Summary of EGC 2022 Country Update Reports on Geothermal Energy in Europe

Burkhard Sanner[1], Miklos Antics[2], Marco Baresi[3], Javier F. Urchueguía[4], Philippe Dumas[5]

[1] EGC 2022 Country Update Report Coordinator, EGEC, 2, place du Champ de Mars, 1050 Brussels, Belgium

[2] GPC IP, Paris Nord 2 - Bât. 4A, 165 rue de la Belle Etoile, 95700 Roissy CDG, France

[3] TURBODEN S.p.A., Via Cernaia, 10, 25124 Brescia, Italy

[4] ITACA, Universidad Politécnica de Valencia, Camino de Vera s/n; 46022 Valencia, Spain

[5] EGEC, 2, place du Champ de Mars, 1050 Brussels, Belgium

sanner@sanner-geo.de

Keywords: geothermal potential, geothermal power, geothermal direct use, geothermal heat pumps, policy, country update.

ABSTRACT

The European status of geothermal energy use by the year 2021 is presented. 32 countries have reported for EGC 2022, from a total of 40 with known geothermal activities in Europe. The situation varies from country to country according to the geothermal technology that best suits the available natural resource. The opportunities include power generation from high enthalpy resources, binary power production and/or direct use of hydrothermal resources in sedimentary basins, and shallow geothermal applications available everywhere, the latter mostly harnessed by ground source heat pump installations.

Geothermal power generation in Europe currently stands at 3496 MW_e installed capacity. The installed capacity of geothermal heating from medium to low temperature sources exceeds 11’600 MW_{th}, of which about half is used in district heating. Concerning shallow geothermal energy (ground source heat pumps – GSHP and Underground Thermal Energy Storage – UTES), there is still a steady growth, and a capacity of at least 30’300 MW_{th} was achieved by the end of 2021, distributed over more than 2.1 Mio GSHP installations.

1. INTRODUCTION

In most countries in Europa, geothermal energy is firmly established on the heat market, with shallow geothermal energy (GSHP) used in virtually all of Europe. Direct use of deep geothermal resources is more regionally concentrated, due to its dependence upon suitable geological settings, and is mainly used in the East/South-East of Europe, France, Germany, and some more. Recent development in Belgium and the Netherlands is very encouraging for increased direct use of geothermal energy. Geothermal power generation still is centred in few countries, with only Iceland, Italy and Turkey having substantial shares of geothermal power in the national electricity mix.

The growth of geothermal electricity is also reflected in the shares the different sectors have in installed capacity in Europe. As can be seen in Figure 1, the share of power generation capacity increased from 7.3 % to 7.7 % over three years (it was at just 6.0 % at the time of EGC 2016). Shallow geothermal plants make up the largest share of about 2/3 of all capacity installed.

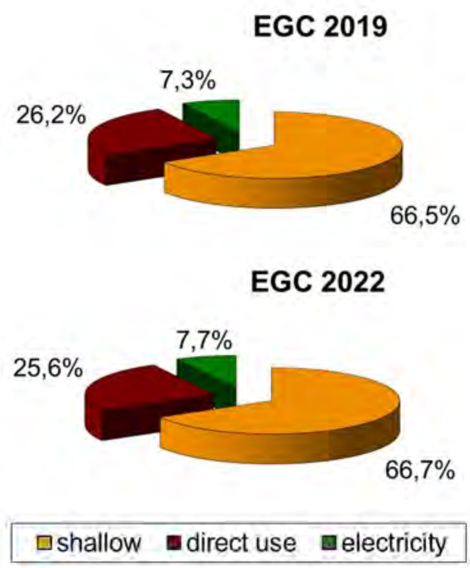


Figure 1: Share of installed capacity in the three geothermal sub-sectors in Europe as reported at EGC 2019 and EGC 2022

The coverage of the European situation by the country update reports is rather complete. 32 countries have reported for EGC 2022, from a total of about 40 with known geothermal activities in Europe (see table 1 at the end of this paper). For missing countries or data, information was taken from previous WGC and EGC editions, where available. The EGC country update reports complement nicely the annual EGEC Market report (EGEC, 2022), which offers more details on individual installations, but is only available to EGEC members.

2. GEOTHERMAL POWER PRODUCTION

The implementation of geothermal power in Europe at the end of 2021 is listed in table 2, at the end of this paper. Figure 2 shows the development as reported at the various WGC and EGC events since 1995, and the forecast to 2028. In electricity, the minimum target of the Ferrara Declaration (EGEC, 1999) for the year 2020, set to 3000 MW_e, was surpassed in the meantime and reached almost 3500 MW_e in 2021. The average load factor is at ca. 77 % and can be expected to rise further once all new plants are in full, routine operation with start-up problems fixed. Iceland achieved an excellent average load factor of 90.1 %, and some individual plants in Europe can report values close to 100 %.

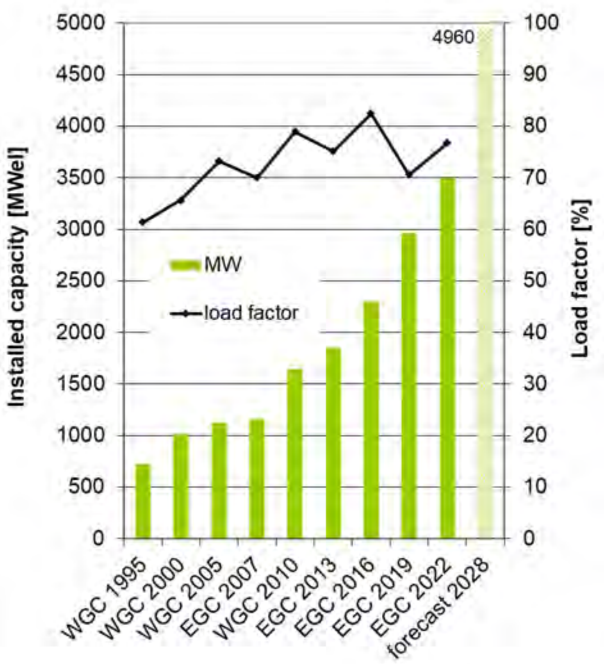


Figure 2: Installed capacity and average load factor for geothermal electricity in Europe as reported at various events, and forecast of installed capacity to 2028.

The number of countries having operational geothermal power plants remained at 10 [1], a number expected to rise to about 20 by 2028, as the data given in the reports suggest. In most of the countries considered, geothermal electricity production is growing slowly, but steadily (Figure 3), with the notable exception of Türkiye, showing a spectacular growth of about 430 MW_e in installed capacity since the last reporting (for EGC 2019, cf. Figure 4, left). Growth can be seen both in the traditional high-enthalpy areas, and in the low-medium temperature resources through the extensive utilization of binary plants technologies (e.g. in Germany).

The development of installed capacity and annual production in the currently producing countries is shown in figure 3 for the time since the reporting of WGC 2005. The extraordinary growth in Türkiye over the last decade is apparent. Installed capacity is steady on a high level in Italy, with efforts focusing on keeping production in known fields sustainable, and to develop new fields. Iceland has almost 100 MW_e of additional capacity on line, after some time without much increase. In Germany, the increase of almost 10 MW is mainly brought by two ORC plants in the Bavarian Molasse basin (Holzkirchen, 2018, and Garching an der Alz, 2021).

The development in Türkiye and Germany is shown separately in figure 4, highlighting the strong increase in geothermal power production in Türkiye, with good average load factor of about 74 %. The growth of installed capacity in Germany is on a similar trend, albeit on a much lower level; the increase in electricity production, however, lags behind. One reason is that some of the ORC-plants also provide district heating, with a higher share of the geothermal heat going into heating in wintertime. Contrary to high-enthalpy power plants, where heat is a kind of residual product, lower-temperature resources often need to divide the geothermal heat for either heating or power production. This is reflected in the relatively modest load factor of about 46 % on average for Germany.

Figure 5 shows the installed capacity for the different countries as reported at EGC 2013, 2016, 2019 and 2022, and the values expected to be reached by 2028. It can be seen from this figure that the huge potential that EGS might offer (cf. Geoelec, 2013) is not reflected in the growth expectations up to 2028. Most reported and expected geothermal power production is based on the currently available high enthalpy resources and low-to-medium-temperature binary power plants. The number of countries with current production and stated expectations is at least 20 (Figure 5). Some additional countries have not reported any expectations for 2028, albeit conducting experiments in geothermal power (e.g. Belgium), or had stated expectations in earlier reports, so the actual number of countries with geothermal power by the end of this decade might be beyond 20.

It seems like all geothermal binary power plants are of the ORC type today. The application of the Kalina technology, met with high expectations in the 2000s, apparently did not survive the harsh conditions of real power plant operation. The two known plants, Husavik in Iceland and Unterhaching in Germany, have been retired in the meantime.

[1] Russia has reported geothermal power production in the national report, however, this is not considered in this European summary, as the respective plants belong to the Circum-Pacific geothermal realm.

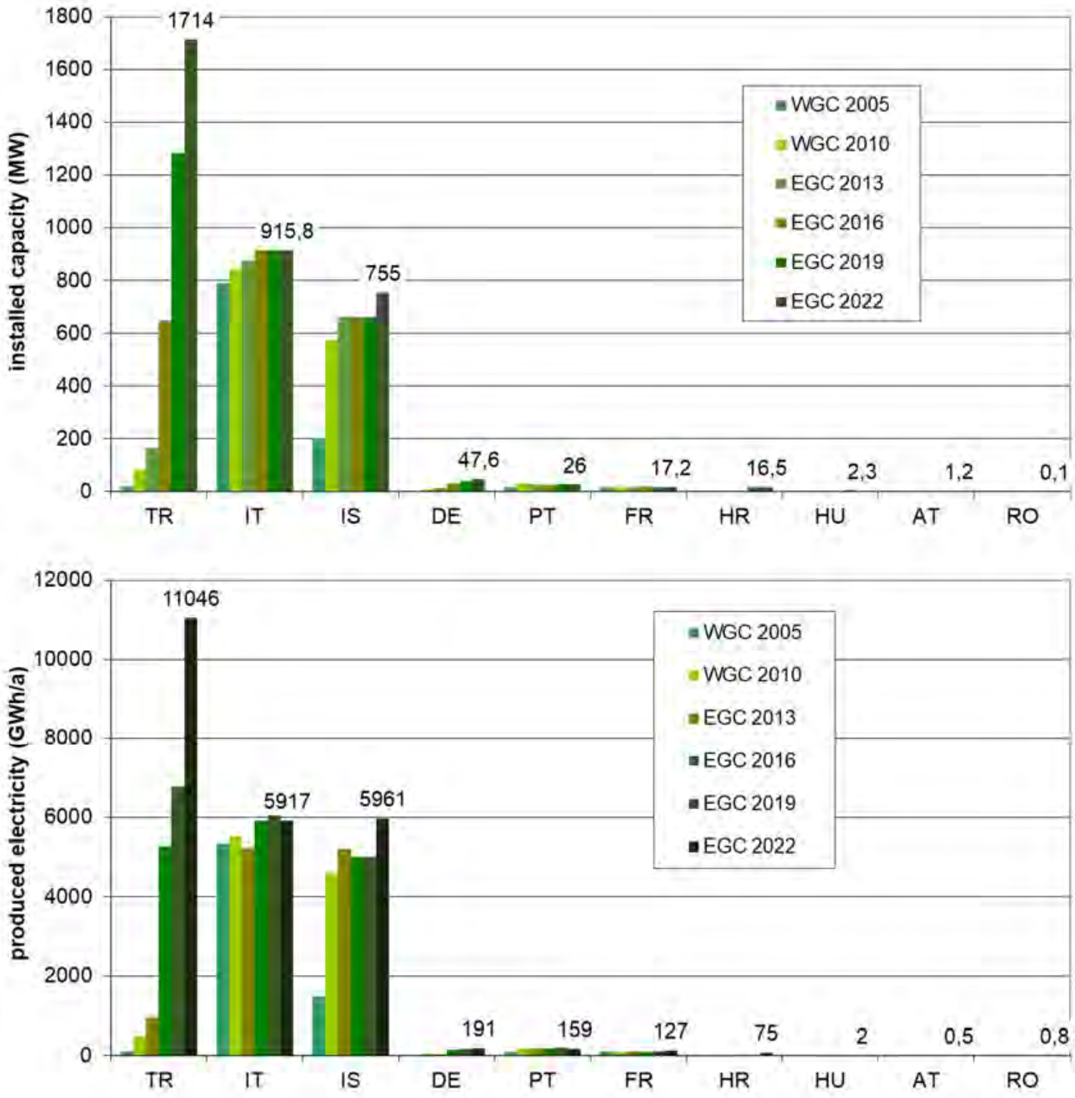


Figure 3: Installed geothermal power (top) and annual production (bottom) in Europe after country update reports since WGC 2005.

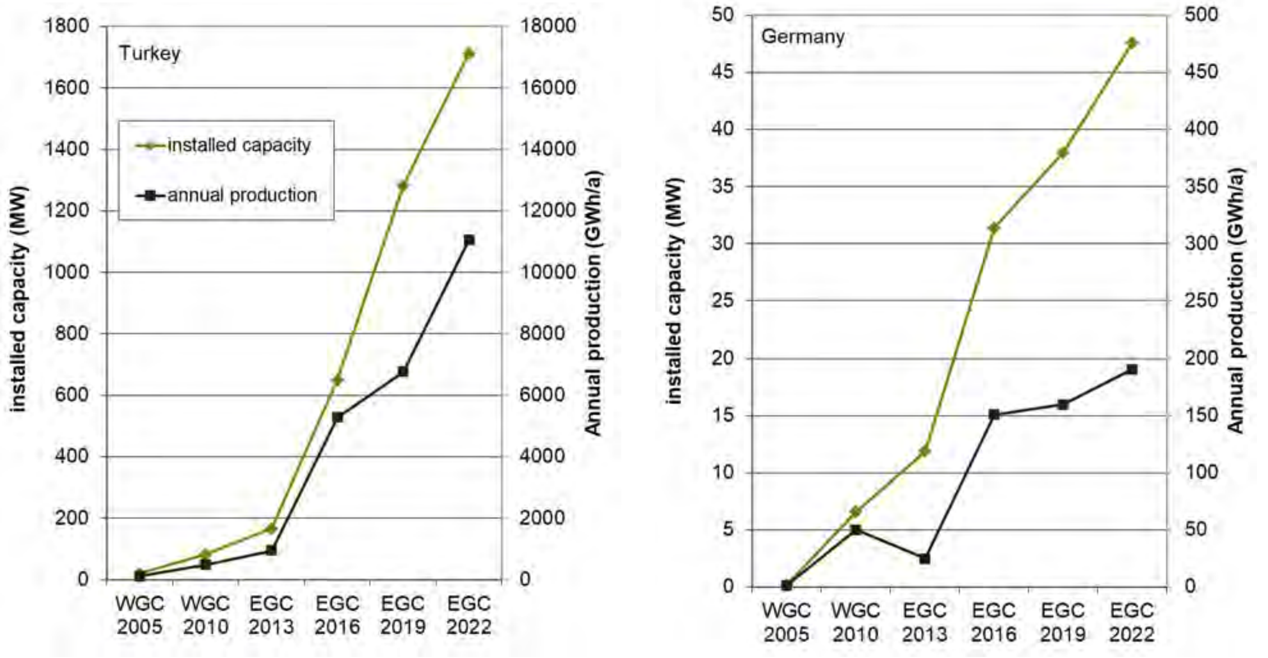


Figure 4: Development of installed geothermal power and annual production in Türkiye (left) and in Germany (right), after country update reports since WGC 2005.

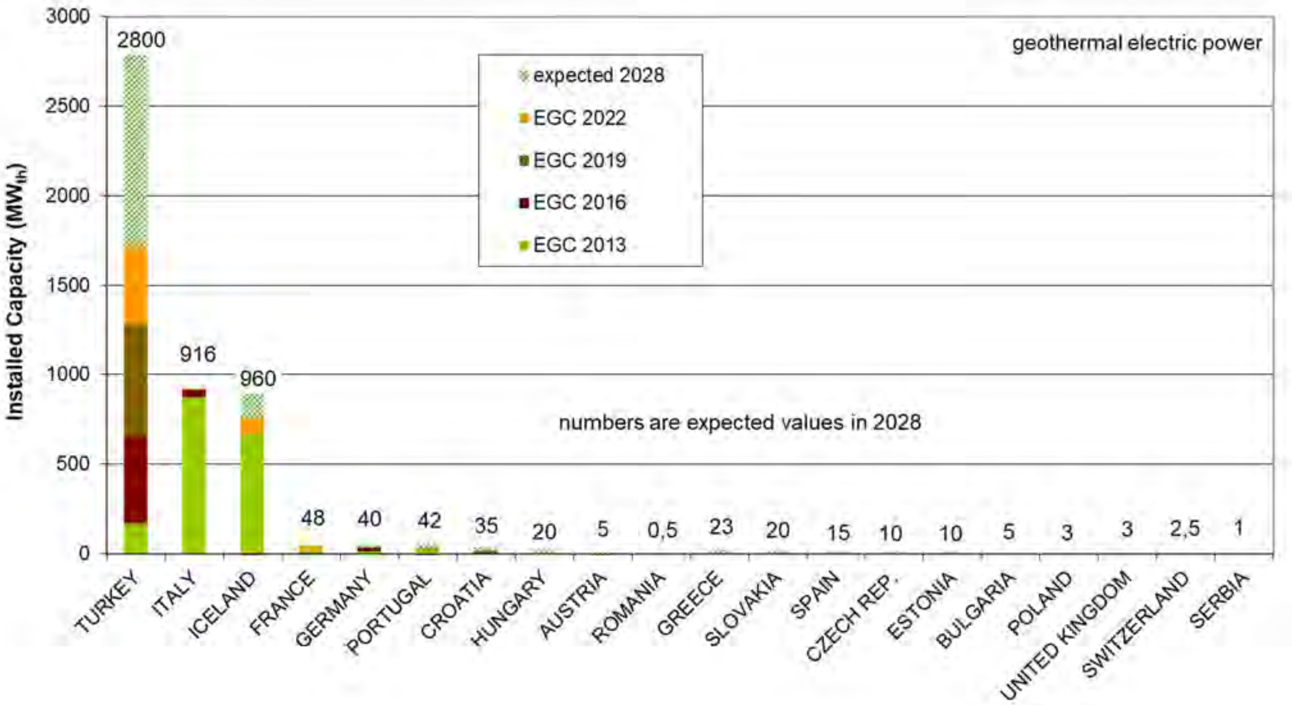


Figure 5: Installed geothermal power in Europe 2012-2021, after EGC 2013, 2016, 2019 and 2022, and reported expectations towards 2028.

3. GEOTHERMAL DIRECT USES

The reporting according to different types of direct use of (deep) geothermal resources as attempted since EGC 2013, and adjusted for EGC 2016, is working well. A meaningful distinction between district heating and other type of direct use could be made. The amount of geothermal heat used in spas and balneology was mostly reported, albeit being difficult to determine. Similar distinction meanwhile is applied for the WGC (world-wide) reports also, making comparisons easier, and allowing to fill some gaps in the EGC 2022 reporting with data from WGC 2020 (cf. Table 3 at the end of this paper).

Figure 6 shows five country-specific examples of the distribution into the different sectors, and the European mean distribution, with pie charts highlighting the big differences that can be found. 72 % of geothermal heat goes into district heating in Germany, and a remarkable 76 % in Iceland. In Hungary, geothermal heat for agriculture etc. has the biggest share with 47 %. In Italy, heat for individual buildings and other applications is in the lead with 46 %, with district heating accounting for only 10 %. More than 30 % of the heat is used for balneology and spas in Hungary, Italy and Türkiye. District heating accounts for 48 % of the heat use in Europe on average.

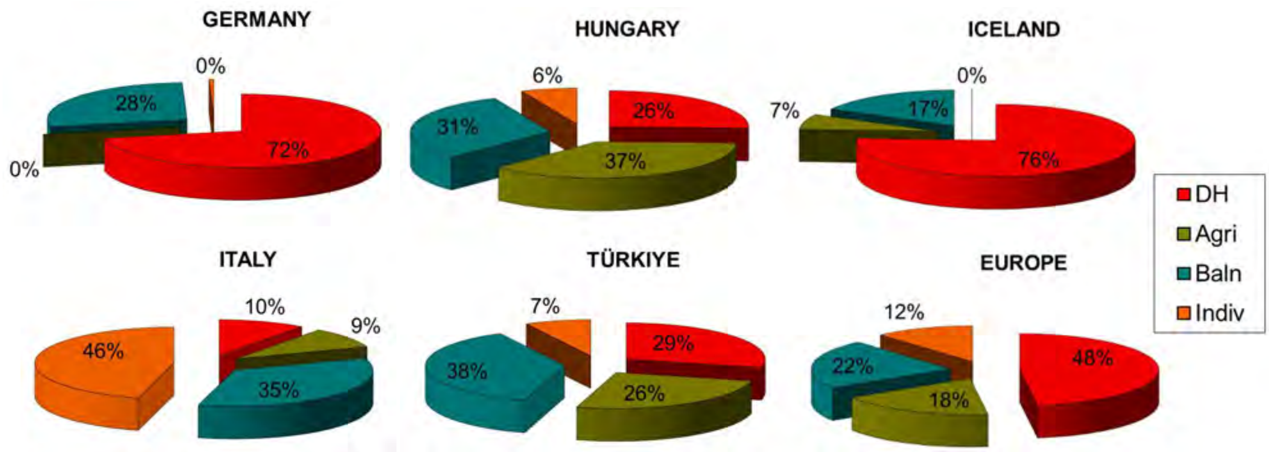


Figure 6: Share of geothermal heat production in district heating, agricultural uses, balneology and individual buildings in deep geothermal direct use in 5 European countries and in Europe on average.

The reported values for 2021 (or 2020) for each country are listed in table 3 at the end of this paper. Figure 7 shows the total values for each country and the share of geothermal district heating thereof. Some countries like Turkey, Italy, Hungary, Slovakia and the Netherlands have a high share of other direct uses and would be much undervalued if only geothermal district heating is considered. In other countries, like Iceland, France, Germany, Romania and Poland, district heating is the main use of geothermal heat. Figure 8 is a synopsis of the values reported at the EGCs since 2013, and the forecast for 2028. Not many countries state high expectations for the future growth, with the notable exceptions of Türkiye and France. The goal of 20 GW_{th} installed capacity in Türkiye towards the end of this decade is very ambitious indeed.

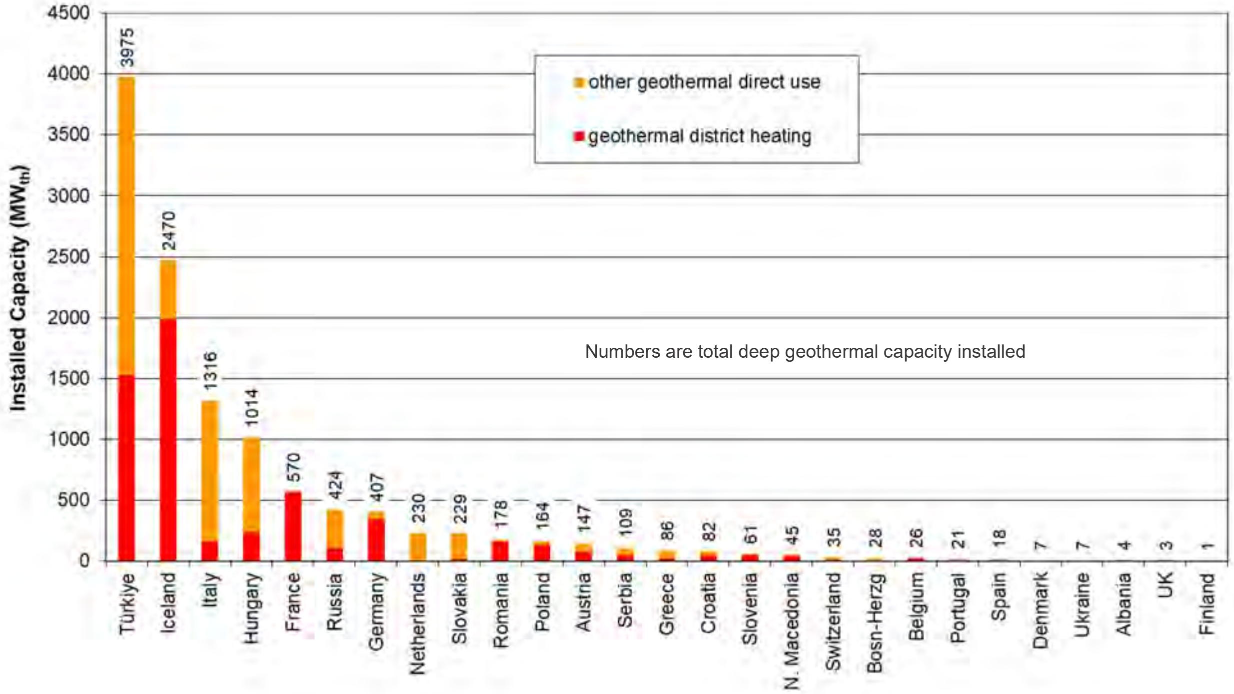


Figure 7: Installed capacity in geothermal direct use in Europe 2021, showing the share of district heating in the total deep geothermal direct use.

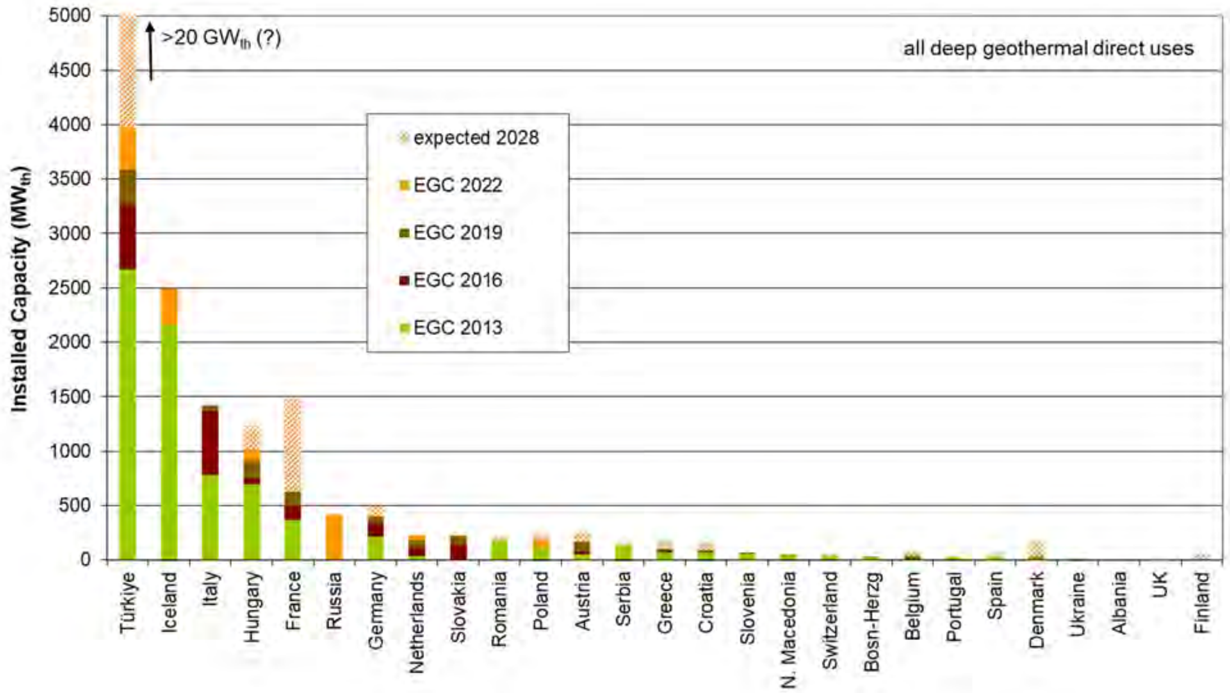


Figure 8: Installed capacity in deep geothermal direct use in Europe 2012-2021, after EGC 2013, 2016, 2019 and 2022, and reported expectations towards 2028.

4. SHALLOW GEOTHERMAL APPLICATIONS

In terms of number of installations, installed capacity and energy produced this is by far the largest sector of geothermal energy use in Europe, with the shallow geothermal share amounting to over 66 % of installed capacity (cf. figure 1). It enjoys the widest deployment among European countries; the data for 2022 from the individual countries are summarised in Table 4 at the end of this paper.

The total number of geothermal heat pumps installed in Europe is more than 2.1 Mio units. The leader by far is Sweden; Germany, with a population more than eight times larger, comes in second, France still is owns the 3rd rank, but due to a relatively low annual number of new installations might lose that soon to Finland. Figure 9 shows the numbers of installed heat pumps per country for countries with at least 1000 existing units reported, compared to the annual sales (not all countries reported the sales number).

For countries with an early market uptake in the 1980s like Sweden, Switzerland and Austria, new installations per year typically amount to ca. 2-3 % of the existing stock, a sign for a well developed market. A noteworthy exception among the “old” countries is Germany with 6.2 %, driven by an economy favourable for heat pumps and supported by policy measures and incentives. Other countries with new installations per year exceeding 6 % of the existing stock are more in the category of emerging markets; they include Denmark, Italy, Poland. Slovenia, Türkiye, the UK and the Baltic countries (cf. Figure 9).

We can see a strong demand for GSHP in many countries under the current energy price explosion in the wake of the Russian invasion of Ukraine in February 2022. A further, intensified increase in installations can be expected throughout Europe, the limiting factor currently being the shortage in supply of material and, in particular, in skilled workforce.

Heat pump unit numbers are a way to understand the markets in the individual countries. The reasons for the differences among the countries are manifold and can be attributed to energy prices, incentives, regulation, awareness, knowledge, but also active salesforce and installers. As the average size of heat pumps differ, the sheer number does not say how much capacity is installed in shallow geothermal energy within a country. The recent development of installed capacity of shallow geothermal in Europe can be seen from figure 10, where data from EGC 2013 to EGC 2022 are shown in comparison. Sweden is again the country leading by installed capacity, followed by Germany, France, Finland and Switzerland. Shallow geothermal energy is used also in some countries that did not report to EGC 2022 (Luxembourg can serve as a small, but interesting example here, with good growth and some large installations), and we can state that there is virtually no country in Europe without some shallow geothermal installation (cf. Table 4 at the end of this paper).

The ranking of countries for GSHP unit numbers or installed capacity as seen in Figures 9 and 10 does not in any way take into account the size of the respective country. Ladislaus Rybach started to show numbers corrected for the country area already in the 1990s, at various presentations and in some publications; the most recent might be Rybach and Sanner (2017), and this approach was also taken world-wide in Lund and Toth (2020). To get a sense of the areal density of GSHP in a country and to assess the limits of sustain-able use, the areal approach is helpful. To understand the status and limits of a market in a country, a correc-tion of the GSHP numbers by the number of inhabitants can be used.

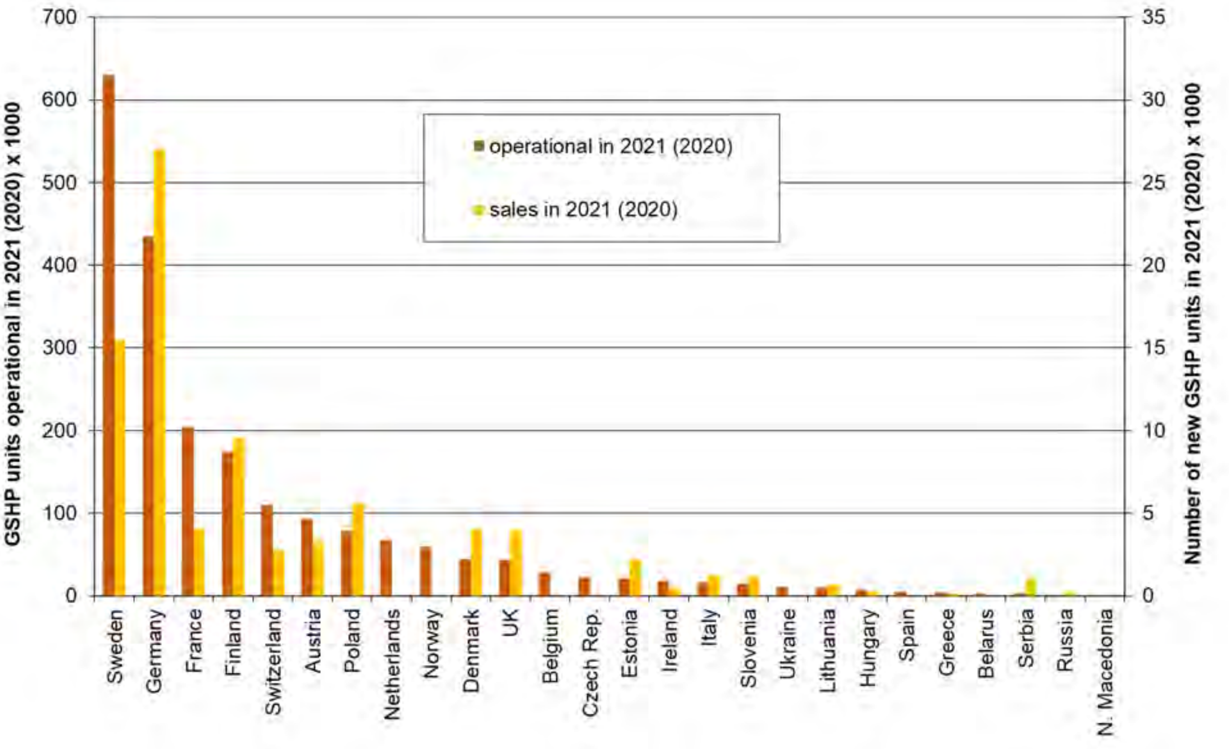


Figure 9: Total number of existing GSHP units and new sales in 2021 (some countries 2020) as stated in EGC 2022 country update reports; only countries reporting at least 1000 existing GSHP units are shown.

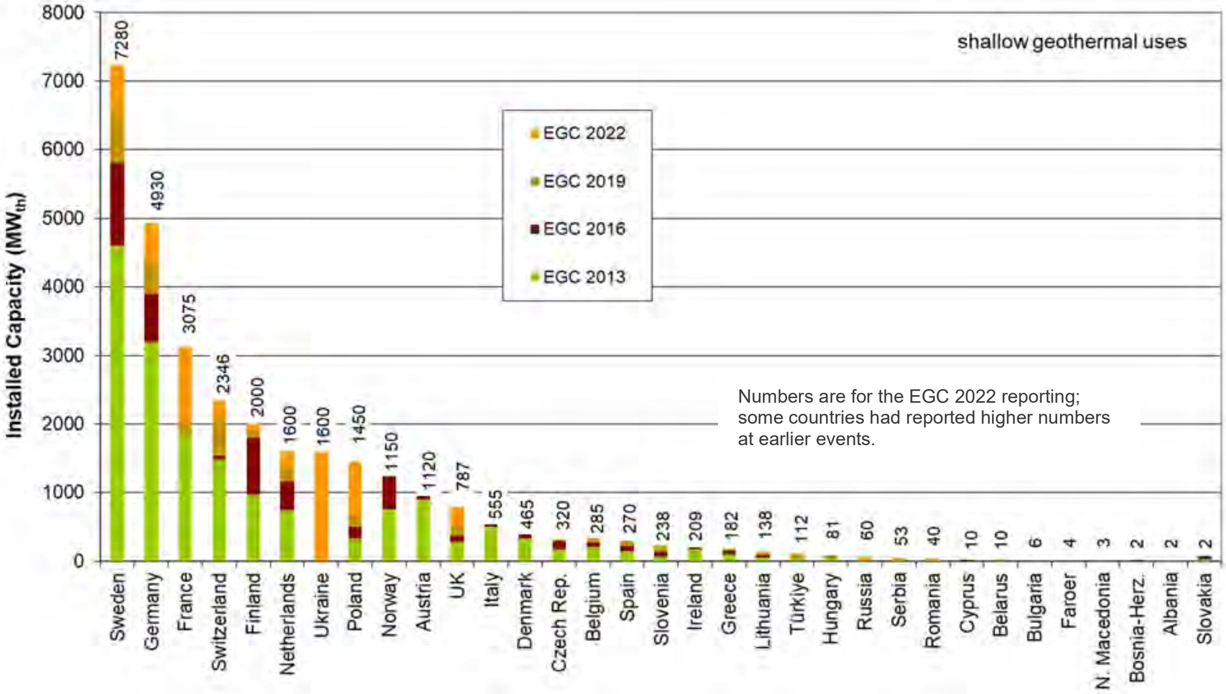


Figure 10: Installed capacity in geothermal heat pumps in Europe after EGC 2013, 2016, 2019 and 2022.

Both corrections have been applied to the EGC 2022 data on GSHP unit numbers (Figures 11 and 12). Concerning the number per area, Switzerland still owns the first rank by a good margin, followed by the Netherlands. Larger countries with a high number of units are on ranks 3 and 4 (Sweden and Germany). The rest of the Top 20 is dominated by smaller countries again (Austria, Denmark, Belgium etc., cf. Figure 11). From these data it is understandable that Switzerland was the first country to work on the sustainable extraction of heat from the shallow underground and to develop methods and regulations for balancing or recharging the thermally influenced underground volumes.

Looking at the GSHP units per inhabitants (Figure 12), the countries with the highest market penetration stand out. The Scandinavian and Baltic countries are high on the list, with Sweden and Finland taking the top places. Switzerland and Austria are on rank 4 and 6, respectively, and Germany with its population of >83 Mio just makes it to rank 10, despite being second in total numbers (Figure 9).

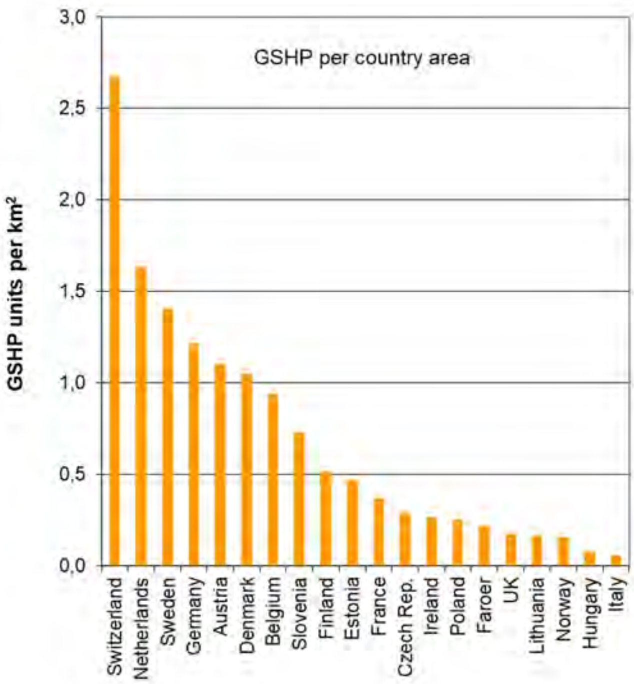


Figure 11: GSHP units per country area in 2020/21, top 20 countries only.

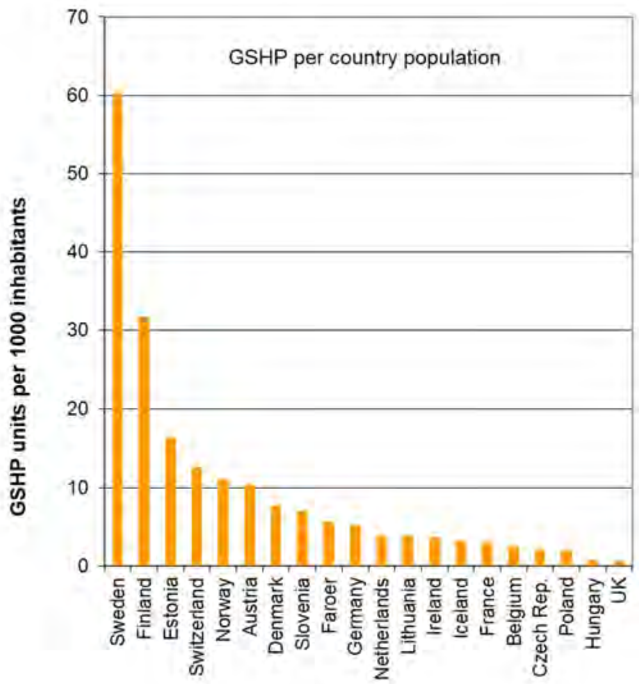


Figure 12: GSHP units per country population in 2020/21, top 20 countries only.

5. MARKET SITUATION

Not all countries reported on the financial aspects and workforce requirement of the geothermal market. Hence the numbers given here should be considered as a minimum only. Investment in geothermal energy was at least 12 billion € in 2021, with the highest share for shallow geothermal energy (Figure 13). The second highest is for electric power, in line with the big increase in installed capacity in Türkiye. However, the investment as reported for EGC 2022 is significantly lower as for EGC 2019, albeit virtually the same countries reported. Türkiye and Sweden are the countries with the highest investment in geothermal energy by far (Figure 15), while values for Germany have not been reported.

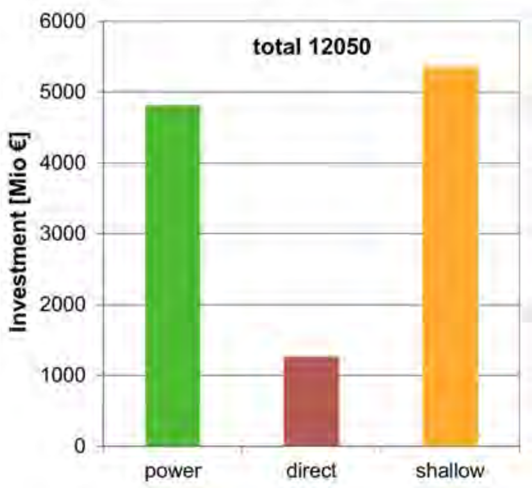


Figure 13: Investment in the different fields of the geothermal sector (only 20 countries reporting, for a further 6 countries values from WGC 2020 were used)

For employment, we can state that at least 27’000 persons work in the geothermal sector, somewhat less than reported for EGC 2019 (34’000 persons); for EGC 2016, an even higher number was reported (36’000 persons). It is not clear if that is a real trend, or if more accuracy in reporting has replaced overestimation. The shallow geothermal sector definitely dominates the workforce (Figure 14), with about 20’000 persons, half of which in Sweden only (Figure 15). The true number of geothermal personnel in Europe will be definitely higher, considering the limited number of countries reporting, and partial sectoral reporting only in some cases.

The breakdown of investment and personnel per country is shown in figure 15 for the larger reporting countries.

6. CONCLUSIONS

In geothermal power, Turkey has strengthened its position further with very dynamic development, while Iceland has a moderate and Italy virtually no growth. Furthermore, the players in particular from Iceland are active elsewhere in the world to develop new geothermal projects and to transfer their experience.

