 401 units sold) [EURObserv'ER 2018].

However, in 2017 air-to-air heat pumps led sales in the European market with about 3.12 million units (a 3 % increase with respect to 2016). This is due to lower installation costs and easier installation making them more suitable for the renovation segment. Furthermore, their reversibility means they are more in demand to meet increasing cooling needs in the EU due to high summer temperatures. Sales were strong especially in Italy, France and Spain [EURObserv'ER 2018].

The GSHP market nonetheless appears to be stabilising after several years of declining sales. The heat pump market is dynamic with around 80.000 units sold annually in the EU. Leading markets include Sweden, Germany and Finland. Poland is a fast-evolving market, as are Belgium, the Netherlands and Estonia. Adoption in colder countries is a growing trend due to low operating costs. Production from geothermal heat pump systems is increasing in all of the main markets [EGEC 2018].

In Europe, most units are sized for the heating load and are often designed to provide the base load with peaking by fossil fuel. There is a trend towards larger installations using shallow geothermal energy for heating and cooling. An installation is considered large if it has more than 10 km of borehole heat exchangers (BHE). Data on the number of plants of this type is fragmented, but there are at least 171 known plants in Europe, with the Nordic countries leading, followed by Germany and Switzerland [EGEC 2018].

2.4 Underground thermal energy storage (UTES/ATES)

A key challenge for the heating and cooling sector relates to the seasonal offset between thermal energy demand and supply. Underground Thermal Energy Storage is an attractive option to deal this offset.

UTES at 40-90°C in particular can directly supply heat for low temperature industrial needs such as batch processes or seasonal industries (e.g. sugar refineries), where periods of heat (and/or cold) demand are followed by phases of inactivity.

UTES is preferable for long-term energy storage due to its high storage efficiencies and storage capacities. UTES can be subdivided into open-loop or closed-loop systems. In open-loop systems, also referred to as Aquifer Thermal Energy Storage (ATES), heat and cold is temporarily stored in the subsurface through injection and withdrawal of groundwater.

The key requirement for ATES is the existence of an aquifer. The vast majority of ATES systems use unconsolidated aquifers[5] as a storage medium. Deeper systems typically utilise sandstones or highly fractured rocks. The suitability of the subsurface depends on several hydrogeological characteristics such as aquifer thickness, hydraulic conductivity or groundwater flow velocity. ATES is particularly suited to provide heating and cooling for large scale applications such as public and commercial buildings, district heating or industrial purposes [Fleuchaus et al. 2018].

Closed loop Borehole Thermal Energy Storage (BTES) systems are another common form of UTES. However, unlike ATES, BTES stores thermal energy in the bedrock underground and are hence not limited to locations with aquifers underneath. This kind of system uses borehole heat exchangers to circulate thermal energy in a liquid medium and then discharge it into or out of the bedrock. Closed loop BTES can be used for both small and large-scale applications.

Worldwide, over 2800 ATES systems are in operation, providing 2.5 TWh of heating and cooling per year. Most are low temperature systems, with storage temperatures of <25°C. The majority (85 %) are located in the Netherlands, in Sweden, Denmark and Belgium. Interest in the technology is growing in the United Kingdom, Germany, Japan, Turkey and China. The slow market development is due to socio-economic and legislative barriers [Fleuchaus et al. 2018].

[5] Aquifers composed of unconsolidated materials, such as silt or clay, sand or gravel.

3 Market overview

In this chapter the market for each of the main components of geothermal technologies will be discussed: geothermal turbines, ground source heat pumps (GSHP), and other geothermal direct use applications. For each, a description of the market, its structure and segmentation is given. The EU market share for each sub-technology is discussed.

3.1 Geothermal power

3.1.1 Market segmentation

Globally, the EU has the second highest number of geothermal entities following the USA, with around 181 entities (Figure 5). However, the majority of these parties globally are not involved in manufacturing components. The highest share of companies is in fact project developers, utilities or operators. Exploration & drilling companies and university or research institutes are also important. The suppliers of geothermal equipment for underground installations are from the oil and gas industry, and for above-ground installations (e.g. turbines) from the conventional energy sector [Magagna et al. 2017].

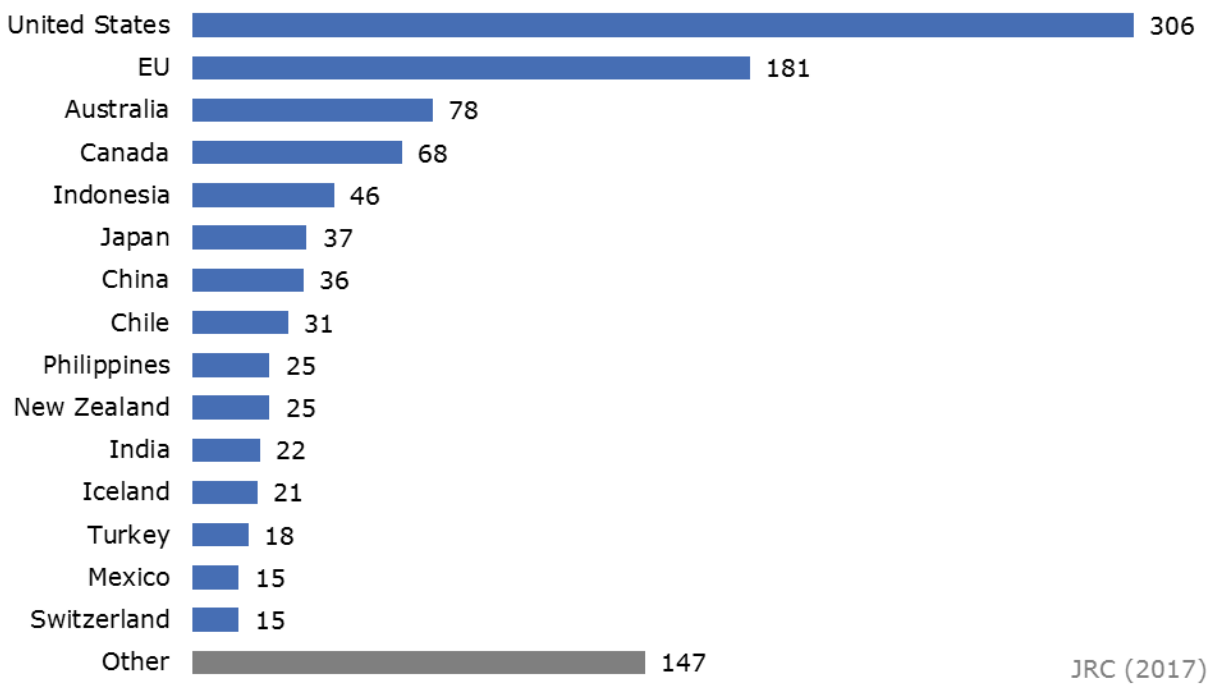


Figure 5. Entities in the geothermal power energy sector sorted by country/region. Source: [BNEF 2016b]

Production well drilling and facility construction are responsible for the majority of costs of a geothermal project. Globally, only a handful of companies are specialised in geothermal drilling only and about 20 more perform drilling in the oil, gas and geothermal sectors [Goldstein & Braccio 2014]. The market for facility construction is very competitive. Many geothermal field operators or power plant operators are national (public) companies such as KenGen in Kenya and CFE in Mexico [EGEC 2017]. In addition, some large private operators exist, such as Calpine, TerraGenm, ENEL, Ormat. Most operators are trying to expand their activity and aim to broaden their geographical footprint beyond their country of origin. Chevron, one of the biggest operators, has announced its departure from the geothermal sector and sold its 1.3 GW_{el} installed capacity to preserve its dividend [EGEC 2017].

3.1.2 Power turbines market

Despite the existence of highly specialised smaller companies, the geothermal power plant turbine market is dominated by large industrial corporations that are also active in other energy sectors. Some of those companies such as Ansaldo Energia not only supply turbines but also offer additional services ranging from civil and mechanical design to installation and commissioning of whole plants. At the end of 2017, the five biggest global market players were Toshiba, Fuji Electric, Mitsubishi, Ormat and Ansaldo Energia [BNEF 2018]. Ten manufactures count for 97 % of the turbine market globally in terms of installed capacity (Table 1). Four major manufacturers (Toshiba, Fuji, Mitsubishi, Ormat) account for about 80 % of the installed capacity [BNEF 2018].

Flash technologies, including double and triple flash, compose around 58 % of installed capacity globally, while dry steam is about a 25 % and binary is a remaining 16 %. The remainder includes back pressure and other developing and experimental types of geothermal technologies [Matek 2016]. The market share of the others segments, which includes hybrid plants, and experimental technologies is expected to witness a significant increase in the near future.

Table 1. Market share of geothermal turbine manufacturers (includes fully operational and grid connected geothermal projects until end 2017). Source [BNEF 2018]

Rank	Company	Installed Capacity (MW)	Market share (%)
1	Toshiba Power System	3203.0	23.0
2	Fuji Electric Co.	3012.1	21.6
3	Mitsubishi Heavy Industries	2652.8	19.0
4	Ormat Technologies	2092.6	15.0
5	Ansaldo Energia	1092.5	7.8
6	General Electric	1056.4	7.6
7	Exergy	312.9	2.2
8	Atlas Copco	102.6	0.7
9	TAS Energy	90.1	0.6
10	Green Energy Group	81.1	0.6
11	Highstat	80.2	0.6
12	LA Turbine	60.0	0.4
13	Qingdao Jieneng Group	21.0	0.2
14	United Technologies	20.5	0.1
15	Kawasaki Heavy Industries	15.0	0.1
16	Harbin Electric	11.3	0.1
17	Enex HF	9.4	0.0
18	Parsons	5.0	0.0
19	Ebara	4.5	0.0
20	Barber Nichols	3.7	0.0

Geothermal power plants are currently installed in eight European countries of which six are EU-28 Member States. From 2012-2016, the majority of total installed capacity in Europe was conventional flash/ steam technology, however, since 2012 nearly 80 % of newly installed capacity was binary technology, all ORC [EGEC 2018].

The four major European ORC manufacturers are Ormat (USA), Turboden (Italy), Atlas Copco (Sweden) and Exergy (Italy), all currently most active in Turkey and Portugal. Toshiba is dominant in Turkey as a flash turbine supplier, as is Fuji in Iceland. Chinese turbine manufacturer Kaishan recently entered the European market supplying an ORC turbo-generator to a Hungarian power plant [EGEC 2018].

Figure 6 shows global trade flows of geothermal power plant turbines from 2005 to 2015. In this period, most exports of binary cycle turbines came from Israel, United States, Italy, and Germany. The flash cycle and dry steam turbine market was dominated by Japan, Italy, and the United States. The biggest 'receiving' markets over the last ten years were the United States, Indonesia, New Zealand, Kenya, Iceland; of course reflecting the power capacity additions.

