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Geothermal Energy in Switzerland – Country Update 2015-2020

Katharina Link[1], Nicole Lupi[2], Gunter Siddiqi[3]

[1] info@geo-future.expert

[2] nicole.lupi@bfe.admin.ch

[3] gunter.siddiqi@bfe.admin.ch

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ABSTRACT

Shallow and near surface geothermal projects are a success story in Switzerland with a wide range of applications. The oldest are highly popular thermal baths and natural spas. However, most common are systems based on ground-coupled heat pumps for heating residential houses, office buildings etc. In recent years, cooling especially during summer time has become increasingly important. Even tunnel waters are alternately used for geothermal heating and cooling. Nonetheless, ground-coupled heat pump systems are still the most common application amounting to 85 % of the totally installed thermal capacity.

To date, direct use of geothermal energy and power remain marginal with only few such projects realized and, until now, no geothermal power is produced in Switzerland. Since 2011, however, Switzerland has developed an Energy Strategy 2050, whose first phase of implementation aims, among other objectives, to increase the power and heat supply from renewable energies. Tailored measures and incentives have been implemented to enable geothermal power production and direct use to overcome its principal barrier for development, the resource risk that owes to poor knowledge of Switzerland's subsurface. Policy support has generated great interest, in particular for direct use geothermal projects, which have substantial potential to not only increase the share of renewables in the energy system but also contribute to Switzerland's climate targets.

Figure 1: The thermal baths of d'Ovronnaz in the Western Swiss Alps ("Les bains d'Ovronnaz").

In 2018, the total heating capacity of all geothermal systems in Switzerland was 2'196.8 MW. Of this total, 1'843.8 MW (83.9 %) was attributable to borehole heat exchanges (in the Swiss geothermal energy statistics this includes geothermal baskets and ground registers). Also contributing to Switzerland's geothermal heating output are: shallow groundwater 291.5 MW (13.3 %), geostructures 26.3 MW (1.2 %), deep aquifers 5.4 MW (0.2 %), tunnel water uses 3.9 MW (0.2 %), thermal baths 23.3 MW (1.1 %), direct deep aquifer uses 1.5 MW (0.1 %) and direct tunnel water uses (n/a).

The heating energy produced from geothermal systems amounted to 3'692.1 GWh in 2018, with a share of geothermal and thus renewable energy of 2'758.2 GWh (74.7 %). The other part of the heating energy produced represents the electricity contribution of the heat pumps.

The heating energy supplied came mainly from heat pump systems with a share of 94.6 % (3’491.1 GWh). Of this, 85.4 % was accounted for by borehole heat exchangers (2’981.6 GWh). The other geothermal heat pump uses were divided into shallow groundwater (12.2 %, 425.9 GWh), geostructures (1.6 %, 54.5 GWh), deep aquifer uses (0.6 %, 20.1 GWh), tunnel water (0.2 %, 6.5 GWh) and deep borehole heat exchangers (0.1 %, 2.5 GWh).

Direct geothermal uses without heat pumps supplied a total of 201.0 GWh in 2018, corresponding to 5.4 % of the total heating energy produced. Most of the direct use was via thermal baths (193.8 GWh). In addition, the Riehen system also supplied part of the deep aquifer use directly without a heat pump (5.2 GWh). At the Lötschberg tunnel, a large part of the geothermal heat was used directly for fish farming without a heat pump (2.0 GWh).

1. INTRODUCTION

With an area of approximately 41’000 km^2, Switzerland is located in central Europe. Most of the 8.5 Million inhabitants (in 2018) live in the Swiss Midlands north of the Alps.

Direct use of geothermal energy has had a long tradition in Switzerland. The oldest utilisations are popular thermal baths. Geothermal heat pump applications have been an unabated success story with compound annual growth rates of up to 12 %. Switzerland has one of the highest densities of ground source heat pump systems in the world. The deployment of shallow geothermal energy applications is mainly restricted by water protection regulations but not constrained by its natural potential.

The theoretical potential for direct use geothermal and geothermal for power generation is considered very large. The main obstacle of a widespread application is the limited knowledge of the deeper subsurface. As part of the realignment of Switzerland's energy and climate policy, a comprehensive package of measures and incentive schemes has been in place since 2018 to overcome this barrier.

2. SWISS ENERGY POLICIES

Switzerland has developed energy policies with an energy scenario for 2050 in mind (Figure 2). Measures to improve energy efficiency and to promote energy savings are the most important with high saving potentials and efficiency gains to be realised in the transportation and heating sectors; all along with switching from fossil fuels to a strong preference for renewables to play a much bigger role in the energy mix.

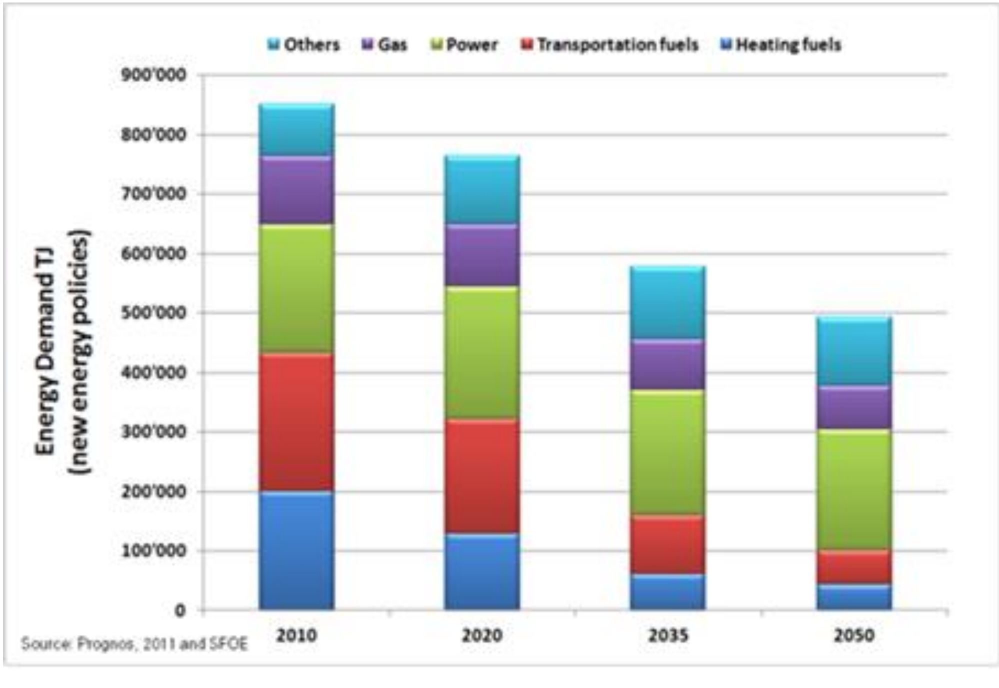


Figure 2: Energy demand of Switzerland: possible development from 2010 up to 2050 according to Prognos and the Swiss Federal Office of Energy (SFOE).

This development was instigated by the Swiss Federal Assembly in May 2011 with the aim to realign the country’s energy policies and, among many other changes, to phase out nuclear energy power plants. Both chambers of parliament voted on the new energy act and its package of measures in autumn 2016. As the final step, the Swiss population voted in favour of the new energy act in a national referendum on 21 May 2017. The new legislation entered into force on 1 January 2018. Several new measures and incentives were then introduced to boost the development of geothermal energy (Chap. 6.2).

In addition, in early 2017 the Swiss Federal Council decided not to recommend a ban on hydraulic stimulation to Switzerland’s cantons who govern the subsurface on their territory. Hydraulic stimulation is treated as a technology that enhances well and reservoir productivity for a number of applications, not just hydrocarbon production. Of course, highest regulatory and industry standards have to be upheld when deploying this production technology.

Because nuclear power plants are currently the second largest electricity producer in Switzerland (31.7 % in 2017), power production from renewable energies has to grow at substantial rates. An increased deployment of renewable energy technologies is therefore another very important pillar of Switzerland's energy strategy.

One of the renewable energy sources, which has been attributed substantial potential, is deep geothermal energy (Hirschberg et al., 2015). Against this backdrop, Switzerland's energy strategy 2050 has taken into consideration the development of geothermal energy.

Scenarios out to 2050 suggest that ~4'400 GWh_{el} per year may be supplied by geothermal power plants (Figure 3). In comparison, the current annual energy consumption in Switzerland is about 58'000 GWh_{el} (2017, UVEK 2017). Unlocking the potential of geothermal energy for power will also unlock vast amounts of geothermal heat for direct (and other) uses. It is expected that combined heat-and-power plants and direct use heating projects will be utilised to develop Switzerland's geothermal energy potential.