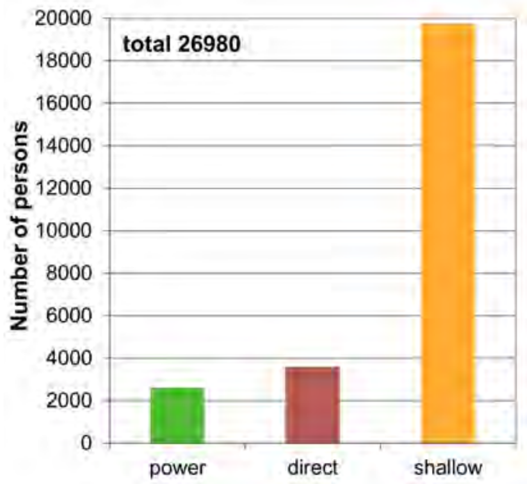
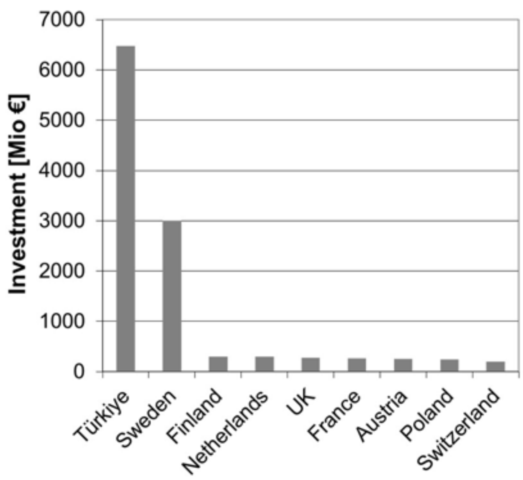


Figure 14: Number of persons working in the different fields of the geothermal sector (only 22 countries reporting, for a further 5 countries values from WGC 2020 were used)



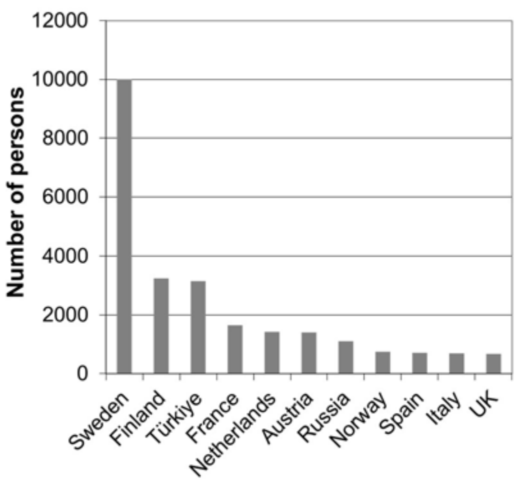


Figure 15: Total geothermal investment for countries with more than 100 Mio €/a (top) and personnel in countries with more than 500 geothermal workers (bottom)

For direct uses, some countries have a good development in the agricultural sector, in particular the Netherlands and Hungary. District heating is growing steadily, however, the share of district heating in all direct uses of geothermal energy decreased slightly to 46 %. The shallow geothermal sector has a sound development, with poor sales numbers in some countries (France is still an example), and positive markets in others. Germany is an example for a good market development driven by policies and incentives, and some other markets with substantial growth include Denmark, Italy, Poland. Slovenia, Türkiye, the UK and the Baltic countries.

The country update reports for WGC and EGC still serve an important task, as national statistics cannot (yet?) deliver the data and insights requested. Documents like the EGEC Market Report are intended for use in industry (and limited in availability, e.g. for members only). The individual country updates and summary reports are a source open to everybody. For more detail on the resources, technology and policies, readers are encouraged to study the individual country update reports that form a part of the EGC 2022 proceedings.

REFERENCES

Antics, M., Sanner, B.: Status of Geothermal Energy Use and Resources in Europe, *Proc. EGC 2007*, Unterhaching, paper #082, 1-8 (2007).

Antics, M., Bertani, R., Sanner, B.: Summary of EGC 2013 Country Update Reports on Geothermal Energy in Europe, *Proc. EGC 2013*, Pisa, paper keynote-1, 1-18 (2013).

Antics, M., Bertani, R., Sanner, B.: Summary of EGC 2016 Country Update Reports on Geothermal Energy in Europe, *Proc. EGC 2016*, Strasbourg, paper K1, 1-16 (2016).

EGEC: Ferrara Declaration / Dichiarazione di Ferrara. *EGEC Business Seminar Ferrara,* Brussels, 1-2, (1999). [2]

EGEC: 2021 EGEC Geothermal Market Report – Full Report. EGEC, Brussels, restricted to EGEC members. (2022). [3]

Geoelec: A prospective study on the geothermal potential in the EU, *D2.5, Geoelec*, Brussels (2013), 1-97

Lund, J.W., Toth, A.N.: Direct Utilization of Geothermal Energy 2020 Worldwide Review. *Proc. WGC 2020*, Reykjavik, Iceland (2020).

Rybach, L., Sanner, B.: Geothermal Heat Pump Development: Trends and Achievements in Europe. in: Bertani, R. (ed.), Perspectives for Geothermal Energy in Europe, 215-253, World Scientific Publishing, New Jersey (2017)

Sanner, B.: Summary of EGC 2019 Country Update Reports on Geothermal Energy in Europe. *Proc. EGC 2019* Den Haag, paper CUR-00, 1-14 (2019).

Acknowledgements

The authors of this summary like to sincerely thank all contributors to the country update reports for EGC 2022 (see table 1), who devoted considerable time and effort to research, verify and write the individual country papers. These papers, as available in the proceedings of EGC 2022, give a detailed account of geothermal resources, regulatory framework, actual use and potential future development in the individual countries, and enabled the authors of this summary to once again endeavour in painting the overall picture of the development in Europe.

[2] for download e.g. at: https://www.sanner-geo.de/media/a9008fdc446be240ffff800efffffef.pdf
[3] “Key Facts” for download at: https://www.egec.org/wp-content/uploads/2022/06/MR21_KF.pdf

Table 1: EGC 2022 country update reports.

Author(s)	Country
Polo, N., Kodhelaj, N., Bozgo, S., Karamani, E., Aliko, A., Shehaj, E.	Albania
Goldbrunner, J.E., Goetzl, G.	Austria
Dupont, N., Petitclerc, E., Broothaers, M., Kaufmann, O.	Belgium
Samardžić, N., Hrvatović, H., Skopljak. F.	Bosnia and Herzegovina
Deneva, B., Kolev, S., Valchev, S., Toteva, A.	Bulgaria
Živković, S., Kolbah, S., Tumara, D., Škrlec, M., Bilić, T., Vajdić, M.	Croatia
Mathiesen, A., Nielsen, L. H., Vosgerau, H., Erbs Poulsen, S., Andersen, T.R., Tordrup, K.W., Røgen B., Ditlefsen, C., Vang-kilde-Pedersen, Th.	Denmark
Soesoo, A., Bauert, H.	Estonia
Arola, T., Wiberg, M.	Finland
Schmidlé-Bloch, V., Pomart, A., Boissavy, C., Maurel, C., Philippe, M., Cardona-Maestro, A., Genter, A.	France
Weber, J., Born, H., Pester, S., Schifflechner, C., Moeck, I.	Germany
Mendrinos, D., Karytsas, C., Kapiris, M., Papachristou, M., Dalampakis, P., Arvanitis, A., Andritsos, N.	Greece
Nádor, A., Kujbus, A., Tóth, A.	Hungary
Ragnarsson, Á., Steingrímsson, B., Thorhallsson, S.	Iceland
Pasquali, R., Blake, S., Braiden, A.K., McCormack, N.	Ireland

Author(s)	Country
Della Vedova, B., Bottio, I., Cei, M., Conti, P., Giudetti, G., Gola, G., Spadoni, L., Vaccaro, M., Xodo, L.	Italy
Zinevičius, F..	Lithuania
Provoost, M., Agterberg, F.	Netherlands
Popovska-Vasilevska, S., Stavreva, S.	North Macedonia
Kępińska, B., Hajto, M.	Poland
Nunes, J.C., Coelho, L., Martins Carvalho, J., do Rosário Carvalho, M.	Portugal
Gavriliuc, R., Rosca, M., Cucueteanu, D.	Romania
Svalova, V.	Russia
Oudech, S., Djokic, I.	Serbia
Fričovský, B., Marcin, D., Benková, K., Černák, R., Fordinál, K., Pelech, O.	Slovakia
Rajver, D., Lapanje, A., Rman, N., Prestor, J.	Slovenia
Arrizabalaga, I., De Gregorio, M., De Santiago, C., García de la Noceda, C., Pérez, P., Urchueguía, J.F.	Spain
Gehlin, S., Andersson, O., Rosberg, J.-E.	Sweden
Link, K., Minnig, C.	Switzerland
Mertoglu. O., Şimşek, Ş., Başarir, N., Paksoy, H., Cetin, A.	Türkiye
Abesser, C., Curtis, R., Raine, R., Claridge, H.	United Kingdom
Morozov, Y., Barylo, A., Lysak, O.	Ukraine

Further Countries with known geothermal activities in Europe (mainly shallow geothermal)		
Country	Type of activity	Latest reporting
Belarus	Resource exploration, GSHP	EGC 2019, WGC 2020
Cyprus	R&D, GSHP	EGC 2019, WGC 2020
Czech Republic	Resource exploration, R&D, GSHP	EGC 2019, WGC 2020
Faroe Islands	Resource exploration, GSHP	WGC 2020
Latvia	R&D, GSHP	*WGC 2015 (only policies)*
Luxembourg	GSHP	*Personal communications*
Montenegro	Resource exploration, *GSHP ?*	EU-project LEGEND 2012-14
Norway	Resource exploration, R&D, GSHP	EGC 2019, WGC 2020

Table 2: Geothermal Electric Power in Europe in 2020/21.

	2021 installed capacity	2021 electricity produced	2021 load factor	Inst. cap. expected 2028
	[MW_{el}]	[GWh_{el}/yr]	[%]	[MW_{el}]
Austria	1.2	0.5*	4.8*	5
Belgium				*4.5*
Bulgaria				5
Croatia	16.5	74.7	51.6	34.8
Czech Republic				*10*
Estonia				10
France	17.2	127	84.3	42.2
Germany	47.6	190.6	46.7	47.6
Greece				23
Hungary	2.3	2.0	9.9	20
Iceland	755	5961	90.1	960
Italy	916	5917	73.8	916
Poland				*3*
Portugal	26	158.9	69.8	40
Romania	0.1	0.8	91.3	0.1
Serbia				1
Slovakia				20
Spain				15
Switzerland				5
Türkiye	1714	11046	73.6	2800
UK				3
Total	3496	23478	average 76.7	4958

* low load factor due to Altheim plant not operational

Italics: No expectations for 2028 reported to EGC 2022, but to EGC 2019 for the year 2025.

Table 3: Geothermal Direct Use in Europe in 2020/21.

	Geothermal DH Plants		Geothermal heat in agriculture		Geothermal heat in balneology		Geothermal heat in other and indiv. Bldg.	
Country	Capacity [MW_{th}]	Production [GWh_{th}/yr]	Capacity [MW_{th}]	Production [GWh_{th}/yr]	Capacity [MW_{th}]	Production [GWh_{th}/yr]	Capacity [MW_{th}]	Production [GWh_{th}/yr]
Albania	1.9						1.9	9.2
Austria	75.1	223.6	18.8	63.0	43.1	350.0	9.8	24.0
Belgium	25.5	17.7						
Bosnia-Herz.			0,84	0,986	9,55	16,304	17,36	43,64
Bulgaria			*1.7*	*9.2*	*91.1*	*415.6*	*3.3*	*18.0*
Croatia	42.3	21.1	6.8	19.4	18.3	14.0	14.1	11.2
Cyprus			*0.07*	*0.01*				
Denmark	7.0	15.0						
Finland	1.0	1.5						
France	570	1733		236		31		
Germany	345.8	1233.1			56.8	474.6	4.38	10
Greece	17	52	24	76	43	72	2	5
Hungary	235.3	641.4	429.5	925	263	778.5	86.1	163.4
Iceland	1990	7551	145	672	335	1714		
Italy	164	238	147	221	387	813	618	1078
Netherlands			230	1546				
N. Macedonia	42.6	106	2.8	12.5				
Poland	137.5	281.5	4	6	12	35	10	25
Portugal	2.1	12.3			17.1	125	2.0	3.2
Romania	160	305.2	8	50	10	12		
Russia	110	600	200	1000	4	18	110	600
Serbia	47.7	113.9	11.6	61.7	35.5	182.7	14.5	71.1
Slovakia	20.6	64.2	41.2	81.3	134.2	245	33.4	80.2
Slovenia	49.6	99.1	6.4	30.4	3.2	3.9	1.6	1.6
Spain	2.6	14.6	14.9	26.2				
Switzerland	11.7	30.1			22.3	185.3	1.1	2.3
Turkey	1528	4840	821.5	4327.3	1205	6338.4	420	1288.5
UK	1.7	20.1			1	9.4		
Ukraine					7	26.8		
Total	5588.9	18214.4	2114.2	9363.	2698.1	11860.3	1349.5	3434.3

Italics: Values from WGC 2020.

Table 4: Ground Source Heat Pump Use in Europe in 2020/21.

Country	Number of GSHP	Capacity [MW_{th}]	Production [GWh_{th}/year]	kW_{th} per unit	Full-load hours per year
				Calculated from reported data	
Albania		1.9			
Austria	92400	1120	1850	12.1	1652
Belarus	*3000*	*10*	*40.3*	*3.3*	*4031*
Belgium	*28782*	*284.6*	*1027.5*	*9.9*	*3610*
Bosnia-Herzeg.	500				
Bulgaria			1174		
Cyprus	*175*	*10.2*	*18.1*	*58.5*	*1766*
Czech Rep.	*22740*	*320*	*472*	*14.1*	*1477*
Denmark	45000	465	815	10.3	1753
Estonia	21260				
Faroe Islands	*304*	*3.7*	*5.6*	*12.0*	*1519*
Finland	175000	2000		11.4	
France	205000	3075	4770	15.0	1551
Germany	435000	4930	7140	11.3	1448
Greece	3878	182	478	46.9	2626
Hungary	7353	80.9	161.	11.0	1991
Iceland	120	1.2	5	10.0	4167
Ireland	18746	209	269	11.1	1287
Italy	16145	555	946	34.4	1705
Lithuania	10647	138.2	314.3	13.0	2274
Netherlands	68000	1600	1352.8	23.5	845
N. Macedonia	1000	2.5	21	2.5	8400
Norway	*60000*	*1150*	*3502.8*	*19.2*	*3046*
Poland	78400	1450	1850	18.5	1276
Portugal	54	0.7	0.9	12.0	1340
Romania	600	40	100	66.7	2500
Russia	1200	60	270	50.0	4500
Serbia	2850	52.6	116.9	18.5	2223
Slovakia	10	1.6	14.2	160.0	8875
Slovenia	14818	237.8	329.3	16.0	1385
Spain	4889	270.2		55.3	
Sweden	630000	7280	25500	11.6	3503
Switzerland	110247	2345.5	3797.9	21.3	1619
Turkey	161	112	984	695.7	8786
UK	43700	787	1316	18.0	1672
Ukraine	11000	1600	1386	145	866
Total	2112979	30376	58642	average 14.4	average 1931

Italics: Values from WGC 2020.

Geothermal Energy Use, Country Update for Albania, 2015-2022

Nevina Polo[1], Nevton Kodhelaj[1], Shkëlqim Bozgo[1], Erison Karamani[1], Abaz Aliko[2], Entela Shehaj[2]

[1] Energy Resources Department, Faculty of Geology and Mining, Polytechnic University of Tirana, Elbasani street – Tirana, Albania

[2] Tirana Business University College, Tirana, Albania

nevtonkodheli@yahoo.com; nevton.kodhelaj@fgjm.edu.al

Keywords: Geothermal, temperature, heat exchanger, cascade, integral, combined, direct use.

ABSTRACT

Albania, though a small country, could be considered rich in natural resources, including fossil fuels and renewable energies. Part of the renewable resources is the geothermal energy, so far not used at all for its energy potential, but only for its health and curative values. The latest developments regarding the GHG emissions awareness make imperative to find a solution by diversifying the energy portfolio. The aim of this paper is to show the efforts and progress towards the use of geothermal as a source of energy supply in Albania.

1. INTRODUCTION

During the reporting period Albania has approved several laws;

- *Law No. 124/2015 "On Energy Efficiency"* whose aim is to: Compile regulatory and national policies on promotion and improvement of energy efficiency with primary focus on energy saving, supply reliability and removal of barriers on the electrical energy market; Setting of a National Target regarding the energy efficiency; Increase of competition between different operators.
- *Law No.116/2016 "On the Energetic Performance of the Buildings"* whose aim is to: Establish the legal framework regarding the energetic performance of new buildings, considering the local and climatic conditions, buildings comfort as well as cost effectiveness.
- *Law No. 7/2017 "On Promotion of the Renewable Energy Resources usage"* whose aim is to: To promote the generation of electrical energy from renewable resources of energy; Decrease the import of organic fuels, greenhouses gas emissions & enhance environmental protection; Promote the development of the electrical energy market, generated from renewable resources, as well as the regional integration; Support the diversification of energy resources; Support the development of rural and remote areas by improving their energy supply.
- *DoCM No. 179, dated 28.3.2018 "On Approval of the National Action Plan on the Renewable Energy Resources, 2018-2020".*

In the frame of diversifying the energetic portfolio in Albania some important developments have taken place in the sector of solar energy, by issuing and having constructed and/or under construction a number of photovoltaic parks:

- Karavasta Photovoltaic Park – Voltalia (voltalia.com). Expected investment is above 100 Mio Euros for an installed capacity of 140 MW. PPA is signed for 70 MW pricing 24.89 Euros/MW for a duration of 15 years;
- Spitalla Photovoltaic Park – Voltalia. Expected investment is around 80 Mio Euros for an installed capacity of 100 MW. The PPA is signed for 70 MW pricing 29.89 Euros/MW for a duration of 15 years;
- Sheq Marinas, Topojë, Fieri Region: "LM Energy Corporate - installed capacity is 50 MW;
- Floating Photovoltaic Implant of Banja – Statkraft (www.statkraft.al): In the frame of the Devolli Cascade development, Statkraft did an investment of 2 Mio Euros for an installed capacity of 2 MW (finalized on June, 2021) nearby the Banja HPP dam. The installation is composed of 4 floating units (0.5 MW/unit). Each unit has a diameter of 70 m.

Still there is so much to do regarding the legal basis and most important to incentivize the development of the renewable energy sector, and not remaining focused mainly on hydro and solar energies.

2. GEOLOGICAL BACKGROUND

Albania is a small country, only 28,787 km^2 in surface area, ~ 4,500,000 inhabitants, and is situated in the southwestern part of the Balkan Peninsula. This paper provides some details on the electricity generation, geothermal energy, resources, geological features, and geothermal reserves. Surface manifestations of geothermal resources are found throughout Albania, ranging from the region of Peshkopia in the northeast, where hot springs with water temperature are about 43 °C and an outflow above 14 l/s are found, through the central part of the country with different sources (including the springs of Llixha-Elbasan) with temperatures above 66 °C, to the Peri-Adriatic depression (see Figure 1), which has a number of wells drilled for oil & gas exploration, producing water with temperatures around 40 °C, at variable yields. The thermal water in Albania is only used for balneology. This form of use dates back from early times in history, or from the time of the Roman Empire (i.e., the Sarandaporo's thermal baths) (Kodhelaj et al. 2021).

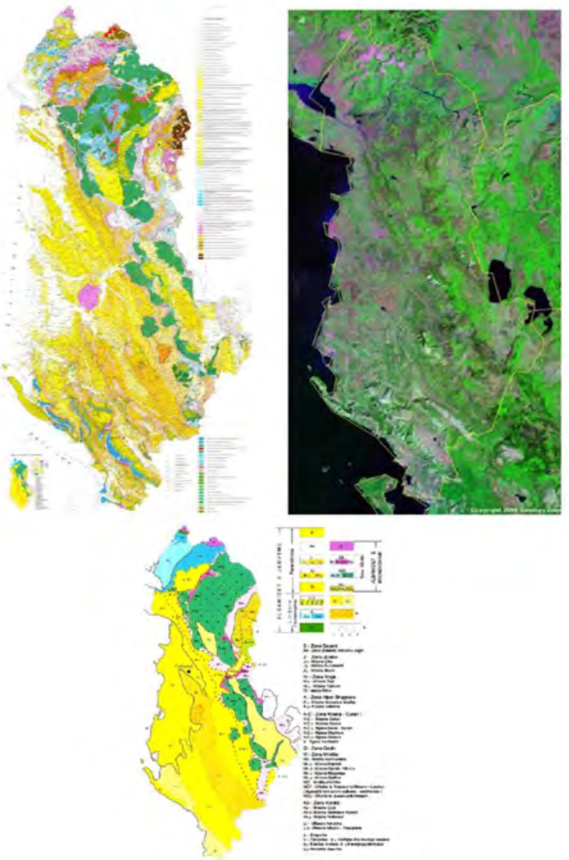


Figure 1: Geological map of Albania.

The geothermal fluids, in springs and wells, of Albania are located in three zones: Kruja, Ardenica and Peshkopia (Frashëri et al. 2004). The three zones differ from each-other by the geological characteristics and thermo-hydrogeological features, as shown in Figure 2. They are related with the regional tectonic and the seismological activities.

The main geothermal springs of Albania and some technical data on them, are presented in the Table 1 (Frashëri et al. 2004).

Throughout the second half of the XXth century in Albania, there has been very intensive drilling for oil and gas exploration. During the drilling, some of the wells "accidentally" blew out "hot water" or brine. Table 2 present all "geothermal wells" of Albania as well some important technical data about them (Frashëri et al. 2004).

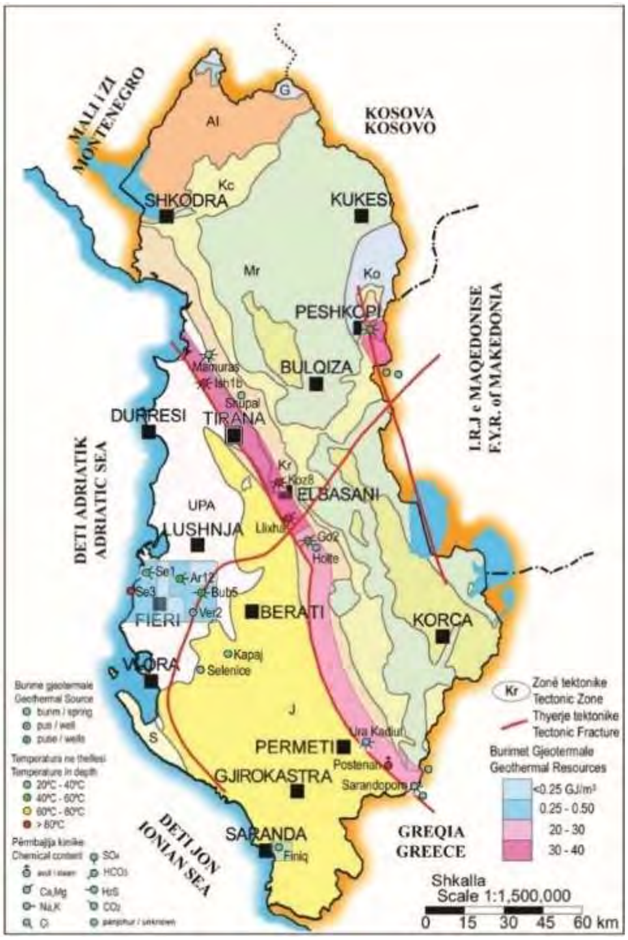


Figure 2: Geothermal map of Albania.

Table 1: Geothermal springs of Albania.

No	Spring and location	Temperature (°C)	Coordinates		Yield (l/s)
			Latitude (N)	Longitude (E)	
1	Mamurras 1 & 2	21÷22	41°42'24"	19°42'48"	11.7
2	Shupal	29.5	41°26'9"	19°55'24"	<10
3	Llixha, Elbasan	60	41°02'	20°04'20"	15
4	Hydraj, Elbasan	55	41°1'20"	20°5'15"	18
5	Peshkopia	43.5	41°42'10"	20°27'15"	14
6	Katiut Bridge, Lëngarica, Përmet	30	40°14'36"	20°26'	>160
7	Vronomer, Sarandaporo, Leskovik	26.7	40°5'54"	20°40'18"	>10
8	Finiq, Sarandë	34	39°52'54"	20°03'	<10
9	Holta Creek, Gramsh	24	40°55'30"	20°33'36"	>10
10	Postenan, Leskovik	Steam source	40°10'24"	19°48'42"	N/A
11	Kapaj, Mallakastër	16.9÷17.9	40°32'30"	19°39'30"	12
12	Selenicë, Vlorë	35.3	40°32'18"	19°39'30"	<10

The aquatic potential of Albania has the following main characteristics (Frashëri et al. 2004):

- The volume of the underground water is estimated to be in the range of 12.8 km^3;
- The underground water flow width is estimated to be in the range of 295 mm;

- The average modulus of the underground water yield is estimated to be in the range of 9.5 l/(s*km^2).

Table 2: Geothermal wells of Albania.

No	Well	Tempera-ture (°C)	Coordinates		Yield (l/s)
			Latitude (N)	Longitude (E)	
1	Kozani 8	65.5	41°06'"	20°01'6"	10.3
2	Ishmi 1/b	60	41°29'2"	19°40'4"	3.5
3	Letan	50	41°07'9"	20°22'49"	5.5
4	Galigati 2	45÷50	40°57'6"	20°09'24"	0.9
5	Bubullima 5	48÷50	41°19'18"	19°40'36"	
6	Ardenica 3	38	40°48'48"	19°35'36"	15÷18
7	Semani 1	35	40°50'	19°26'	5
8	Semani 3	67	40°46'12"	19°22'24"	30
9	Ardenica 12	32	40°48'12"	19°35'42"	
10	Verbasi 2	29.3			1÷3

The groundwater of Albania makes up 31% of the total aquatic reserves of the country. Thus far, the geothermal resources have been used only for their balneological values and unfortunately not at all for their energy potential. Albanian geothermal fluids have temperatures up to the lower limits of the middle enthalpy, with the exception the Postenani steam spring, which gives hope to find resources with temperatures in the range of 80 °C.

2.1 Kruja geothermal zone

Kruja geothermal zone represents a zone with large geothermal resources, as shown in Figure 3. The Kruja Geothermal Zone extends over a length of 180 km from the Adriatic Sea in the North, down to the Southeastern area of Albania, and further S-E to the Konitza area in Greece (Frashëri et al. 2003). The geothermal aquifer is represented by a carstified neritic carbonate formation with numerous fissures and micro fissures. Three boreholes produce hot and mineralized water, Ishmi - 1/b (Ishmi - 1/b), Kozani - 8 (Ko - 8) and Galigati - 2 (Ga - 2). Thermal springs of the Llixha Elbasani spa are located about 12 km S of Elbasani city (Frashëri et al. 2004).

The Ishmi - 1/b is the northernmost borehole of Kruja geothermal field, about 20 km NW of Tirana. Ishmi 1-b well was drilled in the upper part of the fissured and karstified limestone in 1964. The borehole intercepts the limestone section at 1300 m depth and continues through more than 1000 m of carbonate strata. Effective porosity is less than 1% and the permeability ranges from 0.05 - 3.5 mD. The hydraulic conductivity of the limestone section varies between 8.6 x 10^{-10} and 8.8 x 10^{-8} m/s and the transmissivity ranges from 8.6 x 10^{-7} to 8.5 x 10^{-5} m^2/s. The Kozani - 8 well was drilled in 1989 and is located 26 km SE of Tirana. It encounters limestone strata at 1819 m, penetrating 10 m into the section.

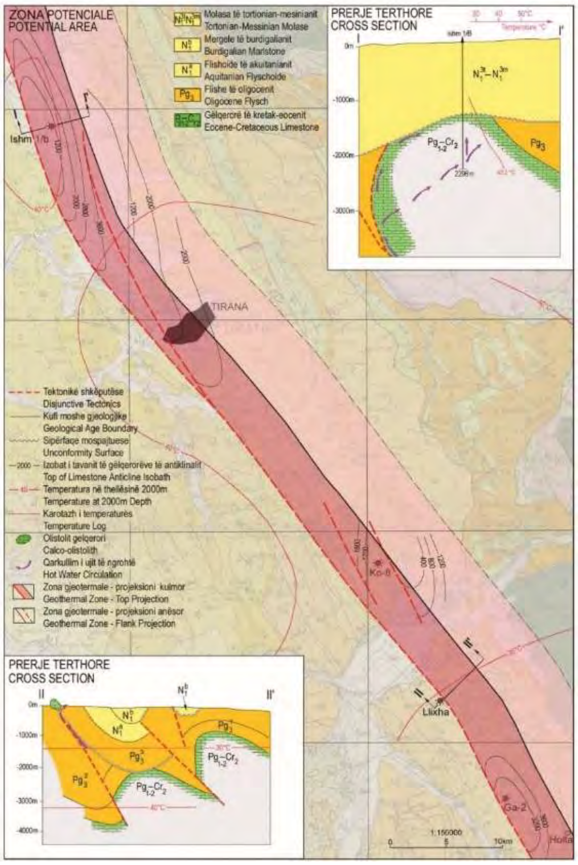


Figure 3: Kruja geothermal zone map.

Hot water has continuously discharged from the Ishmi-1/b and Kozani - 8 boreholes at rates of 3.5 l/s and 10.3 l/s, respectively, since the end of drilling operations in1964 and 1988, respectively. Galigati-2 borehole is located on a hill, about 50 km SE of Tirana. At depth of 2800 m, it discloses an 85 m thick limestone section. Elbasani Llixha watering place is about 12 km South of Elbasani. There are seven spring groups that extend like a belt with 320° of azimuth. All of them are connected with the main regional disjunctive tectonics of Kruja zone. Thermal waters flow out through the contact between the conglomerate layer and the calcolystolith layer, as shown in Figure 4 (Frashëri et al. 2004).

In this area the reservoir is represented by the Llixha limestone structure. These springs have been known since before the Second World War. Surface water temperatures in the Tirana-Elbasani zone vary from 60 °C to 65.5 °C. In the aquifer top in the well trunk of Kozani - 8 the temperature is 80 °C. Hot water has a salinity of 4.6-19.3 g/l. Elbasani Llixha water contains Ca, Na, Cl, SO_4, and H_2S (Avgustinsky et al., 1957) while in the Tirana-Elbasani, thermal waters are of Mg-Cl type. They contain the cations Ca, Mg, Na and K, as well as the anions Cl, SO_4, and HCO_3 with pH to 6.7-8 and density of 1.001 - 1.006 g/cm^3. Elbasani Nosi Llixha water has the following formula (Avgustinsky V.L. 1957):

$$H_2S_{0.403}M_{7.1}\frac{Cl_{59}SO^{4}_{38}}{Na_{46}Ca_{35}}$$

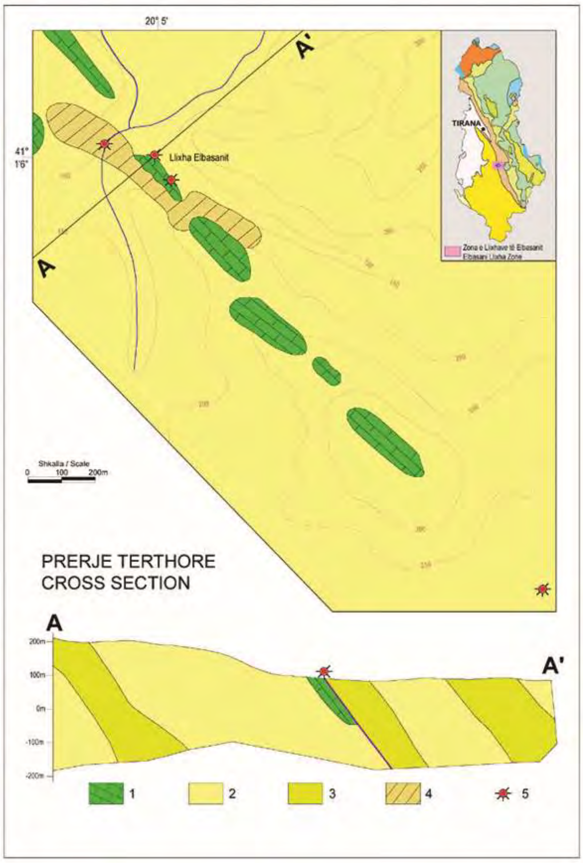


Figure 4: Geological map of Llixha springs.

Wellhead temperatures in the Tirana-Elbasani zone vary from 60 - 65.5 °C. The temperature at the top of aquifer reaches 80 °C in the Kozani-8 hole. According to the temperature logs in Ishmi - 1/b and Galigati - 2, temperatures at depth in the carbonate section are 42.2 °C and 52.8 °C, respectively. The difference between the temperature of thermal water gushing at the surface and of the limestone section at depth shows that a mixture of waters from different depths and temperatures has occurred. The Lëngarica river thermal springs, near of the Vjosa River Valley, Postenani steam springs and the Sarandaporo springs can be found south of the Kruja geothermal area. Thermal water flows out from the contact between the Eocene fissured and carstified limestones and the flysch section. The steam flows from tectonic fault. On both sides of the Lëngarica River, shores are located Bënja thermal springs, well known from the Roman era, as shown in Figure 5.

These waters are much different. They do not contain H_2S, CO_2 and are a factor of 7-9 times less mineralized than waters from the Tirana-Elbasani zone. The mineral water of these springs is drinkable. Water temperature is 29 °C. Yield is 30-40 l/s (Frashëri et al. 2004). Nearby the Albanian-Greek border is located Sarandaporo's thermal spring with mineral drinkable water, the temperature is 27.6 °C and yields more than 40 l/s. Geothermal springs at Kavasila in Greece is located in southern part of Sarandaporo riverside. Kavasila thermal springs and Sarandaporo in Albanian side are springs belong to a single geothermal system, on the northern side it continues with the steam springs of Postenan Mountain in Leskovik and Bënja geothermal springs of Përmet. Table 3 shows the fluid temperatures measured with different geo-thermometers.

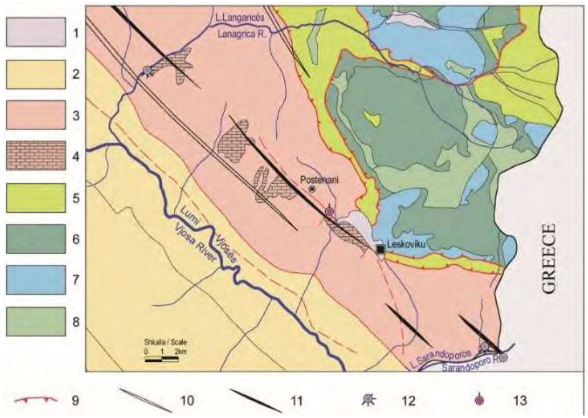


Figure 5: Lëngarica springs geological map.

Table 3: Kruja zone springs temperatures.

Geo-thermometer	Llixha Elbasan springs	Mamurrasi springs	
		Spring 1	Spring 2
Fournier	254	241	220
Truesdell	235	184	191
Na+Ka+Ca	143	130	132

The Kruja geothermal area concentrates most geothermal resources in Albania. The most important resources, explored until now, are located in the Northern half of Kruja Geothermal Area, from Llixha-Elbasan in the South, to Ishmi north of Tirana. For the Tirana-Elbasani subzone heat in place (Ho) is 5.87 x 10^{18} - 50.8 x 10^{18} J, identified resources (Hi) are 0.59 x 10^{18} - 5.08 x 10^{18} J, while the specific reserves range between values of 38.5-39.6 GJ/m^2. The second subzone, Galigati, has lower concentration of resources 20.63 GJ/m^2, while geothermal resources amount to 0.65 x 10^{18} J. These reserves have been extrapolated for this whole subzone up to the Albanian-Greek border (Frashëri et al. 2004).

2.2 Ardenica geothermal zone

Ardenica geothermal zone is located in the coastal area of Albania, in sandstone reservoirs, as shown in Figure 6.

The Ardenica geothermal area is situated 40 km N of Vlora within the Peri-Adriatic Depression. It is comprised of the molasses Neogene brachy anticline Ardenica, the Semani anticline, the northern pericline of Patos-Verbasi carbonate structure, and the overlying Neogene molasses. The Ardenica geothermal area is intercepted by the Vlora-Elbasan-Dibra transversal fault. The Ardenica geothermal reservoir comprises sandstone sections of Serravalian, Tortonian and Pliocene age. These sandstone layers are composed of coarse, medium and fine grains. Effective porosity of the aquifers is about 15.5% and the permeability reaches 283 mD. Hydraulic conductivity is 4.98 m/s and transmissivity have a value 8.9 x 10^{-5} m^2/s. These reservoir properties translate into an output of 5-18 l/s.

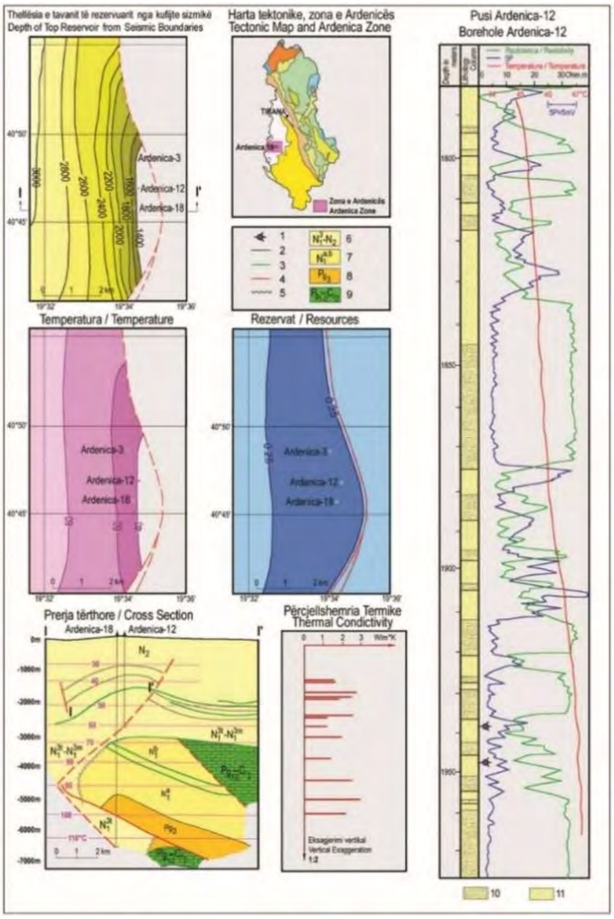


Figure 6: Ardenica geothermal zone map.

Hot water discharges from the boreholes Ardenica-3 (Ard-3) and Ardenica-12 (Ard-12), both situated in the Ardenica brachy anticline, Semani – 1 (Sem - 1) and Semani - 3 (Sem - 3) boreholes in the Semani anticline structure, in the Verbasi - 2 (Ver - 2) drilled in the Patosi monocline and the Bubullima - 5 (Bub - 5) borehole that intercepts the carbonate section of the Patos-Verbasi structure. At the surface, the boreholes discharge waters at temperatures of 32-67 °C. Water flows into these boreholes at depth intervals of 1200 ÷ 1700 m (Ard - 3), 1935-1955 m (Ard - 12), 2250-2275 m (Sem - 1), 2698-2704 m and 3758 m (Sem - 3), 875-1935 m (Ver - 2) and 2385-2425 m (Bub - 5). Ardenica thermal water is Ca-Cl type, with 21.2 mg/l iodine, 110 mg/l bromide and 71 mg/l boric acid, and has a formula:

$$M_{58.8}\frac{Cl_{98}}{Na_{86}}$$

Electrical resistivity and SP logs in the Ardenica –12 and Semani - 1 boreholes, show that the sandstone section has a thickness of 445-1165 m. As an example, these geophysical logs for the Ardenica - 12 borehole are shown together with the temperature log and lithologic column. It is clearly shown that the aquifer temperatures are higher in the sandstone layer than above or beneath it. At the wellhead, temperatures are 32 °C for Ardenica - 12 well, 35 °C for Semani - 1 well, 38 °C for Ardenica - 3 well and 67 °C for the well Semani - 3. However, the temperature in the aquifers at depth of 1935-1955 m is 45.8 °C. Ardenica reservoir has energy reserves in the range of 0.82 x 10^{18} J. Resources density varies from 0.25-0.39 GJ/m^2. The boreholes have been abandoned from a long time and await renewed investments to be converted into geothermal exploration (Frashëri et al. 2004).

2.3 Peshkopia geothermal zone

Peshkopia geothermal zone is located in the Northeast of Albania, in the Korabi hydrogeologic zone, Figure 7 (Çollaku A. et. al 1992).

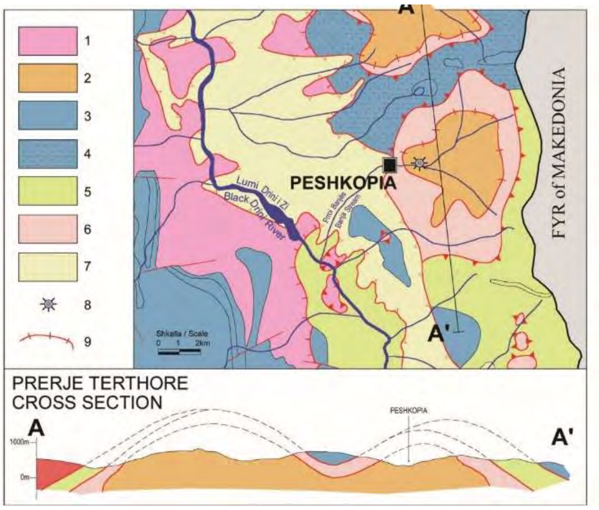


Figure 7: Peshkopia geothermal zone map.

At a distance of two kilometers east of Peshkopia, water at 43.5 °C flows out of a group of thermal springs on a river slope composed of flysch deposits. Some of the springs yield flow rates up to 14 l/s. Occurrence of these springs is associated with a deep fault at the periphery of a gypsum diapir of Triassic age that has penetrated Eocene flysch, which surrounds it like a ring. These springs are linked with the disjunctive tectonic of seismic-active belt Ohrid Lake-Dibër, at periphery of the gypsum diapir. This tectonic belt links the Banjishte and Kosovrasti thermal springs, which are located in the North Macedonian territory, close to the Albania-North Macedonia border (Frashëri A., Pano N. 2003, Micevsky E. 2003). Evaporite diapir extends vertically over 3-4 km (Kodra A. et al. 1993) and comprises the main aquifer of this geothermal system. The occurrence of thermal waters is connected with the low circulation zone always under water pressure. Where gypsum plunges, under the level of free circulation zone, the presence of H_2S can be detected in the water. The thermal waters are of sulphate-calcium type, with a mineralization of up to 4.4 g/l, containing 50 mg/l H_2S. Their chemical formula is (Avgustinsky V. L. 1957):

$$H_2S_{0.0495}M_{4.4}\frac{SO_{56}^4}{Ca_{65}}$$

In the riverbed, outcrops of anhydrides and gypsum are located, also with a big yield of cold mineralized water springs, sulphate-calcium type. The temperature is 12 °C. Different geothermometers indicate the reservoir temperatures are 140 – 270 °C. Considering the regional geothermal gradient, temperatures of 220 °C would be found at depth of 8 - 12 km. However, the gypsum diapir represents e high thermal conductivity body focusing heat from its surroundings. Therefore, water could become warmer at shallow depths, suggested by the geothermal gradient. Water temperature, big yield, stability, and also aquifer temperature of Peshkopia Geothermal Area, are similar with those of Kruja Geothermal Area. For this reason, the geothermal resources of Peshkopia Area have been estimated to be similar to those of Tirana-Elbasani area (Frashëri et al. 2004).

3. CONCLUSIONS

Yet there is much to do in Albania, regarding the Geothermal Energy. Unfortunately, progress has been made mostly on the legal basis. Three laws and one DoCM have been approved paving the road toward its utilization. Although the geothermal regime of the country does not seem to promote and support electric energy generation via the conventional schemes, still it shows significant potential on the direct use. The limited number of units (heat pumps) installed as of today proofs that the country still is only on the first steps of its use. It remains to the Albanian authorities and to financial institutions to create a portfolio with the clear aim of incentive the sector. Otherwise, it shall be at the mercy of sporadic investments of small investors/donors, and limited to the health purposes, but never reaching the real potential that country has.