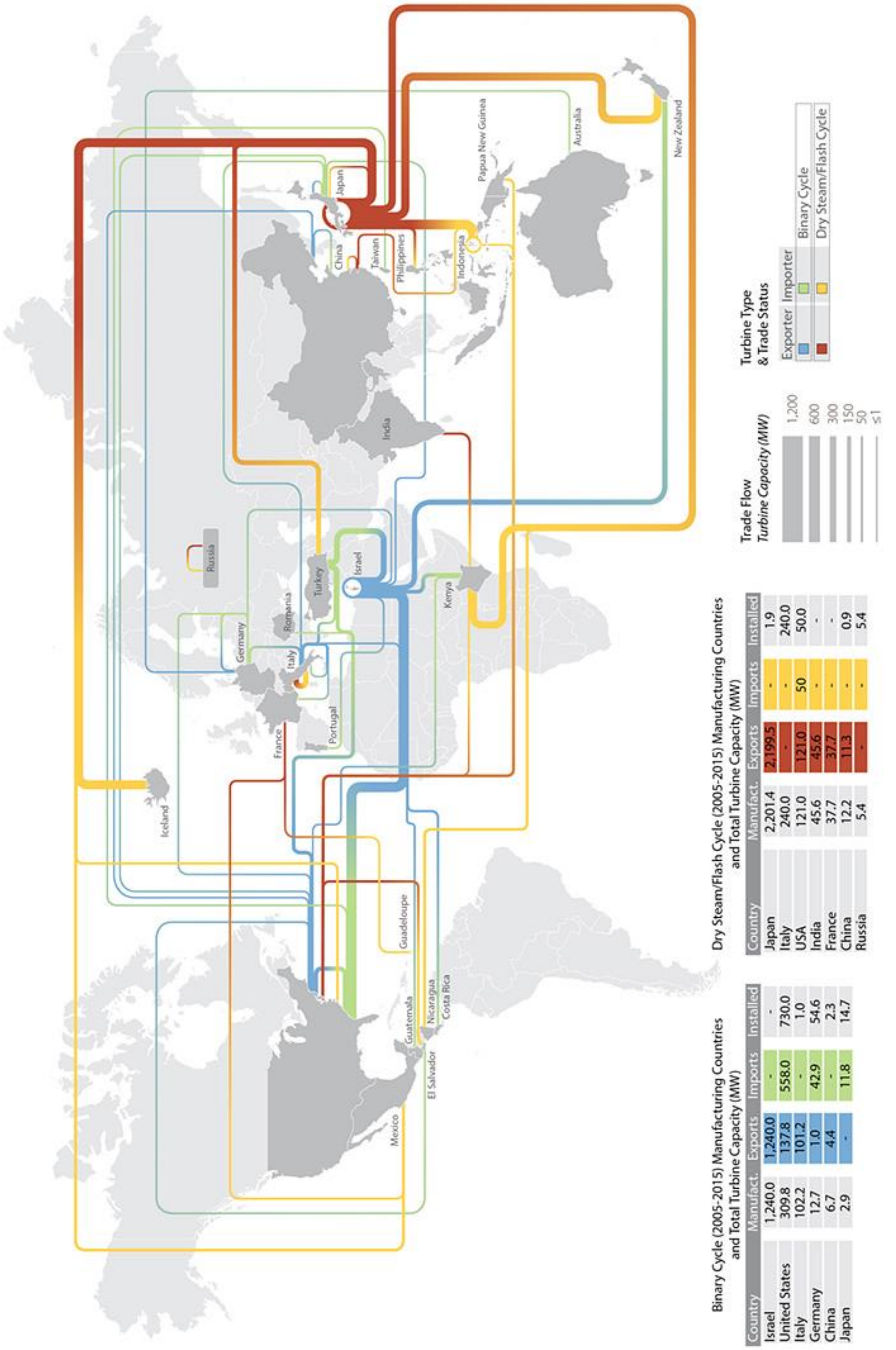
3.2 Geothermal direct use

District heating and systems are the largest and fastest growing direct use application of geothermal energy in the EU. Direct-use technologies closely resemble geothermal electric systems, except the heat is used for another purpose. Data and information about players active in the direct use supply and value chain is scarce. Most suppliers of geothermal equipment for the underground part of the installations are from the oil & gas industry (e.g. exploration, drilling, pipes, and pumps). Major providers for pumps, valves, and control systems include Schlumberger, Baker & Hughes, GE, ITT/Goulds, Halliburton, Weatherford International, Flowserve (all US), Canadian ESP (Canada), Borets (Russia) (Angelino et al., 2017). Heat exchangers are supplied mainly by Alfa Laval (Sweden), Danfoss (Denmark), Kelvion Holdings (Germany), SPX Corporation (US), Xylem (US),Hamon & Cie, Modine Manufacturing Company (US), SWEP International (Denmark).

3.3 Ground source heat pumps

Heat pumps are generally grouped into three main categories: i) ground source heat pumps, which extract heat from the ground; ii) hydrothermal heat pumps, that draw heat from water (the water table, rivers or lakes), and iii) air source heat pumps, whose heat source is air (outside, exhaust or indoor air). Heat pumps are available in different sizes, however, data is lacking for medium and large heat pumps. Smaller heat pumps that use ambient energy dominate the market. Air source heat pumps are the most prevalent, and made up 50 % of total sales, followed by hot water heat pumps (6 %) and air source heat pumps (30 %) and geothermal systems (4 %).

Ground source heat pumps make up the largest segment of the geothermal energy market in the EU (22.8 GW_{th} installed) [Magagna et al. 2017]. The geothermal heat pump market, in terms of end-users can be segmented into residential (53 %) and non-residential (47 %). The global geothermal heat pump market was valued at EUR 13 billion in 2016 and is expected to reach EUR 23 billion in 2021. EMEA dominated the global geothermal heat pump market with a 52 % share in 2016. The main vendors internationally are Carrier Corporation, Daikin, Mitsubishi, Danfoss and NIBE. Other prominent vendors and collaborators are BDR Thermea, Bosch Thermotechnology, Bryant Heating & Cooling systems, CIAT, Hitachi Appliances, LSB Industries and SIRAC.



Binary Cycle (2005-2015) Manufacturing Countries and Total Turbine Capacity (MW)

Country	Manufact.	Exports	Imports	Installed
Israel	1,240.0	1,240.0	-	-
United States	309.8	137.8	558.0	730.0
Italy	102.2	101.2	-	1.0
Germany	12.7	1.0	42.9	54.6
China	6.7	4.4	-	2.3
Japan	2.9	-	11.8	14.7

Dry Steam/Flash Cycle (2005-2015) Manufacturing Countries and Total Turbine Capacity (MW)

Country	Manufact.	Exports	Imports	Installed
Japan	2,201.4	2,199.5	-	1.9
Italy	240.0	-	-	240.0
USA	121.0	121.0	50	50.0
India	45.6	45.6	-	-
France	37.7	37.7	-	-
China	12.2	11.3	-	0.9
Russia	5.4	-	-	5.4

Figure 6. Geothermal power plant turbines trade flows. Source: [CEMAC 2016]

The global geothermal heat pump market is highly fragmented with the presence of many vendors. Vendors are highly diversified and operate on international, regional, and local levels.

Many local and regional vendors provide highly-customised and energy-efficient heat pumps at lower prices when compared with those provided by international vendors, although they must compete with international vendors on quality, features, and services. Competition exists however, for international players like Daikin or Mitsubishi in the form of vendors offering much cheaper reconditioned and refurbished geothermal heat pumps [Technavio 2017]. The total number of geothermal heat pump installations in Europe was over 1.7 million units in 2015 [EGEC 2018]. Table 2 shows the major European GSHP manufacturers and brands. Heat pump markets and penetration rates in the EU vary considerably depending on climate. In north, central and eastern Europe, heat pumps are mostly used for heating, whereas in temperate to hot climates (western and southern Europe), more cooling is required and reversible heat pumps are more popular [EURObserv'ER 2018].

Table 2. Overview of major European GSHP manufacturers and brands. Source: [Magagna et al. 2017]

Company	**Brand**	**Country**	**Capacity range (kW)**	**Comments**
BDR Thermea (NL)	De Dietrich/ Remeha	France	5.7-27.9	10 000 heat pumps sold in 2014
	Baxi	UK	4-20	GSHP offer discontinued
	Brötje	Germany	5.9-14.9	
	Sofath	France	2.8-29.5	50 000 GSHP units sold so far
Bosch Thermo-technik (DE)	Junkers	Germany	5.8-54	
	Buderus	Germany	7-70	
	IVT Industrier	Sweden	6-16	Swan-labelled GSHP
Danfoss (DK)	Thermia Värme	Sweden	4-45	
Nibe (SE)	Alpha-InnoTec	Germany	5-30	Belongs to Schulthess (daughter of Nibe)
	Nibe Energy Systems	Sweden	5-17	Largest EU manufacturer of dom. Heating
	KNV	Austria	4-78	Acquired 2008. 13 000 heat pumps sold
Vaillant (DE)	Vaillant	Germany	6-46	Second largest HVAC manufacturer
Viessmann (DE)	Viessmann	Germany	5-2000	
	Satag Thermotechnik	Switzerland	3-19	Acquired in 2004
	KWT	Switzerland	6-2000	One of the pioneers in GSHP
Ochsner (AT)	Ochsner	Austria	5-76	130 000 heat pumps sold so far
Stiebel Eltron (DE)	Stiebel Eltron	Germany	4.8-56	Acquired 35 % of share capital of Ochsner

4 Market outlook

This chapter discusses the market prospects for geothermal energy, focusing on the power and the heat sectors. A thorough discussion on the main technical and non-technical market barriers which hinder geothermal expansion is also proposed.

4.1 Market prospects

4.1.1 Global prospects – IEA

The Energy Technology Perspective study by the International Energy Agency [IEA 2017b] provides both a focus on short-term prospects and long-term scenarios for a number of energy technologies, including geothermal.

Globally, geothermal power experienced a regular growth from the beginning of the century (averagely about 3% per year), reaching 84 TWh in 2016 in terms of annual electricity generation (see Section 2.1). Such a pace, however, is not compatible with the levels needed for global sustainable scenarios (Figure 7).

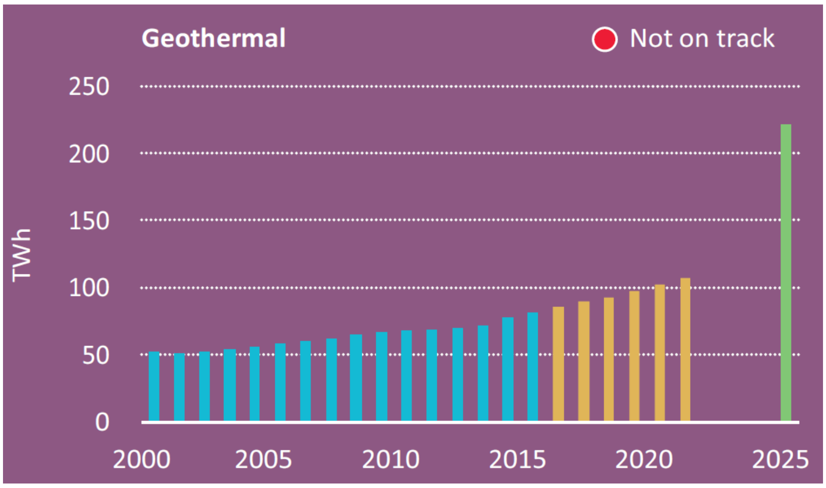


Figure 7. Global geothermal power generation: historical values, near-future forecast, and 2025 sustainable target. Source: [IEA 2017b]

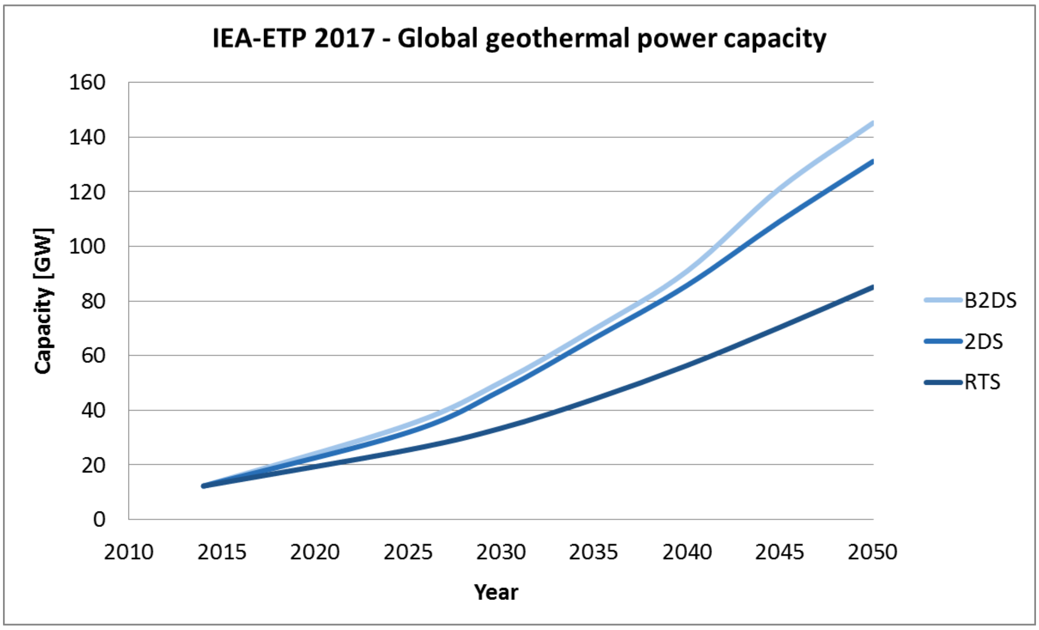
More in detail, [IEA 2017b] develops three main long-term scenarios.

- The Reference Technology Scenario (RTS) considers the commitments made by countries to limit GHG emissions and improve energy efficiency, including the NDCs pledged under the Paris Agreement. This would represent an important deviation from the historical patterns, but it would not be sufficient to achieve ambitious mitigation targets, as the average global temperature increase in 2100 with respect the pre-industrial levels would achieve 2.7°C.

- The 2°C Scenario (2DS) develops a GHG emission pathway consistent with at least a 50 % chance of limiting the long-term temperature increase to 2°C. The 2025 sustainable target reported in Figure 7 refers to this scenario.

- The Beyond 2°C Scenario (B2DS) takes to the extremes the technology developments needed to reach the 2DS and aims at achieving a temperature increase of 1.75°C in 2100.

A substantial geothermal expansion is envisioned in all these scenarios, as shown in Figure 8.