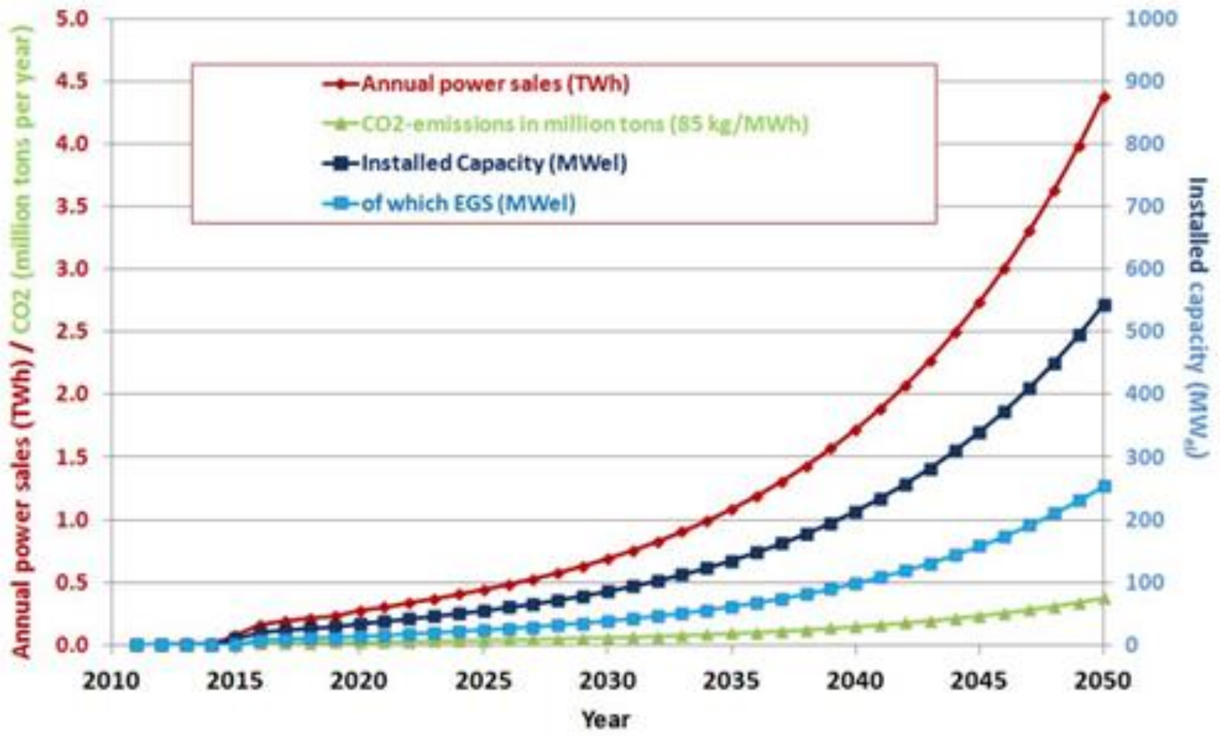


Figure 3: Scenario for growth of installed electrical capacity and geothermal power production within the framework of Switzerland's energy strategy 2050 (Source: Swiss Federal Office of Energy SFOE).

This vision is ambitious and can only be realised if there are adequate framework conditions and a geothermal industry capable to plan, develop and operate geothermal projects efficiently. A number of Switzerland's cantons have developed targets for geothermal heat, which are expected to have an effect on the development of national policies.

3. GEOLOGICAL BACKGROUND

Switzerland is roughly divided into the Tabular and the Folded Jura in the West and North (blue units in Figure 4), the Swiss Molasse Basin (Swiss Midland) (yellow unit) and the Alpine orogen in the central and southern parts (other colours, Figure 4).

The Swiss basement (purple units) consists of crystalline rocks containing troughs with permo-carboniferous sediments. This basement is exposed immediately north of the Swiss-German resp. French border («Schwarzwald», «Vosges» in Figure 4) and in parts of the Alps. The Tabular and Folded Jura are built up by Mesozoic units. The basement and its Mesozoic topset beds were flexed downwards in Oligocene to Miocene times due to the weight of the emerging alpine orogenic wedge. The resulting basin in front of the orogen was filled by the erosion debris of the Alps (molasse sediments). For that reason, the shape of the basin - and the corresponding thickness of the molasse sediments - are asymmetric with a maximum thickness up to about 6 km in its southernmost part, in front of the Alps (Figure 5).

The surface of the Swiss Midland is structured by Quaternary glaciations and subsequent alluvial and colluvial processes.

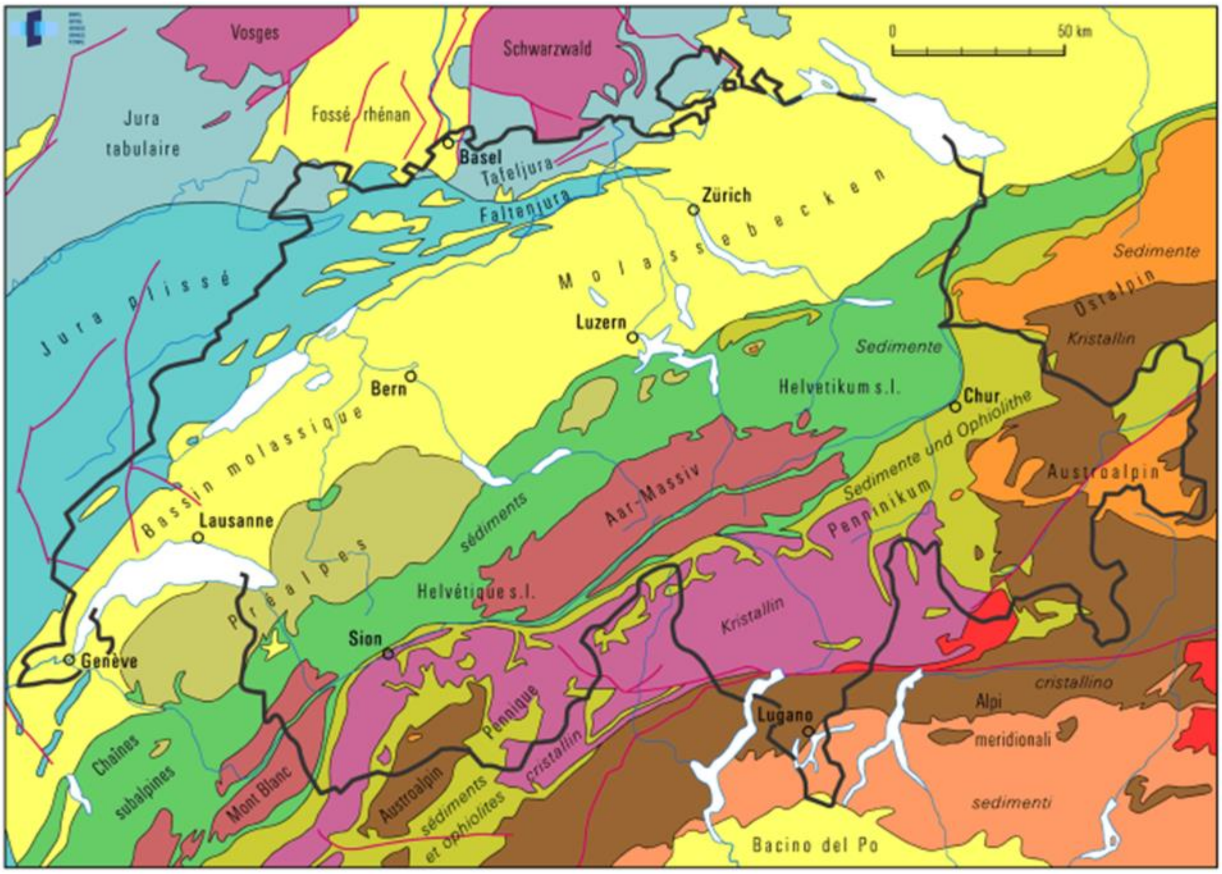


Figure 4: Approximate geological classification of Switzerland (Source: Swiss Federal Office of Topography swisstopo).

Compared to many other countries, the underground of Switzerland at depths below 2000 m has hardly been investigated.

The geothermal potential has been estimated by numerous studies on a local, regional or national level. Especially municipal energy suppliers perform local studies, with regional studies mandated by different cantons (Link and Zingg 2017).

In the Swiss Molasse basin, the geothermal gradients are considered to be normal, with values between 25 and 40 °C/km. The heat flow values range from 40 to 140 mW/m^2, with an average of 60 mW/m^2 (Signorelli and Kohl 2006; Baujard et al. 2007).

