2020 Annual Report

IEA Geothermal

May 2022

IEA Geothermal

Contents

Message from the Chair

Dear Reader,

Welcome to the 2020 IEA Geothermal Annual Report. The document describes the work of IEA Geothermal and our Working Groups, providing you with information about geothermal sector activities in our participating nations, as well as market, technology, research, and statistical information.

It is pleasing to see geothermal energy utilisation continuing to grow along with the interest that nations are showing in this renewable energy. The growth in direct geothermal use applications is notable with annual global growth rates of 10% or greater being seen in recent years.

2020 was the 23rd year for the IEA Geothermal Technology Collaboration Programme. The year was different for us because of the Covid-19 pandemic which resulted in all activities being held virtually.

The 2020 GeoTHERM Expo and Congress was postponed by the Exhibition Centre Management because of the pandemic. IEA Geothermal had a North Atlantic Symposium prepared for delivery at the event which was also postponed.

The World Geothermal Congress scheduled for 27th April – 1st May 2020 was postponed with the event being rescheduled for 2021 as a combination of virtual and in person events. Activities that we had proposed to run in association with this event; in particular the 43rd Executive Committee meeting, and the Mine Water Geothermal Energy Symposium in Edinburgh with a Field trip to the Mine Water Research Site at the Glasgow Observatory, Scotland, were reorganised as virtual events and in the case of the field trip this was cancelled.

Virtual activity also included the 44th Executive Committee and Working Group meetings held on the 13th – 14th October 2020.

We have seen leadership changes through 2020 and in this regard I wish to acknowledge Katharina Link's leadership of the Direct Use Working Group, Working Group 8. She has been in the role for eight years, relinquishing it in July 2020 having taken it on in September 2012. Thank you very much Katharina for your dedication to this Working Group, to IEA Geothermal and for the efforts you have put in for us.

I would like to thank contributors to our work, those who have provided material and assisted in preparing this report, the Working Groups and the Working Group leaders.

Please enjoy the read.

Dr Lothar Wissing

Chair IEA Geothermal (2020)

Executive Summary

The work of IEA Geothermal, and highlights from 2020, are presented in this report. IEA Geothermal had 16 participating members; 13 country members; the European Commission; and two industry organization/company sponsors. The group foster the sustainable use of geothermal energy through international collaboration, collating and distributing quality information, supporting the development and uptake of geothermal technologies, and communicating geothermal energy's strategic, economic and environmental benefits. Please visit our website, participate in our Working Groups, join one of our workshops, or become a member of IEA Geothermal.

Geothermal energy is used around the world in direct use applications: space heating and cooling, greenhouse heating, aquaculture, bathing, thermal city networks, and industrial uses. In certain parts of the world where appropriate conditions are found, geothermal energy is also used to generate electricity.

The interest in geothermal heat is growing rapidly as value from this renewable energy source is being realised. It is not only heat in the traditional sense but also cooling. The interest is right across sectors from residential to city scale. Large integrated smart city energy systems are being developed with the potential for significant reductions in city CO_2 emission footprints. Volcanic geothermal systems that are superheated or supercritical are the focus of studies seeking to release usable energy from them. The Enhanced Geothermal System (EGS) environment offers enormous potential that is yet to be realised and significant investment in EGS technology and development is occurring.

2020 was a difficult year with much of the activity cancelled or in hiatus because of the Covid 19 pandemic. That said activity continued on a number of work fronts and in many of our participant nations. The executive summary identifies achievements of our Working Groups and highlights from the geothermal sector in our participating nations.

Working Group Activities

Working Group 1 (WG1)

Working Group 1 has the following goals:

a) encourage the sustainable development of geothermal energy resources;
b) quantify and seek ways to balance any adverse impacts that geothermal energy development may have on the environment; and
c) identify ways of avoiding, remedying or mitigating adverse effects.

Networking and cooperation amongst participating countries' researchers, operators, policy-makers and funding-agencies continued during 2020, albeit somewhat constrained, contributing to a number of publications raising awareness internationally of successful mitigation schemes and beneficial environmental and social outcomes.

Highlights for the year include:

- Completion of environmental and society collaboration papers for WGC2020.
- Compiled information in preparation for a book on environmental and social impacts.
- Networking and cooperation amongst researchers, operators, policy-makers and funding-agencies within the participating countries (e.g. GEOENVI, Europe).

- Raising international awareness of successful mitigation schemes and beneficial environmental or social outcomes.
- Supporting relevant presentations and publications by scientists from member countries at international conferences and workshops.

The presentations at several workshops and publications in conference proceedings, include at the Stanford Geothermal Workshop, the New Zealand Geothermal Workshop and joint WG1 papers on “Environmental and Social Impacts” completed for the WGC2020. (Refer list of material in the references section at the end of Chapter 2).

Working Group 8 (WG8)

Direct use of geothermal energy is growing worldwide with many applications from heating and cooling buildings, innovative smart district thermal grids, heat pump applications, industrial applications, bathing, agriculture, horticulture, food processing and fish farming. Working Group 8 focuses on providing quality information, communicating and transferring knowledge to reduce barriers to the uptake of direct geothermal use. In 2020, there were 5 active tasks:

- New and Innovative Geothermal Direct Use Applications
- Communication
- Statistics for Geothermal Heat Pump Applications
- Design Configuration and Engineering Standards
- Costs of Geothermal Heat Pump Applications

WG 8 was very active in 2019 through symposia and workshop activity but much less so during 2020 due to travel and gathering restrictions that were implemented by various nations seeking to limit the spread of Covid-19 as part of the global response to the pandemic. During 2020 the COVID 19 pandemic restrictions resulted in deferral of the planned WG8 symposium activity as congresses and conferences where cancelled or deferred. These symposia will be discussed in the report year that they are held.

There were two symposiums that were held in 2019 that have not previously been reported in a WG8 report:

- The two-day International Geothermal Energy Workshop held at Instituto Tecnológico de Canarias, Pozo Izquierdo, Gran Canaria, on the 8th and 9th April 2019. Presentations are available from iea-gia.org/workshop-presentations/2019-gran-canaria-geothermal-energy-workshop/, and
- The two-day International Geothermal Energy Workshop in San Jose, Costa Rica on the 11th and 12th November 2019. Presentations are available from iea-gia.org/workshop-presentations/2019-costa-rica-geothermal-workshop/.

In July 2020 Katharina Link’s contract concluded and with it her leadership of WG8 which spanned over eight years since September 2012. The working group acknowledges and thanks Katharina Link for her dedication to this Working Group and for the effort she has put into running it.

Working Group 10 (WG10)

Internationally, there is a growing demand for reliable information on renewable energy capacity and energy production. Working Group 10 is seeking to fulfil some of that demand for geothermal data. Data analysis work by IEA Geothermal has been on hold during 2020 pending contract renewal with the Leibniz Institute for Applied Geophysics.

Earlier reports can be accessed from the IEA Geothermal web site.

Two IEA Geothermal papers on data and reporting were written for the proceedings of the World Geothermal Congress 2020.

> Weber,J., Wissing, L., Ten Years of Geothermal Trend Reporting and Statistics by IEA Geothermal. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021)
>
> Song, Y., Link, K., Yasukawa, K., Weber, K., Proposal of New Data Collection Methodology for Geothermal Heat Pumps Statistics - an Outcome of IEA Geothermal Working Group Activities. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021)

Working Group 12 (WG12)

This WG focuses on the deep roots of volcanic systems and has enthusiastic participation from a number of IEA Geothermal member countries who are working on very high temperature geothermal systems. Energy utilisation from these geothermal conditions requires improved modelling methods, fundamental geochemical characterisation, development of downhole measurement tools, and advancing the understanding of water-rock-gas interaction at high temperatures and pressures.

2020 saw a number of peer reviewed papers prepared, presentations at international conferences and preparation of joint papers for the WGC2020. A comprehensive reference list at the end of the Chapter 5 provides the details.

Working Group 13 (WG13)

Working Group 13 covers a broad spectrum of geothermal activity including exploration, drilling, reservoir creation and enhancement, corrosion, scaling, tracers, and the mitigation of induced seismicity. The goal is to provide quality information to facilitate the utilization of geothermal energy worldwide. The development of innovative technologies is being pushed by expert collaboration between countries and the results made available in documents and presentations at conferences and workshops.

Work is carried out in six tasks:

- Exploration (A1), Measurement and Logging (A2),
- Drilling Technology (B),
- Reservoir Creation and Enhancement (C),
- Induced Seismicity (D),
- Surface Technology (E) - Heat and Electricity Production, Corrosion, Scaling, Tracer Technology.

For most Tasks work during 2020 was at a very low level, producing no new outputs.

Task D (Induced Seismicity) was active through 2020 with the primary effort focussed on encouraging collaboration of researchers and the sharing of results of the considerable amount of funded research undertaken by participants in this area.

A paper prepared for the WGC2020 meeting was postponed, to be presented in 2021. Papers were published in the proceedings of several major international geothermal workshops including the; 45th Stanford Geothermal Workshop (February, California), 42nd New Zealand Geothermal Workshop (November, Paihia, New Zealand) and the GEMex Final European Conference (February, Potsdam, Germany). A special issue in the Geothermics Journal was on the Pohang earthquake and its association with the nearby EGS project.

National Activities

The material immediately below is a summary of 2020 activity from each of our member countries. Each participant's geothermal programme provides the basis for IEA Geothermal cooperative activity. The country material is written up in more detail in chapters 7 to 20. Not all participants have been able to complete the 2020 material for this report and where 2019 material is used it is recorded in the section heading.

Australia

The transition of Australia's electricity sector to renewables is proceeding rapidly with renewable generation exceeding 52,000 GWh in 2020 well above the 2011 Renewable Energy Target of 33,000GWh. Renewables contributed 20% of total electricity generated in 2020 which is a 17% increase on the previous year. Emissions from the electricity sector in 2020 were 172 $MtCO_{2e}$ with 111 $MtCO_{2e}$ the 2030 projection

Commercial factors are driving ongoing investment, with projections of ~30% of grid connected capacity coming from roof top solar by 2030.

The 310 kW ORC geothermal power plant in the remote community of Winton, Queensland operated through 2020 after the plant was commissioned in December 2019. The town's water supply is sourced from the Great Artesian Basin with 77 l/s of water emerging from a network of 1330m deep bores at 86°C. This water is used as the heat source for the ORC power plant with generation automatically modulated to match water consumption.

The geothermal heat supply to the Traralgon Gippsland Regional Aquatic Centre (GRAC) was successfully commissioned in November 2020. The heat is supplied from 65°C water taken from wells drilled into the Traralgon aquifer with the water returned to the aquifer at between 40 to 53 °C depending on the heat load required. Maximum power is $3MW_{th}$, with annual carbon emissions reductions of 700 tonnes and annual savings of $400K from gas heating. The project is scheduled for completion early in 2021.

Interest in the Hot Spring and wellness sector is flourishing with seven projects nationwide either under construction or finalising planning and financing. A two year expansion project at the Peninsula Hot Spring facility, Mornington Peninsula, Victoria was completed in December 2020. A PhD project, at the Victoria University, Melbourne, studying the social, environmental and economic impacts of hot springs on communities across Australia commenced in 2020.

A three-year study funded by ARENA on the performance of 'deep well direct exchange' (DWDX) ground source heat pumps installed in the Fairwater Living Lab, a residential community, in Western Sydney continued through 2020, with the study due for completion in 2022.

No national geothermal conferences were held during 2020 because of the Covid 19 pandemic.

European Commission

The European Commission is supporting the development of the geothermal sector through funding from the Horizon 2020 and the European Regional Development Fund programs, and policy initiatives in the SET-Plan which includes the Deep Geothermal Implementation Plan (DG-IP). The DG-IP which was updated in 2020 is being implemented through the Deep Geothermal Implementation Working Group. A Support Unit was established in 2019 to assist the Working Group in delivering implementation activities.

The EU Clean Energy Package established a binding target of 32% renewables by 2030. EU member states delivered their 10-year integrated national energy and climate plans (NECP) covering the period 2021 to 2030 before the beginning of 2020. The aspiration expressed by the European Commission President is for Europe to become the world's first climate-neutral continent by 2050.

Horizon 2020 concludes in 2020 and the programme replacing it is Horizon Europe which commences in the spring of 2021 and runs from 2021 to 2027. Geothermal energy is included under the Climate, Energy and Mobility subprogramme. In Chapter 8 there is a comprehensive listing of geothermal outputs funded through Horizon 2020 – please note that some of the individual funded workstreams run until 2024.

The European Investment Bank together with the European Commission are implementing the InnovFin Energy Demo Projects (EDP) scheme which provides loan support for first-of-a kind projects. InnovFin aims to facilitate and accelerate access to finance for innovative businesses and projects in unproven markets in Europe. The scheme reduces the financial risk of demonstration projects and offers equity and loans tailored to the need of a project.

At the end of 2019 there were 130 geothermal power plants with a total capacity of 3.3GWe in operation in Europe.2019. The geothermal electricity production in the EU amounted to some 7 TWh which is ~0.2% of the total EU electricity consumption.

The European district heating market continues to grow with 130 MW_{th} capacity installed in 2019. 100 MW of this is in the Netherlands. At the end of 2019 there are 327 geothermal district heating plants in operation in 25 countries in Europe with a total capacity of 5.5 GW_{th}. Poland and Denmark have a number of plants under investigation or in development.

Geothermal Heat Pumps are widely used across Europe with ~2 million systems installed as of end 2019, with a corresponding capacity of about 28 GW_{th}.

France

The installed capacity for geothermal heating and cooling is ~2800 MW_{th} with about 660 MW_{th} of this being associated with the deeper reservoirs in the Paris area, and the balance being shallow geothermal resource use across France. The number of geothermal installations feeding collective housing and residential blocks, including office buildings, is growing whilst the individual residential market is flat.

Geothermal electricity capacity of ~17.2 MW_e produced some 124 GWh in 2020. Of the two geothermal doublets drilled more recently near Strasbourg, the Illkirch cogeneration project is expected to move to completion in coming years whilst further development of the Vendenheim geothermal project will not now be undertaken.

Total geothermal heat pump capacity is some 2130 MW producing some 13.8 Pj/yr of energy. The residential market has seen about 2500 geothermal probes installed annually since 2016. This market continues to face strong competition from air/water and air/air heat pump systems. In 2020, a differentiated tax credit was implemented between geothermal and air heat pumps unfortunately the differentiated rate won't be effective for new builds or for more affluent households who are more like to be interested in renewable energy.

Several schemes have been implemented to assist geothermal sector development;

- A geological risk mitigation tool providing for failure in locating geothermal resources, insufficient temperature, insufficient flow rates or highly aggressive fluid chemistry.
- The SAF Environment guarantee for deep aquifer heat production has a proven track record over 40 years.
- Aquapac covers the geological risk for the first well drilled, up to 200m deep for open loop systems, and then the geothermal production during the first 10 years of operation.
- The Renewable Heat Fund (Fonds Chaleur Renouvelable) created in 2009, to subsidise geothermal installations in collective housing, tertiary, industry and agriculture. 700 projects have received support from the fund.
- Establishment of a regional network of geothermal co-ordinators – 4 co-coordinators are in place at the end of 2020.

Geothermal energy research and development is supported from funding from ADEME, the National Agency for Research and the Fund for Industrial Clusters. From two project calls 171 laboratories receive(d) funding. National technological clusters have been established to develop collaborative industry / research institute projects including: GEODEEP (export focus), Pôle AVENIA (deep applications), and SYNERGILE (renewable energy in offshore territories).

Géodénergies, an Institute of Excellence, created in July 2015 supports development of underground activities in: CO_2 storage, energy storage, and geothermal energy production (heat and electricity). Géodénergies has launched a number of research projects seeking to bridge gaps in technology. In 2019-2020 period Géodénergies will evolve into a research institute jointly owned by public - private participants.

Germany

A shift in emphasis is occurring in Germany with geothermal energy increasing being considered as heat for city and district heating networks rather than for electricity generation. At the beginning of 2020 there were 38 geothermal production operations across Germany with an associated thermal energy delivery capacity of 350 megawatts (thermal). Nine of these facilities generate electricity (capacity of around 47 MWe) either exclusively or supplementary to the heat supply. The feed-in-tariff for geothermal electricity continues to be 25.2 Euro-cents per KWh.

Stadtwerke München (SWM) is working to provide the entire district heating for Munich from renewable energy by 2040, with the majority being geothermal. Project GeoMARE initiated in 2018 continued through 2020 providing both conceptual and comprehensive design of the district heating system with the project overall targeting adaption of citywide heating infrastructure supported from a 400 MW sustainable geothermal heat supply. Heizkraftwerk Süd in Munich is going to become the largest inner-city geothermal plant in Europe with SWM planning to supply around 80,000 residents.

The Market Incentive Programme of the Federal Government promotes renewable energy systems that provide energy for space heating, hot water, cooling and process heat. It covers smaller buildings administered by the Federal Office of Economics and Export Control (BAFA), and larger buildings and commercial uses being a component of the KfW Banking Group renewable energies program. MAP subsidizes the installation of efficient heat pump systems in residential buildings through a repayment bonus, depending on the installation size.

The Federal Government has a strategic approach for technology and innovation transfer using living labs to bring new, promising technological solutions to market through exploring and mastering the challenges under real-life conditions, and then later implementing the tested technologies on a large scale.

For deep geothermal research in 2020, the BMWi approved funding of around 41 million Euros and an additional 14.4 million Euros was invested in 106 ongoing research projects.

The Federal Government supports international collaboration and cooperation through a number of agency activities, including; the implementation of the EU SET-Plan, activities under the IEA and by participation in transnational funding instruments such as GEOTHERMICA.

Iceland

Iceland has developed expertise and experience in harnessing geothermal resources for both space heating and for electricity generation. Over 90% of Icelandic households are heated with geothermal energy and 30% of the nation's electricity is generated from geothermal energy.

The fourth Icelandic Master Plan for Nature Protection and Energy utilization was completed in 2020. The third plan, presented to the Minister for Industry in September 2016 remains unconfirmed. The 10 projects identified in the third plan remain on hold as work cannot commence until the plan is confirmed.

At the end of 2020 the installed geothermal electricity capacity was 757 MW_e. In 2020 5960 GWh of geothermal electricity and 33.7 PJ of geothermal heat (2019 data) were produced.

An Energy fund, operated by Orkustofnun, supports geothermal development in areas where geothermal energy is not yet used for heating. The financial support comprises a lump sum of 16 years-worth of subsidies to assist in establishing either geothermal heating or a more efficient heating system, such as using heat pumps. No market incentives apply to geothermal electricity development.

The Reykjavík Energy CarbFix and SulFix projects reinjecting gases extracted from geothermal fluid at Hellisheiði power plant are progressing well with the gases mineralizing in the basalt bedrock in less than two years. Currently 65% of the H_2S and 30% of the CO_2 are returned underground.

The main purpose of the IDDP work is to determine if it is economically feasible to extract energy and chemicals from hydrothermal systems at supercritical conditions. Planning for an IDDP-3 well in the Hengill area (near the Hellisheiði power plant) continues.

The 2020 World Geothermal Congress was rescheduled due to Covid 19 into 2021.

A hydrogen pilot plant has been established at Hellisheiði. The concept is that off peak electricity is transformed into hydrogen and stored for later use.

In January 2020 the name of the United Nations University-Geothermal Training Programme, programme changed to the UNESCO GRÓ Geothermal Training Programme with this programme now operating under the auspices of UNESCO.

Italy (2019)

At the end of 2018 the Italian Installed geothermal capacity was 915,5 MWe. The gross electricity generation for 2018 was 6,105 GWh.

No new geothermal electricity generation plants were commissioned in 2019.

At the end of 2017 direct geothermal use capacity was more than 1400 MWt, with corresponding total energy use for 2017 of 10.9 Pj/yr. The geothermal energy use is broken down with the main sector use as follows: space heating 42%, thermal balneology 32% and fish farming 18%. Agricultural applications, industrial processes and other minor uses amount to less than 8% of the total annual energy use.

Installed ground-source heat pump (GSHPs) capacity is some 532 MW_{th} delivering ~3.3 Pj/yr of energy. District heating systems with a total installed capacity of ~150MWt annually supply 863 Tj/yr of energy, ~8% of the total geothermal heat. The district heating systems are mainly in the Tuscany Region and District heating is the only sector growing significantly.

Recent official Italian documents forecasting renewable energy production in Italy envisage limited growth in geothermal energy applications. The 2017 Italian Energy Strategy (MISE, 2017) predicts a rather limited increase in geothermal electricity production whilst proposing to establish a support scheme for innovative geothermal technologies demonstrating power production with zero emissions. In July 2019 geothermal power was excluded from participating in the incentive schemes offered for electrical energy produced from renewables. At the end of 2019 the support scheme for zero emission or other innovative geothermal technologies had not been established.

Recent Italian research projects focussing on sustainable development, and reducing and mitigating environmental impacts have achieved good results:

- In 2019 the EU H2020 program Matching concluded. The Matching project achieved the target of an up to 15% reduction in evaporative losses from geothermal cooling towers, through the replacement of wet cooling towers with hybrid towers.

- The Spirulina cultivation project successfully demonstrated use of geothermal CO_2 and heat to grow spirulina algae. This integrated geothermal and algae production process reduces CO_2 emissions from a geothermal facility.

The H2020 Geoenvi project was established in 2019. Scheduled for completion by April 2021 the project aims to define Guidelines for Life Cycle Analysis (LCA) and environmental impact assessments of geothermal energy facilities.

Japan

Japanese geothermal electricity capacity had grown to ~554 MW_e with 3.9 MW_e of new capacity coming online during 2020. Geothermal energy production was some 2400 GWh over the 12 month period (ending March 2018.

Direct geothermal use capacity is ~2400 MW_{th} producing ~30 PJ/year of energy.

The installation of GSHP has been increasing rapidly in recent years, with a total of 2,662 geothermal heat pump installed, with a capacity of ~160 MWth delivering about 770 TJ/year of energy (2019 data).

Promotional measures in play since 2011 to intensify deployment of Renewable Energy have brought renewed interest in geothermal energy development. A feed in tariff (FIT) was introduced in 2012 payable in advance to renewable electricity generation projects certified in a given year. The FIT for geothermal projects has been maintained over the years whilst for solar and wind the tariff has been reducing year on year.

METI has been supporting geothermal through other funding mechanisms and in 2020 ~6 billion JPY in grant subsidy, in total, had been paid to 22 projects receiving this support from JOGMEC.

Social acceptance of geothermal development remains difficult, especially amongst hot spring resort owners. METI began a program in 2013 to improve social acceptance of geothermal power generation. It is a subsidy scheme for general public educational activities undertaken by local governments and/or the private sector. In 2020 eight projects were adopted. 2020 saw the annual JOGMEC Geothermal Symposium run virtually with attendance of more than 2000 people. This attendance was 4 times greater than been achieved at in-person events previously.

Since 2013 JOGMEC has been undertaking airborne helicopter geophysical surveys, land based geological and geophysical surveys augmented with some drilling in some areas. By the end of 2020 18 areas in Hokkaido, Honshu and Kyushu had been surveyed.

NEDO began research in 2017 on subduction-origin supercritical geothermal resources, which have potential for 10’s of giga-watts of power generation for Japan, with a pilot plant targeted to be in place by 2040. Fundamental studies are being conducted by the National Institute of Advanced Industrial Science and Technology (AIST) and Kyoto University looking to utilise 500°C super critical fluids at up to 5km depths.

Mexico

The installed geothermal electricity capacity in 2020 was unchanged from 2019, being ~1006 MW installed and 948 MW operational. This operational capacity represents ~1.1% of the country's total installed electricity generating capacity. During 2020, 5,061 GWh of electricity was produced from geothermal energy (1.6% of Mexico's electricity).

In 2019 21.4% of the total electricity generated in Mexico was from clean energy sources. The Energy Transition Law has set a national target to produce 35% of the total electrical energy from clean sources by 2024.

Direct use of geothermal energy in Mexico remains largely undeveloped from what has been estimated to a very large potential (40,000MW_{th}). Some geothermal direct use demonstration projects have been sponsored by CeMIEGeo in the period 2014-2019.

No changes or new policies regulating geothermal energy use were introduced in Mexico during 2020.

As of December 2020 six exploitation concessions and 26 exploration permits (of three year duration and renewable for an additional 3 years) had been awarded by the Energy Ministry. The Covid pandemic has held back 2020 exploration activity.

The Inter-American Development Bank (IDB) and the Mexican development bank Nafin have developed a financing and risk transfer program for geothermal projects, Geothermal Financing Mexican Program (PGM), structured to finance up to 300 MW of geothermal capacity over ten years. It includes risk mitigation, financing support for exploration and execution, and technical assistance to support execution. The total amount is US$108.6 million. The goal is to leverage other public and private funds to contribute to Mexico's geothermal sector.

The GEMex bilateral initiative between Mexico (SENER-CONACyT Energetic Sustainability Fund) and the European Community under Horizon 2020 is investigating an EGS system in Acoculco, Pue., and a superhot system at Los Humeros. The European workgroups finished their tasks in May 2020, and the Mexican groups are scheduled to finish in July 2021. The final GEMex European consortium conference took place in February 2020. The 7th GEMex Mexican consortium workshop was held virtually in December 2020. Public information is available from http://www.gemex-h2020.eu including the proceedings of the final European conference. Further reports will be lodged when the project concludes in the second half of 2021.

CeMIEGeo's digital collection contains technical papers and thesis generated by CeMIEGeo's projects in the period 2014 to 2019. The digital collection includes papers in refereed international journals, thesis, and conference posters, accessible through https://colecciondigital.cemiegeo.org/xmlui/?locale-attribute=en.

The Mexican Geothermal Association's Annual Congress was postponed due to the Covid pandemic.

New Zealand

In 2020 electricity generated from geothermal energy contributed 17.8% to national electricity production from an operational geothermal capacity of ~1030 MWe.

The New Zealand Government announced a strategic target of 100% renewable electricity generation by 2035, in a normal hydro-generation year. This is additional to the target of 90% renewable by 2025 established a number of years ago.

The 31.5 MWe expansion (OEC4) of the Ngawha project was operational in December 2020 six months ahead of schedule.

Construction activity has commenced on the 168 Mwe steam turbine facility as the next stage of the Tauhara II project which is scheduled to be operational by the end of 2023.

The 25 MWe Taheke Geothermal Project, a joint venture between Taheke 8C Trust (15%) and Eastland Generation (85%) was announced in July 2020. It is supported by a Government Provincial Growth Fund grant of NZD 11.9 million.

There is interest from policy makers and investors in direct geothermal heat use in New Zealand. The Bay of Plenty Region and the Taupo District are fostering the uptake of geothermal heat use in the process sector. The nation-wide geothermal Geoheat Strategy for Aotearoa NZ, 2017 – 2030 has goals of increasing the direct use of geothermal energy by 7.5 PJ per annum (primary energy) and fostering an additional 500 jobs in those enterprises that use it. The associated Geoheat Action Plan 2020 – 2021 was launched in January 2020.

In 2020, the weighted average CO_2 equivalent atmospheric emissions factor from New Zealand Geothermal power stations was 69 g/KWh, with an interquartile range for the individual power stations of 39 to 96 g/KWh. Mercury, Contact and Top Energy have initiated studies examining the feasibility of injecting non-condensing gasses from binary cycle power plants.

Geo40 has expanded the silica extraction plant at Ohaaki to a commercial operation processing 6800 tonnes/day of geothermal water to produce colloidal silica 'sol' for the international market. Geo40 are investigating the extraction of various species including lithium and boron through small scale trials.

Through 2020 GNS Science used core science funding to fund NZ$2.5M in geothermal research through the "New Zealand's Geothermal Future" programme, under four themes:

- Shallow resources and direct use,
- Taupo Volcanic Zone - Structure and Dynamics,
- Taupo Volcanic Zone – Source models; and
- Reservoir Chemistry.

The "Endeavour Fund" has supported research into "Empowering Geothermal Energy; Increased Utilisation of Geothermal Energy Through New Integrated Geoscience Methods". This project addresses geoscientific uncertainties of accessing underground resources. The project is funded at NZ$1.3M / yr until 2022.

A 5-year Endeavour fund research program (2019-2024), Geothermal the Next Generation, funded at a level of about NZ$2M / yr, continued through 2020. The programme is studying supercritical fluid resources that are likely to occur in the deep roots of volcanic-hosted geothermal systems in the Taupo Volcanic Zone in New Zealand. This research will: define heat transfer mechanisms from magma to surface; investigate the composition of supercritical fluids; detail interactions between rocks and fluids; find the best exploration drilling targets for supercritical fluids; map the potential of these resources, and translate the science, making information accessible. This project will also investigate technologies to capture and reinject gas emissions. An International advisory panel has been established as part of the work.

An ongoing 2-year "Marsden" research project (2019-2021) addresses the topic of improved understanding of natural CO_2 flux passing through Taupo Volcanic Zone geothermal systems from deep underground through the surface to the atmosphere.

The University of Auckland PGCert geothermal diploma course was suspended through 2020 because of COVID19 travel restrictions for overseas students. Masters and PhD activity in geothermal topics continued through 2020 and the University of Canterbury continued to run geothermal graduate programs: a Geothermal Energy Systems Engineering Group within the College of Engineering, and a Geothermal Resource Research Group within the School of Earth and Environment.

The annual New Zealand Geothermal Association seminar usually held in the middle of the year was not able to be run due to COVID19.

The 42nd New Zealand Geothermal Workshop organised by the Geothermal Institute, University of Auckland, was held at Waitangi, Bay of Islands on 24-26th of November. Attendees had the opportunity to visit and learn more about the Ngawha OEC4 project as part of a field trip run in conjunction with the workshop.

Norway

Geothermal energy use in Norway is dominated by the widespread deployment of geothermal heat pumps. Statistics from the Norwegian heat pump organization (NOVAP) identifies a peak of 3979 GHP installations in 2018. Recent installations number more than 3000 units annually with the increase a consequence of the ban on fossil oil for heating buildings which comes into effect in 2020. Total capacity installed is some 900 MWth (from older 2017 data).

There is no electricity production from geothermal resources in Norway and no geothermal energy installations with wells deeper than 1500m in operation.

Increasing the use of geothermal energy in Norway is aligned with the country´s energy policy of increasing the use of renewable energy resources.

The Research Council of Norway supports geothermal research projects through its ENERGIX programme. Funding from national agencies "Enova" and "Innovation Norway" is also possible for larger industrial projects such as deep well drilling. Norway is contributing to the EU funded Horizon 2020 programme with the Institute for Energy Technology involved in the deep geothermal programmes; GECO and REFLECT.

Norwegian industrial and academic expertise in off-shore technologies is anticipated to be readily utilised in an emerging geothermal industry with an emphasis on deep drilling, well technology, reservoir management, corrosion and scaling mitigation, and tracer technology.

Republic of Korea

The total installed capacity of geothermal heat pumps in Korea at the end of 2020 was estimated to exceeded 1,536 MWth. Since 2012 capacity has been growing at a rate of about 100 MWth per year.

Korean geothermal research expenditure was of the order of 0.83 million USD in 2020, with contributions from both government and industry.

The government is keen to foster renewable energy deployment to substitute for nuclear power, however the deep geothermal investment outlook is poor as all deep geothermal exploration activity was stopped and has remained in hiatus since the 2017 Mw 5.4 Pohang earthquake that occurred close to the EGS site.

A GHP system installed at the KIGAM Daejeon office designed to quantify the benefits of GHP compared to air-source heat pumps has been in operation since 2019. Two separate heat pumps each with a capacity of ~25 kW are operational. The system is equipped with a borehole which can be used as a closed-loop heat exchanger or an open-loop pumped well, or both at the same time. Performance monitoring continued through 2020 and as yet no comprehensive analysis has been undertaken.

Switzerland

Geothermal use in Switzerland is dominated by shallow lower temperature use with ~2250 MW_{th} of geothermal heat pump capacity installed. Smart thermal grids are expected to become a focus in a number of cities and research is underway on low temperature storage of heat and cool. The use of geothermal and heat pump technology will continue to grow as the push for renewable heat intensifies over the coming years.

Large infrastructure projects, such as rail and road tunnels, are being used as sources of geothermal energy (~12 MW_{th}).

Direct geothermal use is dominated by Spa use, with an estimated capacity of ~25 MWth.

There are no geothermal power facilities operational in Switzerland. One EGS power project (Haute Sorne), one energy storage (Forsthaus Bern), a deep geothermal probe district heating scheme (Lausanne-Plaine du Loup) and 13 hydrothermal heat / combined heat and power are in the planning phases. In Western Switzerland an investigative programme is being advanced by the Cantons of Geneva and Vaud working to decarbonise the heating sector.

Switzerland's Energy Strategy 2050 is supported through an entirely revised Energy Act (2018) and a partially revised CO_2-Act. some of the measures in these Acts provide support geothermal heating and cooling and geothermal power generation.

During 2020 financial measures supporting geothermal energy available were:

- Financial support for geothermal prospecting and exploration to a maximum of 60% of the eligible cost, capped at CHF 50 million (1 CHF ~ 1 US$) per year. The scheme runs until the end of 2030.
- Financial support for direct use geothermal energy projects, maximum 60% of the eligible costs, capped at CHF 30 million per year. The scheme runs until the end of 2025.
- Feed-in tariffs for a 15 year period, for power production from hydrothermal and EGS projects are available up until 1 January 2023.

Switzerland's geothermal research expenditure for 2019 was some 2$ million USD. The Swiss Competence Centers for Energy Research (SCCER) concluded at the end of 2020. The **SW**iss**E**nergy research for the **E**nergy **T**ransition (SWEET) funding programme to 2032 is the follow up to the SCCER programme. The goal of SWEET is to accelerate innovations crucial to implementation of Switzerland's Energy Strategy 2050 and the country's climate policy ambitions. Consortia will respond to calls within themed areas. Public research institutions from abroad may be part of a consortium and may be eligible for Swiss funding. The calls will not be specific to a certain energy type, so geothermal energy will compete against other renewables. The first SWEET call for proposals opened in June 2020.

Research highlights for 2020:

- Experiments at the Bedretto Underground Laboratory
    - MISS -Mitigating Induced Seismicity for Successful Geo-Resources Applications
    - Valter-Validating Technologies for Reservoir Engineering
    - FEAR - Fault Activation and Earthquake Rupture
- GEOTHERMICA projects
    - ZoDrEx – zonal isolation
    - Heatstore
    - COSEISMIQ
- DESTRESS (International) – Demonstration of Soft Stimulation treatments
- RT-RAMSIS – Real-Time Risk Assessment and Mitigation System for Induced Seismicity
- Shallow geothermal applications:
    - smart thermal grids,
    - geothermal heat storage,
    - quality assurance and control, and
    - enhancing efficiency.

The Swiss Federal Office of Energy actively participates in:

- GEOTHERMICA,
- the International Partnership for Geothermal Technology, and
- the IEA Geothermal Technology Collaboration Program.

Geothermal conferences or conferences with significant geothermal content in 2019 and 2020:

- Gurtensymposium Geothermie, online, 4 November 2020
- Journées romandes de la géothermie 2019, Lausanne (VD), 29 January 2019
- SCCER-SoE Annual Conference in Lausanne (VD) from 4 September 2019.

Spain

The Spanish Government lodged the Integrated National Energy and Climate Plan (INECP) 2021-2030 with the European Commission at the beginning of 2020 with the plan focused on achieving carbon neutrality by 2050. Over the next ten years a 30% reduction in greenhouse gas emissions relative to current levels of emissions is targeted, which is expected to see a doubling in the utilization renewable energy.

In March 2020 the Spanish Ministry for the Ecological Transition and the Demographic Challenge approved a call for the first renewable energy auction. The auction will establish a target quota of 3,000 MW, of which at least 1,000 MW are for photovoltaic, a 1,000 MW are for onshore wind, with the remainder to be auctioned without technological restriction.

In 2020 the Spanish Association of Heating and Cooling Networks (ADHAC) identified 9 geothermal district heating and cooling systems in operation, with GeoDH systems 2 planned.

Geothermal energy continues to advance, primarily for domestic and industrial uses, with installations producing heat, cooling and sanitary hot water through ground based geothermal heat pump systems. The total installed capacity is estimated to be well above 350 MW_{th}.

The first deep exploitation well in Spain was drilled in 2020 as part of a project to heat greenhouses in Níjar, Almería. This 8 MW heat supply project could be the forerunner of greater geothermal energy use in the agriculture sector in Spain.

There is renewed Spanish Government and Canary Islands Administration interest in the development of a geothermal electricity generation plant in the Islands.

Spain is active in several EU funded projects including,

- GEO-URBAN – The project includes the county of Vallès, Catalonia which is the subject of feasibility study on the utilisation of geothermal resources. The project concludes in June 2021.
- GEO-ENERGY EUROPE focused on the transnational European cluster dedicated to the development and improving competitiveness of small and medium sized geothermal enterprises. In the second phase GEO-ENERGY EUROPE 2 which seeks to assist the European SME member companies to win business and export to third-country markets is underway.
- CROWDTHERMAL. The project released a video explaining the objectives and presents several case studies.

Geoplat was involved in five workshop / conference events during 2020:

- Technical workshop 'Geothermal Energy: Renewable and Efficient Heating and Cooling for All'. Energy & Environment International Fair – GENERA 2020. Madrid, 5th February 2020
- Round table 'Energy technologies: Innovation in Health, Agriculture and Industry'. European Meeting on Science, Technology and Innovation – TRANSFIERE 2020 Málaga, 12th February 2020.
- GEOPLAT Annual Assembly, July 2020, themed the '2020-2030 Geothermal Decade' took place virtually because of the pandemic.
- GEOPLAT Annual Assembly 2020 '2020-2030 Geothermal Decade'. Online, 23rd July 2020.
- Coordination Committee of the Spanish Energy Technology Platforms (CCPTE) - II CCPTE workshop: "Spanish technology in the scenario of energy transition and globalization of the economy". Online, 15th October 2020.

United Kingdom

The most significant use of geothermal energy in the United Kingdom is through geothermal heat pump installations with a total capacity of ~700 MWth (2019 data).

The United Downs Deep Geothermal Power project (UDDGPP) project is led by Geothermal Engineering Ltd. and is the first commercial project in the UK to develop deep geothermal for power generation. The production well (UD1) and reinjection well (UD2) were completed in 2019. Initial injection tests undertaken on UD2 in the spring of 2020 were promising. Testing will not be completed until early 2021 because of delays as a consequence of Covid 19.

The Eden project, a second, deep geothermal project in Cornwall situated on the St Austell granite is being developed by Eden Geothermal Ltd. The project is targeting a deep crustal fracture and an initial well to a depth to 4.5 km is scheduled for drilling to commence in the spring of 2021. The heat will be used in Eden's Biomes, offices and greenhouses. Covid 19 restrictions have held up progress during 2020.

There is growing interest in utilising the waters within disused mine systems for their geothermal potential. Although in many cases the temperature of the water will be at normal ground water temperatures, the high abstraction rates possible make these ideal for large capacity open loop ground source heat pump systems. Additionally at some former colliery sites pumping of the mine waters is already undertaken for environmental reasons. The Coal Authority are developing geothermal heating schemes at a number of their pumped sites.

The Glasgow Geothermal Energy Research Field Site (GGERFS) is operational with 12 wells equipped with high resolution monitoring equipment now open to the UK science community and international researchers.

United States of America

The United States leads the world in installed geothermal electricity capacity, with ~3.7 GW installed. 95% of this is in the western USA, in California and Nevada.

The published 2019 GeoVISION roadmap to 2050 was used to guide planning undertaken in 2020 which established a GTO lead priority for the next 8-10 years to demonstrate geothermal energy's value as the baseload renewable of the future in the U.S. This overarching priority is supported by three objectives:

- Unlock the potential of enhanced geothermal systems.
- Increase geothermal energy on the U.S. electricity grid by reduce risk and costs associated with all aspects of geothermal energy.
- Expand geothermal energy opportunities throughout the United States increasing a: Increase deployment.

Drilling activity at the Milford EGS Frontier Observatory for Research in Geothermal Energy site in Utah saw the completion of the first of two injection / production wells. The well 16A was drilled to 3353m reaching a final inclination of 65 degrees. The use of PDC bits and techniques developed by Texas A&M University resulted in drilling penetration rates averaging 12 m per hour.

The EGS Collab work launched in 2017 continued through 2020. The work is focussed on controlled, small-scale, in-situ experiments to advance the understanding of rock fracture behaviour and permeability enhancement. It serves as an intermediate-scale field site where the geothermal reservoir modelling and research community is validating models against in-situ experiments. A Wiki has been developed from where more than 120 papers, reports, and presentations are accessible. Experiment 1 to validate geothermal reservoir and fracture models with real-time geophysical and other fracture characterization data during stimulation was completed in 2020. The Experiment 1 site has now been decommissioned. During 2020 the site for Experiment 2, targeting stimulation of existing fractures was established at the 4100' level. Preparatory drilling is to be undertaken up until the middle of 2021.

The Play Fairway Analysis (PFA) project concluded in 2020 with a number of new methodologies developed and tested. The work has seen more than 100 publications produced.

The Deep Direct-Use (DDU) project concluded in 2020. The DDU studies provided information on costs and other attributes to end-users and developers assess projects. The analyses indicated that when environmental, societal, resiliency and sustainability are included the levelized cost of heat can be reduced by as much as 70%. The analyses were unique in scope and breadth in modelling evaluating locations that had not been previously evaluated. A large-scale, fully integrated DDU geothermal system is yet to be realized in the United States, but work continues at a number of sites, including studies for an installation at Cornell University which were launched in 2020.

GTO is funding investigations into underground geothermal energy storage and identification of areas suitable for subsurface storage. These research activities will continue into 2021.

Geothermal drilling research advanced drill bit materials, a downhole rotary piston motor, acoustic sensors, thermal shock resistant cement, and high temperature percussive hammers.

GeoDAWN was established in 2020 which continues the use of machine learning activities from other programmes and adds an element of critical minerals perspectivity focussed on a specific location in Nevada.

GTO delivered two keynotes at the 45th Annual Stanford Geothermal Workshop, and the GRC 2020 Annual Meeting. Research and Development reviews were presented at the American Rock Mechanics Association (ARMA), the Society of Manufacturing Engineers (SME), and the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP).

1. Introduction

Progress reducing and mitigating greenhouse gas emissions along with the increasing use of renewable energy sources is occurring in many nations with geothermal energy utilisation providing an invaluable contribution.

Geothermal energy is renewable energy, available 24/7 independent of the time of day or the weather. Heat energy can also be stored in the ground for later retrieval and use, such as in borehole energy storage or aquifer energy storage systems. Geothermal resource use and investigations continued to grow through 2019 with a number of nations making significant investments in the direct use of geothermal energy and in geothermal heat pump technology. Growth rates in these sectors are globally running at 10% or more per annum. Globally direct geothermal energy use uptake rates are out pacing the growth rates in geothermal electricity generation.

To develop non-traditional (ultra-high temperature, supercritical and EGS) geothermal resources, technology development is vital. Research in EGS is needed to release the vast geothermal energy potential contained within the earth. Supercritical research is being undertaken in Japan, Iceland, Italy and New Zealand. EGS research is a particular focus in countries in Europe and the USA. Reliable technology needs to be developed to be able to release the energy potential from these earth energy sources.

1.1 IEA Geothermal

The International Energy Agency (IEA) Technology Collaboration Programmes look for solutions to long-term energy challenges through government and industry collaboration. IEA Geothermal seeks to:
Promote the sustainable use of geothermal energy through collaboration, facilitating knowledge transfer, providing high quality information, and communicating geothermal's strategic, economic and environmental value.

IEA Geothermal has 16 members, 13 countries (Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, Norway, the Republic of Korea, Switzerland, the United Kingdom and the United States of America), Ormat Technologies Ltd (industrial company), the Spanish Geothermal Technology Platform (GEOPLAT) and the European Commission.

IEA Geothermal members focus activities into the Working Groups. Working Group activity is further subdivided into tasks. Task Involvement is determined by members' current interests and their research and development programmes.

IEA Geothermal collects and collates geothermal energy data annually as part of Working Group 10. The data is assembled into annual trend and power statistics reports. These can be found under Working Group Publications tab on the IEA Geothermal website.

The activities of IEA Geothermal are managed by an Executive Committee. Because of the Covid pandemic the two Committee meetings held in 2020 were hosted on virtual platform. All symposium activity was deferred.

This report provides details on the activities carried out by the Working Groups along with the geothermal activities in member countries. The status, activities and 2020 achievements of the

Working Groups are described in Chapters 2 to 6. Information on member activity is found in Chapters 7 to 21. There are many references to up-to-date information contained within the report which can be found at the end of each chapter.

Appendix 1 details the IEA Geothermal Executive Officers at the end of December 2020, and Appendix 2 the IEA Geothermal Executive Committee Members and Alternates.

For more information on IEA Geothermal please visit our website iea-gia.org or email iea-giasec@gns.cri.nz.

2. Working Group 1 – Environmental Impacts

Chris Bromley

GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo, New Zealand.
Email: c.bromley@gns.cri.nz

2.1 Introduction

Working Group 1 (Environmental Impacts) has the following goals:

d) encourage the sustainable development of geothermal energy resources in an economic and environmentally responsible manner;
e) quantify and seek ways to balance any adverse impacts that geothermal energy development may have on the environment; and
f) identify ways of avoiding, remedying or mitigating adverse effects.

The Working Group 1 (WG 1) web page on the IEA Geothermal web site can be accessed through this hyperlink.

Collaboration activity commenced in 1997. At that time the activity was referred to as Annex 1. The tasks have changed over time, as different environmental and social issues have been identified and discussed by participants at meetings and workshops. Outputs have consisted of published papers (including three Geothermics Journal Special Issues), recommended protocols, environmental workshops, or conference sessions.

In 2020, many activities and new initiatives were constrained by the COVID19 pandemic. Topics that were in focus for the working group are briefly described below:

A) Impacts on natural features: monitoring surface thermal feature and ecosystem changes and devising techniques to avoid or mitigate adverse impacts, while encouraging beneficial effects.

B) Discharge and reinjection: gas emissions (CO_2 & H_2S); chemical contamination of water, subsidence, scaling and corrosion, and treatment options (e.g. injection).

C) Methods of impact mitigation and environmental procedures: analysis of issues, procedures, efficient policies, protocols, effective compliance, and successful mitigation strategies to address social and environmental effects.

D) Sustainable utilisation strategies: long-term reservoir simulation, optimized operational strategies, recharge factors, recovery times, improved reservoir performance, and sustainability protocol indicators.

The countries officially participating in the WG 1 are Australia, Iceland, Italy, Japan, New Zealand, Norway, Switzerland, and the United States.

2.2 Highlights

Highlights for the year include:

- Completion of environmental and society collaboration papers for WGC2020.
- Compiled information in preparation for a book on environmental and social impacts.
- Networking and cooperation amongst researchers, operators, policy-makers and funding-agencies within the participating countries (e.g. GEOENVI, Europe).
- Raising international awareness of successful mitigation schemes and beneficial environmental or social outcomes.
- Supporting relevant presentations and publications by scientists from member countries at international conferences and workshops.

2.3 Task Progress and Outputs

2.3.1 Progress in 2020

WG1 focusses on networking and connecting researchers, policy makers and operators from different countries to increase awareness of environmental improvement opportunities and successful strategies mitigating adverse effects.

Cooperation between WG1 participating countries continues, and members are involved in a range of national and international research projects. An example was the European Horizon 2020 funded "GEOENVI" project https://www.geoenvi.eu/ with collaboration between France, Italy, Iceland, Turkey, Belgium and Hungary, and peer review support from other WG1 participating countries. The objective was to exchange best practices across the group, establish an environmental database and develop a life-cycle assessment methodology to calculate net environmental impacts and benefits for geothermal facilities.

Progress reports on WG 1 activities were presented at the virtual (online) Executive Committee meetings held on 20/4/2020 and 13/10/2019.

WG 1 participants were encouraged to address the following issues:

a) Gas emissions, reinjection of non-condensable gases (CO_2);
b) H_2S abatement technology;
c) shallow thermal groundwater changes (heating or cooling);
d) insurance industry outreach (communication of risks & solutions);
e) power-plant visibility (acceptable design for a given landscape environment);
f) casing integrity (monitoring corrosion rates);
g) sustainability protocols in practical applications;
h) Improvements in shallow/surface feature and ecosystem monitoring using drones;
i) thermal imaging and satellite imagery;
j) subsidence monitoring and improved modelling of reservoir deformation processes;
k) policy initiatives and sustainability discussions

Selected publications during 2020 by geothermal environmental researchers from participating countries are listed below. A number of these papers were presented and discussed at the following conferences: Stanford Geothermal Workshop (Palo Alto, USA), Geothermal Resources Council Annual Meeting (Virtual) and New Zealand Geothermal Workshop (NZGW). Papers may be downloaded through the www.geothermal-energy.org conference database.

2.3.2 Outputs

The 2020 environmental outputs are linked with task activities, through member country participation or cooperation. These include presentations at several workshops and publications in conference proceedings, including Stanford Geothermal Workshop and NZGW (Refer the References section).

Joint WG1 papers on "Environmental and Social Impacts" were completed for WGC2020 (Refer list of collaborative articles in the References section).

2.4 Future Activities

Future work includes presentation of collaborative papers on environmental topics at the World Geothermal Congress (WGC2020, postponed from April 2020 to May-October 2021), and continuing work on the existing tasks.

Ongoing efforts include:

a) Preparation of a book describing international geothermal environmental codes-of-practice, and effective protocols and policies for environmental management of geothermal projects.

> Sub topics include: construction and drilling environmental effects; induced seismicity; production & injection effects (noise, effluents, emissions); social impacts; promotion of beneficial effects and mitigation of adverse effects; methods of drilling/producing/injecting deep beneath protected areas with negligible surface impact; subsidence mitigation by injection; avoiding groundwater contamination; Biochemical remediation/treatment of condensates; Monitoring of casing integrity to protect groundwater; Appropriately allocating geothermal systems for protection or development using categories and criteria; Streamlining EIA by standardising common issues and good practice procedures; cooling, stimulation and make-up water issues; tools to monitor, model and manage sustainable reservoir performance and long term reinjection; communication with local and indigenous stakeholders.

b) Organising workshops or special sessions on, for example, sustainability and surface feature monitoring.

c) Collating results of trials; using targeted shallow reinjection of hot fluids to remedy adverse effects; on gas injection; and on water treatment to remove potentially harmful species.

2.5 References

Journal papers:

Gregorius Riyan Aditya, Guillermo A. Narsilio, "Environmental assessment of hybrid ground source heat pump systems" Geothermics, V87, 2020, 101868

Conference papers (accessible through www.geothermal-energy.org/cpdb/search.php)

WGC2020: (postponed from April 2020 to 2021), Reykjavik, Iceland

Chris BROMLEY, Lauren BOYD, Adele MANZELLA, Kasumi YASUKAWA : Review of Environmental & Social Aspects and Best-Practice Mitigation Measures from an IEA-Geothermal Perspective. Paper #02007.