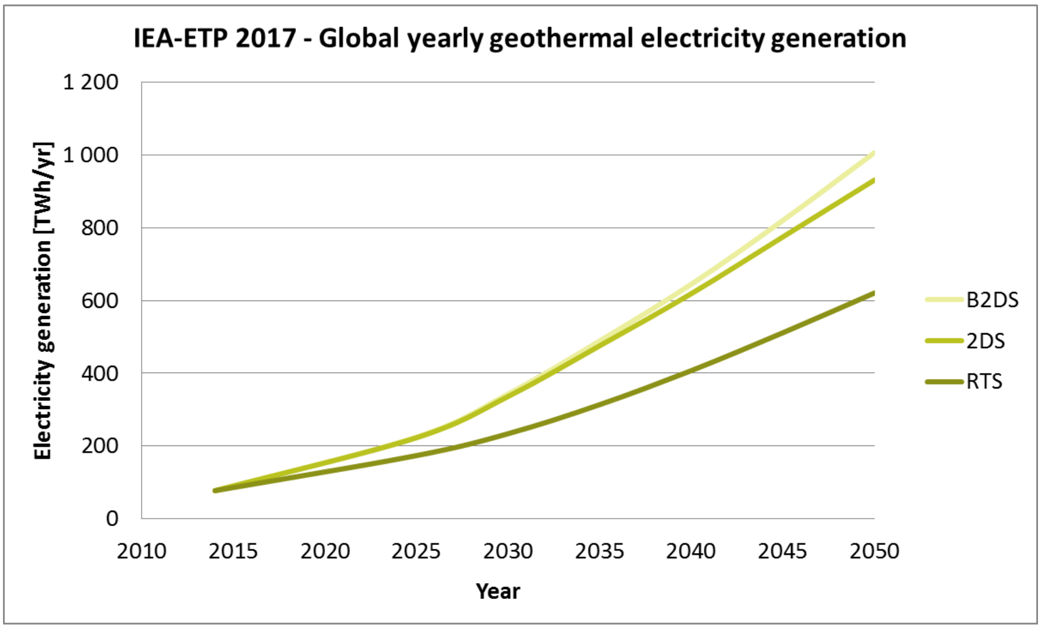


Figure 8. 2050 prospects for global geothermal power generation according to IEA scenarios: capacity (top) and electricity generation (bottom). Source: Own elaboration based on [IEA 2017b]

Global installed capacity (currently at 13 GW_{el}) increases by a factor of 6 in the RTS (85 GW_{el}) and a factor of 10 and 11 in the two ambitious mitigation scenarios, respectively (131 GW_{el} in the 2DS and 145 GW_{el} in the B2DS). The electricity generation increase is proportionally higher, as it reaches 621 TWh_{el} in the RTS, 931 TWh_{el} in 2DS and 1007 TWh_{el} in the B2DS, i.e. a factor of 7, 11, and 12, respectively. This means that the capacity factor is also expected to increase from about 70 % to about 80 %.

Despite this significant growth, however, geothermal power is expected to lag well behind all of the other main renewable technologies: even in the B2DS, deployment rates never exceed few gigawatts per year, against tens or even hundreds of gigawatts per year achieved by wind, solar, hydro, and biomass (Figure 9).

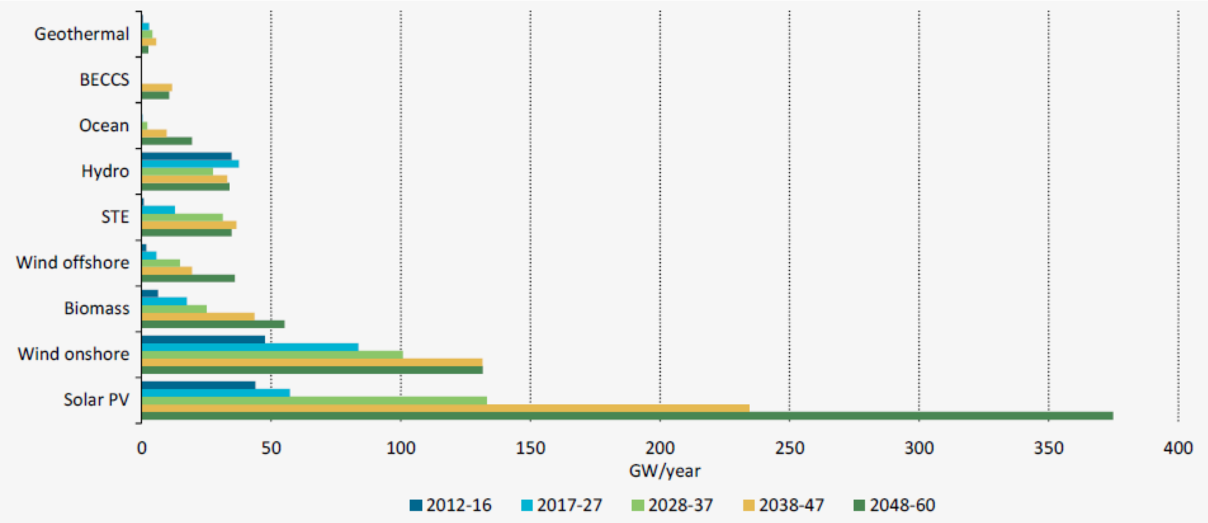


Figure 9. Deployment rates for renewables-based power technologies in the B2DS. Source: [IEA 2017b]

Direct heat generation from geothermal follows a similar path as electricity (Figure 10): moderate growth in the RTS, stronger growth in 2DS and B2DS. It is noted that IEA provides the overall fuel input for electricity and direct heat generation: in order to calculate the heat used for electricity and thus disaggregate the two inputs, a 12%-thermal efficiency has been assumed for power plants and applied to the values reported in Figure 8 [Zarrouk & Moon 2014]. As a result, the geothermal share in the overall energy input for electricity and heat generation substantially grows over the decades, and exceeds 10 % in 2050 in the 2DS and B2DS, see Figure 11 (it should be reminded that this number is influenced by the low thermal efficiency of geothermal power plants).

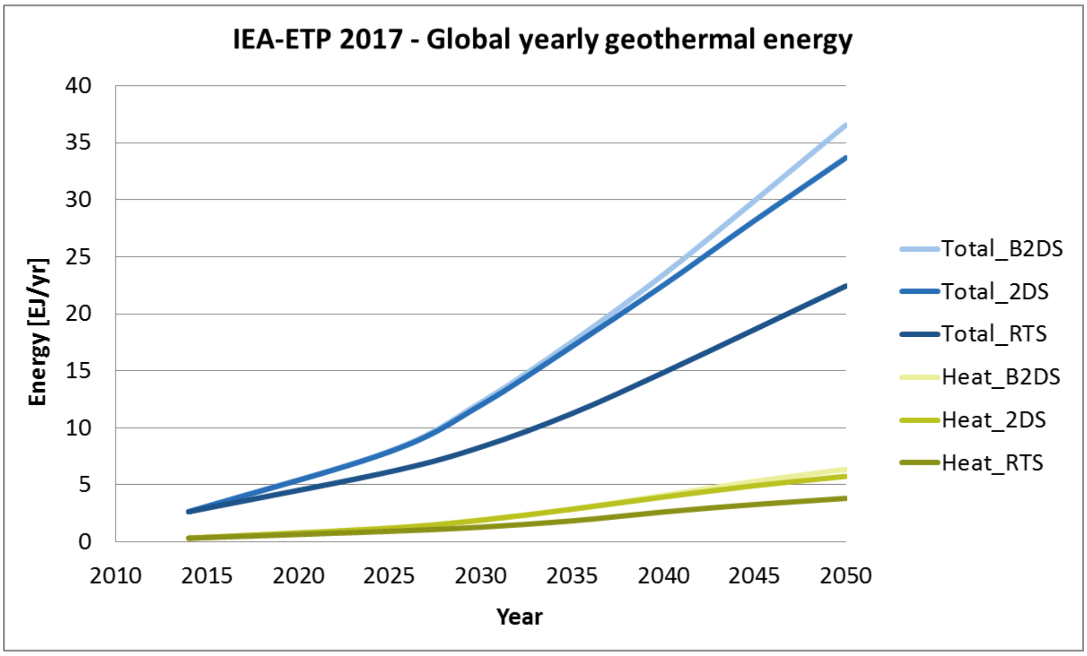


Figure 10. Deployment rates for renewables-based power technologies in the B2DS. Source: Own elaboration based on [IEA 2017b]

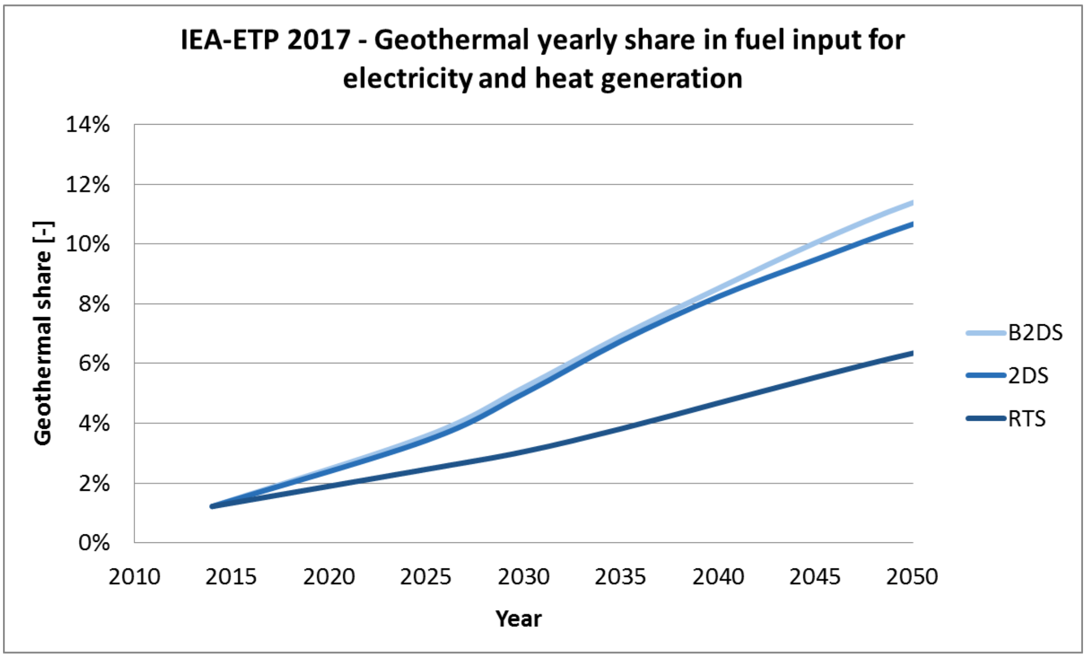


Figure 11. Geothermal yearly share in the fuel input for electricity and heat generation. Source: Own elaboration based on [IEA 2017b]

4.1.2 EU prospects – JRC-TIMES

In-house scenarios have been developed with the JRC-EU-TIMES model to explore energy prospects within the EU in the framework of LCEO [JRC 2018]. These include three main storylines (Baseline, Diversified, and ProRes) and several complementary sensitivities. The three storylines and an additional sensitivity (Near_Zero) will be considered in this report.

1. Baseline: it is a "business-as-usual" scenario which does not envision any dedicated efforts aimed at stabilising the atmospheric concentration of GHGs. In this scenario, the EU is assumed to reduce its energy-related CO_2 emissions by 48 % by 2050 with respect to 1990, as in the EU Reference Scenario 2016 [EC 2016].
2. Diversified: this is a mitigation scenario comparable to the IEA-B2DS, where all known supply, efficiency and mitigation options (including nuclear and Carbon Capture and Storage, CCS) are deployed in order to achieve a long-term temperature increase lower than 2°C. In the EU, this corresponds to an 80%-reduction of CO_2 emissions in 2050 with respect to 1990.
3. ProRes: this scenario achieves the same long-term climate targets as the previous one, but with a stronger focus on renewables, as nuclear is phased out and CCS is not deployed (however, Carbon Utilisation technologies are allowed, the main of which is the production of diesel/kerosene by combining hydrogen and CO_2).
4. Near_Zero: this scenario shares the main technological assumption as ProRes, but the decarbonisation effort is taken to the extreme, as the EU achieves a 95%-reduction of CO_2 emissions in 2050 with respect to 1990.

As shown in Figure 12, JRC-EU-TIMES projects practically no geothermal expansion in the Baseline scenario. This is in line with the baseline scenario developed by the European Commission for its long-term strategy "A Clean Plant for All" [EC 2018a], where the 2050 primary energy produced from geothermal is projected to be similar to 2015, and specifically geothermal heat represents marginal shares of the energy consumption.

Mitigation scenarios (Diversified, ProRes, and Near_Zero) lead to larger geothermal deployment, instead, even if in absolute terms this is well lower than the other main renewable solutions, coherently with the global trends depicted by the IEA scenarios (see Figure 9). Expansion is moderate in the Diversified scenario (and quantitatively similar to the comparable IEA-B2DS), while it is more marked in ProRes and Near_Zero, where renewables are promoted.