It is obvious that Albania has much to do for a deeper understanding, assessment and utilization of the Geothermal Resources. Private investments are not yet attracted by its use; therefore, the authorities should consider ways to incentivize and promote the development of this sector. Although significant progress has been done toward the completion of the legal framework to promote the usage of the Renewable Resources of energy in Albania, more should be done regarding the financing of such projects. Attracted from the high energetic values of Llixha Elbasan springs as well as of the water gushing from Kozani 8 well, a private investor has started the preparation of the preliminary design for their use, however it is very difficult to make any accurate and reliable estimation on the time when this shall start, and the respective completion date.

REFERENCES

Avgustinsky V. L., Astashkina A. A. Shukeviç L. I., 1957: Mineral Springs and Health Centers in Albania. Ministry of Health, Tirana, Albania.

Frashëri E. 2003: Geothermal Energy Low, Republic of Albania. Draft. UNDP, GEF/SGP, Tirana Office Project.

Frashëri A., Islami B., Pano N., Bushati S., Çela B., Malasi E., 2003: “Direct use of Geothermal Energy for Greenhouses heating and cooling”, Project idea, UNDP, GEF/SGP, Tirana Office Project.

Frashëri N., Mati I., 2003: Pictures of the steam springs, Postenani Mountain, Leskovik. UNDP, GEF/SGP, Tirana Office Project.

Frashëri A., Pano N., Bushati S., 2003: Use of environmentally friendly geothermal energy. UNDP-GEF SGP Project, Tirana.

Frashëri A., Pano N., 2003: Outlook on platform for integrated and cascade direct use of the geothermal energy in Albania. EAGE Conference Stavanger 2003. 2-6 June 2003, Stavanger, Norway.

Frashëri A., Pano N., 2003: Evaluation of the transborder geothermal field Bënja – Përmet - Postenan - Sarandaporo Leskovik - Konitza. International Conference Water Paths-Communication Ways Amongst People. Lakes & Rivers of the Balkans. Thessaloniki, Greece.

Frashëri A., Pano N. 2003: Geothermal Energy in Central/Eastern part of Albania. Geothermal Potential of South-Western part of Macedonia Workshop, Ohrid 29 November 2003. Macedonian Geothermal Association.

Frashëri A., Simaku Gj., Pano N., Bushati S., Çela B., Frashëri S., 2003: “Direct use of the Borehole Heat Exchanger - Geothermal Heat Pump System of space heating and cooling”, Project idea, UNDP, GEF/SGP, Tirana Office Project.

Frashëri, A., Čermak, V.: The geothermal atlas of Albania. Sh. B. L. U. Tirana, 65-89, 2004.

Fytikas M.D., Kolios N.P. 1979: Preliminary Heat Flow Map of Greece, pp 197 - 205. Institute of Geophysical and Mining Research. Athens, Greece

Fytikas M.D. et al., 1989: Inventory of Low enthalpy geothermal resources discovered through deep oil and gas exploration wells.

Kodhelaj N., Çela B., Aleti R., Thodhorjani S., Bushati S. Bozgo Sh., 2021: Albanian Progress on Geothermal Usage, 2015-2019, World Geothermal Congress 2020+1

Koreneos C.J., Andritsos N., Fytikas M., 1999: The State of Geothermal Energy in Greece. Recent Development. International Geothermal days “OREGON ‘99”. Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, Oregon, USA.

Acknowledgements

This paper goes in memory of Prof. Dr. Alfred Frashëri, and Academic Prof. Dr. Salvatore Bushati, the pioneers of the Geothermal Energy in Albania, two man who did herculean efforts to promote its usage for the energy potential, the promotors of the law on “Renewable Energies” in Albania.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	0	0	2,283	7,629	0	0
Under construction end of 2021	0	0	557.8	2,453	0	0
Total projected by 2023	0	0	1,204	5,391	0	0
Total expected by 2028	N/A	N/A	4494,8	15573	N/A	N/A
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

No geothermal power plants currently in Albania.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	1.907	1902.7	0	0	1.907	1902.7	N/A	N/A
Under constru-ction end 2021	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total projected by 2023	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total expected by 2028	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

No geothermal district heating currently in Albania

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Tirana	Pallati i Kulturës	2001	Y	0.5	0.5	$2.4*10^{-3}$	$3.14*10^{-5}$	Ministry of Culture
Tirana	Twin Towers	2003	Y	1.2	1.2	$5.76*10^{-3}$	$7.536*10^{-5}$	Private
Shkodra	Peter Mahringer High School	2004	Y	0.18	0.18	$0.88*10^{-3}$	$1.04*10^{-5}$	Municipal
Korça	Kindergarten	2006	N	0.0227	0.0227	$0.108*10^{-3}$	$0.108*10^{-5}$	Municipal
total				1.9027	1.9027	$9.148*10^{-3}$	$11.72*10^{-5}$	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	11	1.9027	$9.148*10^{-3}$	N/A	0	0
Of which networks **	N/A	0	0	N/A	0	0
Projected total by 2023	N/A					

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No geothermal UTES plants currently in Albania

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	0	0	0	0
Geothermal direct uses	N/A	N/A	N/A	N/A
Shallow geothermal	0	0	0	0
total	**N/A**	**N/A**	**N/A**	**N/A**

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	N/A	N/A	N/A
Financial Incentives – Investment	N/A	N/A	N/A
Financial Incentives – Operation/Production	N/A	N/A	N/A
Information activities – promotion for the public	N/A	N/A	N/A
Information activities – geological information	N/A	N/A	N/A
Education/Training – Academic	N/A	N/A	N/A
Education/Training – Vocational	N/A	N/A	N/A

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for Austria

Johann E. Goldbrunner[1], Gregor Goetzl[2],

[1] Geoteam Ges. m.b.H., Bahnhofgürtel 77 A-8020 Graz

[2] Geological Survey of Austria, Neulinggasse 38, A-1030 Vienna

goldbrunner@geoteam.at

Keywords: Austria, Shallow Geothermal, Deep Geothermal, Market Overview

ABSTRACT

Since the late 1970s geothermal energy is used in Austria for heat generation, leading to an average development of geothermal applications in an European comparison. Currently, installed capacities are at a level of 1.2 MW_{el} (electricity production), 103.7 MW_{th} (direct use) and around 1'120 MW_{th} (ground source heat pumps). As in many other European countries, the geothermal market is dominated by ground source heat pump systems (factor of some 1:10 regarding installed capacities). However, the share of geothermal energy inside the installed renewables for heating is still very low (~2%) and for renewable electricity production insignificant (<0.1%). This is due to a general low level of public awareness of geothermal technologies, the lack of political will and a non-favourable legal framework.

Since 2016, the direct geothermal use (hydrogeo-thermal use) is again increasing based on a new installation for agricultural use in Styria (Frutura Project) and the remarkable extension of the district heating project of Ried/Mehrnbach in the Upper Austria Molasse Basin. In the upcoming decade new district heating developments can be expected in the cities of Vienna, Upper Austria and Salzburg. In general, district heating based on geothermal has proven to be economically successful so that the existing grids are being steadily expanded.

Ground source heat pump installations show annual growth rate of around 5% and a share of 24% inside the heat pump market. The increasing demand on cooling and seasonal heat storage might offer further opportunities for enhancing the overall share of geothermal in the RES market in Austria.

1. INTRODUCTION

1.1 Geographical and socio-economic overview

Austria covers an area of 83'871 km^2 and has 8.9 million inhabitants. Its surface is dominated by the Alps (62.8%) and the Bohemian Massif (10.2%), thus reducing the share of the densely populated lowlands to only 27%. Based on numbers referring to 2020[1], the level of urbanization reaches 59% in Austria, compared to 75% as an average of the European Union. At a GDP of around 40'300 EUR per inhabitant (2019), Austria is one of the richest countries in the European Union.

The use of renewable energy sources (RES) has a long tradition in Austria due to the availability of hydropower. In 2020, the total end-user consumption of energy for all sectors reached 1055 PJ (BMK, 2021) at a RES share of 36.5% (Biermayr & Bauer, 2021). The highest share of RES was reported for electric power production (78.2%), followed by heating and cooling (35%) and traffic (10.3%). Austria is still very much depending on energy imports at an estimated share of around 61%, whereof almost 90% represent fossil fuels, referring to gross energy production in 2021. Fossil fuels represent 64.4% of the gross energy consumption, which is slightly below the average of EU-27 (based on BMK, 2021).

Referring to Biermayr & Bauer (2021), hydropower is dominating renewable electricity production (75.6%), followed by wind energy (12.4%), biomass (5.7%) and photovoltaic (3.7%). Although installed at two locations in Austria, geothermal electricity production has a negligible share (<0.1%) inside the RES consumption. The production of renewable heat is dominated by biomass (52.7%), followed by district heating (share of RES at 22.3%), black liquors (12.0%) and ambient heat (8.3%). In the recent years, the strongest growth inside RES can be reported for photovoltaic, wind energy and ambient heat, while bioenergy exhibited moderate growth rate.

The share of geothermal heat production for direct use and ground source heat pump supplied heating listed inside ambient heat is estimated at around 2.5%. Here,

[1] Source: https://data.worldbank.org

shallow geothermal energy use is covering around 90% of the geothermal heat supplied.

1.2 Geothermal overview

The geothermal conditions in Austria generally differ grossly between the Alpine region at the one hand and the main sedimentary basins (Molasse basin, Styrian Basin, Vienna and Pannonian Basin) at the other. As shown in Figure 1, elevated heat flow densities of more than 100 mW/m^2 can be observed in the eastern part of Austria (Pannonian Basin, Styrian Basin), which are related to crustal thinning at the Pannonian Basin. Local anomalies in the Molasse Basin (up to 90 mW/m^2) and the Vienna Basin are associated with local to regional scale hydrothermal systems.

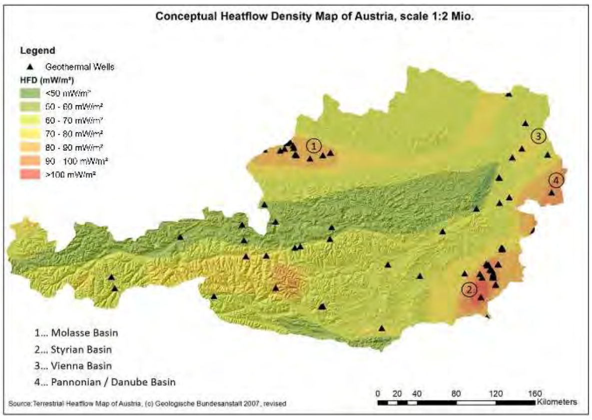


Figure 1: Conceptual heat flow map of Austria, displaying the location of geothermal wells.

Inside the Alpine Orogeny, the heat flow densities are generally lowered due to crustal thickening. Especially in the Northern Alps, long-range infiltration systems of meteoric water lead to a further reduction of the heat flow density down to less than 50 mW/m^2. Elevated heat flow densities within the Alps only can be found in the area of the Central Gneiss due to radioactive heat production within this unit. Natural springs with temperature up to 46 °C are used for balneological purposes at Bad Gastein (Salzburg).

As shown in Figure 2, the Austrian basin regions (Molasse Basin, Vienna Basin, Pannonian Basin, Styrian Basin) generally offer the option for using geothermal reservoirs, whilst high temperature reservoir systems, above 100 °C have yet been identified in some regions only referring to the results of hydrocarbon drillings in the past decades. Still, there are possibly promising regions in Austria for hydrogeothermal energy use, which have not or hardly been explored by the hydrocarbon industry so far. This applies to parts of the Northern Calcareous Alps (Upper Austroalpine carbonates) and deep sections of the Vienna- or Molasse Basin.

1.3 The role of geothermal energy in national energy policy

Although mentioned, geothermal energy played a minor strategic role inside the National Energy and Climate Plan (NECP) for Austria. Since then, the current Austrian government, which came into power in January 2020, put a slightly higher interest in the use of geothermal energy related to the involvement of the Austrian Green Party. The agreement of the current government aims at modernizing the legal framework for geothermal energy and at investigating the options for a better integration into district heating. However, the Austrian Act on renewable energy use for electricity production ('Erneuerbaren Ausbau Gesetz – EAG', BGBl. I Nr. 150/2021) resulted in drawbacks for geothermal energy production as no more incentives have been foreseen so far.

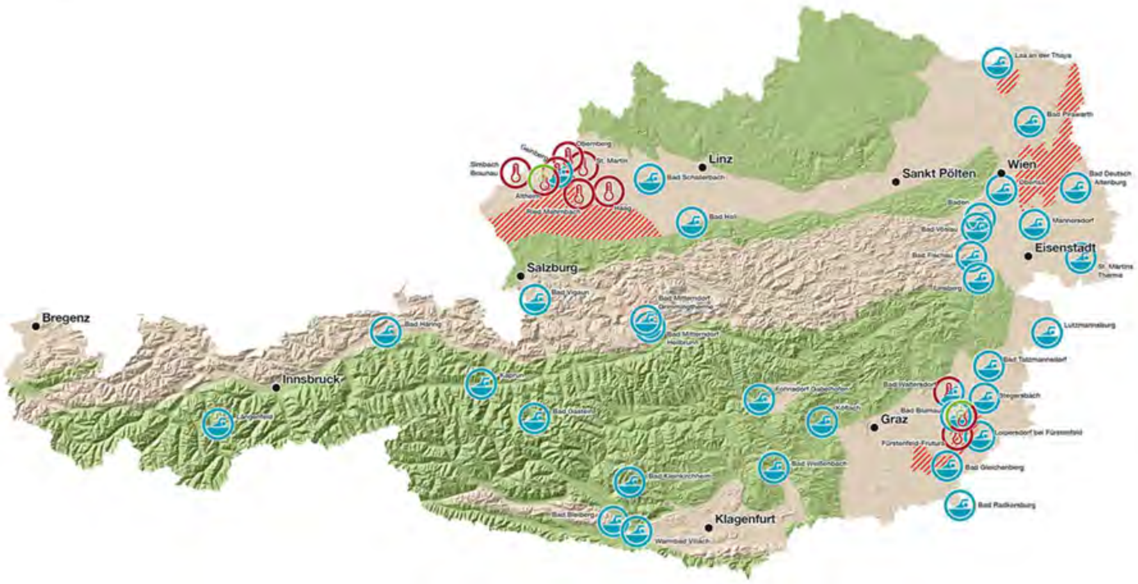


Figure 2: Overview of the hydrogeothermal conditions in Austria, combined with existing sites of direct geothermal energy use (source: Austrian Geothermal Association, www.geothermie-oesterreich.at**).** Blue symbols refer to balneological use, red symbols to direct heat production and green symbols to electricity production. Regions suitable for hydrogeothermal use are marked in light red colour, while red shaded areas indicate the existence of thermal water systems above 100°C.

In 2022, the Austrian Federal Ministry for Climate (BMK) published the first “R&D Roadmap for Geothermal Energy” in Austria (Zillner et al., 2022). It covers objectives and key strategic research questions related to shallow- and deep geothermal energy use as well as underground thermal energy storage. The R& D roadmap identified the following, partly thematically cross-cutting priority fields:

- Urban geothermal energy use,
- Web based information systems and e-Government,
- Geothermal energy supply of the existing building stock,
- Geothermal heating and cooling networks,
- Integration of UTES into heating and cooling networks,
- Reduction of development time and modern permitting procedures,
- Demonstration of innovative and promising geothermal concepts and technologies.

Recently, the city of Vienna government released an funding scheme related to investments in local heating and cooling networks in existing buildings, which cannot be supplied by district heating. It represents the first of its kind in Austria and aims at promoting the use of geothermal energy in multivalent heating and cooling networks.

In 2019, the Austrian Geothermal Association (‘Geothermie Oesterreich – GTOE’) went into operation for supporting the development and knowledge transfer related to the use of geothermal energy in Austria. Since then, the level of awareness among policy makers in Austria significantly increased, which resulted into important milestones like the first R&D Roadmap for Geothermal Energy use in Austria as mentioned above.

2. DEEP GEOTHERMAL USE

2.1 General overview and actual market development

The use of natural thermal waters (hydrogeothermal use) for balneological and energetic purposes has a long tradition in Austria, leading to more than 75 geothermal drilling projects and currently 136 km of drillings (see Table 1). After a period of extensive development in the 1990s and early 2000s, a period of reduced activities had to be observed (see also Figure 3). Since 2014, developments for the energetic use of thermal water slightly increased while balneological uses are stagnant. Table 2 gives details on the main hydro-geothermal regions in Austria.

Currently, geothermal energy is used at 10 locations for direct heat supply at a total capacity of 104 MW_{th} (+12 MW_{th} since the last Country Report 2019) and a gross heat production of 311 GWh. Additionally installed capacities refer to full operation of the geothermal district heating System Ried – Mehrnbach, which now constitutes the largest geothermal direct use installation is Austria (21 MW_{th}). Nine of the 10 existing geothermal installations supply local heating networks, while the second largest installation supplies an industrial horticulture plant (Frutura, 19 MW_{th}) since 2016. At three sites, energetic use is combined with balneological purposes by the use of ‘geothermal cascades’ (Bad Waltersdorf, Geinberg and Bad Blumau), which underlines the former importance of balneology as a market driver for investments into deep geothermal energy in the late 1990s and early 2000s. While the average installed capacities for direct geothermal heat supply are rather moderate at a level of 10.4 MW_{th}, the latest installations indicate a shift of paradigm towards large-scale applications.

Table 1: Geothermal drillings in Austria (period 1977 – 2021).

Unit	Total number of wells	Cumulative depth [m]
Styrian Basin	29	48 740m
Upper Austrian Molasse Basin	14	30 828 m
Vienna Basin and Lower Austrian Molasse Basin	8	12 605 m
Northern Calcareous Alps and Upper Austroalpine Units (mainly carbonate rocks)	7	14 802 m
Lower and Uppe Austroalpine Units (mainly crystalline rocks)	19	27 483 m
Pannonian Basin	1	860 m
Total	**78**	**135 818 m**

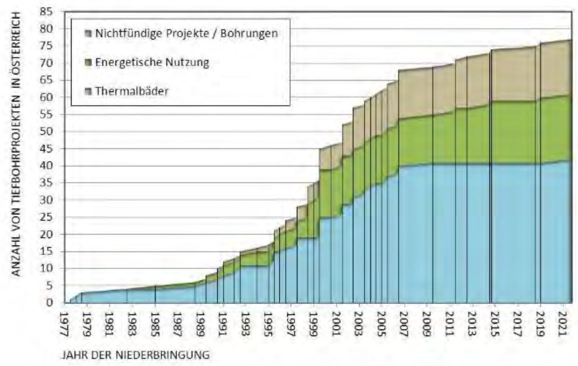


Figure 3: Geothermal drilling projects in Austria for the period 1977 - 2021. Blue: balneological purposes, green: energetic use, red: non-successful drilling projects.

Geothermal energy was used to produce electricity at two sites in Austria (Bad Blumau and Altheim). Both plants were installed in the early 2000s and constituted lighthouse projects for binary-cycle based geothermal power plants in central Europe. Due to the unfavourable financial framework conditions in Austria, no further plant was developed since then. Recently, the geothermal power plant at Altheim is under revision and therefore does not produce electric energy.

Table 2: Overview of hydrogeothermal regions in Austria

Region	Geothermal Settings	Hydrogeological Settings	Current Use and Future Options
Molasse Basin (Upper Austria)	Enhanced heat-flow due to hydro-dynamic convection.	Wide spread reservoir system of low mineralization (Upper Jurassic Malm system) in the central and northern part. Poorly known reservoir (Malm) in the southern part at higher level of mineralization.	Well developed in the northern part of the reservoir system, southern part not used yet.
Molasse Basin (Lower Austria)	Locally confined enhanced heat-flow due to hydrodynamic convection.	Locally confined carbonates (Upper Jurassic Malm system) and wide spread clastic reservoirs (Middle Jurassic Dogger); enhanced mineralization.	Not developed yet due to low density of users. Single balneological use.
Styrian Basin	Regionally enhanced heat-flow due to thinning of the crust and hydro-dynamic convection.	Locally confined Miocene (clastic) and Devonian (carbonatic) reservoirs; varying degree of mineralization.	Developed for most prosperous regions.
Vienna Basin	Moderate heat-flow due to high subsidence rates. Locally confined enhanced heat-flow due to hydro-dynamic convection.	Several reservoirs in Austroalpine carbonate rocks; minor reservoirs in Miocene clastic sediments.	Central part: Not developed yet Southern part: balneological use

2.2 Recent developments

Molasse Basin (Upper Austria)

As reported in Goldbrunner & Goetzl (2019), a third well, namely Mehrnbach Th 3.1/3.1a was successfully finished by the end of January 2019. Following a long-term pumping and reinjection test in March/April 2019 using Th 3.1/1a as producer and Mehrnbach Th 1/1a as injector (Figure 4), the regular operation of the geothermal plant Ried started by the end of 2019. It followed the trial operation of wells Mehrnbach Th 2 as producer and Th 1/1a as injector.

The maximum flow volume of the producer Th 3 is 100 l/s at a wellhead temperature of 105 °C. The geothermal capacity of 21 MW_{th} makes Ried Mehrnbach currently the biggest hydrothermal installation in Austria. The total heating capacity installed within the network is 39.1 MW_{th}, but due to the high temperature and flow volume, the proportion of additional heating with fossil fuels can be kept at almost zero.

The heating net has currently a total length of some 46 km. The hydrothermal plant supplies more than 2'500 apartments, 350 single-family houses, around 105 commercial companies and 10 industrial customers.

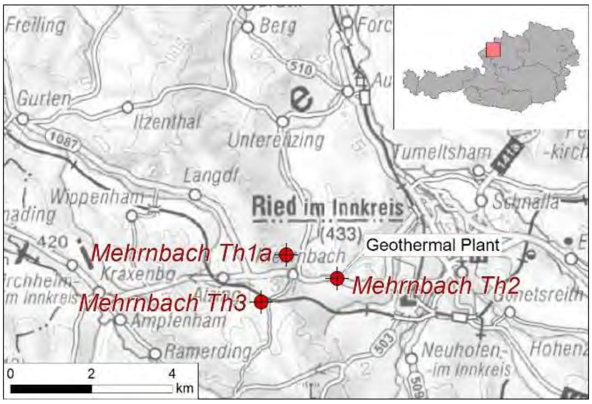


Figure 4: Site Mehrnbach (location of geothermal plant and of well Mehrnbach Th 1 – 3)

The production and reinjection from and in respectively the wells Mehrnbach Th 3.1/3.1a and Th 1/1a allow the formation of a hydraulic dipole at the down-thrown block (Braunau Block) of the Ried Fault. Well Mehrnbach Th 2, which is isolated by the Ried Fault from the Braunau Block, is currently shut down or serves as a replacement well in times of revision work on the producer Mehrnbach Th 3.1/3.1a. Due to the high demand, considerations are made to establish a second doublet, formed by Mehrnbach Th 2 and a new well Mehrnbach Th 4 at the upthrown block of the Ried Fault (Ried-Schwanenstadt Block).

In 1980, Geinberg was the first project to use deep hydrothermal energy, along with Waltersdorf in Eastern Styria (Styrian Basin). In 1998 a doublet was established, formed by the new well Geinberg Th 2 as producer and the abandoned hydrocarbon well Geinberg 1 as injector.

The hydrothermal project Geinberg which covers the heating demand of the district heating net at the village Geinberg and the spa hotel "Therme Geinberg" was extended in late 2021 by supplying a greenhouse of some 10 ha and an installed capacity of 10 MW_{th}. The envisaged heating demand is 51 GWh. To cover this additional requirement, a larger pump was installed in the Geinberg Th2 well, which allows for a maximum production of 65 l/s. A slot liner was also installed in the borehole.

Styrian Basin

In 2021 an expansion drilling for the thermal water resort of Loipersdorf near the town of Fürstenfeld, approx. 60 km east of the provincial capital Graz, was successfully tested for its suitability as a thermal water borehole for spa use. It is the fourth well overall which will replace the well "Binderberg 1" of 1972 which was drilled as a hydrocarbon exploration well and was adapted for thermal water production.

The target of the exploration drilling were Neogene sands at some 1'200 m depth.

Vienna Basin

In December 2021, a successful well test has been completed in the former geothermal exploration well Essling-TH1, situated at the Eastern part of Vienna. After missing its main target located in Triassic carbonates ('Hauptdolomit') inside the basement of the Vienna Basin, the well Essling-TH1 was preserved and re-entered for investigating a secondary target represented by Neogene conglomerates. The well test revealed thermal water at above 90°C (Figure 5) and marks an important milestone for the future use of geothermal energy for the supply of the district heating network of Vienna. The well Essling-TH1 itself is not considered for geothermal energy production but might be used as an observation well in case the investigated reservoir will be developed in future projects.

Figure 5: Thermal water trapped at the successful test in the well 'Essling-TH1', Vienna (photo: Austrian Geothermal Association, December 2021)**.**

Other regions

Apart from the activities reported for the Molasse-, Styrian- and Vienna Basin, there is no ongoing development of hydrogeothermal projects in Austria.

2.3 Recent and actual research activities

Since 2019, research and exploration activities can be reported for the Eastern part of the Molasse Basin (project HTPO) and the Vienna Basin (project GeoTief). Recently, a resource study was also initiated for the Styrian Basin, which will not be presented in this article.

Eastern Molasse

The EU Interreg project HTPO (Austria – Czech Republic) investigated hydrogeothermal resources and trans-boundary management approaches for the region southwards of Laa / Thaya (Austria) and Pasohlávky (Czech Republic). HTPO focused on a cross-border Upper Jurassic carbonate reservoir ('Altenmarkt Formation') inside the basement of the Molasse Basin, which is already used for balneological purpose at the locations mentioned above. In addition, a stratigraphically lower formation consisting of Middle Triassic arenites was investigated for possible future high-temperature applications. The research activities are based on monitoring data from the existing balneological sites as well as on exploration data from the hydrocarbon industry. The focus was set on the creation of harmonized transboundary datasets and joint geoscientific models (cf. Figure 6).

Furthermore, HTPO addressed stakeholder analyses and derived general strategies how to develop the existing geothermal resources in a sustainable way.

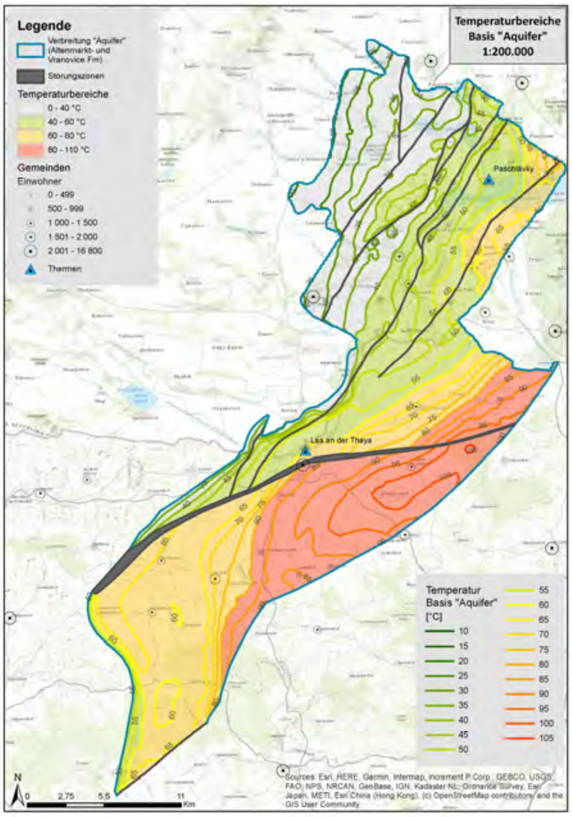


Figure 6: Temperature map of the Upper Jurassic carbonatic reservoir in the Eastern Molasse Basin.

Vienna Basin

Since 2016, several 2D and 3D seismic exploration campaigns have been conducted in the framework of the GeoTief initiative (http://www.geotiefwien.at) in the eastern part of the city of Vienna. The energy supplier of Vienna intends to shift a significant share of the district heating supply to hydrogeothermal energy sources. The main exploration targets are Triassic carbonates, which belong to Austroalpine units, in depth ranges between 3'000 and >5'000 metres. In addition, Neogene conglomerates of the sedimentary fillings of the Vienna Basin in depths of 2'000 to 3'500 metres below surface, which recently have been tested successfully, represent a further target.

Since 2021, the national research project 'ATES-Vienna' (funded by Klima- und Energiefonds) investigates resources for high-temperature underground thermal energy storage in Neogene sedimentary layers, which have partly been used for hydrocarbon exploitation in the past. The most favourable reservoirs are expected in depths between 1’000 and 2’500 metres. The results of these activities will be presented in the next Country Report for Austria.

2.4 Summary and outlook on the period 2022 - 2025

After a decade of moderate developments in deep geothermal energy use resulting in just two new installations, an increasing momentum can be observed in the use of deep geothermal energy for district heating supply and agricultural use in Austria. For 2025, at least the first pilot well, possibly even the first geothermal doublet, can be expected in Vienna for supply of the district heating systems. Outside of Vienna, exploration activities have been increased in the Styrian- and Molasse Basin, leading to the at least two additional projects under investigation.

3. SHALLOW GEOTHERMAL USE

3.1 Actual market development

During the last years the heat pump market in Austria is growing significantly at annual growth rates above 10%. However, air based heat pumps are dominating the market with shares in domestic sales of more than 80%. The historical development of heat pump utilization in Austria can be separated in three main phases: Until the early 2000s, single-cycle (direct expansion) horizontal loop systems were dominating the market, afterwards replaced by ground source heat pumps using borehole heat exchangers. The financial crisis of 2008 then led to a shift towards cheaper air-source heat pump systems. Based on the numbers presented in Biermayr et al. 2021), the market share of ground source heat pumps increases in line with the capacity requirements and still dominates the market at capacity levels above 50 kW_{th}.

Inside ground source heat pumps, brine based solutions have a share of 85%, followed by water based systems (11%) and single-cycle heat pumps (4%). Currently around 92’000 ground source heat pumps are estimated to be operating in Austria at a total net capacity, excluding electricity consumption of the heat pump, of around 1,100 MW_{th} for 2021. The total gross heat supply was estimated to 2.3 GWh_{th}. Unfortunately, no comprehensive register on shallow geothermal installations exists in Austria.

After a period of continuous market decrease, a slight increase of interest in using ground source heat pumps can be observed since the start of the pandemic in 2020 (see also Figure 7). Since 2022, the request on ground source heat pumps significantly increased referring to reports from Austrian service providers. As a result, the current interest leads to waiting periods for drilling services of several months.

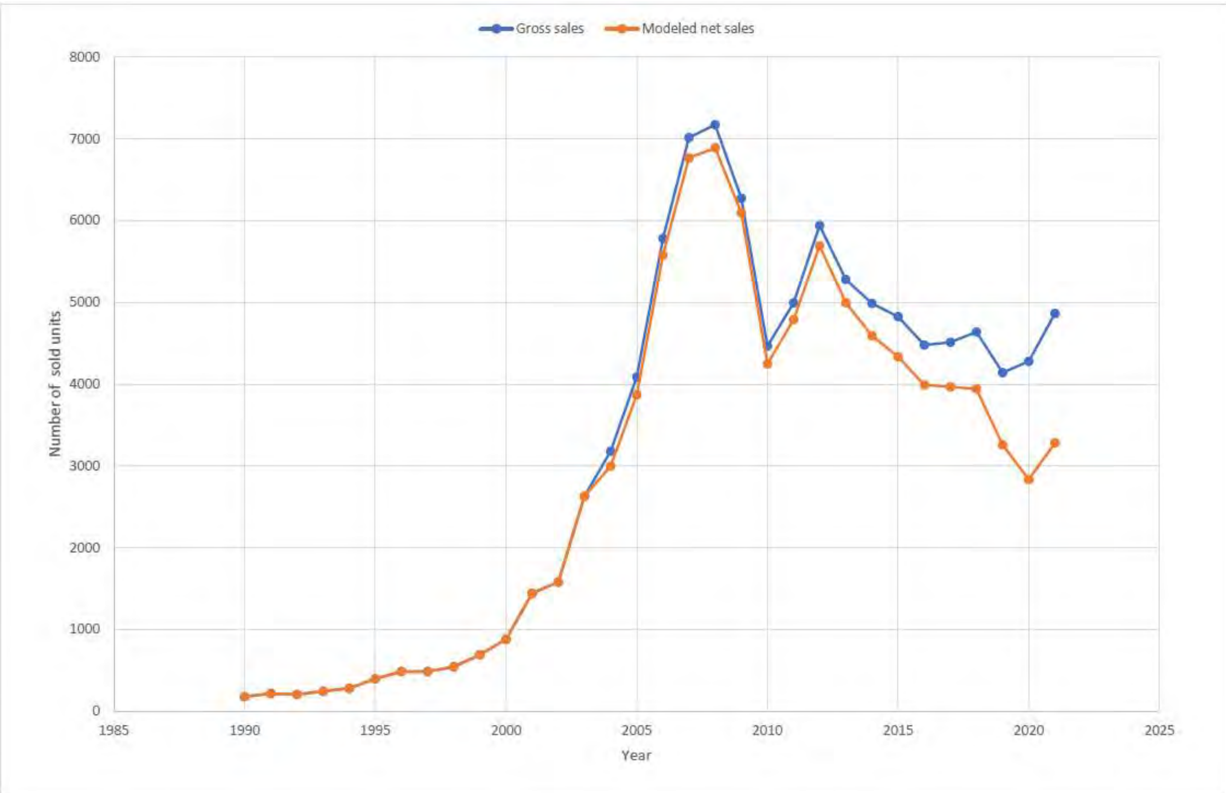


Figure 7: Historical development of ground source heat pump sales between 1990 and 2021 (based on data from Biermayr et al. 2021)**.** Blue line: reported gross domestic sales for brine and water based heat pumps; Orange line: net sales model including a heat pump renovation period of 20 years.

Current development and research trends focus on large-scale ground source heat pump installations for commercial and housing buildings leading to a shift of operation from pure heating supply to combined operational modes (heating & cooling) or entire seasonal heat storage in multivalent solutions. Recently, the city administration of Vienna launched a funding scheme for investments in local heating and cooling networks connecting different buildings in case no district heating supply is possible.

3.2 Summary and outlook on the period 2022 - 2025

The recent geopolitical developments as well as the increased awareness on the ongoing climate crisis resulted in a strong interest in heat pump utilization in the housing sector in Austria. Although air based heat pumps are expected to dominate the market in the upcoming years, the use of ground source heat pumps is estimated to significantly increase as well. This especially applies to large capacity installations in large buildings or inside low temperature heating and cooling networks. Based on rough estimations collected in interviews with drilling service providers, the current service capacities are limited to around 6’000 projects per year either based on borehole heat exchangers or groundwater wells. After a series of years with declines of annual sales, assuming a renovation period for heat pumps of 20 years, the sales increased by around +16% from 2020 to 2021. If a further increase of growth appears, which is quite likely, the capacity of Austrian drilling service providers might be reached until or even before 2025. This bears a certain risk for the development of shallow geothermal energy use in Austria and should be mitigated with qualification programs for service providers including fostering one-stop-shop services.

4. CONCLUSIONS

Austria represents a country with a long tradition on geothermal energy use and is still above European average regarding its application. We currently account for more than 80 springs or wells for balneological purposes, 10 locations with direct geothermal use, whereof 2 sites with geothermal CHP, as well as more than 90’000 ground source heat pump installations, which leads to an estimated net energy production of around 2’500 GWh_{th} and 0.5 GWh_{el}. However, the share of geothermal energy in the Austrian energy consumption is still very low, estimating around 1.5% for heating and <<0.1% for electricity.

The past decade was characterized by a continuous transition in the use of geothermal energy. Direct use moved away from balneology, a former key market driver, towards energetic use for district heating and agricultural purposes. Large energy suppliers like ‘Wien Energie’ in Vienna started systematic exploration and development programs to generate portfolios of geothermal heating plants in the next years or decades. Other investors might follow this approach as well. Regarding shallow geothermal energy use, the significant growth of heat pump utilization in the building sector was not transferred to ground source heat pumps for small to medium scale applications (e.g. single to double family homes). However, large-scale heat pump installations and low temperature heating and cooling networks using shallow geothermal as heat source and storage started to develop in the past years in Austria and offer interesting market opportunities for the future.

In 2019, the Austrian Geothermal Association (GTOE) published a position paper on the technical potential of geothermal energy for energy supply in Austria for 2040. Table 3 shows key figures in comparison with the recent energy study ‘ONE^{100}’ by the Austrian Gas Grid Management GmbH (AGGM), which was published in 2021 (AGGM 2021). ONE^{100} applied an energy-economic optimization model for a complete replacement of fossil fuels in Austria based on a ‘greenfield approach’ (ignoring existing energy distribution pipelines) and sector coupling. The study revealed that geothermal energy will be crucial for heat pump supply to avoid peak load shortcomings and grid balancing (heat storage) as well as for electricity production (base load supply).

Table 3: Comparison of long-term development goals of geothermal heat supply between the Austrian Geothermal Association (GTOE) and the recently published study ONE^{100}.

Heat supply category	GTOE (2019)	ONE^{100} (2021)
Low temperature heating supply (<30°C)	15 TWh	≤43 TWh
Direct heat supply (<150°C)	10.2 TWh	4.2 TWh
Electricity production	0.7 TWh	2.3 TWh

The 2040 strategic development goals, shown Table3, require a massive roll-out of geothermal energy technologies in the coming years. In order to achieve these aims, the following main barriers still need to be removed:

Access to services: Due to the complexity of installing geothermal energy compared to other RES, qualification programs for service providers, especially drillers and planners, need to be expanded or even introduced as soon as possible to avoid long waiting times or failures due to low quality services.

Efficient licensing procedures: In the past 10 years, only two deep geothermal installations have been commissioned in Austria. The number of geothermal plants for direct heat and CHP might multiply in the coming 15 to 20 years, which requires an efficient regulatory framework as well as timely licensing procedures and trained public employees for the evaluation of applications.

Access to information: Austria is still lacking comprehensive uniform access points to geoscientific data for shallow- and deep geothermal energy use. The

Geological Survey of Austria has developed several regional pilot systems, which need to be extended and harmonized as well as linked to e-government solutions, ideally. Moreover, the legal framework needs to be modernised for granting access to valuable exploration data from decades of hydrocarbon exploration in Austria.

Incentives and risk mitigation schemes: In the past decade, existing financial incentive schemes covered individual heat pump investments and feed in tariffs for geothermal electricity production. However, the incentives turned out to have a low impact as the existing geothermal power plants have been constructed prior to the introduction of feed in tariffs in 2009 and the funding scheme for private investments into ground source heat pumps did not compensate for the lower costs of air-source heat pumps. Incentive schemes are needed to support investments in exploration and development linked to portfolio build-ups and risk mitigation in deep geothermal. For shallow geothermal, public investments would be helpful to increase the number of public service providers, aiming at one-stop-shop services, as well as to offer long-term financial incentives linked to tax reliefs for efficient and environmentally sustainable installations (e.g., local heating and cooling networks).

ACKNOWLEDGEMENTS

The authors want to thank the operators of Austrian deep geothermal installations for providing the updated operational figures.

REFERENCES

AGGM Austrian Gas Grid Management AG (2021), ONE^{100}: Austria's Sustainable Energy System - 100% Decarbonized - The Economically Optimized Energy System for a Climate Neutral Austria; AGGM, Vienna.

Biermayr, P., Bauer, H. (2021), Erneuerbare Energie 2020 – Entwicklung in Österreich; Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (BMK), Wien.

Biermayr, P., Dißauer, C., Eberl, M., Enigl, M., Fechner, H., Fürnsinn, B., Jaksch-Fliegenschnee, M., Leonhartsberger, K., Moidl, S., Prem, E., Schmidl, C., Strasser, C., Weiss, W., Wittmann, M., Wonisch, P., Wopienka, E. (2021), Innovative Energietechnologien in Österreich: Marktentwicklung 2020 - Biomasse, Photovoltaik, Solarthermie, Wärmepumpen und Windkraft; BMK, Vienna.

BMK (2021), Energie in Österreich – Zahlen, Daten, Fakten; Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (BMK), Wien.

Zillner T., Bauer H., Lutter E., Warmuth H., Haslinger E., Goetzl G. (2022), FTI Roadmap Geothermie: Vision und FTI-politische Fragestellungen; BMK, Klima- und Energiefonds, Vienna; download at: https://nachhaltigwirtschaften.at/resources/nw_pdf/BMK_Geothermie_Roadmap.pdf

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	1.2	0.5		72558*	<0.1%	<0.1%
Under construction end of 2021	0	0			<0.1%	<0.1%
Total projected by 2023	1.2	1.5			<0.1%	<0.1%
Total expected by 2028	5	22			<0.1%	<0.1%
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Styria	Bad Blumau	2001	1 (RI)	O	B-ORC	0.2	0.2	0.5
Upper Austria	Altheim	2002	1 (RI)	N	B-ORC	1	0	0
total						**1.2**	**0.2**	**0.5**

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
R	Retired / decommissioned	2F	Double Flash	O	Other

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	75.1	223.6	18.8	63	9.8	24	43.1	~350
Under constru-ction end 2021			5	17			0.4	3.2
Total projected by 2023	75.1	240	23,8	80	9.8	24	~45	~350
Total expected by 2028	150	825	30	100	9.8	24	~45	~350

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Calculation based on inflow temperature into the facility neglecting heat losses referring to discharge temperature of 20°C.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Bad Waltersdorf	Bad Waltersdorf	1979	N	N	2.3	5*	6	70*
Haag am Hausruck	Doublet Haag	1996	N	N (RI)	1	1*	6	100*
St. Martin im Innkreis	Doublet St. Martin	2002	N	N (RI)	8.5	29*	34.2	60*
Geinberg	Doublet Geinberg	1997	N	N (RI)	16.8	n.a.	25	100*
Obernberg	Doublet Obernberg	1996	N	N (RI)	7	7*	14	100*
Bad Blumau	Doublet Blumau	2001	Y	N (RI)	7.5	7.5*	18	100*
Simbach a. Inn / Braunau a. Inn	Doublet Simbach-Braunau	2000	N	N (RI)	9.4	42.3*	46.9	66*
Altheim	Doublet Altheim	1991	Y	N (RI)	11.4	n.a.	27.1	100*
Ried im Innkreis	Doublet Mehrnbach	2014	N	N (RI)	21	n.a.	70.4	n.a.
total					**84.9**		**247.6**	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Fürstenfeld	Frutura	2016	N (RI)	18.8	18.8	63	100	Frutura
total				**18.8**	**18.8**	**63**		

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total***			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	92’400	1’120	1’850	3’300	160	17% [a]
Of which networks **	<100	n.a.	n.a.	n.a.	n.a.	n.a.
Projected total by 2023	~102’000	~1’200	~2’000			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

*** Excluding single-cycle (direct expansion) horizontal loop systems (estimated stock around 5000 units)

[a] Share of domestic heat pump sales in 2021

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

	Aquifer Thermal Energy Storage (ATES)			Borehole Thermal Energy Storage (BTES)		
	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold
In operation end of 2021 *	0	H: C:	H: C:	>10	H: n.a. C: n.a.	H: n.a. C:
New (additional) in 2021 *	0	H: C:	H: C:	unknown	H: C:	H: C:
Projected total by 2023	0	H: C:	H: C:	unknown	H: C:	H: C:

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	0	3	5	5
Geothermal direct uses	10	200	50	700
Shallow geothermal	240	~1200	270	~1400
total	**250**	**~1400**	**325**	**~2100**

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	O: National research funds on renewable energy	O: National research funds on renewable energy	O: National research funds on renewable energy
Financial Incentives – Investment	No	DIS	DIS, REQ (partly)
Financial Incentives – Operation/Production	No	No	No
Information activities – promotion for the public	No	Technical guidelines (OEWAV)	Guidelines for permitting and licensing procedures, technical guidelines (OEWAV)
Information activities – geological information	Data services of Geological Survey of Austria (regional coverage, www.geologie.ac.at)		
Education/Training – Academic	No	Partly covered university studies	Partly covered in colleagues and university studies
Education/Training – Vocational	No	No	Qualification schemes for drillers and installers (e.g. WPA, AIT)

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for Belgium

Nicolas Dupont[1], Estelle Petitclerc [2], Matsen Broothaers[3], Olivier Kaufmann[1].