Jonas KETILSSON, Chris BROMLEY : Adaptive Leadership Roles and Tools of Government to Assist Geothermal Developers in Overcoming Barriers. Paper #03037

Abdul NISHAR, Chris BROMLEY, Fabian SEPULVEDA, Kerin BROCKBANK : Review of Subsidence at Ohaaki geothermal field, New Zealand. Paper #13061

45th Stanford Geothermal Workshop, February 2020

FEIGL, K L., E. C. REINISCH, S.A. BATZLI, H. SONE, M. A. CARDIFF, J.C. HAMPTON, N.E. LORD, C.H. THURBER, H. F. WANG, C. SHERMAN, C. MORENCY, I. WARREN, C. KREEMER "Spatio-Temporal Analysis of Deformation at San Emidio Geothermal Field, Nevada, USA Between 1992 and 2010"

L. THOMAS, J. TINJUM, F. HOLCOMB "Environmental Life Cycle Assessment of a Deep Direct-Use Geothermal System in Champaign, Illinois"

Transactions Geothermal Resources Council Annual Meeting October 2020 (Virtual)

Garabetian, T.; Dumas, P.; Le Guénan, T.; K?pi?ska, B.; Kasztelewicz, A.; Karytsas, S.; Siddiqi, G.; Lupi, N.; Seyidov, F.; Nador, A.; Kaufhold, J.; Boissavy, C.; Schmidlé, V.; Yildirim, C.; Bozkurt, C.; Kujbus, A.; Spyridonos, E.; Dincer, E.; "Risk Mitigation and Insurance Schemes Adapted to Geothermal Market Maturity: Presentation of the Findings of the GEORISK Project"

Lambert, C. E.; McComas, K. A. "Public Attitudes Towards Enhanced Geothermal Heating: The Role of Place, Community, and Visions of Energy Futures"

Petursdottir, A.; Massey, A.; Desjardins, E.; Brophy, R.; Harvey, W. "Assessing Geothermal Projects Using Envision"

42nd New Zealand Geothermal Workshop, November 2020, Paihia, New Zealand:

S.M. Beadel, C.M. Bycroft, K.M. Lloyd, and W.B. Shaw "Ecological Information for Geothermal Sites in Waikato Region"

M. Collins "Changing Resource Management of Surface Water Allocation to Meet Drilling Rig Demands"

K.M. Luketina, J. Lebe, A.D. Cody and B. Lynne "Sinter-Forming Springs of the Waikato Region, NZ"

K. McLean, I. Richardson, J. Quinao, T. Clark, L. Owens "Greenhouse Gas Emissions from New Zealand Geothermal: Power Generation and Industrial Direct Use"

K. Luketina and J. McLeod "Twenty-Five Years of Geothermal Monitoring by Waikato Regional Council: Embracing Change, Collaboration, and Innovation"

D. Kissick, S. Bendall, M. Climo "New Zealand's Regulatory and Planning Framework for Conventional Geothermal Resource Use"

3. Working Group 8 – Direct Use of Geothermal Energy

Brian Carey

Executive Secretary, IEA Geothermal. Email: iea-giasec@gns.cri.nz

3.1 Introduction

During recent decades the direct use of geothermal energy has become more important with steadily increasing uptake worldwide. Applications include: facilities heating, area/district heating schemes, greenhouse heating, crop drying, aquaculture, snow melting, spas and bathing, therapeutic applications, industrial process heat, and small and large heat pump applications. The heat pump applications include "smart thermal" low-temperature grids combined with underground thermal storage. Additionally, cooling using geothermal energy is becoming important.

The Working Group (WG) gathers and disseminates quality information seeking to reduce barriers and enhance direct geothermal utilisation. The main objectives are to collaborate, cooperate, share knowledge, and boost awareness, fostering the uptake of direct geothermal use technologies.

In 2013, WG 8 was restructured to include five tasks, with one task (E) continuing from earlier work and four tasks initiated:

A. New and Innovative Geothermal Direct Use Applications,
B. Communication,
C. Guidelines on Geothermal Energy Statistics,
D. Guidelines on Statistics for Geothermal Heat Pump Applications and
E. Design Configuration and Engineering Standards (continued).

In 2018, Task F was launched, Costs of Geothermal Heat Pump Systems.

In 2019, Task G was launched, Monitoring Systems. This was to capture interaction associated with the IEA HPT Annex 52 and IEA ECES Technology Collaboration Programmes.

More details on the scope of each of the tasks is provided in the Task Statements in Section 3.3.

Task C was completed in 2017 following GEOSTAT activity funded through the Geothermal ERA-NET which developed from the Ketilsson et al (2015) publication 'International Collection of Geothermal Energy Statistics – Towards reducing fragmentation and improving consistency'.

Current participants of WG 8 are France, Germany, Iceland, Japan, Mexico, New Zealand, Republic of Korea, Switzerland, United Kingdom, and United States of America. Observing guests are Australia, Norway, and the European Commission.

Geothermie-Schweiz, the Swiss Geothermal Association (https://geothermie-schweiz.ch/) has been the Operating Agent for WG 8 since September 2012. At the 28th Meeting of the Executive Committee held in Pisa, Italy, Katharina Link from Geo-Future GmbH took on leadership of the Working Group. She led the work until the end of July 2020 when contract funding for her role ceased. The WG lead role remained vacant to the end of 2020 and beyond.

3.2 Highlights

WG 8 was very active in 2019 through symposia and workshop activity but much less so during 2020 due to travel and gathering restrictions that were implemented by various nations seeking to limit the spread of Covid-19 as part of the global response to the pandemic. The work undertaken during 2019 has not previously been reported so several of the highlights are noted in this chapter along with those for 2020.

3.2.1 2019 highlights:

On 14 February 2019, Brian Carey presented at the Geotherm Expo and Congress on 'Research, Development and Deployment. Advancing Deep Geothermal Energy Utilisation and Geothermal Technology' (hyperlink to presentation).

The two-day International Geothermal Energy Workshop was held at ITC, Pozo Izquierdo, Gran Canaria, on the 8th and 9th April 2019 – iea-gia.org/workshop-presentations/2019-gran-canaria-geothermal-energy-workshop/.

Figure 1: Participants at the 2019 International Geothermal Energy Workshop at ITC, Pozo Izquierdo, Gran Canaria.

There was also a two-day International Geothermal Energy Workshop in San Jose, Costa Rica on the 11th and 12th November 2019 – iea-gia.org/workshop-presentations/2019-costa-rica-geothermal-workshop/

Figure 2: Participants at the 2019 International Geothermal Energy Workshop in San Jose, Costa Rica.

3.2.2 2020 highlights:

Three WG 8 publications were completed for inclusion in the proceedings of the World Geothermal Congress 2020+1:

> Link, K., Carey, B., Geothermal Direct Use - International Energy Agency Geothermal TCP. (pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/28029.pdf)
>
> Song, Y., Link, K., Yasukawa, K., Weber, J., Proposal of New Data Collecting Spreadsheet for Geothermal Heat Pumps Statistics: An Outcome of IEA Geothermal Working Group Activities. (pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/29009.pdf)
>
> Farr, G., Busby, J., The Thermal Resource of Mine Waters in Abandoned Coalfields; Opportunities and Challenges for the United Kingdom. (pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/41021.pdf)

The IEA Geothermal prepared a North Atlantic Symposium for delivery at the 2020 GeoTHERM Expo and Congress in Offenburg on the 5th and 6th March. However, this was postponed by the Exhibition Centre Management because of the Covid-19 pandemic. The symposium will be held at a future event, the date of which has not yet been determined.

The Mine Water Geothermal Energy Symposium scheduled for April 2020 in Edinburgh, which included a field trip to Glasgow, was rescheduled for March 2021 as a web-based event. Through 2020, work continued with Gareth Farr, Jon Busby and Christina Edwards from the British Geological Survey in developing the event, with registrations for the symposium reopening on the 24th November 2020.

3.3 Task Activity

3.3.1 Task A – New and Innovative Geothermal Direct Use Applications

The North Atlantic Symposium prepared for the 2020 GeoTHERM Expo and Congress is postponed to a later date.

With the April / May 2020 World Geothermal Congress postponed, presentations of papers prepared for it have been delayed until the virtual event in 2021.

Preparations for the BGS/BEIS/IEA Geothermal Mine Water Geothermal Energy Symposium continued through 2020. The event was restructured from an in-person event in Edinburgh (22nd April 2020) to two three-hour webinar sessions on consecutive days on the 10th and 11th March 2021. The Glasgow field trip to the Mine Water Research Site scheduled for 23rd April 2020 was cancelled.

A number of innovative geothermal heat pump projects are being assembled as two-page case studies to be uploaded to the IEA Geothermal website (URL to web page).

3.3.2 Task B – Communication

Presentations from IEA Geothermal symposiums and workshops are available in PDF form, downloadable from the IEA Geothermal website, including the 2019 Gran Canaria and Costa Rican workshops.

The WG is aware of a ground source heat pump questionnaire developed by the Japanese Government (NEDO) which seeks to quantify initiatives which have been beneficial in fostering the uptake of these energy efficient systems. The questionnaire was developed in November 2019 and the census conducted across several countries from December 2019 to early 2020. This work was not undertaken as part of this Task, it is however a useful initiative to look at if your nation is considering ways to further foster the uptake of GSHP / geothermal heat pumps. Please request the questionnaire from the Japanese Member of IEA Geothermal if you wish to receive a copy.

3.3.3 Task C – Guidelines for Geothermal Energy Statistics

Task completed and closed in 2017.

3.3.4 Task D – Statistics for Geothermal Heat Pump Applications

The guidelines for collecting and reporting this statistical data were written up in Song et al (2021) as a paper in the proceedings of the World Geothermal Congress 2020+1.

Presentation of the paper at the World Geothermal Congress in 2021 will complete Task D.

3.3.5 Task E – Design Configuration and Engineering Standards

Proposed future work is to update a compiled list of design and engineering standards and upload it to the IEA Geothermal website.

3.3.6 Task F – Costs of Geothermal Heat Pump Applications

A study on life cycle costs of geothermal heat pump systems in Switzerland is being complied and will be reported once complete.

Information about the costs of geothermal heat pump systems is proposed to be collected from the WG member countries with the results analysed and interpreted.

3.4 Concluding Remarks

Figure 3: Katharina Link (2017).

The working group acknowledges Katharina Link's leadership over eight years since September 2012 when she took on the role of leading Working Group 8. Thank you very much Katharina for your dedication to this Working Group and for the effort you have put into running it.

3.5 References

Farr, G., Busby, J., The Thermal Resource of Mine Waters in Abandoned Coalfields; Opportunities and Challenges for the United Kingdom. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021)
Paper: https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/41021.pdf

Ketilsson, J., Sigurðsson, T., Bragadóttir, E.R., International Collection of Geothermal Energy Statistics – Towards reducing fragmentation and improving consistency, Orkustofnun, February 2015 (2015) ISBN: 978-9979-68-351-3. (URL for document)

Link, K., Carey, B., Geothermal Direct Use - International Energy Agency Geothermal TCP. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021)
Paper: https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/28029.pdf

Song, Y., Link, K., Yasukawa, K., Weber, K., Proposal of New Data Collection Methodology for Geothermal Heat Pumps Statistics - an Outcome of IEA Geothermal Working Group Activities. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021)
Paper: https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/29009.pdf

4. Working Group 10 – Data Collection and Information

Brian Carey

Executive Secretary, IEA Geothermal, email: iea-giasec@gns.cri.nz

4.1 Introduction

Working Group 10 activity focuses on collecting geothermal energy use data, analyzing statistical trends and tracking geothermal developments in IEA Geothermal member countries. This material is published in IEA Geothermal Trend Reports (iea-gia.org/publications-2/working-group-publications). All Contracting Parties participate in this Working Group and some sponsors also contribute.

The Operating Agent for the Working Group is the Leibniz Institute for Applied Geophysics (LIAG), Germany led by Josef Weber. The contract funding for this work stream has been interrupted since the beginning of 2020, with funding anticipated to be accessible again from later in 2021. This has resulted in the data collection and analysis task not being completed for the last 3 years.

The task of data collection and information is important in terms of the demand for reliable renewable geothermal energy use data. Data collection activities commenced in 2011 with data collated for the 2010 year. Additional data from nations that are not IEA Geothermal participants but have significant geothermal energy developments are also compiled and analyzed, seeking to provide more complete comparative analysis on global trends.

The Geothermal Trend Report provides a brief overview of key data on geothermal energy use and shows the national progress in the development of geothermal energy activities.

Data on geothermal power utilization is easier to obtain than heat utilization data, and since 2016 IEA Geothermal have produced a separate Geothermal Power Statistics Report earlier in the year than the Trend Report. This short report includes tables and figures on the development of geothermal power in IEA Geothermal member countries along with an overview of the latest geothermal power plants commissioned.

Work is in progress to collaborate with other institutions and organizations operating internationally in the field of geothermal energy data in an effort to expand the database to include geothermal energy use data from an increasing number of non-member countries as geothermal development increases worldwide.

4.2 Highlights

Two IEA Geothermal papers on data and reporting were included in the proceedings of the World Geothermal Congress 2020+1.

Weber,J., Wissing, L., Ten Years of Geothermal Trend Reporting and Statistics by IEA Geothermal. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021) Paper: https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/40000.pdf

Song, Y., Link, K., Yasukawa, K., Weber, K., Proposal of New Data Collection Methodology for Geothermal Heat Pumps Statistics - an Outcome of IEA Geothermal Working Group Activities. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021)

Paper: https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/29009.pdf

4.3 Progress in 2020

Data analysis work has been on hold during 2020 pending contract renewal with the Leibniz Institute for Applied Geophysics.

4.4 Outputs

See highlights section above.

4.5 Future Activities

- Preparation and publication of the IEA Geothermal Trend and Power Reports, including analysis of data from 2018 and the preparation of the 2020 reports.
- Continuing collaboration with other organizations and institutions to expand data collection and to extend the countries involved.
- Presentation of World Geothermal Congress papers in 2021.

5. Working Group 12 – Deep Roots of Volcanic Systems

Chris Bromley
GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo, New Zealand.
Email: c.bromley@gns.cri.nz

5.1 Introduction

Within the deep roots of volcanic geothermal systems there are processes involving the flow of magma, flow of single-phase, two-phase or supercritical fluids, heat transfer, and water-rock interactions involving gases, and salts. These processes are difficult to monitor and challenging to simulate using geothermal simulation modelling methods and laboratory experiments. Developing a strategy for deep roots energy utilisation therefore requires improved modelling methods, innovation of measurement tools and better understanding of high temperature water-rock-gas-salt interaction. Advances are being accelerated by collaborative research, cooperation and coordination across international research groups. Many of those are represented by IEA-Geothermal participants in Working Group 12 (WG 12).

WG 12 strategies to address these challenges, are:

> Task A: Compilation of conceptual models of the roots of volcanic geothermal systems and associated research methods, using open-source information from participating countries to provide background material for deep-roots research, including information on exploration and modelling methods and tools.
>
> Task B: Advancement of methods for deep geothermal exploration to disseminate information on advances in exploration methods, facilitate cooperation amongst research-groups, and enhance the depth resolution of available methods by using the power of joint data-set interpretation.
>
> Task C: Methods for modelling conditions and processes in deep geothermal resources, by advancement of methods applied in the modelling of physical processes, revealing the overall process of upwards heat transfer, improving geothermal reservoir modelling, and enhancing synergy by avoiding duplication of effort through improved sharing of open-source software and information.

5.2 Highlights

Key highlights for WG12 in 2020 are:

- Joint preparation of collaboration paper for WGC2020 (see the References section)
- Presentations by scientists from member countries at international conferences and workshops (GRC, NZGW, and Stanford workshops).
- Peer reviewed papers by scientists from member countries.
- Strengthening of internal cooperation between WG12 participating countries; along with expanded involvement in various national and international research projects.

5.3 Progress and Outputs

5.3.1 Progress in 2020

WG12 activities to date have been jointly coordinated by Gudni Axelsson (Iceland), and Chris Bromley (New Zealand). Enthusiastic participation from other country representatives (especially Japan, USA, Switzerland and Italy) continues.

The compilation of references from relevant conferences are listed in the References section.

Below is a review of the most significant 2020 activities. Some constraints on activities were caused by the COVID19 pandemic.

Internal cooperation between WG 12 participating countries continued to be strengthened. The list below identifies WG 12 participant involvement in national and international research projects:

- COTHERM, Switzerland (exploration and modelling)
- IMAGE, EU funded (exploration) – Completed
- DESCRAMBLE, EU funded (Completed - deep drilling in Italy and research)
- DEEPEGS, EU funded (deep stimulation in Iceland and France, with international research cooperation)
- GEOWELL, EU funded (drilling technology)
- GEMEX, Funded by EU and Mexican Gov – Completed
- Super-critical research in Japan (AIST and JOGMEC)
- Supercritical ("Geothermal the Next Generation") and super-hot fluids research (funded by New Zealand government)
- IDDP, Iceland deep drilling project (4-5 km) – Two wells drilled and IDDP-3 to be drilled after 2022
- GEORG DRG, Deep roots exploration and utilization in Iceland – Completed, but deep roots research will continue through the GEORG cooperation, which has international participation
- FUTUREVOLC (volcanology and hazards)
- Krafla Magma Testbed (KMT)
- IPGT- cooperation, for example, in supercritical modelling

5.3.2 Outputs

The 2020 outputs that are linked with WG12, directly or indirectly through participation by member countries or their cooperation, are listed in the References section. These include various presentations at workshops, as well as papers in conference proceedings and peer-reviewed journals.

5.4 Future Activities

An important activity will be the presentation of a joint paper at WCC2020 (postponed from April 2020 to May-October 2021) (see References section). Other future activity will build on the achievements to date, by communicating and sharing research results amongst participating countries and organisations, thereby reducing duplication of effort and accelerating deployment opportunities for supercritical (deep roots) geothermal resource utilisation.

Planning for future activities includes;

- organising an IEA-Geothermal Supercritical Fluids symposium on deep roots research and development, in conjunction with IPGT and 'Geothermal: The Next Generation' and
- Publication of a special issue of a relevant peer-reviewed scientific journal

5.5 References - 2020

Journal publications:

Alfredo Battistelli, Stefan Finsterle, Marica Marcolini, Lehua Pan, "Modeling of coupled wellbore-reservoir flow in steam-like supercritical geothermal systems" Geothermics, V86, 2020, 101793, ISSN 0375-6505

I.O. Thorbjornsson, G.S. Kaldal, B.C. Krogh, B. Palsson, S.H. Markusson, P. Sigurdsson, A. Einarsson, B.S. Gunnarsson, S.S. Jonsson, "Materials investigation of the high temperature IDDP-1 wellhead" Geothermics, V87, 2020, 101866, ISSN 0375-6505

Workshops/meetings:

WGC2020 postponed from April 2020 to May-October 2021

Chris BROMLEY, Gudni AXELSSON, Hiroshi ASANUMA, Adele MANZELLA, Patrick DOBSON : Supercritical Fluids - Learning about the Deep Roots of Geothermal Systems from IEA Geothermal Collaboration. Paper # 37011.

Proc. 44th Stanford Geothermal Workshop, February 2020

S. PETTY, T. CLADOUHOS, J. WATZ, G. GARRISON, C. ARAQUE "Technology Needs for SuperHot EGS Development"

T. XU, G.FENG, Y. WANG "Numerical Modeling on Fluid Dynamics and Phase Changes for a Supercritical Geothermal System"

N. YANAGISAWA, M. SATO, K.OSATO, Y.YAMAMOTO, K.SAKURA, K.LICHTI, B.MOUNTAIN, L.SAJKOWSKI " Corrosion Test of Casing Steel at High Temperature Acid Condition"

Trans. Geothermal Resources Council, Vol. 44, (October 2020):

Granados-Pastrana, J.E; Prol-Ledesma, R.M; O'Sullivan, M.J.; O'Sullivan, J.; Croucher, A. "3D Natural State Model of a Super-Hot Geothermal Reservoir at Los Humeros, México"

Climo, M.; Carey, B.; Chambefort, I.; Bendall, S.; Blair, A. "Developing a Strategy to Accelerate Utilisation of New Zealand's Supercritical Geothermal Resources"

Garrison, G. H.; Uddenberg, M.; Petty, S.; Watz, J.; Hill, B. "Resource Potential of SuperHot Rock"

Nanao, J.; Naganawa, S. "Numerical Simulation on the Performance of Thermal-Shock Enhanced Drill Bit for Supercritical Geothermal Drilling"

Petty, S.; Uddenberg, M.; Garrison, G. H.; Watz, J.I; Hill, B. "Path to SuperHot Geothermal Energy Development"

Shnell, J.; Tucker, M.C. “Developments in Renewable Hydrogen Electrolysis by Supercritical Geothermal Cogeneration”

Uddenberg, M. “A Case for SuperHot Rock Geothermal”

Eichelberger, J.; Lavallee, Y.; Ludden, J.; Papale, P.; Kennedy, B. “Energy from Magma”

Proc. 42nd New Zealand Geothermal Workshop, Paihia, New Zealand (November 2020):

M. Climo, I. Chambefort, B. Carey, S. Bendall, A. Blair “New Zealand’s Supercritical Opportunity: Moving from Potential Resource to Deployed Technology”

J. O’Sullivan, J. Newson, S. Alcaraz, S. Barton, R. Baraza, A. Croucher, S. Scott and M. O’Sullivan “A Robust Supercritical Geothermal Simulator”

R. Ando and S. Naganawa “Simulating Effect of Insulated Drillpipe on Downhole Temperature in Supercritical Geothermal Well Drilling”

6. Working Group 13 – Emerging Geothermal Technologies

Christian Minnig[1], Tae Jong Lee[2], Chris Bromley3

[1] Co-Leader of WG 13, Swisstopo, Swiss Geological Survey, Seftigenstrasse 264, 3084 Wabern, Switzerland, christian.minnig@bfe.admin.ch

[2]Leader of Subtask A2, Deep Subsurface Research Center, KIGAM,, Daejeon, Korea, megi@kigam.re.kr

[3] Leader of Task D, GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo 3352, New Zealand, c.bromley@gns.cri.nz

6.1 Introduction

Working Group (WG) 13, Emerging Geothermal Technologies, was established on 21st April 2015 and work commenced subsequent to a meeting in Hanover, Germany, in September 2015. The working group covers a broad spectrum of geothermal activity including: exploration, drilling, reservoir creation and enhancement, corrosion and scaling in surface facilities, the use of tracers, and the mitigation of induced seismicity.

Work in WG 13 is currently carried out in five tasks:

- A: A1. Exploration (Geothermal Play Types)
  - A2. Measurement and Logging
- B: Drilling Technology
- C: Reservoir Creation and Enhancement
- D: Induced Seismicity
- E: Surface Technology (Heat and Electricity Production, Corrosion, Scaling, Tracer Technology)

The goal of WG 13 is to provide quality information to facilitate and promote the utilization of geothermal energy worldwide. The development of innovative technologies is being pushed by expert collaboration between countries with the results made available in documents and presentations at conferences and workshops.

Participants are Germany (The Leibniz Institute for Applied Geophysics is the Operating Agent, but the position is currently vacant), Switzerland (with Christian Minnig as WG co-leader), Norway (IFE), Korea (KIGAM), New Zealand (GNS Science), Japan, Australia, France, the United States and the European Commission.

6.2 Highlights

2020 saw little activity of the entire working group together due to the ongoing Covid-19 pandemic which made collaboration difficult. Hence no highlights can be reported.

6.3 Task A – Exploration, Measurement and Logging

Task A is targeted at sharing information on new and emerging technologies in exploration, measurement, geophysical and well logging, and sharing experiences from case studies in geothermal fields in different countries.

In 2017, it was decided to subdivide Task A into two subtasks: Task A1 for Exploration (Geothermal Play Types) is led by Prof. Dr. Inga Moeck from the Leibniz Institute for Applied Geophysics (LIAG), in Germany, and Task A2 for Measurement and Logging is led by Dr. Tae Jong Lee from the Korea Institute of Geoscience and Mineral Resources (KIGAM).

6.3.1 Progress in 2020

Subtask A1: Exploration

No activity to report in 2020

Subtask A2: Measurements and logging

Subtask A2 continued to collect and share information on high temperature and high pressure (HTHP) logging tools and services. Two service companies were added to our database Information about the standard processes or manuals were gathered including the one from Schlumberger (Schlumberger, 2011).

6.3.2 Outputs

No outputs to report in 2020

6.3.3 Future Activities

Subtask A1: Exploration

Future activities not planned yet.

Subtask A2: Measurements and logging

It is planned to keep on updating the lists of organizations who can provide downhole measurements and logging services for geothermal applications and on the research projects for developing HTHP tools. Reviews on the standard processes or manuals for conventional logging methods will be carried out.

6.4 Task B – Drilling Technology

Drilling can account for up to 50% of the total costs of a geothermal project. Task B seeks to address the questions of reducing drilling costs and innovative drilling alternatives to rotary methods that are predominantly used. For this purpose, Task B includes the compilation of geothermal well drilling performance and cost information. The aim is to identify problem areas and suggested improvements.

6.4.1 Progress in 2020

The task leader is currently on leave, hence no activity to report in 2020

6.4.2 Outputs

The task leader is currently on leave, hence no output to report in 2020

6.4.3 Future Activities

The task leader is currently on leave, hence no activities are planned so far.

6.5 Task C – Reservoir Creation and Enhancement

Reservoir creation and enhancement technologies are of the utmost importance to exploit the enormous worldwide untapped geothermal energy potential. In most countries, there are no naturally occurring hydrothermal reservoirs which can be used for energy production. Even in countries like New Zealand, Iceland and the Philippines such technologies are crucial, as the favourable hydrothermal conditions providing sufficient natural fluid flow for economic geothermal utilisation are limited to only a very few spatially restricted areas.

As a consequence, in most countries deeper geothermal energy is hardly developed. To utilise the vast quantity of energy stored in the earth, new and innovative technologies to create or enhance artificial reservoirs have to be developed and improved.

The objectives of Task C are to:

- establish a platform for international knowledge and information exchange,
- collate quality information with the overall goal of accelerating the development of these technologies, and
- mitigate the technical and non-technical barriers.

Task C was successfully started with a kick-off meeting in September 2016 in Munich. The work tasks have been defined and prioritised.

6.5.1 Progress in 2020

No activity to report in 2020

6.5.2 Outputs

No output to report in 2020

6.5.3 Future Activities

Future activities not planned yet

6.6 Task D – Induced Seismicity

6.6.1 Progress in 2020

Induced seismicity risk remains an issue for many geothermal projects, particularly those involving deep EGS fracture stimulations, and those located in densely-populated regions, near fragile buildings, or surrounded by people not familiar with natural earthquakes. Collaborative research into this topic commenced in 2004 as a task in Annex 1 then switched to Annex 11, and in 2015 transferred to Task D under WG 13. The initial work focus was on developing a protocol to assist developers and regulators, as well as providing a forum for research collaboration and information exchange. Collaboration with IPGT continued between individuals researching various aspects of geothermal induced seismicity.

6.6.2 Outputs

In 2020, the primary effort of this task was to further encourage collaboration of researchers and to share the results of the considerable amount of funded research undertaken by participants.

Countries with a strong interest in this topic include: Germany, France, Switzerland, Iceland, Japan, USA and New Zealand.

Geothermal participants from IEA-Geothermal countries continued to work on topics such as: consistent earthquake data protocols, understanding mechanisms, and improving advanced forecasting methods using a modified "traffic-light" approach for adaptive response to observed levels of seismicity based on modifying injection and stimulation parameters. Research is also focused on better understanding the key mechanisms behind induced seismicity that may accompany long term injection.

A paper prepared for the WGC2020 meeting was postponed to 2021 (see reference section below). Papers were also published in other geoscientific journals. A special issue in Geothermics Journal was dedicated to the Pohang earthquake and its association with the nearby EGS project. These are listed in the reference section.

Papers on the topic of induced seismicity were presented and published in the proceedings of several major international geothermal workshops. They included: 45th Stanford Geothermal Workshop (February, California), 42nd New Zealand Geothermal Workshop (November, Paihia, New Zealand) and GEMex Final Conference (February, Potsdam, Germany)

The list of induced seismicity publications was updated (see below) for future reference and review purposes. The main topics that were of interest to collaborating researchers during 2020 were similar to previous years, that is: seismicity observations, network design, mechanisms and models, triggers, seismic tomography, risk governance and policy.

6.6.3 Future Activities

In addition to the task of keeping all interested parties up-to-date on the latest research results and technology developments in this topic, further efforts to strengthen international collaboration will continue. Lessons learnt will be summarised to assist developers, policy makers and the general public to make informed opinions about the risks involved. Outcomes will include improved and informed decisions about protocols and recommended monitoring schemes required for new or expanded geothermal projects.

6.7 Task E – Surface Technology (Heat and Electricity Production, Corrosion, Scaling, Tracer Technology)

6.7.1 Progress in 2020

No activity in 2020 due to COVID-19 pandemic. All planned activities were postponed by 1-2 years.

6.7.2 Outputs

No output to report in 2020

6.7.3 Future Activities

We expect to collect and collate available information from technical presentations at international forums, increasing awareness of the work of IEA Geothermal, sharing knowledge with the international community, collaborating, initiating joint actions and research projects with international bodies dealing with similar aspects and issues, and attracting interested new members.

6.8 References

6.8.1 Task A

Schlumberger, 2011, Wireline log quality control reference manual, 274p.

6.8.2 Task D

WGC2020: Reykjavik, Iceland (in press)

Chris BROMLEY and IEA-Geothermal WG13 Task D participants: “Induced Seismicity - a Perspective on Monitoring, Mechanisms and Public Acceptability for Hydrothermal Systems”. Paper #13117.

Pohang EGS Induced Seismicity Virtual Special Issue in Geothermics 2020

B.B.T Wassing, Q. Gan, T. Candela, P.A. Fokker, Effects of fault transmissivity on the potential of fault reactivation and induced seismicity: Implications for understanding induced seismicity at Pohang EGS, Geothermics, 91, https://doi.org/10.1016/j.geothermics.2020.101976.

Hwajung Yoo, Sehyeok Park, Linmao Xie, Kwang-Il Kim, Ki-Bok Min, Jonny Rutqvist, Antonio Pio Rinaldi, Hydro-mechanical modeling of the first and second hydraulic stimulations in a fractured geothermal reservoir in Pohang, South Korea, Geothermics, 89, ISSN 0375-6505,

Márton Pál Farkas, Hannes Hofmann, Günter Zimmermann, Arno Zang, Falko Bethmann, Peter Meier, Mark Cottrell, Neal Josephson, Hydromechanical analysis of the second hydraulic stimulation in well PX-1 at the Pohang fractured geothermal reservoir, South Korea, Geothermics, 89, https://doi.org/10.1016/j.geothermics.2020.101990.

Jin-Han Ree, Kwang-Hee Kim, Hobin Lim, Wooseok Seo, Sungshil Kim, Xiangyi An, YoungHee Kim, Fault reactivation and propagation during the 2017 Pohang earthquake sequence, Geothermics, 92, https://doi.org/10.1016/j.geothermics.2021.102048.

Rob Westaway, Extrapolation of populations of small earthquakes to predict consequences of low- probability high impact events: The Pohang case study revisited, Geothermics, 92, https://doi.org/10.1016/j.geothermics.2020.102035.

Sehyeok Park, Kwang-Il Kim, Linmao Xie, Hwajung Yoo, Ki-Bok Min, Myungsun Kim, Byoungjoon Yoon, Kwang Yeom Kim, Günter Zimmermann, Frédéric Guinot, Peter Meier, Observations and analyses of the first two hydraulic stimulations in the Pohang geothermal development site, South Korea, Geothermics, 88, https://doi.org/10.1016/j.geothermics.2020.101905.

David Banks, Adrian J. Boyce, Rob Westaway, Neil M. Burnside, Sulphur isotopes in deep groundwater reservoirs: Evidence from post-stimulation flowback at the Pohang geothermal facility, Korea, Geothermics, 91, https://doi.org/10.1016/j.geothermics.2020.102003.

2020 Other Journal articles

Tharaka Dilanka Rathnaweeraa, Wei Wua, Yinlin Jia, Ranjith Pathegama Gamage “Understanding injection-induced seismicity in enhanced geothermal systems: From the coupled thermo-hydro-mechanical-chemical process to anthropogenic earthquake prediction” Earth Science Reviews, 205, https://doi.org/10.1016/j.earscirev.2020.103182

Lu, Jianrong "Multiscale modeling of fractured reservoir stimulation and induced seismicity" https://hdl.handle.net/11244/326640

Khajehdehi, Omid; Karimi, Kamran; Davidsen Joern "The spatial footprint of seismic activity and aftershock triggering in a conceptual model of fluid-induced seismicity" Earth and Space Science Open Archive ESSOAr; Washington, Dec 12, 2020. DOI:10.1002/essoar.10505267.1

Toni Kraft, Philippe Roth, Stefan Weimer; "Good Practice Guide for Managing Induced Seismicity in Deep Geothermal Energy Projects in Switzerland" https://doi.org/10.3929/ethz-b-000453228, SED, Swiss Seismological Service at ETH Zürich

James P. Verdon, Julian J. Bommer 'Comment on "Activation rate of seismicity for hydraulic fracture wells in the Western Canadian Sedimentary Basin" by Ghofrani and Atkinson (2020)' https://www1.gly.bris.ac.uk/~gljpv/PDFS/Verdon_Bommer_2020.pdf

Patricia Martínez-Garzón, Grzegorz Kwiatek, Stephan Bentz, Marco Bohnhoff, and Georg Dresen "Induced earthquake potential in geothermal reservoirs: Insights from The Geysers, California" https://doi.org/10.1190/tle39120873.1 The Leading Edge, Volume 39, Issue 12.

Rike Koepke, Emmanuel Gaucher, Thomas Kohl; "Pseudo-probabilistic identification of fracture network in seismic clouds driven by source parameters" Geophysical Journal International, Volume 223, Issue 3 https://doi.org/10.1093/gji/ggaa441

LP Frash "Fracture caging to control earthquake magnitude from induced seismicity: Preventing a repeat of Pohang" 54th US Rock Mechanics/Geomechanics Symposium, 2020 - onepetro.org, ARMA-2020-1716.

Stabile, T.A., Rinaldi, A.P. & Pankow, K. "Induced seismicity: observations, monitoring, and risk management strategies". Preface to the special issue, J Seismol 24, 917–919 (2020). https://doi.org/10.1007/s10950-020-09956-

Stefan Baisch, "Inferring In-Situ Hydraulic Pressure From Induced Seismicity Observations: An Application to the Cooper Basin (Australia) Geothermal Reservoir". JGR Sold Earth, Volume125, Issue8. https://doi.org/10.1029/2019JB019070

Kyosuke Okamoto, Li Yi, Hiroshi Asanuma, Takashi Okabe, Yasuyuki Abe, Masatoshi Tsuzuki; Activation and Inactivation of Seismicity: The Terminations of Two Injection Tests in Okuaizu Geothermal Field, Japan. Seismological Research Letters 2020;; 91 (5): 2730–2743. doi: https://doi.org/10.1785/0220200084

S Mroczek, MK Savage, C Hopp, Anisotropy as an indicator for reservoir changes: example from the Rotokawa and Ngatamariki geothermal fields, New Zealand. Geophysical Journal International, 220, 1, 1–17, https://doi.org/10.1093/gji/ggz400

Proc. 45th Stanford Geothermal Workshop, February 2020

Kristine PANKOW, Maria MESIMERI, John MCLENNAN, Phil WANNAMAKER, and Joe MOORE. "Seismic Monitoring at the Utah Frontier Observatory for Research in Geothermal Energy".

Luke FRASH, Jesse HAMPTON, Marte GUTIERREZ, EGS COLLAB Team. "Fracture Caging to Control Induced Seismicity with Inspiration from the EGS Collab Project".

J. Olaf GUSTAFSON, Teresa E. JORDAN, Larry D. BROWN, Daniel MAY, Frank HOROWITZ, Koenraad BECKERS, Jefferson W. TESTER. "Cornell University Earth Source Heat Project: Preliminary Assessment of Geologic Factors Affecting Reservoir Structure and Seismic Hazard Analysis"

Chengping CHAI, Monica MACEIRA, Hector J. SANTOS-VILLALOBOS, Singanallur V. VENKATAKRISHNAN, Martin SCHOENBALL, EGS Collab Team. "Automatic Seismic Phase Picking Using Deep Learning for the EGS Collab Project"

Junzo KASAHARA, Yoko HASADA, Haruyasu KUZUME. "Possibility of High Vp/Vs Zone in the Geothermal Filed Suggested by the P-to-S Conversion".

Proc. 42nd New Zealand Geothermal Workshop, November 2020, Paihia, New Zealand:

P. Aguilera, L. Adam and G. Lamessa "B-Value Mapping for Volcanic-Related Geothermal System: a Case Study of Nevado Del Ruiz Volcano, Colombia"

7. Australia

Betina Bendall, Barry A. Goldstein

Department for Energy and Mining, Government of South Australia, Level 7, 11 Waymouth St, Adelaide, South Australia 5000.

Email: betina.bendall@sa.gov.au; barry.goldstein@sa.gov.au

7.1 Introduction

Activity in geothermal electricity generation in Australia peaked in the 2009 to 2015 period with a focus on the development of Engineered Geothermal (EGS) and Hot Sedimentary Aquifer (HSA) Systems. At this time about 10 unconventional geothermal projects were under development and significant technical successes were achieved including the creation of EGS reservoirs by Geodynamics Ltd at the Habanero field in the Cooper Basin, South Australia and by Petratherm Ltd at Paralana, South Australia

The technical achievements made during this period were tempered by a lack of commercial success, largely influenced by a combination of high drilling costs, poor market conditions leading to the retraction of private venture capital for speculative investments, and an uncertain policy environment for renewable technologies. Succinct discussions of these issues and the current climate faced by the generation sector in Australia are provided by Budd and Gerner (2015) and a report by the Australian Geothermal Association (Ballesteros et al, 2019).

A number of companies continue to hold geothermal exploration licences across Australia (*Figure 7.1*) and recently there has been renewed interest in developing small-scale geothermal generation in remote regional centres using waste heat from bore water infrastructure, such as the recently commissioned ORC plant at Winton, Queensland.

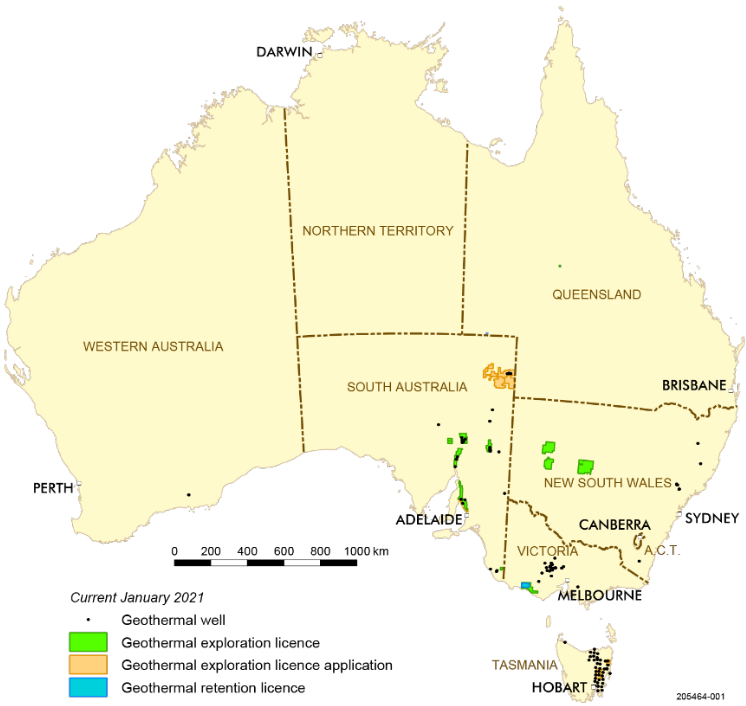
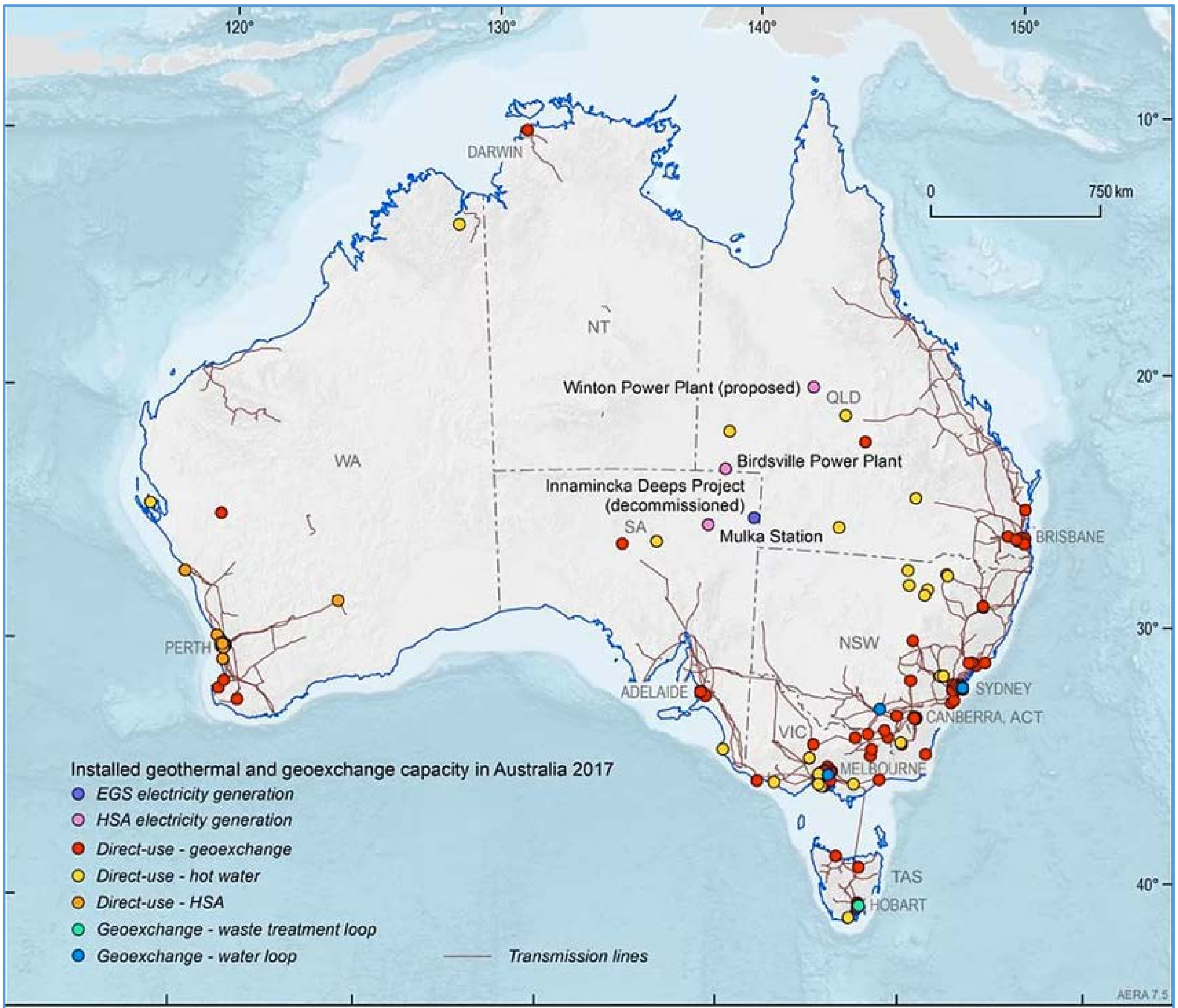


Figure 7.1: Geothermal licences, applications and gazettal areas as at 15 January 2021.

A census of geothermal energy installations in Australia undertaken by the Australian Geothermal Association (AGA, 2019) has highlighted the increasing interest and investment in Ground Source Heat Pumps (GSHP) and Direct Use geothermal applications (Figure 7.2, Figure 7.3). The census results have exposed the previously underestimated deployment of GSHPs, particularly in New South Wales, and drawn attention to the upswing in new developments of geothermal aquatic centres and hot spring spa resorts. These developments are largely concentrated in the states of Western Australia and Victoria (Beardsmore et al, 2021) with aquatic centre projects generally funded from local government infrastructure budgets, whereas the current surge in hot spring developments is being driven by private industry investment.



Source: Geoscience Australia, 2017.

Figure 7.2 *Installed geothermal and geoexchange capacity in Australia circa 2017 (after AGA, 2019).*

These developments occur largely in the absence of supporting policy incentives since Direct Use geothermal technologies, including GSHPs, remain ineligible under the Australian Commonwealth Government's Small-Scale Renewable Energy Target program. Lack of supporting policy mechanisms and low community awareness of the potential of GSHP and direct use geothermal continue to be major impediments to the wider deployment of these technologies.

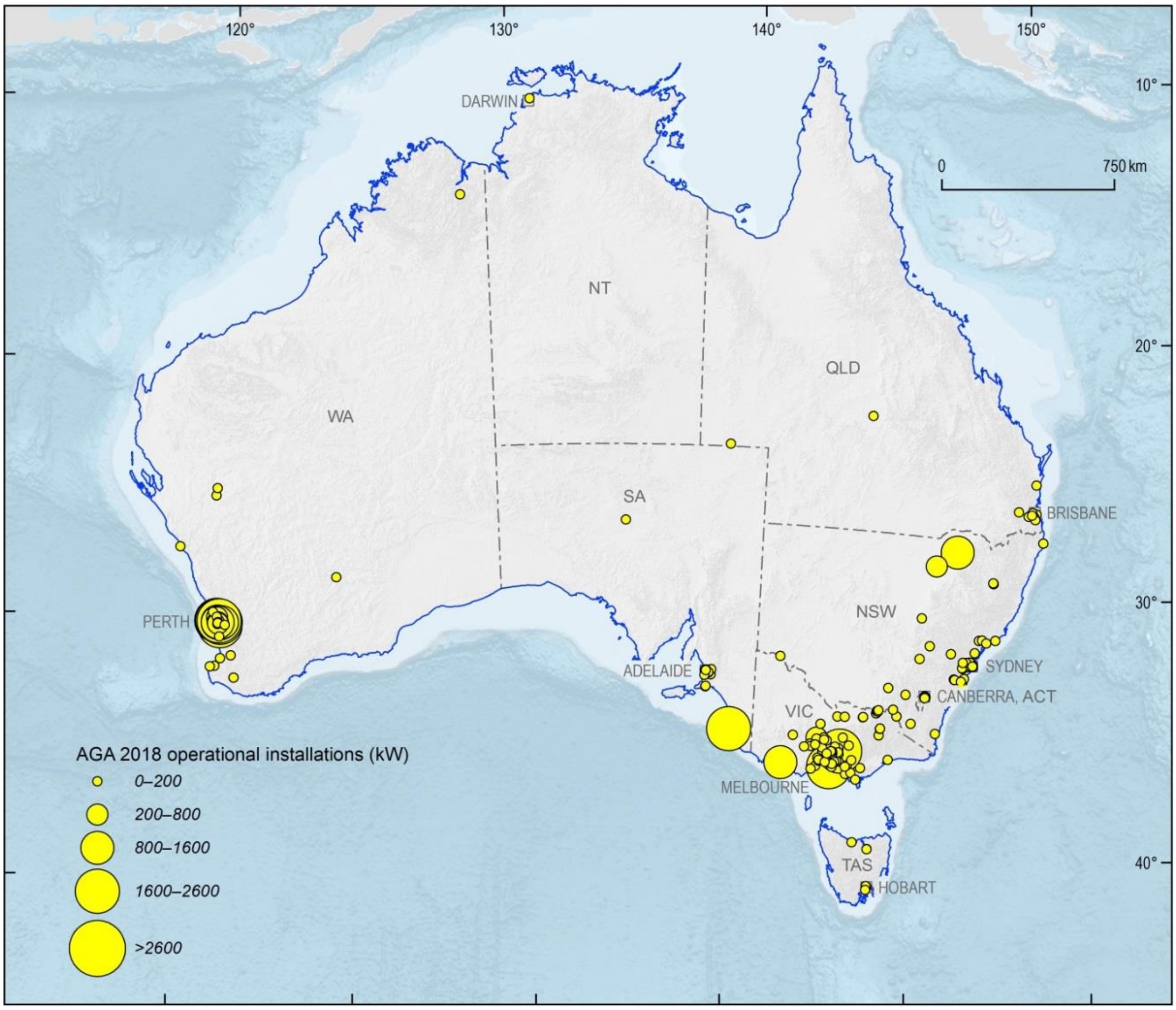


Figure 7.3 ***Operational geothermal and geoexchange capacity in Australia circa 2017 (after AGA, 2019).***

Table 7.1 Geothermal energy usage in Australia for the calendar year 2020.

Electricity		Direct Use	
Total Installed Capacity (MW_e)	0.3	Total Installed Capacity (MW_{th})	71.2
New Installed Capacity (MW_e)	0	New Installed Capacity (MW_{th})	1.4
Total Running Capacity (MW_e)	N/A	Total Heat Used (PJ/yr) [GWh/yr]	310.4
Contribution to National Capacity (%)	N/A	Total Installed Capacity Heat Pumps (MW_{th})	78.9
Total Generation (GWh)	N/A	Total Net Heat Pump Use [GWh/yr]	30.9*
Contribution to National Generation (%)	0	Target (PJ/yr)	N/A

(N/A = data not available)

(* indicates estimated values from 2019)

7.2 Changes to Policy Supporting Geothermal Development

At the international level, Australia's commitment under the 2015 Paris Agreement is to reduce emissions by 26–28% below 2005 levels by 2030. A revised Renewable Energy Target (RET) scheme in operation since 2011 has been the main incentive for delivering this target through the deployment target of 33,000 GWh of renewable generation by 2020 (Clean Energy Regulator, 2020; DISER, 2020b; Li et al, 2020). This target was achieved in 2019 with a total of 6.3 GW of additional renewable generation capacity being delivered, an increase of 24% above 2018 levels, taking the total share of renewables to 25% of the total National Electricity Market. This new capacity overachieves on the 20% by 2020 target leaving no further legislated incentive for growth in new renewables, however at the close of 2019 a future 37 GW of new renewable generation had received development approval, driven primarily by favourable commercial factors (Clean Energy Regulator, 2020; DISER, 2020a).

No new policies have been developed by the current Commonwealth Government and in the absence of additional national level policy directives, many Australian states and territories have introduced their own renewable energy and emission reduction targets (Table 7.2). South Australia, Tasmania and Queensland are developing significant renewable generation and storage capabilities. Tasmania already regularly achieves over 100% renewable generation and exports the excess to the mainland states. South Australia also regularly generates over 50% of their supply from renewables. The Australian Energy Market Operator (AEMO), foresees renewables offering the least-cost solution to replace aging fossil fuel fired generators as they are retired in the coming decades (Clean Energy Regulator, 2020; DISER, 2020a; Li et al, 2020).