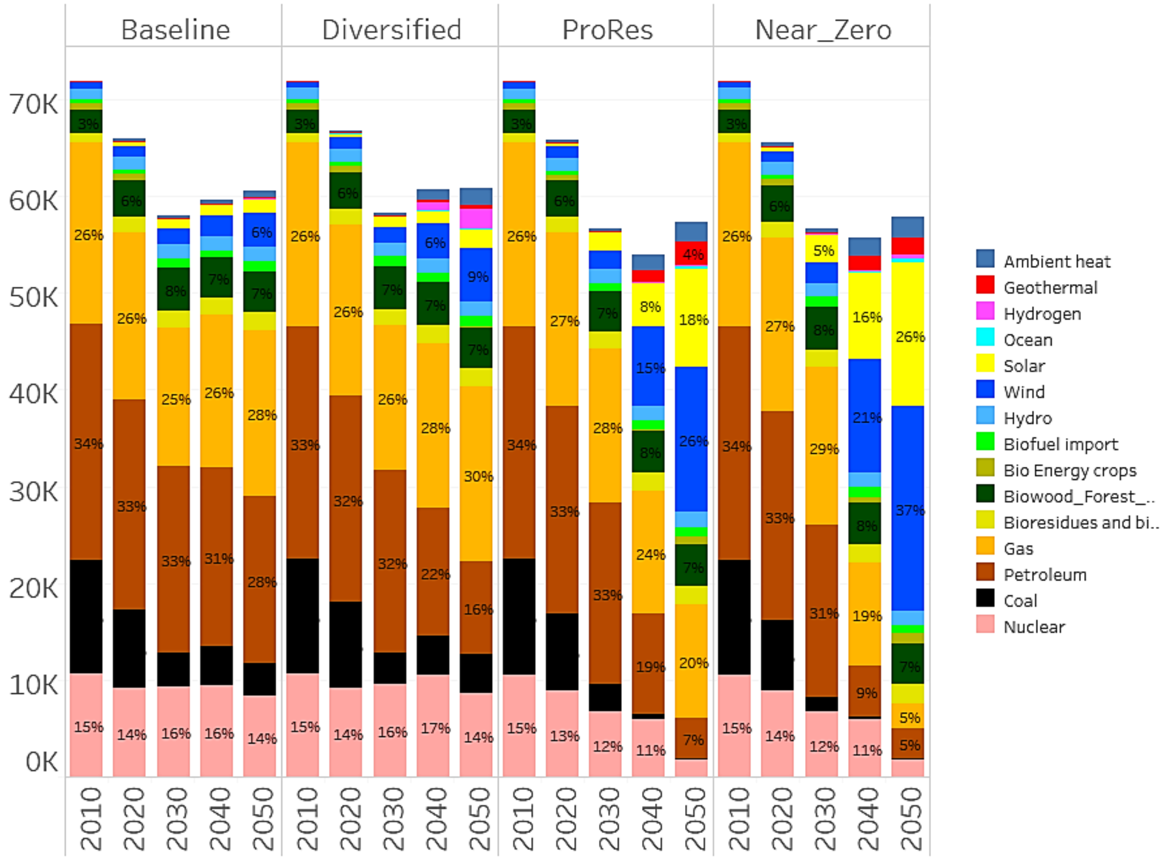


Figure 12. EU gross primary energy consumption (PJ/yr).

Figure 13 allows a comparison of the investment in the different low-carbon technologies across scenarios. Wind, solar PV, and batteries in Electric Vehicles (EV) receive by far the most significant share of investment. Investment increases as the mitigation targets become more and more stringent. Focusing on geothermal, the graph clearly shows that investment in this technology is very low in the Baseline and not particularly higher in the Diversified scenario, i.e. in a system aiming at emission mitigation where CCS is allowed. Investment instead massively grows if CCS (as well as nuclear) is not available: a sevenfold increase is found from the Diversified to the ProRes scenario, despite the same overall emission reduction target. A further doubling of investment is found if the 2050 emission reduction is fixed at least at -95 %. To put these values in perspective, there is a two-order of magnitude difference between investment in wind and geothermal in the scenarios with CCS, while only a one-order of magnitude difference in the scenarios without CCS. In absolute terms, investment in geothermal averagely accounts for EUR 0.2-0.8 billion per year in the Baseline and Diversified scenarios, which increases to EUR 6-12 billion per year in the ProRes and Near_Zero scenarios.

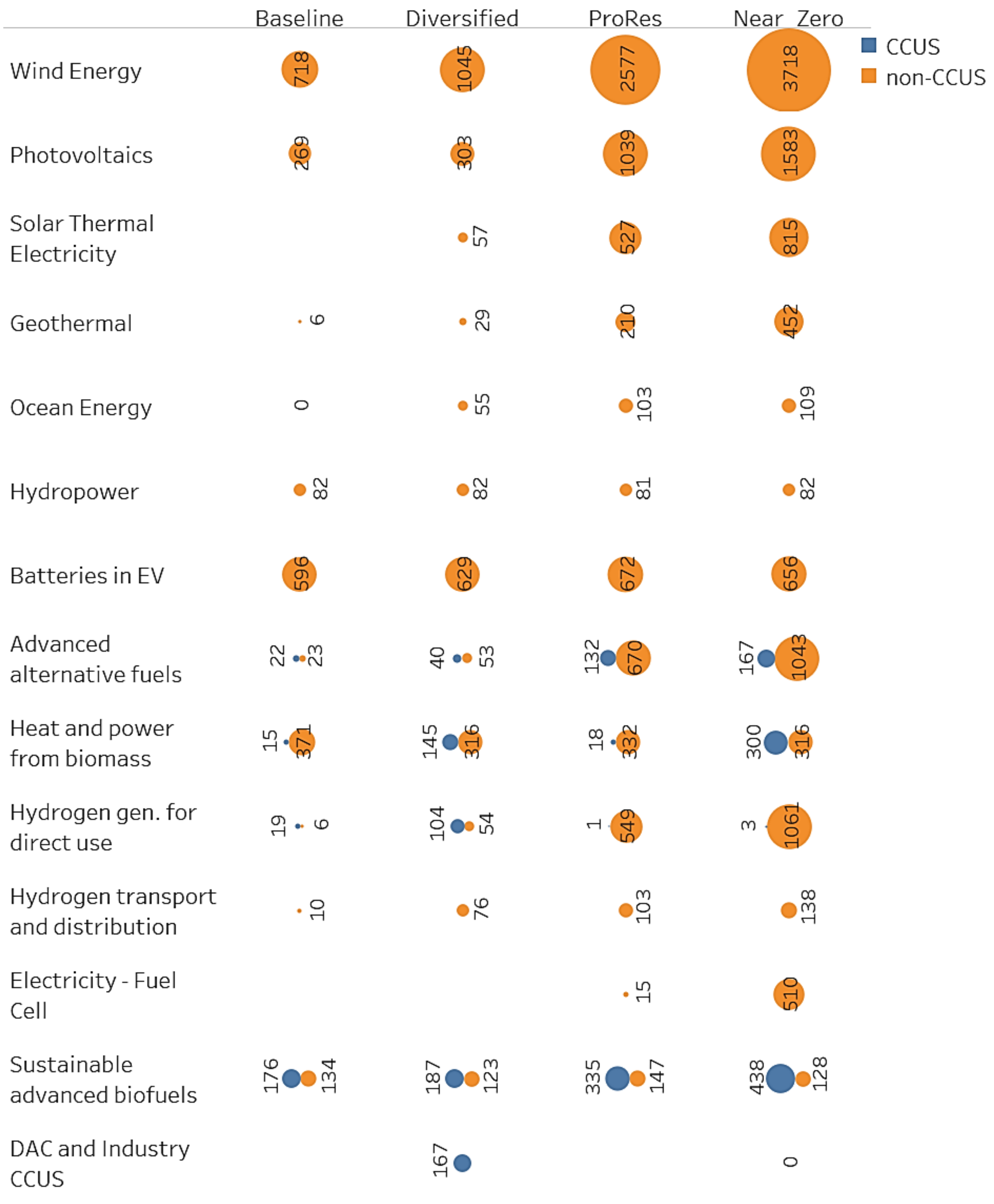


Figure 13. Cumulative investments in low-carbon technologies up to 2050 (billion euros). Source: [JRC 2018]

The level of geothermal energy also depends on the level of learning (not directly discussed in this report, see [JRC 2018] for details). With the foreseen cost reductions from SET-Plan learning (bringing the CAPEX of EGS to below 6000 EUR/kW), geothermal heat for electricity and district heat reaches 3876 PJ in 2050, which is 75 % of the full sustainable potential. Finally, the geothermal energy depends on whether it is included in the limitation of total primary energy consumption. In fact, the full potential of geothermal is used if a restriction on the total primary energy consumption is not applied (based on non-LCEO scenarios). Without limits on the total energy use, geothermal based electricity production becomes economic, even though it uses a lot of primary resource (geothermal heat) to produce only a "small" amount of electricity.

In JRC-EU-TIMES, the geothermal heat can be used for power or directly for district heating. A shift is taking place from using geothermal heat for power to using it for district heat in the Near_Zero scenario. The reason is that geothermal district heating outcompetes fossil based or electricity based district heating. In -80 % scenarios (Diversified and ProRes), electricity is used in some countries for district heating as a way to use and store electricity from variable renewable sources. In the Near_Zero scenario, which considers a 95%-emission reduction, another form of storage is required. Here in fact, in contrast to -80 % scenarios, the power system does not have any longer flexible gas power plants. For that reason, part of the electricity is stored as hydrogen to be converted back to electricity.

4.2 Barriers to market expansion

Barriers to geothermal market expansion are both technical and non-technical. The main barriers for using low-enthalpy (< 180°C) deep geothermal resources in the EU are the high up-front costs for geothermal projects, decentralised production of geothermal heat, lack of uniformity among geothermal projects, geological uncertainties, and geotechnical risks [Limberger et al. 2018].

Policy for renewable heat in general remains underdeveloped, since policy-makers have tended to focus mainly on electricity production from renewables. Heat markets are less well understood than electricity markets due to their complexity: heat demand in buildings varies considerably due to climate, building fabric efficiency, occupancy and behaviour. Industrial processes also have differing heat requirements [Collier 2014] further classifies barriers for renewable heat sources like geothermal as being economic or non-economic.

Economic barriers for renewable heat include capital costs, competition from low –price fossil heating fuels (due to market price or subsidies), split incentives in the private rented sector and lack of economies of scale due to early market growth phase.

Non-economic barriers include lack of building suitability; very high temperature requirements of industry; lack of awareness/confidence in the technology; lack of supply chain or trained workforce; distressed purchase and consumer inertia; disruption or hassle of retrofitting; lack of heat data and statistics on favourable locations [Collier 2014].

For GSHPs in particular, factors impeding market growth relate to the high upfront cost of installation for small scale users, the competition from refurbished pumps and their adverse impact on the grid system [Technavio 2017]. Heat pumps also pose a serious challenge to the electricity grid systems. The use of variable renewable energy sources for heat pumps may result in a mismatch between energy supply and heating demand. It will be necessary to deploy seasonal energy storage (such as UTES) to deal with this mismatch. Geothermal electricity may also play a part in providing baseload power to replace conventional sources.

The SET-Plan working group has identified key research areas to overcome technical barriers [SET-Plan Temporary Working Group Deep Geothermal 2018] as well as some cross cutting and non-technical issues for deep geothermal. Key non-technical barriers for deep geothermal energy have also been identified in greater detail by the ETIP-DG non-technical working group [ETIP-DG 2018]. These relate to

- policy and regulation,
- public acceptance,
- competitiveness,
- risk management,

- financing,
- legal and regulatory aspects,
- information access,
- skills, human and material resources,
- environmental impacts and pollution,
- seismicity.

These barriers also exist to some extent for direct uses and GSHP, and have been highlighted in [Prieto & Baez 2016].

4.2.1 Policy and regulation

The FROnT project, supported under the Intelligent Energy Europe Programme[6] has identified major barriers on the supply side of renewable heating and cooling technologies as being the lack of strategic priorities in EU and national policy-making and unfair market conditions [Prieto & Baez 2016]. Inconsistencies in EU legislation and short and long-term objectives show a lack of overall long-term strategy which results in counter-productive legislation and a lack of stability and trust, which inhibits the deployment of renewables.

Persistent market failures exist meaning that comparisons between the cost of fossil and RES installations are not possible, as long as, in most MS, fossil-based heating appliances (e.g. condensing gas and oil boilers) remain heavily subsidised and while fossil fuel prices are still regulated and the carbon not substantially priced. Technologies consistent with EU climate objectives face major challenges to develop and deploy in an unfair market [Prieto & Baez 2016].

A level playing field for geothermal energy in relation to other energy sources is needed. Even though it is known that fossil fuel subsidies remain a problematic barrier to the EU's clean energy transition, the EU has not put in place clear mechanisms to ensure the phase out of fossil fuel subsidies [Gençsü et al. 2017].

4.2.2 Public acceptance

Public acceptance has long been a major barrier to all renewable energy projects, and this particularly applies to geothermal, due to a generally limited knowledge and understanding of geothermal energy among the general public [Vargas Payera 2018].

In Germany in particular, media reports have increasingly drawn attention to the risk of micro-seismicity from geothermal operations, following earthquakes in the Rhine river area for example at the Swiss EGS plant in Basel in 2006 or in Landau in 2009. As a result, risk perceptions and local opposition have grown. The future development of deep geothermal technologies will likely face strong conflicts of acceptance, which may slow its dissemination significantly [Kunze & Hertel 2017]. Approaches such as risk communication may improve the situation [Vargas Payera 2018].

However, in many cases, it is the process of energy policy making which simply fails to take account of the concerns of citizens, hence creating a lack of trust and increasing the likelihood of opposition [Sovacool & Dworkin 2015]. Methods to ensure that the ethical concerns of citizens regarding energy projects are taken into account, whilst at the same time providing transparent information and education on the projects are needed. More research in this area would be beneficial, as well as in relation to improved communication and promotion of geothermal applications in the EU. Using successful community projects such as the Heerlen energy project in the Netherlands [Verhoeven et

[6] http://www.front-rhc.eu/

al. 2014] may help to showcase the community benefits that can be enjoyed from the use of geothermal energy (and other) sources.