Possible targets of deep hydrothermal projects for heat and power production are potential Mesozoic aquifers (e.g. “Oberer Malm”, “Oberer Muschelkalk”), the top crystalline basement, and fault zones (Figure 5). EGS (or “petrothermal” projects in German parlance) are in theory possible throughout the entire country. Currently, the crystalline basement north of the Alps is considered a prime EGS target.

The potential of hydrothermal systems has been interpreted to be limited in Switzerland, but data hardly exist. The local feasibility of heat and power production has to be evaluated by geophysical surveys and exploration wells. In contrast, the potential of EGS is assumed to be large in Switzerland, as in many other places. According to a study by the Paul Scherrer Institute PSI (Hirschberg et al., 2015), about 600’000 TWh_{th} could be gained theoretically beneath Switzerland when cooling the 1.5 km thick rock layer between 4 and 5.5 km by 20°C. More realistic estimates of the technical and economic potential (and in the presence of support mechanisms) is limited to between 1 and 20 TWh_{el} along with associated co-produced heat. The annual power consumption in Switzerland is about 58 TWh_{el} (in 2018) and heat demand is about 85 TWh_{th}.

The project “GeoMol CH” assessed the subsurface potentials of parts of the Swiss Molasse basin for sustainable planning and use of natural resources. “GeoMol CH” is a part of the transnational project “GeoMol”, covering also the Slovenian, Austrian, German, French and Italian parts of the alpine foreland basins.

The "Seismic Atlas of the Swiss Molasse Basin” (Sommaruga et al. 2012) and a detailed study on the geothermal potential of Switzerland (Hirschberg et al. 2015) provide useful overviews on deep geothermal energy in Switzerland.

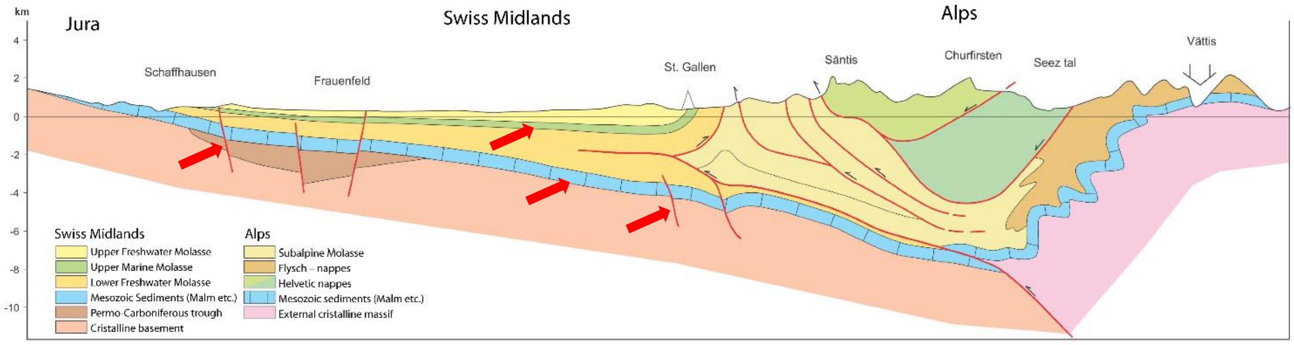


Figure 5: Possible hydrothermal target horizons and/or target areas along fault zones (red arrows) in the region of the Swiss Molasse Basin.

4. GEOTHERMAL UTILISATION

4.1 Electric power generation

No geothermal power plant has yet been built in Switzerland so far-. However, EGS projects are in the planning phase and a first project has been approved for realisation. Furthermore, one conventional (hydrothermal) combined heat and power project is in the planning phase (Chap. 5).

4.2 Geothermal heat use

Different kinds of geothermal direct use applications have been realised in Switzerland (e.g. Figure 6 or 8). Details regarding the geothermal energy use in Switzerland, like the thermal capacity or produced energy, are compiled and described in detail in the annually published Swiss geothermal energy statistics (e.g. Link 2019 for the year 2018).

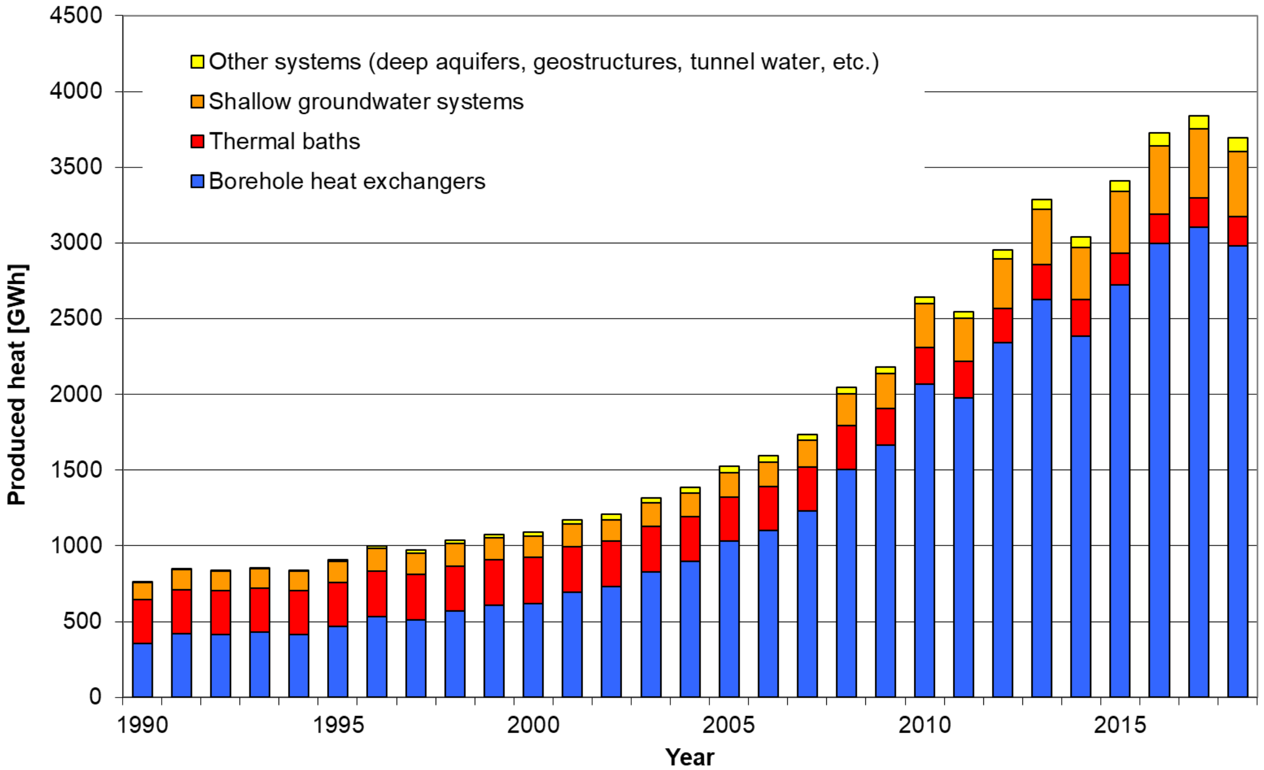
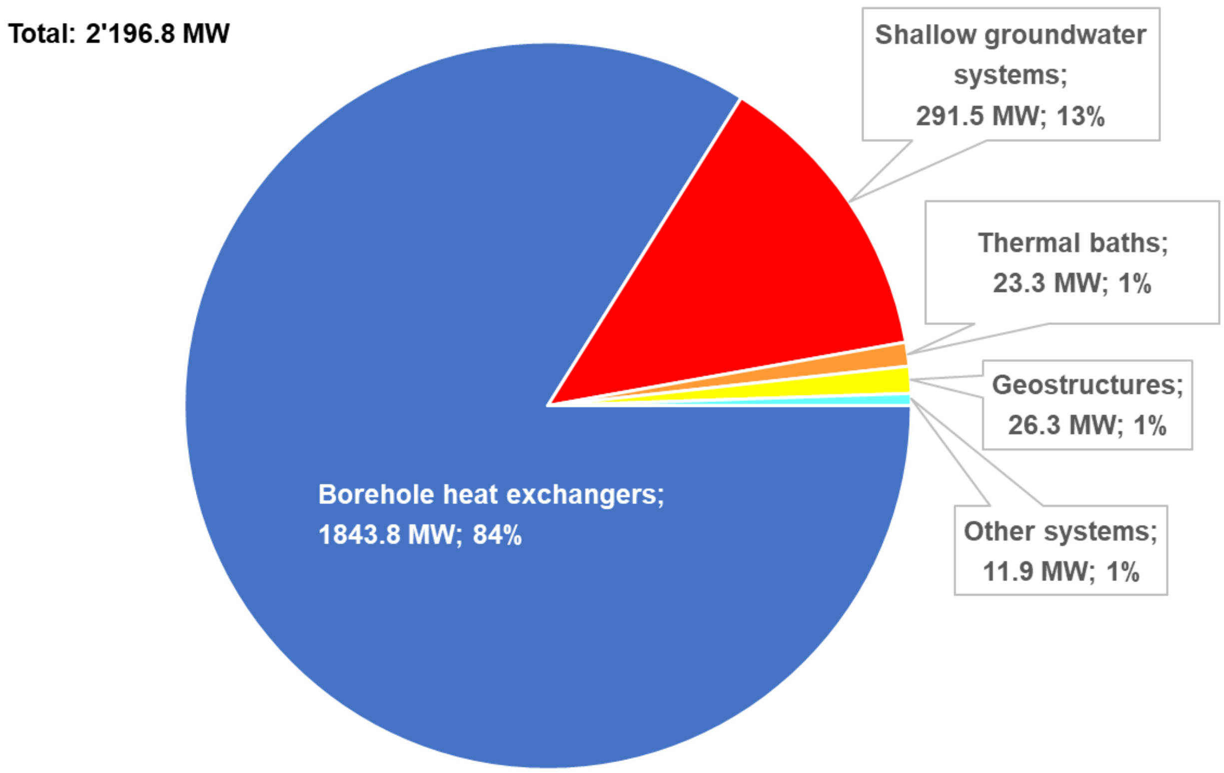