Table 7.2 ***2020 State level Renewable Energy and Emissions Targets.***

State	Renewables	Net Emissions
Tasmania	100% by 2022	Zero by 2050
Australian Capital Territory	100% by 2020	Zero by 2045
South Australia	100% by 2030	Zero by 2050
Victoria	40% by 2025	Zero by 2050
Queensland	50% by 2030	Zero by 2050
New South Wales		Zero by 2050
Northern Territory	50% by 2030	
Western Australia		Zero by 2050

In the fiscal year 2018-19, total electricity generation in Australia rose by about 1% to 264,000 GWh. Renewable generation across all technologies increased by 17% contributing 20% of total generation, led by a 50% increase in solar and 17% increase in wind generation (DISER, 2020a). The steady increase in renewable generation continues to drive significant reductions in greenhouse gas emissions from the electricity generation sector. Emissions from the sector in 2020 were 172 MtCO2e and are projected to decline to 111 MtCO2e by 2030 (DISER, 2020b). The latest cumulative emissions projections from all sectors suggest that Australia's abatement task to reach the 2030 target is between 56 – 123 MtCO2e. If the 2020 target overachievement is included in projections, Australia will overachieve on the 2030 target by an estimated 336 to 403 MtCO2e. These 2020 emissions projections include savings attributed to over 24GW of deployed small scale (rooftop) PV and the impact of the COVID 19 pandemic which has restricted transport activity and increased uptake of digital (teleworking) technologies (DISER 2020b). By 2030 small scale (rooftop) PV is projected to be the largest electricity generation type comprising ~30% of grid connected capacity.

In Australia, jurisdiction for the legislation, permitting and regulation of geothermal exploration and development is a State and Territory government responsibility. Currently there are no national policies or grant structures which specifically target geothermal technologies. There has been some support for individual projects however by State and local Governments under general funding mechanisms for renewable technologies and infrastructure.

7.3 Geothermal Project Development

7.3.1 Projects Commissioned

Construction is nearing completion on the AU$57 million Gippsland Regional Aquatic Centre (GRAC) in Traralgon, a regional centre located in south-eastern Victoria, with the centre expected to open in early 2021. The project involves the construction of a large aquatic centre including 5 pools, splash park, 2 large water slides, gym, fitness rooms, and wellness suites. A geothermal heating system provides heating for the pool water along with the air in the pool hall. After the successful completion of a 24hr flow test, the geothermal system was commissioned in November 2020. The production bore provides water at approximately 68°C from the Traralgon aquifer and the rejected water pumped back to aquifer via the injection bore is between 40 - 53°C depending on the heat load required. The geothermal system is designed to maintain sealed conditions and avoid geochemical precipitation by avoiding exposure of the geothermal water supply to atmospheric conditions, pumping and injecting within the same aquifer and maintaining positive operation pressures. Maximum power is 3000kWt with about <350ML/year of groundwater circulation required to produce <2800kW of geothermal energy. It is anticipated that the use of geothermal energy in this project will save around $400k per year in gas costs and offset about 700 tonnes of carbon emissions annually.

Interest in the Australian Hot Springs and wellness sector is flourishing with seven projects nationwide either under construction or finalising planning and finance. This includes the Burketown, Talaroo Station and Cunnamulla projects in Queensland, the Alba, Metunga and Saltwater Hot Springs projects all under construction in Victoria, and the Tawarri Hot Springs project in Perth, Western Australia.

Commenced in 2018, a $13 m (total) expansion to the existing Peninsula Hot Spring facility at Mornington Peninsula Victoria has progressed to the third development phase. Early development stages saw the construction of a new wing of hot pools, saunas, an ice cave and an outdoor amphitheatre. The second and latest stage involving the construction of luxury on site glamping accommodation is complete and opened in December 2020.

Figure 7.4 ***Geothermal heating system plant room at the Gippsland Aquatic Centre, Victoria, Australia.***

7.3.2 Projects Operational

Construction and commissioning of a 310 kW ORC geothermal power plant in the remote community of Winton, Queensland was completed in 2019, and the plant began operation in December 2019. Production statistics for the Winton plant are not yet available.

Winton township is located in central western Queensland with a population of about 900 people. It is situated toward the end of the existing regional transmission grid and suffers from poor security of supply, relying on diesel backup generators when common brown outs and power interruptions occur. The town's water supply is sourced from the Great Artesian Basin. Water emerges from a networked bore system drilled to 1330m depth at 86°C with a flow rate of 77 l/s which was originally cooled in ponds before being reticulated throughout the town for use. The small modular ORC plant is comprised of two 155kW modules which generate electricity using the heat from the town water supply. Generation from the plant is automatically modulated to match water consumption.

Figure 7.5 ***Winton Shire ORC geothermal plant.***

7.4 Research Highlights

Government funded geothermal research is largely conducted by government research institutions and universities, supported by both State and Commonwealth Government funding including the Australian Research Council (ARC) and the Australian Renewable Energy Agency (ARENA). As the principal agency for the funding and support of renewable energy technologies in Australia, ARENA's objectives are to increase the supply and competitiveness of renewable energy in Australia. ARENA is currently funding a three-year study, due for completion in 2022, on the performance of 'deep well direct exchange' (DWDX) ground source heat pumps installed at the Fairwater Living Lab, a residential community in Western Sydney (ARENA, 2019).

A PhD project to study and review the social, environmental and economic impacts of hot springs on communities across Australia commenced in 2020 at the Victoria University, Melbourne. This study is jointly funded and supervised by 10 hot springs industry tourism operators, the Australian Geothermal Association (AGA) and the Victoria University School for the Visitor Economy.

7.5 Other National Activities

7.5.1 Geothermal Education

No new educational programmes commenced in 2020.

7.5.2 Conferences

No national geothermal conference program was held in 2020.

7.5.3 Publications

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Li, H.X., Edwards, D.J., Reza Hosseini, M., and Costin, G.P., (2020).
A review on renewable energy transition in Australia: An updated depiction. Journal of Cleaner Production, January 2020, https://doi.org/10.1016/j.jclepro.2019.118475

7.5.4 Useful Websites

https://www.australiangeothermal.org.au/

http://www.ga.gov.au/scientific-topics/energy/resources/geothermal-energy-resources

http://www.wearepeak.com.au/wintongeothermal

https://www.youtube.com/watch?v=ArML2QVbH08

https://www.uts.edu.au/sites/default/files/LNCLET_Winton_Fact_sheet_finalV3.pdf

https://www.bing.com/videos/search?q=winton+geothermal&docid=608050502521259273&mid=9138C7D7AD9E3E7D60E19138C7D7AD9E3E7D60E1&view=detail&FORM=VIRE

https://www.facebook.com/watch/?v=416280545936162

http://www.latrobe.vic.gov.au/Building_and_Planning/Major_Projects/Latrobe_Valley_Sports_and_Community_Initiative/Gippsland_Regional_Aquatic_Centre

7.6 Future Activity

Key activities scheduled for 2021 include completion of the Gippsland Aquatic Centre in Victoria and commencement of construction of a number of hot springs developments in Victoria and Western Australia.

7.7 References

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Ballesteros, M., Pujol, M., Walsh, F., and Teubner, J., (2019). Geothermal energy electricity generation in Australia: recent developments and future potential. Report prepared for the Australian Geothermal Association. https://0f7740a0-ff70-4bb8-9bda-923c19113c61.filesusr.com/ugd/75fc4e_cb45515bc7444756adfde8ea5c6a3206.pdf

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8. European Union

Samuel Carrara and Matthijs Soede

European Commission:
Joint Research Centre, Netherlands and DG Research and Innovation, CDMA 03/046, B-1049 Brussels.
Email: Samuel.Carrara@ec.europa.eu matthijs.soede@ec.europa.eu

8.1 Introduction

Up to 2020, the European Commission has been supporting the development of the geothermal sector through an array of activities based on two major policy initiatives: the European Green Deal and the SET-Plan.

In November 2019, the European Commission President Ursula von der Leyen said that she wants Europe to become the world's first climate-neutral continent by 2050 and presented the European Green Deal. It will be the most ambitious package of measures that should enable European citizens and businesses to benefit from sustainable green transition. Following this package, the European Commission presented in 2020 a EU strategy on energy system integration, an Industrial Strategy for a green and digital Europe, and initiated a revision of several directives.

The European Commission cooperates closely with its Member States to increase support for geothermal energy. The SET-Plan steering group has adopted the Deep Geothermal Implementation Plan (DG-IP) and a Deep Geothermal Implementation Working Group (DG-IWG) is being established to advance the DG-IP.

The European Commission continued to support geothermal energy research and development via their funding programs like Horizon 2020 and the European Regional Development Fund.

In 2019, the geothermal electricity production in the EU amounted to 7 TWh_{el} which is approximately 0.2% of the total electricity consumption of the EU[1].

8.2 Changes to Policy Supporting Geothermal Development

The European Commission is supporting the development of the geothermal sector through an array of activities based on two major policy initiatives: the European Green Deal and the SET-Plan. Geothermal energy is promoted by the Climate and Energy objectives of the European Union (EU). The regulatory and policy framework for geothermal energy is complex, and 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 main areas:

- 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.

[1] European Commission, SWD(2020)953/F1 - EN (europa.eu)

The Renewable Energy Directive has 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. In November 2018, the European Parliament adopted the revision of the Renewable Energy Directive, the Energy Efficiency Directive and the Governance of the Energy Union Regulation, which lay out the European climate and energy regulatory framework after 2020. The EU Clean Energy Package sets a 32% binding target for renewables in 2030. Considering the increased ambition with the European Green Deal the different directives will have to be aligned again.

To meet the EU's energy and climate targets for 2030, EU Member States need to establish a 10-year integrated national energy and climate plan (NECP) from 2021 to 2030. The NECPs were introduced by the Regulation on the governance of the energy union and climate action (EU/2018/1999)[2]. The national plans outline how the EU Member States intend to address energy efficiency, renewables, emissions reductions, and research and innovation. This approach requires a coordination of purpose across all governmental departments. It also provides a level of planning that will ease public and private investment. The fact that all EU Member States are using a similar template means that they can work together to make efficiency gains across borders. All the EU Member States were asked to submit their plans before the end of 2019. EU countries have submitted their national long-term strategies and they must ensure consistency between long-term-strategies and the NECPs. The NECPs are published on the website of the European Commission[3].

The new European Commission President Ursula von der Leyen said that she wants Europe to become the world's first climate-neutral continent by 2050. It will be the greatest challenge and opportunity of our times. To achieve this, the European Commission presented the European Green Deal[4]. It will be the most ambitious package of measures that should enable European citizens and businesses to benefit from sustainable green transition. Measures accompanied with an initial roadmap of key policies range from ambitiously cutting emissions, to investing in cutting-edge research and innovation, to preserving Europe's natural environment.

Supported by investments in green technologies, sustainable solutions and new businesses, the Green Deal can be a new EU growth strategy. Involvement and commitment of the public and of all stakeholders is crucial to its success. The European Green Deal sets a path for a transition that is just and socially fair. It is designed in such a way as to leave no individual or region behind in the great transformation ahead.

Geothermal developments have been shown to benefit from government support. Several Member States of the EU 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, i.e. power production, direct use, ground source heat pumps (GSHP). For geothermal power, support schemes at EU or national level

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[2] https://ec.europa.eu/energy/topics/energy-strategy/energy-union_en?redir=1#content-heading-2
[3] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/national-energy-climate-plans
[4] https://ec.europa.eu/info/publications/communication-european-green-deal_en

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. A report of the Joint Research Centre (JRC) shows all policy instruments available for geothermal electricity, and heating and cooling [Shortall et al. 2019].

The geothermal energy sector is also supported at a European level through the Cohesion Fund, the European Regional Development Fund, the European Social Fund and the European Agricultural Fund for Rural Development [ETIP-DG 2018a]. Financial instruments provide technical assistance, soft loans schemes or revolving funding.

Horizon 2020 (H2020) is the main EU R&I programme with nearly EUR 80 billion of funding available over seven years (2014 to 2020), which provided funding to geothermal R&D projects since its inception. In 2020 there was still one last call to support the European Green Deal and included a specific topic asking for projects on renewable energy innovations.

Horizon Europe will be the successor of Horizon 2020 and the budget proposal for Research and Innovation is EUR 95.5 billion for the period 2021-2027. After adoption, the programme will commence in spring 2021 and will include topics on geothermal energy development under the Climate, Energy and Mobility subprogramme.

The European Investment Bank (EIB) is owned by the Member States and works closely with other EU institutions to implement EU policy focusing on specific priorities such as climate action and strategic infrastructure. It supports projects through loans, technical assistance, guarantees or venture capital [ETIP-DG 2018a]. The EIB together with the European Commission is implementing the InnovFin Energy Demo Projects (EDP) scheme which provides support in the form of loans for first-of-a kind projects. InnovFin aims to facilitate and accelerate access to finance for innovative businesses and projects in unproven markets in Europe. The scheme helps by reducing the financial risk of demonstration projects, and offering equity and loans tailored to the need of the project.

From 2021 onward, the InvestEU Programme will bring together under one roof the multitude of EU financial instruments currently available and expand the successful model of the Investment Plan for Europe, the Juncker Plan. With InvestEU, the Commission will further boost investment, innovation and job creation.

8.3 Geothermal Project Development

8.3.1 Geothermal power

As of end 2019, there are 130 geothermal power plants in operation in Europe, corresponding to 3.3 GW_{el} of installed capacity. However, most of this capacity is located in two non-EU countries, namely Turkey (1.5 GW_{el}) and Iceland (0.8 GW_{el}). Hence, only 1 GW_{el} is installed in the EU, almost entirely in Italy (0.9 GW_{el}) [EGEC 2020]. In order to put this value in perspective, the economic potential of geothermal power in the EU is estimated at 522 GW_{el} by 2050 [Limberger et al. 2014].

Turkey is also the country that installed most additional capacity in 2019, amounting to 150 MW_{el} distributed across five plants. Outside Turkey, a new project was commissioned in Germany (3 MW_{el}) and an old plant was retrofitted in Iceland (5 MW_{el}) [EGEC 2020].

There are currently 36 projects under development and 124 projects in the planning phase in Europe, which suggests that the number of operational plants could double over the next

5-8 years. About three quarters of these new projects are located within the EU, notably in Italy, France, Greece, and Germany [EGEC 2020].

In 2019, the yearly electricity generation from geothermal sources in the EU amounted to 7 TWh_{el} (6 TWh_{el} in Italy), corresponding to 0.2% of the total electricity consumption[EGEC 2020] [IEA 2020]. Outside the EU, geothermal electricity generation amounted to 8 TWh_{el} in Turkey and 6 TWh_{el} in Iceland [EGEC 2020].

Most geothermal energy in the EU is produced from hydrothermal resources. Only four Enhanced Geothermal Systems (EGS) plants exist within the EU. Three EGS plants with Hot Sedimentary Aquifers (HAS) 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 [Shortall et al. 2019].

8.3.2 Geothermal direct use

Geothermal heat can be used for a variety of applications, including district heating and cooling, industry, services and agriculture. District heating for households remains the main application. As of end 2019, a total of 327 geothermal district heating systems are installed in 25 countries in Europe, corresponding to a capacity of 5.5 GW_{th} [EGEC 2020].

As with geothermal power, Iceland and Turkey are the main markets. Installed capacities are 2.2 GW_{th} and 1.0 GW_{th}, respectively. Additional 2.1 GW_{th} are distributed across the EU, notably in France (0.65 GW_{th}) Germany (0.35 GW_{th}), Hungary (0.26 GW_{th}), and the Netherlands (0.21 GW_{th}).

The Netherlands has shown constantly growing trends in the past years and it accounted for the vast majority of the new installed capacity in 2019 in Europe (100 MW_{th} out of 130 MW_{th}). Installations also occurred in Italy, Greece, and Spain. Other EU countries with a considerable number of geothermal district heating plants under development or investigation are Poland and Denmark [EGEC 2020].

8.3.3 Geothermal heat pumps

GSHPs represent the most common and widespread form of geothermal energy use in Europe: 2 million systems are installed as of end 2019, with a corresponding capacity of about 28 GW_{th} [EGEC 2020] [Lund and Toth 2020].

Different from the geothermal power and direct use sectors, EU countries have the lion's share of this sector in Europe. Sweden is a mature market with an average of over 13 GSHPs per 100 households, resulting in an overall amount of 0.6 million systems and a corresponding capacity of 6.7 GW_{th}. Other significant countries are Germany (0.38 million GSHPs, 4.4 GW_{th}), France (0.17 million GSHPs, 2.0 GW_{th}), and Finland (0.14 million, 2.3 GW_{th}). The most relevant non-EU European countries are Switzerland (0.10 million GSHPs, 2.2 GW_{th}) and Norway (0.04 million GSHPs, 1.2 GW_{th}) [EGEC 2020] [Lund and Toth 2020].

8.4 Research Highlights

The H2020 energy Work Programme for 2018-2020 [European Commission 2017] included six R&D topics specifically targeting geothermal energy, thus covering the whole range of technology development, from TRL 3 (experimental proof of concept) to TRL 8 (system complete and qualified)[5].

Figure 8.1 shows the EU contribution to co-funded projects from 2004 to 2020. The chart reports funds from H2020 and from the Framework Programmes which preceded H2020, i.e. FP6 (2002-2006) and FP7 (2007-2013), as well as from two other funding schemes called Intelligent Energy Europe (IEE) and NER300. Projects are aggregated according to their start date.

The total amount of funds granted by the EU to geothermal energy in the considered period is EUR 411 million, shared among 112 projects. Figure 8.1 shows that more R&D funding has been allocated during H2020 (EUR 249 million, 60 projects) than in any other previous funding programme, although with a marked variability across the years. In particular, a considerable drop in funding was observed in 2020.

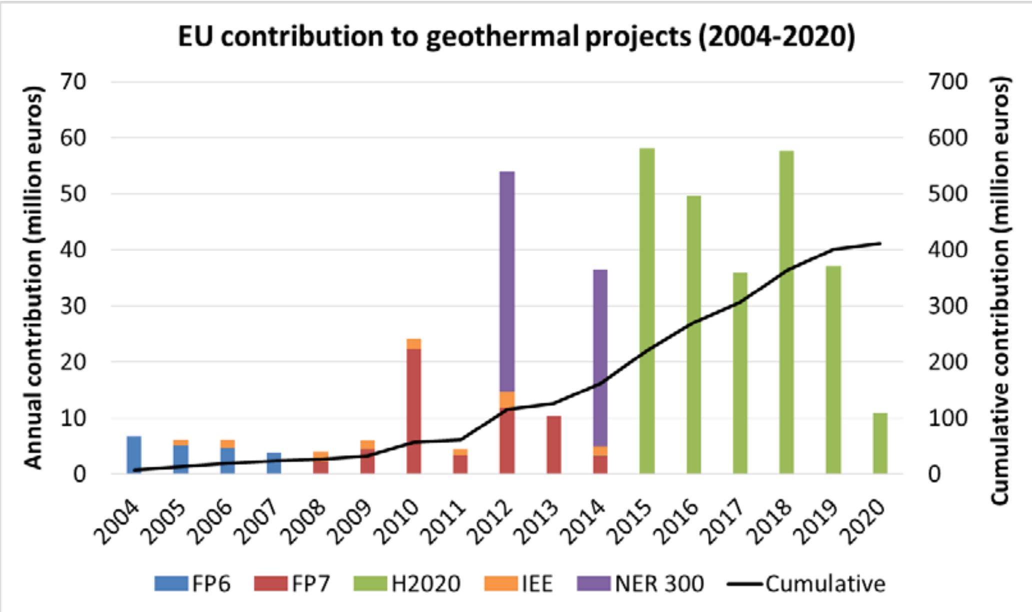

Figure 8.1 EU contribution to co-funded projects from 2004 to 2020. Source: JRC elaboration based on CORDIS

The most recent H2020 projects are listed in the following sections. Projects are sorted by those:

- completed in 2020
- ongoing in 2020
- started in 2020

Each section lists projects in descending order of EU funding. A link to the relevant webpage in the CORDIS project database is provided for each project.

8.4.1 H2020 projects completed in 2020

DEEPEGS – Deployment of deep enhanced geothermal systems for sustainable energy business[6] (December 2015 – April 2020, EUR 19.0 million EU funding, topic: Demonstration of renewable electricity and heating/cooling technologies)

[5] Technology Readiness Level
[6] https://cordis.europa.eu/project/id/690771

The goal of the project was to demonstrate the feasibility of EGSs for delivering energy from renewable resources in Europe. Testing of stimulating technologies for EGS in deep wells in different geologies delivered new innovative solutions and models for wider deployments of EGS reservoirs with sufficient permeability for delivering significant amounts of geothermal power across Europe.

GEMex – Cooperation in Geothermal energy research Europe-Mexico for development of Enhanced Geothermal Systems and Superhot Geothermal Systems[7] (October 2016 – May 2020, EUR 10.0 million EU funding, topic: International Cooperation with Mexico on geothermal energy)

The project was a complementary effort of a European consortium with a corresponding consortium from Mexico, who submitted an equivalent proposal for cooperation. The joint effort was based on three pillars: (i) resource assessment at two unconventional geothermal sites (for EGS development and for a super-hot resource); (ii) reservoir characterisation using techniques and approaches developed at conventional geothermal sites, including novel geophysical and geological methods to be tested and refined for their application at the two project sites; and (iii) concepts for site development.

S4CE – Science for Clean Energy[8] (September 2017 – December 2020, EUR 9.8 million EU funding, topic: Measuring, monitoring and controlling the potential risks of subsurface operations related to CCS[9] and unconventional hydrocarbons)

The project included fundamental studies of fluid transport and reactivity, development of new instruments and methods for the detection and quantification of emissions, micro-seismic events, lab and field testing of such new technologies, and the deployment of the successful detection and quantification technologies in sub-surface sites for continuous monitoring of the risks identified by the European Commission. The project used monitoring data acquired in four field sites in order to (i) quantify the environmental impact of sub-surface geo-energy applications; (ii) demonstrate new technologies; (iii) collect data during and potentially after the end of the project. Using reliable data, innovative analytical models and software, the project quantified the likelihood of environmental risks such as fugitive emissions, water contamination, induced micro-seismicity, and local impacts. The project set up a probabilistic methodology to assess and mitigate both the short and the long-term environmental risks connected to the exploration and exploitation of sub-surface geo-energy.

ENIGMA – European training Network for In situ imaGing of dynaMic processes in heterogeneous subsurfAce environments[10] (January 2017 – December 2020, EUR 3.9 million EU funding, topic: Innovative Training Networks)

The ENIGMA network trained a new generation of young researchers in the development of innovative sensors, field survey techniques and inverse modelling approaches. This enhanced the ability to understand and monitor dynamic subsurface processes that are key to the protection and sustainable use of water resources. The project focused mainly on critical zone observation, but the anticipated technological developments and scientific findings also

[7] https://cordis.europa.eu/project/id/727550
[8] https://cordis.europa.eu/project/id/764810
[9] Carbon Capture and Storage
[10] https://cordis.europa.eu/project/id/722028

contributed to monitor and model the environmental footprint of other subsurface activities, including large-scale water abstraction and storage, EGS, and waste and carbon storage.

8.4.2 H2020 projects ongoing in 2020

GeoSmart – Technologies for geothermal to enhance competitiveness in smart and flexible operation[11] (June 2019 – May 2023, EUR 17.4 million EU funding, topic: Demonstrate highly performant renewable technologies for combined heat and power (CHP) generation and their integration in the EU's energy system)

The project works on methods to store heat energy when demand is low so as to release it when demand is high. It also plans to create a hybrid cooling system for the organic Rankine cycle plant that will prevent efficiency degradation due to seasonal changes. The aim is to allow geothermal plants to cost-effectively respond to different heat and power demands.

GECO – Geothermal Emission Gas Control[12] (October 2018 – September 2022, EUR 15.6 million EU funding, topic: Demonstrate solutions that significantly reduce the cost of renewable power generation)

The project applies an innovative technology, recently developed and proved successfully at pilot scale in the context of the FP7 CarbFix project in Iceland, which can limit the production of emissions from geothermal plants by condensing and re-injecting gases or turning the emissions into commercial products. To both increase public acceptance and to generalise this approach, it is being applied in four distinct geothermal systems in four different European countries.

DESTRESS – Demonstration of soft stimulation treatments of geothermal reservoirs[13] (March 2016 – May 2021, EUR 10.7 million EU funding, topic: Demonstration of renewable electricity and heating/cooling technologies)

The project is aimed at creating EGS reservoirs with sufficient permeability, fracture orientation and spacing for economic use of underground heat. The concepts are based on experience in previous projects, on scientific progress and developments in other fields, mainly the oil & gas sector. Recently developed stimulation methods are adapted to geothermal needs, applied to new geothermal sites, and prepared for market uptake. Understanding of risks in each area (whether technological, in business processes, for particular business cases, or otherwise), risk ownership, and possible risk mitigation are the scope of specific work packages.

MEET – Multidisciplinary and multi-context demonstration of EGS exploration and Exploitation Techniques and potentials[14] (May 2018 – October 2021, EUR 10.0 million EU funding, topic: EGS in different geological conditions)

The project aims at demonstrating 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.

[11] https://cordis.europa.eu/project/id/818576
[12] https://cordis.europa.eu/project/id/818169
[13] https://cordis.europa.eu/project/id/691728
[14] https://cordis.europa.eu/project/id/792037

GeoFit – Deployment of novel GEOthermal systems, technologies and tools for energy efficient building retroFITting[15] (May 2018 – April 2022, EUR 7.9 million EU funding, topic: Easier to install and more efficient geothermal systems for retrofitting buildings)

The project is an integrated industry-driven effort aimed at deployment of cost effective EGS for energy-efficient building retrofitting. This entails the technical development of innovative EGS and its components, namely, non-standard heat exchanger configurations, novel hybrid heat pumps, and electrically driven compression heat pump systems. It also includes developing a suite of heating and cooling components to be integrated with the novel GSHP concepts, all specially designed to be applied in energy-efficient retrofitting projects.

GEOTHERMICA – ERA NET Cofund Geothermal[16] (January 2017 – June 2022, EUR 7.0 million EU funding, topic: Joint Actions towards the demonstration and validation of innovative energy solutions)

The objective of the project is to combine the financial resources and know-how of 16 geothermal energy research and innovation programme owners and managers from 13 countries, to launch joint actions that demonstrate and validate novel concepts of geothermal energy utilisation within the energy system, and that identify paths to commerciality. Joint actions comprise joint calls and coordination activities, which will strengthen Europe's geothermal energy sector by building a tightly interconnected and well-coordinated network of European funding agents.

GEO4CIVHIC – Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings[17] (April 2018 – March 2022, EUR 6.8 million EU funding, topic: Easier to install and more efficient geothermal systems for retrofitting buildings)

The project identifies and, where missing, develops building block solutions in drilling (machines and methods), ground source heat exchanger types, heat pumps and other renewable energy/storage technologies, heating and cooling terminals with the focus on every type of built environment, civil and historical. It will also generate and demonstrate the easiest to install and most cost-effective geothermal energy solutions using and improving existing and new tools.

EUROVOLC – European Network of Observatories and Research Infrastructures for Volcanology[18] (February 2018 – November 2021, EUR 5.0 million EU funding, topic: Integrating Activities for Starting Communities)

The project is constructing an integrated and harmonised European volcanological community able to fully support, exploit and build-upon existing and emerging national and pan-European research infrastructures, including e-Infrastructures of the European Supersite volcanoes. Among other outcomes, the project will open pathways for enterprise to better exploit geo-resources in volcanic areas such as using geothermal energy.

[15] https://cordis.europa.eu/project/id/792210
[16] https://cordis.europa.eu/project/id/731117
[17] https://cordis.europa.eu/project/id/792355
[18] https://cordis.europa.eu/project/id/731070

Geo-Drill – Development of novel and cost-effective drilling technology for Geothermal Systems[19] (April 2019 – September 2022, EUR 5.0 million EU funding, topic: Developing solutions to reduce the cost and increase performance of renewable technologies)

The project aims to reduce drilling cost for geothermal systems with increased penetration rate and reduced tripping due to improved tool durability. It proposes drilling technology incorporating a bi-stable fluidic amplifier driven mud hammer, low cost 3D printed sensors & cables, a drill monitoring system, and graphene-based materials and coatings.

GeoHex – Advanced material for cost-efficient and enhanced heat exchange performance for geothermal application[20] (November 2019 – October 2022, EUR 5.0 million EU funding, topic: Developing the next generation of renewable energy technologies)

The project relies on the use of low-cost carbon steel as the base material for heat exchangers for geothermal power plants. Through modifying the surface with nano porous coating and controlling the surface chemistry (along with the surface structure), the project will significantly improve the heat transfer performance of single phase and phase change heat transfer processes, respectively.

GEOPRO – Accurate Geofluid Properties as key to Geothermal Process Optimisation[21] (November 2019 – October 2022, EUR 4.9 million EU funding, topic: Optimising manufacturing and system operation)

The project aims at producing experimental data on heat and mass transfer behaviour of high-concentration fluids in very high temperatures. Data serve as input in a set of new design and operation tools that should allow the geothermal power plants to design and operate systems more effectively, reducing the levelised cost of energy to competitive levels.

Geo-Coat – Development of novel and cost effective corrosion resistant coatings for high temperature geothermal applications[22] (February 2018 – May 2021, EUR 4.7 million EU funding, topic: Developing the next generation technologies of renewable electricity and heating/cooling)

The project develops new resistant materials in the form of high performance coatings of novel targeted "High Entropy Alloys" and Cermets, thermally applied to the key specified vulnerable process stages (components in turbines, valves, pumps, heat exchangers and pipe bends) in response to the specific corrosion and erosion forces that are found at each point. It also captures the underlying principles of the material resistance, to proactively design the equipment for performance while minimising overall capex costs from these expensive materials.

MPC-. GT – Model Predictive Control and Innovative System Integration of GEOTABS in Hybrid Low Grade Thermal Energy Systems[23] (September 2016 – February 2021, EUR 4 million EU funding, topic: New heating and cooling solutions using low grade sources of thermal energy)

The project brought together a transdisciplinary team of small and medium enterprises, large industry, and research institutes, experienced in research and application of design and control

[19] https://cordis.europa.eu/project/id/815319
[20] https://cordis.europa.eu/project/id/851917
[21] https://cordis.europa.eu/project/id/851816
[22] https://cordis.europa.eu/project/id/764086
[23] https://cordis.europa.eu/project/id/723649

systems in the combined building and energy world. Based on prior research, supported by (joint) EU and national projects and practical experience, the bottlenecks were identified that currently prevent a real breakthrough of geothermal heat pumps combined with thermally activated building systems. The innovative concepts aim at increasing the share of low valued (low-grade) energy sources by means of using low exergy systems on the one hand and aim at upgrading low/moderate temperature resources on the other hand.

GEOCOND – Advanced materials and processes to improve performance and cost-efficiency of Shallow Geothermal systems and Underground Thermal Storage[24] (May 2017 – February 2021, EUR 4.0 million EU funding, topic: Developing the next generation technologies of renewable electricity and heating/cooling)

By a combination of different material solutions under the umbrella of sophisticated engineering, optimisation, testing and on-site validation, the project develops solutions to increase the thermal performance of different subsystems, configuring a Shallow Geothermal Energy System (SGES) and an Underground Thermal Energy Storage (UTES).

TEMPO – TEMPerature Optimisation for Low Temperature District Heating across Europe[25] (October 2017 – September 2021, EUR 3.1 million EU funding, topic: New heating and cooling solutions using low grade sources of thermal energy)

The technical and economic viability of today's district heating networks are undermined by transitions to highly efficient building stocks and ineffective business models which fail to benefit all stakeholders. The project tackles this by (i) innovations to create low temperature networks for increased network efficiency and integration options for renewable and residual heat sources, and (ii) new business models to boost network competitiveness and attractiveness for stakeholder investment.

GEOENVI – Tackling the environmental concerns for deploying geothermal energy in Europe[26] (November 2018 – April 2021, EUR 2.5 million EU funding, topic: Market Uptake support)

The first objective of the project is to make sure that deep geothermal energy can play its role in Europe's future energy supply in a sustainable way. It aims to create a robust strategy to respond to environmental concerns: (i) by assessing the environmental impacts and risks of geothermal projects operational or in development in Europe; (ii) by providing a robust framework to propose recommendations on environmental regulations to the decision-makers; an adapted methodology for assessing environment impact to the project developers, and finally (iii) by communicating properly on environmental concerns with the general public. The project also aims at engaging with both decision-makers and geothermal market actors, to have the recommendations on regulations adopted and to see the Life Cycle Assessment (LCA) methodology implemented by geothermal stakeholders.

CROWDTHERMAL – Community-based development schemes for geothermal energy[27] (September 2019 – August 2022, EUR 2.3 million EU funding, topic: Market Uptake support)

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[24] https://cordis.europa.eu/project/id/727583
[25] https://cordis.europa.eu/project/id/768936
[26] https://cordis.europa.eu/project/id/818242
[27] https://cordis.europa.eu/project/id/857830

The project aims to empower the European public to directly participate in the development of geothermal projects with the help of alternative financing schemes (crowdfunding) and social engagement tools. In order to reach this goal, the project first increases the transparency of geothermal projects and technologies by creating one to one links between geothermal actors and the public so that a Social Licence to Operate (SLO) could be obtained. The project is creating a social acceptance model for geothermal energy that will be used as a baseline in subsequent actions for inspiring public support for geothermal energy. Parallel and synergetic with this, the project is working out details of alternative financing and risk mitigation options covering the different types of geothermal resources and various socio-geographical settings.

GEORISK – Developing geothermal and renewable energy projects by mitigating their risks[28] (October 2018 – September 2021, EUR 2.2 million EU funding, topic: Market Uptake support)

A geothermal project development has several risky components, the most important one being the resource risk. This concerns mainly deep geothermal projects, but some shallow geothermal open systems could also be included in this category of projects. Beyond exploration, the bankability of a geothermal project is threatened by this geological risk. The project works to establish such risk insurance all over Europe (and, in some key target, third countries) to cover the exploration phase and the first drilling (test).

CarbFix2 – Upscaling and optimizing subsurface, in situ carbon mineralization as an economically viable industrial option[29] (August 2017 – January 2021, EUR 2.2 million EU funding, topic: Geological storage pilots)

The project builds upon the FP7 CarbFix project. CarbFix developed a novel, safe, and efficient geologic carbon storage method – applied at the Hellisheidi geothermal power plant (Iceland) – which successfully converted injected CO_2 into stable carbonate rocks within two years. CarbFix2 was designed to make the CarbFix geological storage method economically viable with a complete CCS chain and to make the technology transportable throughout Europe. This is done through a comprehensive project consisting of i) the co-injection of impure CO_2 and other water-soluble polluting gases into the subsurface, ii) developing the technology to perform the CarbFix geological carbon storage method using seawater injection into submarine basalts, and iii) integrating the CarbFix method with novel air-capture technology.

BigMac – Microfluidic Approaches mimicking BIoGeological conditions to investigate subsurface CO_2 recyclings[30] (November 2017 – October 2022, EUR 2.0 million EU funding, topic: ERC Consolidator Grant)

The objective of this project is to develop and use "Biological Geological Laboratories on a Chip - BioGLoCs" mimicking reservoir conditions in order to gain greater understanding in the mechanisms associated with the biogeological conversion process of CO_2 to methane at pore scale. New generic lab scale tools are also being made available for investigating geological-related topics (enhanced oil recovery, deep geothermal energy, bioremediation of groundwater, shale gas recovery).

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28 https://cordis.europa.eu/project/id/818232
29 https://cordis.europa.eu/project/id/764760
30 https://cordis.europa.eu/project/id/725100

GEoREST – predictinG EaRthquakES induced by fluid injecTion[31] (February 2019 – January 2024, EUR 1.4 million EU funding, topic: ERC Starting Grant)

Forecasting injection-induced earthquakes is a big challenge that must be overcome to deploy geo-energies. The objective of this project is to develop a novel methodology to predict and mitigate induced seismicity. The project proposes an interdisciplinary approach that integrates the thermo-hydro-mechanical-seismic (THMS) processes that occur in the subsurface as a result of fluid injection.

ENeRAG – Excellency Network Building for Comprehensive Research and Assessment of Geofluids[32] (October 2018 – September 2021, EUR 1.0 million EU funding, topic: Twinning)

The project significantly strengthens research and innovation capacities in geofluids' research and aligns geological resource assessment of groundwater, geothermal energy and hydrothermal mineral resources at Eötvös Loránd University (ELTE, Hungary) by capacity enhancement through cooperation with Geological Survey of Finland (GTK) and University of Milan (UMIL, Italy), with seven supporting stakeholders.

GeoTwinn – Strengthening research in the Croatian Geological Survey: Geoscience-Twinning to develop state-of-the-art subsurface modelling capability and scientific impact[33] (October 2018 – September 2021, EUR 1.0 million EU funding, topic: Twinning)

This project addresses the need to spread excellence and widen participation across the European Union by the twinning of research institutions. It proposes to twin the Croatian Geological Survey (HGI-CGS) with the Geological Survey of Denmark and Greenland and the British Geological Survey of the United Kingdom Research and Innovation, to significantly strengthen HGI-CGS's research, and transform its capability in a number of areas, such as (i) 3D geological surveying and modelling; (ii) groundwater flow and contaminant transport modelling; (iii) geological hazards; (iv) geothermal energy.

MATHROCKS – Multiscale Inversion of Porous Rock Physics using High-Performance Simulators: Bridging the Gap between Mathematics and Geophysics[34] (April 2018 – March 2023, EUR 0.8 million EU funding, topic: Research and Innovation Staff Exchange)

The project develops and exchanges knowledge on applied mathematics, high-performance computing, and geophysics to better characterise the Earth's subsurface. The aim is to better understand porous rocks physics in the context of elasto-acoustic wave propagation phenomena. To verify and validate the developed tools and methods, results are applied to: characterise hydrocarbon reservoirs, determine optimal locations for geothermal energy production, analyse earthquake propagation, and jointly invert deep-azimuthal resistivity and elasto-acoustic borehole measurements.

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[31] https://cordis.europa.eu/project/id/801809
[32] https://cordis.europa.eu/project/id/810980
[33] https://cordis.europa.eu/project/id/809943
[34] https://cordis.europa.eu/project/id/777778

NERUDA – Numerical and ERT stUdies for Diffusive and Advective high-enthalpy systems[35] (November 2018 – April 2021, EUR 0.2 million EU funding, topic: Individual Fellowships)

The project proposes an innovative and multidisciplinary approach to predict the role of faults on fluid flow, combining numerical simulations of fluid flow with deep Electric Resistivity Tomography (ERT). The project aims at constraining the tectonic control on fluid flow in hydrothermal systems.

8.4.3 H2020 projects started in 2020

REFLECT – Redefining geothermal fluid properties at extreme conditions to optimize future geothermal energy extraction[36] (January 2020 – December 2022, EUR 5.0 million EU funding, topic: Optimising manufacturing and system operation)

The efficiency of geothermal utilisation depends on the behaviour of fluids that transfer heat between the geosphere and the engineered components of a power plant. The project aims to avoid problems related to fluid chemistry rather than treat them. The physical and chemical fluid properties are often poorly defined, as in situ sampling and measurements at extreme conditions are difficult to date. Therefore, large uncertainties in current model predictions prevail, which will be tackled by collecting new, high-quality data in critical areas. These data will be implemented in a European geothermal fluid atlas and in predictive models for providing recommendations on how to best operate geothermal systems for sustainable use.

EASYGO – Efficiency and Safety in Geothermal Operations[37] (November 2020 – October 2024, EUR 3.4 million EU funding, topic: Innovative Training Networks)

The project develops system components, monitoring concepts and operational paradigms to enhance the safety and efficiency of geothermal systems. By connecting academia and industry with real-scale research infrastructure, the project is preparing young researchers with both experimental and practical knowledge.

PRD-Trigger – Precipitation triggered rock dynamics: the missing mesoscopic link[38] (February 2020 – January 2025, EUR 1.5 million EU funding, topic: ERC Starting Grant)

Cyclic changes during rock weathering or at geothermal or CO_2-sequestration sites lead to precipitation-dissolution cycles of salts, natural constituents of brines inside rocks, which might degrade rocks' structure. What triggers rock dynamics into fracturing during salt precipitation? Can we ultimately control this trigger? The project advocates that the answer lies at the mesoscale, the scale of the pore network. It will combine 4D X-ray imaging with a mesoscopic numerical simulator integrated into the image analysis workflow to identify key factors in precipitation-induced damage. Damage control and crack healing will then be demonstrated on core-scale rocks.

GeoUS – Geothermal Energy in Special Underground Structures[39] (January 2020 – December 2022, EUR 0.8 million EU funding, topic: Twinning)

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35 https://cordis.europa.eu/project/id/793662
36 https://cordis.europa.eu/project/id/850626
37 https://cordis.europa.eu/project/id/956965
38 https://cordis.europa.eu/project/id/850853
39 https://cordis.europa.eu/project/id/856670

The project will enable the VSB - Technical University of Ostrava (VSB-TUO) in the Czech Republic to enhance the scientific excellence of its personnel and collaborate with leading international research institutions in the field. Young researchers will have the chance to study fundamental and practical aspects of developing geothermal energy sustainably. Research results will be shared with local and national authorities.

THERM – Transport of Heat in hEteRogeneous Media[40] (September 2020 – August 2022, EUR 0.2 million EU funding, topic: Individual Fellowships)

To develop and test new technologies for energy production and storage in geothermal reservoirs, deep understanding of heat transport in fractured media is critically needed. The project focuses on the investigation of heat transport and associated thermo-hydro-mechanical processes occurring during the lifetime of a geothermal reservoir.

8.5 Other activities

8.5.1 DG ETIP

The European Technology and Innovation Platform on Deep Geothermal (DG ETIP) was created in 2016[41]. It complements the ETIP on Heating and Cooling, as well as the other existing thematic ETIPs on renewable energy technologies[42].

In 2017, DG ETIP received almost EUR 0.6 million of EU funding through topic LCE-36-2016-2017 of Horizon 2020. The project was launched in July 2017 and lasted until June 2019. DG ETIP has developed a comprehensive Strategic Research Agenda for the geothermal sector, clarifying its R&D priorities for years to come [ETIP-DG 2018b]. The Strategic Research Agenda and Implementation roadmap for deep geothermal were published in 2019. Furthermore, DG ETIP has developed a dedicated Roadmap and suggested ideal ways to finance geothermal energy players and projects in ad-hoc factsheets.

8.5.2 SET-Plan Deep Geothermal Implementation Plan

The Deep Geothermal Implementation Plan was developed by national representatives from Belgium, Cyprus, France, Germany, Iceland, Italy, The Netherlands, Portugal, Spain, Switzerland, and Turkey, the European Energy Research Alliance Joint Programme Geothermal Energy (EERA JPGE), DG ETIP, the European Geothermal Energy Council (EGEC), Euroheat & Power District Heating and Cooling Technology Platform, and the European Technology and Innovation Platform on Renewable Heating and Cooling (Finland, Ireland, and Sweden also joined at a later stage). The plan was adopted in early 2018 by the SET-Plan steering group.

The Deep Geothermal Implementation Plan (DG-IP) provides a comprehensive approach articulated in eight key research and innovation activities and two non-technical barriers. It

[40] https://cordis.europa.eu/project/id/838508
[41] https://www.etip-dg.eu/
[42] ETIPs are networks of R&D experts coordinated at European level. As such, they play a pivotal role in defining the research priorities of their sectors and communicating them to decision-makers in charge of EU and national R&D funds. For this reason, they are strategic players in the EU energy and climate policy framework, contributing to the implementation of the SET-Plan and accelerating the development and deployment of low-carbon technologies.

provides a blueprint for the allocation of national and EU funds for geothermal R&D [SET-Plan Temporary Working Group Deep Geothermal 2018].

A high-level Deep Geothermal Implementation Working Group (DG-IWG) has been established to advance the DG-IP, with the aim of reaching collectively the technology targets that will place Europe at the forefront of the next generation of low carbon technologies. A support unit will help the DG-IWG (SU-DG-IWG) to achieve its goals efficiently and productively. The SU-DG-IWG kicked-off in 2019 and has three main work streams:

- provide the DG-IWG with relevant information and data from the various stakeholder groups to support the decision-making process and the implementation actions of the DG-IWG on required actions
- promote and organise initiatives to mobilise growth of and implementation within the geothermal community, e.g. workshops, brokerages, consortium building and exploitation of RD&I results
- provide a secretariat for the DG-IWG for assistance on administrative issues and synergies & strategy support.

An updated version of the DG-IP was adopted in 2020 [SET-Plan Implementation Working Group Deep Geothermal 2020]. The document partly redefines the eight research and innovation activities and introduces two cross-cutting issues: knowledge transfer & training and recommendation of an open-access policy to geothermal information.

8.6 References

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9. France

Virginie Schmidlé-Bloch and Christian Boissavy

Association Française des Professionnels de la Géothermie, 77 rue Claude Bernard, 75005 Paris, France.
Email: virginie.schmidle@afpg.asso.fr, christian.boissavy@orange.fr.

9.1 Introduction

The Geothermal Market Update in France (AFGP 2019) from the French Geothermal Association of Professionals (AFPG) documents that there are about 175,000 heat pumps in operation for a production of 3,4TWh. Regarding deep geothermal energy for heating applications we estimate that the production is around 2,29 TWh related to the deep reservoirs in the Paris area and the 80 geothermal district heating systems in operation.

Since 2009, the vertical geothermal probe single housing market has dramatically decreased due to competition with gas boilers and air-air heat pumps benefiting from the same tax credits as geothermal. The market for geothermal probes for individual housing has reduced from more than 20,000 installations annually to less than 2500 between 2010 and 2020 (1/7th of the 2010 installs). In contrast, the number of geothermal installations feeding collective housing and residential blocks, including office buildings, is growing significantly. The main barriers to more rapid geothermal uptake are the energy calculation rules for new buildings (RT 2020) even if free-cooling applications is included. In 2023, the geothermal market will reach 3000 MWth installed; if ecologically driven 3500 MWth could be attained.

Direct geothermal uses are mainly concentrated in Ile-de-France: the construction of geothermal doublet installations has been conducted with support from ADEME Heat funds, and more than 20 new deep wells have been drilled in Ile-de-France in the last 3 years.

For electricity generation, no new installations have been commissioned.

The following table provides information on geothermal energy use in France in 2020.

Table 9.1 Geothermal energy use in France in 2020

Electricity		Heating and cooling productions	
Total Installed Capacity (MW_e)	17,2	Total Installed Capacity (MW_{th})	657,9
New Installed Capacity (MW_e)	0,06	New Installed Capacity (MW_{th})	68,5
Total Running Capacity (MW_e)	17,2	Total Heat Used (PJ/yr)	17,17
Contribution to National Capacity (%) (Total France in 2020 = 122385,7MWe **)	0,014	Total Installed Capacity Heat Pumps (MW_{th})	2131
Total Generation (GWh)	124	Total Net Heat Pump Use [PJ/yr]s	13,8
Contribution to National Generation (%) (total France production in 2020 = 500TWh)	0,025	Target 2017 – 2030 (PJ/yr Primary Energy)	N/A
Target (% national generation in 2023)	0,05	Estimated Country Potential (MW_{th} or PJ/yr or GWh/yr)	100 000 MWth*

Estimated Country Potential (MW_e)	300*	(no significant change in estimated direct use)	

(N/A = data not available)(* indicates estimated values)(** RTE data)

In 2016, the Bouillante plant exploited by ORMAT had an installed capacity of 15 MWe to be upgraded to 25 MWe in the future.

Only one of the two geothermal doublets drilled near Strasbourg (3500 and 5500m depth) will continue. Because the Vendenheim geothermal cogeneration plant has led to significant seismic events during its test phases, the regional authority has stopped further development of the project. The project designed by Electricité de Strasbourg in Illkirch should be completed in the next years if authorization to restart is decided.

Small capacity ORCs (20-40 kWe) have been installed, one in Soultz-sous-Forêts in Alsace on the existing EGS plant and one in Chaunoy in Ile de France using old oil wells.

9.2 Changes to Policy Supporting Geothermal Development

The PPE (Programmation Pluriannuelle de l'Energie) adopted beginning 2020 marks the end of the Feed-In-Tariff (FIT; 246 €/MWh) for geothermal electricity in mainland France. This is expected to be a strong disincentive for new EGS deployment, however around ten EGS projects that are already underway should continue to benefit from the earlier tariff. The existing FIT (170€/MWh) will be maintained for overseas French territories.

Launched by ADEME in collaboration with French operators and local authorities, works on the refunding of the SAF Environment guarantee started this Autumn 2020. This risk mitigation scheme covers geological risk in deep geothermal projects for heat production in order to guarantee dry wells or lower resource output than expected. The first results have opened possibilities to an extension of the Fund to other geothermal areas of France (traditionally, 95% of projects covered by the Fund are based in the Paris Region where the Dogger aquifer represents a very well know geothermal resource and where the Regional Authority provides the Fund with 25% additional financial guarantees). The new Fund would take into account 3 main geothermal zones with different levels of risks determining different levels of premium and guarantees to cover deep geothermal drillings. Discussions have started with government to get this new Fund launched by 2022 with a total amount between 150 and 300 million euros. This new scheme should contribute to the realization of approx. 70 deep geothermal drilling projects in the next 10 years and to reaching the new French Energy Programming's objectives set at between 4 and 5,2 TWh at Horizon 2030.

At the beginning of 2020, the GEODEEP SAS Risk mitigation fund was adopted by the European Commission. It allows ADEME to feed the fund for EGS (16 M€) in addition to the share capital given by "La Caisse des Dépôts et Consignations" and the private shareholder companies. Nevertheless, due to the suppression of FIT for geothermal electricity and the resulting lack of viability for investors, the scheme was definitively closed by main stakeholders. This fund was created to cover the geological and hydrogeological risk of onshore exploration drilling for heat and/or electricity EGS projects in France. In this perspective, no new EGS projects are going to be implemented in France in the near future.

9.3 Geothermal deep project development

The Paris basin has five large aquifers, including the Dogger which has the largest number of low-energy geothermal operations in the world, providing geothermal energy to about 8 % of the total population of 11 million people. The geothermal use is limited to collective heating and production of sanitary hot water. A conventional plant covers the needs of 4,000 to 6,000 houses. The Dogger covers an area of over 150,000 km^2 with the temperature measured directly below the Paris region varying between 56 °C and 85 °C according to the depth of the reservoir (between 1,500 and 2,800 m vertical depth).

Regarding new geothermal doublets created from scratch, in the last 3 years there were:

- 3 projects tapping the Dogger aquifer: in Grigny, in Dammarie Les Lys and more recently in Champs-sur-Marne
- 2 tapping the Albian sands (Saclay).
- 1 tapping the Triassic sandstone in Bobigny but that appeared to be unproductive and led to again targeting the Dogger limestone. The failure to produce from the Triassic reservoir was reimbursed by the French RMS system.
- Champs-sur-Marne and Bobigny projects are expected to furnish water at around 350m^3/h at 70°C. Champs-sur-Marne doublet will also be equipped with heat pumps in order to lower the reinjection temperature.

Other drilling has been carried out to revamp old installations, creating:

- new doublets such as in Cachan (new doublet using horizontal drilling technology with a section in the reservoir up to 800m in length)
- and triplets whose development strategy is generally based on drilling new production wells with big diameters in order to upgrade the flowrate of installations from 200 - 250 to 300 - 350 m^3/h. The following sites have been revamped: La Courneuve Nord, Villiers Le Bel, Vigneux, Thiais and Bonneuil.