In general, more attention should be paid to the understanding of environmental impacts and safety aspect and possible mitigation actions taken.

4.2.3 Competitiveness

The competitiveness of the European geothermal sector is affected by domestic market factors on the demand side, market factors on the supply side, innovation-friendly regulation in the MS, technological capability of the MS and the structure of actors and competitiveness of related industry clusters in the MS [Walz & Köhler 2014].

Demand-side factors include demand and price advantage and market structure. Growing demand domestically can result in economies of scale and hence cost reductions. If the market has lead users, it can take up global demands before others.

Supply side factors such as transfer and export advantages are also important. If countries can demonstrate a technology successfully, they can export more easily. If the EU can successfully demonstrate EGS plants, then it may have a competitive advantage compared to others.

Regulation must be innovation-friendly and exemplary for other countries. It must lead to a correction of market failures and externalities, otherwise the demand will be lower. For instance, in the case of geothermal energy, regulation would need to recognise its benefits compared to fossil fuels and support it accordingly.

If a country has a comparatively high knowledge base, it also has an additional advantage in developing and marketing future technologies. For example, Italy has a very long history of geothermal energy usage for generation and as a result companies like Ansaldo Energia are among the leading geothermal turbine manufacturers globally, competing against the four major manufacturers (Toshiba, Mitsubishi, Ormat, Fuji).

If there is a competitive market structure among suppliers, this encourages higher performance among economic actors. Social and learning networks within the industry are also important. Currently the EU is underrepresented in certain parts of the value chain such as exploration and drilling services [Magagna et al. 2017], key areas for the advancement of EGS technology.

4.2.4 Risk management and financing

Geothermal energy projects have specific risk factors, such as resource risk, which must be managed. Solutions are available in various forms (see Section 2.7), however, harmonisation of evaluation standards, integration of exploration costs into portfolio management models or the creation of a pan-European risk sharing facility may also help [ETIP-DG 2018].

4.2.5 Legal aspects

The regulatory framework around geothermal energy development is rather complex and this may cause unnecessary delays in implementing projects. In many European countries geothermal energy is regulated by national Mining or Water Acts and responsibilities are spread out among different ministries or institutes. International cooperation and a harmonisation of legislation is also problematic due to legislative inconsistencies [Somogyi et al. 2017, Dumas 2019]. Other legal issues, relating to resource ownership, licensing, environmental protection, water extraction, cultural and amenity values and grid access have been outlined in [Dumas et al. 2013, Tsagarakis et al. 2018].

4.2.6 Information access

Access to information on various aspects of geothermal energy development is fragmented and hence it is difficult for developers to effectively leverage it. Accessing information on the underground is particularly problematic, but also having harmonised sources of information on regulatory aspects, economics, social acceptance, training and education would aid decision makers and facilitate developers [Manzella et al. 2013, Colmenar-Santos et al. 2015].

5 Deployment policies

5.1 EU deployment in the NREAPs perspective

Eighteen EU countries have included geothermal energy in their 2020 National Renewable Energy Action Plans (NREAPs): twelve countries consider both geothermal heat and electricity, while six only heat.

In the power sector, the current EU deployment is 52 % of the NREAP 2020 levels. In several countries no geothermal power plants have been installed at all (Figure 14).

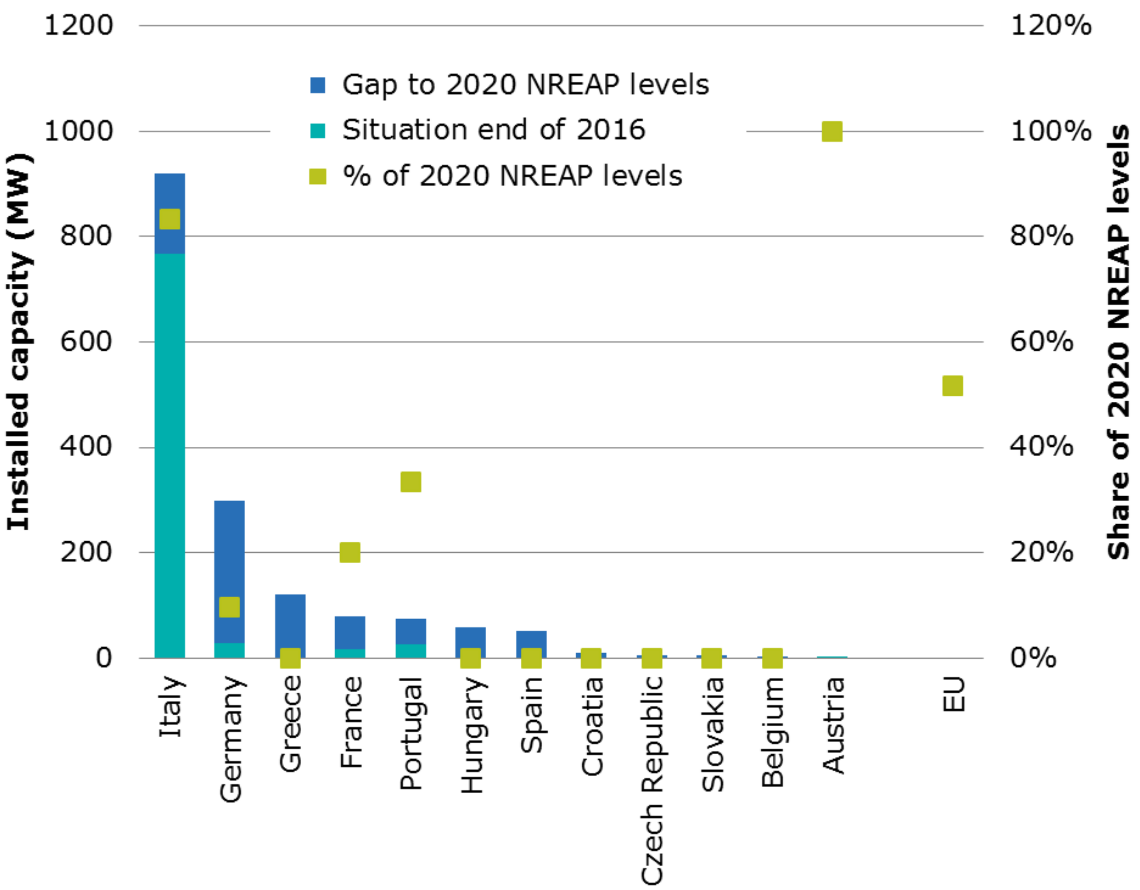


Figure 14. 2016 status of countries including geothermal electricity in their NREAPs. Source: [EC 2018b]

Figure 15 shows the status of countries in the geothermal heat sector. The EU has reached only about 29 % of the levels reported in the NREAPs for 2020, even if a huge variability can be found: some countries (Bulgaria, Slovenia, Spain) have already reached (and indeed markedly exceeded) those levels, while others are very far (e.g. Czech Republic 0 %, Poland 6 %, Slovakia 6 %).

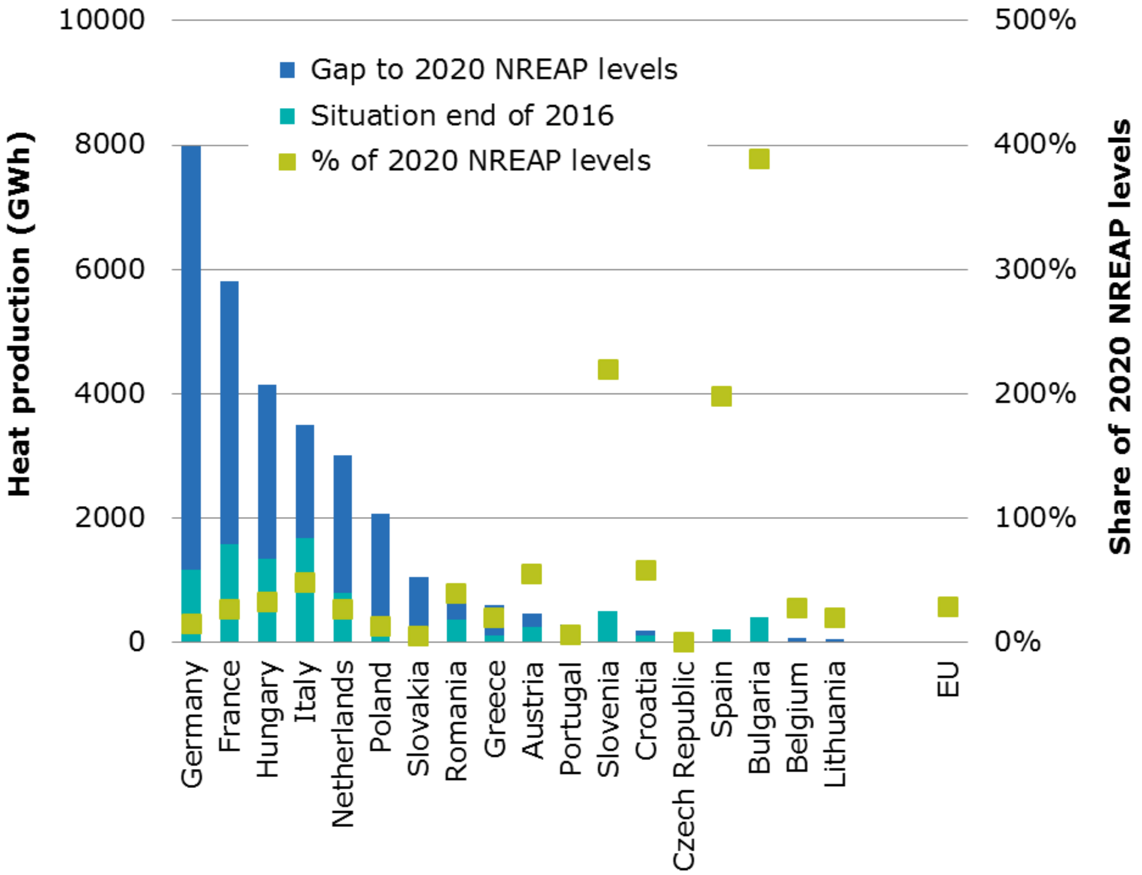


Figure 15. 2016 status of countries including geothermal heat in their NREAPs. Source: [EC 2018b]

5.2 Direct incentives, support policies and their impact

Geothermal energy development faces a combination of challenges, depending on the regional circumstances, described in detail in Section 4.2. In this section we look at the policy context and support mechanisms for geothermal energy in the EU and their impact. We also look at the approaches specifically for risk mitigation for geothermal projects, which may involve government support.

5.2.1 Policy context

At the European level, geothermal energy is promoted by the EU's Climate and Energy objectives. The regulatory and policy framework for geothermal energy is complex (Figure 16). This complexity may discourage investment in geothermal energy development. [ETIP-DG 2018].

The specific requirements of geothermal developments – related to drilling, geothermal fluid extraction and possible gas emissions – put deep geothermal projects within the scope of several European environmental legislations. As a young technology, deep geothermal projects also benefit from European policies to support research, development and innovation [Subir K. Sanyal et al. 2016].

National and regional frameworks may vary significantly from the European level, by applying more regionally specific policies. The European Climate and Energy Framework is structured around two axes:

- Climate and energy targets (on renewable energy, energy efficiency and carbon emission reduction) and the related legislative texts, such as the Renewable Energy Directive or the Energy Efficiency Directive;
- The Emission Trading Scheme (ETS): the largest existing carbon market and associated mechanisms.

The Renewable Energy Directive introduced key provisions for the development of innovative energy technologies. The directive requires a binding target for the share of renewables by 2020, hence countries have been obliged to specify sources of renewable energies to develop. Under the directive, priority of dispatch and priority access is given to geothermal electricity, which provides investors with certainty when supporting demonstration projects. Feed-in tariffs or premiums that incentivise investments in new deep geothermal projects were also established.

The Emission Trading Scheme is the European carbon market for large facilities. The NER 300 funding programme was set up using the revenues of the EU-ETS and provided grants to innovative renewable energy and Carbon Capture Utilisation and Storage (CCUS) projects. NER 300 has provided direct support to several EGS projects in recent years. NER 300 will be succeeded by an Innovation Fund and a Modernisation Fund.[7]

EU Structural and Investments Funds of interest for the geothermal sector include the Cohesion Fund, the European Regional Development Fund (ERDF), the European Social Fund (ESF) and the European Agricultural Fund for Rural Development (EAFRD). [ETIP-DG 2018]. Financial Instruments (FI) provide technical assistance, soft loans schemes or revolving funding [ETIP-DG 2018]. Horizon 2020 is the main EU R&I programme with nearly EUR 80 billion of funding available over 7 years (2014 to 2020). H2020 has provided funding to geothermal R&D projects since its inception. The European Investment Bank (EIB) is owned by the Member States and works closely with other EU institutions to implement EU policy focussing on specific priorities such as climate action and strategic infrastructure. It supports projects through loans, technical assistance, guarantees or venture capital [ETIP-DG 2018].

Geothermal developments have been shown to benefit from government support. Several EU MS have implemented support policy instruments that have resulted in an acceleration of geothermal development [Subir K. Sanyal et al. 2016].