[1] University of Mons, Place du Parc 20, 7000 Mons, Belgium

[2] Geological Survey of Belgium, Jennerstraat 13, 1000 Brussels, Belgium

[3] VITO – Vlaamse Instelling voor Technologisch Onderzoek, Boeretang 200, 2400 Mol, Belgium

nicolas.dupont@umons.ac.be

Keywords: Belgium, Geothermal Energy, country update.

ABSTRACT

The development and production of geothermal energy in Belgium remains very low compared to other renewable energies. Although shallow geothermal systems represent the major part of the sector in Belgium, the potential of deep geothermal energy is important but still little used. Only four geothermal plants are currently operational and supply heating networks (Saint-Ghislain, Douvrain, Ghlin, Balmatt) and a fifth is under construction (Beerse). Other projects are currently under investigation in Flanders (Turnhout, Herentals and Lommel).

Besides deep and shallow geothermal systems, the geothermal potential of abandoned coal mines of Wallonia has recently been evaluated. Its potential to produce heat and cold (as well as for the storage of thermal energy) is very promising and has encouraged the funding of feasibility studies for pilot projects in this region.

In the scope of speeding up the energy transition, the policies of the different regions continue to support both shallow and deep geothermal projects, through subsidies for research and/or project development and by updating some regulatory constraints.

Belgian scientists from different institutes and universities are involved in several ongoing geothermal research projects, which are briefly introduced in this paper.

1. INTRODUCTION

In Belgium, geothermal energy is mainly produced from shallow systems, although there is a significant but as yet undefined potential for deep geothermal energy.

Shallow geothermal energy is strongly established in the northern part of the country (Flanders), in particular due to the existence of a thicker soft cover (clays, sands) above the Paleozoic bedrock. It is very difficult to evaluate the number of shallow geothermal systems installed in Belgium as well as their capacity. No public organization centralizes this information and the data collected via the professional federations are not exhaustive.

Deep geothermal energy remains fairly marginal but continues to develop from the Dinantian limestone reservoir, present in both Flanders and Wallonia (Figure 1). This reservoir is currently used for heat extraction only.

In Wallonia, deep geothermal energy has been produced for several decades in Hainaut (SW Belgium) by the intermunicipal association IDEA, from three single wells supplying heating networks. These three wells are those at Saint-Ghislain, Douvrain and Ghlin (Figure 1), drilled between 1973 and 1981. The targeted reservoir is that of the Dinantian carbonates. In this area, this reservoir is very thick (>2 km thick) and contains highly permeable levels with karstified zones and brecciated levels. The water produced from these three wells has a temperature of around 70 °C and its salt content is fairly low (1 to 2 g/l), although the wells have reached the productive levels at different depths (1.5 to 2.5 km deep).

2. POLICY DEVELOPMENT FOR GEOTHERMAL ENERGY

2.1 Policy development in Flanders

The Flemish Decree of 8 May 2009 concerning the deep subsurface regulates the licensing for deep, i.e. deeper than 500 m, geothermal projects. It follows a two steps procedure with exploration and production licenses. These grant the exclusive rights for exploration of and production from a well-defined 3D volume in the subsurface, respectively. The standard validity period of the exploration permit is 5 years, allowing the operator to drill and test wells, and to come up with a production plan, which is required for a production license. Apart from the exploration / production permit, also an environmental permit is needed.

Since the end of 2018 an insurance system for geological risk is in place. The aim of this insurance system is to should help stimulate investments in deep geothermal energy, which is characterized by high initial investment cost and high uncertainty risk. The insurance covers the geological or exploration risk only. This helps stimulating new projects in Flanders.

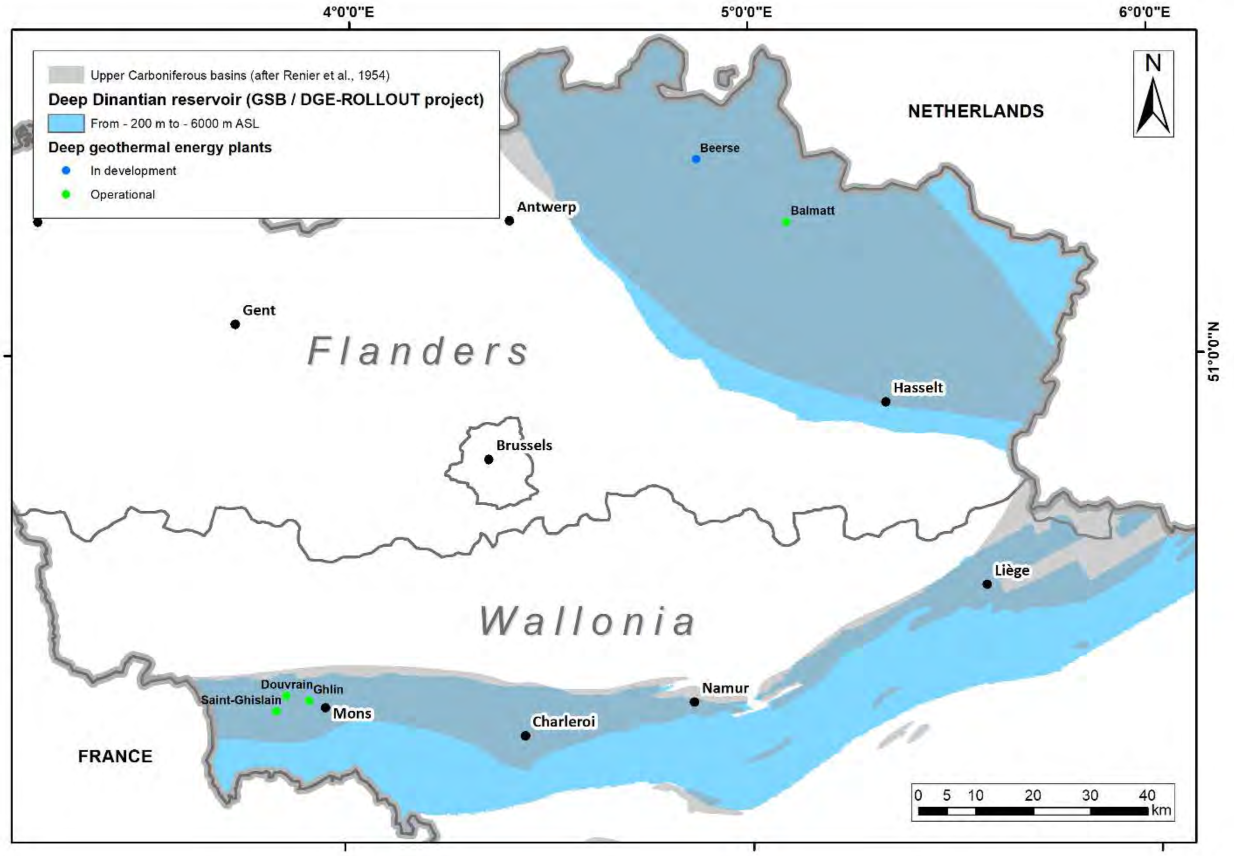


Figure 1: Situation of the Upper Carboniferous basins and the deep Dinantian reservoir in Belgium

2.2 Policy development in Wallonia

According to the latest version of its "Air Climate Energy Plan" ("PACE 2030"), the Walloon Region intended to reach a 23.5% share of renewable energy of the final gross energy consumption by 2030. A new PACE 2030 should be prepared by the end of 2022 and will highlight ambitious goals for geothermal energy following the RePowerEU plan.

In March 2021, the Energy Efficiency Directive (2012/27/EU- ART.14) concerning the strategy for heating and cooling networks powered by cogeneration, waste energy or renewable energy sources was adopted by the Walloon Government (WG).

In March 2022, the final Walloon recovery plan (joint proposal from WG members) was adopted to determine the prioritization of the recovery plan projects. In its third priority, an action program called "Strengthening energy independence and energy transition" (including 6 projects and 1 portfolio), one of the 6 projects is "Support deep geothermal energy and geothermal mining in the Walloon Region" for which a total fund of 25.5 M€ will be devoted.

The regional guarantee system for deep geothermal projects introduced in the previous country update (Lagrou et al., 2019) proposed by WG did not succeed. Nevertheless, this proposal was kept as a major recommendation for the deep geothermal sector deployment in Wallonia.

A shallow geothermal call for projects was launched in spring 2021 with a budget of 7.5M€ (Kyoto Funds and the Walloon recovery plan funds). The call aimed at directly supporting shallow geothermal open and closed projects (≤500 m depth) as well as pilot geothermal mining projects (<1200 m depth). In view of the large number of applicants (18) to the first call, the Walloon Government reiterated this call for shallow and mining projects in July 2022 with a new budget of 22 M€.

The new subsoil decree mentioned in Lagrou et al. (2019) is still under adoption procedure. It will regulate the underground resources exploration and extraction in Wallonia. Within this new regulation, deep geothermal is defined as "*renewable energy whose set of processes allow the extraction of geothermal energy and its recovery, whether thermal or electrical. It is the energy stored in the form of heat under the surface of the solid earth, at depths greater than five hundred meters*". This subsoil decree will detail deep geothermal energy exploration and extraction conditions (with exclusive permits principle) and should be implemented by mid-2023.

For shallow open systems (ATES), some changes in environmental permit classes (especially for the water reinjection) are under evaluation to facilitate the installation of such kind of technology (only one ATES system is currently set up, in the Liège area).

2.3 Policy development in Brussels

Early November 2018, the Brussels Government approved a decree regulating groundwater abstraction and geothermal systems in open circuit. This text was in application in 2019. At the Brussels administration in charge of geothermal energy (*Bruxelles Environment, BE*), about 100 geothermal systems are currently listed in their database (with 17 open systems already permitted or under permitting procedure). Because it was not mandatory to declare closed-loops systems before 2018, it is still complicated to get a proper estimation of installed systems. Thanks to the Brugeo project (ERDF-Brussels funding), the main geoscientific information on Brussels geology, shallow geothermal potential and existing systems is now available through the webtool called BrugeoTool (https://geodata.environnement.brussels/client/brugeotool/home). A clear increase of permit requests was observed since 2019 for various projects: single houses, residential buildings, office buildings, schools, municipality, university, shopping centre, museum. Among them, 12 open systems are installed or in preparation mainly using the Cambrian bedrock as resource.

The short and medium perspectives for the Brussels administration are:

- Agree on a driller certification valid in the two other Belgian regions (2023);
- Set up a dedicated legal framework for closed-loop systems (early 2024);
- Adapt regulations for open systems (some changes are already in place since few months, e.g. a monitoring piezometer must be installed for every open system) (early 2024);
- Put policy measures in place to reach Renewable Energy goals by 2030 in accordance to the results of the large study on thermal energy carriers (benchmarking on renewable heat solutions).

3. DEEP GEOTHERMAL PROJECTS IN FLANDERS

3.1 Operational projects

After a period of suspension of 22 months (July 2019 – April 2021), test operations were started up again at the Balmatt geothermal site in Mol. In the meantime, a number of changes and improvements were made to the geothermal installations in order to cope with the challenges identified during well testing and during the first start-up phase in 2018-2019 (Broothaers et al., 2021). In parallel, the seismic monitoring network was extended.

Between April 2021 and April 2022, nine test phases were carried out, with gradually increasing duration, flow rate and injection pressure (Broothaers et al., 2022). The longest test phase lasted for 4½ months, from November 2021 to April 2022. The connection to the heating grid was reinstalled in August 2021, allowing heat to be delivered to the buildings of VITO and SCK/CEN. Further tests are planned in the coming months.

3.2 Projects under development

Janssen Pharmaceutica has been developing a geothermal plant on their research campus in Beerse (Figure 1). The project targeted permeable zones in the Carboniferous Limestone Group. The first well (Beerse-GT-01) was spudded in December 2019 and drilled to a total depth of 2’725 m MD (2’052 m TVD). This well is intended for injection. A second well (Beerse-GT-01) was spudded in February 2020 and reached a total depth of 2’558 m MD (2’235 m TVD). An extended well test (circulation test) was carried out in the summer of 2020. Positive results were communicated in December 2020, mentioning a production temperature up to 85 °C. Since then, Janssen Pharmaceutica has been working on the surface installations and heating network and intends to bring the geothermal system into operation in fall of 2022. The aim is to reduce CO_2 emissions by 30 %.

3.3 Projects under investigation

The geothermal development company HITA started with the development of three projects in the Campine Basin since 2020. They carried out three seismic surveys to explore the subsurface at selected project locations in Turnhout, Herentals and Lommel. These surveys were initially set up as 2.5D, but processing allowed to come up with a full 3D result. In all three cases, the seismic data were used to construct a 3D static geologic model.

A first survey was carried out in May 2020 on the northwestern side of Turnhout, in the vicinity of the hospital of AZ Sint-Jozef. This project targets the Carboniferous Limestone Group at a depth between 2’000 and 2’500 m, allowing a temperature around 90-100 °C. The resulting geological model served as input for a dynamic model to simulate several scenarios with varying reservoir properties and operational parameters. The goal of the simulations is to evaluate the pressure and temperature impact in the reservoir around the wells. They also provide insights for well planning, the potential output of the geothermal site, and the required license area/volume. For the Turnhout project, the results were subsequently used to apply for an exploration license in the area, which is currently under review by the Flemish authorities.

A second project was initiated in the fall of 2020 with a survey in the area between Herentals and Olen. This project also targets the Carboniferous Limestone Group, and the results indicate it is present at a depth varying between 1’500 and 2’000 m. A temperature around 80 °C is expected. As for the project in Turnhout, dynamic reservoir simulations were performed based on the static geological model. The project will initially focus on delivering heat to a nearby horticultural area and existing as well as new dwellings in the city of Herentals.

Finally, a third survey was executed in the summer of 2021 in the industrial area of Maatheide in Lommel. The latter tied into a regional 2D survey carried out in 2020 on behalf of VITO in the framework of the Interreg NWE project DGE-ROLLOUT. This allowed exploring the wider area and connecting to existing seismic data and deep geothermal wells in Mol and Dessel. In addition to the Carboniferous Limestone Group, the project in Lommel also targets shallower geothermal reservoirs as the sandstone of the Triassic Buntsandstein Formation or the Upper Carboniferous Neeroeteren Formation. The geological modelling reveals the Buntsandstein Formation is present between 1’000 and 1’300 m depth, where an average temperature of 50 °C is expected. The underlying Neeroeteren Formation may bring the combined thickness of the sandstone interval to 500 m, with a temperature at the base around 65 °C. The Carboniferous Limestone Group is expected at around 4’000 m depth (>150 °C).

4. GEOTHERMAL PROJECTS IN WALLONIA

4.1 Introduction

In Hainaut (SW Belgium), deep geothermal energy is a locally proven resource for heating applications. This resource is under-exploited and the infrastructures that currently exploit it are ageing. However, the development of new projects is struggling to emerge despite the climatic challenges and the local heating needs linked to the population density and the quality of the existing buildings. To encourage the development of new projects in this region, the study of the Dinantian limestone reservoir continues, both for its structure and its hydrogeological characteristics (MORE-GEO project).

Elsewhere in Wallonia, the Dinantian limestone reservoir remains the main target for deep geothermal energy. The global study of this reservoir on the scale of North-Western Europe has been conducted through the DGE-ROLLOUT project (see chapter 6).

The Mijnwater pilot experiment in Heerlen (Netherlands) has shown the value that flooded old coal mines could have for energy production, especially for 5th generation district heating and cooling systems (Boesten et al., 2019). The development of this resource also deserves to be supported in the Walloon Upper Carboniferous coal basin (Figure 1). Therefore, a first study of the potential of geothermal energy from mine water was conducted in 2019-2020 (Harcouët-Menou et al., 2020).

Finally, both the Walloon old mines and the Dinantian limestones of Hainaut are part of the reservoirs on which the DESIGNATE project is evaluating scenarios for the development of deep geothermal projects in Belgium, beside the Dinantian limestones and Cretaceous chalks of Campine in Flanders.

4.2 MORE-GEO

The MORE-GEO project, led by University of Mons, had begun in 2017 and was introduced in the previous Country Update (Lagrou et al., 2019). Despite the abandonment of the "Porte de Nimy" deep geothermal doublet in Mons, this ERDF project continues and focussed on 1) the acquisition and interpretation of data to refine the structure and characteristics of the reservoir and 2) the design of a geothermal resource management tool to promote the implementation of new projects in the region.

The Hainaut2019 2D seismic survey was conducted in the first quarter of 2019. It is composed of 5 north-south profiles of about 20 km each, positioned to supplement the acquisitions of the Mons2012 survey. The global interpretation of the results makes it possible to distinguish two main compartments in the Dinantian reservoir, separated by an important synsedimentary structure: 1) a very thick reservoir, sloping southwards (cf. Saint-Ghislain well) and 2) a thinner and subhorizontal reservoir (cf. Jeumont-Marpent well in France) (Dupont, 2021). Together with direct data, these results have allowed to propose a new geometric model of the Dinantian reservoir (Dupont, 2021) and a delineation of inferred high-transmissivity zones within the reservoir (Dupont et al., 2021a). In addition, the geophysical interpretations led to a revised definition of the Variscan front units in Hainaut (Dupont et al., 2021b)

Geological and hydrogeological modelling of the Dinantian reservoir is still ongoing, updating the various models with the new data acquired and interpretations proposed. These will form the basis for the resource management tools that will be developed over the coming months.

4.3 DESIGNATE

As partner of the DESIGNATE project, funded by the Belgian Science Policy, the University of Mons is developing hydrogeological modelling solutions for use in the simulation tool for geothermal energy exploitation scenarios. The reservoirs considered for Wallonia are the Dinantian limestones of Hainaut and the abandoned coal mines.

4.4 Minewater systems

Initiated and funded by the Walloon Administration, the assessment of the geothermal potential of the old mines of Wallonia has been completed in 2020 by a consortium composed of VITO, University of Mons, ABO-Group and Mijnwater BV. The potential has been calculated in the context of the implementation of a 5th generation network as implemented in Heerlen (NL) for the Mijnwater project. In this type of system, mining reservoirs can be used for heating, cooling and energy storage. The methodology used is based on proxies extracted from mining data such as minimum and maximum mining depths and the number of coal layers mined. A high spatial resolution (0.1 km) was chosen to map the potential at the neighbourhood level.

In order to serve as a decision support tool, a mapping of potential of projects similar to the Mijnwater project was made. In addition to mapping the potential, other tasks were carried out such as modelling a business plan for a pilot project in Wallonia and proposing an action plan to promote the sustainable development of this sector in Wallonia. The main results show that a significant potential exists in the region. Compared to the Mijnwater project and based on conservative assumptions on the state of the old Walloon mines, the total potential has been estimated to 1'690 GWh, which would represent 11 projects equivalent to that of Heerlen (Harcouët-Menou et al., 2020).

In order to develop this potential, the Walloon Administration has launched calls for projects in 2021 to study the feasibility of a pilot mining geothermal project for each of the three most interesting coal basins (Borinage, Charleroi, Liège). The results of these studies are expected in 2023.

4.5 GEOWAL

The Walloon government launch a 2 years-study in 2020 to assess the shallow geothermal potential of the region. VITO, ULiege, GSB, Deplasse and Geogreen worked together to produce technical potential maps which are combined with the economic potential at the surface (heat demand mainly). The project results for the potential evaluation for closed and open systems will be available in October 2022.

5. GEOTHERMAL PROJECTS IN BRUSSELS

In 2019, the Belgian Science Policy approved the project "GeoCamb : Geothermal Energy potential in Cambrian rocks focusing on public buildings" [1] which will run until 2024. The BRAIN-be 2.0 program (Belgian Research Action through Interdisciplinary Networks) funded a budget of 1 M€ for this project in order to support the sustainable exploitation of renewable natural resources and reduce CO_2 emissions. In Belgium, the heating sector counts for 48% of the total use of energy. In this respect, the GeoCamb project focuses on investigating the geothermal potential of the Cambrian basement of the Brabant Massif (BM) in Brussels and its surroundings in order to advise the potential transformation of the main heating source of public buildings. Geological, hydrogeological and geophysical explorations are ongoing in two public case studies and several win-win cases with external partners (Petitclerc, et al, 2019, 2020, 2021). The win-win approach consists of the execution of extra tests and analysis of the monitoring data of existing geothermal projects (both open and closed systems).

Today, the GeoCamb project can rely on 22 sites. In parallel of the geothermal reservoir evaluation, the energy demand of specific public buildings is incorporated in the case-studies to maximise the efficiency of the system. By providing a better knowledge of the Brabant Massif and by demonstrating the efficiency of geothermal systems, the GeoCamb research project will help reducing investment risk, allowing better planning of subsurface resources at policy level and in the end lead to a more secure, carbon-lean and affordable energy cost for the end-users.

6. TRANSNATIONAL GEOTHERMAL PROJECTS

The transnational EU Interreg North-West Europe funded project DGE-ROLLOUT ("Roll-out of Deep Geothermal Energy in North-West Europe") aims to promote the DGE potential of Lower Carboniferous carbonate rocks. The latter occur widespread in the NW European subsurface and are expected to represent a favourable reservoir for hydrothermal energy extraction as it is demonstrated in Belgium, where 3 wells are in exploitation since the 1980's in the Mons basin (Wallonia) and several more recent projects in the Campine basin (Flanders). The Rhenohercynian Basin is investigated following a multi-disciplinary approach. The DGE-ROLLOUT website [2] contains the reports of the different project deliverables.

Belgian exploration will be led by seismic surveys, 2 new profiles of 50 km are scheduled in autumn 2022. In two pilots (Balmatt, BE; Bochum, DE) the production optimizing will be tested by implementing high temperature heat pumps and new cascading schemes from high (>100 °C, big network) to low temperature (> 50°C, single enterprise) and gain a CO_2 reduction of 25'000 tons/year. 10 years after project's end at least 1'000'000 t/y will be achieved, but it is expected to reach up to 5'000'000 t/y in the long run. Further activities will apply innovative decision and exploration strategies that are cheaper, risks minimizing, more reliable and see a 3D Atlas of the complex geological situation as the spatial basis usable for DGE. To set the stage for DGE tools to increase social acceptance will be checked out, (planning) legal conditions as well as business models for enterprises will be evaluated and compiled, a network "NWE-DGE" will be set up to sustain the outputs and investments in the long-term roll-out after the end of the project.

7. CONCLUSIONS

Geothermal energy production remains relatively marginal in Belgium compared to other renewable energies (mainly wind and photovoltaic). Nevertheless, the development of this sector continues, especially for shallow geothermal energy, but also for deep geothermal energy. The development of a fifth deep geothermal plant is underway in Beerse and new projects are under development in Turnhout, Herentals and Lommel. In the meantime, several research projects

[1] https://www.belspo.be/belspo/brain2-be/project_p1_en.stm#GEOCAMB

[2] https://www.nweurope.eu/projects/project-search/dge-rollout-roll-out-of-deep-geothermal-energy-in-nwe/

aiming to precise the geothermal resource and the means to exploit it are underway.

Mining geothermal energy is of growing interest for the production of heat, cold, and for the storage of thermal energy. Its important potential, recently evaluated in Wallonia from the perspective of 5th generation heat network, has motivated the public funding of feasibility studies for the implementation of pilot projects in the most promising parts of the region (Borinage, Charleroi, Liège).

The policies of the different regions continue to support the sector for both shallow and deep geothermal projects, through subsidies for research and/or project development and by updating regulatory constraints.

REFERENCES

Boesten, S., Ivens, W., Dekker, S.C. and Eijdems, H.: 5th generation district heating and cooling systems as a solution for renewable urban thermal energy supply, *Advances in Geosciences*, **49**, (2019), 129-136, https://doi.org/10.5194/adgeo-49-129-2019

Broothaers, M., Lagrou, D., Laenen, B., Harcouët-Menou, V. and Vos, D.: Deep geothermal energy in the Lower Carboniferous carbonates of the Campine Basin, northern Belgium: An overview from the 1950's to 2020, *Z. Dt. Ges. Geowiss. (J. Appl. Reg. Geol.)*, **172**, (2021), 211-225, https://doi.org/10.1127/zdgg/2021/0285

Broothaers, M., Cox, K., Harcouët-Menou, V., Kinscher, J., Kremers, S., Laenen, B., Lagrou, D., Pogacnik, J. and Van Meensel, S.: Deep geothermal energy in the Lower Carboniferous carbonates in the Belgian Campine Basin: status and insights from second start-up phase of the Balmatt project in Mol, *Proceedings of the European Geothermal Congress 2022*, Berlin, Germany, (2022), paper #388, 1-7.

Dupont, N. : Analyse de la structure du socle paléozoïque hainuyer, implications sur les caractéristiques des réservoirs profonds, *unpublished PhD thesis report*, University of Mons (Belgium), (2021), 374p.

Dupont, N., Kaufmann, O., Baele, JM., Delineation of inferred high-transmittivity zones in the Dinantian geothermal reservoir of Hainaut (SW Belgium), *Proceedings of the Geologica Belgica Congress 2021*, Tervuren, Belgium, (2021), 2 p.

Dupont, N., Kaufmann, O., Baele, JM., Redefinition of the structural units of the Variscan Front based on the results of the Mons2012 and Hainaut2019 seismic surveys in the Hainaut (SW Belgium), *Proceedings of the Geologica Belgica Congress 2021*, Tervuren, Belgium, (2021), 2 p.

Harcouët-Menou, V., Matthijs, J., Dupont, N., Kaufmann, O., Le Mevel B., Reyskens, R., Rabaut, M., and Eijdems, H.: Détermination du potentiel géothermique des anciennes mines désaffectées en Wallonie, *published report*, (2020), 133p., https://energie.wallonie.be/servlet/Repository/rapport-final-geothermie-mines-wallonie.pdf?ID=64987

Lagrou, D., Petitclerc, E., Hoes, H., Dupont, N. and Laenen B., Geothermal Energy Use, Country Update for Belgium, *Proceedings of the European Geothermal Congress 2019*, Den Haag, Netherlands, (2019), 9p., https://europeangeothermalcongress.eu/wp-content/uploads/2019/07/CUR-03-Belgium.pdf

Petitclerc, E., Agniel, M., Gaudaré, L. and Devleeschouwer, X.: Outlooks in geothermal mapping and resource management at Brussels, *European Shallow geothermal days 2019,* Brussels, Belgium, *(2019).*

Petitclerc, E.: Geological context of Brussels: Why and how does geothermal energy work, *Shallow geothermal days 2020,* online (2020). https://www.egec.org/wp-content/uploads/2020/12/EU-shallow-geothermal-days_SGE-Brussels_Estelle.pdf

Petitclerc, E., Agniel, M., Van Lysebetten, G., Huysmans, M., François, B., Van Camp, M., Walraevens, K., Devleeschouwer, X., Gurung, P., Duren, T., Van Steenwinkel, J. and Gerard, P.: New geological, hydrogeological and geothermal insights into the potential of the Cambrian basement for geothermal energy in Brussels, Belgium, *Proceedings of the International Association of Hydrogeologist 2021*, (2021), 292.

Acknowledgements

University of Mons thanks ERDF Funds, Walloon Region and BelSpo for their financial support in the scope of the MORE-GEO and DESIGNATE projects.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

There are no geothermal power plants in Belgium

Table B: Existing geothermal power plants, individual sites

There are no geothermal power plants in Belgium

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021	25-26	17.69	?	?	?	?	0	0
Under construction end 2021								
Total projected by 2023	33-37	60-100						
Total expected by 2028	50-60	400-450	10-15	?	?	?	0	0

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commissioned	CHP	Cooling	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 production (GWh_{th}/y)	Geoth. share in total prod. (%)
Saint-Ghislain	Saint-Ghislain	1985	N	N	6	6	13.13	100
Baudour	Douvrain	1985	N	N	4	4	2.86	100
Ghlin	Geothermia	2017	N	N	7	7	0.16	100
Mol	Balmatt	2018	N	N (RI)	8-9	n.a.	1.54	n.a.
total					25-26		17.69	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

The table could not be updated for 2020/2021.

Table F: Investment and Employment in geothermal energy

The table could not be updated for 2020/2021.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	Yes, if appropriate in certain regional/federal research program	Yes, if appropriate in certain regional/federal research program	Yes, if appropriate in certain regional/federal research program
Financial Incentives – Investment	RC (only in Flanders and for geological/exploratory risk)	RC (only in Flanders and for geological/exploratory risk)	No, except a public call for projects funded for Wallonia
Financial Incentives – Operation/Production	No	No	No
Information activities – promotion for the public	No	Yes, as result of certain R&D projects	Yes, as result of certain R&D projects
Information activities – geological information	No	Yes, as result of certain R&D projects	Yes, as result of certain R&D projects
Education/Training – Academic	No	No	No
Education/Training – Vocational	No	No	Yes

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for Bosnia and Herzegovina

Natalija Samardžić[1], Hazim Hrvatović[2], Ferid Skopljak[1]

[1] Geological Survey of Federation of Bosnia and Herzegovina - Sarajevo, Ustanička 11, 71210 Ilidža, BiH

[2] Academy of Sciences and Arts of Bosnia and Herzegovina, Bistrik 7, 71000 Sarajevo, BiH

natalija.samardzic@fzzg.gov.ba

Keywords: geothermal energy, direct use, GSHP, production of electricity, oil and gas exploration, Bosnia and Herzegovina (BiH)

ABSTRACT

The paper gives an overview on the development and use of geothermal energy in Bosnia and Herzegovina (BiH) in the period 2019-2021. Two important geothermal energy research projects of local communities have been launched in this period: 1) District heating project from geothermal springs Ilidža (Sarajevo) and 2) Geothermal energy use study in Domaljevac-Šamac Municipality. These projects are financially supported by the Environmental Protection Fund of Federation of Bosnia and Herzegovina.

Geothermal projects DARLINGe and GeoConnect3d, co-financed by EU funds, have been successfully completed. Both projects covered part of the territory of BiH (Pannonian Basin) and included partners from BiH.

At the beginning of 2022, the project "Geothermal energy and underground storage of CO_2, sustainable energy carriers and heat & cold" was positively evaluated by the European Commission. More than 20 European geological surveys participate in the project, including the Geological Survey of Federation of Bosnia and Herzegovina.

BiH is using geothermal energy obtained from deep geothermal reservoirs (approx. 80 %) and on a small scale energy from shallow horizons (up to 200 m) with water temperature t <20 °C by using heat pumps (approx. 20 %).

In the period 2019-2021, the direct use of geothermal energy remained at about the same level as in the previous reporting period. Direct use of geothermal energy is present at 25 locations, of which 19 are spa and/or recreation centers, while at four locations thermal waters are used in industrial processes (production of milk, meat and vegetable products). The most spas and recreation centers are heated from geothermal sources. At two locations, geothermal waters are used only for space heating (Termalna rivijera - Ilidža and Slobomir). A new recreational center Terme Ozren with 11 indoor and outdoor swimming pools in the municipality of Petrovo started operation in 2020; this recreation complex is based on the use of thermomineral CO_2 waters of well TGP-3 Kakmuž ($Q_{pump.}$ = 50 l/s, t = 38.3 °C).

A new thermal water reservoir has been discovered by well IEBM-1 (Mujanić) in Blažuj. In this well, with total depth of 41 m, water is obtained at a temperature of 18 °C and pumping capacity of 2 l/s with drawdown of 7.31 m. The lithological composition detected during drilling is as follows: alluvial gravels up to 14 m and deeper are clay marls, clays and sandstone interlayers (probably flysch K_2).

Also, a growth in installation of heat pumps is evident, which are increasingly applied due to the available supporting mechanisms for renewable energy sources and energy efficiency, but no institution in the state yet provides data on the number of installed units.

BiH is still without geothermal power plants and there are no plans yet for their construction.

1. INTRODUCTION

Energy transition and higher energy production with lower CO_2 emissions are being gradually implemented, so in this context, geothermal energy is starting to get significant importance in strategic documents of Bosnia and Herzegovina. Oil and gas are also being explored as more environmentally friendly energy sources compared to coal.

New post-war oil and gas exploration has been conducted in the Republic of Srpska from 2012 until now; in the Federation of Bosnia and Herzegovina legislation is adopted and staff who will be engaged in the exploration projects are trained.

More recently, a growing interest of local communities in the use of geothermal energy for heating purposes is evident. The reasons for that lie most often in the fact that many cities in Bosnia and Herzegovina have a problem with air pollution that is especially present in cities where thermal power plants and larger industrial facilities are located.

Foreign investors are increasingly interested in the possibilities of using geothermal energy for the purpose of development of spa tourism, agriculture (greenhouses) and even for the production of electricity from geothermal sources, but there are still no concrete projects and investment.

2. STRATEGIC ENERGY DOCUMENTS, GEOTHERMAL REGULATION AND SUPPORTING MECHANISMS IN BOSNIA AND HERZEGOVINA

2.1 Strategic energy documents

The energy sector in Bosnia and Herzegovina (BiH) is mainly under the competence of the entities: Federation of Bosnia and Herzegovina (FBiH) and Republic of Srpska (RS).

The Ministry of Foreign Trade and Economic Relations of Bosnia and Herzegovina (MOFTER BiH) is responsible for energy transport and coordination with respect to international integration and obligations. Second the role of the ministry is to coordinate activities of the state government and entity governments regarding implementation of the energy directives of EU.

Responsible authorities for energy at entity level are: Federal Ministry of Energy, Mining and Industry and Ministry of Industry, Energy and Mining of Republic of Srpska. In addition, the cantons in the Federation of Bosnia and Herzegovina have certain responsibilities in the field of energy, which relate to the adoption of regulations on local energy production facilities and ensuring their availability.

Strategic energy document on the state level adopted by the Council of Ministers of BiH are the following:

1) National Emission Reduction Plan for BiH (NERP BiH), adopted on 30 December 2015.
2) National Renewable Energy Action Plan (NREAP BiH), adopted on 30 March 2016.
3) Energy Efficiency Action Plans of BiH for the period 2016-2018 (NEEAP), adopted on 4 December 2017 and
4) Framework Energy Strategy of BiH until 2035, adopted on 29 August 2018.

The development of the Indicative Plan for Energy and Climate in BiH (NCEP) is in the progress.

Strategic energy documents on entity level are the following:

1) Energy Strategy of RS up to 2035, adopted on 21 June 2018 and
2) Framework Energy Strategy of FBiH until 2035.

The Framework Energy Strategy of BiH until 2035 is based on entity strategies, so that this strategy summarizes practically everything related to energy from two entity strategies. In the strategy geothermal energy is recognized as a source that can contribute in the heating sector; geothermal potential in the city of Bijeljina is rated as promising potential for investigation and establishing of district heating system, and also this possibility should be considered in the cities Gradiška and Derventa. The strategy emphasizes that efforts should be made to use geothermal energy for individual heating wherever it is possible.

The use of geothermal energy is elaborated in more detail in the following action plans:

1) Action Plan for Energy Efficiency of BiH (NEEAP) for the period 2019-2021.
2) Energy Efficiency Action Plan of FBiH (EEAPF) for the period from 2019 to 2021, adopted on 4 February, 2021.
3) Action Plan for Energy Efficiency in RS for the period 2019-2021 (APEE RS).

In February 2021, the Government of the FBiH adopted the Energy Efficiency Action Plan (EEAPF) for the period from 2019 to 2021, which is an integral part of the National Action Plan for Energy Efficiency of BiH (NEEAP BiH) for the same period. In this Plan, as “direct energy efficiency improvement measures” in the residential, industrial, public and commercial sectors, as well as households are predicted the production of electricity and/or heat from renewable sources, including geothermal energy and the use of heat pumps for district heating.

2.2 Geothermal regulation

The regulatory framework for geothermal energy in Bosnia and Herzegovina has been elaborated in detail through the DARLINGe project. Procedures, conditions and relevant contact points for obtaining permits for exploration and use of geothermal energy are available on the interactive web portal DRGP (www.darlinge.eu) in the "Legislation" module (https://www.darlinge.eu/#/legislationintro).

2.3 Geothermal energy support mechanisms

Depending on the territory, the following loans, support measures and grants for geothermal energy development in BiH are available:

1) On the territory of the entire BiH:

- The EU/EBRD Western Balkans Sustainable Energy Credit Line Facility II (WeBSEFF II)-loan with a grant for private and public sector. This credit line for financing energy efficiency and renewable energy projects is provided by the European Bank for Reconstruction and Development (EBRD) and it is distributed via two banks in B&H: UniCredit Bank and Raiffeisen BANK.
- The EBRD through the GEFF program encourages energy efficient technologies with participation in the project up to 20% from EU funds. Funds are placed through banks and microcredit organizations operating in BiH: UniCredit Bank

Mostar, UniCredit Bank Banja Luka, Partner Mkf, Sparkasse Bank of BiH, ProCredit Bank of BiH, Microcredit Company Mikrofin, Intesa Sanpaolo Bank of BiH.

- Loans from IFC Funds - a loan program (IFC Canadian climate change program) for small and medium-sized enterprises in purpose: a) Energy efficiency projects (EE) - reconstruction, renovation or adaptation within buildings, b) Renewable energy projects (RE) - installation, construction or expansion into fixed assets (except wind power plants), c) Energy efficiency (EE) and renewable energy (RE) equipment design projects. Loans is available in BiH through UniCredit Bank.
- KfW Entwicklungsbank (German Development Bank) - KfW promotes primarily wind energy, hydropower and solar energy but also geothermal heat and biomasses. A credit line, which supports projects in the area of improving energy efficiency and reducing CO_2 emissions is available in Bosnia and Herzegovina via Raiffeisen BANK.

2) On the territory of FBiH:

- Support measures for projects in the field of environmental protection that is provided and managed by Fund for Environmental Protection of FB&H (includes financing the preparation of Studies and Research Projects for geothermal energy, procurement of technologies for the use of geothermal energy, etc.);
- Development Bank of FBiH is providing a credit line for long-term crediting of renewable energy projects (wind, solar, hydropower, geothermal energy, biomass and biofuels) and other environmentally friendly renewable sources. Beneficiaries of the loan can be: all companies, as well as natural persons (craftsmen) and administrative bodies / budget users / public institutions / public companies / public utility companies / institutes / agencies and other institutions registered at the federal / cantonal or local administrative level.

3) On the territory of each canton (10) in the FBiH:

- The government of each canton (10) in FBiH provides incentives (grants) for projects that contribute to the protection of environment; institutions that managing the funding process are cantonal ministries that are responsible for physical planning and / or environmental protection.

4) On the territory of Tuzla Canton in FBiH:

- "Model / mechanism of co-financing measures to increase energy efficiency of the housing sector" - this financial mechanism was established as a financial instrument for energy saving and implementation of measures to increase energy efficiency of residential objects in Tuzla Canton. Within this measure, the Government of Tuzla Canton, through the Ministry of Physical Planning and Environmental Protection of Tuzla Canton, provides co-financing of project documentation and installation of heat pumps for heating and cooling of individual residential units.

5) On the territory of RS:

- Support measures based on Law on Renewable energy sources and efficient cogeneration which providing the Government of RS (System Operator of Renewables Production Stimulation is the body that managing funding process);
- Co-financing investment in RES that is provided and managed by Fund for Environmental Protection of the Republic of Srpska.

3. PRODUCTION OF ELECTRICITY

Most of the electricity in BiH is produced in thermal power plants (5) and hydro power plants (16). Electricity production data following in the text are given according to Annual reports of the State Electricity Regulatory Commission (SERC - DERK), while production plans are shown according to the Indicative development plan production for period 2022-2031 (Independent System Operator in Bosnia and Herzegovina – NOS BiH).

Total installed capacity of generation units in BiH amounts to 4'530.64 MW in 2020, from which is 2'076.60 MW in the major hydro power plants and 2'065.00 MW in thermal power plants and 86.6 MW in larger wind power plants; rest of 302.44 MW represent installed capacity of small hydro (172.19 MW), solar (34.89 MW), biogas and biomass (2.11 MW), small wind (0.40 MW) and industrial powers plants (92.85 MW).

In operation was 4'608.26 MW (installed capacity) at the end of 2021 with total annual production of 17'055.44 GWh/yr (cf. Table A in the appendix).

Gross electricity production in BiH was 17'055.44 GWh in 2021, what is 1'664.0 GWh more than in 2020, but similar to 2018 (Table 1). Favourable hydrological conditions in 2021 resulted in production of 6'313.99 GWh (37.02 %) in hydro power plants. Production in thermal power plants reached amount of 9'820.98 GWh (57.6 %). The first three wind farms constructed in BiH (Mesihovina, Jelovača, Podveležje) connected to the transmission system injected 381.84 GWh (2.24 %) into the electrical network in 2021. Production in smaller renewable sources (small hydropower plants, wind, solar, biomass and biogas power plants) amounted to 518.67 GWh (3.04 %) while 19.98 GWh (0.12 %) was produced in power plants of industrial producers.

The share of renewable energy sources in total production is 7'214.48 GWh, what is 42.3 %. Total electricity consumption in 2021 was 12’169.78 GWh (Table 1).

Electricity generation, consumption, imports and exports in BiH for the period 2017-2021 are shown in Table 1.

Table 1. Data on the total electricity production in BiH, the share of renewable sources in total production, import and export in the period 2018-2021 (Source: Annual Reports of SERC - DERK for 2018-2020 and unpublished data of SERC – DERK for 2021)

Year	2018	2019	2020	2021
Total production (GWh)	17’873.0	16’074.01	15’390.67	17'055.44
Production from renewa-ble sources (GWh)	6’919,24	6’461,03	4’947.69	7'214.48
Consumption (GWh)	13’293.95	12’330.13	11’329.50	12'169.78
Import (GWh)	1’865.00	2’133.00	1’496.00	1'390.00
Export (GWh)	6’472.00	5’879.00	5’543.00	6'173.00

The first wind farm Mesihovina with installed capacity of 50.6 MW started work in 2018; after that Jelovača (36 MW) and Podveležje (48 MW) were constructed and they were put into operation in 2018 and 2020. Several other wind power plants are under construction.

In B&H, electricity is not generated from geothermal sources, nor is it foreseen by the NREAP B&H until 2020. However, the northern region of Bosnia (Posavina, Semberija) is considered as having the potential for finding geothermal sources for electricity generation (120 °C or higher) or installing such plants, which may use water having the temperature of 96 °C (Domaljevac) for electric power generation (Miošić et al., 2010).

4. STATUS OF OIL AND GAS RESEARCH

Activities on oil and gas exploration and preparation for the development of oil projects are taking place in both entities. The first post-war oil and gas explorations in the Republic of Srpska were conducted in 2012 and 2013, while in the Federation of BiH significant legislation has been prepared up today. Also, in the past two years continuous education of staff in Federation of BiH who will be engaged in the research projects are conducted. The training is organized by Deloitte company and funded by the U.S. Department of State, Bureau of Energy Resources, Energy Governance and Capacity Initiative (EGCI).

Company “Jadran – Naftagas – Banja Luka”, which was founded in 2010 by the Russian joint stock company “Neftegazovaja inovacionnaja Korporacija” (NeftegazInKor) and Serbian company “Naftna industrija Srbije – Novi Sad (NIS-Novi Sad)”, from 2011 has a concession for exploration and exploitation of crude oil and gas on the territory of RS for a period of 28 years.