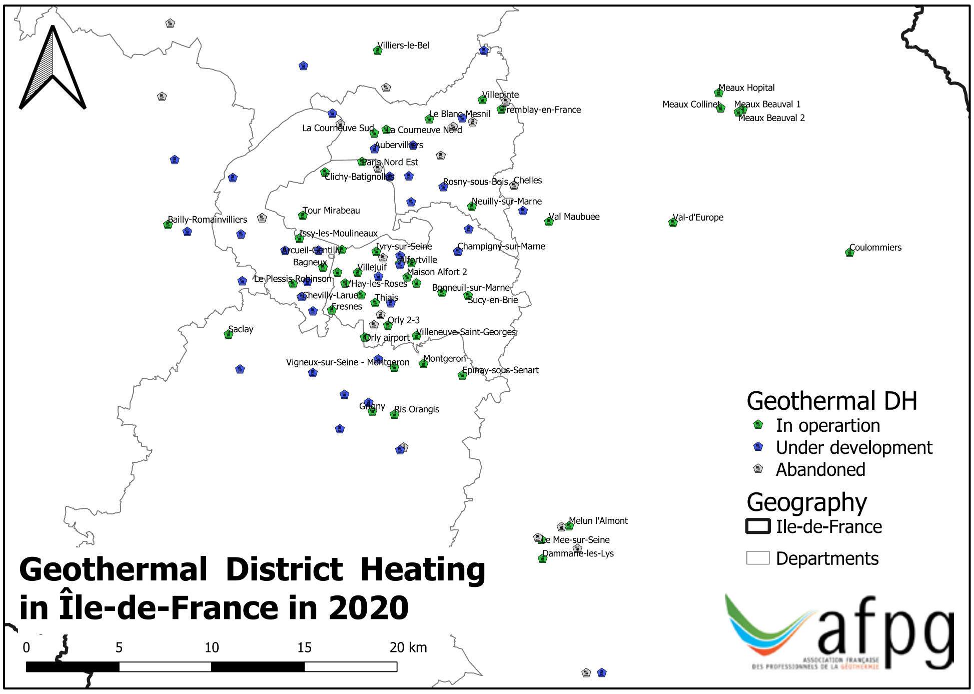

Figure 9.1 - Overview of the geothermal plants running in the Paris basin end of 2020

The district heating networks supplied by the Dogger geothermal resource are mainly exploited by private companies such as Dalkia (EDF Group), Cofely (ENGIE Group), IDEX Energie and Coriance, but also by local public-private ventures (Sociétés d'Economie Mixte). They have been operating for more than forty years and for many of them have thus been fully amortized, with an average availability rate still approaching 95%. The oldest of these installations is located at Melun-l'Almont, commissioned in 1969.

Recent technologies have been developed to exploit the Dogger resource, for example the use of horizontal drilling and the deployment of composite materials in order to cope with corrosion problems.

Sub-horizontal geothermal wells in Cachan (Val de Marne)

In 2018, GPC IP successfully tested the second sub-horizontal geothermal (injection) well, GCAJ2 in the Cachan site, thus validating an innovative well architecture, initiated on the previously drilled production well. The well design features two 1,001 m (GCAH1) / 1,005 m (GCAH2) long, 87 to 93° slanted, 8"1/2 open hole drains, drilled in the Dogger at 1,550 m true vertical (TVD) and 3,000 m drilled (mD) depths. Targeted at 450 -500 m^3/h production rate, the new doublet, managed by DALKIA (EDF Group) and the municipality of Cachan replace two existing, ageing (34 years) doublets rated 180 and 170 m^3/h respectively.

The concept raises considerable interest among geothermal operators reclaiming areas undergoing moderate to poor reservoir performance.

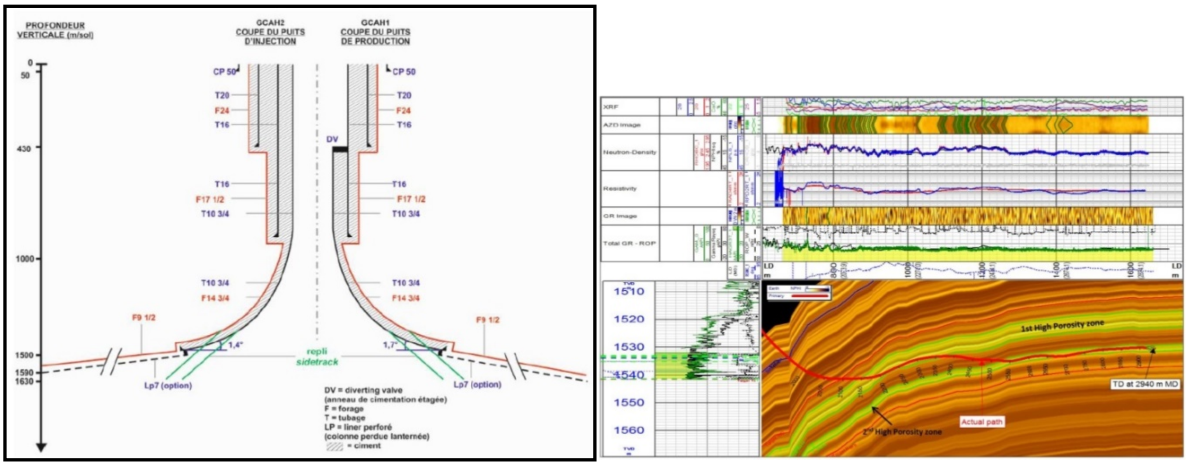

Figure 9.2 Well concept in Cachan (left) and wireline log (NMR-CMC and Sonic dipole porosity, permeability tools) correlating with well productive segments (GPC IP).

New sophisticated technologies while drilling have been deployed to secure optimum project achievement. These parameters recorded while drilling were linked to the conceptual reservoir model, making it possible to (re)adjust the well trajectory in real time. Within the context of the Paris Basin Dogger carbonate platform, geochemical monitoring based on (XRF / X-Ray fluorescence) elemental and (XRD / X-Ray diffraction) mineralogical analyses on cuttings sampled while drilling was implemented with a view to appraising varying reservoir properties in response to facies changes and diagenetic impacts on porosity/permeability trends.

Use of composite casings

In 2018 a new production well was drilled in order to replace an old well that had a small diameter and was out of order. The use of composite casings had already been tested: in Villeneuve la Garenne in 1976; in Melun that is still in operation; in La Courneuve Sud where the pumping chamber partly had composite casing that was extracted 13 years after and showed no degradation; and more recently in 2015 by CFG in Chevilly-Larue and L'Hay Les Roses to reline 2 production wells with excellent results. This technology can be considered as an interesting alternative to standard steel casings in order to facilitate high production flow rates and to avoid corrosion and scaling.

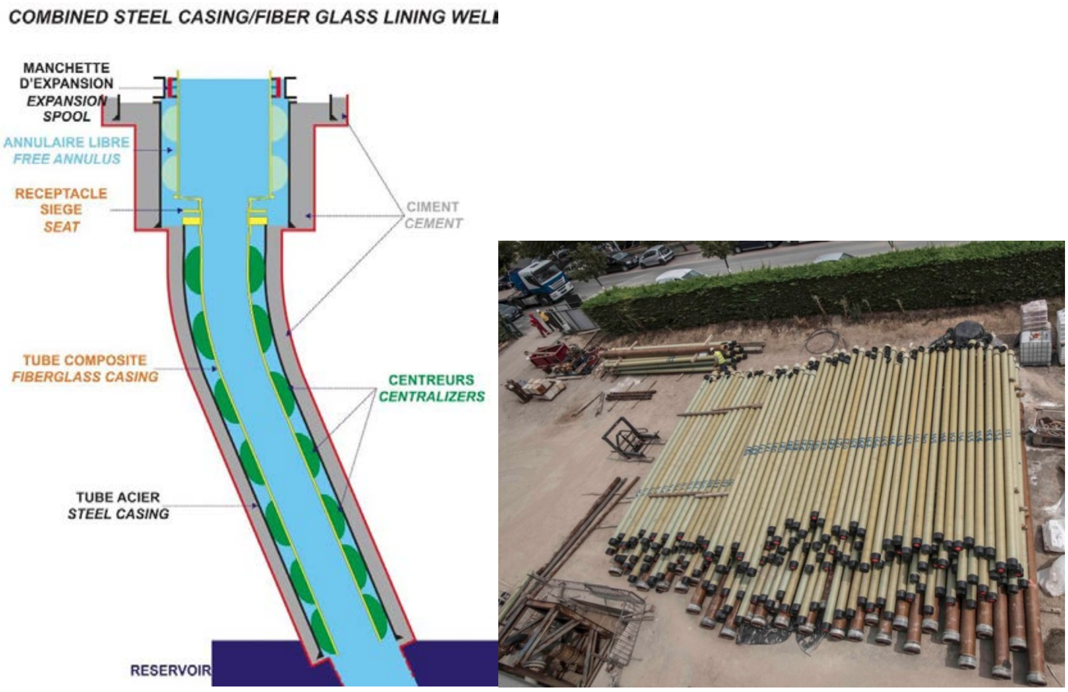

Figure 9.3 Concept of composite well and composite casing installed in Bonneuil (GPC IP)

Multi drain technology

The latest experiment to develop the Dogger geothermal reservoir was carried out by ENGIE Solutions in Vélizy-Villacoublay, with the drilling of an experimental doublet utilizing the multi drain technology in October 2020 (Figure 9.4). The wells were drilled and tested successfully, with 3 legs in the first one for a total length of about (600 - 450 - 60m). The flowrate is up to 400m^3/h which is 30% above the productivity of one standard doublet with an associated 15% limited increase in the CAPEX.

This first demonstration plant is a disruption in the geothermal district heating sector in France which validates a new potential development of more than 200 MWth West of Ile de France where the transmissivity of the aquifer is lower compared to the deepest part of the basin in the East.

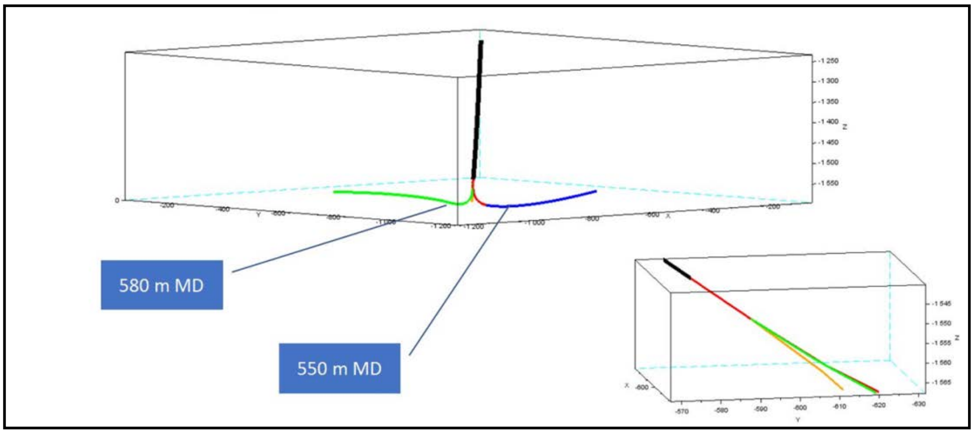

Figure 9.4 Multi-drain for the project of Velizy-Villacoublay (SW of Paris) - Source ENGIE Solutions

Recently Albian and Neocomian aquifers (Early Cretaceous) have been used for geothermal district heating and cooling applications, using big power heat pumps and for smaller housing projects. There are now 6 doublets using this resource: Paris Mirabeau, Issy Les Moulineaux, Le Plessis Robinson, Paris-Batignolles, Saclay 1 and Saclay 2. In 2020, new drilling was completed in Saint-Germain en Laye with the double objective to produce heat and tap water.

The second zone for direct use is **Aquitaine** with around 15 single production wells: these operations were installed in the beginning of the 1980s and this technical situation (no reinjection) was chosen as the geothermal water can be discharged at the surface. The regional geology is moreover quite complicated and the aquifers to be produced are made of sands and sandstones inter-bedded with clays. In these conditions, reinjection becomes a difficulty. In addition, the temperature is lower than in the Paris basin which makes the profitability of a doublet harder to achieve. Nowadays, secondary uses of the resource, as irrigation and agricultural uses are also being investigated.

A new plant launched mid 2019 on the right bank of the Garonne River will feed a district heating system constructed by Cofely Services. The geothermal production target was the Jurassic limestones which had never been drilled in the Bordeaux region. The deep limestones were not productive, consequently the doublet was installed in the well-known Cenomano-Turonien sandstones and the French RMS system reimbursed the extra cost related to the deep exploration.

9.4 Geothermal Heat pumps

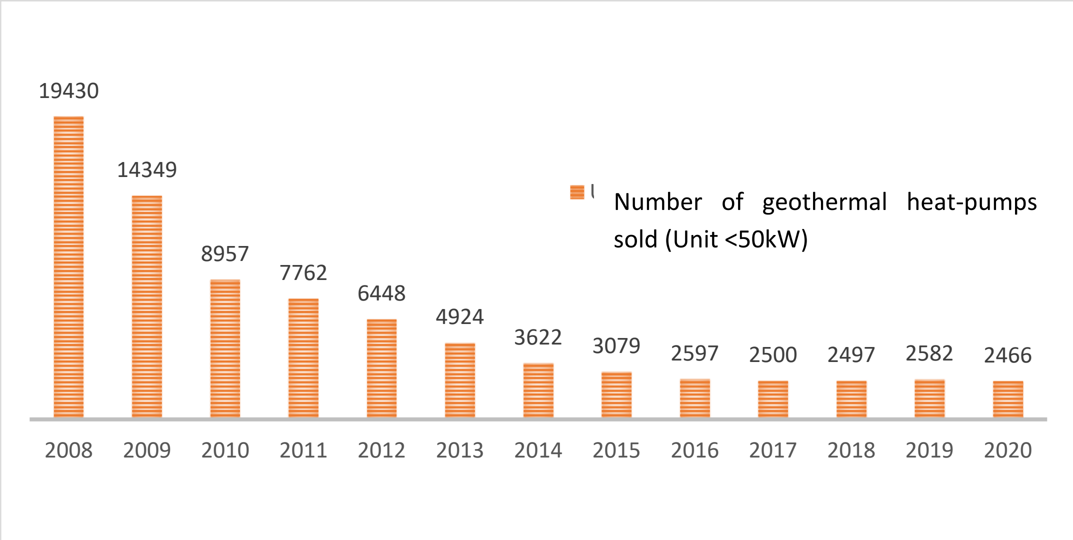

Figure 9.5 Sales of geothermal HP in the individual housing market (2008-2020)

Over the last 4 years about 2500 geothermal heat pumps have been sold each year and the market remains flat for individual housing. This market is facing strong competition from air/water and air/air systems. The French regions leading the geothermal market (individual housing and collectives), except horizontal geothermal, are Ile de France, Rhone-Alps, Midi-Pyrenees, Brittany, Alsace and Pays de la Loire.

At the country level the distribution of the types of installations is: 5% for single housing open loop, 25% for collective open loop based on water, 25% for individual vertical exchanger and 45% for collective vertical exchanger. Horizontal loops represent about 25% of the geothermal market for individual housing. Currently thermo-active foundations remain largely underdeveloped.

In 2020, a differentiated tax credit was implemented between geothermal and air heat pumps resulting in more geothermal installations in the individual housing market. Nevertheless, this differentiated rate won't be effective for new buildings or for well-off households who are usually renewable energy users.

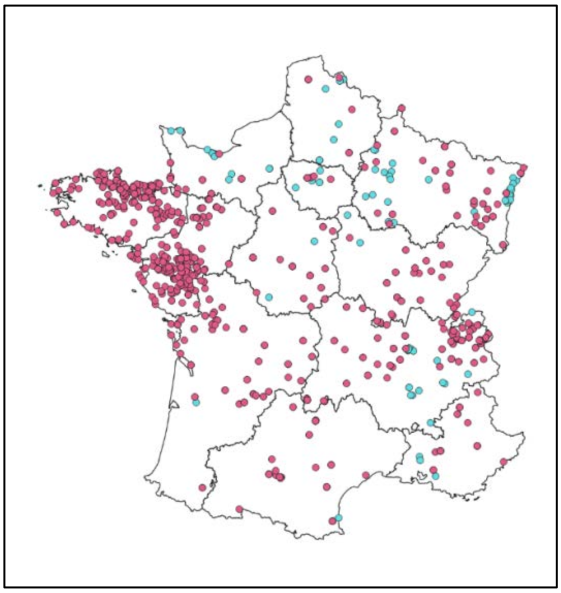

Figure 9.6 GSHP projects in the last 3years (In blue open loop based on water and in red closed loops: mainly vertical probes).

The French energy policy is very supportive for geothermal in collective housing. A study published by The Observ'ER (2018) shows there is a 10% per annum increase in the GSHP market in this sector. There were around 600 new plants installed in France in 2019. The concept of the low temperature geothermal loop, kind of "thermal smart grid", has been adopted in several towns with installed capacities between 1 and 4 MW.

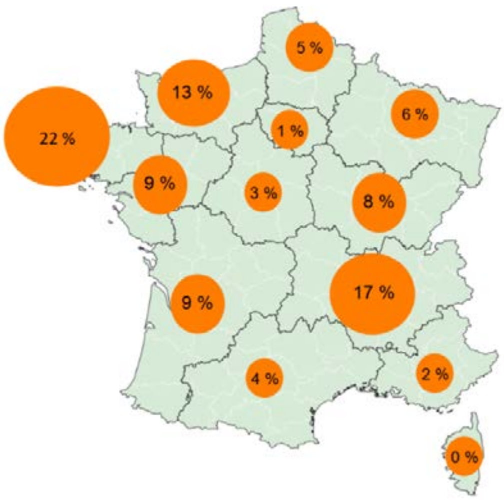

Figure 9.7 GSHP for individual housing in 2019: geographical distribution

The regional distribution of individual housing installations is shown in Figure 9.7 which identifies that the largest percentage of geothermal facilities in individual housing is found in the Bretagne region followed by the Auvergne-Rhône-Alpes region.

9.5 Schemes supporting geothermal energy industry

France has developed different schemes to assist geothermal sector development. One of them is the geological risk mitigation tool. The geological risk is linked to the fact that the exploitable geothermal energy resource can only be known after drilling the first borehole. This costly operation (more than 5 Million € for a 2000m geothermal target) may result in failure (e.g. due to a lack of resources, temperature or exploitable flow rates in relation to the forecasts, or the inability to exploit the geothermal fluid due to aggressive geothermal fluid chemistry).

For deep aquifer heat production, the SAF Environment guarantee has been existing for 40 years. For shallow drilling ranging up to 200m depth, the “Aquapac” guarantee (funded by ADEME, EDF and SAF), has been in place for 30 years ; it covers the geological risk for the first well drilled (open loops) and then the geothermal production during 10 years of exploitation.

Furthermore, there is a financial support scheme for heat production called “Renewable Heat Fund” (Fonds Chaleur Renouvelable in French). It was created in 2009 for collective housing, tertiary, industry and agriculture projects and aims at reducing the difference in investment between “conventional” energy solutions and renewable ones. At the end of 2020, 700 geothermal installations (including 600 geothermal heat pump) have been subsidized by the Fund. A total of 141 M€ has been given to the new heat plants (plotted by number by region) shown on Figure 9.8. The total additional heat production is some 2,79 TWh.

The recently voted PPE has also set up the objective to establish a regional network of geothermal coordinators. We can already count on 4 people doing the job that consists of creating a favourable eco-system for geothermal energy regionally and in giving better visibility to this renewable energy whose biggest benefit is to be discrete!

We can also quote the deployment of the French regulation for shallow geothermal energy called “Géothermie de minime Importance”. This regulation that came into force in 2015 has extended the simple declaration procedure to drilling to 200m depth. In return, French drillers need to get a state qualification to have the right to drill for geothermal projects, according to a zoning map composed of green (simple declaration), orange (expert advice is required) and red (authorization procedure) areas. Since 2020, French geothermal stakeholders have been working on the development of those regional zoning maps.

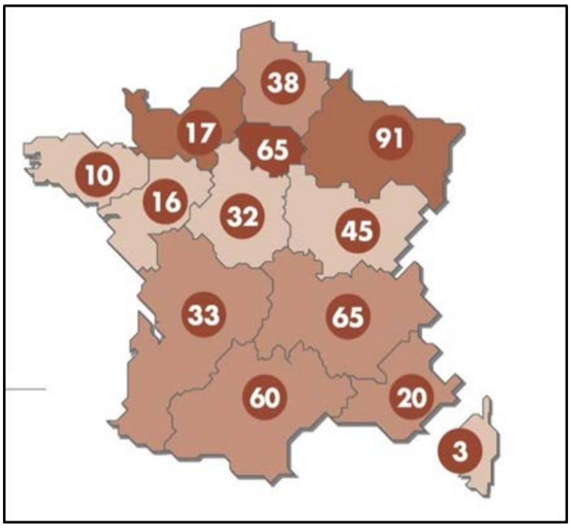

Figure 9.8 Heat fund subsidies recorded by region, showing the number of facilities supported between 2009 and 2018.

9.6 Research Highlights

Most of the national R&D budget for geothermal energy is managed by ADEME. Some funding can be accessed through upstream research funded by ANR (National Agency for Research) and technological innovation funded by FUI (Fund for Industrial Clusters).

After two calls for projects in all research domains in France, 171 Laboratories of Excellence (LabEx) received funding awards. The "G-Eau-Thermie Profonde" Laboratory received its official quality label in March 2012. Based in Alsace, it has a focus on deep geothermal energy and received an initial 3 M€ funding award for a 9-year period. At the moment, the yearly funding is around 2M€, sustained by National and European research projects, Electricité de Strasbourg, Strasbourg University, IDEX and CNRS. This illustrates and strengthens industry-university partnership engaged in the "Investments for the Future" framework. New partners such as Total and the Engie group have joined.

An Institute of Excellence for the use of the underground in the energy transition, called Géodénergies, was created in July 2015. It aims at supporting the development of three industrial sectors:

- CO_2 storage,
- energy storage, and
- geothermal energy production (heat and electricity).

This joint venture brings together industrial and public research organizations under the national funding program "Investments for the Future". In 2019-2020 Géodénergies will evolve into a new research institute jointly owned by public and private participants.

In order to promote the development of geothermal activities, Géodénergies has launched several research projects to bridge technological gaps (drilling hammers, high temperature pumps, monitoring of reservoir cooling), developing methodologies (micro-seismic measurements, exploitation and conceptual reservoir models in grabens) and developing co-activities along with heat utilisation (lithium production, CO_2 storage).

In addition, several national technological clusters have been established to develop collaborative industry and research institute R&D projects including:

- GEODEEP cluster of the AFPG for the promotion of French geothermal know-how for export
- Pôle AVENIA, based in Aquitaine, deals notably with deep geothermal applications;
- SYNERGILE, based in Guadeloupe, aims at developing renewable energies in the overseas territories;

9.7 Geothermal Education

BRGM (French Geological Survey) offers training, such as in drilling or building a geothermal energy project.

AFPG is also involved in geothermal training and will develop an offer dedicated to territories energy managers employed by local authorities or energy agencies. Initially focused on biomass industry, those personnel will develop skills in other heating renewable energies to be able to promote indistinctly all kind of energies.

The MEET project created a geothermal spring school in March 2020 for the students of the different partners of the project.

The University of Cergy-Pontoise delivers a master's degree in Energy including a number of courses in geothermal energy.

9.8 Publications

AFPG is currently writing a technical guide on temperate geothermal closed loops. The aim is to provide key information to engineering consultancies, so they promote the technology.

BRGM is currently translating good practice sheets based on good practice from deep geothermal drilling.

In shallow geothermal, AFPG is finalizing a technical guide with SER (Renewable Energy Union).

AFPG members have prepared many publications for the WGC 2020 in Reykjavik that will illustrate the involvement of both public and private participants in the French geothermal sector.

9.9 Useful Websites

BRGM website (French Geological Survey) and ADEME (the French Agency for Environment and Energy) for professionals and public at large: https://www.geothermies.fr/

AFPG (French Association of Geothermal Energy Professionals) website: http://www.afpg.asso.fr/

BRGM geological and drilling data website: http://infoterre.brgm.fr/viewer/MainTileForward.do

BRGM website with energy data (geothermal, oil & gas, etc): http://www.minergies.fr/fr

9.10 Future Activity

AFPG are promoting an innovative system known as the temperate geothermal closed loop which is a thermal smart grid. The potential is enormous as different energy types can be used; such as geothermal, ocean water, lake or water treatment plant water. In addition, there is no loss of energy due to the sharing of the energy in the loop.

French companies involved in deep geothermal energy are currently working with mining companies on the extraction of metals such as lithium from the Alsace fluids. The potential is great since from ~10 geothermal plants in Alsace (or Central Massif and Pyreneans) the production corresponds to the current needs for lithium for batteries for electric mobility in France.

There are ~20 deep geothermal projects in the pipeline waiting to be realized over the next 3 years and ~20 other projects under study, which if all get implemented will amount to an increase of the installed geothermal heating capacity of ~500 MW by 2028.

9.11 References

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10. Germany

Lothar Wissing

Project Management Jülich PTJ - ESE 4, Division: Energy System - Renewable Energies / Power Plant Technology, Geothermal Energy, Hydropower, Science Communication, Forschungszentrum Jülich GmbH, 52425 Jülich.

Email: l.wissing@fz-juelich.de

10.1 Introduction and Overview

The regions of Germany which have suitable conditions for electricity production are the Molasse Basin in Southern Germany (mainly in Bavaria) and the Upper Rhine Graben in South West Germany, due to an especially high natural increase in temperature at increasing depths in these regions.

According to information from the German Geothermal Association (BVG), there were 38 geothermal power and heating plants in operation across Germany in 2020. Most of these plants exclusively generate heat, with a related installed capacity of 350 MW (thermal). Nine of the geothermal plants generate electricity – either exclusively or supplementary to heat. They have an installed electrical capacity of around 47 MW megawatts.

Region	Location	Mwel	MWth	Power plant
Upper Rhine Graben	Landau	0,8	5	ORC
	Bruchsal	0,44	0	Kalina
	Insheim	4,8	0	ORC
South Molasse Basin	Dürrnhaar	6,0	0	ORC
	Sauerlach	5,0	4,0	ORC
	Kirchstockach	6,0	0	ORC
	Oberhaching-Laufzorn	4,3	40	ORC
	Oberhaching-Taufkirchen	4,3	35	ORC
	Traunreut	5,5	12	Kalina

Figure 10.1 Electricity Producing Geothermal Power Plants in Germany in January 2020.

In Germany, deep geothermal energy is being increasingly used to generate heat. In terms of the prevailing geological conditions in Germany and the existing structure of demand, projects involving heating, such as supplying local and district heating systems, have higher prospects for being economically successful than projects for the generation of electricity only.

10.2 National Programme

In September 2018, the Federal Cabinet adopted the 7th Energy Research Programme entitled "Innovations for the Energy Transition". It contains the guidelines for energy research funding in the coming years. In the context of the 7th Energy Research Programme, the Federal Government is making around €7 billion available for projects.

The Federal Government has developed a new strategic approach and directed the programme's focus toward technology and innovation transfer. This includes the use of living labs to bring new, promising technological solutions to the market, and to explore and master challenges under real-life conditions. The experience gained will set the course for implementing the technologies tested on a large scale later on. Greater involvement by young, creative startups will also play an important role in this process.

The new programme strengthens technology and innovation funding in the energy sector and adds a new focus on systemic and societal questions. This involves placing a greater focus on the major, overarching trends in the energy sector. One of these is sector coupling, which enables interaction between the heat, transport and industrial sectors and is crucial for the development of the system as a whole. Another is digitisation, which plays a key role in modernising the energy system.

Lastly, the Federal Government's 7th Energy Research Programme is also designed around developing closer networking in research at both international and European levels. After all, the energy transition is, and will remain, a global-level challenge. In its preparation of the new programme, the Federal Ministry for Economic Affairs and Energy hosted a broad-based consultation process in which it surveyed a large number of stakeholders from science and business about the innovation steps needed in order to make the energy transition a success. This is because the new programme seeks to foster applied research and development in particular and to support the transformation of highly innovative ideas into successful products and processes. The results of the consultation process were fed into the development of the Energy Research Programme – undertaken by the Federal Ministry for Economic Affairs and Energy together with the Federal Ministry of Education and Research and the Federal Ministry of Food and Agriculture.

10.3 Industry Status and Market Development

Apart from funding carefully selected research projects, the Federal Government is also creating incentives for new projects by remunerating geothermal electricity under the Renewable Energy Sources Act (EEG). The last amendment to the EEG was adopted by the Bundestag (Lower House of Parliament) in 2017. The feed-in-tariff for geothermal electricity remains unchanged, fixed at 25.2 Euro-cents per KWh. For photovoltaics and wind energy an auction model was introduced.

The market incentive programme (MAP) of the German Government promotes renewable energy systems that provide space heating, hot water, cooling and process heat. It has a section for smaller buildings administered by the Federal Office of Economics and Export Control (BAFA), and one for large buildings and commercial uses, the latter being a premium component of the KfW Banking Group renewable energies program. Several geothermal technologies can be supported by the MAP; it subsidizes the installation of efficient heat pump systems in residential buildings with a repayment bonus, depending on the installation size.

The geothermal market predominantly comprises small and medium-sized enterprises from mechanical engineering, as well as some large-scale enterprises, whose portfolios belong more to the classical energy sector such as the hydrocarbon industry.

10.4 Research, Development and Demonstration/Deployment

With the 7th Energy Research Programme, the target of R&D funding has moved from electricity production toward direct heat use. Since more than 50% of primary energy in Germany is used to generate heating, the expansion of geothermal heating and cooling production is a key strategic target to supply energy in the future that is ultra-efficient and based on renewable energy. The increasing use of geothermal as a local energy source also reduces dependence on fuel imports and promotes added value domestically.

For broad market penetration it is important to minimize the risks associated with the use of geothermal and to increase public acceptance through transparent communication of the opportunities and risks based on scientific findings. In addition, energy production costs must be reduced and geothermal storage applications expanded.

R&D funding focuses on the following topics:

- Demonstration projects that implement innovative technological solutions that are easily transferable.
- The continued development of technology focused towards cost reduction, increased efficiency, plant availability, and automation and digitization of geothermal for electricity and heating.
- Further development of heating and cooling storage underground.
- Development of a geological database for potential geothermal uses.
- Security aspects of methods and use cases.
- Research on the material use of extracted geothermal liquids.
- Modelling and simulation of geothermal systems to increase forecasting reliability and minimize financial risk.

In addition to research institutions and companies, users such as energy suppliers and municipal utilities in particular will also be funded. Application-oriented research topics are to be accompanied by targeted demonstration projects. The participants exchange knowledge through the Energy Research Networks, particularly in the Research Network ENERGIEWENDEBAUEN due to the strong relationship with heating supply. In the future, the incorporation of users will become even more visible. Users are particularly well placed to carry the knowledge transfer into widespread use and to provide important feedback to researchers.

The Federal Government also supports international R&D cooperation, for instance through activities under the IEA as well as through the implementation of the SET-Plan and by participating in transnational funding instruments such as GEOTHERMICA.

In the area of geothermal research (deep and shallow), the BMWi approved funding for 41 new projects with a funding volume of around 41 million euros in 2020. At the same time, around 14.4 million euros were invested in 106 already ongoing research projects.

10.4.1 Research Highlights

Geothermal heat for Munich

Munich is located in the Molasse Basin in Bavaria. The underlying geological formations are particularly suited for the extraction of geothermal heat. The rocks are part of Malm, a geological formation that acts like an aquifer for hot thermal water due to its special structure. Stadtwerke München (SWM) intends to provide complete district heating for Munich from renewable energies by 2040, with the majority from geothermal energy.

SWM, as the coordinator, aims to lay an important foundation for this vision with the GRAME project which was finished at the end of 2018. SWM developed a consistent concept for determining what locations would be best suited for extracting heat and how it can then be integrated into the existing district heating network. The project partnered SWM and the Leibniz Institute for Applied Geophysics (LIAG), who completed in 2016 a three-dimensional image of the subsurface and used it to develop a suitable extraction strategy. In general, the results contributed to the better exploitation of the geothermal resources within the Molasse Basin and the utilization of the potential that was opened up for the generation of both electricity and heat.

The goal is to generate electricity of around 50 megawatts or to extract heat in the range of 400 megawatts.

The project partners were using 3D-seismic to determine the structure of the reservoir and to decide about the most promising locations for future drilling. The measurements were taken over an area of 170 square kilometers. Investigations about the potential for geothermal use on this scale have never been carried out in the region before. Conducting 3D-seismic measurements beneath an urban area was also breaking new ground: amongst other things, traffic or construction work on the surface generates incessant vibrations that influence the measured values.

A subsequent project called GeoMARE was granted at the end of 2018 and is still running in 2020. The objective of the project is to provide comprehensive and conceptual design of the district heating system. A citywide efficient operation involves an adapted heat infrastructure along with sustainable reservoir management.

The Heizkraftwerk Süd (southern heating plant) in Munich should become the largest inner-city geothermal plant in Europe. SWM plans to supply around 80,000 Munich residents by 2020 using climate-friendly district heating.

By the end of 2019, six holes had been drilled from one site, which were between 3,700 and 4,300 meters deep. The thermal water temperature is around 100 °C and the flow rate is between 90 and 120 liters per second. A total output of up to 50 MW is thermally calculated.

The success of this project is stimulating further project developments in the Munich region and in Germany.

The main themes of R&D funding for geothermal energy addressed in 2020 were:

- Data collection (GeotIS.de)
- Corrosion and Scaling (for operating power plants)
- Advanced drilling technologies (laser, electro-impulse, plasma)
- Machinery (workover-rig, submersible pump, valves)
- District Heating (Munich, urban areas)
- Microseismisity

Germany is a participant of the EU-project GEOTHERMICA. GEOTHERMICA's objective is to combine the financial resources and know-how of 17 geothermal energy research and innovation programme owners and managers from 14 countries and their regions. Together with financial support from the European Commission, GEOTHERMICA has launched joint projects that demonstrate and validate novel concepts of geothermal energy deployment within the energy system, and that identify paths to commercial large-scale implementation.

10.5 Future Outlook

German Government consistently supports the development of renewable energies with a bundle of support mechanism, e.g. feed-in-tariffs, R&D budgets, investments subsidies.

One of the results is that the renewable energy share of gross electrical consumption is 45.4 %, with 0.04 % produced by geothermal power plants. Renewably-based heating and cooling remains at 179 TWh – 0.8 % from deep geothermal - in 2020.

Numerous efforts have already been made to develop the potential of geothermal energy as a continuously available renewable energy source. These include the exploration and exploitation of suitable reservoirs, the development of drilling technologies, and innovations in plant construction to finally use the extracted heat for power generation or heating purposes.

There were several heat and building regulations that came into force in 2020. The states often have separate supporting programs, e.g. North-Rhine-Westfalia is supporting initiatives for the Rhein-Ruhr region, a former coal mine area. The idea is to substitute coal with geothermal energy for Europe's largest district heating system

Around 20,500 GSHP were newly installed, to a total of 440,000. The total number of heat pumps sold in 2020 was 120,000, which means an increase of 37 %, but with a share of around 79.4%, air heat pumps are dominating the market. The investments in geothermal energy increased to 1,6 bn € per year (heat pumps, deep geothermal power plants, ambient heat). From the beginning of 2021 the support mechanism for geothermal heat use, especially installation of GSHP will be improved.

In future, the use for heating and cooling supply as well as for seasonal heat storage will be expanded. Research projects are primarily designed to help reducing risks and costs, create storage possibilities, and to increase awareness and acceptance of this form of renewable energy.

With the 7th Energy Research Programme and further strategic approaches of the Federal Government, positive development for the use of geothermal heat can be expected.

For details and statistics, it is highly recommended to go to the websites below, often published in English.

10.6 Publications and Websites

Federal Ministry of Economic Affairs and Energy, BMWi:
https://www.bmwi.de/Navigation/EN/Home/home.html

BMWi publications in English: http://www.bmwi.de/EN/Service/publications.html

BMWI Report of Energy research:
https://www.bmwi.de/Redaktion/DE/Downloads/B/bundesbericht-energieforschung-2020.pdf

Reform of the Renewable Energy Sources Act: http://www.bmwi.de/Navigation/EN/Topic/eeg-reform.html

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Marktanreizprogramm (Market Incentive Program, MAP: https://www.erneuerbare-energien.de/EE/Navigation/DE/Foerderung/Foerderprogramme/foerderprogramme.html

KfW-Funding energy and environment:
https://www.kfw.de/inlandsfoerderung/Unternehmen/Energie-Umwelt/F%C3%B6rderprodukte/F%C3%B6rderprodukte-(S3).html

KfW-loans deep geothermal energy:
https://www.kfw.de/inlandsfoerderung/Unternehmen/Energie-

Umwelt/F%C3%B6rderprodukte/Erneuerbare-Energien-Tiefengeothermie-(272-282)/

German Energy statistics (AGEE-Stat): https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html

Database of R&D-projects in renewable energies governmental sponsored: https://www.enargus.de/pub/bscw.cgi/?op=enargus.eps2

7th Energy Research Programme of the Federal Government: https://www.bmwi.de/Redaktion/EN/Artikel/Energy/research-for-an-ecological-reliable-and-affordable-power-supply.html

Energy Research: https://www.forschungsnetzwerke-energie.de/energy-research-networks

Project Management Jülich (Public Funding Agency): https://www.ptj.de/projektfoerderung/angewandte-energieforschung

German Geothermal Association (BVG): http://www.geothermie.de/

Geothermal Information System for Germany (GEOTIS): https://www.geotis.de/homepage/GeotIS-Startpage?url=&loc=en

Electricity Research: https://strom-forschung.de/en/

German heat pump association (bwp): https://www.waermepumpe.de/

GEOTHERMICA: http://www.geothermica.eu/about-geothermica

11. Iceland

María Guðmundsdóttir

Orkustofnun, Grensasvegi 9, IS 108 Reykjavik, Iceland. Email: maria.gudmundsdottir@os.is

11.1 Introduction

Utilisation of geothermal resources has expanded rapidly in Iceland during the last two decades and is expected to increase further in the future. Electricity generation increased from 5.0 TWh in 2016 to 6.0 TWh in 2020 and geothermal heat use from 27.1 PJ in 2015 to 33.7 PJ in 2019. A population growth of 36% is expected by 2050, and geothermal utilization is estimated to increase by over 70% by 2050, to almost 50 PJ. Iceland's long-term objective is to ensure the sustainable utilisation of its resources, and the implementation of the Master Plan for hydro and geothermal energy resources in Iceland is a step in maintaining and sustaining this objective. Iceland has developed a great deal of know-how and experience in the harnessing of geothermal resources, both for space heating and electricity generation.

During the 20th century Iceland has emerged from being a nation dependent upon imported oil and coal, to a country where practically all stationary energy, and close to 90% of primary energy, is derived from domestic renewable sources, with near carbon-free electricity production in 2020. This is the result of an effective policy in making renewable energy a long-term priority in Iceland. Nowhere else does geothermal energy play a greater role in providing a nation's energy supply. **Error! Reference source not found.** identifies the main production wells in Iceland operated for electricity generation (red), and by heat utilities (blue) that have a natural monopoly license. Auto-producers, of which there are over 100 in Iceland, are excluded and they only contribute 14% of the final electricity use. However, for heat use, main activity producers dominate, with 91% of total heat use in 2019.

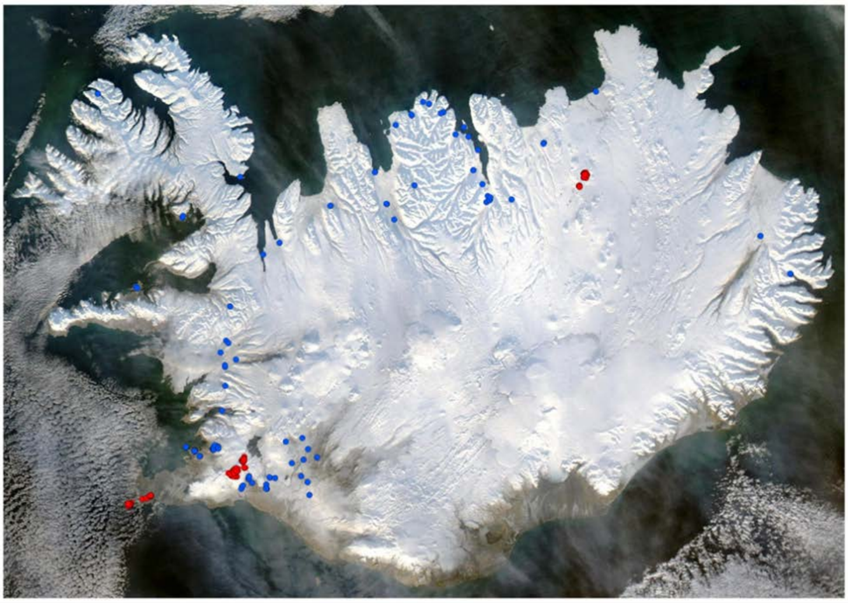

Figure 11.1 Satellite image of Iceland in winter showing geothermal production wells in operation. Geothermal power plants are shown in red, heat utilites in blue.

Table 2 2020 Iceland Geothermal energy use data

Electricity		Direct Use	
Total Installed Capacity (MW_e)	757.4	Total Installed Capacity (MW_{th})	2500*
New Installed Capacity (MW_e)		New Installed Capacity (MW_{th})	12*
Total Running Capacity (MW_e)	755.4	Total Heat Used (PJ/yr) [GWh/yr]	33.7* PJ
Contribution to National Capacity (%)	25.8*	Total Installed Capacity Heat Pumps (MW_{th})	N/A
Total Generation (GWh)	5960.6	Total Net Heat Pump Use [GWh/yr]	N/A
Contribution to National Generation (%)	31.6	Target (PJ/yr)	N/A
Target (MW_e or % national generation)	N/A	Estimated Country Potential (MW_{th} or PJ/yr or GWh/yr)	N/A
Estimated Country Potential (MW_e or GWh)	4255 MW_e		

(N/A = data not available)

(* indicates estimated values)

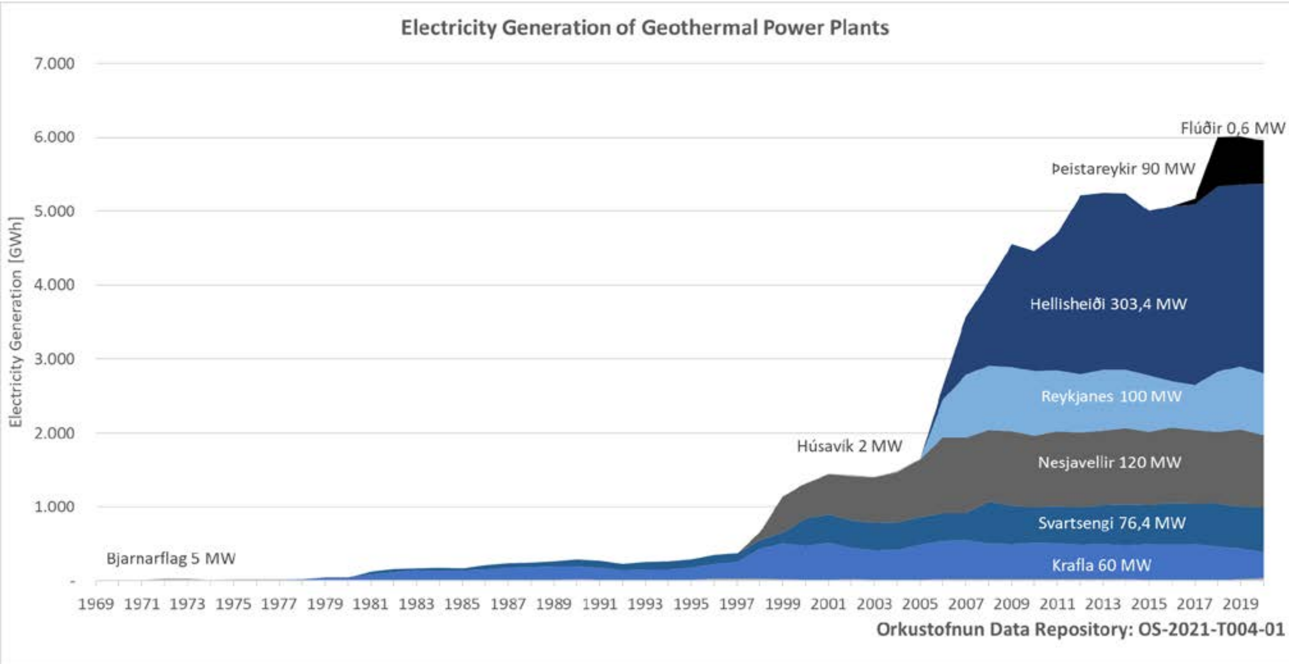

Figure 11.2: Electricity generation from geothermal power plants in Iceland 1969-2020

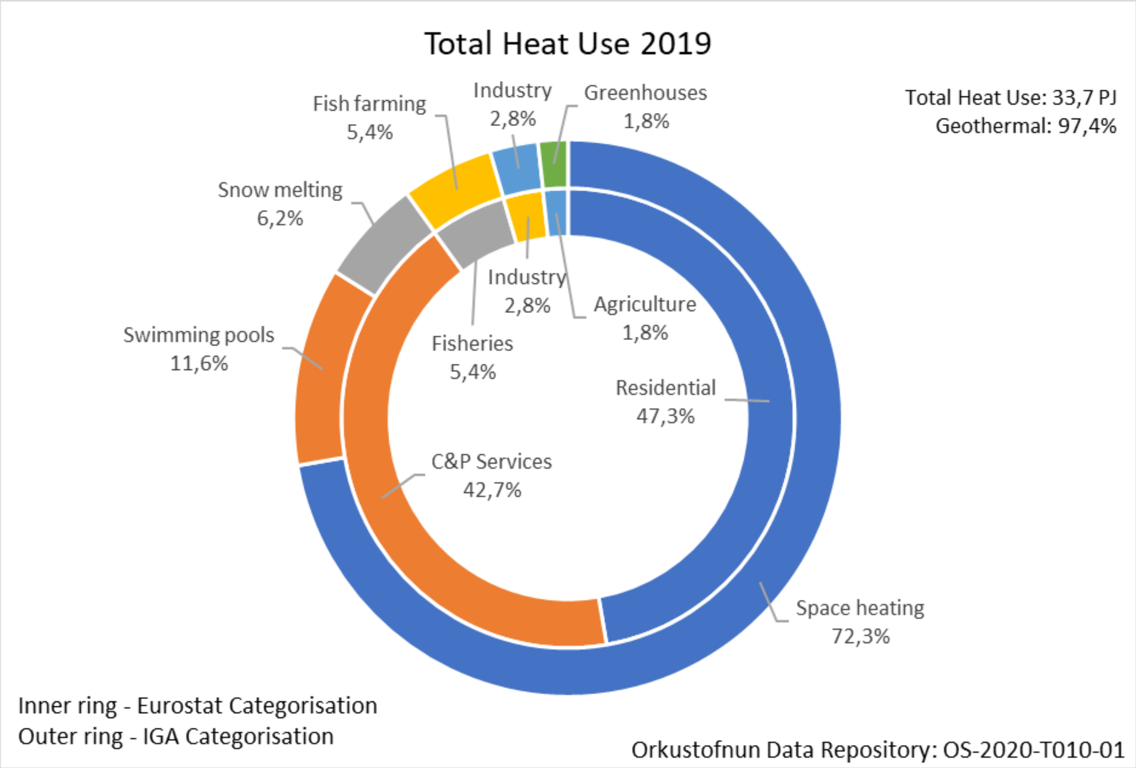

Figure 11.3: Total heat use in Iceland in 2019, of which 97.4% is from geothermal sources.

11.2 Changes to Policy Supporting Geothermal Development

Geothermal policy has essentially remained unchanged in recent years in Iceland. Geothermal development is mature with more than 90% of households using geothermal energy for heating, and over 30% of electricity being produced using geothermal. Geothermal power development is not supported by any market incentives in Iceland. The Energy fund, operated by Orkustofnun, supports geothermal development in areas where geothermal is not used for heating, often referred to as “cold” areas. In the “cold” areas heating is mainly electrical and subsidized by the government since it is more expensive than geothermal heating. A lump sum comprising 16 years-worth of subsidies is available to those who want to establish a geothermal heating system, or other more efficient means of heating, such as heat pumps.

11.3 Geothermal Project Development

11.3.1 Projects Commissioned

Currently there are several geothermal related projects being explored. Many are related to tourism, such as geothermal baths which have proven to be very popular with both visitors and locals. One such project is currently under construction in Eyjafjörður, N Iceland, and will utilise hot water that was unexpectedly discovered when a road tunnel was drilled through the Vaðlaheiði mountain in 2014. The hot water delayed the construction of the tunnel and was considered a nuisance, however the local authorities decided to launch a competition for ideas on how to use the water. The new baths are the result of this process and are expected to open in spring 2022.

Figure 11.4. Hot water in the Vaðlaheiði tunnel in 2014 (Source: Vaðlaheiðargöng)

Cascaded use of geothermal fluid as well as by-products of generation is increasing at Icelandic geothermal power plants. The Reykjanes Resource Park was established several years ago, with companies using wastewater and other waste products from the Svartsengi and Reykjanes power plants. This includes the Blue Lagoon geothermal spa, companies involved in fish drying, fish farming, agriculture and more. Now there are plans for a resource park at the Hellisheiði geothermal plant, including a hydrogen production facility that will use electricity produced by the power plant during off-peak hours. Hydrogen production might prove to be vital to Iceland's future plans for renewables in transport.

Figure 11.5. Hydrogen pilot plant at Hellisheiði (Source: ON power).

11.3.2 Low temperature Electricity and District heating

Several geothermal fields in Iceland have medium-enthalpy geothermal fluid with a temperature of over 100°C that is being used for district heating. However, the temperature of the fluid is too high to be used directly for district heating so in many cases cold water is mixed with the geothermal fluid to bring the temperature down to around 80°C, creating waste heat. In 2016, these areas were mapped by Orkustofnun and their electrical and thermal potential was assessed prompting interest from the geothermal sector (Björn Már Sveinbjörnsson, 2106). In 2018, a new geothermal plant at Flúðir, South Iceland, started producing electricity using water from a well that was already used for district heating. The same company, Varmaorka, is currently constructing two new plants in Reykholt, West Iceland, and Efri-Reykir, South Iceland. These geothermal fields are similar to the Flúðir field, as the geothermal fluid has a temperature over 100°C and is currently being used for district heating.

Figure 11.6. Electricity producing units by Climeon at the Flúðir field (Source: Climeon).

The new geothermal district heating system in Hornafjörður municipality started operations in December 2019. Previously, the town of Höfn (pop. 1710 in 2019) and the surrounding countryside had used subsidized direct electrical heating and district heating using an electric boiler, but now uses geothermal water from the field in Hoffell, 20 km north of the town.