Figure 6: Annual geothermal heat production in Switzerland from 1990 to 2018 (after Link 2019). The data are based on the Swiss heat pump statistics (official sales figures) or on the reporting of the operator. The figures represent real operating data. The annual variations are due to the dependence on the heating degree days in a specific year.

The trends of the individual geothermal direct use applications show a steady increase in deployment, thermal capacity and climate-normalised produced heat. The decline in the operating data of geothermal heat production, e.g. in 2014 or 2018 (Figure 6), is due to a warm winter and thus low number of heating degree days. By far, borehole heat exchangers with heat pumps are still the predominant application in Switzerland, followed by shallow groundwater utilisations and balneology (Figure 6). Other systems including the use of deep aquifers have been of less relevance up to 2018. The statistical figures for "borehole heat exchangers" also include the rarely deployed geothermal baskets and ground registers.



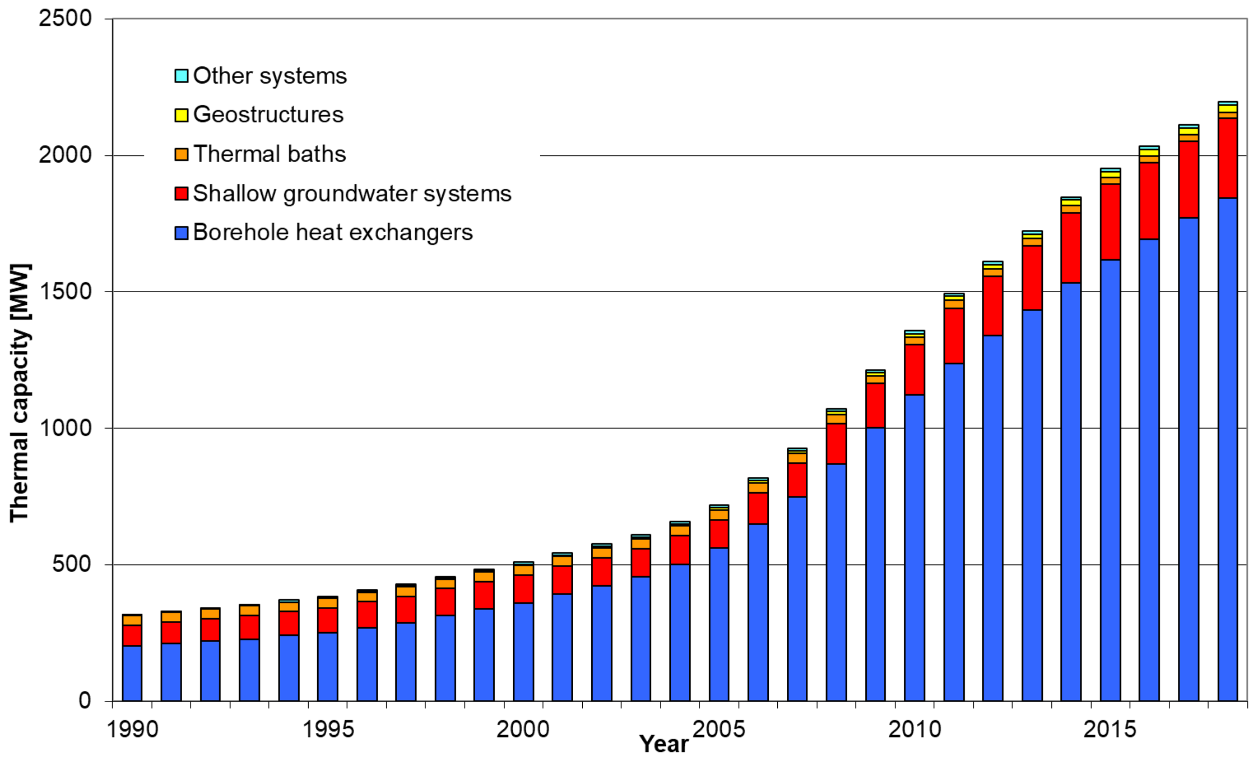


Figure 7: Thermal capacity of geothermal systems in Switzerland in 2018 (upper diagram) and development from 1990 to 2018 (lower diagram; after Link 2019).

In 2018, the total thermal capacity of all geothermal systems in Switzerland was 2’196.8 MW, of which 2’172.0 MW were heat pump systems (Figure 7). The total thermal capacity of all borehole heat exchangers amounted to 1’843.8 MW and reached 291.5 MW in groundwater systems, 26.3 MW in geostructures, 5.4 MW in deep aquifer systems (with heat pumps), 3.9 MW in tunnel water systems (with heat pumps), 1.5 MW in direct applications of deep aquifers and 1.1 MW in deep borehole heat exchangers. The thermal capacity of all thermal baths was 23.2 MW.

In 2018, the geothermal heat production amounted to 3’692.1 GWh (Table 1, Figure 8), with a geothermal and thus renewable energy part of 2’758.2 GWh.

	2015	**2016**	**2017**	**2018**	**%-share total 2018**	***%-share heat pump systems only 2018***
Borehole heat exchangers (incl. geothermal baskets and ground registers)	2‘723.0	2'997.6	3'103.5	2'981.6	*80.8%*	*85.4 %*
Shallow groundwater	405.9	450.2	454.6	425.9	*11.5%*	*12.2 %*
Thermal baths	209.7	192.9	192.8	193.8	*5.3%*	-
Geostructures	42.2	51.7	52.3	54.5	*1.5%*	*1.6 %*
Deep aquifers	13.9	17.9	19.8	20.1	*0.5%*	*0.6 %*
Tunnel water	5.8	6.5	6.5	6.5	*0.2%*	*0.2 %*
Deep aquifers (direct use)	4.2	5.2	4.8	5.2	*0.1%*	-
Tunnel water (direct use)	2.0	2.0	2.0	2.0	*0.1%*	-
Deep borehole heat exchangers	1.5	2.1	2.6	2.5	*0.1%*	*0.1 %*
Total geothermal heat pump systems	**3’192.4**	**3'526.1**	**3'639.3**	**3’491.1**	**94.4 %**	***100 %***
Total thermal spas + direct uses	**215.9**	**200.1**	**199.6**	**201.0**	**5.6 %**	**-**
Total	**3‘408.3**	**3'726.2**	**3'838.9**	**3692.1**	**100 %**	**-**

Table 1: Geothermal heat production [in GWh] of the various application categories in 2015 to 2018 (real operating data; after Link 2019).

80.8 % of the produced geothermal heat came from systems with borehole heat exchangers (2'981.6 GWh). The remaining heat pump-based utilisation was made up by groundwater systems (425.9 GWh), geostructures (54.5 GWh), deep aquifers (20.1 GWh), tunnel water (6.5 GWh) and deep borehole heat exchangers (2.5 GWh).

Geothermal heat pump applications, now increasingly used for heating and cooling, are growing steadily. The areal density of the installed capacity is still one of the highest worldwide (Lund and Boyd, 2015).