Policy support instruments for geothermal energy include both push and pull mechanisms. These differ between member states and depend on the technology in question (power production, direct use, GSHP). For geothermal power, support schemes at EU or national level include feed-in tariffs, feed-in premiums, subsidies, loans, tenders, quota systems, net-metering and tax regulation. For geothermal heating and cooling (including GSHP), subsidies, loans, quota systems, tax regulation and price-based mechanisms are available.

The reader is referenced to [RES Legal 2019] for a thorough and up-to-date overview of the incentive mechanisms adopted in Europe.

[7] The Modernisation Fund is addressed at lower income European Member States for the modernisation of energy or industry facilities. It allocates 2 % of the total ETS revenues. The Innovation fund will use European Trading Scheme revenues to fund innovative energy projects. It should rely more heavily on financial instruments than its predecessor (which awarded all support through grants). Funding would come from the revenues from 400 million carbon allowances in the ETS.

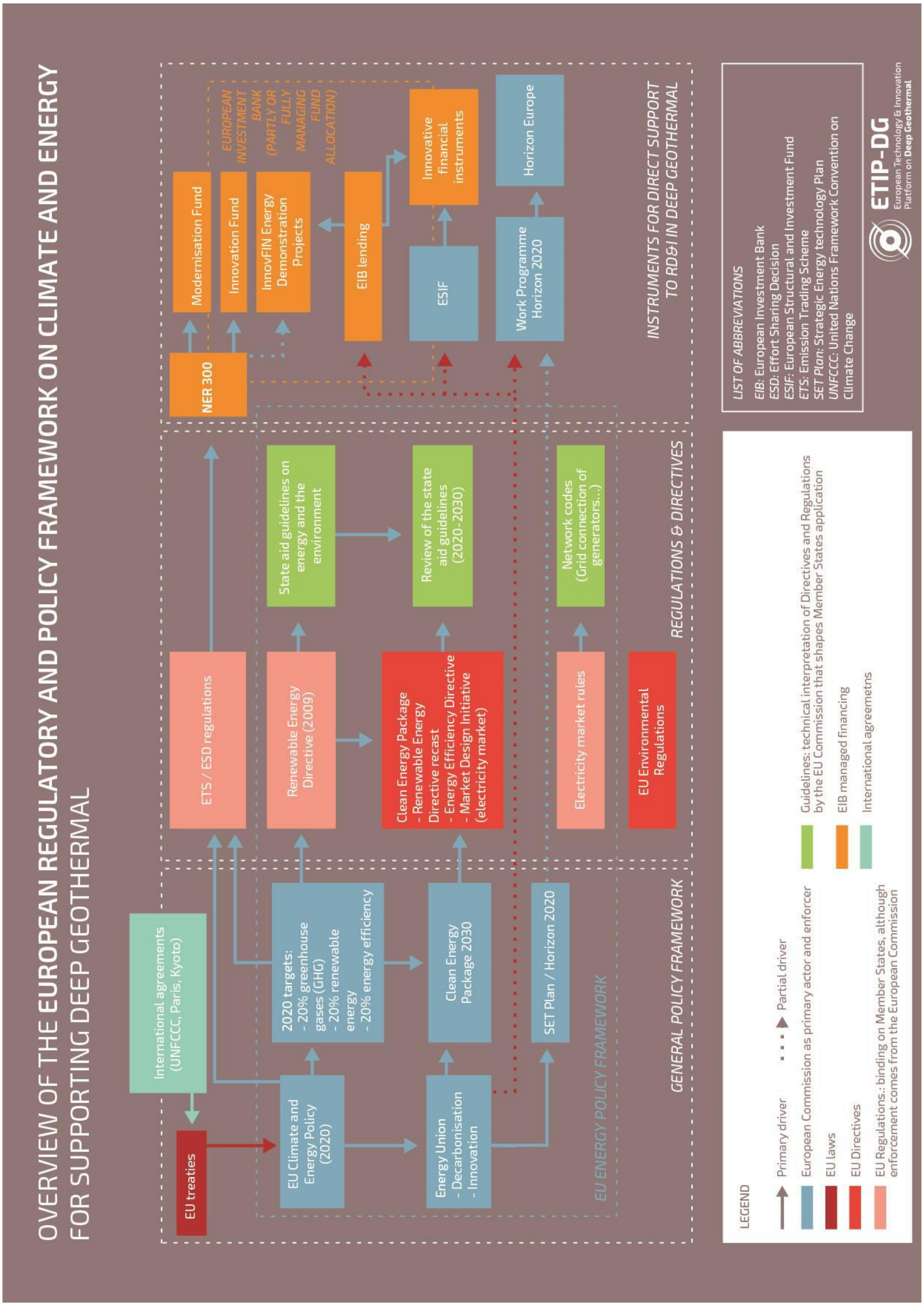


Figure 16. EU regulatory and policy framework for deep geothermal. Source: [ETIP-DG 2018]

5.2.2 Approaches to risk mitigation

Approaches to risk mitigation for geothermal projects are elaborated in an overview article of Subir K. Sanyal at al. [Subir K. Sanyal et al. 2016]. Operating geothermal power plants can provide reliable and environmentally favourable power generation at a steady cost. However, their development is hampered by:

(i) the need for significant up-front capital investment long before revenue is earned from electricity sales

(ii) the high level of resource risk up to the early drilling stage

The entire development process takes two to five years, from surface-based explorations to the confirmation of the resource. Another three to five years is required for additional drilling to build out the well field and construct the power plant before operation can commence.

Incentive schemes drawing on public support that help move risk capital into geothermal exploration drilling include:

1. Government takes on the full resource and other project risks by acting as the total project developer (exploring, discovering, building and operating the project), through state-owned enterprises or other government-backed entities

2. Cost-shared drilling for mobilising private development, where some or all of the risk of drilling to develop the steam field is shifted to the public sector

3. Geothermal resource risk insurance that looks to pool exploration risks across a portfolio of development

4. Early-stage fiscal incentives (exemption from duties, tax credits, etc.) that lower the financial exposure developers would face during exploration drilling.

5.3 R&D investment

The United States is the leader in providing public R&D investment for geothermal energy, followed by Germany, Australia, and Japan. Germany provided more funding than all other EU MS combined, yet has less gross electricity production from geothermal than Italy and France, suggesting that funding is not directly related to electricity generation. Other European countries with high public R&D spending include Switzerland, France, Italy and the Netherlands (Figure 17).

The global amount of public R&D has been increasing in the past 7 years (Figure 18). In 2009, there was a spike due to a large amount of investment by the USA in geothermal, when President Obama signed a Recovery Act Funding for geothermal projects.[8]

In terms of private R&D investment (Figure 19), Germany leads globally, surpassing the USA, Japan, Korea and China. Other European countries are also top investors globally such as Italy, the Netherlands, United Kingdom, Sweden and France. The global annual private R&D invested shows an increasing trend, with higher investments in 2008 and 2010 due to larger than usual German investments (Figure 20).

[8] https://www.energy.gov/eere/geothermal/articles/president-obama-announces-over-467-million-recovery-act-funding-geothermal

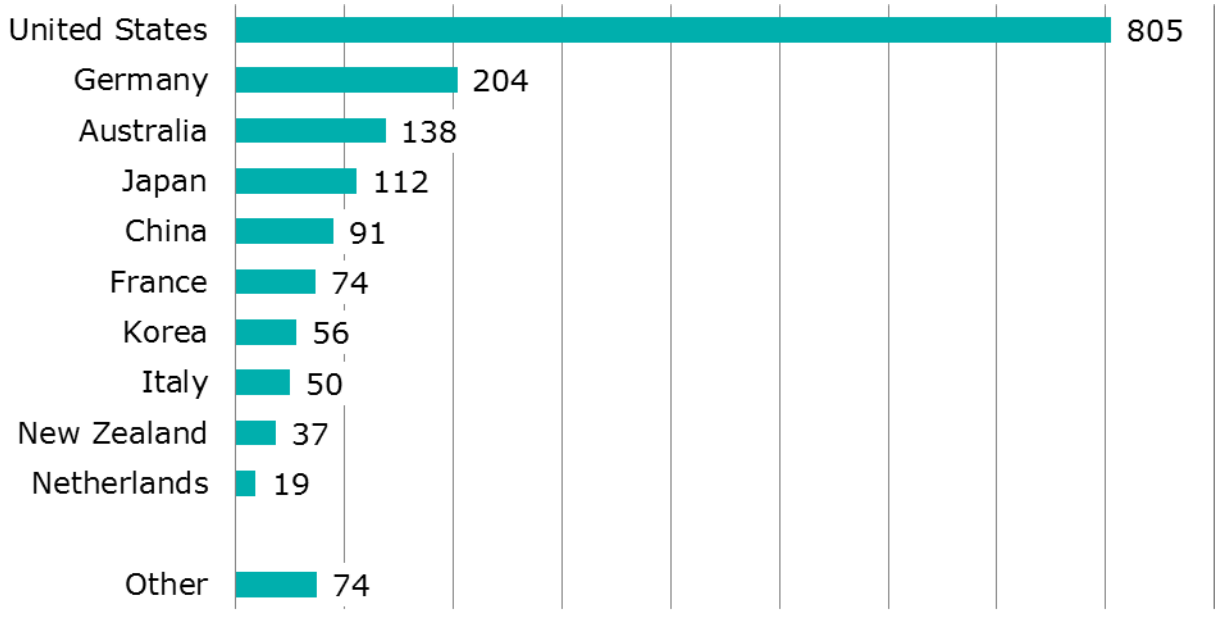


Figure 17. Cumulative public R&D funding for geothermal energy (2000-2016) of top 10 investing countries in EUR million. Source: Joint Research Centre (JRC)

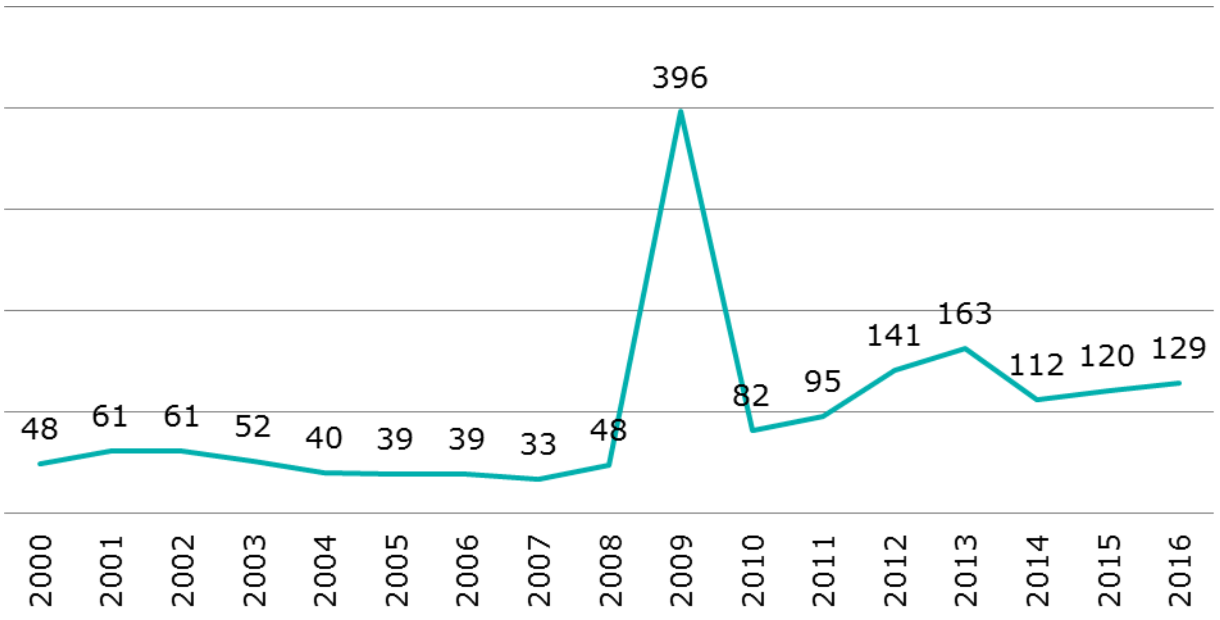


Figure 18. Global public R&D funding for geothermal energy (2000-2016) in EUR million. Source: Joint Research Centre (JRC)