Figure 11.7. Pumping station for the new geothermal district heating system in Hornafjörður municipality, SE-Iceland.

11.4 Research Highlights

New and effective exploration techniques have been developed to discover geothermal resources. This has led to the development of geothermal heating services in regions that were not thought to enjoy suitable geothermal resources. Iceland's geothermal industry is now sufficiently developed for the government to play a more limited role than before. Power companies now take the lead in the exploration for geothermal resources; either in geothermal fields that are already being utilized, or in discovering new fields.

The Icelandic Government supports the Iceland Deep Drilling Project (IDDP) with 342 million ISK, along with the three largest energy companies. If successful, this project could start a new era in geothermal development. The main purpose is to find out if it is economically feasible to extract energy and chemicals out of hydrothermal systems at supercritical conditions. The first well, IDDP-1 in Krafla yielded superheated steam after drilling into magma at roughly 2 km depth. The second well IDDP-2 was drilled from August 2016 to January 2017 in Reykjanes. For this phase Norwegian company Statoil joined the original partners, and the drilling was made possible with a €20 million grant from the EU Horizon 2020 programme. The drilling was successful and reached supercritical conditions at 4,659 m. The temperature was measured to be 427°C with a fluid pressure of 340 bars. Cores were retrieved for further study and the rock appears to be permeable at depth. There are exciting times ahead for this project and the third IDDP well is being planned in the Hengill area.

Figure 11.8: IDDP-2 in the process of drilling (Source: HS Orka).

Orkustofnun also supports several projects coordinated by the Icelandic Geothermal Research Cluster GEORG, e.g. the Deep Roots for Geothermal Systems (DRG-project) aimed at research of the roots of magma-driven high temperature geothermal systems.

The CarbFix and SulFix projects, operated by Reykjavík Energy, reinject gases from geothermal fluid extracted at Hellisheiði power plant with good results. According to research the gases mineralize in the basalt bedrock in less than two years. Currently, around 65% of H_2S and 30% of CO_2 from the power plant is being injected. The project is ongoing and there are plans to expand it at Hellisheiði to capture more emissions, as well as further developing it for use in other locations. In 2019, Reykjavík Energy founded a new subsidiary that will be focused on further developing the CarbFix method. Additionally, there is a carbon capture pilot project, constructed by Climeworks, underway at Hellisheiði power plant, where CO_2 will be captured from the air and injected in already operational injection wells.

Figure 11.9. Climeworks CO_2 collectors at Hellisheiði power plant (Source: Climeworks).

11.5 Other National Activities

11.5.1 Geothermal Education

The UNESCO GRÓ Geothermal training programme (previously the United Nations University-Geothermal Training Programme, UNU-GTP) has been operating in Iceland since 1979, with the aim of assisting developing countries with significant geothermal potential to establish groups of specialists in geothermal exploration and development. A graduate programme was started in 2000 in cooperation with the University of Iceland, and several UNU-GTP students have since continued their studies to obtain MSc and PhD degrees. UNU-GTP receives its funding from the government of Iceland, 5 M US$/yr. Since 1979, 718 scientists have graduated from 63 countries. They have come from countries in Africa (39%), Asia (35%), Latin America (15%), Central and Eastern Europe (10%), and Oceania (1%). Amongst these have been 169 women (23.5%). On January 1, 2020 the name of the programme was changed to UNESCO GRÓ Geothermal Training Programme, as it is now operated under the auspices of UNESCO and no longer affiliated with the United Nations University.

Iceland School of Energy was established at Reykjavik University which offers postgraduate courses in the field of renewable energy. University of Iceland also offers specialized post graduate studies in renewable energy, focusing on geothermal energy.

11.5.2 Conferences

The World Geothermal Congress 2020 which was supposed to take place in Iceland was postponed due to the Covid-19 pandemic. The organisers announced that the event will take place online in 2021, as well as at an in-person event in Reykjavík in October.

11.5.3 Publications

Icelandic scientists produce numerous publications on geothermal development and research every year, in peer reviewed journals such as Geothermics.

Publications on projects supported by GEORG research group:
http://georg.cluster.is/publications/papers/

11.6 Useful Websites

Orkustofnun Data Repository: http://www.nea.is/the-national-energy-authority/energy-data/data-repository/

UNESCO GRÓ Geothermal training programme: https://www.grocentre.is/gtp

GEORG Geothermal Research Cluster: http://georg.cluster.is/

Iceland Deep Drilling Project: http://iddp.is/

Iceland School of Energy. https://en.ru.is/ise/

11.7 Future Activity

The Icelandic Government published a white paper on sustainability in the Icelandic society in 1997, in which the need for the development of a long-term Master Plan for energy use in Iceland was stressed. All proposed projects are to be evaluated and categorized on the basis of energy efficiency and economics, as well as on the basis of the environmental impact of power developments. The vision is to prepare an overview of the various potential energy projects in hydro, geothermal and wind, and to evaluate and rank these based on their energy and economic potential, feasibility, effects on national economy, and the estimated impact that each project would have on nature, environment, cultural heritage and society, as well as the potential for other uses of the areas in question. The Master Plan is to be based on the best available scientific information and the conclusions are to be transparent, reproducible, and made available to the public. It was of vital importance to establish public confidence in the evaluation process. The Master Plan aims to identify power projects that rank highly from an economical point of view, have a minimum negative impact on the environment, and a positive impact on the society. Such a score card for energy projects helps decision makers to filter out which of the proposed projects are likely to become controversial and disputed and which ones not. It also directs attention to those project areas that might have protection value and should be left untouched. The third cycle of the Master Plan, which includes 33 geothermal options, was presented to the Minister for Environment in September 2016, and in May 2017 parliament commenced reviewing the material. As of 2020 the third cycle has not been confirmed by parliament although work on the fourth cycle has also been completed. There are 10 planned geothermal projects categorised for utilisation in the third cycle, but since it has not been confirmed by parliament, development (drilling, construction etc.) cannot begin. The exception is geothermal projects that were also proposed in the second cycle, which is the last cycle to have been confirmed, back in 2013. The future of the Master Plan remains unclear.

Direct geothermal use is expected to increase with population increases. It is estimated that heat use will reach 50 PJ in 2050 (Figure 11.10).

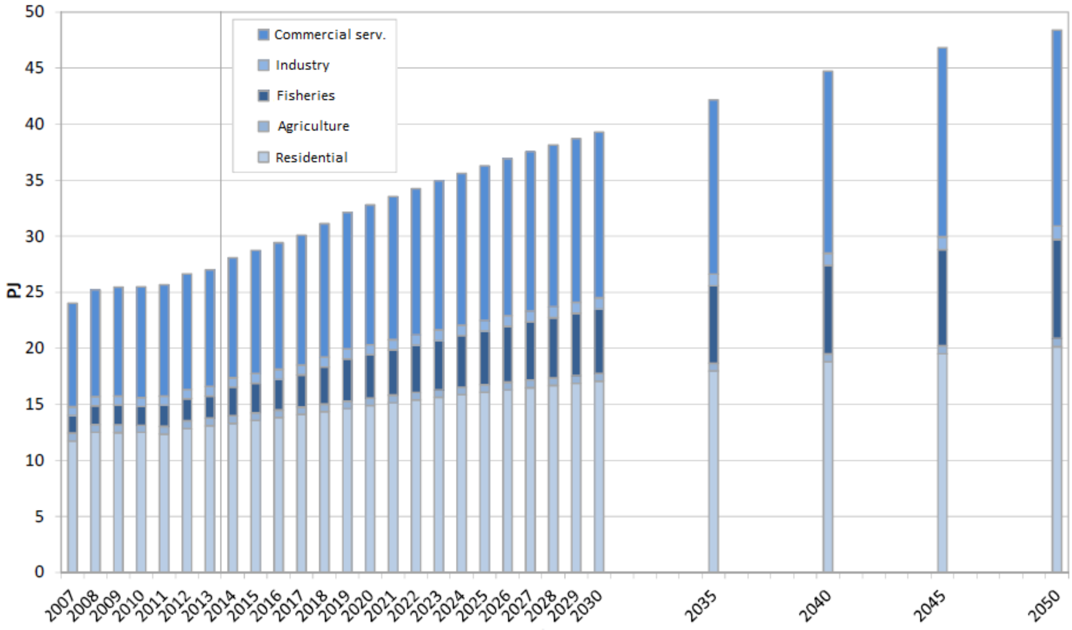

Figure 11.10: Geothermal utilization forecast 2007-2050 (Orkustofnun, 2015).

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Orkustofnun (2021). *OS-2021-T008-01: Primary Energy Use in Iceland 1940-2020* [data file].

Vaðlaheiðargöng (2014). *Mikið vatn eftir rjúkandi gang síðu viku.* https://www.vadlaheidi.is/is/frettir/mikid-vatn-eftir-rjukandi-gang-sidu-viku

Varmaorka (2021). https://varmaorka.is/

12. Italy (2019)

Sara Montomoli and Marco Paci
ENEL Green Power, Geothermal Production, Via Andrea Pisano 120, 56120 Pisa, ITALY.
Email: sara.montomoli@enel.com; marco.paci@enel.com

12.1 Introduction

Figure 12.1: Nuova San Martino Power Plant

In Italy, geothermal resources are used for both electricity generation and direct use. Power plants are located in Tuscany in the two "historical" areas of Larderello-Travale and Mount Amiata. Direct geothermal use is widespread over the whole of Italy.

To date, Enel Green Power (EGP) is the only geo-electricity producer in Italy. At the end of 2018 the installed capacity was 915.5 MW_e and the gross electricity generation for the 2018 year reached 6,105 billion kWh.

No additional capacity was commissioned during 2019.

Regarding direct geothermal use, at the end of 2017 the installed capacity reached more than 1400 MW_t, with a corresponding total energy use of 10915 Tj/yr (+3,7% with respect to 2016). The main sectors using geothermal energy are space heating (42% of the total energy use) and thermal balneology (32% of the total energy use). Fish farming is third with 18% of the total geo-heat utilization. Heat utilization for agricultural applications, industrial processes and other minor uses amounts to less than 8% of the total.

Ground-source heat pumps (GSHPs) constitute the main technology to exploit and deliver geothermal heat, they account for 38% of the total installed capacity and some 30% in terms of energy.

District heating systems represent about 8% of the total geothermal heat utilization (863TJ/yr) with a total installed capacity of about 150MW_t. The main systems are in the Tuscany Region near the geothermal electric power production areas. The other main areas of Italian direct geothermal use applications are Ferrara and Milano.

There is an overall static situation for direct use in Italy, with DHs the only sector with a significant increasing trend, followed by industrial applications, which are still a small fraction of the overall capacity and energy used.

The following table provides information on geothermal energy use for Italy. Official electricity data are for 2018, direct use data for 2017.

Electricity (2018)		Direct Use (2017)	
Total Installed Capacity (MW_e)	915,5	Total Installed Capacity (MW_{th})	1424
New Installed Capacity (MW_e)	0	New Installed Capacity (MW_{th}) (2015-2017)	52
Total Running Capacity (MW_e)	915,5	Total Heat Used (PJ/yr)	10.915
Contribution to National Capacity (%)	0.8	Total Installed Capacity Heat Pumps (MW_{th})	532
Total Gross Generation (GWh)	6105	Total Net Heat Pump Use [PJ/yr]	3.262
Contribution to National Generation (%)	2.1	Direct Use Targets (PJ/yr by when)	N/A
Target (% national generation) (data as 2016)	1080	Estimated Country Potential (MW_{th} or PJ/yr or GWh/yr)	N/A
Estimated Country Potential (MW_e) (data as 2016)	4000	(no significant change in estimated direct use)	

(N/A = data not available)

(* indicates estimated values)

12.2 Changes to Policy Supporting Geothermal Development

In 2018 the electricity needs of Italy reached 321.91 billion kWh, with a domestic contribution of ~87.0% and 13.0% imported (Terna 2018). As regards the 280.2 TWh of net domestic electricity generation, 66.0% comes from thermal, 17.6% from hydro and 16.4% from geothermal, wind and solar. Although the contribution of geothermal electricity generation is ~2.0% of the total Italian generation, it covers over 30% of the electricity needs of Tuscany, giving a substantial contribution in green energy generation.

In 2018 the average market price of electricity was 6.191 Eurocent/kWh (GSE, 2019). In 2018 the value of the GRIN tariff (Ex green certificates) for the geothermal plants that have access to this incentive was 9.9 Eurocent/kWh additional to the average electricity market price. To receive this an application, using the specific reduction coefficients for the technology type and the type of intervention, must be made (GSE, 2018a).

The 2016 FER Decree defined the new “Base Incentive Fee” for geothermal plants reduced by a percentage due to the auction reduction:

- 13.4 Eurocent/kWh (under 1 MWe installed Capacity),
- 9.8 Eurocent/kWh (for plants between 1 MWe and 5 MWe), and
- 8.4 Eurocent/kWh (over 5 MWe installed Capacity).

All these tariffs are inclusive of the average electricity market price (Ministerial Decree D.M. 23/06/2016).

Recent official documents forecasting energy production from renewables (RES) in Italy envisage only a small growth for geothermal energy applications. The Italian Energy Strategy released in 2017 (MISE, 2017) predicts a rather limited increase of production for electricity and declares the wish to establish a support scheme for geothermal innovative technologies demonstrating electrical power production with zero emissions. While a support scheme for zero emission or other innovative technologies has not yet been established, on January 2019 geothermal power plants were excluded from participating in the bids for incentive schemes offered to renewable power plants.

With the FER1 Ministerial Decree (4 July 2019) "Incentivazione dell'energia elettrica prodotta dagli impianti eolici on shore, solari fotovoltaici, idroelettrici e a gas residuati dei processi di depurazione (19A05099) (GU Serie Generale n.186 del 09-08-2019)", geothermal energy has now been formally excluded from incentives. In the previous, 2016 FER geothermal energy was included.

Moreover, in 2019 a new regional regulation in Tuscany has been approved "legge regionale 5 febbraio 2019, n. 7 , Disposizioni in materia di geotermia", with a significant step forward to the vision of the circular economy and environmental & sustainability improvement for geothermal power plants. The main points of the new regulation are that for the issuing of new leases (leases are expiring before 2024) it will be mandatory to:

- Use the best technology and operational procedures available
- limit the hours of non-operation of geothermal plants to no more than 2 percent of the total annual operating hours
- ensure the transfer and reuse of at least 10% of the CO_2 emitted (free of charge)
- ensure the reuse of at least the 50% of the residual thermal energy produced annually that is not used for the production of electricity, to be implemented within one year from the start-up of the plant;

Regarding thermal production, the Italian Energy Strategy released in 2017 (MISE, 2017) does not forecast any specific increase or promotion of heat production from geothermal energy sources, whist only vaguely referring to expanding heat pump uses and district heating infrastructure.

In Italy the promotion of RES in the heating and cooling sector is achieved through tax relief of 55% of the cost of installed RES technologies (the so-called "Conto Termico", i.e. Thermal Account), and as part of wider measures to promote energy savings in the building sector. This latter consists of:

1) for new buildings which are not yet fully operational, the obligation to cover a quota (50%) of their energy needs for domestic hot water with renewable sources, and
2) for existing buildings, the possibility of deducting 55% of the costs incurred for energy retrofit operations from personal income tax (IRPEF) or corporate income tax (IRES) obligations (so-called "Ecobonus").

Since 1998, tax incentives benefit users connected to district heating networks fed by geothermal energy sources. This mechanism pays the end user an incentive for the energy provided by district heating networks supplied by geothermal sources, which was 25.8 €/MWh up to 2014, when it was reduced to 21.95 €/MWh. Moreover, there is an installed capacity incentive of ~21.00 €/kW_{th} paid to the end user through a tax credit mechanism to partially cover the cost of connection.

12.3 Geothermal Project Development

12.3.1 Projects Commissioned

In 2019 no additional geothermal electrical generation units were commissioned.

In 2018 Enel Green Power started the drilling phase for the construction of the 20MWe gross Monterotondo 2 geothermal power plant on a new lease located SE of the existing area, close to Lago Boracifero.

Between 2017 and 2019 four new district heating (DH) networks in geothermal areas in Tuscany have been established: two in the Travale-Radicondoli area (in Radicondoli and Chiusdino villages), and two in the Mount Amaiata area (Piancastagnaio). La Rota in the Mount Amiata area was completed in 2017 and provides heat to 19 enterprises, two farming facilities and a religious centre, with a capacity of 4,4MWt. The network in Radicondoli commenced operation in the winter of 2018-2019, with a capacity of 5.8 MWt. The Piancastagnaio village network development commenced operation in 2019 supplying 1100 buildings, while the Chiusdino network whilst only partially completed commenced production in 2019. An overall installed capacity of 9MWt is foreseen by 2020. The Chiusdino network comprises two districts (one working and one under construction) with energy delivery of 13,68 TJ/yr and 32,40 TJ/yr respectively.

Other DH networks are planned in Tuscany outside the traditional geothermal territories:

- in Castelfiorentino the planned networks will serve 1500 buildings, and
- in Montecatini the planning has recently started.

12.3.2 Projects Operational (at the end of the reporting year)

(a) Geothermal fields

All of the Italian geothermal fields in exploitation for electricity generation are located in Tuscany, Larderello, Travale-Radicondoli, Bagnore and Piancastagnaio (the latter two being located in the Mount Amiata area).

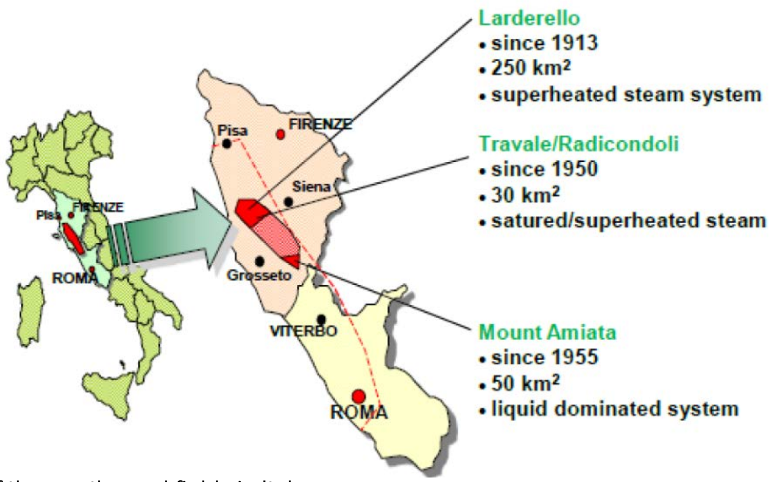

Figure 12.2: location of the geothermal fields in Italy

The activities carried out by EGP over the last three years have been concentrated in the Larderello and Travale-Radicondoli areas targeting field management optimization to reduce and ameliorate decline. Serious acceptability problems from local communities have hindered further developments in the Mt. Amiata area, where the high potential deep geothermal energy for expanded utilisation is located.

In 2018, following surface exploration started some 5 years before, EGP was granted two new development leases, one in Larderello and one in Mount Amiata: Boccheggiano and Roccalbegna.

In the period 2016 - 2018 a total of 27 geothermal wells were drilled in Italy, for a total drilled depth of 46.5 km.

(b) Electricity generation

The historical trend of electricity generation from geothermal resources in Italy is given in Figure 12.3, where two periods of increased geothermal generation are shown: the first in the period from 1930s to the mid 1970s, related to the development of the shallow carbonate reservoir, with well depths down to about 1000 m. The second from the beginning of the 1980s to now, when the fluid production has increased due to deep drilling activity and to the recharge support of the depleted shallow reservoirs by means of the reinjection of water and condensed steam.

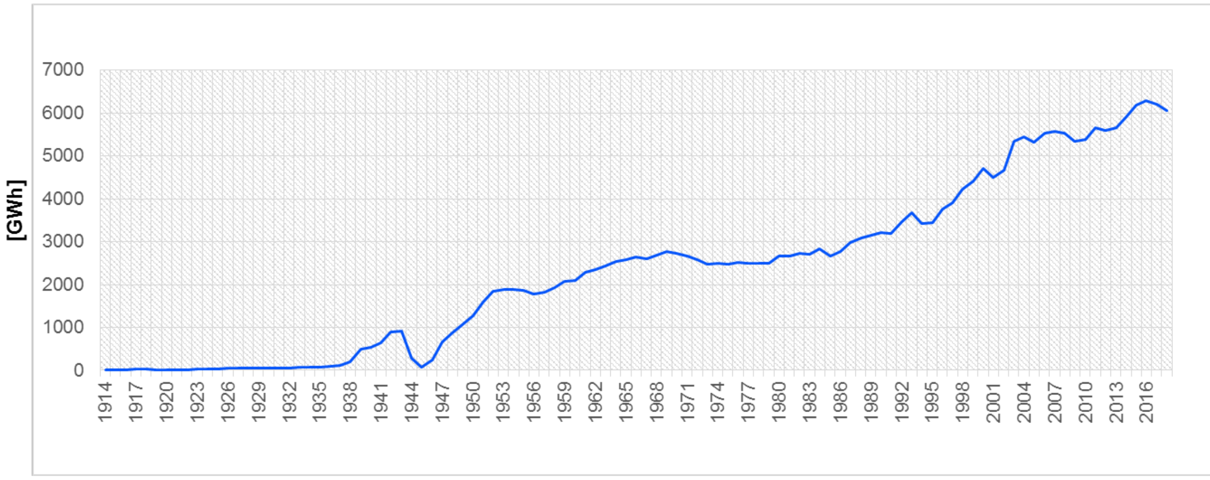

Figure 12.3: Historical trend of electricity generation from geothermal resources in Italy

All 34 of the Italy's geothermal power plants are managed by Enel Green Power. As of 2018 all these power plants had AMIS mercury and hydrogen sulphide abatement plant in operation. The average availability of the AMIS plants (hours of operation vs hours of operation of the associated power plant) exceeded 90%.

All of the geothermal power plants managed by EGP in Italy are remotely controlled and operated from a Remote Control Station located in Larderello, where 12 people work on shift around the clock (24/7) ensuring continuous operator oversight.

For 2018, with an installed capacity of 915.5 MWe, the gross electricity generation was 6064 GWh. A complete list of the operational power plants is given in Figure 12.4; taking into account the actual operating conditions in the different areas (pressure, temperature, non- condensable gas content in the steam, etc), the total running capacity, called Reference Net Capacity, is 806.6 MWe.

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

2) 1F = Single Flash | B = Binary (Rankine Cycle)
2F = Double Flash | H = Hybrid (explain)
3F = Triple Flash | O = Other (please specify)
D = Dry Steam

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity Mwe*	Total Running Capacity Mwe*	Annual Gross Energy Produced 2018 GWh/yr	Total under Constr. or Planned MWe
Larderello									
	Valle Secolo	1991	2		D	120	110,6	929,1	
	Farinello	1995	1		D	60	52,4	488,6	
	Nuova Larderello	2005	1		D	20	16,6	119,1	
	Nuova Gabbro	2002	1		D	20	19,1	148,3	
	Nuova Castelnuovo	2000	1		D	14,5	14,9	126,3	
	Nuova Serrazzano	2002	1		D	60	47,5	320,9	
	Nuova Sasso	1996	1		D	20	14,0	100,9	
	Sasso 2	2009	1		D	20	16,7	135,5	
	Le Prata	1996	1		D	20	18,0	156,9	
	Nuova Monterotondo	2002	1		D	10	8,0	52,0	
	Nuova San Martino	2005	1		D	40	36,2	226,0	
	Nuova Lago	2002	1		D	10	10,9	88,1	
	Nuova Lagoni Rossi	2009	1		D	20	12,7	92,7	
	Cornia 2	1994	1		D	20	12,0	150,7	
	Nuova Molinetto	2002	1		D	20	14,5	95,1	
	Carboli 1	1998	1		D	20	15,4	135,8	
	Carboli 2	1997	1		D	20	15,4	122,5	
	Selva	1997	1		D	20	18,3	68,8	
	Monteverdi 1	1997	1		D	20	17,8	110,6	
	Monteverdi 2	1997	1		D	20	15,6	117,1	
	Sesta	2002	1		D	20	13,9	92,8	
Subtotal			22			594,5	500,5	3877,8	0
Travale-Radicondoli									
	Nuova Radicondoli	2002	2		D	60	58,5	358,2	
	Pianacce	1987	1		D	20	14,1	67,7	
	Rancia	1986	1		D	20	19,1	143,6	
	Rancia 2	1988	1		D	20	19,1	130,2	
	Travale 3	2000	1		D	20	16,5	100,1	
	Travale 4	2002	1		D	40	38,9	196,5	
	Chiusdino 1	2010	1		D	20	19,4	159,9	
Subtotal			8			200	185,6	1156,3	0
Mt. Amiata									
	Bagnore 3	1998	1		1F	20	19,9	175,3	
	Gruppo Binario Bagnore3	2013	1		B-ORC	1	1,0	6,7	
	Bagnore 4	2014	2		1F	40	39,6	363,5	
	Piancastagnaio 3	1990	1		1F	20	20,0	174,7	
	Piancastagnaio 4	1991	1		1F	20	20,0	171,4	
	Piancastagnaio 5	1994	1		1F	20	20,0	179,2	
Subtotal			7			120,99	120,5	1070,9	0
Total			**37**			**915,5**	**806,6**	**6105**	**0**

* Installed capacity is maximum gross output of the plant; running capacity is the Efficient Capacity

Figure 12.4: Existing geothermal power plants, individual sites

The Enel Group Company is present in all continents, globally developing and managing renewable energy generation from a range of renewable sources, water, solar, wind and geothermal, with an annual energy production of 82 TWh, avoiding millions of tons of CO_2 emissions annually.

(c) Thermal production

Between 2015 and 2017 the geothermal applications have grown in terms of both capacity (+1.6%/yr) and energy use (+1.8%/yr). Figure 12.5 and Figure 12.6 show the sector breakdown in energy use and capacity.

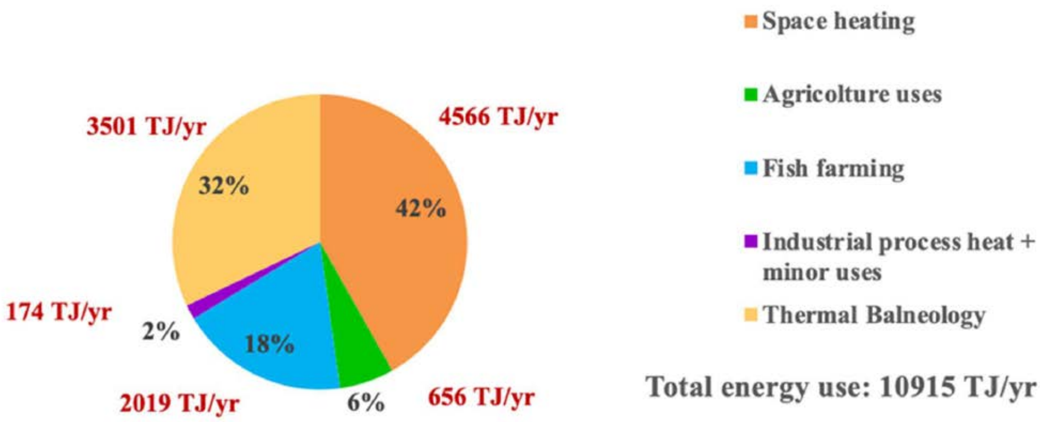

Figure 12.5: Share of geothermal energy utilization of direct uses in 2017

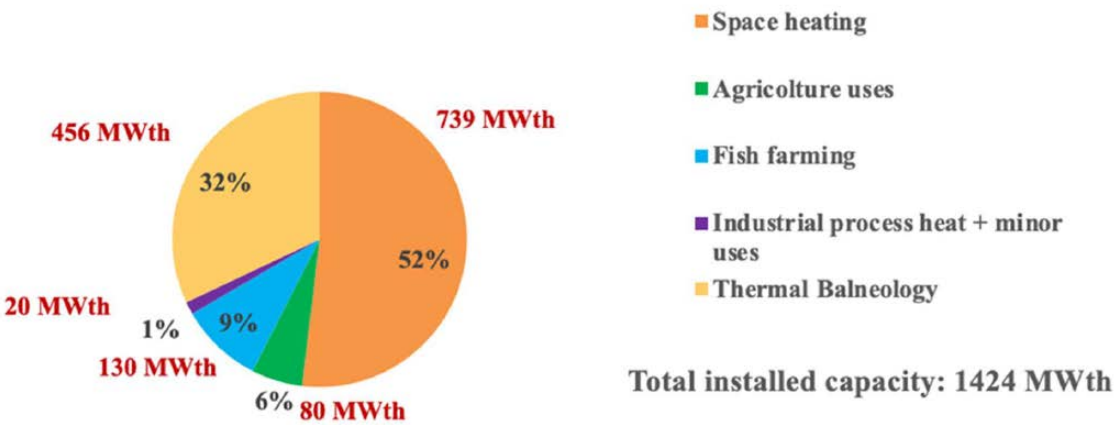

Figure 12.6: Share of geothermal installed capacity for direct uses in 2017

12.4 Research Highlights

In recent years, due to an increasing emphasis on sustainable development, and reducing and mitigating environmental impacts, a number of research projects have been carried out on these topics. Good results have been achieved.

In 2019 the EU H2020 program **Matching** concluded, with excellent results achieved in geothermal energy facilities. The **Matching** project achieved the target of demonstrating an up to 15% reduction in evaporative losses from cooling towers, through the replacement of wet cooling towers with hybrid towers equipped with advanced and more robust materials. The work was undertaken at the Nuova San Martino geothermal power plant.

Under the H2020 framework the **Geoenvi** project was established. Scheduled for completion by April 2021 the project aims to define Guidelines for Life Cycle Analysis (LCA) and environmental impact assessments of geothermal power plants.

The **Spirulina cultivation** project, carried out by Enel Green Power, successfully demonstrated the use of geothermal CO_2 and heat to grow spirulina algae. These integrated geothermal and algae production processes will reduce some CO_2 emissions from a geothermal plant.

Figure 12.7: Spirulina pilot plant at Chiusdino power plant

The recent evolution of the legislative framework (see section 12-2) focusses research towards reducing geothermal gas emissions (mainly CO_2) and the potential reuse of CO_2.

12.5 Publications

https://www.mise.gov.it/index.php/it/198-notizie-stampa/2040101-decreto-fer1-pubblicato-in-gazzetta-ufficiale

https://www.gazzettaufficiale.it/eli/id/2019/05/25/19R00137/S3

12.6 Useful Websites

https://www.unionegeotermica.it/

https://www.egec.org/

https://www.etip-dg.eu/

https://www.enelgreenpower.com/

https://www.enel.com/

https://www.mise.gov.it/index.php/it/198-notizie-stampa/2040101-decreto-fer1-pubblicato-in-gazzetta-ufficiale

https://www.gazzettaufficiale.it/eli/id/2019/05/25/19R00137/S3

http://matching-project.eu/

https://www.geoenvi.eu/

12.7 Future Activity

There are no other geothermal leases seriously under development in Italy other than the Enel Green Power geothermal developments.

Since 2010, with the liberalization of geothermal resource exploitation for power generation, ~120 new permit requests have been made. Ten of those are for permits dedicated to "Research for geothermal Resources focussed on testing with Pilot Plants", with nominal power up to 5 MW.

Currently, 34 Geothermal Research Permits have been released, listed as follows:

- Two located in Tuscany, are applying for the concession;
- Seven are currently applying for the authorization to drill exploratory wells (5 in Tuscany and 2 in Latium);
- One has obtained authorization to drill 2 exploratory wells (Tuscany);
- 20 Permit requests in Latium are waiting the final advice of award.
- Two Pilot Plants obtained EIA acceptance and are waiting for the final approval from both Region Administrations and the MISE (Ministry for Economic Development).

All the other Requests are still in the investigation phase;

The rate of development for geothermal resources for electricity generation in Italy is currently quite slow. There are many difficulties:

- time for authorization is very long and unpredictable,
- the electricity tariff is often not guaranteed for a sufficiently long period of time for business uptake or it results in an increased level of financial risk.
- Support schemes for geothermal energy are very limited in Italy, and the recent exclusion from incentive schemes for geothermal energy generation from the bids offered by RES power plants adds further difficulty, and
- the long period occurring prior to the release of the new FER2 ministerial decree is slowing down activity and investment planning in geothermal projects.

Regarding the direct use of geothermal heat, the lack of effective support schemes and regulation leads to the very slow growth of geothermal energy uptake currently seen in Italy. The situation is particularly evident for both geothermal district heating systems, which could contribute so much more towards residential heating and cooling demand, and for GSHPs, that were expected to grow at a much higher rate because it is well-established technology that is in use in numerous countries.

12.8 References

https://www.terna.it/it/sistema-elettrico/transparency-report/actual-generation

Manzella A., Serra D., Cesar G., Bargiacchi E., Cei M., Cerutti P., Conti P., Giudetti G., Lupi M., Vaccaro M.: Geothermal Energy Use, Country Update for Italy. Proceedings of the European Geothermal Congress 2019, Den Haag, The Netherlands, 11-14 June 2019.

https://unmig.mise.gov.it/index.php/it/dati/risorse-geotermiche

13. Japan

Kasumi Yasukawa
Geothermal Resource Development Department, JOGMEC, 2-10-1 Toranomon, Minato-ku, Tokyo 105-0001 Japan.
Email: yasukawa-kasumi@jogmec.go.jp

13.1 Introduction

Located along the Circum-Pacific Volcanic Belt "Ring of Fire," Japan is blessed with an abundance of geothermal energy. The total capacity of geothermal power plants reached over 500MW in 1995 and then mainly due to socio-economic factors the installation of new capacity stagnated for almost two decades. Measures to intensify deployment of renewable energy by the Ministry of Economy, Trade and Industry (METI), following the nuclear power plant accident in Fukushima in 2011, have renewed interest in geothermal development. Although development progress is modest, two larger capacity geothermal power plants; Matsuo-Hachimantai (7,499 kW) and Wasabizawa (46,199 kW) were commissioned in 2019. In addition many small geothermal power plants have opened in recent years. The rate of progress is in part due to the long lead times required for larger scale geothermal power plants, including time for environmental assessment processes, but also the difficulty in gaining social acceptance, especially from local hot spring resort owners who are worried about the impact of geothermal development on hot spring resources. For local social acceptance the role of the local government is quite important and in some cases the local governments are not well placed to perform this important work.

The promotion of ground source heat pump (GSHP) started in Japan at the beginning of 21st century and the number of installations has been increasing rapidly in recent years with support from Ministry of the Environment (MOE). More details are described in Section 13.5.

Table 13.1 Status of geothermal energy use in Japan in 2020.

Electricity		Direct Use	
Total Installed Capacity (MW_e)*	553.9	Total Installed Capacity (MW_{th}) ***	2,407[2,3]
New Installed Capacity (MW_e) *	3.9	New Installed Capacity (MW_{th})	N/A
Total Running Capacity (MW_e) **	274[1]	Total Heat Used (TJ/yr) ***	29,958[2,3]
Contribution to National Capacity (%)**	0.2%	Total Installed Capacity Heat Pumps (MW_{th}) **	163.4[4]
Total Generation (GWh) **	2,403[1]	Total Net Heat Pump Use (TJ/yr) **	764.9[4]
Contribution to National Generation (%)**	0.2%	Target (PJ/yr)	N/A
Target (% of national generation)	1.0-1.1%	Estimated Country Potential (GWh/yr)	N/A
Estimated Country Potential (MW_e)	23,470[5]		

N/A = data not available

* At December 2020. "New Installed Capacity" shows the change of "Total Installed Capacity" from that of 2019 report.

** Based on the data of FY 2018 (April 2018 to March 2019), which is the latest available data. Running capacity was calculated from total installed capacity of 493.9MW and total generation of 2,403 GWh (capacity factor: 55.5%) in FY 2018.

*** No data exists for recent years. For data year, see the data sources : [2][3] for Direct Use, and [4] for Heat Pumps.

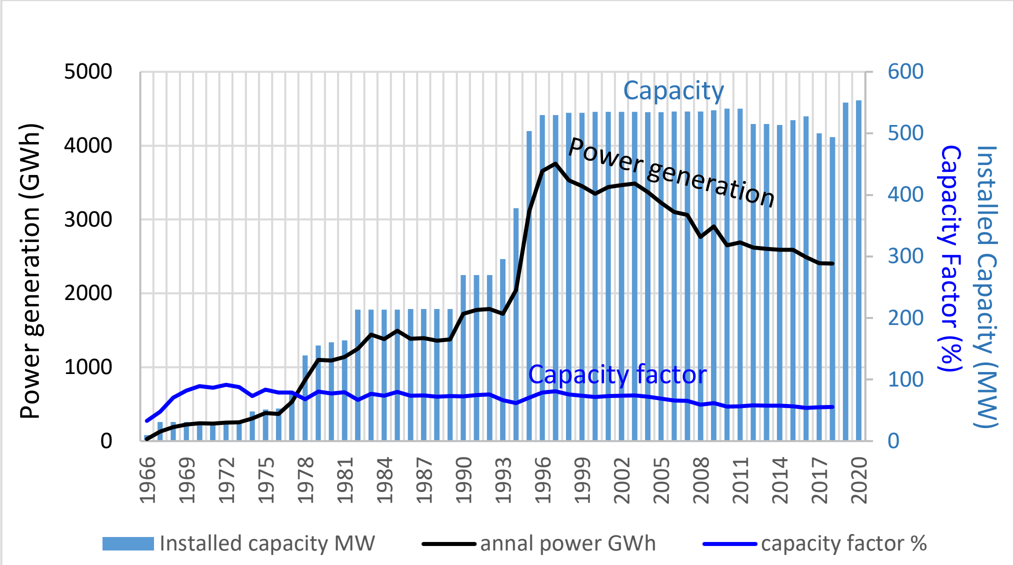

Figure 13.1 Geothermal power in Japan: total installed capacity (blue columns), power generated (black line), and capacity factor (blue line).

Figure 13.1 shows the long-term trend of geothermal power plant capacity and generation in Japan. An issue is that the average capacity factor of the geothermal power plants has been decreasing since the 1970's. The major reason is that in the 20th century, with immature knowledge of geothermal reservoir management, developers built larger capacity power plants that were beyond the ability of the reservoirs to support the facilities long-term, resulting in declining steam production with time. Since 2010 some older power plants have been decommissioned with new units of smaller capacity replacing the older units. Therefore, although the total number of units has increased in recent years, the total capacity decreased between 2012 and 2017. The final increase in capacity during 2019 is from Wasabizawa in Akita and Matsuo-Hachimantai in Iwate. Another reason for decreasing capacity factor is that many of the new small power plants are in operation with quite low capacity factor due to lack of technical investigation beforehand, run by local business people who are attracted by a high FiT price.

13.2 Policy Supporting Geothermal Development

The Japanese government initiated a Feed-in-Tariff (FiT) for wind, geothermal, hydro, and biomass powers in July 2012 to accelerate their deployments while FiT for solar PV had been already available since 2010. For geothermal, hydroelectric, and biomass energy, the tariff is applicable to projects certified in a given year "in advance", in order to reflect the longer leading time of these energy development compared with solar PV or wind power projects. The tariff price of geothermal power has been kept high while that of solar PV and wind power has been lowered every year.

A FiT is applied to geothermal power plant replacements with different FiT payments applying in the case of turbine-generator replacement or in the case that includes replacement of production and/or injection wells.

At present, the government is planning to replace FiT with Feed-in-Premium (FiP) in 2022. In their plan, FiT will partially remain after 2022 under certain conditions, parallel with the new FiP. The condition for geothermal FiT, for example, will be small capacity geothermal power projects led by local government or local community. The details of such conditions are currently under discussion by the special committee under METI.

Beside FiT, METI has been supporting geothermal energy development by various other economical supports. METI's budget for JOGMEC (Japan Oil, Gas and Metals National Corporation) includes subsidies of geothermal exploration including drilling and low interest loans for construction of geothermal power plants. These measures have brought renewed interest in geothermal development by private sector organisations (such as electric power companies, oil companies, construction companies), local governments, and other entities. METI has also been funding geothermal technology developments.

13.3 Geothermal Development Projects

13.3.1 Projects Supported by JOGMEC

A geothermal development project generally takes a long time from exploration to power generation. In addition, there are resource risks, which makes geothermal power projects different from other thermal power projects. In order to assist in managing these risks, JOGMEC supports the development of geothermal resources using three financial support mechanisms;

- grant subsidies,
- equity capital investment, and
- loan liability guarantees for geothermal development.

In FY2020 (April 2020 to March 2021), 22 projects were accepted for grant subsidies (shown in red in Figure 13.3), for which between 50-100% of the investigation cost is supported. Four out of the 22 projects are new. In FY 2020 the total value of grant subsidies was ~6 billion JPY (~55 million USD).

After initial survey work is completed, developers need to estimate the production capacity. At this stage, JOGMEC may invest up to 50% of the cost. The first (2015) of JOGMEC's equity capital project investments was Matsuo-Hachimantai, which successfully reached the estimated production capacity and continued on to construction and operation.

At the construction stage, significant funding is required to drill the wells and to construct the facilities. When private developers construct a geothermal power plant with loans from private financial institutions JOGMEC may provide a liability guarantee of up to 80% of the total loans. To date, JOGMEC have provided loan liablity guarantees for six projects; four (Tsuchiyu, Sugawara, Matsuo-Hachimantai and Wasabizawa) of which have started operation, with two (Minami-Kayabe and Appi) under construction.

Matsuo-Hachimantai is a model case in which JOGMEC's support mechanisms have worked effectively, from grant subsidies, equity capital investment, through to the liability guarantees. The operation of this power plant commenced on January 2019.

Figure 13.2 Matsuo-Hachimantai Geothermal Power Plant (7,499kW, single flash, operational 29 January 2019). Photo by Iwate Geothermal Power Co., Ltd.

13.3.2 Projects Operational

In 2019, Japan has 554 MW of geothermal power capacity, about 4% of the world total. In 2018, it supplied 2,403 GWh of electricity, representing about 0.2% of the country's total electricity supply. Geothermal power plays a minor role in the energy sector in the country.

In 2019, besides several small geothermal power plants, two larger geothermal power plants began commercial operation; Matsuo-Hachimantai in Iwate prefecture (7,499 MW) and Wasabizawa in Akita prefecture (46,199 MW). JOGMEC provided liability guarantees for 80% of the total development loan of these geothermal power plants.

Construction of geothermal power plants has been announced in several other areas such as Minamikayabe in Hokkaido prefecture (6.5 MW, 2022), Oyasu in Akita prefecture ("Katatsumuri-yama GPP", 15 MW, 2024) and Appi in Iwate prefecture (15 MW, 2024). Among them, Oyasu site is currently under environmental assessment required by the local government and the construction has not been begun yet while the others are under construction.

Several old geothermal power plants are on the stage of facility replacement. Onikobe geothermal power plant (15 MW since 1975) was shut down in 2017 and environmental assessment for the new power plant was completed in November 2018. The project is currently under construction with operations scheduled to recommence in 2023. Hachijojima geothermal power plant (3.3 MW since 1999) was shut down in 2019, with the new power plant scheduled to commence operation in 2022 with a 4.4 MW generator. At Otake geothermal power plant, construction of a new power plant began in 2018 when the old power plant (12.5 MW since 1967) was still in operation. It was replaced with the new plant (13.7 MW) on 5 October 2020.

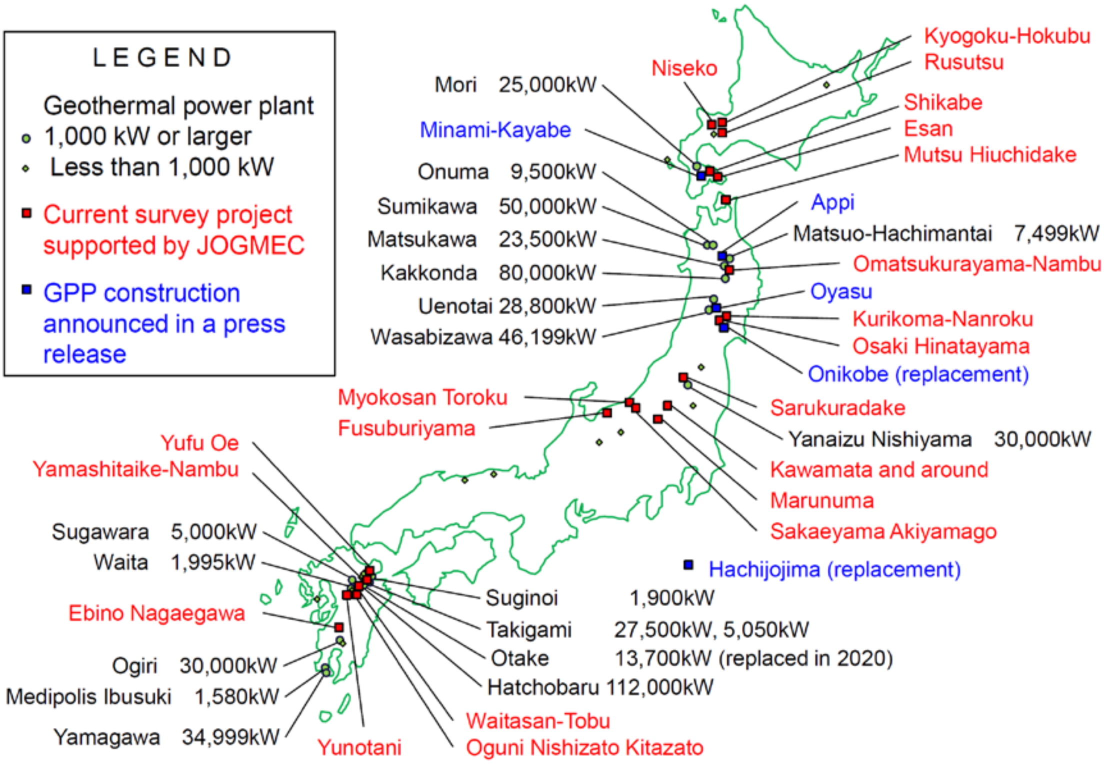

Figure 13.3 Geothermal power plants and ongoing projects in Japan as of December 2020

13.4 Ground Source Heat Pump (GSHP)

13.4.1 Trend and Current Status

The census on GSHP in Japan is conducted every other year by MOE and the latest data will be released in 2021. Therefore, this report shows the same data as the 2019 report. The installation of GSHP in Japan has been increasing exponentially in recent years, although the total number is still rather small (Figure 13.4). The total number of facilities using GSHPs is 2,662 including 2,314 closed-loop, 327 open-loop, and 21 using both[4]. Installed capacity of all the GSHPs is 163 MW_t, and annual energy use is 765 TJ/yr [7]. This is a large increase from that reported at WGC2015, which was 990 installations with a capacity of 62 MW_t [8]. In essence uptake has more than doubled in 5 years.

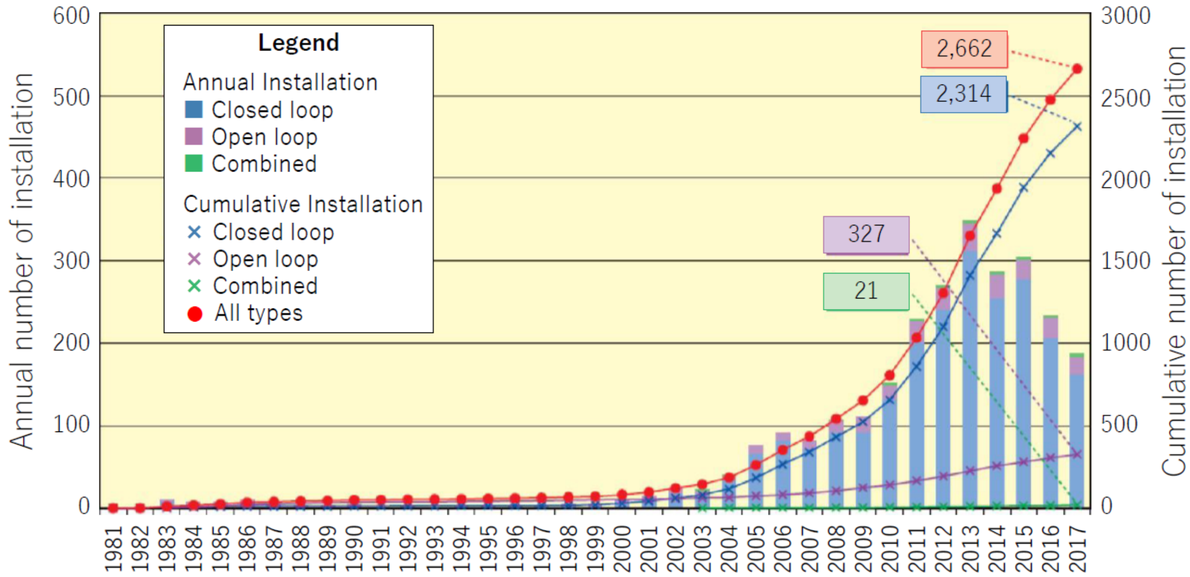

Figure 13.4 **Cumulative and annual installations of GSHP in Japan**[4]

Many systems have been installed in the northern regions including Hokkaido where heating needs are intensive, indicating the economic predominance of GSHPs when they replace an old oil boiler with a GSHP (see Figure 13.5). GSHPs are also widely used in other parts of Japan; cooling needs are quite high in the middle to south-western Japan and GSHP with high performance COPs for cooling are contributing to electricity savings.

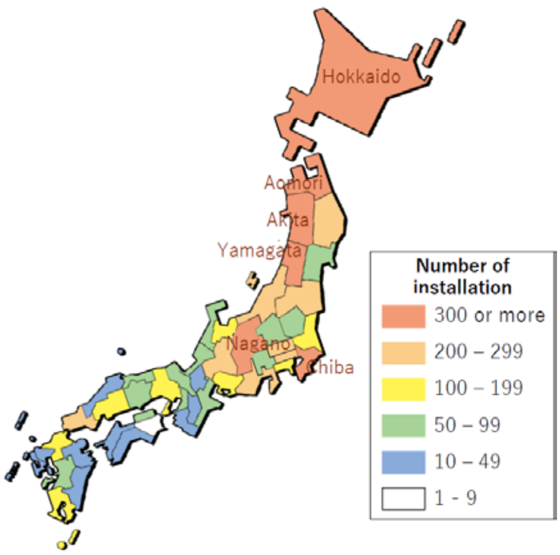

Figure 13.5 The number of GSHP installation in each prefecture in Japan [4]

Figure 13.6 shows the cumulative number of GSHP systems by different facilities[4] category. The largest share is individual houses (44%), followed by offices (12%) and public buildings (7.5%).

Many systems have been installed in the northern regions including Hokkaido where heating needs is intensive, indicating the economical predominance of GSHPs when they replace an old oil boiler into a new GSHP. However, GSHP is widely used in whole Japan because cooling needs is quite high in middle to south-western Japan whereas GSHP shows extremely high performance (COP) for cooling, contributing to electricity saving.