Direct use of geothermal heat without heat pumps is applied mainly for thermal bathing (193.8 GWh) and a doublet system for district heating in Riehen near Basel (5.2 GWh). In Frutigen, at the Lötschberg tunnel“, a large part of the geothermal heat (2 GWh) is used directly for fish farming (Tropenhaus Frutigen).

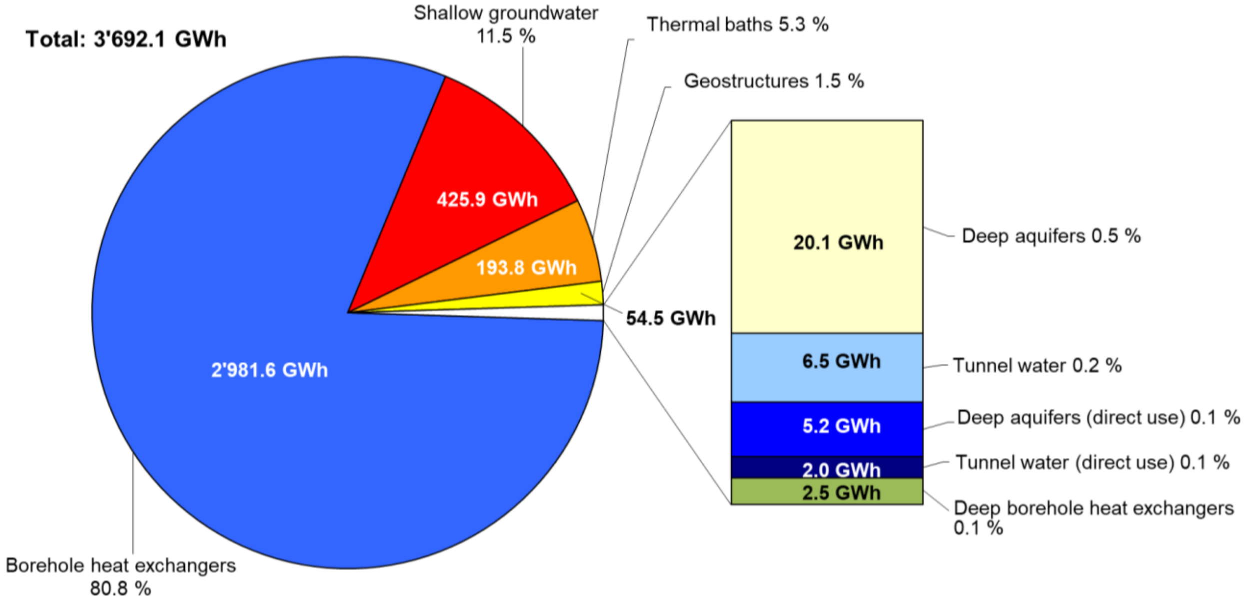


Figure 8: Geothermal heat production [in GWh] of the various direct use categories in 2018 (real operating data; after Link 2019).

4.2.1 Geothermal District Heating plants

The only large geothermal district heating plant is in Riehen near Basel in northern Switzerland. In operation since 1994, the thermal water is produced from an approximately 1.5 km deep aquifer (Middle Triassic Muschelkalk formation) in the area of a fault zone at the Southern End of the Upper Rhine Graben. The 65 °C warm water was initially produced at a rate of 20 l/s. In 1997, the district heating grid was extended to Stetten (Lörrach), Germany. This system represents one of the first transboundary direct use facilities worldwide. From 2010 to 2014, the Project "Riehen Plus" was realised to scale up the district heating system. Following the installation of a new production pump, the flow rate was increased to 23 l/s (May 2014; with a plan to reach 25 to 28 l/s in future) and the production temperature rose to 66 °C. After heat exchange to a secondary fluid and to maximize efficiency, three heat pumps cool the thermal waters down to temperatures of 30–25 °C resulting in a coefficient of performance (COP) of about 6.5.

Further development plans are considered to expand the use of the geothermal reservoir at Riehen. Surface exploration work will be carried out in order to plan a second doublet system.

4.2.2 Geothermal heat in agriculture and industry

There has been no deep geothermal heat use in the agriculture and industry sector to date. The first project in Schlattingen in the Canton of Thurgau has been constructed and is currently undergoing extensive testing. One of the two wells drilled has a nearly 800 m long and almost horizontal section within the approx. 1.5 km deep aquifer. No data from the long-term production test in 2018 have been published.

4.2.3 Tunnel water for heating and cooling

In Switzerland, many tunnels exist in the Alpine orogen and the hilly foreland. The Lötschberg base tunnel has a length of 34.6 km. Tunnels drain the water from the surrounding rock zones and, as a result, a considerable amount of warm water flows in the tunnel towards the portals. Strict environmental regulation prohibits the discharge of large amounts of warm water into nearby rivers. Instead of using energy to cool down the water, this energy resource can be used in various applications: in Switzerland tunnel water is used for space heating, greenhouses, balneology, fish farming etc.

Figure 9: The "Tropenhaus Frutigen" at the northern portal of the Lötschberg base tunnel uses the geothermal heat of the tunnel water for space heating, for raising tropical plants in greenhouses and for producing caviar in a fish farm (source: Tropenhaus Frutigen).

The most straightforward and cheapest form of thermal tunnel water usage is to collect and transport inflowing waters via ducts to the portals. When the temperature level of the tunnel water outflows is too low for direct applications (e.g. for district heating), heat pumps are used.

In 2018, geothermal tunnel water applications (with heat pumps) produced 6.5 GWh, of which 4.6 GWh were of geothermal origin. At the Lötschberg base tunnel, an additional 2 GWh of heat were used directly without heat pumps for fish farming ("Tropenhaus Frutigen", Figure 9). The Lötschberg Tunnel water at the Northern Portal has a flow rate of about 1'380 l/min and has a temperature of about 16-18°C.

In two cases, at the Gotthard and the Mappo Morettina road tunnels, the water is also used for cooling purposes during summer time.

5. CURRENT PROJECTS

5.1 Integrating shallow geothermal energy into an energy system

Smart thermal grids based on shallow geothermal energy have gained enormous importance in Switzerland in recent years. So-called "anergy" grids are now economically competitive and are implemented by private entities without national financial subsidies.

Numerous thermal grids with one or more geothermal probe fields for seasonal heat storage and the provision of heat and cold have been and are being implemented. Other energy resources, like groundwater, can also be integrated into such networks.

A recent example is the Greencity project in Zurich. In several stages, apartments for around 2'000 people, office and commercial premises for 3'000 workplaces, a hotel with 600 beds, a school for 250 children and several small shops will be built. Greencity is the first section of a new urban district that will be fully developed by 2020. Greencity is a certified 2'000-watt area and thus makes an essential contribution to environmental protection and the implementation of Swiss energy and climate policy. The installed capacity in Greencity is 4.8 MW_{th}. The geothermal probe fields and the groundwater systems serve as energy sources. The electricity for the heat pumps is provided by locally installed and proprietary photovoltaic systems.

Energie Wasser Bern (ewb) is also pursuing an innovative project at their Forsthaus site: a geo-heat storage project within 500 m deep sandstone deposits is to be used for seasonal high-temperature heat storage. During the summer, excess heat from a waste incineration plant will be stored in order to be back-produced during the winter months and fed into a district heating network. The project received the relevant permits in October 2018. A detailed description of the technology and project can be found on the website of Geo-Energie Suisse AG.

5.2 Deep geothermal energy

So far, there are only a few deeper geothermal plants for heat utilisation in Switzerland and no geothermal electricity has been generated. A major obstacle is the lack of knowledge about the deep underground.

However, the new incentive schemes introduced at the beginning of 2018 have a strong positive impact on the development of deep geothermal energy in Switzerland. Three new heat projects including the Forsthaus project of ewb (Chapter 5.1) have already obtained subsidies amounting to CHF 25.9 million (*1 Swiss Franc (CHF) is about 1 US Dollar*) and seven more are in the pipeline; In the case of geothermal electricity projects, two projects have received subsidies amounting to CHF 64 million for the EGS project Haute-Sorne and CHF 12 million for the project AGEPP in Lavey-les-Bains. Investigations are underway for 2 further projects.

5.2.1 Programme GEothermie 2020 Canton Geneva

The activities in the field of deep geothermal energy have concentrated in recent years almost exclusively on western Switzerland. The canton of Geneva (GE) in particular is a pioneer in this field with its programme GEothermie 2020. Step by step, various geothermal resources in the canton are to be investigated, characterised, and developed. The aim is to gradually explore the geothermal resources from shallow to resources at greater depths.