In 2012, the new seismic investigation and exploratory drilling began in the northern part of Bosnia. In the first phase, 2D seismic were conducted on the territory of Posavina including municipalities of Šamac, Pelagićevo and Donji Žabari. The exploration was conducted by NIS-Novi Sad through the subsidiary "Jadran-Naftagas" - Banja Luka. In 2013, drilling of the exploration well Ob-2 in the village of Obudovac (Municipality of Šamac) was performed. A year later, during the well testing the oil was obtained and quality was tested in the laboratories of the Science and Technology Centre of NIS in Novi Sad. According to public announcement of company NIS-Novi Sad, results of analysing and defining of all reservoir parameters during the trial operation at the well Ob-2 show that the conditions for the development of the second phase of the Obudovac project in 2021 and 2022 are met (https://www.nis.rs).

Additional seismic 2D surveys were performed in 2021 in the area of Obudovac, and then started the construction of the well Ob-3, which was designed to a depth of 2100 m. The exploration is performed by the company NIS-Novi Sad with aim of finding the oil and gas. Completion of the well was planned for January 2022; the results of this drilling are not yet known to the public.

At the same time, in the FBiH, activities on the preparation of legislation in the field of oil and gas exploration and exploitation have been actively carried out, and the staff of ministries, geological and other Government institutions that will be engaged in these projects has been continuously trained in the last 3 years. These trainings, implemented by Deloitte, are funded by the U.S. Department of State, Bureau of Energy Resources, Energy Governance and Capacity Initiative (EGCI).

Oil and gas exploration and exploitation in FBiH is regulated by the following legal acts:

- Law on Oil and Gas Exploration in the Federation of BiH (Official Gazette of Federation of BiH, No. 77/13) and
- Decree on the content of the concession contract for exploration and exploitation of oil and gas, the method of calculation and payment of fees and control of produced quantities of oil and gas in the Federation of Bosnia and Herzegovina (Official Gazette of Federation of BiH, No. 70/14).

5. GEOTHERMAL DEVELOPMENT IN THE PERIOD 2019-2021

The COVID-19 pandemic has contributed to the stagnation of geothermal energy use in BiH; a smaller number of visitors was recorded in spa and recreational complexes compared to the previous reporting period, and this is especially expressed in 2020, when some recreation centers did not work at all.

On the other hand, energy transition and the commitment of the energy sector to reduce CO_2 emissions, together with animation of authority and the public through the DARLINGe project have contributed to better positioning of geothermal energy in strategic documents in BiH. Such facts also were favorable to the start of two geothermal projects whose end goal are establishment of geothermal district heating systems in Sarajevo (Ilidža Project) and Domaljevac.

Geothermal projects DARLINGe and GeoConnect³d, co-financed by EU funds, have been successfully completed in 2019 and 2021. Both of these projects covered part of the territory of BiH (Pannonian Basin) and included partners from BiH. At the beginning of 2022 project "Geothermal energy and underground storage of CO_2, sustainable energy carriers and heat & cold" prepared by more than 20 European geological institutions was positively evaluated by the European Commission.

1) The DARLINGe project (2017-2019) was implemented in six countries (HU, SLO, HR, SRB, BiH, RO) with aim to improve energy security and efficiency in the Danube Region by promoting the sustainable utilization of the existing and untapped deep geothermal resources in the heating sector. The project was developed and implemented by 15 project partners and 7 associated strategic partners; the lead partner is Mining and Geological Survey of Hungary (MBFSZ). Project partners from BiH was two geological surveys - FZZG and GSRS. The investigated area covers the central and SE-ern part of the Danube Region, encompassing S-Hungary, NE-Slovenia, N-ern and Central Croatia, N-ern parts of Bosnia and Herzegovina and Serbia and W-Romania, altogether 95’000 km^2. DARLINGe project is co-funded by the European Regional Development Fund (1’612’249.99 €) and by the Instrument for Pre-Accession Assistance II (534’646.60 €) under Grant Agreement No. DTP1-099-3.2.[1]
   The key output of the DARLINGe project is an interactive web portal – the Danube Region Geothermal Information Platform [2] with two main parts: 1) a web-map viewer where all spatially referenced data are visualized, and 2) thematic modules (knowledge sharing, glossary, benchmarking, decision tree, risk mitigation and legislation) where are available more detailed information on some selected topics (DARLINGe team, 2019).
   The DARLINGe project has reached a large number of geothermal stakeholders in BiH. It seems that implementation of this project has led to greater interest of local communities for possibilities of using geothermal energy in heating sector.
   The Directorate for European Integration prepared and published (in 2022) a catalogue of project results from the first call of the Danube Transnational Program 2014-2020 in BiH, entitled "Danube Flows of Partnerships and Cooperation" [3]. This catalogue also contains the most significant results of the DARLINGe project, which are important for decision makers in BiH, but also for the general public.

2) The GeoConnect³d project (2018-2022) involved 20 project partners (mainly geological surveys) from 17 European countries including the Geological Survey of Federation of BiH (FZZG); Project coordinator was Royal Belgian Institute of Natural Sciences – Geological Survey of Belgium (RBINS-GSB). A new innovative structural framework model suitable for decision-making and subsurface spatial planning was developed and tested. The model was developed using the Roer-to-Rhine region and the Pannonian Basin, two areas extending over many countries in which geological settings and degree of implementation of subsurface exploitation and management differ greatly. It is primarily focused on geological limits, or broadly planar structures that separate a given geological unit from its neighbouring units. It also includes geomanifestations (anomalies) which often indicate specific geologic conditions and therefore can be important sources of information to improve geological understanding of an area and its subsurface (Barros et al. 2021). Results of project are available in the website: https://geoera.eu/projects/geoconnect3d6/

3) “Geothermal energy and underground storage of CO_2, sustainable energy carriers and heat & cold” is a new project supported by EU funds within the program Sustainable, secure and competitive energy supply (HORIZON-CL5-2021-D3-02). This project that includes territory of BiH will be implemented in period of 5 years.
   Primary project objectives are:
   - Comprehensive inventory of information on geothermal energy resources and subsurface storage capacities for sustainable energy carriers (hydrogen, heat and cold) and sequestration of CO_2.
   - Building and maintaining an integrated European geothermal resources database. Extend the geothermal database with assessed storage options for heat and cold.
   - Preparation and maintaining a European storage atlas for CO_2 and sustainable energy carriers like hydrogen and compressed air. Develop the knowledge for the subsurface management and planning of storage sites for CO_2 and sustainable energy carriers.

[1] http://www.interreg-danube.eu/approved-projects/darlinge
[2] www.darlinge.eu
[3] http://publikacije.dei.gov.ba/publikacija/dunavski-tokovi-partnerstva-i-saradnje/

Two new thermal water deposits were discovered in period 2019-2021:

1) The thermal water well IEBM-1 (Mujanić) in Blažuj was drilled in 2014, but it was not known that the water was thermal, until 2019 when the well was tested and measured water temperature of 18 °C at a pumping capacity of 2 l/s and drowdown of 7.31 m (Čajić and Hrvanović, 2019). The depth of well is 41 m. Lithological composition that was found during drilling as the follow: alluvial gravels up to 14 m and deeper are clay marls, clays and sandstone interlayers (probably flysch K_2). The waters are HCO_3-SO_4-Ca-Mg type. Currently thermal water is used in the production process of the meat industry Mujanić in Blažuj.
2) In Žepče, a new house customer in the village of Ljeskovica (Grozdići), after moving into the house, perceived that the snow around the house melted quickly, and that in winter the grass is green; he just out of curiosity drilled hole up to depth of 1.2 m with a hand simple drill machine and founds the thermal water with artesian outflow. The temperature of the water is not known, but according to the owner of the house where the water was found, the temperature was higher than the temperature suitable for bathing. The artesian outflow disappeared after some time and now is not possible to measure any parameters of waters. Several local media have reported the discovery of thermal waters in Ljeskovica.

Major changes and developments in the use of geothermal energy on the existing locations in the period from 2019 to 2021 are as follows:

- Cantonal utility company for heat production and distribution " KJKP Toplane - Sarajevo Ltd.", with the financial support of the Protection Fund of FBiH, has launched activities on a district heating project from the Ilidža geothermal sources. The realization of the project began with preparation of document "Project of hydrogeological research of thermal waters in the area of Ilidža for the needs of district heating system of KJKP Toplane Sarajevo", which was done in 2020 by the company Institute IPIN - Bijeljina. The procedure for obtaining the Approval for geological exploration under this project is in progress.
- The Environmental Protection Fund of the Federation of Bosnia and Herzegovina financed the preparation of the Study on the Use of Geothermal Energy in the Municipality of Domaljevac-Šamac. The Study was completed and presented in the premises of the Municipality of Domaljevac-Šamac on March 4, 2022.
- A new recreation centre Terme Ozren in the municipality of Petrovo was built and put into operation in 2020. In this recreation complex four outdoor and seven indoor pools are available, of which 10 is with fresh water heated by geothermal energy and one with untreated thermomineral well water. The water temperatures in the swimming pools are from 29 to 36 °C. Investment in this touristic complex was about 5 million EUR.
- Banja Šeher (Šeher Spa, nowadays Srpske Toplice) in Banja Luka has not been in operation for many years. A large reconstruction and renovation of the spa on 7'365 m^2 began in 2021. In addition to the therapeutic program, there is planned a rich recreational content, which includes outdoor and indoor swimming pools, indoor children's pools, sunbathing area, wellness, Turkish bath, saunas, salt rooms, mud treatment, accommodation capacities and other accompanying content. The total value of this centre is about 13 million EUR; the investor is the Institute for Physical Medicine and Rehabilitation "Miroslav Zotović" (Banja Slatina) with the participation of budget funds of the Republic of Srpska with about 40 %.
- Recreation centre "Terme" in Gračanica (PEB-4) now works again only seasonally (3 to 4 months a year); in the period from 2017 to 2020, this centre was opened during all year.
- The Municipality of Gradačac is actively looking for potential investors or a suitable loan to invest in the development of central heating in the city zone with the use of geothermal sources to the extent that it is possible.
- A new user of geothermal water has been registered - Mujanić doo Sarajevo; this company use the geothermal water (well IEBM-1 Blažuj) for industrial purposes (in production processes of meat industry). Water temperature is about 18 °C.

6. GEOTHERMAL UTILIZATION

Bosnia and Herzegovina is using geothermal energy obtained from deep geothermal reservoirs (approx. 80 %) and on a small scale energy from shallow horizons (up to 200 m) with water temperature t <20 °C by using heat pumps (20 %). Geothermal utilization is based on direct use from 26 production wells and 4 springs (Zeleni vir, Sedra-Breza, Toplica-Lepenica and Banja-Kreševo).

The COVID-19 pandemic has contributed to a reduced number of visitors compared to the pre-pandemic period. The outdoor recreational swimming pool Toplica Lepenica did not work in 2020 due to the pandemic. Therefore, the direct use of geothermal energy was lower in 2020 and 2021 but it can still be considered that direct use in the period 2019-2021 remained at the same level as in the previous reporting period thanks to the opening of new large recreation center Terme Ozren with 11 outdoor and indoor swimming pools of which one is with thermomineral CO_2 water, temperature 36 °C (Figure 1).

Only heat energy is used, i.e. in Bosnia and Herzegovina still does not exist any geothermal power plants or plans for this type of use of geothermal potentials, although the areas of Posavina and Semberija are considered as having the potential for finding geothermal sources for electricity generation (120 °C or higher) or installing such plants, which may use water with temperature of 96 °C (Domaljevac) for electric power generation (Miošić et al., 2010). Thermal spas and recreations centers are predominant localities for direct geothermal energy use.

Figure 1. Swimming pool with untreated thermomineral CO_2 water in recreation centre Terme Ozren - Kakmuž (Slavica Samardžić)

6.1 Direct use of geothermal energy

Direct use of geothermal energy is applied at 25 locations (Table D1 in the Appendix, Figure 2). Thermal and thermomineral waters with temperatures from 18 to 75 °C are used in balneology and recreation, then for the space heating and heating of water in swimming pools, industrial processes and as sanitary water. Balneological use is implemented at 11 spas. Recreation took place at 17 locations, out of which at 5 sites the swimming pools are used only in the summer period (3-4 months per year) - Lješljani, Gračanica (PEB-4), Zeleni vir, Lepenica and Kreševo. Total number of sites with individual space heating is 13. All spas (11) except Vrućica have installed geothermal heating systems. Geothermal waters are used at four locations for industrial processes (Gradačac and Blažuj).

Utilization of geothermal energy in 2021 for direct heat expressed in GWh_{th}/yr was the following (Table C in the Appendix):

1) Geothermal heat for buildings (including heating waters in swimming pools) and sanitary waters 43.64 GWh_{th} /yr (71,62 %),
2) Geothermal heat in balneology and recreation 16.30 GWh_{th} /yr (26,75 %),
3) Geothermal heat in industrial processes 0,99 GWh_{th} /yr (1,62 %).

The data in Tables C and D are calculated on the basis of exact data of the maximal flow rate and inlet temperature, while the data on the outlet temperature are estimated at about 30 % of the locations. Users often do not have installed water meters, so production (GWh_{th}/y) in 2021 at these locations is calculated based on estimated water consumption.

Bathing and Swimming. Thermal and thermomineral waters are used at 19 locations for balneological and recreational purposes. Balneological treatments are applied in 11 spas. Majority recreation centres are active only during the summer period (Lješljani, Sanska Ilidža, Gračanica PEB-4, Sedra Breza, Toplica Lepenica, Kreševo). All spas have installed a system of geothermal heating, except the Vrućica spa.

The largest user of geothermal energy in BiH is the recreation centre Termalna rivijera-Ilidža with total installed capacity 5.77 MW_{th} and total annual utilisation 30.422 GWh_{th}/y, where thermomineral water (t = 58 °C) is used for heating of fresh (drinking) water in the swimming pools (about 80 %) during the whole year and for heating of billings (20 %) in winter time.

Water temperatures in spas and recreation centres range from 18 to 75 °C. The total geothermal energy used for bathing and swimming is about 16.30 GWh_{th}/y.

Individual Space Heating. Individual space heating is implemented at 13 locations out of which 8 sites have heat exchangers (Gata, Slatina-Banjaluka, Kulaši, Dvorovi, Terme Ozren, Ilidža Termalna rivijera, Ilidža Terme and Slobomir), and at 5 locations (spas) are in use heat pumps with water temperature t > 20 °C (Laktaši, Sanska Ilidža, Gradačac, Višegradska Banja, Olovo and Fojnica). Average period of heating of buildings is about 6 month per year.

Total geothermal energy for individual space heating is 43.64 GWh_{th}/y.

6.2 Shallow geothermal heat pumps (GSHP)

The various available incentives and favourable loans for the use of renewable energy sources and energy efficiency have contributed to the continuous growth of heat pump installations.

The largest number of shallow geothermal heat pumps is installed in higher cities in the northern part of Bosnia and Herzegovina (Bihać, Prijedor, Banja Luka, Tuzla and Bijeljina).

However, statistical institutions still do not record or report on the number of installed heat pumps. Our rough estimate is that there are about 500 installed units (Table E1). The assessment is based on information collected from companies that install heat pumps (interviews, advertising reports, etc.).

There are more than ten companies that deal with heat pump systems for heating and cooling (LUK-Sarajevo, Qvantum Energi D.O.O – Sarajevo, TehnoElektronik – Sarajevo, Termolux – Banjaluka, MIS TRADE - Nova Topola, ENECO – Bijeljina, PRO-TECHNICS –

Bijeljina, EnergoTerm - Tuzla, Hidro-geoinženjering – Jelah, SOLAR d.o.o – Bosanska Krupa, etc.).

Based on the experiences from the region and trends in the transition to individual heating systems from renewable sources, an expansion of heat pump use in heating and cooling systems is expected.

7. CONCLUSIONS

The commitment of the authorities in Bosnia and Herzegovina to increase the share of renewable energy sources in the production of electricity and heat has led to greater interest in the use of geothermal energy. Thus, two new important national geothermal projects were launched on the basis of budget funds of the Federation of Bosnia and Herzegovina (Ilidža - Sarajevo and Domaljevac).

After the successful completion of the geothermal projects DARLINGe and GeoConnect³d, co-financed by EU funds, the European Commission, within the program "Sustainable, secure and competitive energy supply (HORIZON-CL5-2021-D3-02)", has approved the project "Geothermal energy and underground storage of CO_2, sustainable energy carriers and heat & cold" prepared by more than 20 European geological surveys, which will be implemented in the next 5 years including the territory of BiH; project partner from BiH is Geological survey of FBiH.

Oil and gas are also being explored as more environmentally friendly energy sources compared to coal. Oil and gas exploration has been conducted in the Republic of Srpska from 2012 until now; in the Federation of Bosnia and Herzegovina legislation is adopted and staff who will be engaged in the exploration projects are trained.

In 2021, a total of 17’055.44 GWh of electricity was produced of which 7’214.48 GWh or 42.3 % was from renewable sources. Electricity is not generated from geothermal reservoirs, nor is it foreseen by the current state energy strategies and plans.

Geothermal utilization is based on direct use from 26 production wells and 4 springs and implemented at 25 locations. Geothermal heat energy production in 2021 was about 80 GWh_{th}/y (including shallow heat pumps). The following types of direct use of geothermal energy are present: balneology, recreation, space heating and industry.

Growth in installation of heat pumps is evident, which are increasingly applied due to the available supporting mechanisms for renewable energy sources and energy efficiency. There is not yet any official evidence about installed heat pumps, but it is assumed that their number is close to 500 what is far behind the EU countries in the region.

REFERENCES

Barros R., Piessens K., Dirix K.: Structural framework as the new fundament for international geoscientific cooperation and policy support, *Geologica Belgica Meeting 2021*, September 15-18, Tervuren, Belgium – Abstract Book, p. 118 (2021). https://geologicabelgica2021.africamuseum.be/sites/default/files/media/Geologica%20Belgica%202021%20Abstract%20book.pdf

Čajić E., Hrvanović S.: Elaborat o klasifikaciji, kategorizaciji i proračunu rezervi pitkih podzemnih voda iz istražno-eksploatacione bušotine IEBM-1, Lokalitet Blažuj, Općina Ilidža, Papago d.o.o, Lukavac (2019).

Čičić, S. and Miošić, N.: Guatemala energy Bosnia i Hercegovine, Geoinženjering, Sarajevo, (1986), p. 205.

DARLINGe team: Danube Region Geothermal Information Platform (DRGIP), Ljubljana, GeoZS, 2019, Accessed at https://www.darlinge.eu (on 07 April 2022).

Directorate for European Integration: Danube Flows of Partnerships and Cooperation – Catalogue of projects results of Danube Transnational Programme in Bosnia and Herzegovina, Part I, Project from the first call, Sarajevo, (2002), http://publikacije.dei.gov.ba/publikacija/dunavski-tokovi-partnerstva-i-saradnje/

Hrvatović, H.: Geological guidebook through Bosnia and Herzegovina, *Separate Monograph of Herald Geological,* **25**, Sarajevo (2006), 1-165.

Hrvatović, H., Begić, H. Skopljak, F., Samardžić, N, Šarić, Ć.: Annex 5A: The Federation of Bosnia and Herzegovina, Bosnia and Herzegovina national report in: D.5.4.1. Summary report on heat sector analysis, Medgyes, T. et al., (Ed.), *DARLINGe - Danube Region Leading Geothermal Energy*, Sarajevo, (2017), http://www.interreg-danube.eu/uploads/media/approved_project_output/0001/18/a8f867bec3120b1a205bbd2e5970e24e7a1a7cb2.pdf

Independent System Operator in Bosnia and Herzegovina (ISO BiH - NOS BiH): Indicative generation development plan 2022-2031 (2021),

Miošić N., 1997: Thermomineral water of Gračanica, *Gračanica herald*, **No. 4**, Gračanica.

Miošić, N., Samardžić, N. and Hrvatović, H.: The Current Status of Geothermal Energy Use and Development in Bosnia and Herzegovina, *Proceedings World Geothermal Congress 2010*, 25-29 April 2010, Bali, Indonesia, (2010).

Miošić, N., Samardžić, N. and Hrvatović, H.: Geothermal potential and current status of their use and development, Bosnia and Herzegovina. *Proceedings,* European geothermal congress, Pisa, Italy, 3 – 7 June 2013 (2013).

Miošić, N., Samardžić, N. and Hrvatović H.: The Current Status of Geothermal Energy Research and Use in Bosnia and Herzegovina, *Proceedings,* World Geothermal Congress 2015, 19-25 April 2015, Melbourne, Australia, (2015).

Miošić N., Samardžić N., Hrvatović H., (2020+1): The Current Status of Geothermal Energy Research and Use in Bosnia and Herzegovina, *Proceedings World Geothermal Congress 2020+1*, Reykjavik, Iceland, April - October (2021).

Miošić N., Samardžić N., Hrvatović H., Skopljak F., (2019): Hyperalkaline thermomineral waters of Lješljani, Bosnia and Herzegovina, *II Congress of geologists of Bosnia and Herzegovina*, Laktaši, 2 - 4 October, 2019.

Nádor A. with contribution of Geo-ZS, LEAP, HGI-CGS, ZARA, FMG, MSK, BM, FZZG, GSRS, IGR, Terratechnik: D 6.2.1. Transnational Danube Region Geothermal Strategy, *DARLINGe-Danube Region Leading Geothermal Energy*, (2018). http://www.interreg-danube.eu/uploads/media/approved_project_output/0001/30/a67ba8342250cb1f366e8cacd786b281bc002c8f.pdf

Official Gazette of Federation of BiH, No. 77/13: Law on Oil and Gas Exploration in the Federation of Bosnia and Herzegovina, (2013), https://fmeri.gov.ba/media/1616/law-on-petroleum-products-of-federation-of-bosnia-and-herzegovina.pdf

Official Gazette of Federation of BiH, No. 70/14: Decree on the content of the concession contract for exploration and exploitation of oil and gas, manner of calculation and payment of fees and control of over produced quantities of oil and gas in the Federation of Bosnia and Herzegovina, (2014), https://fmeri.gov.ba/media/1054/official-gazette-of-the-fbh.pdf

Rman N., Bălan L., Bobovečki I., Gál N., Jolović B., Lapanje A., Marković T., Milenić D., Skopljak F., Rotár-Szalkai Á., Samardžić N., Szőcs T., Šolaja D., Toholj N., Vijdea A, Vranješ A.: Geothermal sources and utilization practice in six countries along the southern part of the Pannonian basin, *Environmental Earth Sciences*, (2020), 79:1, https://doi.org/10.1007/s12665-019-8746-6

Samardžić N., 2020: Regulatory framework review for geothermal energy in the Federation of Bosnia and Herzegovina, *Mining geological herald*, **24**, Mostar.

Samardžić, N., Hrvatović H.: Geothermal Energy Use - Country Update Report for Bosnia and Herzegovina, *Proceedings,* European Geothermal Congress 2016, Strasbourg, France, (2016).

Samardžić N., Hrvatović H., 2019: Geothermal Energy Development and Use, Country Update for Bosnia and Herzegovina, *Proceedings,* European Geothermal Congress 2019, Den Haag, The Netherlands, (2019).

Skopljak F.: geotermalni potencijali Federacije Bosne i Hercegovine, sadašnje korištenje i regulatorni okvir, *II Congress of geologists of Bosnia and Herzegovina*, Laktaši, 2 - 4 October, (2019).

Skopljak F., Šarić Ć., Pobrić V.: Contribution to the Genesis of Thermal Water of the North-east Perimeter of the Zenica-Sarajevo Basin, Bosnia and Herzegovina, *The Mining-Geological-Petroleum Engineering Bulletin*, **Anno XXIX, No38**, Zagreb (2017).

Szocs T., Nádor A., Rotár-Szalkai A., Gál N., Kun É., Rman N., Lapanje A., Prestor J., Marković T., Milenic D., Vranješ A., Milanković D., Samardžić N., Vijdea A., 2021: Transboundary aquifers – assessment and management – in the Pannonian Basin, *Book of abstracts,* ISARM2021 2nd International Conference, Transboundary Aquifers Challenges and the way forward, 06 – 09 December 2021 / UNESCO, Paris, (2021).

Websites:

https://www.interreg-danube.eu/approved-projects/darlinge

www.darlinge.eu

https://geoera.eu/projects/geoconnect3d6/

https://rbfbih.ba/dugorocni-krediti/kreditna-linija-za-dugorocno-kreditiranje-projekata-obnovljivih-izvora-energije/

https://www.sparkasse.ba/bs/stanovnistvo/krediti/ostale-vrste-kredita/krediti-za-unapreenje-energetske-efikasnosti

https://www.nis.rs/news/nis-nastavlja-istrazivanja-nafte-i-gasa-u-bih/

https://termeozren.com/en/home/

Acknowledgements

Authors express their gratitude to investors and users of geothermal energy that have provided the new data, research results and other useful information for this report.

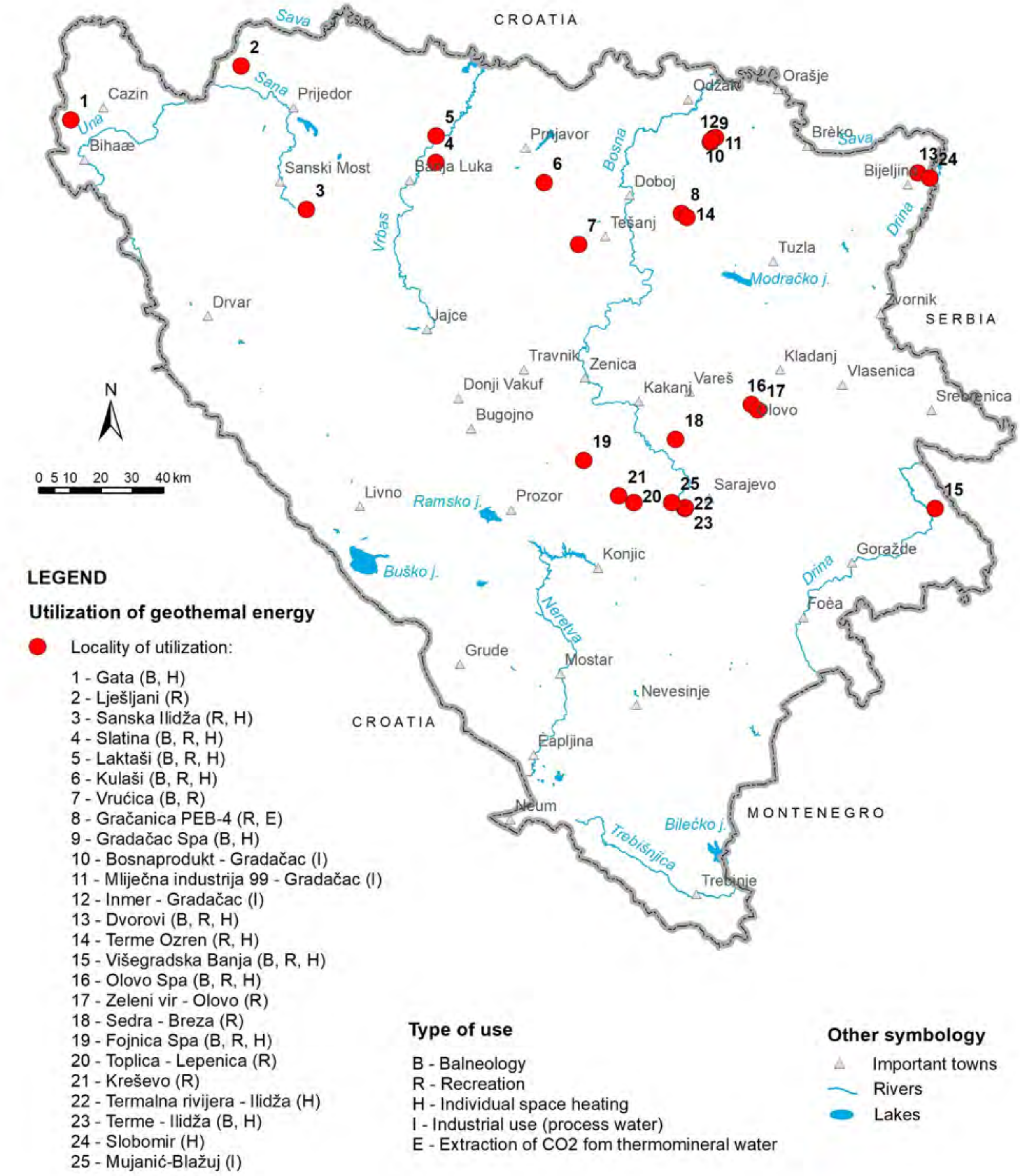


Figure 2. Locations and main utilization types for direct heat use of geothermal energy in Bosnia and Herzegovina

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 * (Source: DERK)	0	0	4'608.26	17'055.44	0	0
Under construction end of 2021 (Source: NOS)	0	0	48			
Total projected by 2023 (Source: NOS)	0	0	4’417.4	16’502.4	0	0
Total expected by 202 (Source: NOS)	0	0	4’164.3	15’809.9	0	0
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

No geothermal power plants exist yet in Bosnia and Herzegovina

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	0	0	0.84	0.986	17.36	43.64	9.55	16.304
Under constru-ction end 2021	0	0						
Total projected by 2023								
Total expected by 2028								

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commissioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
1 - Gata	ZU Lječilište Gata - Bihać	Balneology and individual space heating (heat exchangers)	N	N	0.43		0.072	
2 - Lješljani	Banjsko-rekreativni centar Lješljani – Novi Grad	Recreation	N	N	0.18	0.18	0.114	100
3 - Sanska Ilidža	Banjsko-rekreativni centar “Sanska Ilidža”-Sanski Most	Recreation, individual space heating (GSHP[1])	N	N	0.44	0.44	0.153	100
4 - Slatina-Banjaluka	Zavod za fizikalnu medicinu i rehabilitaciju “Dr Miroslav Zotović”-Banjaluka	Balneology, recreation and individual space heating (heat exchangers)	N	N	1.61		0.875	
5 - Laktaši	Terme Laktaši - Laktaši	Balneology, recreation and individual space heating (GSHP[1])	N	N	0.55		1.028	
6 - Kulaši	Banja Kulaši - Prnjavor	Balneology, recreation and individual space heating (heat exchangers)	N	N	0.44		0.778	
7 - Vrućica	Banja Vrućica-Zdravstveno turistički centar - Teslić	Balneology and recreation	N	N	0.21		0.864	100
8 - Gračan-ica PEB-4	Terme - Gračanica	Recreation	N	N	2.67		0.264	100
9 - Gradačac (Spa Ilidža) - well B-6	Javna zdravstvena ustanova za fizikalnu medicinu, rehabilitaciju i banjsko liječenje “Ilidža Gradačac” - Gradačac	Balneology and individual space heating (GSHP) [1]	N	N	0.08	0.08	0.167	100
10 – Bosna-produkt - Gradačac – well EB-1	Swity d.o.o.-Gradačac	Industrial use (thermal water is used for the washing of fruits and vegetables)	N	N	0.27		0.04	100

Table D1: Existing geothermal district heating (DH) plants, individual sites (continued)

11 - Mliječna industrija 99 – well BZ-1	Mljekara "Mliječna industrija 99"- Gradačac	Industrial use (in the process for producing milk and dairy products)	N	N	0.40		0.36	100
12 - Inmer Gradačac - well BMI-2	Mljekara Inmer d.o.o -Gradačac	Industrial use (in the process for producing milk and dairy products)	N	N	0.12		0.58	100
13 - Dvorovi	JU Banja Dvorovi - Bijeljina	Balneology, recreation and individual space heating (heat exchangers)	N	N	1.30	1.30	1.38	100
14 – Terme Ozren	Hotel Terme Ozren	Recreation and individual space heating	N	N	1.71		5.56	
15 - Višegradska Banja	Rehabilitacioni centar "Vilina Vlas" - Višegrad	Balneology, recreation and individual space heating (GSHP) [1]	N	N	0.40	0.40	0.639	100
16 - Olovo	Banjsko-rekreativni centar Aquatherm-Olovo	Balneology, recreation and individual space heating (GSHP) [1]	N	N	0.32	0.32	3.04	100
17 - Zeleni vir-Olovo	Banjsko-rekreativni centar Aquatherm-Olovo	Recreation	N	N	0.10	0.10	0.30	100
18 - Sedra Breza	Sportsko – rekreacioni centar "Ada"- Breza	Recreation	N	N	0.09	0.09	0.19	100
19 - Fojnica (FB-1 and FB-2)	Lječilište "Reumal"- Fojnica	Balneology (well FB-1) and individual space heating (GSHP) [1] and recreation-well FB-2	N	N	4.68	4.68	2.419	100
20 - Toplica Lepenica		Recreation	N	N	0.24	0.24	0.683	100
21 - Kreševo		Recreation	N	N	0.20	0.20	0.575	100
22 - Ilidža Termalna rivijera	Termalna rivijera- Ilidža	Individual space heating (heat exchangers)	N	N	5.77		30.422	95
23 - Ilidža Terme	Zdravstvena Ustanova Lječilište Banja Terme - Ilidža	Balneology and individual space heating (heat exchangers)	N	N	0.98		5.94	95

Table D1: Existing geothermal district heating (DH) plants, individual sites (continued)

24 - Slobomir	Slobomir Company-Bijeljina	Individual space heating (heat exchangers)	N	N	4.52	4.52	4.50	100
25 – Mujanić Blažuj	Mujanić d. o. o. Sarajevo	Industrial use (meat industry)	N	N	0.05		0.006	100
total					27.75		60.93	

[1] Geothermal heat pump with geothermal source temperatures >20 °C.

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	500					
Of which networks **						
Projected total by 2023						

There is no any evidence on the installed geothermal heat pumps in BiH and we cannot provide accurate information about it; our rough estimate is that their number is about 500.

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

Geothermal Energy Use, Country Update for Bulgaria (2019-2021)

Boryana Deneva[1], Sava Kolev[2], Simeon Valtchev[2], Aglaida Toteva[2]

[1] BORDO Engineering Ltd., Ricardo Vakarini Str., Bl. 4, Sofia, Bulgaria

[2] Geological Institute - Bulgarian Academy of Sciences, Acad. G. Bonchev Str., Bl. 24, Sofia, Bulgaria

boryana_deneva@yahoo.co.uk

Keywords: geothermal fields, geothermal utilization

ABSTRACT

An outline of the use of renewable energy sources in the Republic of Bulgaria is presented, focusing on the use of geothermal energy for the period 2019-2021. The thermal waters of Bulgaria comprise more than 170 geothermal fields with water temperatures in the range 25 ºC-100 ºC and the overall flow rate is approximated to 3,000 l/s. The thermal water utilisation in 2021 is estimated to 39 % of the total resources. In 2020 the geothermal share was 1.4 % of the renewable energy sources in the country. The breakdown of thermal water use in 2021 includes 20.9 % for water supply, 5.9 % for bottling of mineral potable water, 4.4 % for balneology, 1.8 % for geothermal energy and the remaining 67 % used mostly for sports and recreation, spas, baths etc. A summary is included of the future plans and development policies, as defined by national and European strategies and guidelines related to increasing the use of renewable energy sources.

1. INTRODUCTION

There are more than 170 geothermal fields in the Republic of Bulgaria (Petrov et al., 1970), which represent the main sources of geothermal energy in the country. These are spread all over the entire territory of about 110’000 square kilometres. The temperature of the thermal water varies between 25 ºC and 100 ºC, and is below 50 ºC in most of the thermal water sources, approximately 72 % (Hristov et al. 2020).

There are 102 significant geothermal fields, which are exclusively state property and are listed in Annex 2 of the Waters Act. Mineral waters are extracted from these reservoirs at more than 500 sources. Other reservoirs and sources (boreholes and natural springs) of mineral water are public or municipal property.

The use of mineral water in Bulgaria is regulated by the Concessions Act or by abstraction licenses as stipulated in the Waters Act. Because of the relatively low temperature, most of the waters are being used directly for water supply, balneology, hotels and spas, bottling and geothermal energy for heating of buildings and greenhouses.

2. GEOLOGICAL AND HYDROGEOLOGICAL BACKGROUND

The thermal waters in Bulgaria are formed as a result of the particular geological and tectonic conditions. Rocks of various origin, lithological and petrographic composition are widespread, with age covering almost the entire spectrum from the Precambrian to the Quaternary.

In terms of tectonic structure, two zones can be distinguished (Yaranov, 1960; Bonchev, 1971; Yovchev, 1971; Dabovski et al., 2002; Zagorchev, 2009), with radically different conditions of formation and accumulation of thermal waters: Southern Bulgaria (fracture type geothermal waters) and Northern Bulgaria (artesian layer type geothermal waters), divided by the Balkan Mountains (Shterev, 1964; Petrov et al., 1970; Benderev et al., 2016; Fig. 1).

Geologically, the Northern Bulgarian zone comprises the Moesian platform and the adjacent South-Moesian platform and the Pre-Balkan zone (Bokov et al., 2013). The water bearing rock complexes (limestones and dolomites) have a wide horizontal distribution and a diverse lithological composition in the vertical stratigraphic range. The widely distributed aquifers are layered, separated by impermeable rocks (Yovchev and Rizhova, 1962). They are hydraulically connected by tectonic disturbances in isolated places.

The basin is characterized by hydrodynamic, hydrochemical and hydrogeothermal zonality both in vertical and in horizontal direction. In the recharge zones of the aquifers the waters are fresh, with active water exchange and low temperature. The temperature gradually increases in depth (reaching over 100 °C in the deepest levels) and the type of chemical composition and the gas composition changes. Maximum temperatures were measured in the oil field near Dolni Dabnik, reaching up to 115 °C at 3300 m depth (Petrov et al., 1970).

In Northern Bulgaria the thermal aquifers have been penetrated by hundreds of boreholes (some of them deeper than 6000 m). Most of these boreholes have been drilled for the purpose of oil and gas exploration. Following their exploitation, most of the boreholes were decommissioned and sealed in order to prevent mixing of groundwater with very high concentration of total dissolved solids (TDS up to 150 g/l) with fresh water from different upper aquifers. Currently, only some geothermal fields and occurrences along the Balkan and some others along the north-eastern part of Bulgarian Black Sea coast are used for different purposes (mainly for water supply, balneotherapy and spa-hotels).

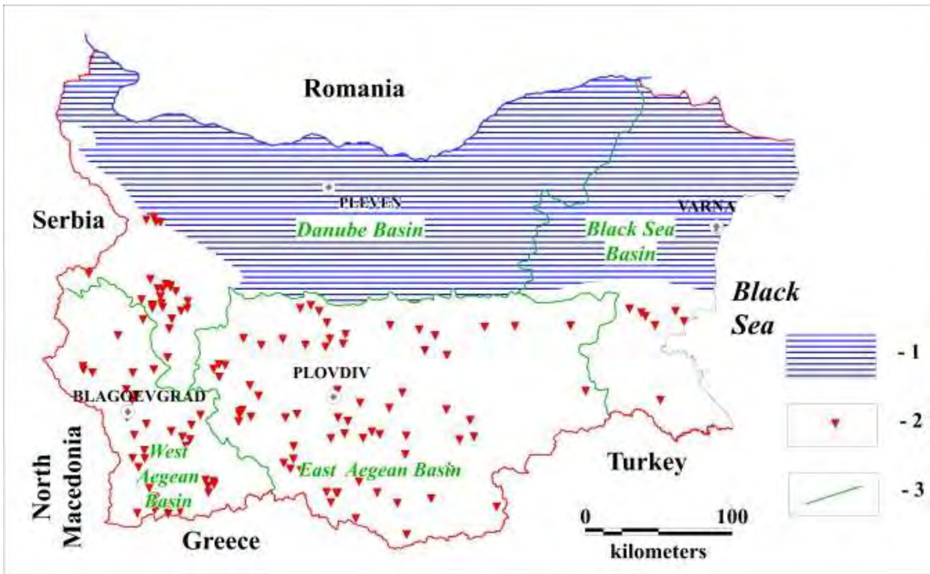


Figure 1: Schematic map with thermal sources (1 – artesian layer type geothermal waters; 2 – fracture type geothermal waters; 3 – Boundary of River Basin Directorates)

The Southern Bulgarian zone is part of the Alpine Thrust Belt and is characterized by a complex tectonic structure that predetermines the presence of fractured confined hydrothermal systems (Shterev, 1964; Petrov et al., 1970). The hydrothermal deposits have a sporadic distribution and are attached to tectonic zones and regions characterized by higher heat flow. Thermal water is most often discharged from natural springs, but in the 20th century a number of boreholes in the areas around the springs were drilled. The depths of the boreholes are significantly smaller (in most cases up to 500-600 m) than in Northern Bulgaria and they reach 2000 m only in some places Total dissolved solids (TDS) of most geothermal waters in Sothern Bulgaria are up to 1.0 g/l (Kusitaseva and Melamed, 1958; Shterev, 1964; Petrov et al., 1970; Pentcheva et al., 1997; Benderev et al., 2016; Vladeva et al., 2000).

According to the Waters Act, 102 of all hydrothermal fields in Bulgaria are specified as exclusive state property. The rest are municipal property for 25 years.

The Waters Act defines three categories for thermal water utilization: water supply, treatment and rehabilitation in hospitals and specialized medical centres, and the third category combines all other applications. The exploitation of thermal waters is administered by four River Basin Directorates (Fig. 1) – Danube, Black Sea, East Aegean and West Aegean.

3. UTILIZATION OF LOW ENTHALPY GEOTHERMAL ENERGY

Most of the electricity in Bulgaria is generated by Thermal Power Stations (TPS) and by one Nuclear Power Plant (NPP). According to National Statistical Institute, the total electric power produced in Bulgaria for 2021 amounts to 47’688 GWh.

In 2020 the share of energy produced by renewable energy sources (RES) in the gross consumption for the country is 23.6 %.

The national target of a share of 16 % of the total internal energy consumption was achieved by the end of 2013, according to the second National Report (http://www.nsi.bg) on the progress of Bulgaria – RES usage (Fig. 2).

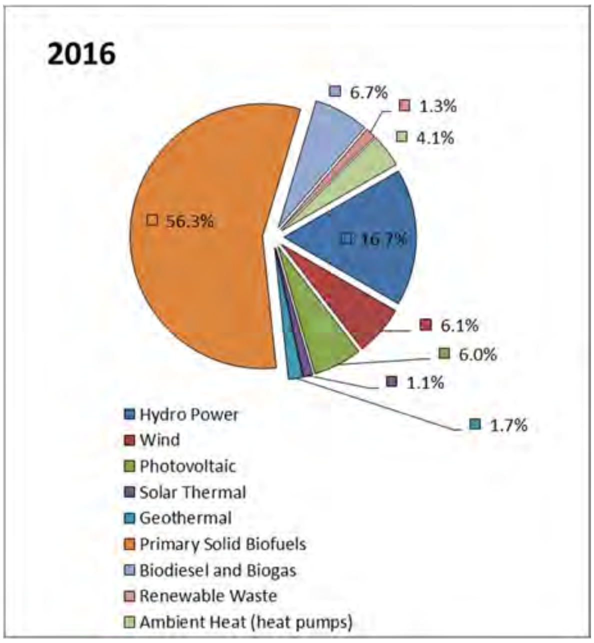
The geothermal share in RES decreased from 1.7 % in 2016 to 1.4 % in 2020 (Fig. 3).

During the last years, the use of geothermal energy through GSHP (Ground Source Heat Pumps) of public and private buildings increased. The lack of systematic data makes it difficult to include these consumers in the overall balance.

Electricity generation from geothermal water is currently not available in the country.