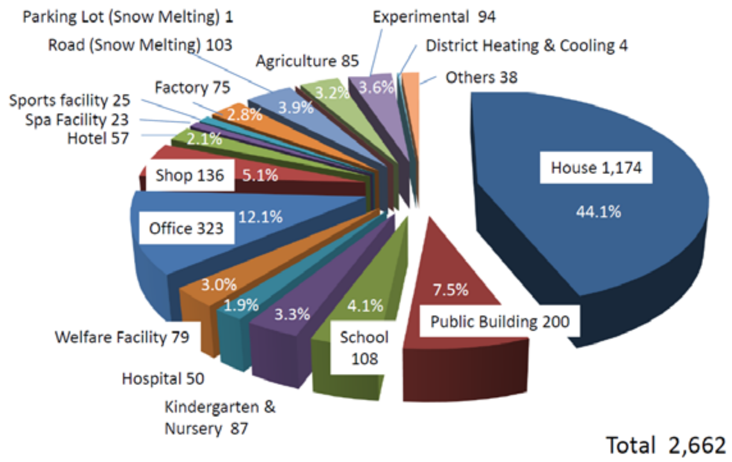

Figure 13.6 The number of facilities using GSHP system [4]

13.4.2 Related Studies - Suitability Mapping

Japan has been developing GSHP system suitability mapping based on groundwater flow modelling in basins and plains. The study funded by NEDO, was initiated by AIST and several universities and companies have subsequently become involved.

In Quaternary basins and plains consisting of unconsolidated sediments in monsoon Asia, effective thermal conductivity of shallow underground rocks largely differs from one place to another due to both the existence of aquifers and the advection effect of groundwater flow. Since saturated rock has a higher thermal conductivity, existence of a shallow aquifer raises the heat exchange rate so that information on the water table becomes important. Also, since higher water velocity gives higher heat exchange rates, information on 3D groundwater flow is useful for designing subsurface heat exchangers.

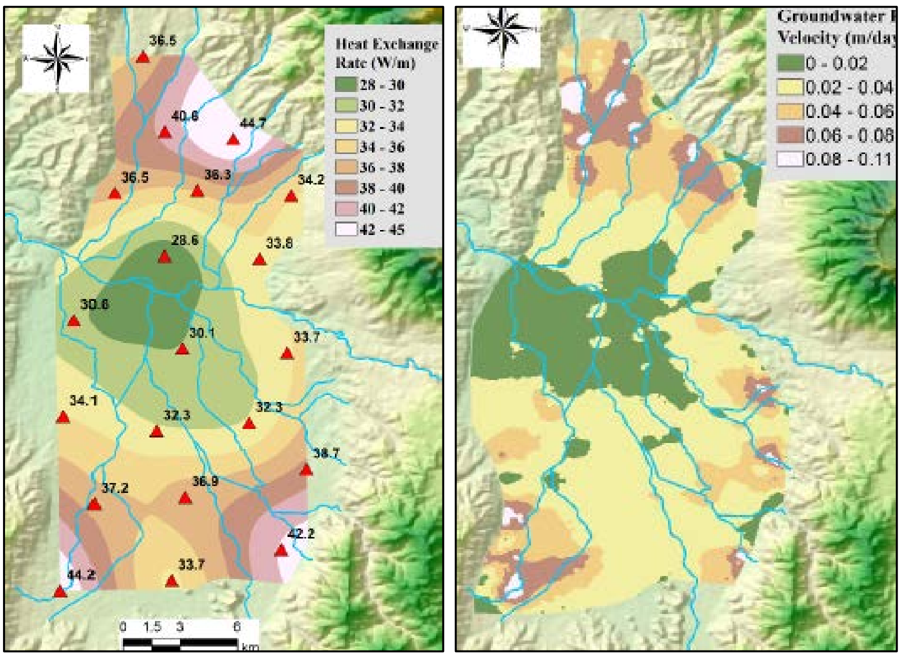

Figure 13.7 Distribution map of sustainable heat exchange rate (left) and groundwater flow velocity (right) [9]

Water table and flow velocity information is indispensable for open loop system design.

Groundwater studies based on field surveying and numerical simulation have been used to prepare separate suitability maps for open and closed loop systems. Separate maps for only heating demand, and heating and cooling demand, have been prepared based on subsurface temperature data. Figure 13.7 shows an example of a suitability map for a closed loop system for heating only (Shrestha et al. 2018)[9]. This identifies suitability for open or closed loop systems according to the site location.

Based on the study results, eleven municipals in Japan have compiled GSHP suitability maps from their own budget resources and opened the information up to their citizens seeking to increase the use of GSHP in their municipality; with benefits from energy saving and environmentally friendly technology.

13.5 Research Highlights

Two METI funded agencies; JOGMEC and NEDO (New Energy and industrial technology Development Organization), started projects in 2013 developing geothermal technology. NEDO began research on subduction-origin supercritical geothermal resources with a target year of 2040 for a pilot plant to be operational. This is one of the NESTI2050 projects, which is looking to contribute to the 2050 CO_2 reduction targets set by the Cabinet of Japan in 2017. The NEDO work is focusing on geothermal technologies that are to be realised in the longer term whilst JOGMEC is focusing on surveys, technologies and support that are effective in the short term.

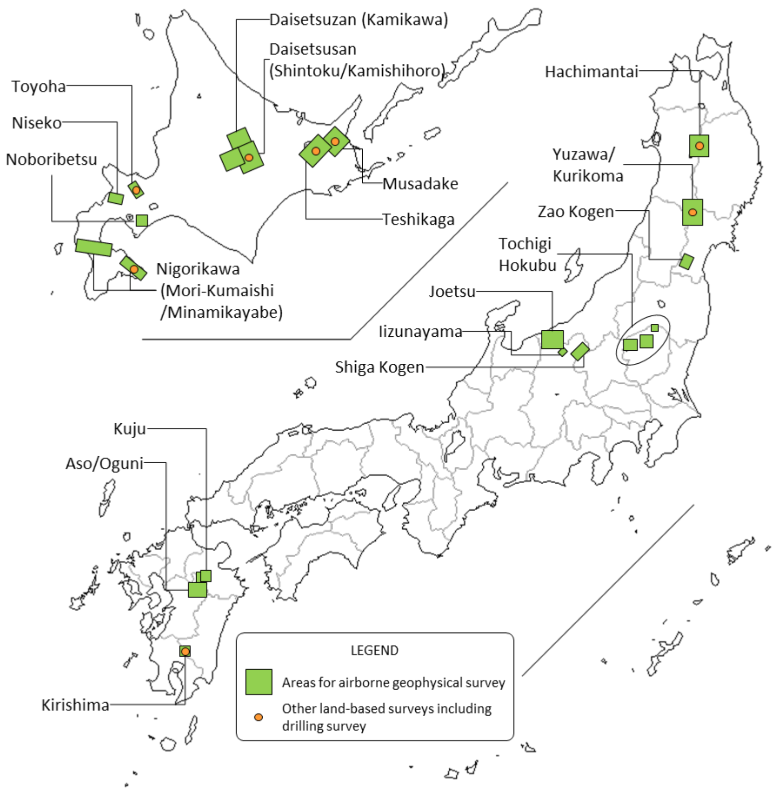

Figure 13.8 Regions for airborne geophysical survey and other surveys conducted by JOGMEC.

In order to promote geothermal development, JOGMEC has undertaken a survey program to acquire basic data for the evaluation of some geothermal prospects since 2013. The program currently consists of airborne helicopter geophysical survey, land-based geological and geophysical surveys, and drilling survey. The acquired data is published and used by private companies to generate their new exploration projects. By the end of 2020 surveying had been conducted in 18 areas; in Hokkaido (8), Honshu (7) and Kyushu (3). (Figure 13.8).

In technology development, JOGMEC has 3 R&D project themes;

- Geothermal Reservoir Evaluation and Management,
- Improvement of Exploration Accuracy, and
- Drilling Technology Development.

In the reservoir evaluation and management theme, a reservoir recharge test has been conducted in Yanaizu Nishiyama geothermal power plant. In the improvement of exploration accuracy theme, passive seismic methods using exploration wells and cost-saving electro-magnetic methods have been develped. Figure 13.9 shows a result of DAS-VSP (Distributed Acoustic Sensing - Vertical Seismic Profiling), which was originally developed in the oil industiry, applied to a geothermal well in this project. An optic fiber sensor, which is resistent to high temperature, was newly applied to this sytem for the field experiment in a geothermal field. In the drilling technology theme, a new PDC bit was developed and tested at a geothermal site in 2018.

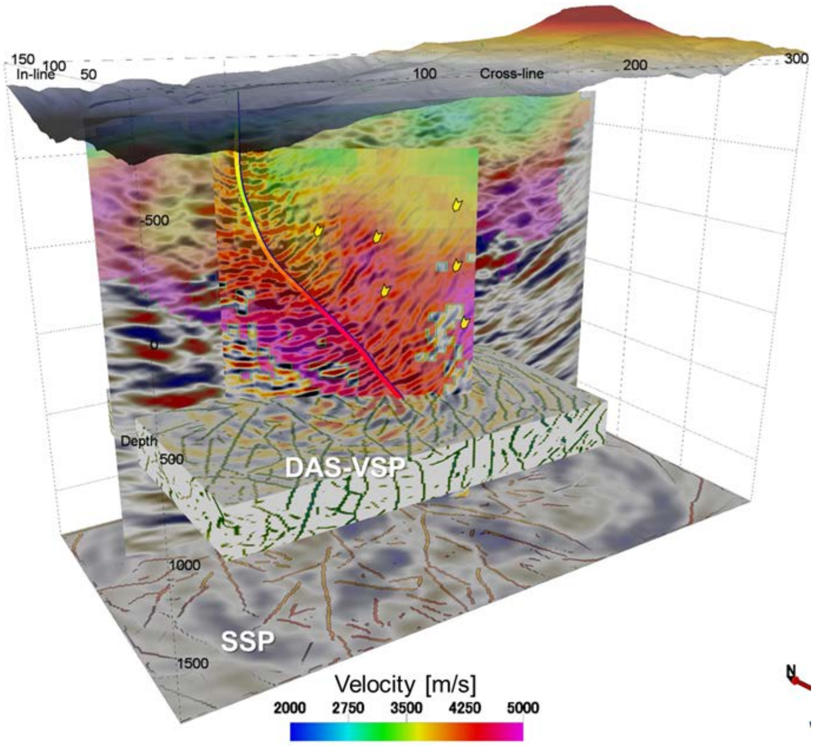

Figure 13.9 A result of DAS-VSP (Distributed Acoustic Sensing - Vertical Seismic Profiling) using a well, showing higher resolution than SSP (Surface Seismig Profiling)

In 2017, NEDO launched an R&D project “Development of subduction-origin supercritical geothermal resources” to utilize 400 to 500°C supercritical fluid at a depth shallower than 5km. Earlier surveys suggested supercritical geothermal resources may exist in/around many of the volcanic zones in Japan with total potential possibly of several tens of giga-watts.

2040 is targeted for the operation of a pilot plant.

To overcome problems with acid fluid in super critical conditions, the project covers various fundamental scientific studies in rock mechanics, material science, and geo-science, as well as technology development, numerical simulation and drilling. The basic studies are being led and conducted by the National Institute of Advanced Industrial Science and Technology (AIST) and Kyoto University.

13.6 Other National Activities

13.6.1 Promotion of Geothermal Development

METI began a program in 2013 to raise social acceptance of geothermal power generation amongst local residents. It is a subsidy scheme for general public educational activities undertaken by local governments and/or private sector organisation. Eight projects were adopted in 2020 (13 in 2019).

Every year since 2013, JOGMEC has held a Geothermal Symposium promoting geothermal power generation amongst the general public, seeking to increase the knowledge and the understanding of geothermal energy use. In 2020, the symposium was held in Sapporo city, Hokkaido and live streamed due to COVID19 problem. Only speakers and staff gathered at the venue in Sapporo and other participants connected online. More than 200o people accessed the symposium from all over Japan while normally an on-site symposium has around 500 (in 2019 in Yuzawa city, Akita, 465 people attended including a member of the Diet, local parliament members, local government members and local citizens).

A wide technical knowledge gap exists between geothermal energy business people and local government officials, making it difficult for the officials to moderate local opinions but local social acceptance is quite important for geothermal projects. Aiming at bridging this gap, JOGMEC established in June 2016 a third-party expert organization, the "Advisory Committee for Geothermal Resources Development". Matters of consultation from six municipals were discussed in 2018 through into 2019.

13.6.2 International collaboration and human capability development

Human resource development is an important issue in the international geothermal community. The Japan International Cooperation Agency (JICA) is organizing training courses for geothermal specialists from developing countries. In 2019 a course was held from 11th June to 21st December at Kyushu University. The course was attended by 14 people from 6 countries (Bolivia, Djibouti, Ethiopia, Nicaragua and Philippines). The program is basically provided by Kyushu University and supported by lecturers from other universities, institutes and private companies in order to cover all aspects of a geothermal energy development. Especially for any on-site training the contribution from the private sector is important. JICA has also been active in conducting Official Development Assistance (ODA) projects in geothermal development in Asian, African and Latin American continents for many decades.

JOGMEC and GNS Science (New Zealand), have a memorandum of understanding for collaboration in geothermal technology. Four joint workshops have been held; in Tokyo, Japan and in Taupo, New Zealand (scaling, community acceptance, reservoir engineering and geothermal geology).

For domestic human capability development, JOGMEC has been providing a three-week-long geothermal training course every December in Kosaka city, Akita prefecture. It covers the basics of geothermal energy including technical and economic aspects of geothermal energy projects. This course is valuable for private developers, many of whom have little experience in geothermal business. In 2019, 29 people mainly from private companies joined the course.

13.7 Useful Websites

- ✧ Ministry of Economy, Trade and Industry (METI): http://www.meti.go.jp/
- ✧ Japan Oil, Gas and Metals National Corporation (JOGMEC): http://www.jogmec.go.jp/
- ✧ New Energy and Industrial Technology Development Organization (NEDO): http://www.nedo.go.jp/
- ✧ Japan International Cooperation Agency (JICA): https://www.jica.go.jp/
- ✧ Geothermal Energy Team, Institute of Advanced Industrial Science and Technology (AIST): https://www.aist.go.jp/fukushima/en/unit/GET_e.html
- ✧ Geothermics, Faculty of Engineering, Kyushu University: https://www.eng.kyushu-u.ac.jp/e/lab_earth03.html

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14. Mexico

José M. Romo-Jones[1], Luis C. Gutiérrez-Negrín[2], Ismael Canchola-Félix[3]

[1] CICESE - CeMIE-Geo, jromo@cicese.mx

[2] Geoconsul, S.A. de C.V. - CeMIE-Geo, l.g.negrin@gmail.com

[3] Gerencia de Proyectos Geotermoeléctricos, CFE, ismael.canchola@cfe.gob.mx

14.1 Introduction

Figure 14.1 Los Humeros geothermal field (photo courtesy of CFE).

The Mexican Ministry of Energy´s most recent report includes installed capacity data updated to October 2020, and electricity generation data updated only until 2019. In October 2020, the total installed capacity for electric power generation in the country was 87,893 MW_e. Out of that, 64.9% of the installed capacity in the country comes from fossil fuels, mainly natural gas and coal, and the remaining 35.1% from clean energy sources, composed of hydroelectric plants 14.4%, wind power plants 8.1%, solar (photovoltaic) 6.9%, efficient cogeneration 2.4%, nuclear 1.8%, bioenergy 0.5%, and geothermal-electric plants 1.1% (SENER, 2021).

A little more than half (44,831 MW_e) of the installed capacity is owned and operated by the government utility CFE (Comisión Federal de Electricidad), including almost all (97%) of the installed geothermal-electric capacity. The remaining power plants in operation are owned and operated by private companies, except 920 MW_e owned and operated by PEMEX, the other state-productive company, to supply part of its consumption.

The geothermal electricity capacity in October 2020 was the same as that in 2019, with 1005.8 MW_e, installed in five geothermal fields in operation: Cerro Prieto, Los Azufres, Los Humeros, Las Tres Vírgenes, and Domo de San Pedro. The running or operational capacity was also the same, 947.8 MW_e, as reported last year (Table 1).

Table 14.1. Status of geothermal energy use for electric power generation and direct uses in Mexico in October 2020.

Electricity		Direct uses	
Total Installed Capacity (MW_e)	1005.8	Total Installed Capacity (MW_{th})	156.0
New Installed Capacity (MW_e)	0	New Installed Capacity (MW_{th})	0
Total Running Capacity (MW_e)	947.8	Total Heat Used (GWh/yr)	1,162.1
Contribution to National Capacity (%)	1.1	Total Installed Capacity Heat Pumps (MW_{th})	0.13
Total Generation (GWh) (2018)	5,375.0	Total Net Heat Pump Use [GWh/yr]	N/A
Contribution to National Generation in 2018 (%)	1.7	Target (PJ/yr)	Not set
Target (MW_e or % national generation)	Not set[a]	Estimated Country Potential (MW_{th})	40,589[c]
Estimated Country Potential (MW_e)	2,500[b]		

a) There is no specific target set for geothermal energy. A target of 35% of the total installed power generation capacity is set for clean energy sources by 2024. "Clean energy sources" are defined by law as those producing little or no greenhouse gas emissions to the atmosphere, and they include geothermal energy and the rest of renewable sources, but also nuclear, efficient cogeneration, and other clean technologies.

b) Estimated potential from conventional hydrothermal resources with temperatures > 150°C (Gutiérrez-Negrín et al., 2020). A recent estimate of EGS potential in Mexico, comprising hot-dry resources located between 3 and 7 km depth, is around 47,000 MW_e (Hernández-Ochoa et al., 2020).

c) 0.1 % of recoverable resources using a world average load factor of 0.27, based on Iglesias et al., 2015, for resources between 36°C and 208°C.

The electricity generation during 2019 was 317,236 GWh, of which 249,228 GWh were generated by fossil-fuelled (natural gas and coal) power plants, representing 78.6% of the total. The remaining 21.4%, i.e., 68,008 GWh, was produced by clean energy sources, composed of 7.3% of hydroelectric plants, 5.3% of wind, 2.6% of solar (PV), 0.2% of bioenergy, 3.4 of nuclear power plants, 1.0% of efficient cogeneration and 1.6% (5,061 GWh) from geothermal plants (SENER, 2021).

It is worth mentioning that the share (21.4%) of clean energy sources out of the total electricity generated in the country in 2019 seems to lag behind what is necessary to comply with the national goal of 35% of the total electric energy produced from clean-energy sources by 2024, according to the Energy Transition Law (Gutiérrez-Negrín et al., 2020). It is even a little lower than the share in 2018, which was 21.9%. However, in January-October 2020, the electric generation from clean energy sources increased to 25.4%, probably due to the lower electricity demand because of the lockdowns and reduced economic activities resulting from the Covid 19 pandemic in the country.

Regarding direct uses of geothermal heat, these remain scarcely developed in Mexico. They are limited basically to bathing and swimming facilities with recreational or therapeutic purposes, despite the large amounts of thermal manifestations identified at the surface. Balneology is still the primary direct use of geothermal heat in Mexico, representing around 155.3 MW_{th} in heated pools and spas, with ~0.8 MW_{th} of other direct uses (heating, drying, and GHP), giving a total of

156.1 MW_{th}. These amounts are the same as reported for 2019 (Table 1; Gutiérrez-Negrín et al., 2020).

The potential for developing geothermal heat uses in Mexico is enormous. Based on surveys made by CFE in the eighties, Iglesias et al. (2015) estimated that there are more than 1,600 points with hot springs and other thermal manifestations, which they grouped into more than 900 geothermal systems, in 26 states of the country. About one-half of those systems have temperatures in the range 62 to 100°C, 40% with temperatures 100-149°C, and 10% with temperatures below 62°C (5%) or higher than 149°C (5%). The authors estimated that if only 0.1% of these resources were used, it would represent more than 40,000 MW_{th} of installed capacity (Iglesias et al., 2015).

In addition, several demonstration projects were developed in the period 2014-2019 sponsored by the Mexican Center for Innovation in Geothermal Energy (CeMIE-Geo) to promote the direct use of geothermal heat (Romo-Jones and Group CeMIEGeo, 2015). The first geothermal heat pumps (GHP) installed in Mexico followed from this effort. After these demonstration projects, 11 GHP units were operating in four locations in the country, representing an installed capacity of 133 kW_{th} (Table 1).

14.2 Changes to Policy Supporting Geothermal Development

The Geothermal Energy Law and its regulatory framework remain in force in Mexico. The former Geothermal Direction of the Energy Ministry (SENER) had awarded six exploitation concessions and 26 exploration permits as of December 2020. The awarded concessions were for the four geothermal fields that CFE is currently operating and for the Cerritos Colorados field that CFE explored in the eighties and is still on standby; the sixth concession was for Grupo Dragón (Geodesa) at the Domo San Pedro field. All of these exploitation concessions are currently valid.

One half of the 26 exploration permits were granted to CFE, and the other half to seven different private companies. At least a couple of the latter have probably expired by now because the exploration permits were issued for three years, even though they can be extended another three years upon request of the developer and authorization of SENER. There is no updated information about it because of the setbacks caused by the pandemic. Some exploration activities have been carried out by CFE and the private developers in most of the awarded zones, including drilling a couple of deep exploration wells in one of them with good outcomes. Two different private developers tried to file for exploration permits in additional geothermal zones, but the SENER's offices have suspended these administrative procedures since March 2020. It is expected the offices will re-open services by mid-2021.

Regarding financing and risk-mitigation, the Inter-American Development Bank (IDB) and the Mexican development bank Nafin have prepared a financing and risk transfer program for geothermal projects called Geothermal Financing Mexican Program (PGM), structured under the global loan modality. It consists of two main components: risk mitigation for geothermal projects and financing adapted to the different phases of project exploration and execution. Besides, it will have a third component of technical assistance to support execution and other implementation costs. The program's total amount is US$108.6 million: US$54.3 million financed with resources from the IDB's Ordinary Capital, US$51.5 million from a contingent recovery grant financed with resources from the Clean Technology Fund (CTF); and US$2.8 million in technical cooperation. The program's goal is to finance up to 300 MW of geothermal capacity over ten years. It also hopes to leverage other public and private funds to contribute to Mexico's geothermal sector with estimated investment levels to the tune of US$4.2 billion for proven geothermal reserves (IGA News, 2018).

In 2019-2020 two parallel processes were developed. First, an International Public Tender to pick the drilling companies that will be in charge of constructing the exploration wells during the exploration phase; and second, a Call for the Selection of the Eligible Developers interested in participating in the program. Both bidding processes were conducted by the INEEL (National Institute for Electricity and Clean Energy) on behalf of the IDB-Nafin.

The idea of the risk mitigation procedure is as follows. The developer that gets the grant designs the features of the exploration well proposed to be financed: location, depth, well deviation, target interval, casings, lithology column, expected faults, etc., and presents the technical surveys and studies that support their proposal. The INEEL experts assess the information and eventually approve it. Then, the drilling companies previously selected in the tender present economic offers, and one is chosen. This company will drill the well, under the developer's direction and the overview of INEEL, and will be paid directly by the PGM, under the consent of the developer and approval of INEEL. The payments will go directly from the PGM to the drilling company. Once the well is finished and assessed, the developer should reimburse the cost to the PGM if it is successful. If the well failed, the costs are entirely absorbed by the PGM.

In February 2020 a call for developers was published who hold an exploration permit for one or more geothermal zones in the PGM website (https://www2.ineel.mx/geotermia/). Three proposals from CFE and five from the other four private companies were presented in June, and the results of the tender were published in August. Four geothermal zones were finally selected, the three submitted by CFE (Los Negritos, San Marcos, and the extension of Las Tres Vírgenes) and one from Grupo Dragón for the extension of Domo de San Pedro. CFE and Grupo Dragón are currently preparing their specific proposals for one exploration well in each zone, which have yet to be evaluated and approved by INEEL.

Even though it is not public policy in Mexico, it is worth mentioning that the Geothermal Development Facility for Latin America (GDF-Latam) has been open for projects in Mexico in 2020. GDF Latam is an initiative launched in 2014 in the framework of the COP20 in Lima, Peru, providing financial support to assist in mitigating geothermal exploration risk. The main donors are the German Federal Ministry for Economic Cooperation Development (BMZ) and the EU through the Latin America Investment Facility (EU-LAIF). The first call for Expressions of Interest (EoI) was launched in 2017 (https://gdflac.com/about/). For 2020 and 2021, CFE and a couple of private developers have submitted EoIs, with no known results up to now.

14.3 Geothermal Projects Development

14.3.1 Projects Commissioned in 2020

No additional projects were commissioned in 2020.

14.3.2 Projects Operational in 2020

There are five operational geothermal fields in the country: Cerro Prieto, Los Azufres, Los Humeros, Las Tres Vírgenes, and Domo de San Pedro. Please refer to the 2019 report for detailed information about them.

Figure 14.2 Top: Los Azufres Power Plant at night (photo courtesy of Luis C. Gutiérrez-Negrín). Bottom: Cerro Prieto from the air (photo courtesy of CFE).

14.4 Research Highlights

In February 2017, the GEMex project started officially in Mexico. GEMex was a bilateral initiative between Mexico and the European Community under the European Horizon 2020 and the

SENER-CONACyT Energy Sustainability Fund in Mexico. This ambitious project aims to investigate two unconventional geothermal opportunities: a possible EGS system in Acoculco, Pue., and a superhot system in Los Humeros, Pue., both sites licensed to CFE for geothermal exploration and exploitation, respectively. The Mexican group is led by the Universidad Michoacana de San Nicolás de Hidalgo (UMSNH), while the GFZ German Research Centre for Geosciences led the European group that finished its tasks in May 2020. The Mexican consortium is scheduled to finish in July 2021. Several multidisciplinary results about Los Humeros geothermal field and the Acoculco prospect area have been reported in specialized journals and made available to CFE for decision making. New integration reports will be provided by the end of the project in the second half of 2021.

14.5 Other National Activities

14.5.1 Geothermal Education

Several Mexican universities offer training in science or engineering in topics relating to geothermal energy. Most offer undergraduate programs in geosciences, physics, chemistry, engineering, and energy. Specialized graduate programs are available at a few universities and scientific research institutions.

Centro Mexicano de Innovación en Energía Geotérmica (CeMIEGeo) promoted the inclusion of geothermal courses in the teaching programs of several academic institutions. It also offered specialized classroom and online courses, sponsored student research stays abroad, and supported student participation in research projects. Over the last five years, more than a hundred students graduated completing theses related to geothermal projects, both at the undergraduate and graduate levels. Additionally, CeMIEGeo offered twelve short courses taught by international experts, both foreign and national, with at least thirty students in each course. The online course Introducción a la Geotermia has registered almost 9,000 attendees and graduated more than 600 students (https://es.coursera.org/learn/geotermia).

14.5.2 Conferences

The 27th annual congress of the Mexican Geothermal Association (AGM), initially scheduled for 2020, has been postponed to 2021 due to the Covid-19 pandemic.

The Final Conference of the GEMex European consortium took place at Potsdam, Germany, on 8-10 February 2020. The proceedings and more information are available at http://www.gemex-h2020.eu/. The 7th Workshop of the GEMex Mexican consortium was held in a virtual format in December 2020. The Mexican consortium participants shared and discussed advances and results about their work activity on Los Humeros and Acoculco geothermal areas.

The Mexican Geophysical Union (UGM) annual meeting took place in Guadalajara, Jal., on 1-6 August 2020 with a hybrid format, virtual and in-person. Two sessions about geothermal and renewable energy were held, with 23 presentations in total.

14.5.3 Publications

CeMIEGeo's Digital Collection (https://coleccciondigital.cemiegeo.org/xmlui/) includes 114 papers in peer-reviewed international journals, 118 theses, and 45 conference posters. It contains 1,727 registers of papers published about Mexican geothermal fields since 1970. These papers were compiled from the GRC Geothermal Library, the IGA's Geothermal Paper Database, DOE Scientific and Technical Information repository, SCOPUS, and WEB of Science.

14.5.4 Useful Websites

Asociación Geotérmica Mexicana (in Spanish): www.geotermia.org.mx

Centro de Investigación Científica y de Estudios Superiores de Ensenada (CICESE) (in Spanish): http://www.cicese.edu.mx/

Centro Mexicano de Innovación en Energía Geotérmica (CeMIEGeo) (in Spanish, with parts in English): http://www.cemiegeo.org/?lang=1

Colección digital CeMIEGeo: https://colecciondigital.cemiegeo.org/xmlui/

Comisión Federal de Electricidad (in Spanish): http://www.cfe.gob.mx/paginas/Home.aspx

Instituto Nacional de Electricidad y Energías Limpias (INEEL) (in Spanish): https://www.ineel.mx//inicio.html

Proyecto GEMex: http://www.gemex-h2020.eu/index.php?lang=en

Secretaría de Energía (SENER) (in Spanish): http://www.gob.mx/sener#prensa

14.6 Future Activity

The expected geothermal electric capacity by 2025 is 1,051 MW_e, considering the dismantling of around 30 MW_e of the oldest power units in Los Azufres and Los Humeros geothermal fields. It also includes the probable installation of small plants of 10 MW_e in some of the geothermal zones currently under exploration by the CFE and other private companies (Gutiérrez-Negrín et al., 2020). This amount is only 12% higher than the operating capacity in December 2020, and it is in agreement with the Geothermal Technology Roadmap for Mexico, which anticipates 1,025 MW_e in 2024 (SENER, 2017).

A geothermal roadmap for direct uses of geothermal heat in Mexico was published by SENER in 2018 . According to it, it is expected that 3,800 MW_{th} will be in operation by 2030, out of which 2,400 MW_{th} would be installations that use the separated brine in the geothermal fields forecast to be in operation by that year (cascading use), 1,000 MW_{th} in applications scattered in the country outside the geothermal fields, and 400 MW_{th} in GHP (SENER, 2018). This seems to be an overestimation in light of the reduction of economic activities due to the pandemic.

The Mexican government wants to strengthen energy companies owned by the state, particularly the oil companies PEMEX and CFE. The CFE's geothermal-electric area might benefit from such a policy and get more resources to develop its portfolio of 13 geothermal zones that have been granted to it. This area of CFE has its own expertise but also can be supported by the CeMIEGeo and financed by the Energy Sustainability Fund or its successor.

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15. New Zealand

Chris Bromley

GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo, New Zealand. Email: c.bromley@gns.cri.nz

15.1 Introduction

During 2020, most of the 21 geothermal generation facilities within New Zealand ran at near maximum capacity. Geothermal generation contributed a total of ~17.8 % of the national electricity supply, amounting to 7610 GWh (slightly more than in 2019).

Optimization of the operation of existing geothermal power-plants has continued, with adjustments in well operation for changes in production well discharge enthalpy, CO_2 content, and injection strategy improvements for more efficient utilization and better sustainability.

A staged expansion of the Tauhara II project near Wairakei and Taupo township, has commenced. Site preparation, drilling and well testing is underway, using existing resource consents (up to 250 MWe). The next stage (168 MWe single axle, triple flash, turbine) is planned to be operational by late 2023 (Contact Energy, 2021).

Construction of the Top Energy Ngawha geothermal project (OEC4 expansion by 31.5 MWe) was completed and successfully commissioned in December 2020.

Interest from policy makers and investors in direct geothermal heat use in New Zealand has continued. The Bay of Plenty Region and the Taupo District Steaming hot – geothermal opportunities abound for wider Bay of Plenty (bayofconnections.com) are promoting geothermal business development seeking to increase the direct use of geothermal energy. Implementation continued of a nation-wide geothermal direct use strategy initiative through the New Zealand Geothermal Association (NZGA, 2021). Although delayed by COVID19, several operators and investors are working on commercial projects that would benefit economically from a supply of geothermal fluids.

The following table provides information on geothermal energy use in New Zealand for 2020. Electricity generation information is from a government ministry (MBIE, 2021), while the direct use information is from material prepared for the New Zealand Country update report to the WGC2020+1. (Carey et al 2021)

Electricity		Direct Use	
Total Installed Capacity (MW_e)	1064	Total Installed Capacity (MW_{th})	500 *
New Installed Capacity (MWe)	31.5	New Installed Capacity (MWth)	0
Total Net Running Capacity (MWe)	1027	Total Heat Used (PJ/yr)	9.7
Contribution to National Capacity (%)	11%	Total Installed Capacity Heat Pumps (MWth)	~20
Total Generation (GWh)	7610	Total Net Heat Pump Use [PJ/yr]	0.4
Contribution to National Generation (%)	17.8%	Target 2017 – 2030 (PJ/yr Primary Energy)	+7.5

Target (% national generation)	20-25%	Estimated Country Potential (MWth or PJ/yr or GWh/yr)	N/A
Estimated Country Potential (MWe)	4000	(no significant change in estimated direct use)	

(N/A = data not available), (* indicates estimated values)

In 2020, the weighted average CO_2 (equiv) emissions factor from New Zealand Geothermal power stations was 69 g/KWh (a reduction from 73 g/KWh in 2019) with an interquartile range for individual power stations of 39 to 96 g/KWh (NZGA 2021, McLean, NZGW2020). This is a significant reduction from previous weighted average emissions factor calculations for New Zealand (140 g/KWh in 1990, MBIE, 2021, Figure 2). The emissions factor decline rate over the past 5 years has been 6% per annum. The emission factors in New Zealand are declining because of degassing of the reservoirs (typically by about 50% per decade) and selective utilization of wells with lower gas contents. The weighted average emissions factor is also reducing because of reduced fluid production from reservoirs with higher gas content (e.g. Ohaaki).

15.2 Changes to Policy Supporting Geothermal Development

The Government Minister for Climate Change established the New Zealand Climate Change Commission (CCC) in December 2019, (Climate Change Response (Zero Carbon) Amendment Act 2019) and during 2020 the CCC established the steps needed for New Zealand to meet its CO_2 emissions reduction obligations. The CCC issued its report in January 2021, which recommended accelerated conversion of transport from fossil fuels to electricity, supporting demand for renewable electricity generation growth (including geothermal).

Although there are no government subsidies for renewable energy to reduce greenhouse gas emissions in New Zealand, a strategic (albeit challenging) target of 100% renewable electricity generation by 2035, in a normal hydro-generation year, has been announced. (This is in addition to the previous target of 90% renewable by 2025).

The New Zealand government is also exploring the establishment of targets for renewable heat and electrified transport in addition to its targets for renewable electricity. The Energy Efficiency and Conservation Authority in conjunction with MBIE continues to develop a strategy on Process Heat in New Zealand.

The New Zealand geothermal Association submitted to the government, in February 2020, a response to "Accelerating Renewable Energy and Energy Efficiency", a policy discussion document associated with the role of geothermal resources in delivering a Zero Carbon future in New Zealand by 2050. https://www.nzgeothermal.org.nz/news--events/nzga-submission-on-accelerating-renewable-energy-and-energy-efficiency-discussion-document/. The four main messages were: support writing business cases to assist with geothermal utilisation; advocate wood and geothermal energy symbiosis to leverage advantage; assist further emissions reduction initiatives from geothermal facilities; and support direct use geothermal resource availability study.

15.3 Geothermal Project Development

15.3.1 Projects Commissioned

The 31.5 MWe Ngawha expansion (OEC4) geothermal power project was commissioned in December 2020. This brings the combined output at Ngawha to 56 MWe, the total New Zealand operating net running capacity to 1027 MWe, and has changed the relative distribution of power plant manufacturers to the following: Ormat (OEM or hybrid) 37%, Fuji 28%, Toshiba 15%, Mitsubishi 4%, and British Thomson & Houston (the original Wairakei turbines) plus others 16% (Daysh et al, 2021).

15.3.2 Projects Operational (at the end of the reporting year)

During 2020, normal operation of most existing geothermal power plants continued at near maximum generation capacity, specifically at Wairakei-Tauhara, Mokai, Rotokawa, Ngatamariki, Kawerau and Ngawha. Ohaaki has continued to operate at reduced capacity owing to constraints on fluid supply, as described in previous annual reports. New Zealand geothermal power-plant availability factors are typically 85-99%. These vary depending on individual turbine performance (including refurbishments that facilitate operation at greater than nameplate capacity), seasonal atmospheric conditions (e.g. air-cooling efficiency for OEC turbines), and reservoir performance (especially changes in fluid enthalpy and operating pressure). Pressure changes induce boiling or resaturation of producing steam zones, and recharge may be induced from source fluid, marginal fluid, or reinjected fluid).

Deep drilling activities of 7 wells in 2020 included a production makeup well at Rotokawa, and a production and 2 reinjection wells at Tauhara for the Tauhara II expansion. Two deep production makeup wells were drilled at Kawerau and one observation/exploration/delineation well at Mokai. The MB Century Rig 32 was used for five of these wells and the Big Ben rig for the other two. Shallow drilling for direct use or monitoring purposes included 2 production and 1 observation well at Tauranga (a low enthalpy field in the Bay of Plenty region), 2 reinjection wells at Rotorua, and 2 shallow production wells at Taupo.

The Geo40 project (https://geo40.com/), a collaborative development at Ohaaki, involving Contact Energy, and Ngati Tahu Trust, has seen further expansion of a demonstration silica extraction plant into a successful commercial operation producing colloidal silica 'sol' for the international market. The plant processes 6800 tonnes/day of separated geothermal water prior to reinjection. Geo40 are also investigating the extraction of various species including lithium and boron through small scale trials. Following successful trials of near-battery grade lithium extraction, construction has started on a lithium extraction pilot plant at Ohaaki.

The 31.5 MWe expansion (OEC4) of the Ngawha project is complete. Pipeline, power-station and transmission line construction were complete with commissioning by December 2020, 6 months earlier than planned http://ngawhageneration.co.nz/constructing-the-new-power-stations/.

During 2020, at the Mokai Geothermal Field, Halcyon Power New Zealand has been constructing a 1.5 MW pilot 'green' hydrogen manufacturing facility, using geothermal electricity directly from the Mokai geothermal power plant. The facility is a joint venture between Tuaropaki Trust and Japan's Obayashi Corporation (https://www.facebook.com/jacindaardern/videos/824262991443480/).

Large industrial direct use applications (paper manufacture, timber drying, space heating, aquaculture, milk processing and horticulture) at Kawerau, Tauhara, Ohaaki, Wairakei and Mokai, continued as per previous years. In addition to Norske Skog, industrial direct heat uses in Kawerau include CHH wood products, Asaleo Care (tissue paper), Oji Fibre Solutions (pulp and paper), Sequal Lumber (timber drying) and the Waiū milk processing factory (about 20 MWth). While the demand for newsprint has diminished, the demand for renewable energy to process pulp, toilet paper and tissue paper has expanded. "Natures Flame" geothermally-heated wood-pellet manufacturing facility in Taupo has expanded its operation to 85,000 tonnes/year (https://www.youtube.com/watch?v=ZaiOTsNzJ9A). Smaller-scale direct-use applications for bathing, building heat, tourist facilities, etc, also continued at a similar level to previous years.

15.4 Research Highlights

"Geothermal: The Next Generation" (https://www.geothermalnextgeneration.com/) is a 5-Year Endeavour Research project (2019-2024) funded at NZ$2M/year by the New Zealand Ministry of Business, Innovation and Employment, looking towards the future of geothermal prospects, and in particular the deeper supercritical temperature resources (>5 km, >400 °C). This research will: define heat transfer mechanisms from magma to surface; investigate the composition of supercritical fluids; detail interactions between rocks and fluids; find the best exploration drilling targets for supercritical fluids; map the potential of these resources, and translate the science, making information accessible (Climo at el, 2020+1). The research involves significant international collaboration and will also investigate technologies to capture and reinject gas emissions.

Core geothermal research funded by the government at about NZ$2.5M / yr continued at GNS Science under the title "New Zealand's Geothermal Future". Topics are:

- Shallow resources and direct use,
- TVZ - Structure and Dynamics;
- TVZ – Source models; and
- Reservoir Chemistry.

The "Endeavour Fund" has supported research into "Empowering Geothermal Energy; Increased Utilisation of Geothermal Energy Through New Integrated Geoscience Methods". This project addresses the geoscientific uncertainties of accessing underground resources. The project is funded at NZ$1.3M / yr until 2022.

An ongoing 2-year "Marsden" research project (2019-2021) addresses the topic of improved understanding of natural CO_2 flux passing through Taupo Volcanic Zone geothermal systems from deep underground through the surface to the atmosphere.

Industry-funded research activities also continue. They include applied research projects through collaboration between government-funded, company-funded and university graduate research programs. These activities focus on opportunities and practical problem-solving tasks associated with diverse topics such as: scaling, tracer performance, mineral extraction, subsidence, reservoir simulation and injection technology.

MB Century and Western Energy continue to improve and develop practical technology for servicing the geothermal industry, both locally and internationally.

Waikato and Bay-of-Plenty Regional Council science staff continue investigating methods and commissioning research to improve environmental monitoring of surface geothermal features

The potential for utilisation of deep hot brines in abandoned oil wells within the Taranaki province (west coast North island) remains under investigation.

University of Auckland, Geothermal Institute research outputs include simulation modelling of Ohaaki CO_2 gas emissions (both natural and through the power station) by O'Sullivan et al (2021). This work demonstrated that production-induced depletion of reservoir gases that occurs during a typical production cycle (~100 years), when following by a period of natural recovery (~200 years), results in a net zero emission effect from the power project when considered over the long term (~300 years). That is, the increased anthropogenic power station emissions of a project are offset by reduced natural emissions.

15.5 Other National Activities

15.5.1 Geothermal Education

The University of Auckland normally operates the PGCert geothermal diploma course, but this was suspended in 2020 because of COVID19 travel restrictions for overseas students. In normal years government-sponsored scholarships (up to 25 students) target the training needs of countries such as Indonesia, Philippines, Mexico, Kenya and the Caribbean. The Geothermal Institute also supervises research, involving Masters or PhD students, on a variety of topics including reservoir modelling, subsidence, induced seismicity, 2-phase flow, etc.

The University of Canterbury continues to run a geothermal graduate program (Geothermal Energy Systems Engineering Group within College of Engineering, and Geothermal Resource Research Group within the School of Earth and Environment).
https://www.canterbury.ac.nz/engineering/schools/mechanical/research/geothermal-energy/

https://www.canterbury.ac.nz/science/schools/earth-and-environment/research/geothermal-resource/

The NZ Ministry of Foreign Affairs and Trade (MFAT) working with NZTE (Trade and Enterprise) provides funds for joint off-shore geothermal projects in Africa (NZAfrica Geothermal Facility, Comoros partnership), Indonesia (geothermal training, scholarships, and technical assistance for the World Bank), and Latin America– Caribbean (partnership).

15.5.2 Conferences

The 2020 (42nd) New Zealand Geothermal Workshop was organised by the Geothermal Institute, University of Auckland, and was held at Waitangi, Bay of Islands on 24-26th of November. It involved 60 oral presentations, 8 posters and 17 industry update presentations. A program is available from https://www.geothermalworkshop.co.nz/2020-workshop-2/. Papers can be accessed through the IGA database of conference papers. The workshop was held in Northland to provide attendees with the opportunity to visit and learn more about the Ngawha OEC4 project.

Unfortunately the mid-winter seminar usually organised by the New Zealand Geothermal Association in Taupo had to be cancelled due to COVID19.

15.6 Publications

Publications documenting recent geothermal research and operational history from New Zealand can be found in the following conference proceedings and journals for 2020 : World Geothermal Congress (2020+1), NZ Geothermal Workshop, Stanford Geothermal Workshop, Geothermal Resources Council conference, and Geothermics journal. Examples of relevant publications are: Alcaraz et al (2020+1), Climo et al (2020+1), Daysh et al (2020+1), McLean et al (2020), Seward and Carey (2020+1). Regular newsletters from the New Zealand Geothermal Association (NZGA) provide topical information on industry trends: https://www.nzgeothermal.org.nz/newsletters/ and an industry update is provided by NZGA (2020).

15.7 Useful Websites

NZGA: https://nzgeothermal.org.nz/

Geoheat: http://www.nzgeoheat.nz

MBIE: https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-publications-and-technical-papers/new-zealand-energy-quarterly/

Geothermal Institute: http://www.geothermal.auckland.ac.nz/

GNS: http://data.gns.cri.nz/geothermal

IPGT: https://ipgtgeothermal.org/about-us/

GNG, Geothermal the Next Generation: https://www.geothermalnextgeneration.com/

IGA papers database: https://www.geothermal-energy.org/explore/our-databases/conference-paper-database/

15.8 Future Activity

Figure 1 shows an updated historical (to 2020) and projected growth (from 2015 to 2025) in geothermal electricity generation for New Zealand, relative to other generation options. Combined renewable power generation decreased in 2020 from 82.4% to 80.8% due to dry hydrological conditions affecting hydro generation. The forward projection assumes a demand growth rate of 0.5% per year. Although recent demand growth has been relatively static, electric vehicle uptake is expected to contribute to renewable electricity demand growth, perhaps by up to 15% over the next 10 years (NZGA , 2021). Solar power is expected to grow from 0.2% to 0.5% of total generation, and bio-gas/wood waste generation to about 1.5 %. If new or expanded geothermal (rising to about 24%) and wind projects (rising to 8%) eventuate, as predicted, then coal-fired generation is expected to reduce to near zero, and gas-fired generation to about 9%, resulting in more than 90% renewable electricity generation, which is a key 2025 strategy target set by the New Zealand government.

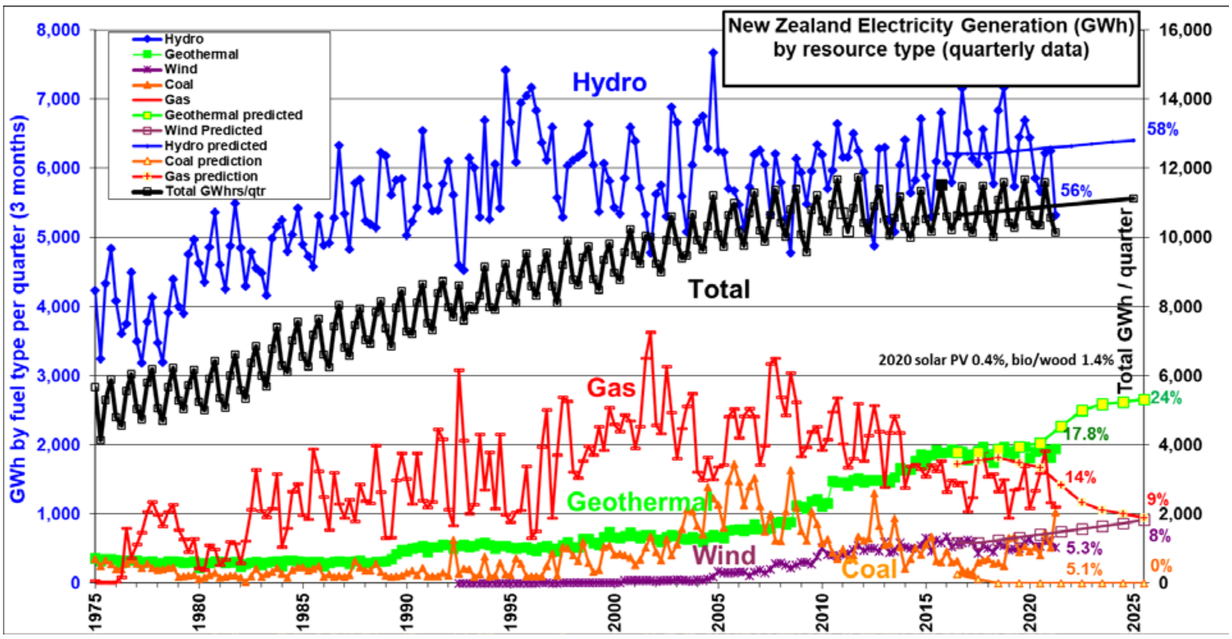

Figure 1. Updated plot of actual (>1975) and projected growth (to 2025, since 2015) in generation fuel-types in New Zealand. The geothermal share of 17.8% in 2020 is projected to grow to as much as 24% by 2025, if investment conditions remain favourable. Historical data source: MBIE (2021).

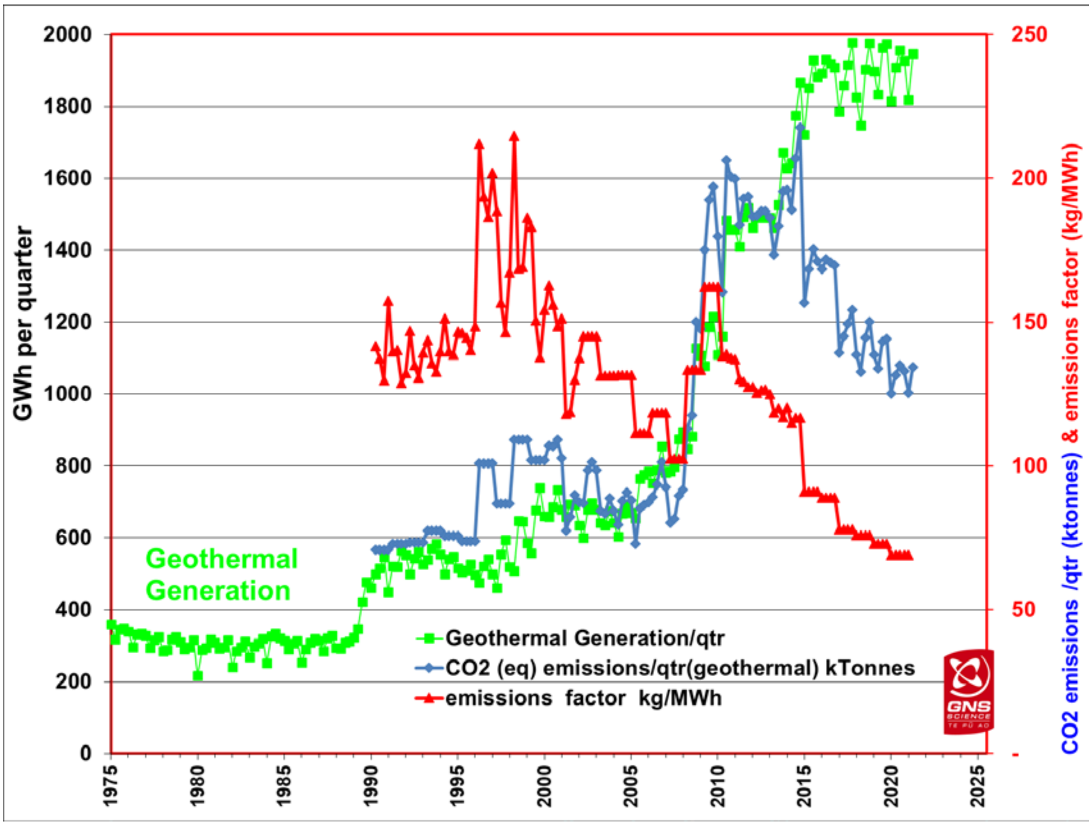

Figure 2. Historical trends in geothermal CO2 emissions and weighted average emissions factor (kg CO2 eq/MWh) compared with generation from New Zealand geothermal power plants. Data from MBIE (2021) and McLean et al (2020)

Kawerau: the Te Ahi O Maui (TAOH) (Eastland Generation) 25 MW binary power plant at Kawerau (up to 15 kt/day fluid) completed its second year of commercial operation in 2020. NTGA (Kawerau) has consents in place for an expansion of fluid take and injection (45 kt/day) for industrial direct heat and power. Demand for steam from NTGA is growing, with new continuous timber drying kilns, the Waiū facility for milk drying, Sequal Lumber timber drying kilns, and Oji-fibre Solutions taking process steam from the NTGA clean steam plant to power some of their pulp production. With the drilling of KA57 in 2020, and modifications to the clean steam facility, NTGA anticipate they will be able to meet demand growth.