A first exploration well was successfully drilled at Satigny in 2018. The results are very promising: artesian water from the 744 m deep well arrive on surface with a temperature of 33°C at a flow rate of 50 l/s. This well provides important information on the geology and the stratigraphy that controls a number of geothermal prospects in the Canton of Geneva. A number of additional wells will be drilled throughout the canton until 2020 to further characterize Geneva's subsurface. The drilling of the second exploration well started at Lully in 2019. Building on the knowledge acquired, the cantonal utility company, Services Industriels de Genève SIG, will then explore for geothermal energy resources at depths of more than 1'500 m.

5.2.2 Other deep geothermal heat projects

In the City of Riehen, the largest geothermal heat plant in Switzerland has been in operation since 1994. As part of the Geo2Riehen project, the operators plan to expand the plant by a second doublet bringing the number of production and injection wells to a total of four.

Activities of the project EnergeÔ La Côte on Lake Geneva have also progressed; the project aims to exploit geothermal energy by tapping into aquifers expected at depths of 2200 m. The project has already obtained the relevant permits and pre-spud activities are scheduled to start in 2020. Of the four potential sites currently under investigation by EnergeÔ La Côte, the area of Gland/Vinzel has been targeted as the first site for an exploration well (Figure 10). At a later stage, additional aquifers expected at depths of about 5000 m will be targeted.

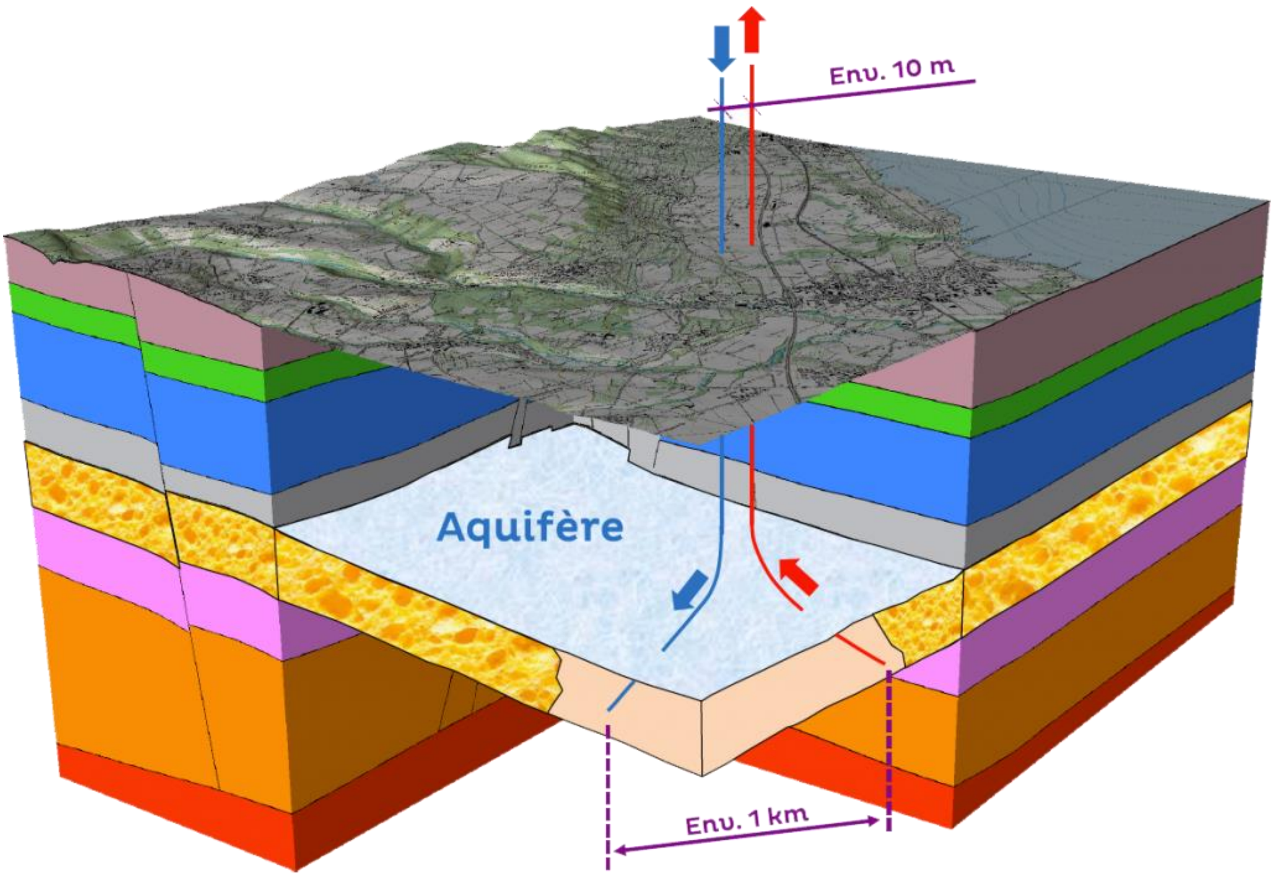


Figure 10: Planned geothermal project EnergeÔ Vinzel (source: EnergeÔ Vinzel).

Additional geothermal heating projects are being planned, including a project in Brig-Glis (Canton Valais), which is located in the intra-orogenic Rhône Valley.

5.2.3 EGS Projects

Geo-Energie Suisse AG aims at developing the EGS technology to unlock the enormous potential of heat stored in solid rock for electricity generation. Based on lessons learnt from previous EGS projects, Geo-Energie Suisse has developed a multi-stage stimulation system where a large number of smaller sections of a reservoir will be stimulated in sequential fashion.

The most advanced project of Geo-Energie Suisse AG is located in Haute-Sorne (Canton Jura). The Cantonal authorities have already granted approvals in June 2015. However, 5 neighbours opposed the decision of the Canton, took legal recourse and eventually appealed to Switzerland's highest court, the Federal Tribunal. In late 2018, however, the Federal Tribunal rejected the appeal and essentially gave the green light to the Haute-Sorne project.

In addition to the Haute-Sorne project, there are four other project sites in the Swiss midlands. Investigations are also being conducted at various locations in the Alps.

5.2.4 AGEPP Project

The Alpine Geothermal Power Production (AGEPP) project (Figure 11) is located in the Rhône Valley (Swiss Alps) near Lavey-les-Bains, one of the best-known geothermal sites in Switzerland. The existence of a significant geothermal resource in the region has been known since the 19th century. Being the hottest springs in Switzerland, they are at the origin of the development of Lavey Spa.

The objective of the project is to produce water at 110°C at a flow rate of 40 l/s, conditions that allow the generation of 4.2 GWh electricity (gross) and 15.5 GWh of thermal energy to supply the Lavey Spa with thermal waters and for heating pools and buildings. In the longer term, AGEPP plans to use residual heat for district heating, fish farms, and potentially for greenhouses. The project has already obtained the relevant permits and pre-spud activities are scheduled to start in 2020.