The geothermal waters on the territory of Bulgaria have been used since ancient times. Because of the relatively low temperatures (<100 °C), thermal waters have only direct application. Traditionally, their major application is in the field of balneotherapy, which includes prophylaxis and treatment, rehabilitation, sports, etc.

Figure 2: Share of renewable energy sources in the total energy use in Bulgaria



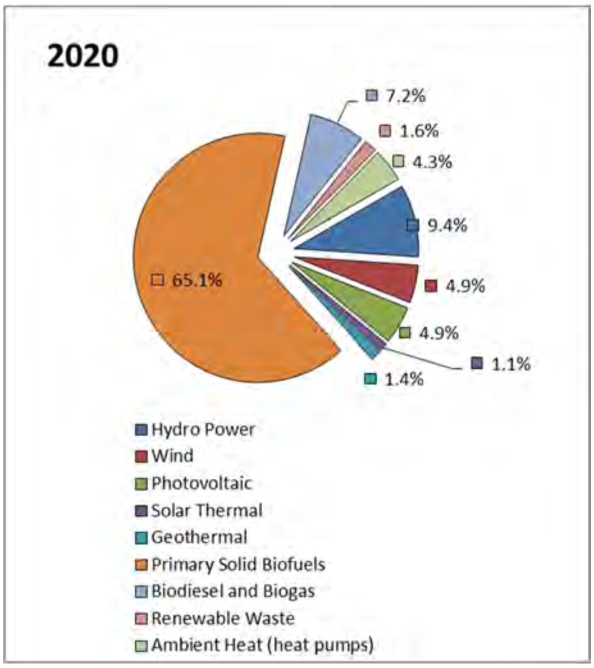


Figure 3: Comparison between 2016 and 2020 of share of RES application in Bulgaria

In general, the exploitation of thermal waters is concentrated at water sources in Southern Bulgaria and the low-mineralized thermal waters in the artesian basin in Northern Bulgaria – mainly the Varna Artesian Basin. So far, there is almost no interest in waters with higher temperatures in the deep parts of aquifers with very high TDS (up to 150 g/l).

The total hydrothermal capacity of Bulgaria is estimated to 9957 TJ/year (2'765'855 MWh or approximately 315 MW_{th}; Petrov et al., 1998).

The overall application of thermal waters is 39 % of the estimated resources, based on analysis of data published by the Basin Directorates, Municipalities and Concession register, by the end of 2021.

According to that analysis (Fig. 4), the variety of uses includes: water supply (20.9 %), balneology (4.4 %), bottling of potable water and soft drinks (5.9 %), geothermal energy (1.8 %) and others (67.7 %, including sport, swimming pools, spa procedures, bathing in local public baths, etc.).

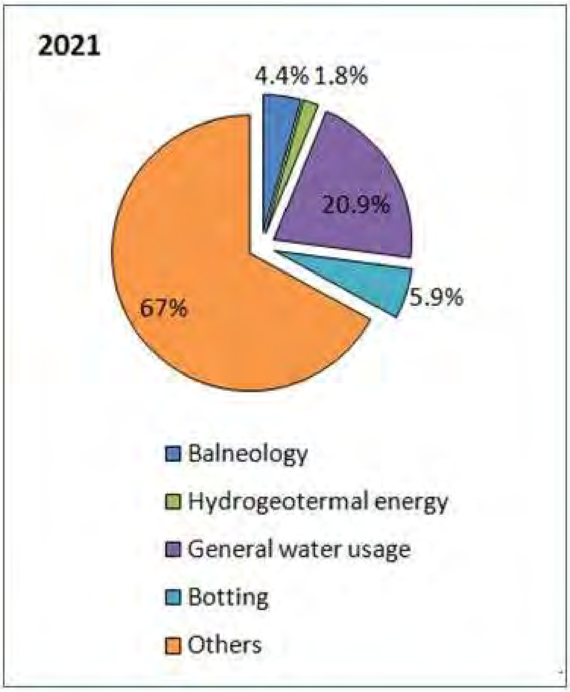


Figure 4: Thermal mineral water utilization in Bulgaria for 2021

Heating by thermal waters is provided only to individual buildings and greenhouses and it is not connected in a district heating system.

The relative share of balneology in thermal water use dropped from approx. 60 % in 2014 (Bojadgieva et al., 2015) to less than 5 % because of a change in reporting – the water used for sports, pools, public baths, etc. is no longer included in the share of balneotherapy.

Bottling of mineral potable water is regulated by the Concessions Act. The main reasons for the development of bottling include the generally low

TDS (<1 g/l) and the wide variety of chemical compositions of the mineral waters in Southern Bulgaria. Bottling of mineral potable water increased from 3.7 % in 2018 to 5.9 % in 2020 and it is one of the very fast developing businesses during the last 30 years. According to registers of Ministry of Health the total number of factories bottling mineral water by the end of 2021 is 21.

4. FUTURE OUTLOOKS FOR GEOTHERMAL UTILIZATION

The capital of the country – city of Sofia is one of the richest cities in Europe in terms of thermal water occurrences. It was founded around a thermal water source in ancient times. This natural spring still exists and currently is exploited for public water use (known as “Sofia-Centre Spring”). There are a number of thermal water fields on the territory of the capital and its surroundings. All of them belong to a regional hydrothermal system defined as Sofia hydrogeo-thermal basin (Shterev and Galabov, 2017). The waters are characterized by different formation conditions, chemical composition and temperatures - within the range from 30 ºC to 80 ºC.

Sofia Municipality adopted a Strategy for the utilization of the resource potential from mineral water and geothermal energy and a Program for utilization of the hydrothermal resources of the municipality. These plans foresee the designing of a geothermal plant that would utilize the thermal water from the Sofia - Centre geothermal field to provide heating of municipal and state buildings in the center of Sofia.

In 2022, sixteen projects have been approved by the Energy Efficiency in Buildings procedure (BGENERGY-2.002) financed by the Renewable Energy, Energy Efficiency, Energy Security Programme of the Financial Mechanism of the European Economic Area 2014-2021. It is a partner-ship and cooperation agreement between Bulgaria and the donor countries Norway, Iceland and Liechtenstein for improving the energy efficiency of significant public buildings.

The national energy strategy aims at increasing the share of energy from renewable sources in the total energy use. The increase has been significant in the last years when the share of energy from renewable sources doubled from 10.3 % in 2008 to 21.6 % in 2019. The Integrated Energy and Climate Plan of the Republic of Bulgaria 2021-2030 has the objective to raise the share of renewable energy to at least 27 %.

The Plan for Reconstruction and Sustainability includes a project for exploration and development of a pilot project for combined production of heat and electricity from geothermal sources. The project consists of updating the information on the geothermal potential in the country and producing a provisional solution for a pilot system for utilisation of geothermal energy for combined production of heat and electricity. The preliminary investigations indicate that the power plant could achieve a maximum capacity of up to 20 MW electrical power and up to 65 MW heat power. The pilot project will be developed on the basis of analysis of the conditions at 6 potential locations in Bulgaria (Council of Ministers of The Republic of Bulgaria, 2022).

5. CONCLUSIONS

Based on the information and data for 2019-2021, as provided by the Ministry of Energy and the Ministry of Environment and Water, the following conclusions could be drawn:

- There is no significant change in the use of geothermal energy during the period 2019-2021 as compared to the preceding period (2014-2018).
- The breakdown of thermal water exploitation shows that the use is mainly not related to energy production but to other purposes, such as sport, recreation, rehabilitation and, in some places, for residential water supply.
- Currently, geothermal water as a source of geothermal energy is used in local heating systems and greenhouses. This usage represents only a small fraction (1.8 %) of the total thermal water use.
- The government strategy for energy development anticipates considerable increase in the use of renewable energy sources and in particular geothermal energy. For this purpose, a pilot project is proposed for the development of power plant for combined electricity and heat production.
- The use of geothermal energy in Bulgaria increases, following the European and worldwide trend of decreasing the carbon emissions from fossil fuels. Regulatory change is one of the planned steps forward, which will result in better utilisation and management of the geothermal resources.

REFERENCES

Benderev, A., V. Hristov, K. Bojadgieva, B. Mihaylova. Thermal waters in Bulgaria. In: Papić, P. (Ed.). Mineral and Thermal Waters of Southeastern Europe. Switzerland, Springer International Publishing, pp 47–64, 2016.

Bokov P., Monahov I., Popov S., Atanasov A., Tectonic zoning, In: Geology and oil and gas prospectivity of the Moesian Platform in Central Northern Bulgaria. Technika, Sofia, pp 78-81, 1983 (in Bulgarian).

Bonchev, E.,. Problems of Bulgarian geotechtonics, Tehnika, Sofia, 204 p, 1971 (in Bulgarian).

Council of Ministers of the Republic of Bulgaria. Plan for Reconstruction and Sustainability. 2022.

Dabovski, C., I. Boyanov, K. Khrischev, T. Nikolov, I. Sapounov, Y. Yanev, I. Zagorchev. Structure and Alpine evolution of Bulgaria. Geol. Balc. 32 (2–4), pp 9-15. 2002.

Hristov,V. , A. Benderev, N. Stoyanov, D. Antonov, M. Trayanova, S. Kolev. Geothermal Update for Bulgaria (2014-2018). Proceedings World Geothermal Congress 2020. 2020.

Kusitaseva, V., Y. Melamed. Composition of Bulgarian mineral waters. Medicina i fizk., Sofia 280 p. 1958 (in Bulgarian).

Pentcheva, E., L. Van't Dack, E. Veldeman, V. Hristov, R. Gijbels. Hydrogeochemical characteristics of geothermal systems in South Bulgaria. Universiteit Antwerpen (UIA), Belgium, 121 p. 1997.

Petrov, P., S. Martinov, K. Limonadov, Y. Straka. Hydrogeological investigations of mineral waters in Bulgaria. DI Tehnika, Sofia, 196 p. 1970 (in Bulgarian).

Shterev, K. Mineral waters in Bulgaria. Nauka i izkustvo, Sofia, 172 p. 1964 (in Bulgarian).

Shterev, K., M. Galabov, Strategy for the utilization of the resource potential for mineral water and geothermal energy on the territory of Sofia Municipality. Sofia Municipality. 2017. (in Bulgarian). Online at: https://nag.sofia.bg/FileBrowser/File?path=esoft.portal%2Fmineralni vodi%2FSTRATEGIYA - MINERALNI VODI.pdf

Vladeva, L., D. Krasteva, Y. Yordanov, D. Kostadinov. Reference book of Bulgarian mineral waters. Nauka i tehnika, Sofia, 225 p. 2000 (in Bulgarian).

Yaranov, D. Tectonics of Bulgaria. Tehnika, Sofia, 280 p. 1960 (in Bulgarian).

Yovchev R., Rizhova V. Groundwaters in North Bulgaria, Sofia, GUGOZN, 222 p., 1962 (in Russian).

Yovchev, Y. (ed.). Tectonic structure of Bulgaria. Tehnika, Sofia, 558 p. 1971 (in Bulgarian).

Zagorchev, I. Geomorphological zonation of Bulgaria. Principles and state of the art. Comptes rendus de l'Academie Bulgare des Sciences, 62, 8, pp. 981-982. 2009.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	-	-	12'668	47'688	0	0
Under construction end of 2021	-	-				
Total projected by 2023	-	-				
Total expected by 2028	5	43.8				
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

Geothermal power plants are currently not available in Bulgaria.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

Geothermal DH and other plants are currently not available in Bulgaria.

Table D1 and D2: Existing geothermal district heating (DH) plants, individual sites

Geothermal district heating (DH) and other plants are currently not available in Bulgaria.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *			1174			
Of which networks **						
Projected total by 2023						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

Shallow geothermal UTES plants are currently not available in Bulgaria.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	-		10.7	
Geothermal direct uses				
Shallow geothermal				
total				

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D			
Financial Incentives – Investment			
Financial Incentives – Operation/Production			
Information activities – promotion for the public			
Information activities – geological information			
Education/Training – Academic	yes	yes	yes
Education/Training – Vocational	yes	yes	yes

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

European Geothermal Congress 2022
Berlin, Germany | 17-21 October 2022
www.europeangeothermalcongress.eu

Geothermal Energy Use, Country Update for Croatia

Sanja Živković[1], Slobodan Kolbah[2], Dražen Tumara[1], Mladen Škrlec[2], Tena Bilić[3], Matija Vajdić[1]

[1] Energy Institute Hrvoje Požar, Savska cesta 163, Zagreb, Croatia

[2] Geotermalna energija, Ltd., Ibrišimovićeva 9, Zagreb, Croatia

[3]Geotermalni izvori, Ltd., Vladimira Nazora 3, Babina Greda, Croatia

szivkovic@eihp.hr

Keywords: Geothermal resources, power production, direct energy utilization, geothermal exploration and production, Croatia.

ABSTRACT

The Croatian part of the Pannonian basin area has been long known as a high potential geothermal area. Even though geothermal energy has been used for a long time only for balneological purposes an increasing interest of investors in geothermal exploration for heating purposes and power production is evident. One of the reasons for that is the new Act on exploration and exploitation of hydrocarbons that was adopted in 2018, facilitating licencing procedure. Commissioning of the first geothermal power plant Velika 1, with a capacity of 10 MW, at the Velika Ciglena site in 2018 triggered new developments in geothermal sector. After years of exploration period, two large greenhouses with together more than 10 hectares of tomato production have been recently granted exploitation licenses. The new incentive for geothermal exploration has also recently come from Croatia's recovery and resilience plan, which funds the Croatian Hydrocarbons Agency with almost 30 million EUR intended for confirmation of geothermal potential, including geophysical surveys and the drilling of two exploration wells for geothermal energy in the district heating. Furthermore, Norway Grant's Energy and Climate Change Programme funds four Calls for geothermal developments in Croatia that are currently being implemented. All these funding opportunities triggered increased interest in geothermal exploration from private investors and local communities, resulting in more exploration licenses issued. Consequently, 14 exploration and 7 exploitation licenses for geothermal waters are now active promising new developments in the following years.

1. INTRODUCTION

The Croatian part of the Pannonian Basin has been known for its high geothermal potential. Geothermal energy has long been used mostly for balneological purposes but is recently used in agriculture, district heating, and electricity generation. In the last few years, increased interest in geothermal explorations has been recorded, triggered by the first geothermal power plant commissioning in Croatia. New funding opportunities coming from Croatia's recovery and resilience plan and EEA Grant's Energy and Climate Change Programme motivated the Croatian Hydrocarbons Agency, local communities and private investors to exploration of both known and new geothermal potential. Consequently, 14 exploration and 7 exploitation licenses for geothermal waters are now active promising new developments in the following years.

2. GEOTHERMAL POTENTIAL OF CROATIA

The northern part of Croatia is situated in the southwestern part of the Pannonian Basin, which is well known for its high geothermal potential. It is a direct result of the geological evolution of the area. The formation of the Pannonian Basin started in the early Miocene. Due to convergent movements of the African plate towards the Euroasian plate, subduction of the continental crust caused thermal perturbation in the crust and the formation of a back-arc type basin. The first phase of basin development was characterised by tectonic thinning of the crust and isostatic subsidence. Continental crust thickness in the Pannonian basin area amounts to 25-30 km, influencing heat flow density directly as one of the main parameters of geothermal potential. Consequently, the geothermal gradient of the Croatian part of the Pannonian basin is higher than the average in Europe (Figure 1).

2.1 Geothermal exploration

In the course of oil and gas exploration in the last century, more than 4,000 deep wells were drilled, and nearly fifty oil and gas fields were put into production. Along with oil and gas fields, five geothermal fields were discovered, three of which are in production.

Recently, the interest in geothermal exploration has strongly increased focusing on both direct and indirect use. The new motivation has come from Croatia's recovery and resilience plan, which funds the Croatian Hydrocarbons Agency in the amount of almost 30 million EUR intended for confirmation of geothermal potential, including geophysical surveys and the construction of two exploration wells for geothermal energy in the district heating. Additionally, EEA

Grant's Energy and Climate Change Programme funds four Calls for geothermal developments in Croatia that are currently being implemented.

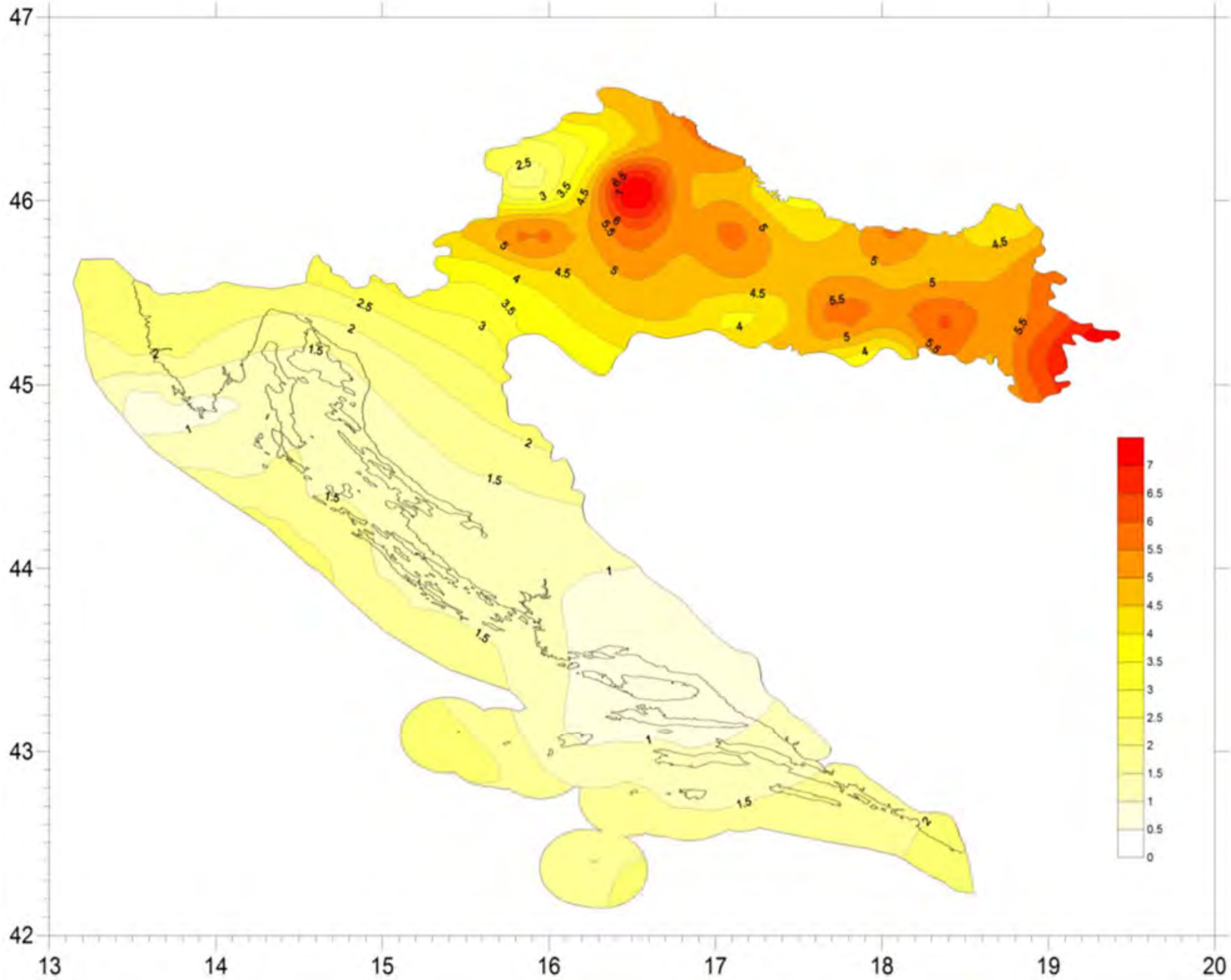


Figure 1: Geothermal gradients in the Republic of Croatia (°C/100m) (Kurevija et al., 2014)

In the area of natural springs are mostly located Spas and recreational centres. Still, in some locations, geothermal potential can provide opportunities for expansion of utilisation for agricultural use or heating purposes (Varaždinske Toplice, Krapinske Toplice, Lipik, Bjelovar, etc.). In the areas where geothermal waters with temperatures ranging from 70-200 °C have been discovered in deep exploration wells, the interest of local communities and private investors is to utilise this potential for heating, balneology, agriculture, and electricity generation.

The most prolific aquifers are in carbonates occurring in the older Mesozoic (Triassic) dolomites, limestones and dolomite breccia, identified by deep drilling all over the Croatian part of the Pannonian basin, mostly at depths of 1,500 to 4,500 m. These aquifers are generally several hundred to a thousand meters thick massive carbonate bodies, tectonically fractured with currently relaxed superconductive zones. Another important reservoir property is developed by re-crystallisation of dolomites and karstification, gaining reservoir volume and transmissibility. Besides these massive carbonate bodies of the basement, good reservoirs are also expected in the fragile quartzite and similar rocks. On top of the basement, geothermal reservoir basin-fill sometimes starts with Paleogene sandstones alternating with shales. The final cover consists of the Neogene sediments and the Pliocene-Quaternary clastic deposits just below the soil surface. Besides the Mid Miocene carbonate bioherms, which sometimes bear good productivity, prevailing sandstone reservoirs, usually have productivity limited to several tens of l/s, diminishing with the burial depth/age, consolidation and petrification. Important massive carbonate reservoirs are Miocene syn-rift breccia, sometimes connected to massive basement carbonate reservoirs.

The expected water temperatures in these deep massive aquifers are well above 120 °C, up to 200 °C, due to regional anomaly enhanced geothermal gradient, which over a wider area has been determined from 45 °C/km to over 60 °C/km and sometimes raised even higher by geothermal fluid convection in several thousand meters thick massive carbonate reservoirs. The expected flow in these reservoirs is around 100 l/s. The main challenge is to drill and case the well, not harming productivity, in conditions of heavy to total loss of circulation.

2. UTILIZATION OF GEOTHERMAL WATERS IN CROATIA

The geothermal potential in Croatia is evident from 30 natural springs of thermal water, mainly in the western part of Croatia, that have been known since Roman times. They exhibit temperatures up to 65 °C and have often been developed with new boreholes to reach waters with higher temperatures or increase flow rates.

Today, geothermal waters are used for bathing and in some places also for space heating, in 16 Spas that are mostly located in the southwestern part of Croatia.

Lately, geothermal wells have been used in agriculture for heating two large greenhouses for tomato production. In both locations, geothermal production is a result of private investors' undertaking.

Geothermal energy is also used in district heating in Topusko, in the central part of Croatia, and in several locations as individual space heating.

The most significant development in geothermal energy use was the commissioning of the first geothermal power plant Velika 1, with a capacity of 10 MW, at the Velika Ciglena site.

In 2021, 252.7 TJ (70.3 GWh_{th}) of heat and 254.3 TJ (74.65 GWh_e) of electricity was produced from geothermal sources.

3. GEOTHERMAL DEVELOPMENTS IN CROATIA

After the commissioning of the first geothermal power plant in Croatia, interest in geothermal exploration increased significantly.

Several sites where geothermal water occurrences were discovered during oil and gas exploration in the second part of the 20th century have come into focus of local communities and private investors. As a result, 14 exploration and 7 exploitation licenses for geothermal waters were granted (Figure 2).

Even though private investors are mostly interested in electricity generation projects, local communities and agricultural entrepreneurs have expressed their interest in geothermal heat production to reduce dependency on fossil fuels and to increase the security of supply. There is also a financial component of the heat projects, where users can save up to 30% on energy bills.

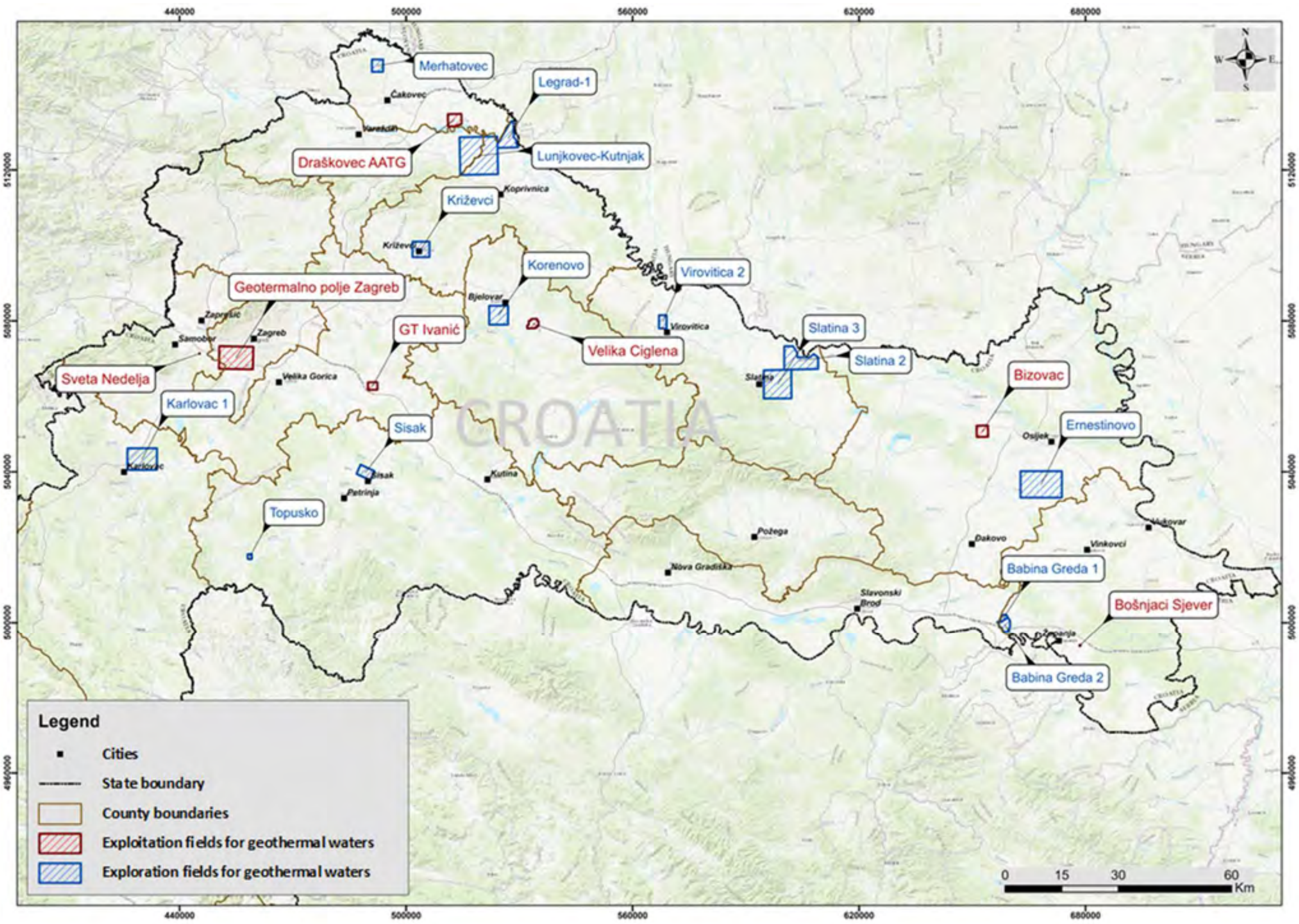


Figure 2: Exploration and exploitation licenses for geothermal water in Croatia (Croatian Hydrocarbon Agency, Feb 2022)

3.1 Available financial mechanisms for geothermal energy utilization

In September 2021 two calls for proposals were published by the Ministry of Regional Development and EU Funds that jointly with the Energy Institute Hrvoje Požar manages the Energy and Climate Change Programme co-financed by the EEA Financial Mechanism 2014-2021.

The focus of the first call was the preparation of the technical documentation for the development of geothermal projects. The call for proposal was in line with the Hydrocarbon Exploration and Exploitation Act (OG 52/18, 52/19 and 30/21), so cofounding was only provided to project proposals whose project scope was designed around the development of the following eligible technical documents: geothermal potential study, the proposal for the publication of a tender notice, preparation of tendering documentation, operations plans and construction plans, environmental impact study, reserve's study, documentation related to the determining the exploitation field and various technical documentation for heating/cooling infrastructure and connections towards district heating system, buildings, or any other commercial usage site. Because of significant interest and restricted budget, out of twenty-six project proposals received, only the ten best projects were selected for co-funding and were offered the contract planned to be signed by the end of May 2022 (Table 1).

The focus of the second call was investments in infrastructure required to utilize geothermal energy. The call supported project proposals that are planning to develop the pilot investments related to the construction or refurbishment of production and injection wells in areas with existing exploration or production licenses, refurbishment and/or extension of existing geothermal heating systems, construction of infrastructure connections to integrate geothermal heat into an existing district heating system or technological and infrastructure changes for existing district heating systems to integrate geothermal energy sources. Project promoters or project partners had to have a valid license for the exploration or production of geothermal water. The call for proposals was also restricted to geothermal energy utilization for heating purposes only and not electricity generation. Because of significant interest and restricted budget, out of seven project proposals received, only the three best projects were selected for co-funding and were offered the contract planned to be signed by the end of May 2022 (Table 2).

In the City of Križevci, the aim of the project is to perform exploratory geothermal and mining works in the existing geothermal well Kža-1, conduct planned trial operations for hydrodynamic and laboratory tests to determine the characteristics of the reservoir, and define the parameters of the reservoir required for the reserves study. Geothermal energy is planned to be used for heating publicly owned buildings, a greenhouse and a public pool located in the immediate vicinity of the existing well.

Table 1: Project proposals selected for co-funding under the open call for project proposals "Technical documentation for geothermal energy".

Project promoter name	Project name	Total eligible budget [EUR]
Sveta Nedelja	Documentation development for the geothermal water exploration phase around Sveta Nedelja	393,611.43
Rehabili-tation centre in Topusko	Topusko smart thermal city	737,277.17
Križevci	Development of technical documentation for geothermal energy utilization around the city of Križevci	495,335.00
GPC Instrument ation process Ltd.	Development of the technical documentation for the utilization of geothermal energy from the exploitation field Zagreb	452,200.00
Vukovar	Clean energy for Vukovar	275,547.41
Sisak	Technical documentation for direct geothermal energy utilization in Sisak	256,606.10
Krapina-Zagorje county	The hydrothermal potential of Krapinske Toplice	299,854.43
Lipik	Development of technical documentation for the exploration field Lipik	243,538.45
Kutina	Development of the technical documentation for geothermal water exploration around Batina, city of Križevci	268,976.22
Bjelovar	Development of the technical documentation for geothermal energy utilization at Veiko Korenovo – Korenovo GT-1 field	314,713.75

The objective of the Bjelovar project is to implement infrastructure works (construction, and mining of geothermal sources/wells) on the well Korenovo GT-1 to exploit geothermal energy, with the ultimate planned combined use of produced energy (district heating and commercial use). Geothermal energy obtained from the Korenovo GT - 1 well will be used for heating purposes of the planned sport and recreation complex in Veliko Korenovo, the future Korenovo Business Zone, and planned greenhouse agricultural production in the Veliko Korenovo area.

Table 2: Project proposals selected for co-funding under the open call for project proposals "Increased geothermal energy production capacity".

Project promoter name	Project name	Total eligible budget [EUR]
Križevci	Setting up the system for geothermal energy production in the city of Križevci	611,640.00
Bjelovar	Increased geothermal energy production capacity – Infrastructural works on the Korenovo GT-1 borehole	3.478,076.98
GeotermiKA Ltd.	Utilization of geothermal energy for the Karlovac district heating system – PREP4KaGT-1	764,316.10

The main project objective in Karlovac is a development of a pilot project with the goal of increasing the capacities for production and usage of heat from geothermal energy in the city's district heating system. The specific project objective is site preparation for the drilling plant and a trial pit for assessing well KaGT-1 as well as for regular development of technological processes of drilling within the exploration block Karlovac 1. By realizing the specific objectives the Applicant will have all the pre-requisites for the beginning of drilling of the exploration well KaGT-1 for which the City of Karlovac has already detected appropriate financing sources.

Many of those projects are going to establish bilateral cooperation with renominated companies from a donor state, Iceland, which will further strengthen the capacity to manage and promote renewable energy and lay the foundation for the continuation of cooperation on future joint projects.

The Programme Operator also established small grant schemes within the Energy and Climate Programme. They published two open calls for proposals to co-finance two projects with a maximum amount of 200,000.00 EUR. One of the calls is related to establishing the public Deep geothermal energy database, and the other to the public Shallow geothermal energy database development. Both calls aim to increase knowledge about deep and shallow geothermal potential in Croatia to facilitate a more significant uptake of geothermal energy.

The programming of the 2022-2029 financial perspective just started and Croatian implementing bodies as well as all the potential beneficiaries and stakeholders showed great interest in the continuation of co-funding projects focused on geothermal energy utilization.

4. CONCLUSIONS

Considering the huge interest in geothermal exploration in the last few years, a large number of new geothermal development in Croatia can be expected in both heat production and electricity generation.

REFERENCES

T. Kurevija, M. Macenić, D. Vulin: Impact of geothermal gradient on ground source heat pump system modelling. *Rudarsko-Geološko-Naftni Zbornik 28(1)*, Zagreb, (2014), 39-45

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	16.5	74.65	4662*	13385.3*	0.35	0.6
Under construction end of 2021	4.3	n/a	n/a	n/a	n/a	n/a
Total projected by 2023	16.5	74.65	5500	13000	0.35	0.6
Total expected by 2028	34.8	350est	6500est	16500est	0.54	2.12
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development: 10	
					Under investigation: 3	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 productio n * (GWh_e/y)
Velika Ciglena	Velika 1	2018	1 RI	O	B-ORC	16.5	10	74.65
total						16.5	10	74.65

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
R	Retired / decommissioned	2F	Double Flash	O	Other

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	42.3	21.1	6.84	19.4	14.1	11.2	18.31	14.0
Under constru-ction end 2021	-	-	-	-	-	-	-	-
Total projected by 2023	45.46	25.7	6.84	19.4	14.1	11.2	18.31	14.0
Total expected by 2028	96.25	230.94	11.49	33.61	14.6	20.1	25.4	26.27

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Topusko	Topusko	1998	-	-	26.3	26.3	7.8	4.6
Zagreb	GP Zagreb (Mladost and KBNZ)	1987	-	-	14.6	14.6	9.0	5.3
Bizovac	Bizovac	1974	-	-	1.4	1.4	4.3	2.5
total					42.3	42.3	21.1	12.5

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

No geothermal large systems for heating and cooling uses other than DH currently in Croatia.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	N/A	N/A	N/A	N/A	N/A	N/A
Of which networks **	N/A	N/A	N/A	N/A	N/A	N/A
Projected total by 2023	N/A	N/A	N/A			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No geothermal UTES installation currently in Croatia.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	N/A	10 (est.)	N/A	20 (est.)
Geothermal direct uses	N/A	30 (est.)	N/A	50 (est.)
Shallow geothermal	N/A	N/A	N/A	N/A
total	N/A	40 (est.)	N/A	70 est

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	-	-	-
Financial Incentives – Investment	-	-	-
Financial Incentives – Operation/Production	FIP	-	-
Information activities – promotion for the public	yes	yes	yes
Information activities – geological information	yes	yes	yes
Education/Training – Academic	yes	yes	yes
Education/Training – Vocational	yes	yes	yes

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update report for Denmark

Anders Mathiesen[1], Lars Henrik Nielsen[1], Henrik Vosgerau[1], Søren Erbs Poulsen[2], Theis Raaschou Andersen[2], Karl Woldum Tordrup[2], Birte Røgen[3], Claus Ditlefsen[4] and Thomas Vangkilde-Pedersen[4]

[1] Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, 1350 Copenhagen, Denmark

[2] VIA University College, Chr. M. Østergaardsvej 4, 8700 Horsens, Denmark

[3] Energistyrelsen, Carsten Niebuhrs Gade 43, 1577 København, Denmark

[4] Geological Survey of Denmark and Greenland (GEUS), C. F. Møllers Allé 8, 8000 Aarhus, Denmark

anm@geus.dk

Keywords: Deep geothermal energy, district heating, geothermal reservoirs, absorption heat pumps, ground source heating and cooling, borehole heat exchangers.

ABSTRACT

The deep Danish onshore subsurface contains huge geothermal resources, but only a very limited fraction of these resources are utilized in three existing geothermal heating plants. At the three plants deep situated warm formation water is pumped to the surface from a production well and, after heat is extracted and distributed to the district heating system, the cooled water is returned to the reservoir through injection well(s).

To stimulate the exploitation of the geothermal resource and thus the transformation to a more sustainable energy mix in Denmark a recently completed research project (GEOTHERM, under the Innovation Fund Denmark) has thoroughly evaluated seismic reflection surveys and well data acquired during former hydrocarbon and geothermal exploration activities. The results of the last years research and geological assessments presented in a public available WebGIS portal have reduced the exploration risks significantly and has stimulated the interest from the industry leading to newly awarded exploration licenses. This development in combination with the large distribution of district heating in Denmark is promising for a much larger utilization of geothermal heat in Denmark.

The Danish basins are classic low enthalpy sedimentary basins characterized by long-term subsidence and infilling by sediments. The widely distributed fluviatile Lower Triassic Bunter Sandstone and the mainly marginal marine Upper Triassic-Lower Jurassic Gassum formations constitute the most important geothermal reservoirs and are utilized in the present geothermal plants. Furthermore, formations with more local distribution also have geothermal potentials. In many areas, where existing detailed geological subsurface data are limited, predrilling reservoir prognosis are associated with large uncertainties, especially regarding the reservoir permeability. The temperature gradient of typical 25–30 °C/km in the Danish subsurface implies that at depths shallower than 800 m the temperature is generally too low, whereas at depths greater than 3000 m, diagenetic alterations related to high pressure-temperature conditions reduce the porosity and permeability of the reservoir sandstones. Pronounced temperature anomalies are absent and variations in the temperature gradients are mainly due to differences in the thermal conductivity of the geological strata.

Shallow geothermal energy (down to c. 250 m) has been utilized in Denmark since the late 1970's following the oil crisis and is commonly described as Ground Source Heating and Cooling. Energy extraction by heat pump technology from shallow geological formations is beginning to play a significant role in Denmark in the transition towards a sustainable heat supply, especially in areas without district heating. The shallow geothermal resources have become more attractive as there are now nine collective 5th generation district heating and cooling grids based on borehole heat exchangers (BHE) and aquifer thermal energy storage (ATES) in Denmark, all being economically feasible when compared to alternative means of supply. A pilot borehole thermal energy storage system (BTES) for storing seasonal heat from solar thermal was operated successfully for several years and proved to live up to the expected storage efficiency but is no longer active.

1. INTRODUCTION

Over the last years there has been an increasing interest in geothermal energy among district heating companies and municipalities. Geothermal plants receive no funding, but high taxes on fossil fuels and the focus on reduction of CO_2 emissions makes it attractive to substitute the burning of fossil fuels on

CHP plants with wind turbine power, biomass and geothermal heat.

Several publicly financed research projects during the last decade have identified the presence of huge deep geothermal resources in the deep Danish subsurface below c. 800 m and have stimulated the interest for utilizing the resource as an important component of a green sustainable energy mix. The recently completed three-year research project (GEOTHERM-project, supported by the Innovation Fund Denmark) further addressed geological, technical and commercial obstacles for utilization of the geothermal resources including the entire geothermal life cycle as well as the whole geothermal brine circuit from reservoir to the plant on the surface and back to the reservoir. The main goal of the project was to provide data and guidelines to ensure stable operation and realization of commercially profitable geothermal projects by describing the governing key elements for utilizing geothermal energy and for optimal integration into the existing district heating infrastructure (e.g. Vosgerau et al. 2022; Weibel et al. 2020). The project also developed a business case model for large-scale utilization of geothermal energy.

Denmark has moderate temperature gradients, but widespread geothermal aquifers and district heating networks in most of the Danish towns supplying heat to 60 % of Danish houses. Aquifers have been identified around many of these towns with sufficient heat to cover 20–50 % of their heat demand for hundreds of years. A previous study has assessed the reserves in a license for Greater Copenhagen Area to 60,000 PJ or 1/3 of the heat demand for about 5000 years (Mahler et al. 2010).

In Denmark shallow geothermal energy is commonly described as Ground Source Heating and Cooling which covers horizontal collectors as well as borehole heat exchangers (vertical or inclined), foundation pile heat exchangers and groundwater based open loop systems. Energy extraction by heat pump technology from shallow geological formations is beginning to play a significant role in Denmark in the transition towards a sustainable heat supply, especially in areas without district heating.

The use of shallow geothermal resources (down to c. 250 m) is still limited, but in recent years, the Termonet concept for collective GSHP-based sustainable heating and cooling outside the district heating network (1/3 of consumers) has emerged, and it has been shown to be economically feasible when compared to alternative solutions. Moreover, the Termonet facilitates passive cooling/seasonal heat storage and balancing of the power grid by storing electrically heated water when electricity prices are favorable, giving it significant added value compared to traditional alternatives.

Shallow geothermal energy has been utilized in Denmark since the late 1970's following the oil crisis. Energy is produced primarily by means of ground source heat pumps with horizontal collectors but also from a limited number of borehole heat exchangers (BHE).

In one case, a pilot borehole thermal energy storage system (BTES) with 48 BHE's to a depth of 45 m was used for storing seasonal heat from solar thermal by the local district heating company in Brædstrup, Denmark. The BTES system was operated successfully for several years and proved to live up to the expected storage efficiency but is no longer active as other local solutions turned out to be more beneficial is used for seasonal heat storage. In addition to closed loop borehole heat exchangers, aquifer thermal energy storage (ATES) systems are used mostly for cooling of e.g. hospitals and larger office buildings but to some extent also for heating.

1.1 Licenses, legislation and administration – Deep geothermal energy

Exploration for and production of deep geothermal energy requires a license pursuant to the provisions of the Danish Subsoil Act. It is the Danish Energy Agency, which administrates and supervise the licenses. The newly updated map of geothermal licenses and applications in Denmark reveals applications for large license areas by private investors whereas the existing holders primarily are municipal holders (Figure 1). This illustrates that the industry is taking interest in geothermal exploration and sees it as a promising business case into which it is willing to invest and share the exploration risks. Especially one major private investor (Innargi A/S) has shown interest and has now been granted license in two lager areas covering Aarhus and the larger Copenhagen area (‘Hovedstadsområdet’ and ‘Copenhagen, Ringsted og Holbæk’ in Figure 1).

1.2 Legislation and administration – Shallow geothermal energy

The shallow Ground Source Heating and Cooling is regulated pursuant to the Danish environmental Protection Act (LBK nr 1218 of 25/11/2019) and The Groundsource Heating Act (BEK nr 240 af 27/02/2017). Permissions are issued by the municipalities, who must include groundwater interests in their considerations.

Protection of the groundwater is normally not a limitation for horizontal collectors, but for borehole heat exchangers, the regulation provides the municipalities with a possibility to increase the required safety distance to water wells and to stipulate special conditions in the permit regarding e.g. the construction of the installation, in order to protect a water catchment against contamination. Some municipalities reject applications for borehole heat exchangers if there is uncertainty regarding a possible content of anti-corrosives in the brine. Others are generally very reluctant to issue permits for borehole heat exchangers because of general considerations regarding the groundwater protection and drinking water quality.