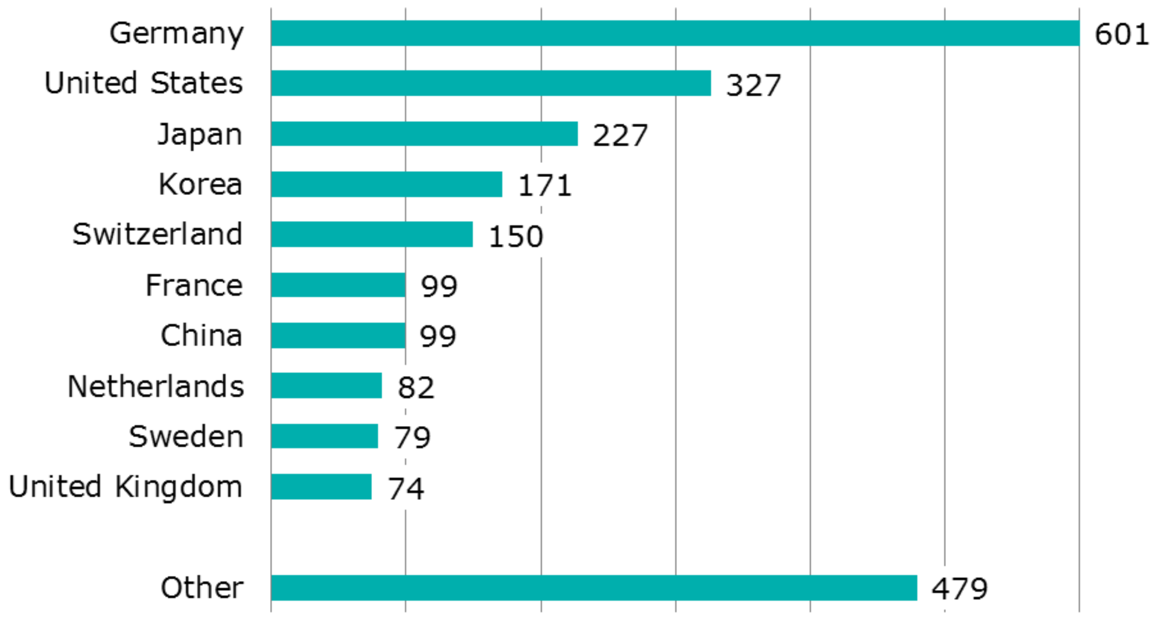


Figure 19. Cumulative private R&D funding for geothermal energy (2003-2014) of top 10 investing countries in EUR million. Source: Joint Research Centre (JRC)

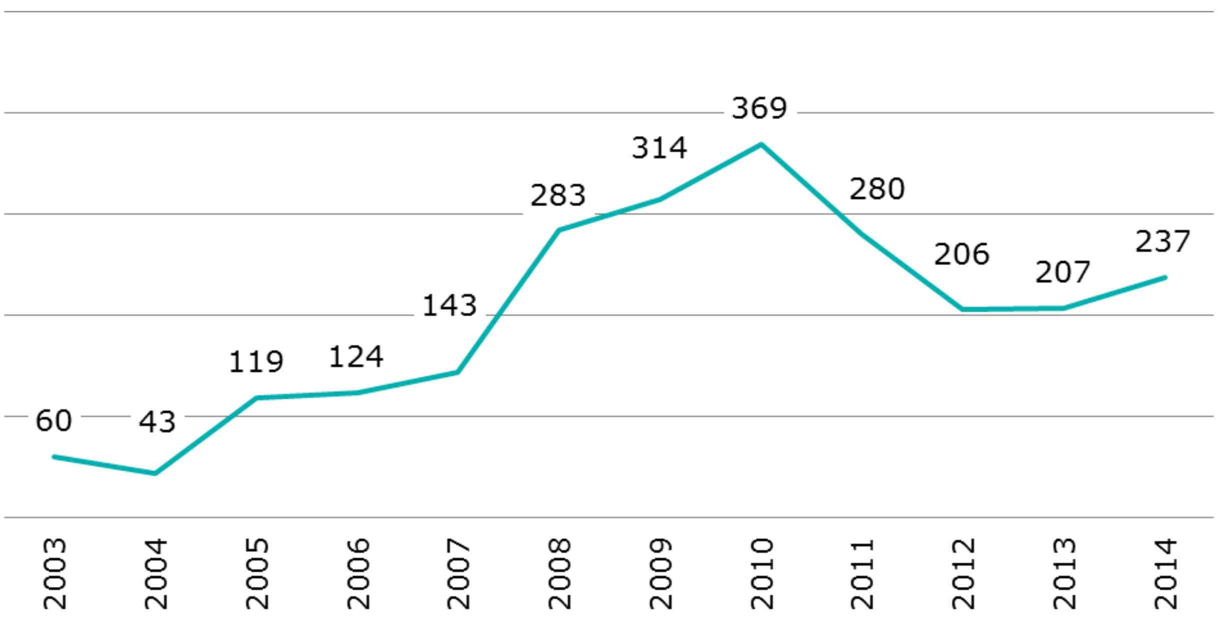


Figure 20. Global private R&D funding for geothermal energy (2003-2014) in EUR million. Source: Joint Research Centre (JRC)

5.4 Patenting trends

Patent submissions provide additional insights into the innovation dimension for technologies and the status of the industrial value chain for specific technologies in terms of geographical regions as well as for organisations. Japan is the world leader with the highest number of patent families in the period 2000-2014, followed by China, Korea, Germany and the USA. France, the Netherlands, United Kingdom, and Sweden are also leaders among the European countries (Figure 21**)**.

For high value patent families (i.e. patents that have been filed in more than one country), the US is the leader followed by Japan, German, Korea and Italy (Figure 22). Interestingly, China ranks only 16th in terms of high value patent families. Japan, Korea, Canada the US and Germany are also leaders in granted patent families, i.e. patents that are protected under law (Figure 23).

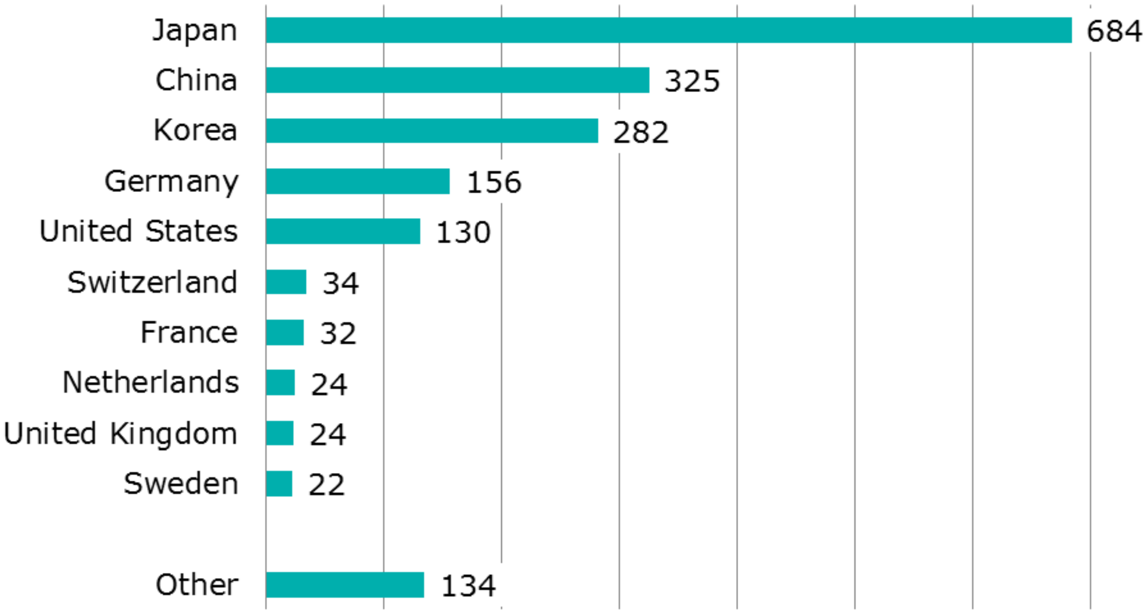


Figure 21. Cumulative number of patent families for geothermal energy (2000-2014) of top 10 patenting countries. Source: Joint Research Centre (JRC)

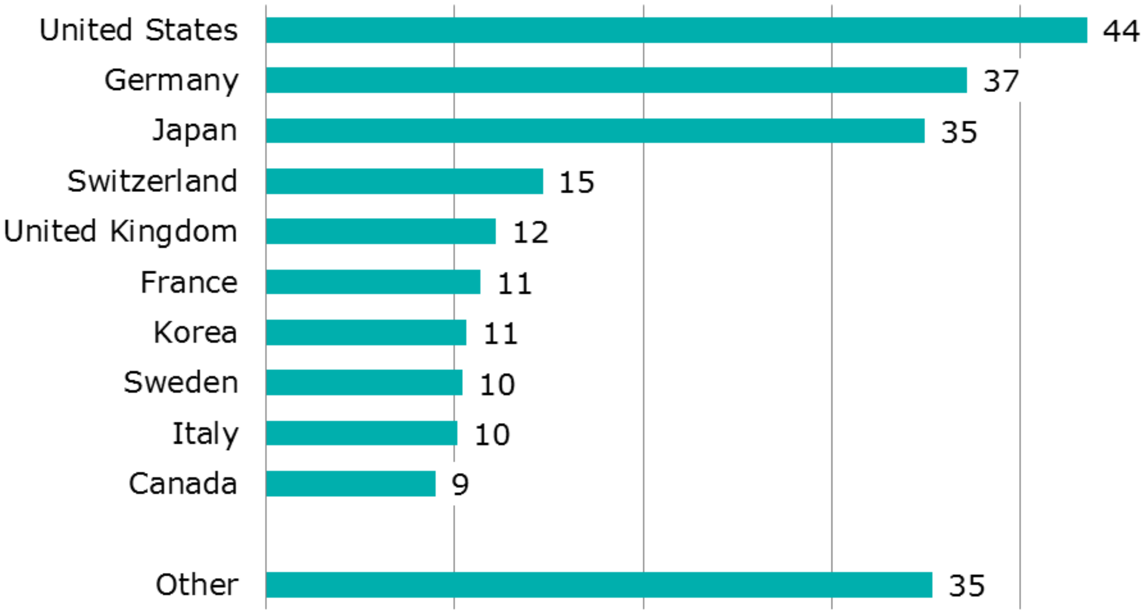


Figure 22. Cumulative number of high value patent families for geothermal energy (2000-2014) of top 10 patenting countries. Source: Joint Research Centre (JRC)

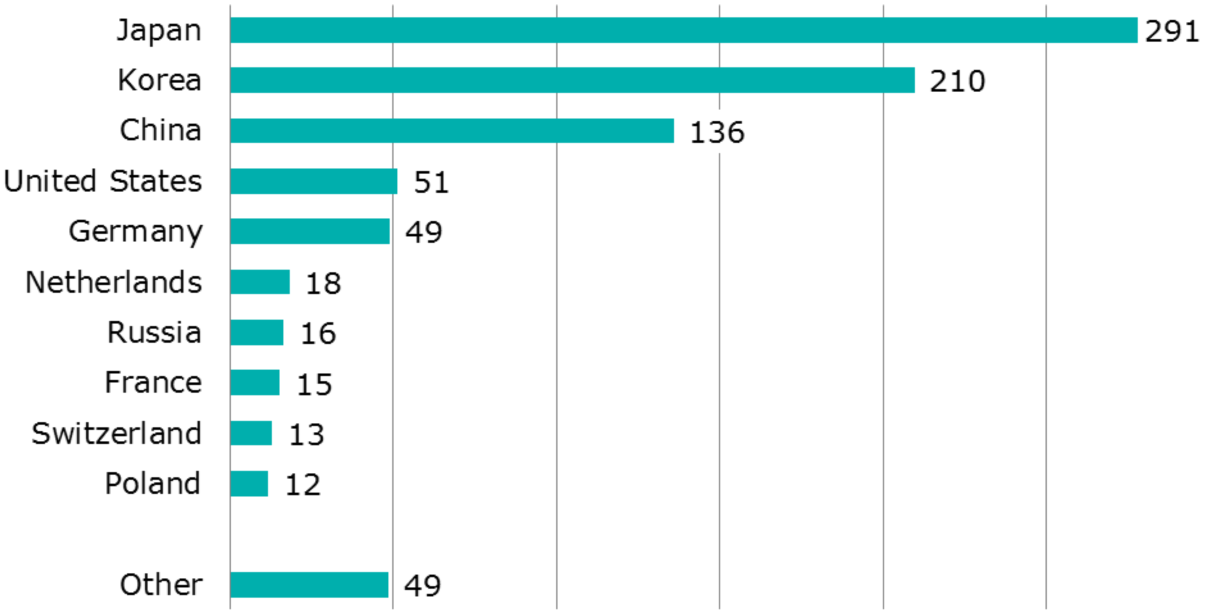


Figure 23. Cumulative number of granted patent families for geothermal energy (2000-2014) of top 10 patenting countries. Source: Joint Research Centre (JRC)

The global annual number of patents has been increasing in the same period (Figure 24). The period 2009-2014 saw a peak in the number of patents, due in part to a sharp increase in patent numbers in Japan and China.