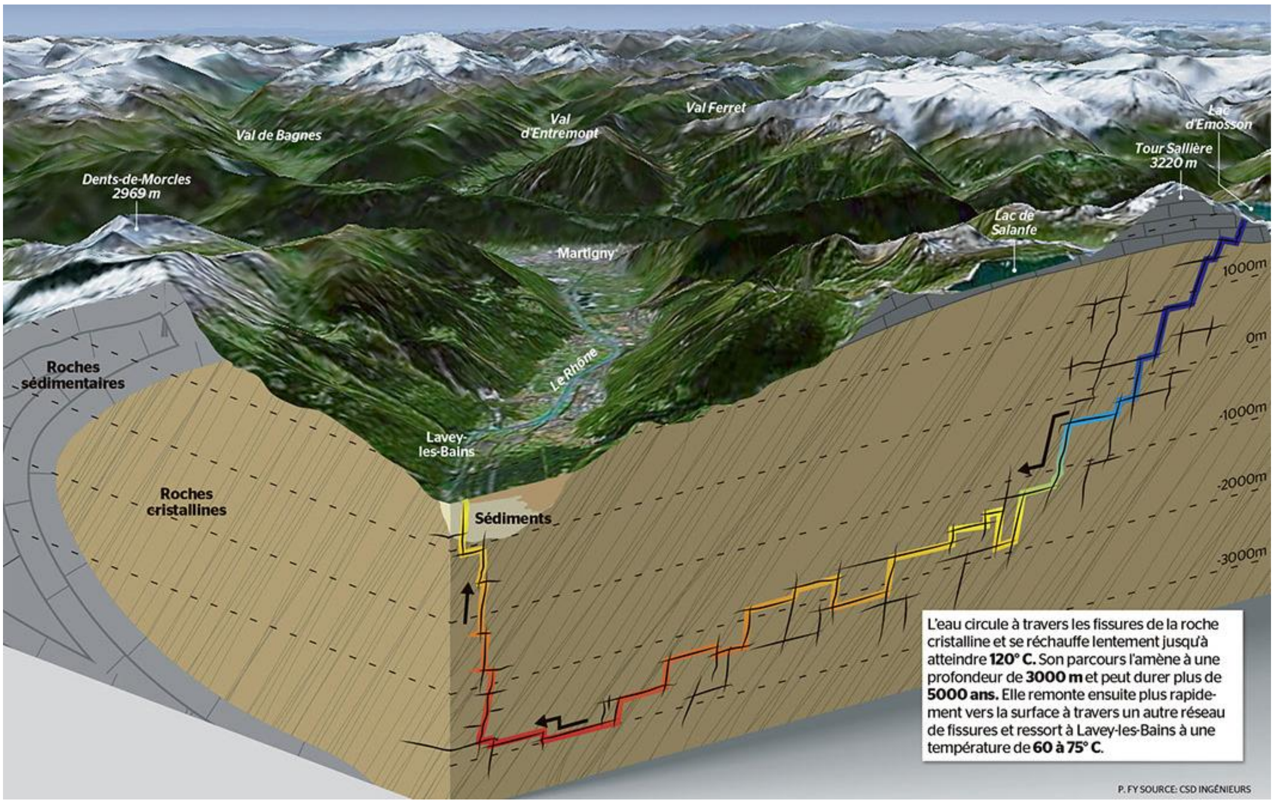


Figure 11: AGEPP project in the Western Swiss Alps (source: AGEPP SA).

6. INCENTIVE SCHEMES

6.1 Shallow geothermal energy

Switzerland does not have a national incentive programme for near-surface geothermal energy, because this falls under cantonal sovereignty. Most cantons, however, have stopped financial support of such systems because life cycle costs are economically viable. Only a few cantons continue to support financially the replacement of an existing fossil fuel heating system.

6.2 Deep geothermal energy

From 2008-2017, Switzerland has operated a geothermal guarantee scheme for geothermal power projects. Under this scheme, up to 50% of the actual subsurface development cost would have been reimbursed to project developers in case of a failure to find a suitable geothermal resource.

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 have been devised to support the development of geothermal energy (*1 Swiss Franc (CHF) is about 1 US Dollar*):

- The geothermal guarantee scheme for geothermal power projects has been overhauled: today's risk coverage has been raised from 50% to 60%, and the eligible costs have been extended to include prospecting expenses. Under current legislation, the scheme runs until 31.12.2030.
- New exploration subsidies covering up to 60% of the cost of surface exploration and exploration drilling are now available for geothermal power projects. At most CHF 50 million per year are dedicated to this risk mitigation scheme. Under current legislation, the scheme runs until 31.12.2030.
- New exploration subsidies for surface and subsurface exploration and development for aiming at the direct use of geothermal energy. At most 60% of the eligible cost will be subsidized. The scheme is funded via Switzerland's levy on fossil fuels used for stationary heat supply; at most CHF 30 million per year are available for direct use projects. Under current legislation, the scheme runs until 31.12.2025.
- Feed-in tariffs for power production from hydrothermal and EGS plants (Table 2; *1 Rappen ~ 1 US Cent*). The feed-in tariff applies now for a period of 15 years (instead of 20 years prior to 2018). From 1.1.2023 onwards, new geothermal power plants will no longer benefit from the feed-in tariff. However, in September 2019, the Federal Council announced that from then on and until 2035, new geothermal power projects will be able to apply for investment subsidies that will also cover part of their planning costs.

Capacity	Hydrothermal Rappen/kWh	EGS 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

(*1 Rappen ~ 1 US Cent*)

Table 2: New feed-in tariffs for geothermal power production.

Another important measure is to publicly make 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 for coordinated energy research". Financial support for geothermal research and innovation has grown considerably in the last 5 years from about CHF 5 million to CHF 15-20 million per year.

7. MARKET DEVELOPMENT

7.1 Shallow geothermal energy

In Switzerland, the market for shallow geothermal energy is mature. There is a clear tendency towards larger, complex, combined heating & cooling systems, applying up to several hundred borehole heat exchangers. Due to the success of ground source heat pump systems, many players have entered the market which now shows signs of consolidation. Most shallow geothermal drilling companies compete on price. Therefore, market conditions for industry players are increasingly challenging.

7.2 Deep geothermal energy

At present, the market for deep geothermal energy is not mature in Switzerland. In order to mitigate the exploration risk and the associated financial down-sides, the federal government has created a comprehensive package of measures and incentive schemes. Numerous projects have already been launched in the first two years. It is expected that with increasing market maturity, substantial cost reductions will result - particularly in the area of drilling – and will pave the way to commercial viability. Further increase in growth is therefore expected in the area of heat and power generation.

8. RESEARCH AND DEVELOPMENT

8.1 Shallow geothermal energy

The Swiss Federal Office of Energy runs a small specific national research and development programme for shallow geothermal applications. Research activities especially concentrate on smart thermal grids (including geothermal heat storage), quality assurance and control, as well as enhancing efficiency.

8.2 Deep geothermal energy

To a very large extent, 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 and innovation). 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 Centres for Energy Research (SCCER), launched in 2014 and running until the end of 2020, have been established to develop (human) capacities and initiate research and innovation in fields 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.

	2017			**2016**			**2015**			**2014**			**2013**		
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	**17.46**	**2.72**	**20.19**	**14.45**	**6.00**	**20.44**	**13.67**	**0.42**	**14.09**	**9.14**	**2.33**	**11.47**	**8.69**	**0.73**	**9.42**
from hydrothermal resources	1.23	1.58	2.81	1.35		1.35	0.99		0.99	1.10	0.20	1.30	1.57	0.06	1.64
from EGS (hot dry rock) resources	2.80	0.98	3.78	1.89	5.61	7.50	2.11		2.11	0.82		0.82	0.78		0.78
Advanced drilling and exploration	4.53		4.53	2.34		2.34	1.16	0.26	1.42	0.34	1.23	1.57	5.23	0.30	5.53
Other geothermal energy (incl. low temp. resources	0.66		0.66	0.42		0.42	0.59	0.16	0.75	0.23	0.90	1.13	0.10	0.29	0.39
Unallocated geothermal energy	8.23	0.17	8.41	8.45	0.38	8.83	8.82		8.82	6.66		6.66	1.01	0.08	1.08

Table 3: Swiss public investment in research, development and deployment of geothermal energy as reported to the IEA. Slightly ahead of countries subscribing to Mission Innovation, Switzerland has effectively doubled its investment into geothermal energy.

R&D funds for 2017 were at a level of US$ 20 million, approximately US$ 3 million of which for piloting and demonstration, with similar levels expected in 2018 and 2019.

A highlight was 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. A further important milestone was the construction of the new "Bedretto Underground Laboratory for Geoenergies" with the inauguration in May 2019. The new Bedretto Lab is located 1.5 km below surface in the middle of a 5.2 km long tunnel.