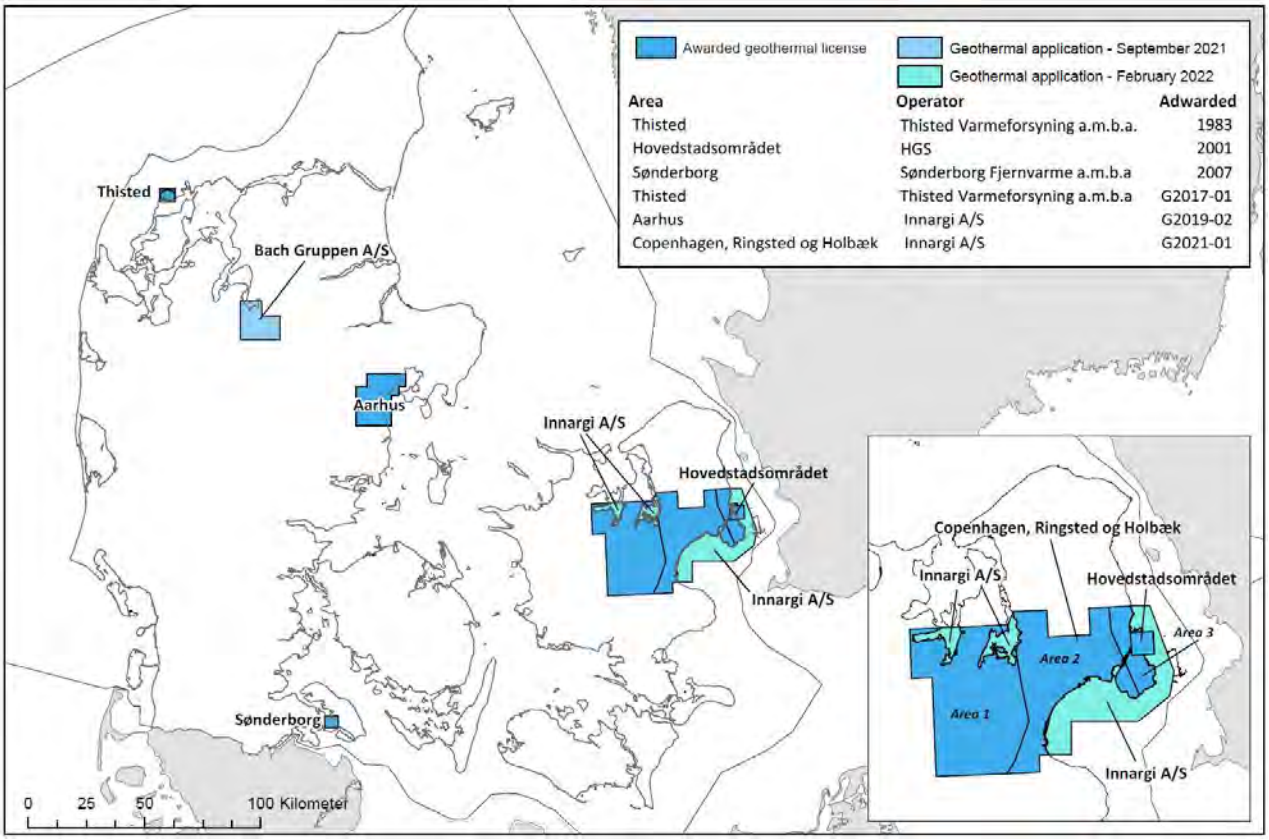


Figure 1: Geothermal licenses and applications in Denmark, February 2022 (modified from www.ens.dk). Solid blue areas around Aarhus and Copenhagen are license areas already granted while areas with light blue and green oblique lines are pending applications.

The Act on "Heat extraction plants and groundwater cooling systems" (BEK no. 1716 of 15/12/2015) is rather strict and specifies investigations and documentation regarding the geology and hydrogeology of the aquifer as well as the hydraulic and hydrothermal properties and the chemical and microbiological conditions. For heat extraction, the average monthly temperature of the water reinjected into the aquifer or infiltrated into the ground must be above 2 °C and for cooling systems and heat storage systems, the average monthly temperature of the injected water must be below 20 °C with a maximum peak temperature below 25 °C. Furthermore, numerical modelling is required in order to document that the temperature of the groundwater in existing catchments will not increase more than 0.5 °C. For "areas of specific drinking water interests" it is required, that the groundwater resource must be exploitable again 10 years after the closing of the installation, which should also be documented by numerical modeling. These requirements are rather costly and imply that only larger installations are economically feasible.

2. GEOLOGICAL BACKGROUND

Information about the deep geological setting in Denmark originates largely from hydrocarbon exploration activities with seismic profiles and wells covering most of the country, however with an uneven distribution (Vosgerau et al. 2016). The interpretation of these data provides information on the regional structural setting and spatial distribution of sedimentary units.

The Danish onshore subsurface is divided into five major structural units (largely from north to south): the Skagerrak-Kattegat Platform (SKP), the Sorgenfrei-Tornquist Zone (STZ), the Danish Basin (DB), the Ringkøbing-Fyn High (RFH) and the North German Basin (NGB). The geothermal resources relate mainly to the to two deep sedimentary basins: the Danish Basin (DB) and the North German Basin (NGB) (Figure 2).

The sedimentary basins contain Palaeozoic, Mesozoic and Cenozoic sedimentary sequences of up to 5–10 km in total thickness. In contrast, sedimentary thicknesses of 1–2 km, and less, are found in areas with shallow basement highs (the RFH and SKP). The Ringkøbing-Fyn High consists of shallow basement blocks, where the thin Mesozoic sedimentary cover mainly comprises erosional remnants of Triassic sediments and Upper Cretaceous Chalk with a low geothermal potential. Both sedimentary basins host very large geothermal resources and several potential reservoirs and are classic low-enthalpy sedimentary basins formed by crustal thinning followed by long-term thermal subsidence and infilling by a variety of sediments (e.g. Michelsen et al. 2003; Michelsen & Nielsen 1991). These structural differences exert a decisive influence on the geothermal prospectively of the Danish subsurface, as they essentially determine the distribution, thicknesses, facies types and burial depths of the potential reservoirs (e.g. Erlström et al. 2018; Weibel et al. 2020).

Figure 2: Well locations and principal structural elements in southern Scandinavia. Based on Nielsen (2003).

Five important geothermal reservoirs have been identified based on their stratigraphical and spatial extent where the best described includes the Lower to Upper Triassic Bunter Sandstone and Skagerrak reservoirs, the Upper Triassic – Lower Jurassic Gassum reservoir (Nielsen et al. 2004; Mathiesen et al. 2010). The other important reservoirs, e.g. the Middle Jurassic Haldager Sand reservoir and the Upper Jurassic – Lower Cretaceous Frederikshavn reservoir and the Upper Cretaceous Arnager Greensand may locally also contain potential aquifers. Each reservoir generally comprises several sandstone layers with reservoir properties. So far, the focus has been on the combined Bunter Sandstone-Skagerrak reservoir and the Gassum reservoir, with current geothermal production (Røgen et al. 2015; Mathiesen et al. 2020).

The geographical coverage and quality of the data vary considerably. The mostly 2D seismic data combined with information from deep wells have been used in a major mapping campaign for mapping of depth, thickness and lateral extent of lithostratigraphic units, and with special emphasis on units known to contain geothermal reservoir sandstones, as well as for identification and mapping of major faults and salt domes (Vosgerau et al. 2016). Regional maps were interpreted in two-way travel time (TWT) and were converted to depth ensuring that the difference between measured depths in wells and those extracted from the depth-converted maps are as small as possible. The deepest mapped seismic reflector is the Top Pre-Zechstein horizon. The maps are accessible from the WebGIS portal, as is a number of seismic cross-sections and an interactive 3D tool that exemplify the structural distribution of the onshore subsurface units. The lack of coverage and high-quality data hampers the interpretation and mapping of the deepest horizons and consequently, mapping uncertainties are generally larger for the deepest horizons than for the shallower horizons and the associated reservoir units.

The derived subsurface 3D structural (and geological) model with main lithological units includes information on potential geothermal reservoirs with burial depth and spatial distribution. Well data contain information about the reservoir quality (e.g. distribution of sandstone layers, facies type, heterogeneity, porosity, and permeability) as well as information on temperature and geochemistry of the formation water, where such data were measured (e.g., Weibel et al. 2017; Kristensen et al. 2016; Olivarius et al. 2015).

The shallow geology is dominated by soft sediments and characterized by a variable depth to the groundwater table. The sediments consist of glacial sand and clay deposits of variable thickness. In the western part of Denmark, they are found on top of Miocene fluvio-deltaic sands and marine silts and muds, whereas in the eastern and northeastern part, the glacial deposits overlay relatively soft limestone from the Danien and Cretaceous.

The energy extraction from shallow installations depends on the thermal properties of the sediments surrounding the heat collectors, (e.g. Vangkilde-Petersen et al. 2012). Relatively few investigations of thermal properties of Danish sediments have been carried out (Balling et al. 1981; Porsvig 1986; Møller et al. 2019), and thermal conductivity values for different rock and sediment types published by e.g. VDI (2010) show large variations for sediments relevant in a shallow geological context. However, a recent investigation has narrowed down this span for a number of relevant shallow sediments (Ditlefsen et al. 2014).

3. DEEP GEOTHERMAL RESOURCES AND POTENTIAL

The geothermal resources in the deep Danish onshore underground are enormous (corresponding to around 3 times the heat from the Danish North Sea oil) and may potentially constitute the district heating to 1/3–1/2 of the Danish households for hundreds of years. At present, only a very limed fraction of the resources is utilized in the three existing geothermal power plants in Thisted, Sønderborg and on Margretheholm near Copenhagen (see locations in Figure 3), and of these, only the first-mentioned plant is in stable production.

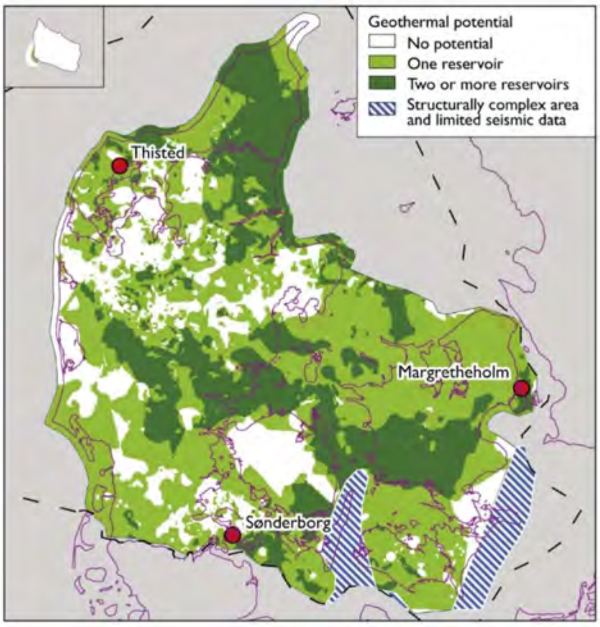


Figure 3: Distribution of lithostratigraphic units with reservoir properties suitable for geothermal exploration in the geothermal depth zone (800–3000 m). Notice the location of the three existing geothermal plants. From the Deep WebGIS Portal (2015) (after Vosgerau et al. 2016).

Several initiatives have been undertaken in order to stimulate the exploitation of the geothermal resource and thus the transformation to a more sustainable energy mix in Denmark. A number of public financed research projects has thus been carried out over the last decades, focusing on the implementation of deep geothermal energy for district heating and thereby replacing fossil fuel, especially coal and oil. These projects have considerably increased our knowledge of the Danish subsurface and confirmed the presence of its huge geothermal resource and indicated where the geological conditions are most suitable for the extraction of deep geothermal energy.

In Denmark, successful geothermal exploitation in the deep subsurface requires the presence of thick and laterally coherent sandstone reservoirs with high porosity and permeability, which can ensure effective and long-term extraction and re-injection of formation water. A thick and coherent reservoir that is not hydraulically compartmentalized by faults, lateral lithological changes (e.g. grain size) or diagenetic features implies that a large volume of warm water may be accessible, and that production and injection wells can be placed at appropriate distances from each other while remaining hydraulically connected.

The temperature gradient of typical 25–30 °C/km in the Danish subsurface implies that at depths shallower than 800 m the temperature is generally not sufficiently high to be economically profitable for a district heating plant, whereas at depths greater than 3000 m, diagenetic alterations related to high pressure–temperature conditions reduce the porosity and permeability of the reservoir sandstones. Thus, most interest is currently devoted to reservoirs with burial depth within the range of 800–3000 m and with a cumulative thickness of reservoir sand of good reservoir quality of more than c. 15 m (Vosgerau et al. 2016).

An outcome of the recent major mapping campaign resulted in 2015 in a user-friendly WebGIS portal providing an overview of the amount and quality of existing geodata, the geological composition of the subsurface, and interpreted thematic products such as depth and thickness maps of potential geothermal reservoirs in the deep Danish subsurface (http://DybGeotermi.GEUS.dk; Vosgerau et al. 2016). An important thematic map outlines where in Denmark the geothermal potential appears most promising based on current knowledge and may thereby ensure that future explorations are directed towards these areas, thereby also reducing the risk of making unsuccessful wells in areas where the geothermal potential is low (Figure 3).

The WebGIS portal have reduced the exploration risks significantly and have stimulated the interest from the industry. It provides a robust and consistent frame for more comprehensive estimates of the geothermal potential. Estimates in specific area more local geothermal license areas must however be based on more detailed analysis of the local dataset defining local geological models that may serve as the geoscientific background for technical and economic considerations.

4. DEEP GEOTHERMAL UTILIZATION

In addition to the three current geothermal plants (positions in Figure 3), exploration activities are planned in the Aarhus license, while activities in the Copenhagen area is at the early planning stage. The three geothermal plants all use absorption heat pumps and produces heat for district heating. Absorption heat pumps can be driven at low cost if other heat producers such as biomass boilers can supply 160 °C driving heat at district heating cost levels.

Furthermore, all the geothermal plants use the doublet concept; warm formation water is pumped to the surface from a production well using no stimulation of the geothermal reservoir. After heat is extracted and distributed to the district heating system, the cooled water is returned to the reservoir through injection well(s). In Thisted, the production well produces c. 44 °C warm water from the Gassum Formation at a depth of 1250 m where the water has a salinity of 15 %. The plant produces up to 7 MW from 200 m^3/h geothermal water and transfer 10 MW heat to the district heating net by heat exchange and through absorption heat pumps driven by heat primarily from a biomass boiler. In Sønderborg, the production well is expected to produce 48 °C warm water from the

Gassum Formation at a depth of 1200 m where the water has a salinity of 15 %. The plant is designed to produce up to 12 MW from 350 m^3/h geothermal water with the use of absorption pumps driven by biomass. The Margretheholm plant exploits a geothermal reservoir in the Lower Triassic Bunter Sandstone Formation at 2600 m depth where 19 % saline geothermal water is available at c. 74°C. The plant is designed to extract 14 MW heat from 235 m^3/h geothermal water and transfer 27 MW heat to the district heating net by heat exchange and through 3 absorption heat pumps driven by 14 MW steam primarily from wood pellet-based CHP plant. Comprehensive descriptions of the technical part of the three geothermal plants is given in previous Country updates, e.g. Mahler, at al. 2010; Mahler et al. 2013 and Røgen et al. 2015, Mathiesen et al. 2020).

4.1 Current status, future development and installations

Assessment of the geothermal resources in Denmark indicates a great potential in large parts of the country. The three existing geothermal plants may potentially produce geothermal heat for district heating from deep Danish geothermal aquifers with a total design rate of 33 MW heat extraction from the 15–20 % saline geothermal water. Several district heating companies are considering the possibilities for establishing geothermal production and new exploration licenses are awarded (Figure 1).

The huge amounts of geothermal energy resources that are present in the Danish subsurface may play an important role in future sustainable energy supply and has resulted in the need for e.g. accurate thermal information and thermal models. A recent published 3D numerical crustal temperature and heat-flow model for onshore Denmark including a comprehensive analysis of well-log data provides well-constrained input for a fully parameterized and calibrated numerical subsurface temperature model (Fuchs et al. 2020). The study shows that pronounced temperature anomalies are absent and variations in the temperature gradients are mainly due to local salt diapirs and differences in the thermal conductivity of the geological strata.

The Danish Government has recently established an expert committee to evaluate applications from license holders who wish to insure themselves against the economic risk associated with geothermal drilling project, and recently, Innargi A/S has been awarded licenses around Aarhus and in the larger Copenhagen area (Figure 1). In Aarhus, Innargi are currently in the exploration phase and have planned seven plants in Aarhus, covering up to 20 % of the city's district heating demand, and taking the full responsibility for exploration, establishment and operational risks the following 30 years. The first exploration well is planned to be drilled 2023, and in 2025 the first plant is expected to supply geothermal district heating. The plan is expected to be completed in 2030 and the geothermal plants are expected to operate in 30 years.

The plants on Margretheholm and in Sønderborg has experienced problems with reinjection causing the plants to be temporary out of operation. In contrast, the Thisted plant has been running smooth since it came into operation in 1984 and without experiencing any breakthrough to the production well of the cooled, re-injected water from the injection well situated c. 1500 m from the production well. An extra injection well was added to the plant in 2018 as the existing injection well over the years gradually demanded more and more electricity for the pumps to inject the cooled water into the reservoir. The new injection well reduces the electricity consumption and extends the lifetime of the plant and will furthermore increase the proportion of geothermal heat of the total district heating supply in Thisted from 15 to 25 %.

Furthermore, during the later years there has been an increasing interest for using the subsurface for seasonal heat storage. Several projects, including the GEOTHERM project are investigating the possibilities of integrating heat storage with exploitation of the geothermal resource. One scenario may thus be to inject surplus heated water in the production well in the summertime, and then extract it when needed during the winter (Major et al. 2018).

Deep Danish aquifers have not been found suitable for power production, as sufficiently permeable sandstone layers are too cold due to the moderate temperature gradient of typical 25–30 °C/km subsurface. They may, however, in the future be used for power production supplied by stored heat from the sun, excess incineration plant heat or heat pumps driven by excess wind turbine power. Thus, geothermal plants can be used for long term heat storage with low temperature losses.

5. SHALLOW GEOTHERMAL ENERGY

Shallow Geothermal Energy encompass Ground Source Heating and Cooling with horizontal collectors as well as borehole heat exchangers (vertical or inclined) and groundwater based open loop systems. Moreover, the term includes ambient temperature district heating and cooling grids that utilize shallow geothermal energy as a primary energy source (termonet/5GDHC - 5th generation district heating and cooling).

Despite a large potential, the application of shallow geothermal energy in Denmark is relatively limited compared to e.g. Sweden or Germany. Between 2009 and 2021 the number of GSHPs installed annually varies between 1800 and 4100 with no clear pattern during the period (Figure 4).

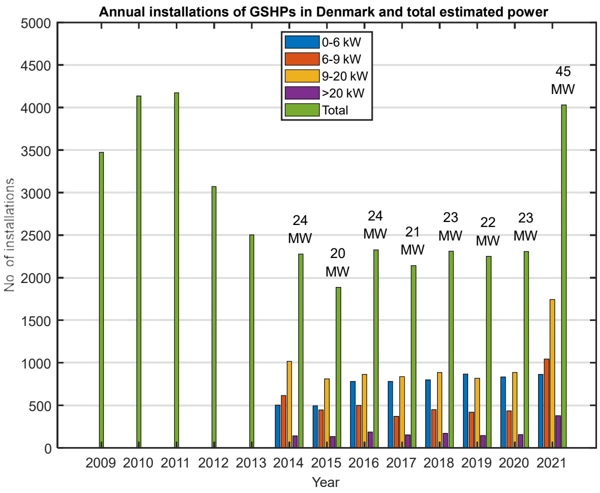


Figure 4: Number of GSHP installed annually and grouped by nominal power for the period 2014-2021. Source: ens.dk

In the period 2014–2021, 9–20 kW heat pumps for larger single-family houses and medium size buildings tend to dominate, followed by the smaller 0–6 kW, typical for terraced houses. The larger heat pumps >20 kW make up only a limited fraction of the total sales.

Most of the existing GSHP systems use horizontal collectors. Only a few hundred are borehole heat exchangers and >40 are groundwater well open loop systems. During the last couple of years, the number of installed BHEs/year has declined somewhat relative to five-ten years ago (Figure 5).

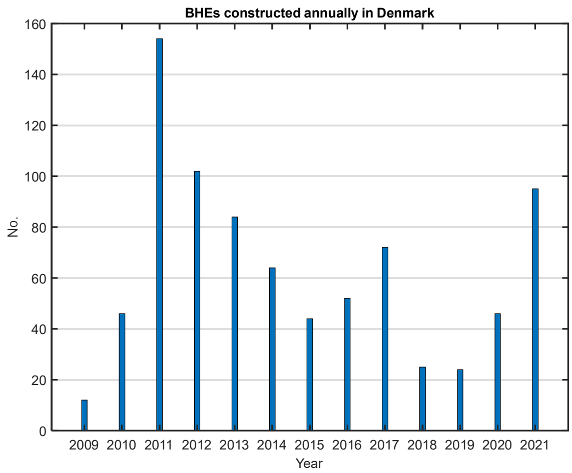


Figure 5: Number of installed borehole heat exchangers (BHE) in the period 2009-2021. BHEs that have not been put into operation are excluded from the plot. Source: geus.dk.

Some open loop systems were installed in the eighties for house heating. Later installations were primarily for industrial cooling and now large systems are applied with alternating operation (heating in winter and cooling in the summertime).

5.1 Underground thermal energy storage

Large scale seasonal storage of heat by means of Underground Thermal Energy Storage (UTES) is also beginning to play a significant role in Denmark. A local district heating company in Brædstrup, Jutland has established a pilot borehole thermal energy storage (BTES) (48 boreholes, 45 m deep) in combination with a thermal solar installation. As mentioned previously, the storage efficiency during operation were according to expectations, but the pilot BTES is no longer in operation and a large air source heat pump now supplies the district heating instead. Another 3-5 district heating companies have established pit thermal energy storage (PTES) also combined with solar energy.

In the HEATSTORE project ("High Temperature Underground Thermal Energy Storage - HEATSTORE" (EUDP, jour.nr. 64018-0301, EU GEOTHERMICA-ERA NET 170153-4401) (Koornneef et al. 2019) the Danish activities have comprised description of lessons learned from existing UTES systems internationally (Kallesøe et al. 2020; Kallesøe & Vangkilde-Pedersen 2019) and development of general specification and design for UTES systems (Nielsen & Vangkilde-Pedersen 2019) as well as establishing a web-based GIS platform demonstrating the technical future potential for underground thermal energy storage in the partner countries (Guglielmetti et al. 2021). Pilot UTES projects have been developed in the Netherlands (high temperature aquifer thermal energy storage, HT-ATES) Switzerland (HT-ATES), France (BTES) and Germany (mine thermal energy storage, MTES), while in Denmark the geological conditions have been characterized in selected areas with a potential for UTES. A stakeholder survey has indicated a specific interest, while Danish BTES and PTES systems have been used as case studies and for modelling of storage efficiency.

5.2 Termonet

A new concept for collective shallow geothermal district heating and cooling of residential areas, without the possibility of traditional district heating, has emerged in Denmark in the past years. The concept is referred to as "termonet" (termonet/5GDHC - 5th generation district heating and cooling) and comprises BHEs connected to a horizontal distribution network of uninsulated geothermal piping from which individual consumers extract energy with heat pumps (Figure 6).

During the hot season, excess heat is stored for the winter by passive cooling of the connected buildings. In addition to improving the COP of the heat pump, seasonal heat storage/passive cooling significantly improves the thermal comfort during the hot season.

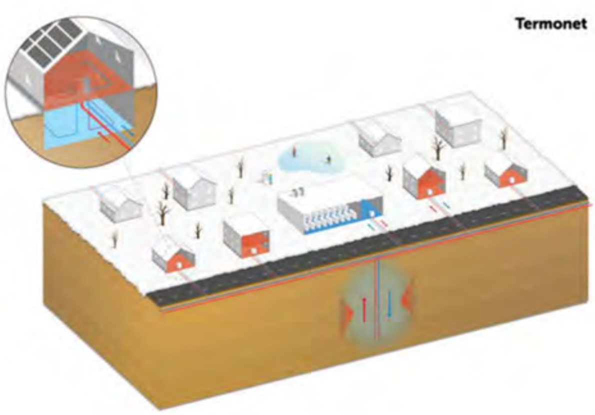


Figure 6: A termonet shown here with BHEs and the horizontal uninsulated distribution network that supplies houses with heating by means of distributed heat pumps and passive cooling/seasonal heat storage. Source: www.termonet.dk

There are currently 9 termonet in operation in Denmark with 3 more being constructed and 1 in the planning phase (Figure 7).

The Silkeborg termonet is owned and operated by the non-profit and consumer-owned, local district heating company (Silkeborg Forsyning), and supplies 15 residential units, utilizing 6 120 m BHEs connected to the horizontal uninsulated distribution network. In the village of Skjoldbjerg, three houses are supplied by three BHEs in a collective district heating and cooling network, whereby savings are made possible relative to establishing individual BHEs. Here, the private company HeatPlan A/S owns and operates the termonet. In a yet-to-be developed residential area in the city of Brenderup, Middelfart Municipality has established a termonet that is jointly owned by the future landowner association. The termonet will supply 13 residential units from 8 BHEs.

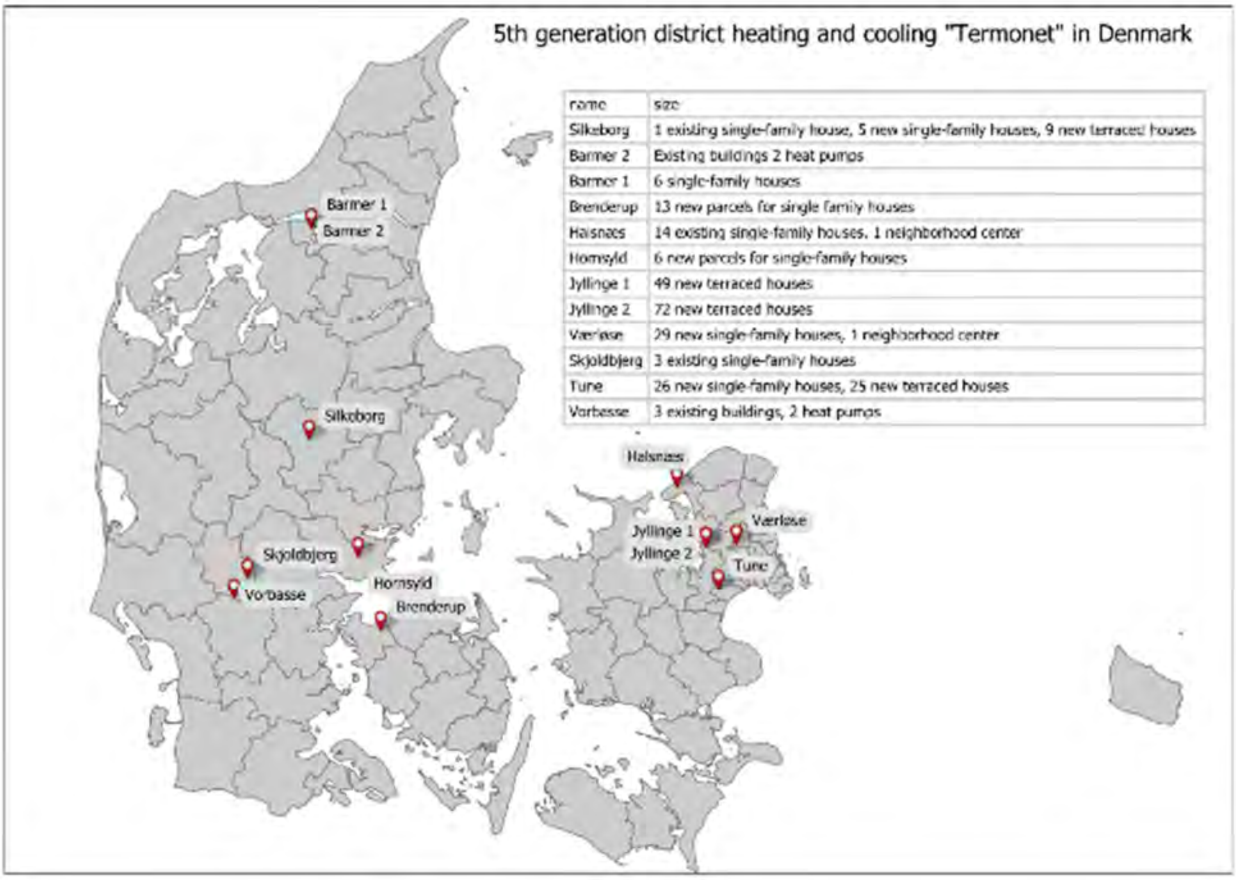


Figure 7: Termonet in Denmark shown with the number of connected consumers and building types. Source: coolgeoheat.eu

5.3 New initiatives

The Interreg ÖKS project COOLGEOHEAT explores the technical and commercial possibilities for 5GDHC in Denmark and Sweden. The project is developing a techno-economic model in the simulation platform Modelica that simulates the heat and fluid transport on 5GDHC grids. The model includes state-of-the-art BHE models (Picard & Helsen, 2014) and considers the thermal exchange between the horizontal grid of uninsulated pipes and the surrounding soil. Furthermore, the model includes accurate heat pump models, capable of estimating the dynamics of electricity consumption for operational 5GDHC grids. The estimated power consumption feeds directly into a parallel computation of the life-cycle-costs, given information about the upfront investment, interest and discount rates and predicted spot prices on electricity. Finally, the project compiles operational data from existing 5GDHC grids in Denmark and Sweden for model validation and to compile general information about the operation of the grids in addition to actual cost estimates. Both the business model and value proposition canvases for 5GDHC have been developed in the project, to streamline stakeholder and end-user communication. This further supports the project work on business models for ownership and operation in addition to the techno-economic model assessments.

REFERENCES

Balling, N., Kristiansen, J.I., Breiner, N., Poulsen, K.D., Rasmussen, R. and Saxov, S.: Geothermal measurements and subsurface temperature, modelling in Denmark. GeoSkrifter 16, 176 pp. Aarhus University, Denmark, (1981)

Ditlefsen, C., Sørensen, I., Slott, M. and Hansen, M.: Estimating thermal conductivity from lithological descriptions – a n + tablesew web-based tool for planning of ground-source heating and cooling. Geological Survey of Denmark and Greenland Bulletin 31, 2014, 55-58, (2014).

Erlström, M., Boldreel, L.O., Lindström, S., Kristensen, L., Mathiesen, A., Kamla, E. and Nielsen, L.H.: Stratigraphy and geothermal assessment of Mesozoic sandstone reservoirs in the Øresund Basin – exemplified by well data and seismic profiles. Bulletin of the Geological Society of Denmark, Vol. 66, pp. 123–149, (2018).

Fuchs, S., Balling, N. and Mathiesen, A.: Deep basin temperature and heat-flow field in Denmark – New insights from borehole analysis and 3D geothermal modelling. Geothermics, 83, pp 1-18 (2020).

Guglielmetti, L., Daniilidis, A., Valley, B., Maragna, C., Maurel, C., Dinkelman, D., Koornneef, J., Oerlemans, P., Drijver, B., Kallesøe, A.J., Mortensen, M.H., Ditlefsen, C., Vangkilde-Pedersen, T. and Klein, S. 2021: Screening of the national potential for UTES. HEATSTORE project report, GEOTHERMICA – ERA NET Cofund Geothermal. 87 pp.

Kallesøe, A.J. and Vangkilde-Pedersen, T. (eds). 2019: Underground Thermal Energy Storage (UTES) – state-of-the-art, example cases and lessons learned. HEATSTORE project report, GEOTHERMICA – ERA NET Cofund Geothermal. 130 pp + appendices.

Kallesøe, A.J., Vangkilde-Pedersen, T., Nielsen, J.E., Bakema, G., Egermann, P., Maragna, C., Hahn, F., Guglielmetti, L., Koornneef, J. 2020: HEATSTORE – Underground Thermal Energy Storage (UTES) – State of the Art, Example Cases and Lessons Learned. Proceedings World Geothermal Congress 2020+1, Online and On-Site, Reykjavik, Iceland, March-October, 2021. 9 pp.

Koornneef, J., Guglielmetti, L., Hahn, F., Egermann, P., Vangkilde-Pedersen, T., Aradóttir, E.S., Allaerts, K., Viveiros, F. & Saaltink, M. 2019: HEATSTORE: high temperature underground thermal energy storage. Proceedings European Geothermal Congress 2019, The Hague, The Netherlands, 11-14 June, 2019. 8 pp.

Kristensen, L., Hjuler, M.L., Frykman, P., Olivarius, M., Weibel, R., Nielsen, L.H. and Mathiesen, A.: Pre-drilling assessments of average porosity and permeability in the geothermal reservoirs of the Danish area. Geotherm Energy, 4(6), 2–27, http://dx.doi.org/ 10.1186/ s40517-016-0048-6, (2016).

Mahler, A. and Magtengaard, J.: Country update report for Denmark, in Proceedings World Geothermal Congress 2010, Bali, Indonesia, 9 pp, (2010).

Mahler, A., Røgen, B., Ditlefsen, C., Nielsen, L.H. and Vangkilde-Petersen, T.: Geothermal Energy Use, Country Update for Denmark. European Geothermal Congress 2013, (2013).

Mathiesen, A., Nielsen, L.H., Vosgerau, H., Poulsen, S.E., Bjørn, H., Røgen, B., Ditlefsen, C. and Vangkilde-Pedersen, T.: Country update report for Denmark, in Proceedings World Geothermal Congress 2020+, Reykjavik, Iceland, 9 pp + tables, (2020)

Major, M., Poulsen, S.E. and Balling, N.: A numerical investigation of combined heat storage and extraction in deep geothermal reservoirs. Gethermal Energy, 6(1), 1, (2018).

Mathiesen, A., Nielsen, L.H. and Bidstrup, T.: Identification of the potential geothermal reservoirs in Denmark. Geological Survey of Denmark and Greenland Bulletin 20, 19-22, (2010).

Michelsen, O., Nielsen, L.H., Johannessen, P., Andsbjerg, J. and Surlyk, F.: Jurassic lithostratigraphy and stratigraphic development onshore and offshore Denmark. In: Ineson, J. R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin 1, 147–216, (2003).

Michelsen, O. and Nielsen, L.H.: Well records on the Phanerozoic stratigraphy in the Fennoscandian Border Zone, Denmark. Hans-1, Sæby-1, and Terne-1 wells. Danm. geol. Unders., Ser. A 29, 39 pp, (1991).

Møller, I., Balling, B and Ditlefsen, C.: Shallow subsurface thermal structure onshore Denmark: temperature, thermal conductivity and heat flow. Bulletin of the Geological Society of Denmark 67, pp-29–52, (2019).

Nielsen, J.E. and Vangkilde-Pedersen, T. (eds.). 2019: Underground Thermal Energy Storage (UTES) –

general specifications and design. HEATSTORE project report, GEOTHERMICA – ERA NET Cofund Geothermal. 58 pp.

Nielsen, L.H., Mathiesen, A. and Bidstrup, T.: Geothermal energy in Denmark. Review of Survey activities 2003. Geological Survey of Denmark and Greenland bulletin 4 p.17–20, (2004).

Nielsen, L.H.: Late Triassic–Jurassic development of the Danish Basin and the Fennoscandian Border Zone, southern Scandinavia. In: Ineson, J.R. & Surlyk, F. (eds): The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin 1, 459–526, (2003).

Olivarius, M., Weibel, R., Hjuler, M.L., Kristensen, L., Mathiesen, A., Nielsen, L.H. and Kjøller, C.: Diagenetic effects on porosity-permeability relationships in red beds of the Lower Triassic Bunter Sandstone Formation in the North German Basin. Sedimentary Geology 321, 139–153, (2015).

Picard, D.; Helsen, L. A New Hybrid Model For Borefield Heat Exchangers Performance Evaluation. In Proceedings of the 2014 Ashrae Annual Conference, Seattle, WA, USA, 28 June–2 July 2014; pp. 857–866, (2014).

Porsvig, M.: Varmeovergangsforhold omkring jordslanger. Energiministeriets varmepumpe-forskningsprogram 33, 56 pp, (1986).

Røgen, B., Ditlefsen; C., Vangkilde-Petersen, T., Nielsen, L.H. and Mahler, A.: Geothermal Energy Use. Country Update for Denmark. World Geothermal Congress 2015, (2015).

Vangkilde-Pedersen, T., Ditlefsen, C. and Højberg, A.L.: Shallow geothermal energy in Denmark. Geological Survey of Denmark and Greenland Bulletin 26, 37–40, (2012).

VDI (Verein Deutscher Ingenieure): Thermische Nutzung des Untergrundes: Grundlagen, Genehmigungen, Umweltaspekte. Richtlinie 4640, Blatt 1, 33 pp. Dusseldorf: Verein Deutscher Ingenieure. 2010, (2010).

Vosgerau, H., , Balling, N., Mathiesen, A., Mathiesen, T., Nielsen, L.H., Oliveira, A. and Weibel, R: Reducing obstacles for large scale utilization of geothermal energy for district heating – the GEOTHERM project. European Geothermal Congress, Berlin, Germany, October 2020. (2022).

Vosgerau, H., Mathiesen, A., Andersen, M.S., Boldreel, L.O., Hjuler, M.L., Kamla, E., Kristensen, L., Pedersen, C.B., Pjetursson, B. and Nielsen, L.H.: A WebGIS portal for exploration of deep geothermal energy based on geological and geophysical data. Geological Survey of Denmark and Greenland Bulletin, 35, 23–26, (2016).

Weibel, R., Olivarius, M., Kristensen; L., Friis, H., Hjuler, M. L., Kjøller, C., Mathiesen, A. and Nielsen, L. H.: Predicting permeability of low enthalpy geothermal reservoirs: examples from the Upper Triassic−Lower Jurassic Gassum Formation, Norwegian–Danish Basin. Geothermics 65, 135-157, (2017).

Weibel, R., Olivarius, M., Vosgerau, H., Mathiesen, A., Kristensen L., Nielsen, C.M. and Nielsen, L.H.: Overview of potential geothermal reservoirs in Denmark. Netherlands Journal of Geosciences, 99, e3, 14 pp., (2020).

ACKNOWLEGDEMENT

The last years deep geothermal energy projects have been funded by the Danish Council for Strategic Research (geothermal energy, project # 2104-09-0082) and the Innovation Fund Denmark (the current project, GEOTHERM - "Geothermal energy from sedimentary reservoirs - Removing obstacles for large scale utilization", project # 6154-00011B). We thank Lars Ole Boldreel (University of Copenhagen) and Morten Sparre Andersen (GEUS) for providing access to the 3D digital structural seismic model.

Table A: Present and planned geothermal power plants, total numbers

No geothermal power plants currently in Denmark.

Table B: Existing geothermal power plants, individual sites

No geothermal power plants currently in Denmark.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	**7**	**15** of 27,5 (norm) due to pump failure						
Under constru-ction end 2021	0	0						
Total projected by 2023	**0**	**0**						
Total expected by 2028	**140**	**700**						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Thisted	Thisted	1984	N	N	7	7	15	12(23)
Copenhagen	Margretheholm	2005	N	N	13,7	-	0	-
Sønderborg	Sønderborg	2013	N	N	12,5	-	0	-
total					**7**	**7**	**15**	**12(23)**

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

No geothermal large systems for heating and cooling uses other than DH exist currently in Denmark.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	40,000-45,000	410-465	720-815	4031	45	Not known
Of which networks **	173	1.8	3			
Projected total by 2023	**264**	**2.7**	**4.8**			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

	Aquifer Thermal Energy Storage (ATES)			Borehole Thermal Energy Storage (BTES)		
	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold
In operation end of 2021 *	c. 45	H:41,000 C:27,000	H: NA C: NA	0	H: C:	H: C:
New (additional) in 2021 *	0	H:0 C:0	H:0 C:0	0	H: C:	H: C:
Projected total by 2023	**c. 47**	**H:43,000** **C:28,000**	**H: NA** **C: NA**	**0**	**H:** **C:**	**H:** **C:**

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	0	0	0	0
Geothermal direct uses	0	15	?	30
Shallow geothermal	80	670	100	840
total	**80**	**685**	**?**	**870**

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D			-None-
Financial Incentives – Investment			DIS
Financial Incentives – Operation/Production			O Reduction of tax on GSHP electricity use above 4 MWh/yr
Information activities – promotion for the public			www.termonet.dk
Information activities – geological information			-None-
Education/Training – Academic			-None-
Education/Training – Vocational			-None-

Key for financial incentives:					
DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

European Geothermal Congress 2022
Berlin, Germany | 17-21 October 2022
www.europeangeothermalcongress.eu

Geothermal Energy Use, Country Update for Estonia

Alvar Soesoo[1] and Heikki Bauert[2]

[1] Estonian Geothermal Association, Ehitajate tee 5, Department of Geology, Tallinn, 19086

[2] Geological Survey of Estonia, FR. Kreutzwaldi 5, Rakvere, 44314

alvar.soesoo@gmail.com

Keywords: Estonia, shallow geothermal, geoenergy pilot project 2021–2024.

ABSTRACT

The low-temperature shallow geothermal energy is the main heat source for geoenergy applications in Estonia whereas the majority of ground source heat pump (GSHP) applications are used for space heating and domestic hot water production for single family houses. Horizontal-loop shallow geothermal systems prevail in Estonia due to lower installation costs compared to vertical borehole heat exchanger (BHE) systems. The number of installed BTES systems is increasing over the last decade with about 400 shallow (depth varying between 50-200 m) BTESs installed annually (current number ca 2400). No research on mid-deep or deep geothermal exploration have been carried out yet in the country, however, the Ministry of Economic Affairs and Communications launched a mid-deep (500 m) geothermal energy research project in August 2021 lasting three years. This project will end supposedly with commissioning of two small-scale geoenergy pilot plants in Estonia. The Geological Survey of Estonia is leading this geoenergy project.

1. INTRODUCTION

Until recently Estonia has been among the European Union countries that are least dependent on energy imports. The major domestic energy supply has been oil shale – an energy-rich sedimentary rock than can be either burned for heat and power generation or used for producing liquid fuels. Due to high CO_2 emissions in oil shale conversion, the Estonian government has announced plans to reach carbon neutrality by 2050 and to stop producing shale oil in 2035. The major alternative energy source in Estonia is wind energy, which is considered the most feasible renewable energy source in the country's north-western coastal region and on the western islands. In addition to wind-, bio-, and solar energy, geothermal energy offers a potential sustainable energy source in Estonia as well.

From a geological viewpoint Estonia lies on the southern slope of the Fennoscandian Shield which is composed of Palaeproterozoic metamorphic and igneous rocks, mostly represented by gneisses and granites. The Proterozoic crystalline basement rocks are overlain by the Ediacaran–Devonian sedimentary rock sequence, the thickness of which gradually increases southwards, starting from 130 m in north Estonia and reaching to 700 m in south-west Estonia. The Ediacaran–Devonian sedimentary rock sequence forms a tripartite complex which starts with the Ediacaran–Cambrian siliciclastic package of siltstones, sandstones and claystones, overlain by the Ordovician–Silurian carbonate rocks. The youngest Lower Palaeozoic sedimentary rocks in southern Estonia are represented by the Devonian siltstones and sandstones.

The Ediacaran sandstones form two major aquifers – the Gdov and Voronka aquifers in less than 250 m depth in north Estonia. The Gdov aquifer groundwater which contains high chloride (500–600 mg/l) concentrations in NE Estonia is not usable as a potable water and due to elevated groundwater temperatures in NE Estonia may have a potential for aquifer thermal energy storage (ATES) system applications in this region.

It should be emphasized that the geothermal energy resource potential in Estonia is still understudied. The preliminary data available indicate that the groundwater temperatures, measured at 500 m depth in north Estonia, vary between 13–17 °C. The average heat flow density in Estonia is 35–40 mWm^{-2} (Jõeleht and Kukkonen, 1996). The thermogeological rock properties in northern Estonia on the whole can be considered at least as good as in southern Finland where numerous economically feasible plants already operate.