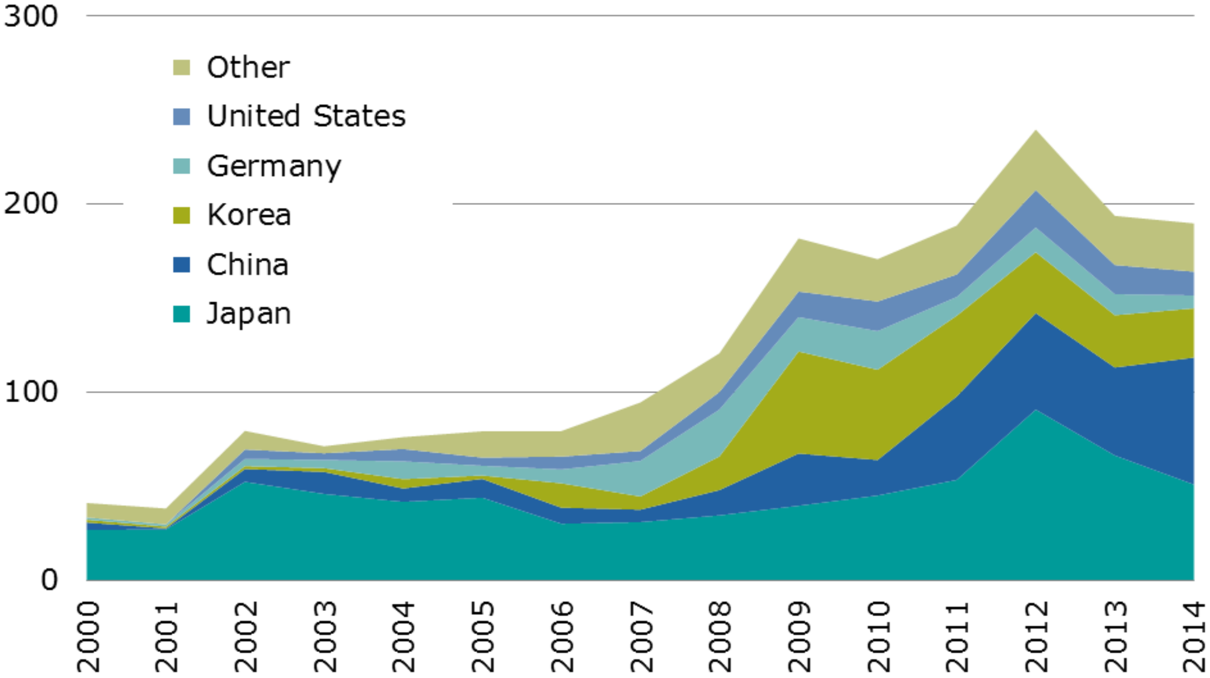


Figure 24. Number of inventions for geothermal energy (2000-2014) of top 5 patenting countries per year. Source: Joint Research Centre (JRC)

Figure 25 shows the global number of inventions for geothermal energy according to Cooperative Patent Classification(CPC). Unfortunately, the majority of patents is assigned to CPC code "Y02E 10/10 - Geothermal energy" without further specification. This category has seen the greatest increase over the years but also patents in the areas of geothermal heat pumps and earth coil heat exchangers have experienced growth between 2000 and 2014.

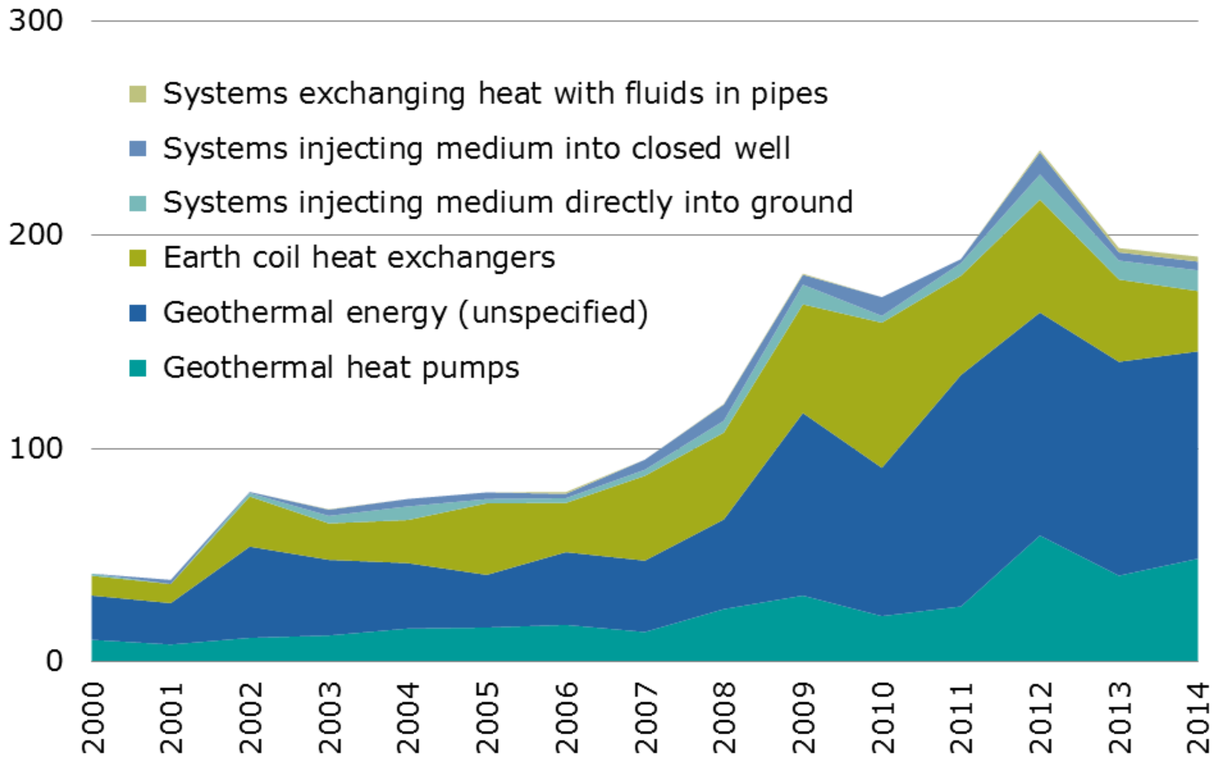


Figure 25. Number of inventions for geothermal energy (2000-2014) according to CPC-Y code. Source: Joint Research Centre (JRC)

6 Summary, conclusion and recommendations

6.1 Summary

The geothermal energy market can be divided in three sectors: power generation, direct use and ground source heat pumps.

Globally, the installed capacity of geothermal power plants is about 12.7 GW_{el}. Installed heating capacity of GSHP systems is over 50 GW_{th}, while direct use applications (excluding heat pumps) have an additional capacity of around 20 GW_{th}. The top countries for using geothermal power are the United States, the Philippines, Indonesia, Turkey, Mexico, New Zealand and Italy. The top countries for using geothermal heat are China, Turkey, Iceland and Japan.

The global geothermal power market is dominated by flash technologies, but hybrid plants and experimental technologies are expected to increase in the near future. The market for geothermal turbines continues to be dominated by a few international players and flash technologies are the most prevalent. The ORC binary turbine market has been growing in Europe since 2012 due to the installation of more low-temperature power plants.

Geothermal heat pumps are the most common form of geothermal energy use in the EU, with around 1.5 million systems installed. However, geothermal district heating is the largest and fastest growing direct use application of geothermal energy. With the recovery of the construction sector, the market for GSHP is expected to grow but there is strong competition with other heat pumps (especially air-to-air).

Public R&D investment in geothermal energy has shown a constantly growing trend in the past years, led by the United States. Germany, France, and Italy allocate the highest public R&D resources within the EU. Private R&D investments have also been increasing, in this case globally led by Germany. Recent trends highlight that private R&D investments tend to amount to about twice as the public ones.

Japan is world leader for number of patent families, even if in the latest years its leadership is being threatened by China and Korea. The United States are leaders in high value patent families. Overall, the global number of patents has been characterised by a considerable growth over the last decade, with a marginal role played by the EU.

In spite of its large potential, the deployment of geothermal energy is slower than other renewables due to various technical and non-technical barriers yet to be overcome. Electrical generation capacity is currently around 1 GW_{el} supply and the installed capacity for geothermal heat in the EU is 1.8 GW_{th}. In the power sector, the current EU geothermal deployment is around 52 % of the levels reported in the National Renewable Energy Action Plans for 2020, while the share is 29 % in the heat sector.

Geothermal energy for both power and heat is expected to grow in the next decades, both at a global and EU level, especially if ambitious climate change mitigation policies are implemented. Yearly investment in the EU can reach some EUR 10 billion if CCS options are not available. However, geothermal is not expected to play a major role in the power sector, as the other main renewable technologies (notably wind and solar PV) will have the lion's share in the low-carbon technology portfolio.

The regulatory environment for geothermal energy is prohibitively complex for new projects, although various support instruments exist. Support instruments for geothermal electricity and heat include feed-in tariffs, feed-in premiums, subsidies, loans, tenders, quota systems, net-metering and tax regulation. Geothermal energy projects continue to rely on government incentives to compete against natural gas and other renewables. Non-technical barriers to market expansion are related to policy and regulation, public acceptance, competitiveness, risk management, legal aspects, information access and skills and human and material resources.

6.2 Conclusions

The geothermal power market in Europe as a whole has seen a 10 % annual growth rate over the last decade. The geothermal district heating market is also growing at around 3 % per annum [EGEC 2018]. Despite this level of market growth, the predicted share in the energy mix is still low, unless EGS technologies succeed in coming into the main stream [Shortall 2018].

Historically, EGS projects have received a large share of EU R&D funding [Shortall 2018] of all geothermal topics, yet only four EGS plants are operating in the EU today. Following some unsuccessful projects since 2008 such as the EGS project in Basel, and subsequent public concern, the R&D focus moved towards risk mitigation and better stimulation techniques. In terms of manufacturing, the global turbine market is dominated by international players with high barriers to entry. The EU imports more components than it exports [CEMAC 2016]. However, other parts of the value chain may hold opportunities. Demonstrating successful EGS projects and associated components could give the EU a market leading position in this geothermal sub-sector. This would mean that key competences in exploration and drilling must be expanded. Currently the EU is underrepresented in this part of the value chain [Magagna et al. 2017].

Although R&D funding and patenting trends show an increasing trend in the last 7 years, it is not clear if this alone is enough to tackle the continuing market barriers that prevent the uptake of cost-effective geothermal energy technology in the EU, particularly, the successful demonstration of EGS technology.

Europe consumes half of its energy for heating and cooling purposes, most of which is used in buildings and industry. Currently only 13 % of this thermal energy comes from renewables, including geothermal energy [Heat Roadmap Europe 2017]. Given the relative abundance of suitable low temperature reservoirs for direct heat uses around Europe, this type of resource should be developed further, since it is currently only used to less than one thousandth of its potential. Spatial cooling shows the largest technical potential, followed by greenhouse heating and spatial heating [Limberger et al. 2018]. The technology for direct use applications are mature, hence these resources represent a low-hanging fruit for heating and cooling in the EU. The Heat Roadmap project has now mapped the renewable heat demands and potential, including geothermal heat in EU member states[9].

Although numerous policy support mechanisms are in place, deployment targets for geothermal heat and electricity nevertheless remain unmet by the majority of EU MS.

6.3 Recommendations for overcoming barriers

A fair market for geothermal would be one in which system costs and externalities are fully integrated into the costs of each energy technology and the security of energy supply also taken into account [Vernier 2013]. The EU ETS should function to reduce CO_2 emissions while promoting new low carbon technologies, but it has suffered from short-comings such as over-allocation of allowances. A carbon price applied to small scale heat installations (under 20 MW) would also benefit the geothermal sector.

While carbon taxation should internalise externalities of fossil energy use, it may still fall short of decarbonising the economy due to market failures such as knowledge spillovers in R&D, time-inconsistent preferences, information asymmetries, non-competitive markets and principal–agent problems. Other policy instruments are required to support renewable technologies not yet competitive under current market conditions [Angelino et al. 2016].

Support schemes for geothermal and other renewable energy sources should compensate for market failures and unfair competition by creating a secure investment environment,

[9] http://heatroadmap.eu

catalysing an initial round of investment and thereby allowing the technology to progress along its learning curve. For geothermal heat pump technology in particular, support schemes may also serve the purpose of increasing awareness and boosting consumer confidence in the technology [Angelino et al. 2016]. However, it should be noted that EU markets and technologies have different maturity levels. Therefore, a one-size-fits-all approach would not address the specificities of each technology or market [Prieto & Baez 2016].

For geothermal power, policy support mechanisms for reducing geothermal risk related to resource identification and exploration and for increasing the attractiveness of geothermal projects to energy investors should be focused on more than those that support the operational phase of the project, e.g. feed-in tariffs or quote obligations [Micale et al. 2014].

Due to the high initial risk of geothermal power projects, the private sector requires higher returns, which increases the Levelised Cost of Electricity (LCOE) of geothermal projects and may result in a tariff increase of 60 %. This increase can however be offset by public measures to mitigate risks such as resource exploration, political instability and currency fluctuation, and provide access to longer-term, lower-cost debt than available on the commercial market. By engaging the private sector, governments could achieve the same amount of electricity generation while providing only 15-35 % of the financial resources they would have spent had they built and operated projects themselves [Oliver & Micale 2015].

A European Geothermal Risk Insurance Fund (EGRIF) has been proposed by EGEC which would work by pooling of the resource risk among EU geothermal electricity projects – it would first be supported by public money but when mature this could be phased out and replaced by private schemes [Vernier 2013].

[Oliver & Micale 2015] recommend setting ambitious deployment targets that recognise the potential of geothermal to give a signal to international private developers, investors and technology providers. They also recommend centralised data-sharing on geothermal resources between public agencies and fee-paying private developers to reduce exploration risks. Accurate survey data can help attract developers into new markets and prevent costly and lengthy legal disputes on ownership.

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