Ngawha: Following commissioning of the 31.5 MWe power plant in 2020, a proposed 2nd-stage expansion within 5 years could ultimately mean the Far North Region (Northland) will become self-sufficient in electricity.

Ngatamariki power station has space for two more ORC units (~40 MWe additional capacity), and the operators (Mercury Energy) are at the early stages of planning for this proposed capacity increase.

Tauhara: As noted above, the Tauhara II 250 MW project has commenced incremental stages of expansion. Well testing and drilling (production and reinjection wells), and design and planning work of a 168 MWe stage were completed in 2020 and commissioning is anticipated by late 2023. The proposed stages of this project are expected to add another 100 MWe between 2023 and 2028.

Wairakei Power Station consents expire in 2026, and preparations have commenced for consent renewal. This involves the planned shutdown of the original Wairakei power stations (A and B) and expansion of the Te Mihi power station by about 82 MWe to utilize a total of 250 kTonnes/day of geothermal fluid.

The proposed 25 MWe Taheke Geothermal Project, a joint venture between Taheke 8C Trust (15%) and Eastland Generation (85%) was announced in July 2020. It is supported by a Government Provincial Growth Fund grant of NZD 11.9 million. This grant is going towards design, consenting, civil works and drilling of a new exploratory geothermal well.

Mercury Energy and Contact Energy have both initiated pilot schemes to examine the feasibility of injecting non-condensing gasses (NCG, ie CO2, CH_4 and H_2S) from binary plants. Top Energy has also experimented with limited NCG re-injection at Ngawha and is investigating further. These experiments are expected to accelerate in the near future.

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16. Norway

Jiri Muller

Institute for Energy Technology, P.O. Box 40, 2027 Kjeller, Norway. Email: jiri@ife.no

16.1 Introduction

Geothermal energy use in Norway is dominated by the relatively widespread deployment of geothermal heat pumps. There is no electricity production from geothermal resources, and there are no deep geothermal energy installations in operation. As the third-largest exporter of energy in the world and with an electricity supply almost totally dominated by hydropower, Norway has a large share of renewable energy in both its total primary energy supply and in its electricity supply. Although energy use per capita is close to the average for European countries, the electricity consumption ratio is very high (23 MWh per capita), second only to Iceland.

There is a strong lobby from academic institutions (universities / research institutes) and industry to promote geothermal energy (including deep geothermal) to politicians and the public. The umbrella organisation is the “Norwegian Centre for Geothermal Energy Research” (CGER) established in 2009. Membership of CGER has been steady since 2016. There are currently the following partner organisations:

- NORCE Norwegian Research Centre AS (host institution, https://www.norceresearch.no/)
- GCE NODE (http://gcenode.no/)
- GTML (http:/www.gtml.energy/)
- GREENSTAT (http://greenstat.no/)
- Huisman (https://www.huismanequipment.com/en/about_huisman/locations/norway)
- Innovative Solutions
- Institute for Energy Technology (IFE, http://www.ife.no/)
- NORSAR
- NTNU (http://www.ntnu.no/)
- SINTEF (https://www.sintef.no/en/)
- EQUINOR (https://www.equinor.com/)
- University of Bergen (http://www.uib.no/)
- University of Stavanger (http://www.uis.no/?lang=en_GB)
- WELL ID AS (http://wellid.no/)

Increasing the use of geothermal energy in Norway is aligned with the country´s energy policy of increasing the use of renewable energy resources. Additionally, the Norwegian industrial and academic expertise in offshore technologies should be readily utilised in an emerging geothermal industry with emphasis on deep drilling, well technology, reservoir management, corrosion and scaling mitigation, and tracer technology.

To date all geothermal installations in Norway are geothermal heat pumps (GHP). Statistics from the Norwegian Heat Pump Association (NOVAP) identifies a peak of 3979 GHP installations in 2018 (Figure 1.1). The high sales figures in 2018 and 2019 are due to a ban on fossil oil for heating in buildings from 2020.

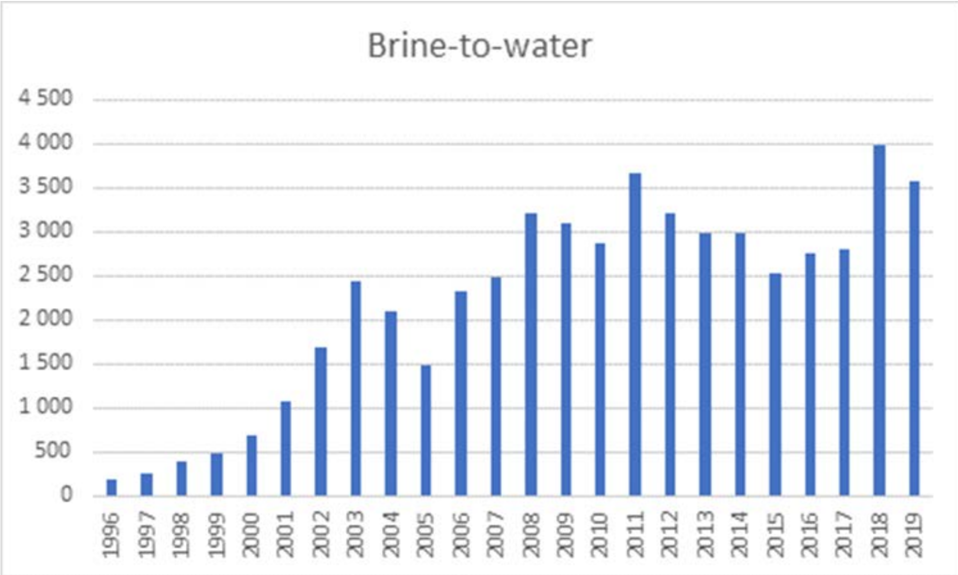

Figure 16.1 Geothermal Heat pump sales statistics for Norway from 1996 to 2019. Source: Norwegian Heat Pump Association (NOVAP)

NOVAPs statistics cover approximately 90% of the Norwegian heat pump market. NOVAP has estimated that there are about 53,336 brine-to-water units sold in Norway in the period 1996-2019.

The majority of the GHP systems in Norway are vertical closed loop systems extracting heat and/or cold from crystalline rocks through borehole heat exchangers (BHE).

A typical Norwegian GHP is based on one or more boreholes drilled to between 50 and 300 meters. A trend towards deeper boreholes has been observed, partly due to reduced drilling costs for deeper boreholes. A representative Norwegian GHP system uses a 115 mm diameter borehole with a single 40 mm U tube installed. Some BHEs use alternative collectors, such as coaxial arrangements or collectors with a rougher surface which produce turbulent flow at lower flow rates. The Norwegian drilling industry has historically been dominated by Norwegian companies, but in the last few years some companies from Finland and Sweden have started servicing the market.

NOVAP collects statistics on heat pump systems in Norway from the leading suppliers in the 0-20kW range. In the over 20kW size, there are a few suppliers that do not provide sales data. NOVAP is seeking to collect this data and will include it in future reports when available. The data from NOVAP is for all types of liquid-to-water heat pumps including systems that source energy from rock, the sea, ground (subsoil) water etc. However, by far the dominant source is heat from rocks. Summary data from NOVAP on liquid-to-water systems is displayed in Table 1.1.

Table 16.1 summarises the status of geothermal energy use in Norway in 2017.

Electricity		Direct Use	
Total Installed Capacity (MW_e)	0	Total Installed Direct Use (MWth)	na
Contribution to National Capacity (%)	0	Total Heat Used TJ/yr Total Heat Used TWh/yr	5746 1,6
Total Generation (GWh)	0	Total Installed Capacity for Heat Pumps (MWth)	904

Table 16.1 Geothermal energy use in Norway 2017.

(The data is based on NOVAP statistics. na=data not available)

It should be emphasized that data in Table Table 16.1 includes only liquid-to-water heat pump systems which are considered truly geothermal. However, Norwegian buildings are primarily heated by less efficient (but cheaper) air-to-air systems and by air-to-water systems. NOVAP also collects statistics for these systems. In the period 1996-2017, 40,175 air-to-water systems and 967,158 air-to-air systems have been sold, with corresponding heat production in 2017 of 0.6 TWh/yr and 6TWh/yr, and installed capacities of 541 MWth and 5,091 MWth. NOVAP identifies the SPF for both of these systems to be 2,5, while the SPF is 3.5 for liquid-to-water systems.

16.2 Changes to Policy Supporting Geothermal Development

The Research Council of Norway (RCN) is supporting geothermal research projects through its programme "ENERGIX" with IPN and KPN projects (see Section 3). Funding from national agencies "Enova" and "Innovation Norway" is also possible for larger industrial projects such as deep well drilling. Norway is contributing to the EU funded Horizon 2020 programme, and some Norwegian organisations have been involved in these geothermal projects.

16.3 Research Highlights

The following section describes the research highlights of some organisations involved in geothermal energy in Norway.

16.3.1 CGER - Norwegian Center for Geothermal Energy Research

Based on a steering group decision, CGER has recently applied to become an affiliated member of the International Geothermal Association

As a result of the covid-19 situation all CGER meeting activities have been moved to online.

CGER has held two meetings. On June 25th CGER held an extended online partner meeting with presentations on ongoing and completed projects. Presentations covered deep geothermal, drilling fluids, casing, scale handling, CO_2 enhanced geothermal systems and modelling of supercritical systems. On September 28th, a webinar was held in collaboration with GCE NODE, with contributions from ISOR on casing solutions for high temperature systems, from EGEC on EU activities and plans, and from Qmatek on drilling solutions. Presentations from the webinar are available on the CGER website.

16.3.2 Current nationally led research projects

Project	Project lead	Project type	Project period
Improving the energy efficiency of geothermal energy utilisation by adjusting the user characteristics	NORCE	EEA	2020-2023
Digitalization of multi-reservoir geothermal systems for optimal control of heat production, storage and peak-load management.	RUDEN AS	IPN	2020-2023
Simulation of governing processes in superheated and supercritical geothermal systems: mathematical models, numerical methods and field data	UiB	KPN	2020-2024
DeepScale - Deep geothermal flow assurance; cost-efficient scale handling and heat fluid robustness.	SINTEF (IFE)	KPN	2019-2022
Low cost drill bit body material for geothermal applications.	Lyng Drilling	IPN	2018-2021
Novel concept for energy efficient hard rock drilling towards cost-effective geothermal energy harvesting	SINTEF		2018-2021
Modeling of high temperature, high pressure geothermal energy production system	NTNU	KPN	2017-2021
Cost-effective and Reliable Engineered Casing Systems for super-HT Geothermal Wells	Equinor	IPN	2017-2021
Thermo-mechanical subsurface energy storage (TheMSES)	UiB		2016-2021
Technology platform for research-based innovations in deep geothermal drilling (INNO-Drill)	Sintef	KPN	2016-2019

Fellesløsning grunnvann til varme og kjøling i Melhus sentrum (ORMEL2)	Melhus kommune		2018-2021
Enhancing geothermal reservoirs - hydraulic and thermal stimulation technology	UiB	KPN	2017-2020
Modeling of high temperature, high pressure geothermal energy production system	NTNU	KPN	2017-2020
Cost-effective and Reliable Engineered Casing Systems for super-HT Geothermal Wells	Statoil ASA	IPN	2017-2020
Integrerte varme- og kjølesystem for sykehusbygg med mål om minimal brutto energibruk	Norconsult	IPN	2017-2020
RockStore - develop, demonstrate and monitor the next generation BTES systems	NORCE	KPN	2018-2021
Cryogenic cooling canister for downhole tools	Norwegian Well	IPN	2018-2020
Deep geothermal flow assurance; cost-efficient scale handling and heat fluid robustness.	Sintef	KPN	2019-2020

In addition, IFE is involved in two EU HORIZON 2020 geothermal projects related to deep geothermal energy (GECO and REFLECT).

16.4 Other National Activities

16.4.1 Geothermal Education

Please refer to previous Norway country reports.

16.4.2 Conferences

CGER is planning the international conference GeoEnergi in 2021 with participation from international scientific guests, politicians and media.

16.4.3 Useful Websites

www.rcn.no
www.cger.no
www.enova.no
http://www.energi21.no/
www.novap.no
www.innovasjonnorge.no
www.nve.no

16.5 Future Activity

The geothermal community in Norway continues expanding its activities. This involves more than academic institutes and universities. Small Norwegian enterprises which are spin-offs from a declining oil industry are motivated to penetrate emerging domestic and international geothermal markets. They are encouraged and co-financed by Norwegian government organizations (RCN, ENOVA, INNOVATION NORWAY) and the EU, which support development and deployment of renewable energies.

17. Republic of Korea

Yoonho SONG, Tae Jong LEE

Deep Subsurface Research Center, Korea Institute of Geoscience and Mineral Resources (KIGAM), Gwahang-no 124, Yuseong-gu, Daejeon 34132, Korea, Email: song@kigam.re.kr; megi@kigam.re.kr

17.1 Introduction

Geothermal utilization in Korea is primarily direct use from ground-source or geothermal heat pump (GHP) installations, because there are no high temperature resources associated with active volcanoes or tectonic activity. Installed GHP capacity has increased rapidly since the middle of the 2000's, with more than 100 MW_{th} of new installation annually, and the total installed capacity estimated to have exceeded 1,500 MW_{th} as at the end of 2020 (See Table 1 below).

All activities associated with deep geothermal development or exploration were stopped after the 15th November 2017 Mw 5.4 earthquake which occurred in the vicinity of the Pohang EGS pilot plant site. R&D funding to other geothermal use such as topics related to geothermal heat pumps was also cut down partly because of the negative perception regarding geothermal.

Table 17.1 Geothermal utilization in Korea as of December 31, 2020.

Electricity		Direct Use	
Total Installed Capacity (MW_e)	-	Total Installed Capacity (MW_{th})	43.6
New Installed Capacity (MW_e)	-	New Installed Capacity (MW_{th})	0
Total Running Capacity (MW_e)	-	Total Heat Used (PJ/yr) [GWh/yr]	0.594 [164.9]
Contribution to National Capacity (%)	-	Total Installed Capacity Heat Pumps (MW_{th})	1,536.5*
Total Generation (GWh)	-	Total Net Heat Pump Use [GWh/yr]	861.4*
Contribution to National Generation (%)	-	Target (PJ/yr)	N/A
Target (MW_e or % national generation)	-	Estimated Country Potential (MW_{th} or PJ/yr or GWh/yr)	N/A
Estimated Country Potential (MW_e or GWh)	19,600 MWe		

(N/A = data not available)

(* indicates estimated values)

17.2 Changes to Policy Supporting Geothermal Development

Renewable energy is becoming a more important element in the national energy policy, but as yet geothermal is not separately specified in the policy. The Third National Energy Master Plan which was finalised and declared in June 2019 by the Korean Government has a vision of "Sustainable growth and improving the quality of people's life through energy transition".

It specifies five major tasks:

1) Converting energy policy paradigm to focusing on consumer innovation,
2) Switching to a clean and safe energy mix,
3) Enlarging distributed and participatory energy systems,
4) Strengthening global competitiveness of energy industry, and
5) Expansion of foundation for energy transition.

For Task 2, it states a target of renewable share of power generation being 30-35% by 2040. There are ongoing subsidy programs and a mandatory act supporting renewable energy deployment which includes geothermal heat pump installation.

In addition, in December 2020 the government declared 'Carbon neutrality' or 'Net zero' by 2050 with 'Green New Deal' policy. Detailed action plans are expected to be set up from 2021.

Renewable power generation, especially solar PV and wind, is expected to increase rapidly under the policy, but investment in geothermal power may not be active due to growing concern on possible links with damaging earthquakes. Table 2 shows geothermal R&D expenditure for the past six years. There was a considerable decrease in R&D investment in 2016 after government funding to the Pohang EGS project ended in 2015. Because the only other investment in deep geothermal, exploration for hydrothermal resources at the remote Ulleung Island, finished in 2016, the total R&D expenditure is decreasing. Especially, there has been a notable decrease of R&D funding since 2019 which means that R&D investments not only for deep geothermal but also for GHP significantly declined. Geothermal R&D investment from major funding agency 'Korea Institute of Energy Technology Evaluation and Planning' zeroed out in 2020. Government funding in 2020 accounts only for basic scientific research within the Korea Institute of Geoscience and Mineral Resources (KIGAM). There may be some other R&D investments, but no information is available.

Table 17.2 Geothermal R&D expenditure for the period 2015-2020 (in *US$ 1,000).

	2015	2016	2017	2018	2019	2020
Government	9,232	6,464	5,842	5,672	1,362	829
Industry	5,772	2,530	2,073	399	301	0
Total	15,004	8,994	7,915	6,071	1,663	829

*Exchange rates (in KRW/USD) are as of July 1st each year - 1,140 (2015), 1,168 (2016), 1,165 (2017), 1,134 (2018), 1,183 (2019), and 1,225 (2020).

17.3 Geothermal Project Development

17.3.1 Projects Commissioned in 2020

No new projects were commissioned in 2020, the same as in 2019. There was active planning for a project initiating geothermal power generation at a remote Ulleung island in the East Sea (see 2016 Country Report). However, after the official report on the relationship between the Pohang earthquake and the nearby EGS project, the project development was stopped.

17.3.2 Projects Operational at the end of 2020

The Pohang EGS pilot project, which was the only active development in Korea, was terminated due to the earthquake, and thus there are currently no operational projects.

17.4 Research Highlights

There were no notable results or publications on EGS or deep geothermal in 2020.

Monitoring of the performance of new GHP systems in comparison to air-source heat pumps by alternating the use of each system in a KIGAM building started in early 2019 (see 2018 Korea Country Report), but no comprehensive analysis is available yet.

As part of Working Group 8 activities of IEA Geothermal, we developed a new data collection spreadsheet for GHP statistics. Data for the new statistical scheme is collected through an Excel spreadsheet with input options for installations including individual residential houses, commercial/institutional/multi-family buildings, and others such as greenhouses separately. By adopting a concept of gross and net energy production with input of equivalent full load hours and seasonal performance factors which are different not only for each installation type but also depending on heating or cooling, annual thermal energy use and renewable energy production are automatically calculated for heating and cooling applications separately. The information sources and the accuracy of the information can also be added, allowing the reliability of the statistics to be evaluated. Additionally, the new statistical questionnaire of IEA Geothermal includes a separated sheet for 'free cooling', if data is available. This questionnaire comes with a user guide to better understand the underlying principle. All the technical details will be presented at the World Geothermal Congress 2020 (Song et al., 2020).

17.5 Other National or Academic Activities

No national or academic activities regarding deep geothermal development are available from 2020. GHP installations continue to track with more than 100 MW_{th} of installations per year since 2012 (except a little bit less in 2019) resulting in more than 1,500 MW_{th} cumulative capacity at the end of 2020. Figure 1 shows the increasing trend of GHP installation since 2006.

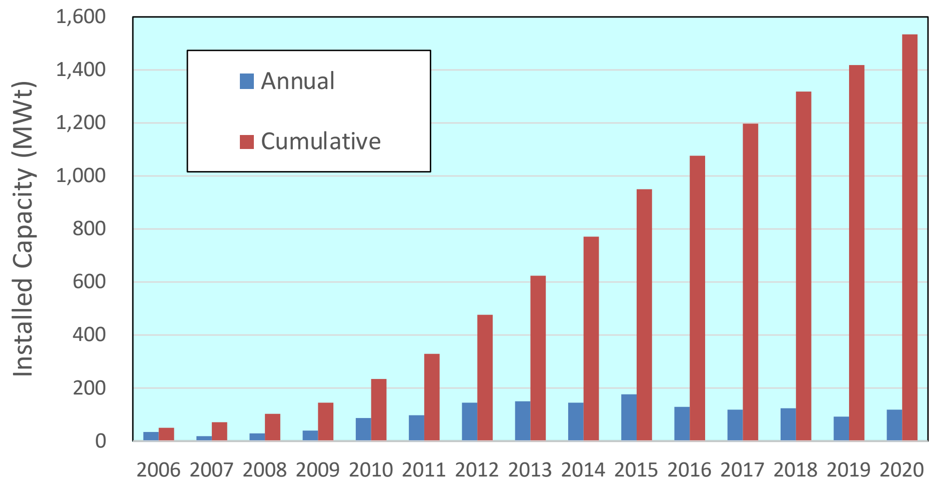

Figure 17.1 Increasing trend of GHP installation since 2006.

17.6 Future Activity

Geothermal utilization in terms of GHP installation will continue to steadily increase but with a lower rate: a bit less than 100 MW_{th} annually is expected. Rapid increase was due to the active subsidy programs and the special 'Mandatory Act'. However, the installation plan of GHP according to the 'Mandatory Act' shows a decreasing trend since 2017, while the total subsidy stays more or less at the same level between 20 and 30 million USD annually.

Geothermal utilization statistics are an on-going issue. In Korea, official geothermal energy statistics deal only with GHP and thus other direct uses including space heating, spas, and greenhouse heating are not included in the national statistics. Korea has been reporting other direct use statistics to IEA Geothermal with the help of hot spring survey data. For GHP statistics, there is no official distinction between heating and cooling, but just a lump sum of all energy production throughout a year, which does not consider the 'pure geothermal contribution' as yet. Effort is needed to establish a revised method of collecting official statistics on geothermal uses that is compatible with international standards such as the IEA statistics. Since 2018, IEA Geothermal has collected GHP statistics with the new scheme proposed as a result of IEA Geothermal Working Group 8 activities (see Chapter 4) and this scheme could guide the updating of Korean GHP statistics once it is accepted by the international community.

The outlook for geothermal power generation in Korea is not positive due to growing concerns of possibly damaging earthquakes. After the Mw 5.4 earthquake occurred close to the Pohang EGS site, all deep geothermal exploration activity was stopped and all projects are currently in hiatus. The government is very keen to foster renewable energy deployment to substitute for nuclear power, but even so the outlook for geothermal investment is not promising for the time being.

17.7 References

Song, Y., Link, K., Yasukawa, K., and Weber, J., 2020, Proposal of new data collecting spreadsheet for geothermal heat pump statistics - An outcome of IEA Geothermal Working Group activities, Proceedings World Geothermal Congress 2020, Reykjavik, Iceland, April 26 - May 2, 2020.

18. Spain

Margarita de Gregorio, Paloma Pérez

Spanish Geothermal Technology Platform, Doctor Castelo 10, 3 C-D. 28009, Madrid, SPAIN.
Email: margadegregorio@geoplat.org pperez@geoplat.org

18.1 Introduction

The Spanish Geothermal Technology and Innovation Platform (GEOPLAT) is a sectorial coordination group led by industry, consisting of all relevant stakeholders in geothermal energy in Spain (Companies and Small to Medium Enterprises, Technology Centres and Foundations, Associations and Cooperatives, Universities, Public Entities, Public Research Centres). It aims at identifying and developing sustainable strategies for the promotion and marketing of geothermal energy in Spain.

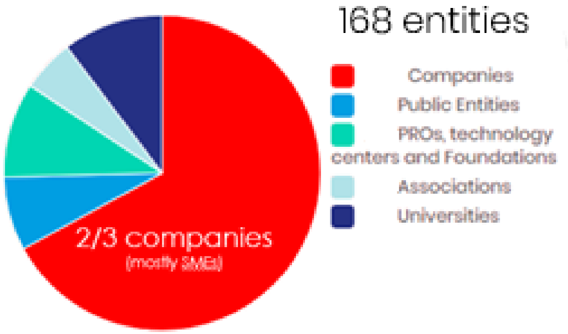

Figure 18.1 GEOPLAT Sponsor Members

GEOPLAT is a public-private entity promoted by the Spanish Ministry of Science and Innovation.

GEOPLAT focuses on geothermal energy as a renewable resource, and associated technologies. It covers the identification and evaluation of geothermal resources, as well as sustainability and regulatory aspects.

GEOPLAT has a Steering Committee to coordinate the actions of the platform, to ensure the compliance of the objectives by each of the working groups, and to encourage participation and connection between them.

GEOPLAT mainly aims at identifying and developing sustainable strategies for the promotion, implementation, and dissemination of geothermal energy in Spain. It covers research, development and innovation activities in terms of identification and evaluation of resources, as well as the use of geothermal energy in all its forms and its technologies. Sustainability and regulatory framework aspects are considered in all activities of the Platform, as well as the relation and collaboration with other similar platforms, both national and European.

18.1.1 Specific objectives:

- To provide a framework within which all agents work together in a coordinated manner to ensure the commercial viability and continuous growth of geothermal, in a competitive and sustainable form.

- To analyze the status of geothermal energy in Spain considering all stages of the value chain, from the different types of resources to their end use, considering all the technologies that allow their use.

- To identify R&D needs and to recommend funding for research in strategic areas.

- To coordinate different participants of the science-technology companies involved in the technological chain (at national and international level), and to encourage business participation in the development of action plans, R&D and marketing.

- To participate in international forums and other activities.

- To publicize the potential of geothermal energy as well as the results and recommendations of GEOPLAT in all related sectors.

- To promote training at all levels related to geothermal energy, to raise awareness and to mobilize society and governments at national, regional and local levels.

18.1.2 Main activities of GEOPLAT:

- Close collaboration with public bodies and institutions with competencies in the geothermal sector at a national level.

- Participation in European and international activities including European Technology Platforms (Deep Geothermal and Renewable Heating and Cooling; Deep Geothermal ETIP), and IEA Geothermal.

- Offer official training courses on geothermal energy. Establishment of the basis of an official professional qualification in geothermal.

- Communication and dissemination: Editing of official documents, reports and analysis from the geothermal sector. Organization of workshops and geothermal events.

18.2 Geothermal Highlights in 2020

At the beginning of 2020, the Spanish Government sent the Integrated National Energy and Climate Plan (INECP) 2021-2030 to the European Commission. This Plan places Spain on the path to achieve climate neutrality by 2050 and comply with the Paris Agreement. The plan foresees to eliminate, in the next ten years, one of every three tons of greenhouse gases that are currently emitted. For this, the presence of renewables in the final use of energy is doubled.

The revision of the Spanish Integrated Energy and Climate Plan 2021-2030 sets the target of installed power in 2030 from other renewables (marine and geothermal energy) at 80 MW. In the thermal field, the Plan sets a target of 34% of renewables in heating & cooling applications compared to 15% currently. In this scenario geothermal could play a very relevant role, as it is the only highly efficient renewable heating & cooling technology capable of providing heat and cooling in the same installation, without outdoor units, without emissions, noise, or cooling towers and without contributing to the 'heat island' effect, which is increasingly present in urban centers.

In March 2020, the Spanish Ministry for the Ecological Transition and the Demographic Challenge approved the first resolution to call for renewable energy auctions with the new remuneration framework. The publication of the first resolution culminated in a regulatory process that would allow offering a stable framework for investment in renewables and transferring to consumers the savings derived from the implementation of new renewable installations. The first auction will establish a target quota of 3,000 MW, of which at least 1,000 MW are for photovoltaic and another 1,000 MW are for onshore wind, leaving the rest of the power to be auctioned without technological restriction, without considering, once again, geothermal energy or other new and innovative technologies.

Even though geothermal energy is not contemplated in the plans or in the renewable electricity auctions, in 2020 geothermal energy in Spain has continued to advance, mainly in its thermal uses, both on a domestic and industrial scale, with installations to produce heat, cooling and domestic hot water through heat pump systems associated with a geothermal exchanger buried in the ground. Total installed capacity is estimated to be well above 350 MWt and the market continues to evolve. Regions such as Galicia, Catalonia, Madrid, and the Basque Country have proven to be at the forefront of the surface geothermal market this year.

Regarding deep geothermal energy, in March 2020, the drilling of the first exploitation well of the first deep geothermal plant in Spain began. The project will heat the greenhouses of the agricultural industry of Níjar (Almería) and will have a capacity of 8 MW of power. This project could be a driver of geothermal energy in the agriculture sector in our country.

There has also been renewed interest on the part of the Spanish Government and the Administration of the Canary Islands in the development of a geothermal plant for electricity generation, a “flagship” project in the Islands.

In July 2020, GEOPLAT also celebrated its Annual Assembly ‘2020-2030 Geothermal Decade’ which took place virtually due to the pandemic. During this Assembly, GEOPLAT reviewed the windows of opportunity and the challenges facing geothermal energy in Spain to consolidate in the 2020-2030 decade. In addition, examples of the transition with geothermal energy at a regional level (Canary Islands, Asturias, and Catalonia) were addressed.

18.3 Geothermal Activities in 2020

18.3.1 Projects Commissioned in 2020

18.3.1.1 Geothermal heating & cooling projects

The sector of shallow geothermal for HVAC (heating, ventilation, and air conditioning) and DHW (domestic hot water) in Spain maintains a slow deployment. According to information provided by the Spanish Association of Heating and Cooling Networks (ADHAC), in 2020 in Spain there were 9 geothermal operational district heating & cooling systems. Of the 468 district heating & cooling systems accounted, geothermal networks represent less than 2%.

GeoDH – operational in 2020			
Name / Operator	**Location**	**Energy consumed**	**Supply**
DH Aroyo Bodonal	Madrid	Geothermal	Heating and Cooling
DH&C Club Pollentia Resort	Puerto de Pollensa (Balearic Islands)	Geothermal	Heating and Cooling
DH Olot	Olot (Girona)	Trigeneration: geothermal+biomass+natural gas	Heating and Cooling
DH Hotel Teguise	Las Palmas (Canary Islands)	Geothermal	Heating
Plaza de Lleó	Barcelona (Catalonia)	Geothermal	Heating
DH Camping la Noguera	Lérida (Catalonia)	Trigeneration: geothermal+biomass+solar thermal	Heating and Cooling
DH Neiker – Tecnalia	Álava (Basque Country)	Biomass+geothermal	Heating and Cooling

Pozo Barredo (Phase 1)	Mieres (Asturias)	Geothermal	Heating and Cooling
Pozo Barredo (Phase 2) D.H.	Mieres (Spain)	Geothermal	Heating

Source: Spanish Association of Heating and Cooling Networks (ADHAC)

Also, there were 2 planned GeoDH systems.

GeoDH – development/investigation				
Name /Operator	**Location**	**Status**	**Energy consumed**	**Supply**
DH Pozo Fondón – HUNOSA	Langreo (Asturias)	Projected by 2021	Geothermal	Heating
Cardial Recursos Alternativos	Almería (Andalucía)	Projected by 2021	Geothermal	Agro-industry; geothermal heat greenhouses

Source: GEOPLAT

18.3.2 Participation of GEOPLAT in geothermal projects during 2020

GEOPLAT works to achieve the commercial implementation of geothermal in Spain and its continuous growth competitively and sustainably. Among its activities, GEOPLAT is participating in several European projects aimed at the development of geothermal energy, which address aspects such as geothermal resource exploration, an increase of the competitiveness of European SMEs, development of alternative financing schemes and public acceptance models for this type of energy.

(a) GEO-URBAN. Identification and Assessment of Deep Geothermal Heat Resources in Challenging Urban Environments

The GEO-URBAN project aims to explore the potential of deep geothermal resources in low-enthalpy regions and to evaluate this energy source as a heating supply for urban areas. The ability to use geothermal resources to generate heat in urban areas, where demand is highest, has the potential to significantly reduce dependence on fossil fuels and to support sustainable national and European Union energy policies. The project focuses on two areas - Dublin, Ireland, and the Vallès in Catalonia, Spain - and will provide a feasibility analysis for the commercial exploitation of geothermal resources in these regions with different types of geology.

The financing of this project is part of the "GEOTHERMICA Cofund" call, which is part of the European Union's ERA-NET plan. The consortium is formed by a total of 10 members from 3 participating countries of the European Union: Ireland (Dublin City Council, DIAS, GDG, GIA, ICRAG), Denmark (GEOOP) and Spain (BSC, ICGC, UB, GEOPLAT). GEOPLAT is in charge of dissemination and communication tasks, as well as the organization of a workshop in Spain, where the results obtained will be shared to promote the adoption of geothermal technology in these urban areas. The project will finish in June 2021.

18.3.2.2 GEO-ENERGY EUROPE. Geo-Energy for the XXIst Century (PHASE 2)

GEO-ENERGY EUROPE was focused on the creation of a transnational cluster dedicated to improving the development and competitiveness of European small and medium enterprises related to the use of the subsoil to obtain geothermal energy in transnational (EU) and global markets. The consortium is composed of 8 members from 7 participating countries of the European Union and the COSME programme (Programme for the Competitiveness of Enterprises and Small and Medium-sized Enterprises): POLE AVENIA (project coordinator) and GEODEEP in France, EGEC in Belgium, GEOENERGY CELLE in Germany, CAPES in Hungary, JESDER in Turkey, GEOSCIENCE IRELAND in Ireland and GEOPLAT in Spain. This project began in January 2018 and ended in December 2019. However, the partners have been working on a new proposal to participate in a second phase of the project, which has been submitted to a new call of the COSME programme.

Among the achievements obtained during the project, there is the creation of a European metacluster of SMEs working in geothermal energy, with special emphasis on those dedicated to high enthalpy.

In a second phase in 2020, the objective of the GEO-ENERGY EUROPE 2 proposal is to assist the European SME member companies to win business and export to third-country markets. This objective will be accomplished through the provision of the services below by the GEO ENERGY EUROPE meta-cluster to its Small and Medium-sized Enterprises (SMEs).

- GeoEnergy Cooperation Agreements – The GEO-ENERGY EUROPE metacluster will act as a pathfinder for its members. It will link with business and research intermediaries (including cluster or business network organisations, academia, technology centres and research or economic development organisations) in target countries identified by member SME's. The rationale for this is to use these contacts to identify third country (non-EU) collaborative partners in the target markets outlined above as well as additional third country markets of opportunity which arise during the duration of the project and beyond. 10 Cooperation agreements will be concluded between the GEO ENERGY EUROPE meta cluster and entities in the target third-country markets. This would include building on the administrative agreement signed between DG Grow and Canada.

- GeoEnergy Business Agreements – The GEO ENERGY EUROPE meta cluster will facilitate collaborative business agreements between its member companies and business (or equivalent) stakeholders in the third country markets. The goal of these agreements will be to increase exports, investment opportunities, employment and the economic performance of the SMEs involved. 10 Business Agreements were concluded between the GEO-ENERGY EUROPE meta cluster members and entities in the target third-country markets during the project period. Additional business agreements will be pursued beyond the funding period.

- GeoEnergy Capacity Building – GEO ENERGY EUROPE 2 will provide advice, training and capacity building support for its SME member companies. The training and capacity building content will be delivered flexibly, through workshops, online training webinars and site visits. Insights relating to the types of content of interest for member company SMEs have been gained over the first phase of the meta clusters operation. Marketing and branding, market entry strategies and business to business networking both with companies in the meta cluster and those based in third-country markets are areas where GEO-ENERGY EUROPE 2 can provide advice and guidance. Beyond these areas, GEO-ENERGY EUROPE 2 will identify and provide training which supports the cross-sectoral application of the skills of meta cluster's member companies in other subsurface industries.

- GeoEnergy Cross-Sectoral Innovation – Knowledge of the subsurface and its exploitation for energy and natural resources is a key enabler of sustainable development. The member companies of the Geo Energy Europe meta cluster are multidisciplinary and have the requisite skills to diversify their service offerings to other sectors that utilise geothermally derived electricity.

- GeoEnergy Communications – GEO-ENERGY EUROPE will disseminate details of procurement opportunities to its member companies. In addition, it will communicate effectively with key procurers of geothermal and other geo energy-related disciplines to highlight the skills and expertise of its member companies. Crafted internal and externally facing communication deliverables will highlight the opportunities associated with the export of geo energy-related services to emerging and mature geo-energy markets. Monthly bulletins, the display of project case studies on the GEO ENERGY EUROPE website and the publication of articles in relevant industry publications will serve to promote the visibility of the meta cluster's member companies. Communication pathways such as those provided by the European Cluster Collaboration Platform will also be capitalised upon to disseminate project activities, workshops and other relevant content.

18.3.2.3 CROWDTHERMAL. Community-based development schemes for geothermal energy

The CROWDTHERMAL project aims to enable the European public to directly participate in the development of geothermal projects with the help of alternative financing systems, such as crowdfunding and social commitment tools. The project has been funded within the framework of the European Union's research and innovation programme Horizon 2020. The consortium is led by the European Federation of Geologists (EFG) and consists of 10 partners from 7 countries, with extensive experience in the development of large-scale geothermal projects, alternative financing, social media engagement, innovation, education, and international geothermal energy networks (EFG, IZES, UoG, GeoT, LPRC, CrowdfundingHub, SZDH, GEORG, Eimur, and GEOPLAT).

CROWDTHERMAL aims to generate new tools and financial services on the different types of geothermal resources; to facilitate the social acceptance of geothermal energy in different geographical environments; and to develop mechanisms for decision-making, evaluation protocols, and analysis and assessment of proposed case studies. With the project, a model of social acceptance of geothermal energy will be created and used as a baseline for subsequent actions to inspire public support for geothermal energy. The models will be developed and validated with the help of case studies in Iceland, Hungary, and Spain.

In 2020, the CROWDTHERMAL project published its presentation video in which it explains the objectives of the project and presents the case studies involved in it. The video, available in four languages, is accessible through the project's YouTube channel.

On CROWDTHERMAL website, all the work developed throughout the last year is collected in:

- International Review of Public Perception Studies
- Case Study Assessment Protocol (GEOPLAT is in charge of this task)
- Stakeholder and Case Study Analysis Report
- Community for Renewable Energy. Best Practices in Europe
- Synthesis of Environmental Factors
- Alternative Finance Risk Inventory

The project has also developed informative infographics on geothermal energy and its uses that can be found on its Twitter page.

18.4 Other National Activities

18.4.1 Geothermal Education and Training

GEOPLAT, jointly with the National Institute of Qualifications of the Spanish Ministry of Education (INCUAL), has worked for the last two years on the development of the basis for qualification of professionals to manage the installation and maintenance of geothermal heat exchange systems. These qualifications will serve to create advanced vocational training courses, as well as vocational training courses for the unemployed. In addition, it will officially accredit experienced installers with the corresponding title. This official qualification will help to advance the professionalization of the sector, assisting to improve the quality of installations.

In 2020, the two qualifications to be published – 'Installations, commissioning and maintenance of closed-loop geothermal exchange facilities' (level 2) and 'Organization and projects of closed-loop geothermal exchange facilities' (level 3) - began to be processed administratively. The publication of these qualifications in the Official State Gazette (BOE) is expected in 2021.

In the framework of Construye 2020+ project, GEOPLAT has collaborated with the Fundación Laboral de la Construcción (coordinator of the project) in the update of the geothermal systems course manual to promoting training for the transition to an efficient, sustainable and competitive industry. Construye 2020+ continues with the Build Up Skills initiative by updating six of its courses.

Construye 2020+ tries to take a step forward in the transition towards an efficient construction industry, in the use of sustainable, competitive energy, through the definition and development of an updated training and accreditation scheme for professionals in "green" skills. During the project, training actions will be implemented to make workers aware of the importance of using different techniques and sustainable construction solutions in all phases of the work, which means an improvement in the energy performance of the building.

18.4.2 Conferences

- **Technical workshop 'Geothermal Energy: Renewable and Efficient Heating and Cooling for All'. Energy & Environment International Fair – GENERA 2020**
  Madrid, 5th February 2020
  Info

- **Round table 'Energy technologies: Innovation in Health, Agriculture and Industry'. European Meeting on Science, Technology and Innovation – TRANSFIERE 2020** Málaga, 12th February 2020
  Info

- **GEOPLAT Annual Assembly 2020 '2020-2030 Geothermal Decade'**
  Online, 23rd July 2020
  Info

- **Coordination Committee of the Spanish Energy Technology Platforms (CCPTE) - II CCPTE workshop: "Spanish technology in the scenario of energy transition and globalization of the economy"**
  Online, 15th October 2020
  Info

18.5 Future Activity

In 2021, GEOPLAT will work primarily to promote and boost the development of R&D&i geothermal projects in Spain (identification of calls, monitoring of proposals, assisting and encouraging the formation of consortia, etc.).

Also, GEOPLAT will continue to explore geothermal training in collaboration with the Hunosa Group and will continue to collaborate with Construye 2020+ project - A new boost for green jobs, growth and sustainability.

In 2021, within the framework of the European projects PIXIL and GEO-URBAN, GEOPLAT will organize an international workshop together with Barcelona Supercomputing Center (BSC) and Pole Avenia about exploration of the subsurface for geothermal energy. The event will take place virtually due to the COVID-19 pandemic.

18.6 References

- GEOPLAT Website: www.geoplat.org
- GEOPLAT Blog: http://blog.geoplat.org
- Spanish Institute for Diversification and Saving of Energy (IDAE): http://www.idae.es
- Geological Survey of Spain (IGME): http://www.igme.es/
- GEO-ENERGY EUROPE project: https://www.geoenergyeurope.com/
- Crowdthermal project: http://www.crowdthermalproject.eu/
- 2020 Census on the existing DHC networks in Spain (ADHAC) http://www.adhac.es/Priv/ClientsImages/AsociacionPerso8_1603709268.pdf
- Spanish Centre for Industrial Technological Development (CDTI)

https://www.cdti.es/

- Spanish State Research Agency (AEI)
  http://www.ciencia.gob.es/portal/site/MICINN/aei

- National Institute of Qualifications of the Spanish Ministry of Education (INCUAL)
  https://www.educacion.gob.es/educa/incual/ice_incual.html

19. Switzerland

Christian Minnig

Swiss Federal Office of Topography swisstopo. Seftigenstrasse 264, CH-3084 Wabern.
Email: christian.minnig@bfe.admin.ch

19.1 Introduction

Switzerland's uptake of shallow geothermal continues unabated and unconstrained by natural potential. The theoretical potential for direct use geothermal and geothermal for power generation is considered very large. Yet arguably, realistic estimates of the technical and economic potential (with support mechanisms) is limited to between 1 and 20 TWh along with associated co-produced heat.

Switzerland's entirely revised Energy Act and a partially revised CO_2-Act, in force since 1 January 2018, contain measures, some of which pertain to geothermal energy for direct use and power generation, supporting Switzerland's Energy Strategy 2050.

Table 19.1 Status of geothermal energy use in Switzerland (figures from 2019)

Electricity		Direct Use	
Total Installed Capacity (MW_e)	0	Total Installed Capacity (MW_{th})	27.4
New Installed Capacity (MW_e)	0	New Installed Capacity (MW_{th})	2.7
Total Running Capacity (MW_e)	0	Total Heat Used (PJ/yr) [GWh/yr]	0.80 (222.7)
Contribution to National Capacity (%)	0	Total Installed Capacity Heat Pumps (MW_{th})	2259.7
Total Generation (GWh)	0	Total Net Heat Pump Use [GWh/yr]	3786.3
Contribution to National Generation (%)	0	Target (PJ/yr)	N/A
Target 2050 (GWh/yr)	2,000	Estimated Country Potential (MW_{th} or PJ/yr or GWh/yr)	N/A
Estimated Country Potential (GWh/yr)	N/A		

(N/A = data not available)

19.2 Changes to Policy Supporting Geothermal Development

Since 2008, Switzerland has operated a geothermal guarantee scheme for geothermal power projects. Under this scheme, up to 50% of the subsurface development cost may be reimbursed to project developers on failure to find a suitable geothermal resource. Additionally, geothermal power production is remunerated by a feed-in tariff.

The Swiss government has developed the Energy Strategy 2050, which targets reducing energy consumption, improving efficiency, and enhancing the utilisation of renewable energies.

Several new measures and incentives aim to boost the development of geothermal energy, e.g.:

- Increasing the guarantee scheme for geothermal power projects from 50% to max. 60% and extending the eligible costs to include prospecting expenses. Under current legislation, the scheme runs until 31 Dec 2030.
- Direct financial support for prospecting and exploration (proving the presence of a reservoir), max. 60% of the eligible cost with a cap of Fr. 50 million (1 Fr. ~ 1 US$) per year (in lieu of the geothermal guarantee). Under current legislation, the scheme runs until 31 Dec 2030.
- Direct financial support for direct use geothermal energy projects, max. 60% of the eligible costs. The scheme is funded from Switzerland's carbon levy on fossil fuels used for stationary heat with a cap of Fr. 30 million per year. Under current legislation, the scheme runs until 31 Dec 2025.
- To account for a revised weighted average cost of capital (now set at 5.44% for a reference plant), feed-in tariffs for power production from hydrothermal and EGS plants have been re-calculated; the feed-in tariff applies now for a period of 15 years instead of 20 years as prior to 2018. Under current legislation, no new projects will be admitted to the feed-in tariff scheme after 1 Jan 2023.

Table 19.2 Current (2020) feed-in tariffs for geothermal power production:

Capacity (MW_e)	Hydrothermal Feed-in tariff (Rappen/kWh)*	EGS Feed-in tariff (Rappen/kWh)
≤5 MW	46.5	54.0
≤10 MW	42.5	50.0
≤20 MW	34.5	42.0
>20 MW	29.2	36.7

*Rappen is one hundredth of a Swiss Franc.

Another important measure is to make publicly available primary and processed primary subsurface data obtained from subsidized projects (seismic data, logs etc.); this process is handled by the Swiss Geological Survey of the Swiss Federal Office of Topography Swisstopo.

The Energy Strategy 2050 also includes an "action plan coordinated energy research".

Financial support for geothermal research and innovation has grown considerably in the last 5 years from about US$ 10 million to US$ 20 million per year.

19.3 Geothermal Project Development

19.3.1 Projects Commissioned

The following projects are in the planning and execution phase in 2020:

Table 19.3 Geothermal projects in 2020

Project name	Project developer	Technology	Energy use
Stoll frères (FR)	Stoll frères	Hydrothermal	Heat for agriculture

Project name	Project developer	Technology	Energy use
Geothermie Schlattingen (TG)	Grob Gemüse GmbH	Hydrothermal	Heat for agriculture; Wells completed, long term production test
geo2riehen	Wärmeverbund Riehen AG	Hydrothermal	District heating
Geothermie Brig-Glis (VS)	Geothermie Brig-Glis AG	Hydrothermal	Heat; Planning phase
AGEPP in Lavey-les-Bains (VD)	JV of regional energy utilities, cantons and communities	Combined heat and power - hydrothermal	Heat, power; planned drilling: start 2021
Aquifer thermal energy storage Forsthaus Bern (BE)	Energie Wasser Bern (ewb)	Energy storage in a sandstone with geothermal potential – radial drilling for reservoir creation	Seasonal storage of heat co-generated at a waste-to-energy plant; district heating; Permit; start drilling in 2021
Haute Sorne (JU)	Geo-Energie Suisse AG	EGS	Power (and heat); Permit granted
La Cote - Aubonne	EnergeÔ SA	Hydrothermal	District heating
La Cote - Etoy	EnergeÔ SA	Hydrothermal	District heating
La Cote - Nyon	EnergeÔ SA	Hydrothermal	District heating
La Cote - Vinzel	EnergeÔ SA	Hydrothermal	Heat; planning phase, drilling in 2021
Lausanne-Plaine du Loup	Services industriels de Lausanne (SiL)	Deep geothermal probe	District heating
Erstfeld (UR)	Basis 57 nachhaltige Wassernutzung AG	Tunnel water	Fish farming
GEo-01 (GE)	Service industriel Genevois (SIG)	Hydrothermal	District heating
GEo-02 (GE)	Service industriel Genevois (SIG)	Hydrothermal	District heating
GEo-03 (GE)	Service industriel Genevois (SIG)	Hydrothermal	District heating
GEo-04 (GE)	Service industriel Genevois (SIG)	Hydrothermal	District heating

19.3.2 Projects Operational

There are no geothermal power projects in operation in 2020. Geothermal direct and indirect use projects in operation in 2020 are listed below, all figures are from 2019, no spas, no deep geothermal probes:

Table 19.4 Geothermal direct and indirect use projects.

Heating project	Capacity [MW]*)	Heating energy [GWh/yr]	Geothermal contribution (without heat pump) [GWh/yr]
Lötschberg base tunnel, Frutigen, direct Tunnel water	1.08	2	See left
Riehen (BS), direct	1.5	4.9	See left
Riehen (BS), heat pumps	3.5	13.47	10.36
Bassersdorf (ZH)	0.24	0.47	0.24
Itingen (BL)	0.08	0.18	0.13
Kloten (ZH)	0.24	0.19	0.06
Seon (AG)	1.35	2.22	1.56
Furka Railway tunnel, Oberwald (VS)	1.43	2.87	2.11
Gotthard road tunnel, Airolo (TI)	0.72	0.86	0.65
Ricken railway tunnel, Kaltbrunn (SG)	0.16	0.25	0.17
Lötschberg base tunnel, Frutigen (BE/VS)	1.08	1.91	1.30
Hauenstein railway tunnel, Trimbach (SO)	0.37	0.38	0.20
Mappo Morettina, road tunnel, Minusio/Tenero (TI)	0.09	0.08	0.03
Kongresszentrum Davos (GR)	No info	No info	No info
Raron (VS)	No info	No info	No info

Table 19.5 Thermal spas in operation in 2020, all figures from 2019:

Thermal spa	Capacity [MW]*)	Heating energy [GWh/yr]
Andeer (GR)	0.04	0.37
Baden (AG)	Currently (2018) under reconstruction	
Bad Ragaz (SG)	2.65	22.01
Bad Schinznach S3 (AG)	0.97	8.07
Brigerbad (VS)	3.71	30.85
Kreuzlingen	0.04	0.31
Lavey-les-Bains (VD)	3.72	30.95
Leukerbad (VS)	7.17	59.64
Lostorf (SO)	Currently not in operation (2018)	

Ovronnaz (VS)	0.16	1.30
Saillon (VS)	2.51	20.86
Stabio (TI)	0.01	0.07
Val d'Illiez (VS)	3.65	30.61
Vals (GR)	0.29	2.44
Yverdon-les-Bains (VD)	0.23	1.89
Bad Zurzach (AG)	0.78	6.45
Total	**25.93**	**215.82**

19.4 Research Highlights

Research and innovation is funded by the Swiss National Science Foundation (fundamental research), the Swiss Federal Office of Energy (applied research, piloting and demonstration) and Innosuisse (market-driven research). Some of the federally funded Swiss Federal Institutes of Technology have allocated funds to be used for geothermal energy research and innovation. Of the five institutes, ETH Zurich, EPF Lausanne and the Paul Scherrer Institute engage in geothermal research and innovation.

Eight Swiss Competence Centers for Energy Research (SCCER), that were launched in 2014 and run until the end of 2020, have been established to develop (human) capacity, and initiate research and innovation in areas deemed critical for Switzerland's Energy Strategy 2050. One of the SCCERs, SCCER – Supply of Electricity or SCCER-SoE, has a focus on geothermal energy and particularly on technologies required to unlock Engineered Geothermal Systems, and as of 2017 for direct use geothermal energy and heat storage. The SCCER's are set up along the lines of a public-private partnership with industry players encouraged to participate.