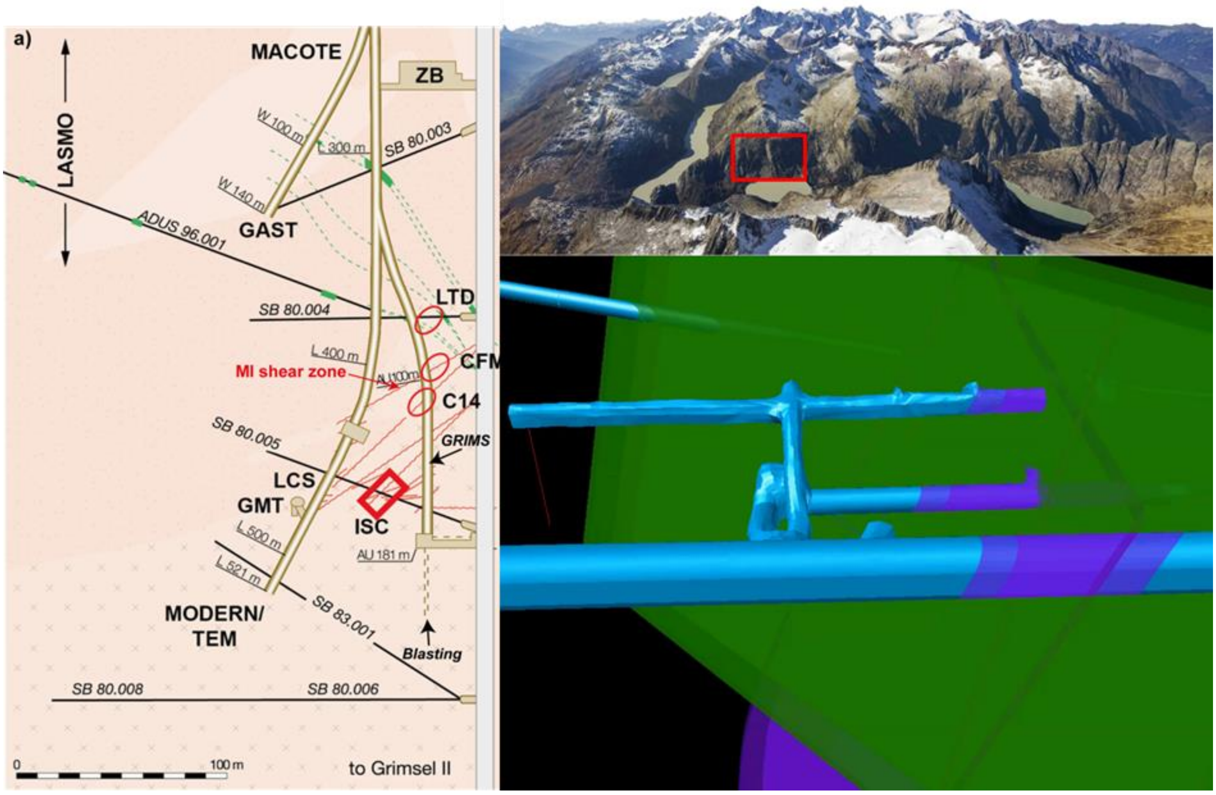


Figure 12: In-situ stimulation and circulation (ISC) in the underground lab at the Grimsel test site (Doetsch et al., 2017).

As of 1 January 2017, Switzerland is once again 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 a 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 the wake of GEOTHERMICA's first call, Switzerland leads the projects ZoDrEx and COSEISMIQ, and is a major contributor to HEATSTORE. A second joint call was launched in summer 2019. 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 are:

- Hydraulic stimulation / fracking tests at the Grimsel Test Site (http://www.grimsel.com/)
- The new Bedretto underground laboratory (http://www.bedrettolab.ethz.ch/home/)
- ThermoDrill (International) – fast track innovative drilling system for deep geothermal challenges in Europe (http://thermodrill.unileoben.ac.at/)
- DESTRESS (International) – Demonstration of Soft Stimulation treatments of geothermal reservoirs (http://www.destress-h2020.eu/home/)
- DG-WOW – Deep Geothermal Well Optimisation Workflow
- RT-RAMSIS – Real-Time Risk Assessment and Mitigation System for Induced Seismicity
- GEOTHERMICA ZoDrEx – Zonal Isolation, Drilling and Exploitation of EGS Projects (http://www.geothermica.eu/projects/zodrex/)
- GEOTHERMICA HEATSTORE (https://www.heatstore.eu/)
- GEOTHERMICA COSEISMIQ (http://www.geothermica.eu/projects/coseismiq/)

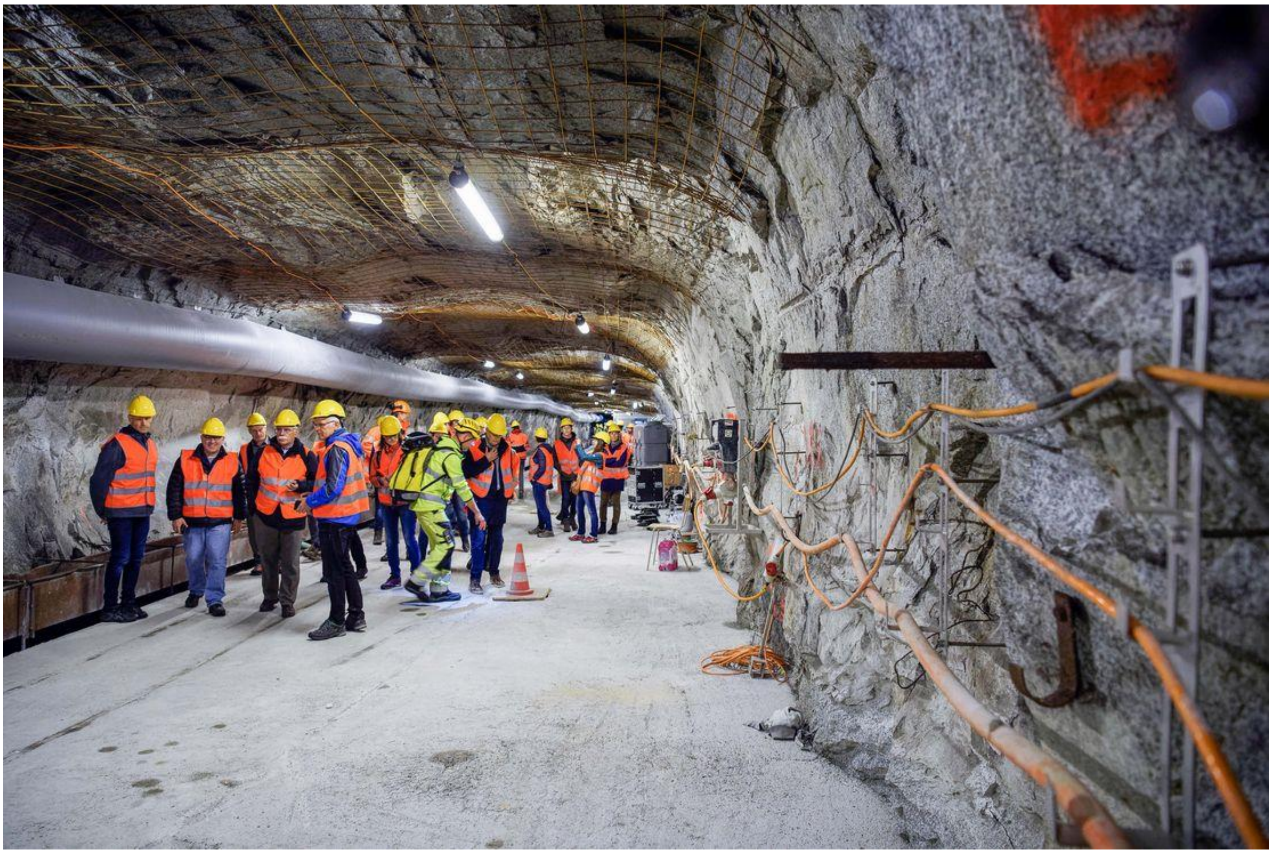


Figure 13 Construction of the new Bedretto Underground Laboratory for Geoenergies (Inauguration in May 2019).

9. FUTURE DEVELOPMENT AND INSTALLATIONS

9.1 Shallow geothermal energy

The success story of shallow geothermal energy in Switzerland will continue. Especially in more densely populated areas, however, the trend is clearly towards smart thermal grids, which can include various geothermal applications. The heart of such systems are usually geothermal probe fields as seasonal storage facilities. With the establishment of the geo-storage technology, new possibilities for temporary energy storage will open up. As a pilot and demonstration project, the Bernese energy utility ewb received the permission to build an underground artificial heat storage site.

9.2 Deep geothermal energy

Geo-Energie Suisse AG is planning to realise at least one EGS project for power and heat production in the near future. The hydrothermal projects in Western Switzerland (Geneva, EnergeÔ Vinzel, and AGEPP) will continue. Services Industriels de Genève SIG continues its canton-wide prospecting and exploration programme to stepwise utilise the different geothermal resources.

The new measures and incentive schemes have a strong positive impact on the development of deep geothermal heat and/or power projects. In particular for the direct use of geothermal energy where the number of projects has increased sharply already in the first two years of the new incentive programs.

10. CONCLUSIONS

Shallow geothermal energy is a success story in Switzerland. Nowhere else in the world is the installed capacity per area greater. Switzerland is also a leader in the field of smart thermal grids. This type of application will play an increasingly important role in Switzerland. Additionally, interest in deep geothermal energy for direct use and electricity production is on the rise. Although there are some successful deep geothermal projects in operation, the great potential available is far from being fully exploited. A geothermal power plant does not yet exist, although a financial incentive has been provided since 2008 with the risk guarantee and the feed-in tariff. As part of the Energy Strategy 2050, several new measures and a revised incentive system have been in place since the beginning of 2018. In particular, new subsidies have been granted for the exploration and development of geothermal resources. The positive effects of this measure are remarkable; numerous new projects have been launched, both in the area of heat and electricity production.

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