As the SCCER program will finish End of 2020, a follow-up funding programme was initiated, called SWEET (SWissEnergy research for the Energy Transition). The goal is to accelerate innovations that are crucial to implement Switzerland's Energy Strategy 2050 and achieve the country's climate policy goals. Consortia will respond to calls that are set within a guiding theme (e.g. increase RES share within the Swiss energy system – CHF 35-45 Mlo) by developing a R&D and P+D portfolio of projects over 6-8 years. Public research institutions from abroad may be part of a consortium and eligible for Swiss funding. The calls are not specific to a certain energy form, so geothermal energy will have to compete against all other renewables. The first SWEET call for proposals opened in June 2020. The SWEET programme will run until 2032.

R&D funds for 2019 were at a level of US$ 24 million, approximately US$ 3 million of which is for pilot and demonstration projects, with similar levels expected in 2020. Slightly ahead of countries subscribing to Mission Innovation, Switzerland has effectively doubled its investment into geothermal energy compared to 2014.

Table 19.6 Swiss public investment in research, development and deployment of geothermal energy as reported to the IEA (until 2019).

	2019			2018			2017			2016			2014		
All figures in Million CHF (1 CHF ~ 1 USD)	R&D	Pilot & Demo	Total	R&D	Pilot & Demo	Total	R&D	Pilot & Demo	Total	R&D	Pilot & Demo	Total	R&D	Pilot & Demo	Total
Geothermal energy	**20.84**	**2.83**	**23.67**	**19.37**	**5.67**	**25.04**	**17.46**	**2.72**	**20.19**	**14.45**	**6.00**	**20.44**	**9.14**	**2.33**	**11.47**
from hydrothermal resources	0.19		0.19	1.08		1.08	1.23	1.58	2.81	1.35		1.35	1.10	0.20	1.30
from EGS (hot dry rock) resources	1.19	0.76	1.96	1.81	4.30	6.11	2.80	0.98	3.78	1.89	5.61	7.50	0.82	0.00	0.82
Advanced drilling and exploration	7.13		7.13	4.74		4.74	4.53		4.53	2.34		2.34	0.34	1.23	1.57
Other geothermal energy (incl. low temp. resources	1.78	1.93	3.71	1.84	1.37	3.21	0.66		0.66	0.42		0.42	0.23	0.90	1.13
Unallocated geothermal energy	10.55	0.14	10.68	9.90		9.90	8.23	0.17	8.41	8.45	0.38	8.83	6.66	0.00	6.66

One highlight has been the research activities of the SCCER-SoE on controlled hydraulic stimulation experiments at the Grimsel Test Site, an underground laboratory in the crystalline basement of the Alps. An important milestone was the construction of the new "Bedretto Underground Laboratory for Geoenergies" with inauguration in May 2019. The Bedretto Lab is located 1.5 km below the surface in the middle of a 5.2 km long tunnel. In 2020, a number of experiments are being realised (see the research highlight list below).

Since 1 January 2017, Switzerland returned to being a fully associated member of the EU research framework program, Horizon 2020. Also, the Swiss Federal Office of Energy, via its dedicated funding program for geothermal energy research and innovation, cooperates with European funding agents in the European Union through the European Research Area Network GEOTHERMICA with a joint call for research, development and deployment of novel geothermal energy concepts. Of the eight projects funded in GEOTHERMICA's first call, Switzerland leads the projects ZoDrEx and COSEISMIQ, and is a major contributor to HEATSTORE. A second joint call was initiated in 2019, the start of the projects is expected in 2021

The Swiss Federal Office of Energy also participates in the International Partnership for Geothermal Technology (with the USA, Iceland, Australia and New Zealand). The longest standing backbone of Switzerland's international engagement continues to be the IEA's Geothermal Technology Collaboration Program.

Industry engages in geothermal development activities mostly in the areas of hydrothermal project development, subsurface heat storage, and EGS. Financial information is not available.

Geothermal research highlights in 2020:

- DESTRESS (International) – Demonstration of Soft Stimulation treatments of geothermal reservoirs (http://www.destress-h2020.eu/home/) (http://www.bedrettolab.ethz.ch/activities/brp/destress/)
- GEOTHERMICA ZoDrEx (International) – Zonal Isolation, Drilling and Exploitation of EGS Projects (http://www.geothermica.eu/projects/zodrex/) (http://www.bedrettolab.ethz.ch/activities/brp/zodrex/)
- Valter-Validating of Technologies for Reservoir Engineering http://www.bedrettolab.ethz.ch/activities/brp/valter/
- MISS -Mitigating Induced Seismicity for Successful Geo-Resources Applications (http://www.bedrettolab.ethz.ch/activities/miss/)

- ➢ FEAR –Fault Activation and Earthquake Rupture (http://www.bedrettolab.ethz.ch/activities/fear/)
- ➢ GEOTHERMICA Heatstore (International – https://www.heatstore.eu/)
- ➢ GEOTHERMICA COSEISMIQ (International – http://www.geothermica.eu/projects/coseismiq/)
- ➢ RT-RAMSIS – Real-Time Risk Assessment and Mitigation System for Induced Seismicity

Research activities in the area of shallow geothermal applications are concentrating on smart thermal grids (including geothermal heat storage), quality assurance and control, as well as enhancing efficiency.

19.5 Other National Activities

19.5.1 Geothermal Education

The University of Neuchâtel runs a successful and popular Certificate for Advance Studies on Exploration & Development of Deep Geothermal Systems (CAS DEEGEOSYS). Through the SCCER-SoE, the significant number of tenured and tenure-track professorships at ETH Zurich, EPF Lausanne, and at the Universities of Geneva and Neuchâtel has given rise to a number of undergraduate and graduate level courses in geothermal energy. An overview of education and training courses related to geothermal energy can be found here: https://geothermie-schweiz.ch/aus-und-weiterbildungen/

19.5.2 Conferences

In 2019 and 2020, a number of national and international geothermal conferences and conferences with significant geothermal interest took place in Switzerland:

- Gurtensymposium Geothermie, online, 4 November 2020
- Journées romandes de la géothermie 2019, Lausanne (VD), 29 January 2019
- SCCER-SoE Annual Conference in Lausanne (VD) from 4 September 2019.

19.5.3 Publications

See the publication websites of the Swiss Federal Office of Energy (https://www.bfe.admin.ch/bfe/de/home/news-und-medien/publikationen.html) and of the SCCER-SoE (http://www.sccer-soe.ch/publications/)

19.6 Useful Websites

Geothermie-Schweiz (Swiss Geothermal Association) http://geothermie-schweiz.ch

Fachvereinigung Wärmepumpen Schweiz FWS (Swiss Heat Pump Association) http://www.fws.ch

Swiss Competence Center for Energy Research – Supply of Energy (SCCER SoE) http://www.sccer-soe.ch

http://www.sccer-soe.ch/research/geo-energy/

Bedretto Underground Laboratory for Geoenergies http://www.bedrettolab.ethz.ch/home/

Grimsel Test Site (Grimsel rock laboratory) http://www.grimsel.com

Geo-Energie Suisse AG (EGS projects) www.geo-energie.ch

GEothermie 2020 https://www.geothermie2020.ch/

19.7 Future Activity

Project development in Western Switzerland advances at a brisk pace and is driven largely by Cantons with a focus on decarbonizing the heating sector. In the last reporting period, this mostly concerned the Cantons of Geneva and Vaud. The Western part of Switzerland is expected to remain the main driver of the geothermal sector in the future, but in the meantime activity in other cantons has picked up and we expect prospection and exploration projects in the near future to come forth in the German speaking central and Eastern parts of Switzerland. In the Bedretto Underground Laboratory for Geoenergies, more project activities will be carried out which are expected to have a significant impact on the development and operation of EGS projects.

Another boost for geothermal prospection and exploration could originate from the increased focus of CO_2 underground storage and its obvious needs for the search of suitable sites. Synergies in the exploration effort is obvious.

19.8 References

Statistical data of geothermal energy use are from:

Link, Katharina: Statistik der geothermischen Nutzung in der Schweiz – Ausgabe 2019. Schlussbericht, 30. Juli 2020.

20. United Kingdom

Jon Busby[1], Noramalina Mansor[2]

[1] British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK. Email: jpbu@bgs.ac.uk

[2] Energy Engineering, Science and Innovation for Climate and Energy, Department for Business, Energy and Industrial Strategy (BEIS), 1 Victoria Street, London, SW1H 0ET, UK. Email: Noramalina.Mansor@beis.gov.uk

20.1 Introduction

Figure 20.1 The Dawdon mine water treatment scheme that is being developed to supply mine water heating to a new housing complex in the northeast of England. Photo credit: The Coal Authority

In March 2020 Covid 19 restrictions were first imposed in the UK in order to limit the spread of the virus. This resulted in three lockdowns during the year, which had a very serious effect on the economy, including the geothermal sector. Restrictions on gatherings of people and movement within the UK meant that business meetings and conferences had to be held by video conferencing, although many were cancelled or postponed.

The most advanced project in the UK is the United Downs Deep Geothermal Power project (UDDGPP). This project, led by Geothermal Engineering Ltd., is the first commercial project in the UK to develop deep geothermal for power generation. The project aims to utilise the natural permeability of the Porthtowan Fault in the Carnmenellis granite in Cornwall. Drilling commenced in November 2018 of two deviated wells to intersect the fault at two different depths in order to create a closed loop circulation system vertically along the fault. The first well, UD1, has a drilled length of 5275 m (5057 m total vertical depth) and is the production well. The second well, UD2, has a drilled length of 2393 m (2214 m total vertical depth) and will act as the injection well. During the early spring of 2020 injection tests proved promising, but full hydrotesting of the wells has been continually delayed by the Covid 19 restrictions and full testing will not be completed until early 2021. A second, deep geothermal project at the Eden project in Cornwall is situated on the St Austell granite. The project is being developed by Eden Geothermal Ltd., which has shareholders comprising Eden Project Ltd., EGS Energy Ltd. and BESTEC (UK) Ltd. The project is also targeting a deep crustal fracture and an initial well to a depth of 4.5 km will be used to heat Eden's Biomes, offices and greenhouses. Covid 19 restrictions have also held up progress, but the site has been prepared for drilling, which is due to commence in the spring of 2021.

There is increasing interest in the UK in utilising the waters within disused mine systems for their geothermal potential. Although in many cases the temperature of the water will be at normal ground water temperatures, the very high abstraction rates that are possible make disused mine systems ideal for large-scale open loop ground source heat pumps. At some former colliery sites pumping of the mine waters is already underway for environmental reasons and so they are ideal for geothermal development. Farr et al., 2020, published a research paper on mine water temperatures, which highlighted that at some pumped sites, near surface groundwater temperatures can be raised up to 20 ºC. A company in northeast England, Lanchester Wines, have developed two schemes to heat warehouses from mine waters that have a total installed capacity of 6.5 MWth. Abandoned mines fall under the jurisdiction of The Coal Authority (CA) who are developing geothermal heating schemes at a number of their pumped sites. The three most advanced comprise;

Seaham Garden Village

This is a new development of housing, a school, shops and medical and innovation centres that will have district heating supplied from the Dawdon treatment scheme. The pumped mine water is at a temperature of 18-20 ºC and has a potential heating capacity of 6 MWth.

Hebburn Minewater District Network

This development involves drilling around 300-400 m into the mine workings of the former Hebburn colliery to heat council owned buildings in the town.

Gateshead District Heat Network

In Gateshead, an existing heat network is to be expanded and supplied from the groundwaters within disused mine workings beneath the town. The development is being funded from a grant of £6M from the UK government's Heat Networks Investment Project (HNIP).

The Department for Business, Energy and Industrial Strategy (BEIS) has been supporting the development of district heat networks. This comprises support through the development stages by the Heat Networks Delivery Unit (HNDU) and projects seeking capital support from the Heat Networks Investment Project (HNIP). A number of projects include a geothermal component.

The Glasgow Geothermal Energy Research Field Site (GGERFS) is now operational and available to third party researchers. The infrastructure comprises 12 wells equipped with high resolution monitoring technology. It will enable the UK science community to study the low-temperature mine water geothermal environment at shallow depth.

Single borehole co-axial scheme development has been mainly put on hold, but a research grant has been awarded so that the borehole at Newcastle (previously known as Science Central, but renamed Helix) can be developed to supply heat to commercial and university buildings and around 450 homes.

The geothermally heated Jubilee Pool at Penzance in Cornwall has now opened to the public. The pool consists of a partitioned sub-section of a seawater pool that is heated with an open loop ground source heat pump supplied from a 400 m deep borehole at an inlet temperature of 25 ºC.

In February, the British Geological Survey organised a stakeholder meeting in London to discuss the barriers to deep geothermal development in the UK. This resulted in a briefing paper

(Abesser, 2020, https://www.bgs.ac.uk/download/science-briefing-note-deep-geothermal/) that has been distributed to government and business.

Table 20.1. Status of geothermal energy use for electric power generation and direct uses in Mexico in October 2020.

Electricity		Direct uses	
Total Installed Capacity (MW_e)	0	Total Installed Capacity (MW_{th})	9.5
New Installed Capacity (MW_e)	0	New Installed Capacity in 2019 (MW_{th})	6.5
		Total Heat Used (GWh/yr)	33.3
		Total Installed Capacity Heat Pumps (MW_{th})	776
		Total Net Heat Pump Use [GWh/yr]	1285*
		New capacity installed in 2019 (MW)	**57#**

These data are from a forecast made in April 2020 based on market trends.

* in calculating the net heat pump use it has been assumed that the hrs/year heating equivalent full load is 1800 hrs/year for domestic systems and 1500 hrs/year for commercial systems.

20.2 Changes to Policy Supporting Geothermal Development

In March 2019 the government announced a Future Homes Standard to be introduced in 2025. The standard includes a ban on all fossil fuel heating in new homes. It is anticipated that much of the heating requirement will be met from air and ground source heat pumps, district heating and direct electrical heating. Therefore, there is likely to be an increase in the development of heat networks via geothermal sources, which is supported by the HNIP and HNDU funding schemes. In order to ensure market growth beyond the lifetime of HNIP, the Government has also published "Heat Networks: ensuring sustained investment and protecting consumers"[43] which sets out three priorities for the market framework: ensuring consumers receive sufficient protections; building investment in the sector; and maximising the potential decarbonisation benefits of heat networks.

Incentives for renewable heat from geothermal are paid through the Renewable Heat Incentive (RHI) scheme. Rates for domestic and non-domestic GSHP and deep geothermal heat in 2019/20 were:

- Non-domestic GSHP has a 2-tiered tariff comprising 9.68 p/kWh for the first 1314 hours of use (tier 1) and 2.89 p/kWh thereafter (tier 2), paid for 20 years.

- Domestic GSHP tariff is 21.16 p/kWh payable for 7 years, but note that new build properties other than self-build are not eligible.

- Deep geothermal (defined as from a minimum depth of 500 m) tariff of 5.00 p/kWh for 20 years.

[43] https://www.gov.uk/government/publications/heat-networks-developing-a-market-framework

The RHI is due to end between 31 March 2021 and 31 March 2022. In July 2020 the government launched a consultation for the successor scheme to the RHI.

Geothermal continued to be eligible to compete in the Contracts for Difference under pot 2 (less established technologies). Contracts for Difference is a mechanism by which the government buys power from renewable technologies with 15-year contracts.

20.3 Geothermal Projects Development

20.3.1 Projects Commissioned

No new projects were commissioned in 2019.

20.3.2 Projects Operational

The only operating deep geothermal project is in the City of Southampton which contributes heat to an inner-city district heating network. This scheme has been under maintenance, and therefore at reduced capacity.

20.4 Research Highlights

UK geothermal research is largely concentrated on developing the potential of less conventional resources as deep hot sedimentary aquifers are only found in a few regions and often not in regions of high heat demand. Much research is undertaken within the Higher Education sector, usually as part of PhD programs.

20.4.1 Selected publications

Abesser, C. (2020) DEEP IMPACT: UNLOCKING THE POTENTIAL OF GEOTHERMAL ENERGY FOR AFFORDABLE, LOW-CARBON HEATING IN THE UK. Science Briefing Note, British Geological Survey. https://www.bgs.ac.uk/download/science-briefing-note-deep-geothermal/

Farr, G., Busby, J., Wyatt, L., Crooks, J., Schofield, D. I. and Holden, A. (2020). The temperature of Britain's coalfields. *Quarterly Journal of Engineering Geology and Hydrogeology*, https://doi.org/10.1144/qjegh2020-109, pp 14.

Parkes, D., Busby, J., Kemp, S. J., Petitclerc, E. and Mounteney, I. (2020). The thermal properties of the Mercia Mudstone Group. *Quarterly Journal of Engineering Geology and Hydrogeology*, https://doi.org/10.1144/qjegh2020-098, pp 10.

Watson, S. M., Falcone, G. and Westaway, R. (2020) Repurposing Hydrocarbon Wells for Geothermal Use in the UK: The Onshore Fields with the Greatest Potential. Energies, **13** ,3541 (http://dx.doi.org/10.3390/en13143541)

20.5 Other National Activities

20.5.1 Geothermal Education

There are no specific higher education courses devoted to the exploration and utilisation of geothermal energy in the UK. However, earth science and renewable energy university courses will often have modules on aspects of geothermal energy.

20.5.2 Conferences

Major conferences were cancelled or postponed in 2020.

20.5.3 Useful Websites

Contracts for Difference

https://www.gov.uk/government/policies/maintaining-uk-energy-security--2/supporting-pages/electricity-market-reform

Renewable Heat Incentive

www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/incentive/incentive.aspx

http://www.energysavingtrust.org.uk/scotland/Generating-energy/Getting-money-back/Renewable-Heat-Incentive-RHI2

Renewable Energy Association Deep Geothermal Group

www.r-e-a.net/member/deep-geothermal

Ground Source Heat Pump Association

www.gshp.org.uk/

20.6 Future Activity

Interest and awareness in geothermal continue to increase, but funding to develop projects remains challenging.

20.7 References

BSIRA 2020. Heat pumps market analysis 2020 - United Kingdom. Report 100945/12

21. United States of America

Geothermal Technologies Office

Geothermal Technologies Office, Energy Efficiency and Renewable Energy, U.S. Department of Energy.
Email: Lauren.Boyd@ee.doe.gov

21.1 Introduction

The United States (U.S.) in 2020 remained the leader in installed geothermal capacity with approximately 3.673 gigawatts (GW); this represents close to 25% of the world's total online capacity. Ninety-five percent of this capacity is in California and Nevada. Geothermal resources in the U.S. are found primarily in the western states, where broad volcanic and mountain-building activity have occurred. Eminent geothermal provinces include portions of the San Andreas Fault running through California from the Imperial Valley to the Golden Bay; the Basin and Range system in Nevada and Utah; and the Cascade Range volcanism in Oregon and Washington.

As of 2020, there are 23 geothermal district heating (GDH) systems in the U.S. The oldest installation dates from 1892 (Boise, Idaho), and the most recent installation was completed in 2017 (Alturas, California)[44].

Geothermal heat pumps maintain approximately 3% annual growth, with current installations exceeding 1.7 million (equivalent 12 kW) units. About 40% of installations are residential; the other 60% are commercial or institutional. Most growth continues to occur in the central and eastern states.

Multiple federal agencies are involved in advancing the U.S.'s geothermal sector; leading the charge is the Department of Energy's (DOE) Geothermal Technologies Office (GTO), which is committed to developing a portfolio of innovative technologies that address critical geothermal exploration and development challenges. GTO and its partners research, develop, and validate cost-competitive technologies and tools to help make geothermal energy more affordable, and to locate, access, and develop geothermal resources within the United States.

21.1.1 *GeoVision* Analysis and Report

The *GeoVision* study, released in May 2019, served as a guiding document for GTO's programmatic R&D planning in 2020, and will continue to do so for years to come.

The *GeoVision* analysis includes the following conclusions:

- Optimized permitting could cut geothermal development timelines in half, leading to a doubling of geothermal (13 GWe by 2050) versus business-as-usual;
- Over the next 30 years, direct use could increase from a current total of 21 geothermal district heating installations to as many as 17,500 nationwide. Geothermal heat pumps could increase to 28 million.
- Geothermal power deployment could reach 60 GWe by 2050 – more than 8 percent of national capacity – with aggressive technology improvements.

[44] 2021 U.S. Geothermal Power Production and District Heating Market Report

21.1.2 2020 U.S. Electricity and Direct-Use Figures

Electricity		Direct-Use	
Total Installed Capacity (MW_e)	3,673	Total Installed Capacity (MW_{th})	485[45,46]
New Installed Capacity (MW_e)	186 (since 2015)	New Installed Capacity (MW_{th})	N/A
Total Running Capacity (MW_e)	Net Summer = 2,555 Net Winter = 2,963	Total Heat Used (PJ/yr) [GWh/yr]	2,120.3
Contribution to National Capacity (%)	0.26 (winter) [47] 0.24 (summer)	Total Installed Capacity Heat Pumps (GW_{th})	20.7 GW[48] (2020)
Total Generation (GWh)	15.47 TWh[49]	Total Net Heat Pump Use [GWh/yr]	32,493 [5]
Contribution to National Generation (%)	0.37%[6]	Target (PJ/yr)	N/A
Target (MW_e or % national generation)	N/A	Estimated Country Potential (GW_{th})	231 GW_{th} by 2050[50]
Estimated Country Potential (GW_e)	~530 [51]		

(N/A = data not available)

21.2 Geothermal Project Development

GTO funds geothermal research, development, deployment, and demonstration (RDD&D) to help stimulate the growth of the geothermal industry and encourage adoption of geothermal technologies by the public and private sectors. GTO's work focuses on four program areas: enhanced geothermal systems (EGS); hydrothermal resources; low temperature and coproduced resources; and data, modelling, and analysis.

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45 United States Direct Utilization Update 2019; Lund, et al., World Geothermal Congress 2020; https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01018.pdf
46 U.S. Geothermal Direct-Use Installations Database: https://gdr.openei.org/submissions/911
47 U.S. Energy Information Administration2019b. "Electric Power Annual 2019." U.S. Energy Information Administration. https://www.eia.gov/electricity/annual/pdf/epa.pdf
48 Calculated based on the 2019 IEA data and the incremental data of geothermal heat pump shipments in 2020.
49 U.S. Energy Information Administration2019b. "Electric Power Annual 2019." U.S. Energy Information Administration. https://www.eia.gov/electricity/annual/pdf/epa.pdf.
50 Estimated Country Potential, Oak Ridge National Laboratory presented March 28, 2018 at International Ground Source Heat Pump Association Conference, Orlando, FL
51 Estimated total for 30 GWe undiscovered hydrothermal resources per the United States Geologic Survey (https://pubs.usgs.gov/fs/2008/3082/pdf/fs2008-3082.pdf) plus an estimated 500 GWe EGS potential per the Massachusetts Institute of Technology (https://energy.mit.edu/wp-content/uploads/2006/11/MITEI-The-Future-of-Geothermal-Energy.pdf)

21.2.1 Projects Commissioned and/or Continued in 2020

21.2.1.1 Frontier Observatory for Research in Geothermal Energy (FORGE)

2020 was a year of considerable achievement at the Frontier Observatory for Research in Geothermal Energy (FORGE) outside Milford, Utah, led by the University of Utah. Phase 3 drilling was conducted during the year, highlighted by completion of the first of two injection/production wells; the first injector/producer well (16A) was directionally drilled at 65 degrees within the basement reservoir rock and completed to a measured depth of about 11,000 feet (3353 m). Most impressively, the well was drilled in about half the time planned owing to the strength of drilling professionals involved and a willingness to adapt modern drilling approaches. This well was drilled with PDC drill bits, a technology originally catalyzed by the DOE in the 1980s and used routinely in oil and gas drilling.

Additionally, the Utah FORGE team engaged with researchers at Texas A&M University, who were awardees on an adjacent GTO initiative named Efficient Drilling for Geothermal Energy (EDGE). The Texas A&M team developed a process employing physics-based limiter redesign workflows that led to a rate of penetration averaging more than 40 feet (12 m) per hour in some sections, and a drill bit life exceeding 700 feet (213 m) per run. Using similar approaches, a 9,000-foot (2743 m) monitoring well is also underway, to be completed in early 2021. The success to date with the injection/production wells demonstrates that advanced PDC bits combined with a data-informed, physics-based workflow can be used in geothermal drilling to significantly improve drilling performance.

An initial FORGE research and development (R&D) solicitation was issued by the University of Utah in 2020, allocating up to $46 million in funding for new and innovative EGS tools and techniques that support reservoir characterization, creation, and sustainability.

The FORGE site is dedicated to research focused on EGS, or manmade geothermal reservoirs. Work performed at this site and the critical knowledge gained will facilitate access to more than 500 GW[52] of geothermal energy in the United States alone and usher transformational change in the geothermal industry.

Critical to broad EGS deployment, FORGE serves as a laboratory where scientists and researchers can learn how to reproducibly engineer these manmade systems. Through the work performed at FORGE, the geothermal community will gain a fundamental understanding of the key mechanisms controlling EGS success; develop, test, and improve new techniques in an ideal EGS environment; and rapidly disseminate technical data and communicate with the public.

A recent video on the FORGE Utah activity can be downloaded through this link.

21.2.1.2 EGS Collab

GTO continued funding the multi-lab, multi-year EGS Collab effort through 2020. Experiment 1 - flow testing, directed toward fracturing of and fluid flow through intact rock at the 4,850-foot (1478 m) level in the Sanford Underground Research Facility (SURF) in Lead, South Dakota, was completed at the very end of 2019 with analysis continuing into 2020. Experiment 1 provided a first-time opportunity to validate geothermal reservoir and fracture models with real-time

[52] The Massachusetts Institute of Technology (https://energy.mit.edu/wp-content/uploads/2006/11/MITEI-The-Future-of-Geothermal-Energy.pdf)

geophysical and other fracture characterization data during stimulation. Further testing and analysis completed in 2020 included pressure tests and high-rate flow tests; following completion of Experiment 1, the site has been decommissioned and repurposed for an unrelated Long-Baseline Neutrino Facility. As noted in last year's IEA Annual Report, the combined ensemble of geophysical tools deployed is providing detailed information on fracturing processes occurring during tests.

The location for Experiment 2, which targets the stimulation of existing fractures, was moved last year to a location at the 4,100-foot (1250 m) level. Working with SURF, this new location was refurbished and modified with a small amount of additional excavation to accommodate both the current experiment and possible future experiments. Experimental design has been supported by site characterization including limited drilling, analyses of core, underground mapping, and stress measurements, as well as supporting numerical modelling. Drilling is underway and is expected to extend into mid-2021.

The Collab project has furthermore been prolific in disseminating information; an informative and up-to-date Wiki has been developed, and more than 120 papers, reports, and presentations have originated via Collab, with more to come in 2021.

The EGS Collab was launched in 2017 and serves as an intermediate-scale field site where the geothermal reservoir modelling and research community is validating against controlled, small-scale, in-situ experiments focused on rock fracture behavior and permeability enhancement. Led by Lawrence Berkeley National Laboratory, the project brings together world-class scientists in subsurface process modelling, geophysical monitoring, and experimentation. Research performed at Collab will act as a bridge between small laboratory-scale mechanics studies and the large field-scale of FORGE Utah.

21.2.1.3 Play Fairway Analysis and GeoDAWN

Play Fairway Analysis (PFA), a technique adapted from oil and gas exploration, wrapped up successfully in 2020 with more than 100 publications and multiple new methodologies developed and tested. PFA ultimately yielded promising results that validated it as an effective tool for identifying prospective geothermal plays.

PFA began in 2014 with 11 Phase 1 teams conducting data analyses to assess geothermal favourability over various geographic regions. In Phase 2, projects moved from desktop analysis to field work, acquiring new geochemical, geophysical, and geological data to develop conceptual models. PFA entered Phase 3 in 2018 with the goal of validating the conceptual models by drilling temperature gradient wells into the resources identified in earlier phases. Drilling and assessment continued in 2019 and was completed late in the year. Drilling sites included two in Nevada, one in Idaho, two in Washington, and one in Hawaii. Initial data was favourable and validated the PFA methodology for use in geothermal exploration and development. By improving success rates for exploration drilling, PFA was demonstrated to significantly lower the costs of geothermal energy while opening new areas to development.

One such area of new development is Western Nevada; in early 2020, GTO initiated interagency discussions with the U.S. Geological Survey (USGS) to jointly provide solutions to domestic needs for both energy and critical minerals. Building from the USGS' existing Earth Mapping Resource Initiative (Earth MRI), the Geoscience Data Acquisition for Western Nevada initiative (GeoDAWN) was launched in late 2020 as a continuation of machine learning R&D that draws from GTO's previous PFA initiative, with the added task of flagging critical minerals prospectivity based on surface and near-surface characteristics. Under the GeoDAWN collaboration, researchers are gathering new subsurface data in the Walker Lane geologic zone in western Nevada, along the border with California. This research could eventually extend into prospective regions of California.

The datasets acquired through this collaboration will form the basis for innovative machine learning that can enhance the ability to remotely characterize the subsurface. The massive scale of the study area and the large datasets that will be captured will enable the application of a variety of advanced machine learning techniques to the problem of locating subsurface resources.

GeoDAWN involves two methods of data capture, including a high-resolution aeromagnetic survey and lidar data collection. These methods allow researchers to detect patterns in subsurface properties that may indicate conditions that are favourable for geothermal and/or mineral resources. The lidar collection was rapidly completed before the end of 2020, with data analysis ongoing in 2021. Aeromagnetic data will be captured in 2021-22 and analysed in conjunction with the lidar data.

The geothermal community is enthusiastic about GeoDAWN because it addresses a large and underutilized region of western Nevada. While Nevada has developed its fair share of geothermal power – second only to California in domestic capacity – it holds great potential for generating even more.

21.2.1.4 Efficient Drilling for Geothermal Energy

In 2018, GTO funded seven projects to advance geothermal drilling development. The projects will focus on improving drilling efficiency and speed through innovative R&D, which can improve the economics of geothermal development significantly. Drilling operations comprise up to 50% of the cost of geothermal development, so more efficient drilling can reduce risk and cost and help spur increased geothermal development in the near-term. In 2019, the selected project leads began research into early-stage R&D techniques and technologies for drilling geothermal wells that reduce non-drilling time and improve rates of penetration. Significant progress in 2020 was made on concepts and prototypes for various EDGE projects, including:

- Development of advanced bit material to increase rate of penetration in geothermal drilling, with a newly developed bit cutter featuring a polycrystalline diamond mount.
- Development of a rotary piston motor for high-temperature directional drilling featuring synthetic diamond bearings.
- Advanced downhole acoustic sensing for wellbore integrity, with R&D focused on cable-free nanotube sensor arrays and/or acoustic contrasting agents embedded within the borehole casing.
- Development of advanced insulating thermal shock-resistant cement – this lightweight composition is being tested in water-saturated conditions up to 500° F.
- Development of a high-temperature percussive hammer using ceramic components and thermal barriers to achieve a greatly increased drilling rate in harsh conditions.

21.2.1.5 Wells of Opportunity

In July 2020, GTO announced up to $10.4 million for three projects under the Wells of Opportunity (WOO) initiative. WOO directly supports R&D at the Utah FORGE site. Research areas now underway include:

- Utilizing several stimulation technologies to improve the permeability of well 16-29 at the Patua Geothermal Field in Churchill County, Nevada to boost electricity generation at the sited power plant.

- Sequential stimulation of three wells at three separate operating fields in Nevada to conduct a comparative analysis of similar simulations in different geologic environments, and to increase production. The wells include Don Campbell well 68-1RD in Mineral County; Jersey Valley well 14-34 in Pershing County; and Tungsten Mountain well 24-22 in Churchill County.
- Stimulation of multiple zones of interest in well 73-18RD at the Coso Geothermal Field in Inyo County, California using innovative packers to achieve zonal isolation to improve production.

21.2.1.6 Zonal Isolation

GTO awarded funding to four projects supporting early-stage research and development of tools and technologies for EGS. These projects, selected in 2018, seek to improve the performance and increase the cost-effectiveness of EGS through research in zonal isolation, which can dramatically improve the performance and economics of EGS. These technologies create extensive and optimized fracture networks by targeting stimulation activities to specific zones efficiently and predictably. In turn, this reduces costs and risks associated with EGS development and operation, and facilitates increased power generation from fewer wellbores.

Research in 2019 focused on developing reliable zonal isolation tools and technologies that 1) present low risk to wellbore integrity or the conductivity of fractures, and 2) operate extensively at high temperatures (and in differential pressures) in corrosive, hard rock environments. Prototypes developed in 2020 will be field tested in 2021 at domestic geothermal fields.

21.2.1.7 Hidden Geothermal Systems in the Basin & Range

This exploration initiative was launched in 2020 and seeks to accelerate discoveries of new, commercially viable hidden geothermal systems in the Great Basin Region (GBR) of the western United States by combining play fairway analysis, machine learning, advanced geostatistics, and other analytical techniques into a comprehensive exploration toolkit. Ultimately this initiative could help reduce the costs and risks associated with geothermal exploration.

21.2.1.8 Deep Direct-Use and Thermal Energy Storage

Deep direct-use (DDU) systems are an emerging technology area in the geothermal sector that draw on lower temperature geothermal resources for direct use applications. In 2020, GTO successfully completed its DDU Feasibility Studies initiative, highlighted by a retrospective presented by the National Renewable Energy Laboratory (NREL) mid-year.

Launched in 2017 at six sites across the country, these comprehensive studies included initial site selection, resource assessment, and feasibility analysis of deep direct-use (DDU) geothermal technology, in hopes of identifying locations where DDU installations could help address net-zero energy demand. The studies used a range of parameters such as well flow rates, utilization rates, taxes and incentives, exploration, and capital costs, to examine the viability of DDU systems of various capacities (in megawatts) throughout the country. By demonstrating the feasibility of systems that match low-temperature geothermal resources with proximate thermal end uses, these DDU projects have expanded the potential for geothermal applications in regions of the country with temperatures below current technical capabilities for geothermal power generation. The studies also provided a model to conduct similar assessments at additional locations.

The DDU studies further provided information on costs and other attributes that can help end-users and developers assess future projects. The DDU analyses confirmed, for instance, that — when environmental, societal, and other benefits such as resiliency and sustainability are included in the feasibility study — the levelized cost of heat can be reduced by as much as 70%.

These analyses were unique in the scope and breadth of locations evaluated and they provide detailed models of DDU systems that were not previously available. A large-scale, fully integrated DDU geothermal system has never been realized in the United States, but the results of the DDU studies could facilitate such an installation.

Advancing DDU over the coming years could result in large-scale, low-temperature geothermal applications that create greater opportunities for geothermal resource development throughout the United States. DDU technologies could usher in the use of low-temperature, thermal resources in subsurface reservoirs in U.S. regions lacking conventional hydrothermal resources. Additionally, at a large scale, DDU applications can potentially be used to replace conventional district heating and cooling systems in military installations, hospital complexes, office buildings, hotels, and other large energy end-uses, expanding geothermal as a renewable thermal energy in large portions of the United States.

DDU potential extends further to bidirectional energy storage using low temperature geothermal applications, a topic area specified in GTO's multi-topic funding opportunity selections announcement in summer 2020. Energy storage is an area of great interest to not only the geothermal community but the renewable energy community at large. For example, research conducted at Portland State University (Oregon) as part of the DDU Feasibility Studies identified prospective subsurface storage solutions within the underutilized Columbia River Basalt Group (CRBG) confined aquifer system.

Further research into DDU was launched in late 2020 at Cornell University, one of the six sites chosen for feasibility analysis. The Cornell study showed a clear pathway to heating a portion of the campus directly from low-temperature geothermal resources; the Eastern U.S. Appalachian Basin underlies the campus. With the technical, economic, and environmental feasibility documented, the Cornell team was approved to move forward with a modern drilling and stimulation technology design coupled with existing surface infrastructure to directly test the concept on their campus.

The proposed solution is to drill a 2.5 km borehole near campus to directly investigate the geologic conditions and thermal state in the underlying Appalachian Basin. This project will build on the technical and economic feasibility explored in Cornell's previous work. This approach to using the renewable thermal energy beneath the campus will open the door to projects of similar characteristics where there is thermal demand in locations above low temperature resources. Another novel part of the assessment is integration of heat pumps to substantially improve operating flexibility and heat recovery. Moving forward, an exploratory borehole being drilled on a suitable campus location will demonstrate the ability to find geothermal resources suitable for the proposed system, with the potential of substantiating geothermal as a 50-state solution.

21.3 Research Priorities

Using the *GeoVision* roadmap as a guide, GTO established a lead priority for the next 8-10 years: To demonstrate geothermal energy's value as the baseload renewable of the future in the U.S. This overarching priority is supported by three objectives:

1) **Unlock the potential of enhanced geothermal systems**: Ensure that engineered reservoirs – created where there is hot rock but little to no natural permeability or fluid saturation present in the subsurface – become commercially viable.

2) **Increase geothermal energy on the U.S. electricity grid**: Reduce risks and costs of all aspects of geothermal energy, including exploration, drilling, and deployment, to make geothermal energy an ever-more attractive piece of the energy portfolio.

3) **Expand geothermal energy opportunities throughout the United States:** Increase deployable technology and awareness of Deep-EGS, geothermal heat pumps, district heating, and thermal energy storage across the entire country.

21.3.1 Geothermal Education

GTO's 2020 student competitions focused on the topics of infographics and GIS mapping, and drew outstanding entries from student teams across the U.S. These entries directly support geothermal R&D and are valuable in gauging and developing future R&D initiatives. In late 2020 the student competition was formally renamed the Geothermal Collegiate Competition, to reflect its focus on university and collegiate engagement.

21.3.2 Conferences

GTO delivered its annual keynote at Stanford University's 45th geothermal workshop. This conference unites engineers, scientists, and managers involved in geothermal reservoir studies and developments; provides a forum for the exchange of ideas on the exploration, development and use of geothermal resources; and enables prompt and open reporting of progress.

Geothermal Rising, formerly known as the Geothermal Resources Council (GRC), held its 2020 Annual Meeting, at which GTO provided a keynote overview of funded research, and led multiple technical sessions. The meeting provides an international forum for the exchange of new and significant research information on all aspects of geothermal resource characterization, exploration, development, and utilization.

Additionally, as part of an elevated outreach push, GTO presented R&D overviews in 2020 to various energy-related organizations including the American Rock Mechanics Association (ARMA), the Society of Manufacturing Engineers (SME), and the Symposium on the Application of

Geophysics to Engineering and Environmental Problems (SAGEEP) via the Environmental and Engineering Geophysical Society (EEGS).

21.3.3 Useful Websites

DOE Website: energy.gov

DOE's Office of Energy Efficiency and Renewable Energy Website: energy.gov/eere/office-energy-efficiency-renewable-energy

GTO Website: energy.gov/eere/geothermal

GeoVision Website: energy.gov/geovision

FORGE Website: energy.gov/forge

GMI Website: energy.gov/grid-modernization-initiative

U.S. Geological Survey - Geothermal Publications:
energy.usgs.gov/OtherEnergy/Geothermal.aspx

GRC Website: www.geothermal.org

AGU Website: www.agu.org

Stanford University Geothermal Website: geothermal.stanford.edu

21.4 Future Activity

FORGE – 2021 marks the launch of R&D under Solicitation 2020-1 (see previous section for details). A second solicitation is slated to launch later in the year.

EGS Collab – Experiment 2 at the 4,100-foot (1250 m) level is underway and will continue in 2021, with a focus on further design, execution, and monitoring of hydraulic shearing of fractures and associated predictive modelling.

GeoDAWN – Data gather and analysis in the Walker Lane region of Nevada will continue into 2022, with updates and results announced during the year. The project could expand into California in 2021.

Machine Learning – The coming year will include further research in application of machine learning techniques to geological, geophysical, geochemical, borehole, and other relevant datasets, with the goal of finding new resources and improving operations. Machine learning R&D extends to datasets gathered through the GeoDAWN initiative.

Subsurface Stress and Lost Circulation – This area of research advances our ability to characterize, monitor, and predict subsurface in situ state of stress and its geomechanical linkages to drilling operations and related wellbore challenges. Improved understanding of the interplay between these concepts in U.S. geothermal settings is key to improving drilling efficiency and reducing the overall costs of geothermal development.

Geothermal Manufacturing Prize – A series of four progressive competitions to harness the rapid advances that additive manufacturing can provide in tool design and functionality. Stage 2 is underway in early 2021, with Stage 3 to commence later in the year. DOE is funding $3.25 million to support a research prize designed to spur innovation and address manufacturing challenges fundamental to operating in harsh geothermal environments. U.S.-based researchers are eligible to compete.

Geothermal Lithium Extraction Prize – Launched in early 2021, this $4 million prize competition seeks to advance technologies that improve the economics and lessen environmental impacts of lithium mining from geothermal brines. Phase 1 completes mid-2021; subsequent phases will carry into 2022. Competitors must be affiliated with a U.S. academic institution.

Energy Storage – GTO will continue funding geothermal advanced energy storage research in 2021. The office will specifically fund investigations into geothermal applications and conditions suitable for subsurface storage.

Appendix 1 – IEA Geothermal Executive Committee

Chair

Dr Lothar Wissing

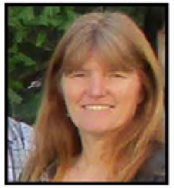
ForschungszentrumJülich GmbH
Project Management Organization
D-52425 Jülich
GERMANY

Ph: +49-2461-61-4843
Fax: +49-2461-61-2840
E-mail: l.wissing@fz-juelich.de

Vice-Chair

Betina Bendall
Energy Resources Division
Department of Energy and Mining
Government of South Australia
GPO Box 1264
Adelaide SA 5001
AUSTRALIA

Tel: +61-8-8429-2438
Fax: +61-8-8463-3229
E-mail: Betina.Bendall@sa.gov.au



Vice-Chair

Kasumi Yasukawa

Councilor, Geothermal Unit
Japan Oil, Gas and Metals National Corporation
Toranomon Twin Building 2-10-1, Minato-ku
Tokyo 105-0001
JAPAN

Tel: +81-3-6758-8643
E-mail: yasukawa-kasumi@jogmec.go.jp

Vice-Chair

Chris Bromley

GNS Science
Wairakei Research Centre
Private Bag 2000
Taupo 3352
NEW ZEALAND

Ph: +64-7-374-8211
Fax +64-7-374-8199
E-mail: c.bromley@gns.cri.nz

Vice-Chair

Jiri Muller

Institute for Energy Technology
P.O. Box 40
NO-2027 Kjeller
NORWAY

Tel: +47-6380-6185
Email: Jiri.Muller@ife.no

Executive Secretary

Brian Carey

GNS Science
Wairakei Research Centre
Private Bag 2000
Taupo 3352
NEW ZEALAND

Ph: +64-7-374-8211
Fax +64-7-374-8199
E-mail: iea-giasec@gns.cri.nz

Appendix 2 - IEA Geothermal Members and Alternates

Country / Name	Delegate	Organization / address	e-mail and phone		Alternate	Address, etc. (where different)	
AUSTRALIA	**Barry Goldstein**	**Director** **Energy Resources Division** **Department of Premier and Cabinet South Australia (DPC)** Government of South Australia GPO Box 1264 Adelaide SA 5001 AUSTRALIA	barry.goldstein@sa.gov.au Tel: +61-8-8463-3200		Betina Bendall *Vice-Chair*	**Energy Resources Division** **Department of Department of Energy and Mining** Betina.Bendall@sa.gov.au Tel: +61-8-8463-3243	
EUROPEAN COMMISSION	**Matthijs Soede**	**Policy Officer** **European Commission** DG Research and Innovation Directorate for Energy Unit G.3 – Renewable Energy Sources Rue du Champs de Mars, 21 (CDMA 00/060) 1049 Brussels Belgium	matthijs.soede@ec.europa.eu Tel +32 2 29 58201		Samuel Carrara	**European Commission – Joint Research Centre** **Directorate for Energy, Transport and Climate** **Unit C7 'Knowledge for the Energy Union'** **Westerduinweg 3, 1755 LE Petten / The Netherlands** samuel.carrara@ec.europa.eu Tel: +31 224 56 5118	
FRANCE	**Virginie Schmidle-Bloch**	Secretary General French Geothermal Association of Professionals (AFPG) 77 rue Claude Bernard 750005 Paris France	virginie.schmidle@afpg.asso.fr Tel. +33(0)7 86 58 67 17		Christian Boissavy	GEODEEP 77 rue Claude Bernard 75005 Paris France christian.boissavy@orange.fr Tel: +33 (0)6 38 83 93 52-	
GERMANY	**Lothar Wissing** ***Chair***	**Forschungszentrum Jülich GmbH** Project Management Organization D-52425 Jülich GERMANY	l.wissing@fz-juelich.de Tel: +49-2461-61-48-43		Manuela Richter	**Forschungszentrum Jülich GmbH** ma.richter@fz-juelich.de Tel: +49-2461-61-9165	
GEOPLAT	**Margarita de Gregorio**	**Spanish Geothermal Technology Platform (GEOPLAT)** **Doctor Castelo 10,** **3 C-D. 28009.** **Madrid** **SPAIN**	margadegregorio@geoplat.org Tel:+34 91 400 96 91		Paloma Pérez	**GEOPLAT** pperez@geoplat.org Tel:+34 91 400 96 91	
ICELAND	**Jónas Ketilsson**	**Orkustofnun** Grensásvegur 9 108 Reykjavik ICELAND	jonas.ketilsson@os.is Tel: +354-569-6000		Guðni Axelsson	**Iceland GeoSurvey** Grensásvegur 9 IS-108 Reykjavik ICELAND gax@isor.is Tel: +354-528-1500	
ITALY	**Sara Montomoli**	**Head of Geothermal Innovation** **ENEL Green Power** Via Andrea Pisano 120 -56120 Pisa, ITALY	sara.montomoli@enel.com Tel: :+39 3287264589		Paci Marco	**Head of Geothermal and Biomass Laboratories** **ENEL Green Power** Via Andrea Pisano 120 -56120 Pisa, ITALY Tel:+393498304052 marco.paci@enel.com	
JAPAN	**Kasumi Yasukawa**	**Councilor, Geothermal Unit** **Japan Oil, Gas and Metals National Corporation (JOGMEC)** Toranomon Twin Building 2-10-1, Minato-ku Tokyo 105-0001 JAPAN	yasukawa-kasumi@jogmec.go.jp Tel: +81-3-6758-8643		Shuhei Harada	**Researcher, Business Coordination Division,** **Geothermal Business Department, Geothermal Unit** **Japan Oil, Gas and Metals National Corporation** 10-1,Toranomon 2-chome, Minato-ku, Tokyo 105-0001, JAPAN harada-shuhei@jogmec.go.jp **+81-3-6758-8593**	
MEXICO	**Jose Manuel Romo Jones**	**Technical Representative at CEMIE-Geo** **Depto. de Geofisica Aplicada , CICESE** Carretera Ensenada-Tijuana #3918, Fraccionamiento Zona Playitas, 22860 Ensenada B.C., Mexico.	jromo @cicese.mx Tel.: +52 (646) 175 0500		Thomas Kretzschmar	**Representative of Specialized Laboratories System at CEMIE-Geo Depto. de Geologia, CICESE** Carretera Ensenada-Tijuana #3918, Fraccionamiento Zona Playitas, 22860 Ensenada B.C., Mexico. tkretzsc@cicese.mx Tel.: +52 (646) 175 0500	

Country / Name	Delegate	Organization / address	e-mail and phone		Alternate	Address, etc. (where different)	
NEW ZEALAND	**Chris Bromley** ***Vice-Chair***	**GNS Science** Wairakei Research Centre Private Bag 2000 Taupo 3352 NEW ZEALAND	c.bromley@gns.cri.nz Tel: +64-7-374-8211		To be appointed		
NORWAY	**Jiri Muller** ***Vice-Chair***	**Institute for Energy Technology** P.O. Box 40 NO-2027 Kjeller NORWAY	Jiri.Muller@ife.no Tel: +47-6380-6185		Carsten F. Sørlie	**Equinor ASA** Arkitekt Ebbells veg 10, 7053 Ranheim, NORWAY cso@equinor.com (+47) 90961827	
ORMAT Technologies, Inc.	**Shimon Hatzir**	Vice-President Engineering **ORMAT Technologies, Inc.** 6225 Neil Road Reno, Nevada 89511-1136 UNITED STATES	Shatzir@ormat.com Tel: +1-775-356-9029		To be appointed		
REPUBLIC of KOREA	**Yoonho Song**	**Geothermal Resources Department** **Korea Institute of Geoscience & Mineral Resources (KIGAM)** 92 Gwahang-no Yuseong-gu Daejeon 305-350 KOREA	song@kigam.re.kr Tel: +82-42-868-3175		Tae Jong Lee	**KIGAM** megi@kigam.re.kr Tel: +82-42-868-3051	
SWITZERLAND	**Gunter Siddiqi**	**Swiss Federal Ministry of the Environment, Transport, Energy and Communications – UVEK** **Federal Office of Energy (BFE)** Division of Energy Economics/Energy Research CH 3003 Berne SWITZERLAND	gunter.siddiqi@bfe.admin.ch Tel: +41-31-322-5324		Christian Minnig	**Swisstopo** Swiss Geological Survey Seftigenstrasse 264 CH-3084 Wabern SWITZERLAND Christian.Minnig@swisstopo.ch Tel. +41 31 963 2568	
UNITED KINGDOM	**Noramalina Mansor**	**Energy Engineering** **Science and Innovation for Climate and Energy Directorate** 1 Victoria Street London SW1H 0ET UNITED KINGDOM	noramalina.mansor@beis.gov.uk Tel: + 44		Jonathan Busby	**British Geological Survey,** Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG. jpbu@bgs.ac.uk Tel: +44 115 9363 440	
UNITED STATES OF AMERICA	**Lauren Boyd**	**Program Manager** **Enhanced Geothermal Systems (EGS)** **Office of Energy Efficiency and Renewable Energy** **US Department of Energy** 1000 Independence Ave, SW Washington, DC 20585 UNITED STATES of AMERICA	Lauren.Boyd@ee.doe.gov Tel: +1- 202-287-1818		To be appointed	-	

Appendix 3 - IEA Geothermal Working Group Leaders

Annex	Descriptive Title	Leader	e-mail and phone	Photo
1	**Environmental Aspects**	Chris Bromley	c.bromley@gns.cri.nz Tel: +64 7 374-8211	
8	**Direct Use**	Katharina Link to end July Vacant since end July.	info@geo-future.expert Tel: +41 79 816-3411	
10	**Data and Information**	Josef Weber,	Josef.Weber@liag-hannover.de Tel: +49 511 643-3442	
12	**Deep Roots of Geothermal Systems**	Guðni Axelsson	gax@isor.is Tel: +35 4 528-1500	
13	**Emerging Geothermal Technologies**	Josef Weber	Josef.Weber@liag-hannover.de Tel: +49 511 643-3442	
		Christian Minnig	Christian.Minnig@swisstopo.ch Tel. +41 31 963 2568	

IEA Geothermal

Executive Secretary

IEA Geothermal

C/ - GNS Science

Wairakei Research Centre

Ph: +64 7 374 8211

E: iea-giasec@gns.cri.nz