2. MARKET DEVELOPMENT

2.1 Current shallow geothermal installations

The application of geothermal energy is still very limited in Estonia, particularly when comparing the number of GSHP systems installed in Nordic countries. There are no deep geothermal installations in operation nor in planning phase at the moment. The typical GSHP applications are mostly used for space heating and domestic hot water production for single family houses. Horizontal-loop geothermal systems installed close to the surface into the Quaternary sediments prevail in Estonia due to lower installation costs compared to vertical borehole heat exchanger (BHE) systems. The reported GSHP sales figures over the past decade have been varying between 1000–1600 units per year, however during the last years GSHP sale has increased up to more that 2190 GSHP last year (Fig. 1). For comparison, the number of air-air heat pumps sold may be higher than 12’000 units per year, while the number of air-water heat pumps sold is around 4500 units per year (Estonian Heat Pump Association, personal communication, 2022). As there are no official statistics on heat pump installations, those numbers are based on the Estonian Heat Pump Association estimates only.

Based on the State data, by the end of year 2021, there are about 100 ATES installations and more that 2400 BTES installations operational/commissioned in Estonia.

Because of the current high electricity prices which increased over two times in 2021, the interest in new shallow GSHP installations is high in Estonia. There is growing commercial interest in planning and installation of mid-deep geothermal plants, however, presently there are no site studies or preparations done yet apart the new project financed by the Government.

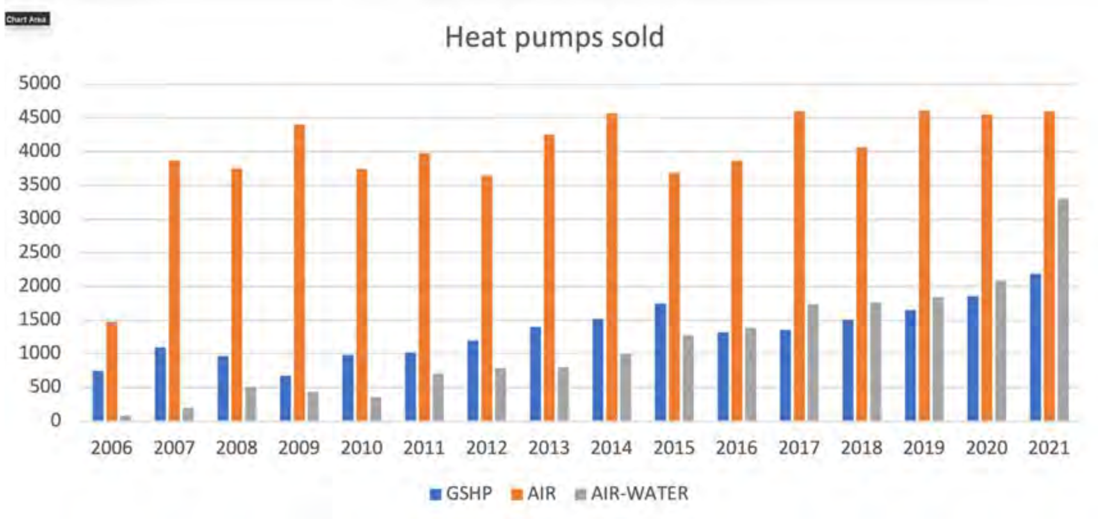


Figure 1: Number of air-air, air-water and ground source heat pumps sold during 2006–2021 (Data source: Estonian Heat Pump Association, 2022).

2.2 Geothermal drilling and pilot plant installation project

In 2021, the Geological Survey of Estonia started a pilot project to explore the geothermal potential of Estonia. The project aims to investigate the usability of geothermal energy and assess the potential of mine water and seawater thermal energy usage. Three target areas are under the investigation: Tallinn capital area (BTES) and northeastern Estonia as a target for possible ATES installation. The third area is located in central Estonia (Roosna-Alliku). Tallinn area would be an important target for follow-up studies and geoenergy pilots as a populated and fast-developing residential and industrial area. There would be markets for a new low-emission energy concept applying geoenergy in heating and cooling systems. Because of higher heat flow in northeastern Estonia, the Narva town region has an increased geoenergy usage potential by using borehole and groundwater applications. The flooded shafts of abandoned oil shale mines could be used as an energy source in the oil shale mining region.

Initiation of a government supported program is suggested to demonstrate the feasibility of versatile geoenergy applications in Estonian conditions, as an integral part of the energy transformation. The research project will be accomplished in cooperation with geothermal energy experts from the Geological Survey of Finland. This would be the way to promote geoenergy for developers and energy companies and speed up commissioning of large-scale geoenergy applications in Estonia.

In addition to applied research, one aim of the project is to raise public awareness and prepare a strategy and action plan for the research and development of geothermal energy in Estonia.

The research project will run until the end of 2024 when two pilot installations will be commissioned. The budget of the project is 3.8 million euros.

3. CONCLUSIONS

The low-temperature shallow geothermal energy is the main heat source for geoenergy applications in Estonia whereas the majority of ground source heat pump applications are used for space heating and domestic hot water production. Shallow horizontal-loop geothermal systems prevail in Estonia due to lower installation costs compared to vertical borehole heat exchanger systems. The number of installed BTES systems is about 2400, with about 400 shallow BTESs installed annually. The number of installed ATES systems is about 100. No research on mid-deep or deep geothermal exploration have been carried out yet. However, the Ministry of Economic Affairs and Communications launched a three-year research project in August 2021 for mid-deep (500 m) geothermal energy usage, which supposedly commences with commissioning of two small-scale geoenergy pilot plants in Estonia.

REFERENCES

Jõeleht, A. and Kukkonen, I.T.: Heat Flow Density in Estonia – Assessment of Palaeoclimatic and Hydrogeological Effects. *Geophysica,* 32, (1996), 291–317.

Tables A, E1 and E2

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	0	0	2337*	5516*	0	0
Under construction end of 2021	0	0			0	0
Total projected by 2023	2					
Total expected by 2028	10					

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	21260	unknown	unknown	2191	unknown	unknown
Of which networks **						
Projected total by 2023						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

	Aquifer Thermal Energy Storage (ATES)			Borehole Thermal Energy Storage (BTES)		
	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold
In operation end of 2021 *	100	H: unknown C: unknown	H: unknown C: unknown	2400	H: unknown C: unknown	H: unknown C: unknown
New (additional) in 2021 *		H: C:	H: C:		H: C:	H: C:
Projected total by 2023		H: C:	H: C:		H: C:	H: C:

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Geothermal Energy Use, Country Update for Finland

Teppo Arola and Meri Wiberg

Geological Survey of Finland, PO Box 96, FI-02151 Espoo Finland

teppo.arola@gtk.fi

Keywords: geothermal energy, Finland.

ABSTRACT

The Finnish geothermal markets are relying on shallow geothermal energy utilisation. Presently, there are at least 45 shallow geothermal borehole heat exchanger sites where one has drilled over 10 km of boreholes in Finland. Shallow geothermal business is growing significantly on large size ground source heat pump category.

The first district cooling geothermal site started as a pilot project in 2020. Energy source is groundwater, and hence it is open-loop system with a cooling power of 1 MW.

The Finnish geothermal market has a strong interest in increasing medium-deep geothermal boreholes (depth 500 to 3000 m). One plan is in operation mode, and five are at the drilling or construction phase.

Another active and growing geothermal area is underground heat storage options. Medium deep and heat storage solutions have introduced new stakeholders to the geothermal business and hence geothermal is rapidly evolving business in Finland.

1. INTRODUCTION

Finland has a long history in geothermal energy R&D work, starting from the late 1970's. Interest in geothermal was triggered by the oil crises. In 1980's several experiences were done to utilise shallow geothermal energy, mainly from closed-loop horizontal and vertical systems but also from open-loop and different energy storage options were studied (eg. Aittomäki 1983, Iihola and Laitinen 1982, Kangas and Lund 1988, Ritola 1994). Technical R&D development was supported by scientific thermophysical studies in 1980's and 1990's (eg. Kukkonen, 1989). However, well started geothermal business suffered due to poor thermogeological design expertise and the possibility of purchasing cheap oil from Russia. For these reasons, geothermal business almost abates in the late 1990's and the beginning of the modern century.

A new strong interest in shallow geothermal utilisation started after 2005. Shallow geothermal was "re-invented" due to the increasing cost of heating oil and electricity. Based on the number of sold ground source heat pump (GSHP) units, the growth was extremely intense from 2005 to 2011 followed by slow depression to current level, which was 9516 GSHP in 2021 (Sulpu 2022). However, even though the number of sold GSHP units has slightly decreased during the last 10 years the tendency has been toward larger units, and hence investments and heat power capacity has been continuously increased from 2016 until today (Sulpu 2022). Total investments for GSHP's were approximately 300 M€ in 2021 (Sulpu 2022). It has been estimated that over 3000 people are currently working in the geothermal industry in Finland.

The driving force for geothermal business development is high heating demand related to modern energy policy in Finland. For example, households used 39,2 TWh of heating energy in Finland in 2021 (Official Statistics of Finland 2022). Also, cooling demand has been increasing over the last 20 years.

Current geothermal utilisation in Finland relies on shallow geothermal systems operating with GSHP. However, there is rapidly increasing interest towards middle-deep (500 to 3000 m) geothermal energy utilisation. One middle-deep geothermal system is working, a few is in drilling phase and more is in planning phase now. There are several reasons for the tendency to drill deeper. The space for drilling in cities is limited. Finnish ground is cold, so one needs to drill deeper to achieve higher temperatures. Currently, shallow geothermal has been property scale business which aims to minimise heating needs from external networks. Higher ground temperatures lure district heating companies to invest in geothermal and hence open possibilities for new geothermal business where geothermal heat can be delivered from the district network. One deep geothermal project has been in development phase, but that project has not progressed as planned during the last years. Almost all geothermal utilisation is related to closed-loop borehole heat exchanger systems. Only a few open-loop systems exist. However, the first district cooling system with cooling power of 1 MW is an open-loop system which started as a pilot project in 2020.

Another rapidly increasing business is geothermal heat storage in Finland. Cities and towns are willing to stop combustion-based energy systems for heat energy production. For that scenario, heat storages are needed to provide enough heating potential for winter.

This paper shows a summary of geothermal systems which are currently operating or are in construction phase. If a geothermal system, for example, geothermal electricity, is not mentioned in this report, such a system does not exist in Finland.

1.1 Thermogeological conditions in Finland

Finland's climate is defined as an intermediate climate with features of both marine and continental climates. The annual average temperature ranges from +5 °C to -2 °C. The wide range of average temperatures is due to Finland's geographical location and the extended area in the north-south direction. The lowest temperatures are as low as -45 °C to -50 °C and the warmest temperature average between 32 °C and 35 °C. Winter typically lasts seven months and snow covers the ground from three to four months in the South and West to more than six months in the North. Annual precipitation in Finland varies between 500 and 650 millimetres. The mean annual ground surface temperatures vary from 7.6 °C in South to 0.5 °C to North.

Finland is located in the Fennoscandian Shield. The age of the crystalline bedrock varies from Archaean (3100–2500 Ma) to Proterozoic (2500–1200 Ma) and is characterised by granitoids, gneisses, migmatites, schists, greenstones, metasedimentary and metavolcanic rocks (Nironen 2017). The bedrock is covered by a thin, almost 100% Quaternary overburden with a mean thickness of 8 m (Lahermo et al., 1990; Lunkka et al., 2004). Groundwater reservoirs in Finland are mostly found in glaciofluvial coarse-grained deposits, i.e. eskers or ice-marginal end moraine complexes, the most extensive of which are the Salpausselkä end moraines.

Finland has a cold and thick lithosphere (Grad et al. 2014) where heat flow varies between 40 to 60 mW/m^2, average being 42 mW/m^2 (Veikkolainen and Kukkonen 2019) and the geothermal gradient varies between 8 and 15 K/km (Kukkonen 1986). The effect of climate change and artificial land use causes a low or negative geothermal gradient from the depth of 10 to 20 m (under seasonal temperature fluctuation zone) to the average depth of 100 to 150 m. “Natural” gradient occurs only after temperature disturbance level.

The Geological Survey of Finland (GTK) has published geothermal potential maps for a) shallow bedrock (below 300 m) heating energy and power potential b) shallow groundwater heating potential and c) deep geothermal district heating potential. GTK has also published a 100 °C contour map (fig. 1). Maps can be downloaded at: https://hakku.gtk.fi/ and https://gtkdata.gtk.fi/maankamara/

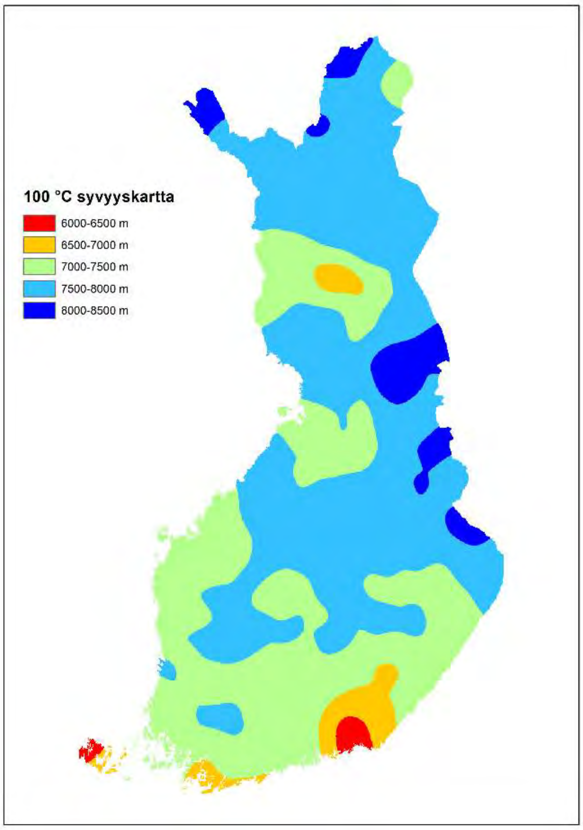


Figure 1. Contour map showing the depth in which the ground temperature can reach 100°C in Finland. The most prominent areas are related to Rapakivi granites and microcline granite intrusions in the Central Lapland.

2. GEOTHERMAL DISTRICT HEATING AND COOLING

Currently, no geothermal district heating plants which produce energy for communal heating networks are in operation in Finland. However, one geothermal district cooling system is operating in Pori, Western Finland. The project is run by local energy company, Pori Energia Oy.

The Pori geothermal cooling system is an open-loop system with one 46 m deep groundwater pumping well. The production well is installed into Quaternary esker deposits. Pumped water is discharged to surface water sewing systems that enter the Kokemäki river. The system started in July 2020 and is still in the pilot phase. It has a cooling capacity of 1 MW and produced 1,2 GWh of cooling energy to the network between July 2020 and August 2021. The production temperature of groundwater is approximately 7 to 8 °C. The system has a pilot permit for operation and continuous environmental impact observation measurements are ongoing. The next step is to apply official permit for continuous operation.

2.1 Medium-deep geothermal systems

Five medium-deep geothermal district heating projects are in drilling or testing phases currently in Finland (table 1). Geographically sites are in Southern Finland.

However, the most optimal location for medium-deep geothermal is Muhos formation near the city of Oulu, central Finland (Martinkauppi and Piipponen 2022).

Five systems will be operated by local energy companies and one, the other Espoo site, is operated by real estate company Nrep Oy. Technically coaxial heat exchanger will be installed into wells and water will flow downwards between heat exchanger and bedrock and heated water will be pumped up inside the heat exchanger. The system can also work in reversible mode. No doublet systems have been tried yet in Finland. This is mainly due to an assumption that the crystalline bedrock has low permeability. All medium-deep geothermal projects require GSHP's to increase the fluid temperature at a reasonable level to DH network. The sites are presented in fig. 2.

Table 1: Medium-deep geothermal DH projects under construction in Finland.

Town	Boreholes (No.)	Depth (km)	Operator
Helsinki	1	2 to 2.5*	Helen Oy
Tampere	1	2.5 to 3**	Tampereen sähkölaitos Oy
Espoo	2	1,5***	Finnoon Syvälämpö Oy
Espoo	3	1,5***	Nrep Oy
Vantaa	3	0.8	Vantaan Energia Oy
Salo	6	1,5 to 2	Lounavoima Oy

*In the Helen Oy project, the aim to produce 0.5 to 0.7 MW of heating power and 0.3 to 0.5 MW of cooling power.
**In Tampere, the aim is firstly to drill at 2.5 to 3 km depth and make further plans according to the results gained from the first stage.
***In both Espoo sites medium-deep geothermal is planned to provide heat to local DH networks.

3. LARGE SCALE GSHP SYSTEMS

Almost 100% of large scale GSHP systems are based on energy wells which are drilled into bedrock. Heat exchangers, mostly U-tubes, are installed into the energy wells. Only one large scale GSHP open-loop system exists in Finland, in Lahti. The sites are presented in fig. 2.

3.1 Individual medium-deep geothermal GSHP systems

One individual medium-deep geothermal system is operating in Espoo by real estate company Nrep Oy. The borehole is drilled to the depth of 1300 m and a steel vacuum insulated tube is used as heat exchanger pipes. Drilling was terminated at a depth 1300 m due to bedrock structure. The temperature at the bottom of well was 25 °C before energy utilisation started. Geothermal gradient is 14,7 K/km at the depth range 200 – 900 m and 16,3 K/km from 900 to 1300 m depth. High geothermal gradient (in the Finnish environment) is due to the occurrence of Rapakivi granites in the area. Rapakivi has a high uranium concentration which leads to high radiogenic heat production.

3.2 Large scale shallow geothermal GSHP systems

Finland has at least 45 shallow geothermal GSHP systems where, collectively, more than 10 km of boreholes have been drilled (table 2 and fig. 2). Most of these systems are also working as seasonal energy storage sites, BTES. The biggest BTES system is the Sipoo logistic centre, where 319 boreholes were drilled to the depth of 300 m. The geothermal industry in Finland is currently following two operational approaches. Firstly, the number of larger BTES systems is increasing. This can be seen from the numbers of sold large GSHP units during in last years (Sulpu 2022). According to the Finnish heat pump association (Sulpu) statistics, >100 kW capacity GSHP were sold 6 in 2017, 11 in 2018, 17 in 2020 and 74 in 2021. The second approach is to drill deeper but still providing the U-tube heat exchanger solution. Nowadays, it is almost routine to drill 400 m deep BHE wells in Finland.

Table 2: Breakdown of large GSHP sites by drilling meters in Finland.

Drilling (km)	Number of sites
10—20	34
20—40	9
40—80	1
Over 80	1

3.3. Energy pile solutions

Energy pile solutions are relatively new and rare in Finland even the first attempts were made over 10 years ago. The most significant project which is in construction phase is in Turku. Under the Turku market square is a postglacial clay formation which is charged and recharged via hundreds (over 500) of energy piles which average depth is 20 to 25 metre. Clay is planned to heat up to 30 to 35 °C during summertime.

4. CONCLUSION

Geothermal energy utilisation in Finland currently relies upon the shallow geothermal systems. Shallow geothermal is and will be a trendy heating energy solution for private houses and for larger buildings. There are at least 45 large shallow geothermal sites operating in the country. Increasing business potential lies in shallow geothermal systems that provide heating and cooling energy for large-scale industrial and apartment buildings or local heating or cooling networks. Shallow geothermal will also provide unique opportunities for heat energy storage option, which is required when cities and towns will transit away from fossil fuels in the heating sector.

Medium-deep geothermal exploration, drilling at a depth of 500 to 3000 m, is growing fast in Finland. However, the high drilling costs associated with uncertainties about a subsurface resource are currently preventing the full expansion of the medium-deep geothermal market. Even though medium-deep geothermal wells have potential to become one of major geothermal solution in Finland, it still needs to further increase R&D work to achieve commercial successful in the heating market. Particularly, the drilling and BHE techniques should be improved and fundamental research defining the thermogeological conditions of the Finnish setting must be refined in detail chasing for new opportunities for geothermal exploration.

Groundwater energy solutions has not yet been widely recognised in Finland. However, the first geothermal communal network system is based on open loop geothermal solution. Finland has a high potential for groundwater energy utilisation (Arola et al. 2014). However, groundwater energy utilisation requires specific thermogeological expertise, which currently is lacking among the Finish geothermal stakeholders.

REFERENCES

Aittomäki, A. Maaperä ja vesistöt lämmönlähteenä. Tampere University of Technology report 37 (1983).

Arola, T., Eskola, L., Hellen, J. and Korkka-Niemi, K. Mapping the low entalphy geothermal potential of shallow Quaternary aquifers in Finland. *Geothermal Energy* 2:9 (2014) doi:10.1186/s40517-014-0009-x.

Grad, M., Tiira, T. & ESC working group. European plate Moho depth map. *Poster on Litospehere symbosium, Helsinki 2010*. Helsinki (2010).

Iihola, H. and Laitinen T. Pohjavesivarojen energiataloudellinen hyödyntäminen. Oy Vesi-Hydro Ab. Project report. (1982).

Kangas, MT. and Lund PD. Thermal Analyses of Aquifer Energy Storage Systems. Helsinki University of Technology report TKK-F-A-623 (1988).

Kukkonen, I. Terrestrial heat flow in Finland, the central Fennoscandian Shield. Geological Survey of Finland Report YST-68 (1989).

Kukkonen, I.T. The effect of past climatic changes on bedrock temperatures and temperature gradients in Finland. Geological Survey of Finland, Nuclear Waste Disposal Research. Espoo (1986).

Lahermo, P., Ilmasti, M., Juntunen, R. and Taka M. The hydrogeochemical mapping of Finnish aquifers. *Geochemical Atlas of Finland, part 1*. Geological Survey of Finland. Espoo. 66 pp. (1990).

Lunkka, JP., Johansson, P., Saarnisto, M. and Sallasmaa, O. Glaciation in Finland. In: *Ehlers J, Gibbard PL (eds) Quaternary Glaciations – Extent and Chronology*. Elsevier, Amsterdam. pp. 93-100. (2004).

Martinkauppi, A. and Piipponen, K. Possibilities for medium-deep geothermal energy utilization in the Muhos Formation, northern Finland. Accepted research paper to European Geothermal Congress 2022, Berlin, Germany, (2022).

Nironen, M. Bedrock of Finland at the scale 1:1 000 000–Major stratigraphic units, metamorphism and tectonic evolution. *Geological Survey of Finland. Special paper 60*. Espoo Finland (2017)

Official Statistics of Finland (OSF): Energy consumption in households [e-publication]. ISSN=2323-329X. 2020, Appendix table 2. Energy consumption in households by energy source in 2020, GWh . Helsinki: Statistics Finland [referred: 19.4.2022]. Access method: http://www.stat.fi/til/asen/2020/asen_2020_2021-12-16_tau_002_en.html

Ritola J. Sjökulla high temperature pit storage with menbrane liner. *Proceedings of the Colorstock'94*, Espoo, Finland (1994).

Sulpu (Finnish Heat Pump Association). Heat pump sales statistic for 2021 (2022). Statistics available: https://www.sulpu.fi/wp-content/uploads/2022/01/Heat-Pump-market-in-Finland-2021-slidesf-1.pdf

Veikkolainen, THK and Kukkonen, IT. Highly varying radiogenic heat production in Finland, Fennoscandian Shield. *Tectonophysics, vol. 750, no.1. (2019)*, pp. 93-116. https://doi.org/10.1016/j.tecto.2018.11.006.

Acknowledgements

Authors express their gratitude to the following companies and individuals:

- Helen Oy, Sami Mustonen
- Tampereen sähkölaitos, Mika Pekkinen
- Renor Oy, Timo Sinelampi
- Pori Energia Oy, Ari Savola
- Nolla€, Jerker Brandt
- Geological Survey of Finland, Sami Vallin, Alan Bischoff and other Geothermal energy team members.

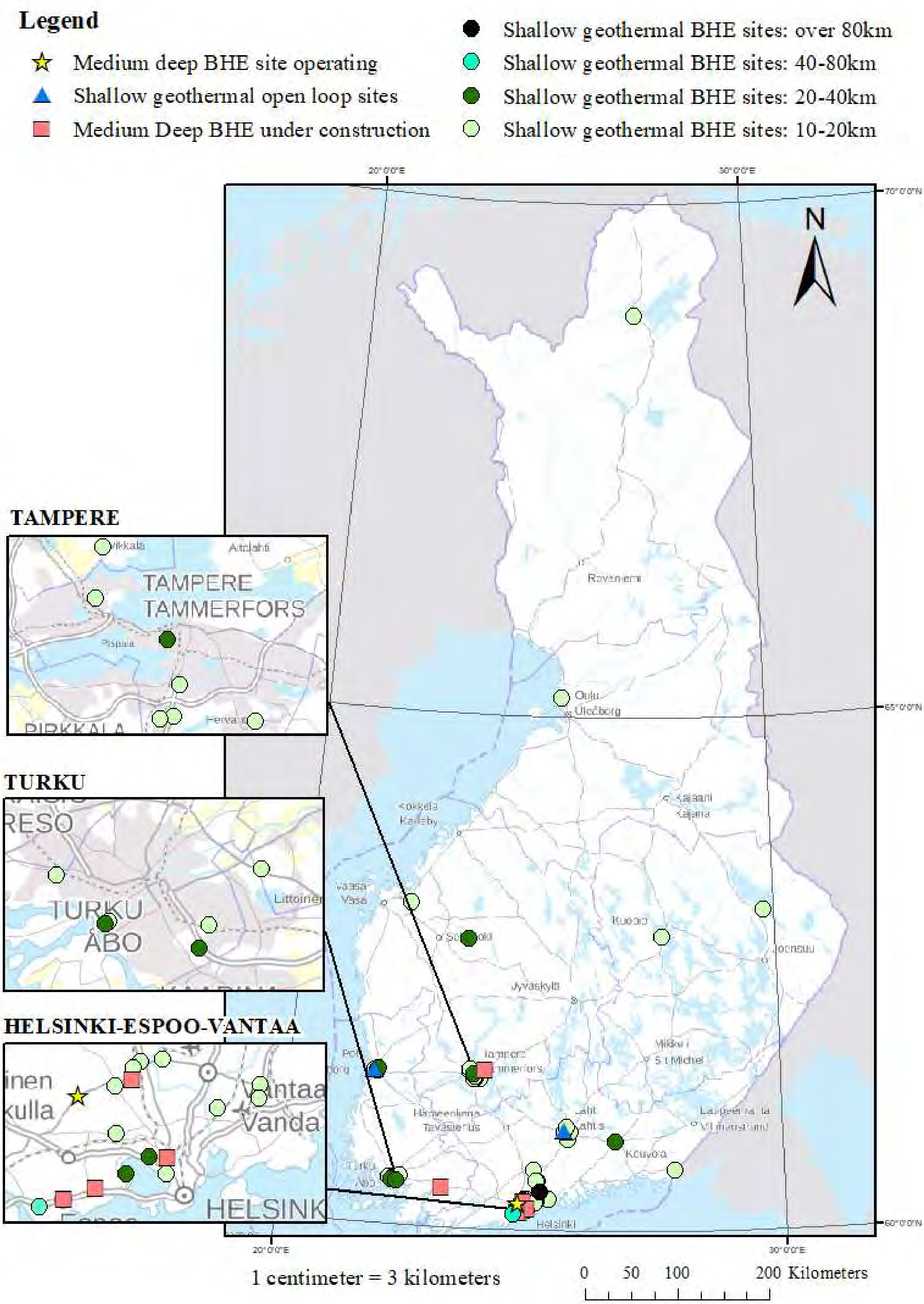


Figure 2: Large scale geothermal sites in Finland.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers –

No geothermal power plants exist currently in Finland.

Table B: Existing geothermal power plants, individual sites

No geothermal power plants exist currently in Finland.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	1 (note: cooling plant)	1 to 1,5 (note: cooling plant)						
Under constru-ction end 2021***	est. 5 to 6	est. 15						
Total projected by 2023***	est. 10 to 15	est. 30 to 40						
Total expected by 2028***	est. 50 to 60	est. 150 to 200						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

*** Estimations: heating power and energy from ground, before heat pump.

Table D1: Existing geothermal district heating (DH) plants, individual sites

No geothermal district heating plants exist currently in Finland.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Espoo	Koskelo	2019	Y					Nrep Oy
total								

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	175 000	est. 2000		9516	est. 160	est. 50
Of which networks **						
Projected total by 2023	est. 190 000	est. 2200				

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No geothermal UTES plants exist currently in Finland.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power				
Geothermal direct uses				
Shallow geothermal	300	est. 3000 to 3500	est. 350	est. 3500 to 4000
total				

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D			
Financial Incentives – Investment			
Financial Incentives – Operation/Production			
Information activities – promotion for the public			
Information activities – geological information			
Education/Training – Academic			
Education/Training – Vocational			

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for France

Virginie Schmidlé-Bloch[1], Armand Pomart[1], Christian Boissavy[1], Camille Maurel[2], Mikaël Philippe[2], Astrid Cardona-Maestro[3], Albert Genter[4]

[1]AFPG – 77 rue Claude Bernard, 75005 Paris – France

[2] BRGM – 3 avenue Claude-Guillemin, 45060 Orléans Cedex – France

[3]ADEME – 500 Route des Lucioles, 06560 Valbonne – France

[4] Électricité de Strasbourg Géothermie – 26 Boulevard du Président Wilson, 67000 Strasbourg – France

virginie.schmidle@afpg.asso.fr

Keywords: Electricity generation, EGS, heating and cooling production, geothermal HP, R&D, energy targets 2030 PPE, France

ABSTRACT

The last market study (edition of 2021, figures of 2020) carried out in France by the French Association of Geothermal Professionals (AFPG) regarding the geothermal domain has demonstrated that the installed power for heating and cooling reaches 2500 MW_{th}. Nearly 600 MW_{th} are related to the exploitation of the deep reservoirs in the Paris area in 2020 and the remaining majority is linked to recent and strong development of shallow geothermal resources over the whole country.

The market for single housing using vertical geothermal probes has however dramatically decreased since 2009 due to the competition with natural gas and tax credit at 30 % for geothermal heat pump without any bonuses compared to the installation of efficient gas boiler or air-air heat pumps. The market for single housing has decreased by almost 88 % between 2010 and 2018, from more than 20’000 installations to less than 2500. On the contrary, the number of installations to feed collective housing and residential blocks including office buildings is growing constantly.

There are 72 deep geothermal installations in 2020 for direct uses and the majority is concentrated mainly in the Île-de-France region. Geothermal doublet constructions have been facilitated with the support of the Heat Funds managed by ADEME. Since 2018, around 10 new doublets were drilled in Île-de-France. The main barrier remains the energy calculation rules for new buildings (RT2012) which still encourage gas over geothermal energy.

For electricity generation, no more installations have been commissioned, but the Soultz-sous-Forêts plant has been revamped. The Bouillante plant has been sold by BRGM to ORMAT in 2016 and the plant capacity will be increased from 15.5 MW_e in 2020 (and in 2021) to 25 MW_e in the coming years with the building of new units. Two geothermal sites are currently in stand-by (doublets between 3500 and 5000 m depth) around Strasbourg. Another site in Massif-Central has just received the authorization to drill.

1. DIRECT USES OF DEEP GEOTHERMAL ENERGY

Direct uses of deep geothermal energy in France can be considered over nearly half of the territory due to large sedimentary basins (Paris Basin, Aquitaine Basin, Rhine graben, Limagnes, Bresse and Rhodanien corridors, South-East Basin). In France, geothermal direct uses deliver energy to district heating networks, greenhouses and fish farms, industrial processes, swimming pools and thermal baths.

1.1 Objectives

French authorities, with consultation of geothermal players, have planned an ambitious objective to reach 3 TWh of heat production by 2023, and between 4 and 5.2 TWh within 2028 which means doubling geothermal heat production within the 2030 horizon. CAPGEMINI Invent has estimated that between 6 and 10 new installations (mainly doublets) per year should be implemented to reach these objectives.

It is now essential that new geothermal projects be developed beyond the Dogger limestone aquifer in the Paris Basin, in new aquifers and formations that have been less explored or exploited up to now.

1.2 State of the art

Geothermal energy for direct uses found its first application in France in the 1970’s. Indeed, the oldest installation is located in Melun-l’Almont (Île-de-France region) and was commissioned in 1969. The installation has now been extended and a doublet remains in operation in 2022.

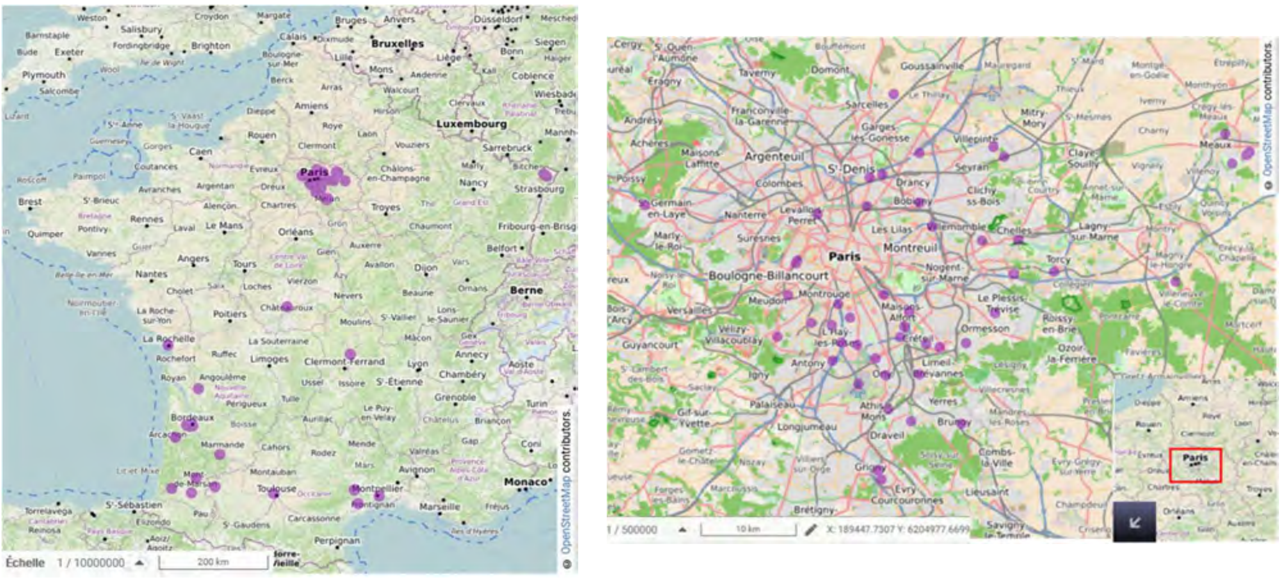
Geothermal competitiveness was supported by high fossil fuels prices in the 1980's. Then, for 20 years on, the development of the resource has been deserted due to the abundance (and relatively low price) of natural gaz. Deep geothermal exploitation resumed in 2008 and 2009 thanks to the launch of the Heat Fund (*Fonds chaleur*) from ADEME (French ecological agency) which aimed at supporting the development of thermal renewable energies and facilitated the creation of new doublets.

a) Synthesis of deep geothermal plants in France for heat distribution

In 2020, 72 geothermal operations are responsible for the production of 2.0 TWh of heat in France (Figure 1a) and 87% of the energy is delivered through district heating networks (DHN), mostly in the Île-de-France region (Paris area as shown in Figure 1b) according to the deep geothermal database *Sybase* (BRGM). There are 41 doublets and 7 triplets (generally two producers and one injector) in operation in 2020 in this region alone. Most of them valorises heat at a depth between 1500 and 1900 m in the Dogger limestone (Middle Jurassic) aquifer.

The Dogger reservoir covers an area of over 150 000 km² with the temperature measured directly below the Paris region varying between 56°C and 85°C according to the depth of the reservoir. To a lesser extent, the sand aquifers of the Albian and the Neocomian (Early to Lower Cretaceous) are also targeted in the Île-de-France region with depths between 500 and 800 meters and temperatures varying between 25°C and 30°C.

Other deep installations are dispatched mostly over the Aquitaine Basin where 14 sites are currently active, for a total heat production of 107 GWh delivering energy to greenhouses, fish farming and swimming pools or thermal baths.



a. b.

Figure 1.a and 1.b: Deep geothermal operations in France and in the Île-de-France region for heat production (source: Sybase ADEME & BRGM 2022).

An installation for industrial purpose is located in the Grand-Est region (Rittershoffen in the Rhine graben, former Alsace region) and produces about 10 % of the total French heat production from deep resources in 2020 (182 GWh_{th}). The plant supplies high temperature heat to an agro-industrial site. Other production sites are located in the Occitanie region (near Toulouse, Montpelier, Pézenas), in the Centre Val-de-Loire region (in Chateauroux) and in Auvergne (Aigueperse). Small geothermal installations located in the former Lorraine region are now closed.

b) Exploitations over the Paris and Aquitaine Basins

Over the last 3 years, 3 operations have been developed in Paris area to replace old doublets (Bonneuil-sur-Marne 2, Cachan 3, Vigneux-sur-Seine 2). Since 2018, 10 new doublets have been drilled (including the 3 previous sites, Bordeaux PGE, Bobigny-Drancy 1 and 2, Champs-sur-Marne, Evry, Rueil-Malmaison, Vélizy-Villacoublay) and a simplet (Saint-Germain-en-Laye). This site has the specificity of being a drinking water well in which heat is valorised to supply a district heating network. Two projects of oil and geothermal energy co-production have also been connected to buildings in Aquitaine Basin (near Arcachon).

For old doublets, the development strategy is in general to drill a new production well in larger diameter (generally 8" or 8"½) in order to increase the flowrate of the installation from 200-250 to 300-350 m^3/h and operate as a triplet. Finally, when a well of the triplet sees its performances decrease, a fourth well can be drilled so that the initial doublet is abandoned to operate with a new doublet.

In 2020, between 4000 and 8240 housing equivalents can be heated and supplied with domestic hot water by one deep geothermal installation supplying a district heating network in the Paris region (Sybase, 2021). The extracted power per installation can be increased thanks to high temperature heat pumps that will lower the reinjection temperature. Approximately 1 million people are living in spaces heated with deep geothermal energy in France (mainly in Île-de-France).

The DHN supplied by the geothermal resource of the Dogger limestone aquifer are mainly exploited by private companies such as *Dalkia* (*EDF Group*), *ENGIE Solutions* (*ENGIE Group*), *IDEX Energie* and *Coriance*, but also by local public-private ventures (*Sociétés d'Economie Mixte*). Some of the DHN have been in operation for more than forty years. The average availability rate approaches 95 % in the Paris Basin.

Recently Albian and Neocomian aquifers (Early to Lower Cretaceous) have been used for geothermal district heating and cooling application using heat pumps. In 2020 there were 6 doublets targeting this resource: Paris Mirabeau, Issy-Les-Moulineaux, Le Plessis-Robinson, Paris-Batignolles. Saclay 1 and Saclay 2. Due to reinjection problems and screen clogging with fine particles, some of these installations have not been able to produce at nominal flow rates and investigation are currently being carried out to investigate the mechanisms at stake. In 2021, a new well has been completed in Saint-Germain-en-Laye in the Albian sand aquifer with the double objective to produce heat and supply drinking water. Heat will be valorised before the production of drinking water and will allow overcoming the reinjection issues faced in these clastic environments.

The second largest zone for direct use in France is the Nouvelle-Aquitaine region (South-West of France) where 13 single production wells, one doublet (Bègles) and three co-production installations (oil and heat) are currently in operation in 2020. These installations were set up in the beginning of the 1980's and the vast majority were built as single well installations as geothermal water discharge could be managed at the surface. Nowadays, secondary uses of the resource, as irrigation and agricultural uses are also investigated, along with reinjection of fluids using the doublet technology for new installations.

In this region, a new plant will be launched in 2022 on the right bank of the Garonne river in Bordeaux. The plant will supply a DHN build by ENGIE using the doublet technology. The target was initially the limestones dating from the Jurassic, which were never targeted before in the sector. Finally, as the limestones were not productive in the specific area investigated, the doublet was reoriented to produce from the well-known reservoir of Cenomano-Turonien sandstones (notably exploited over the area for geothermal uses).

1.3 Innovations

Recent technologies have been developed to exploit the Dogger reservoir of the Paris Basin: the use of multi-lateral wells to increase production and injection indexes and the deployment of composite materials in order to cope with corrosion problems.

- **Use of composite casings**

In 2018 in Bonneuil-sur-Marne a new production well has been drilled in order to replace an old well in small diameter and out of order. The use of composite casings (see Figure 2) has been already tested in the Villeneuve la Garenne installation in 1976, in the Melun installation (which remains active in 2021) and also in La Courneuve Sud where the pumping chamber was equipped partly with a composite casing. At this site, the composite casing was extracted 13 years after being installed and showed no sign of wear. More recently, in 2015, CFG installed composite in Chevilly-Larue and L'Hay-Les-Roses to reline two production wells with an excellent result. This technology can be considered as an interesting alternative to standard steel casings to facilitate high production flow rates and to avoid corrosion and scaling.

Recent laboratory studies conducted by CFG have shown that a composite casing cemented in a new well has 1000 times more wear than a steel casing. The study also revealed that rubber protections can largely reduce the wear phenomena (to reach the same level as in a steel casing). Payback time is expected at 15 years in comparison with the use of traditional materials.

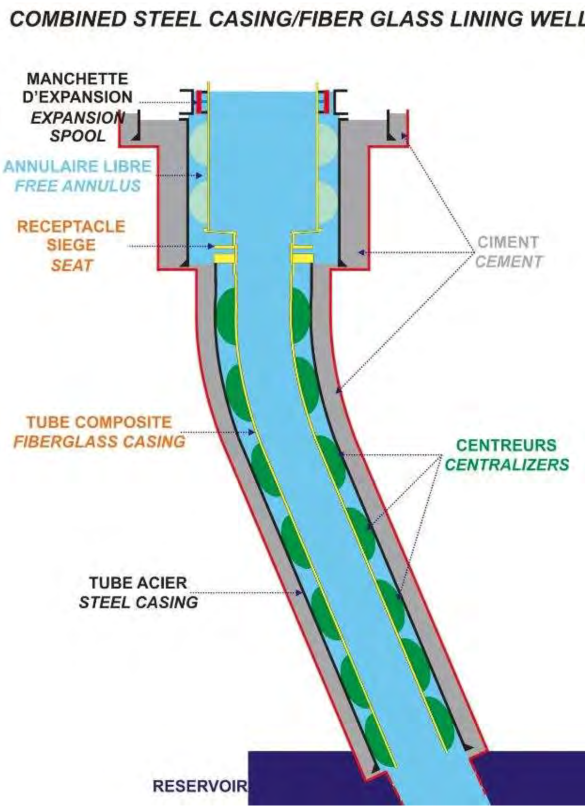


Figure 2: Concept of composite casing installed in Bonneuil (source: GPC IP).

- **Multi-lateral well in Vélizy-Villacoublay**

Below Vélizy-Villacoublay (Paris area), the Dogger limestone aquifer is known to be less favourable for the development of geothermal energy as petrophysical properties are degraded compared to areas targeted until now. With a conventional doublet using two deviated wells, the project would have most probably been un-economical.

ANTEA Group and ENGIE Solutions have designed a special well architecture to maximize the exchange surface in contact with the targeted Dogger reservoir (see Figure 3 and 4). At the bottom of both production and injection well, U shape drains were drilled in addition to the classical termination of well (i.e. sedimentation leg). The angle (70°) is higher than in a deviated well to better penetrate the reservoir. RSS Archer (Schlumberger) was used to drill these drains. After acidification, the results are the following:

- Productivity index multiplied by 6.4;
- Flowrate above 320 m^3/h (expected 200 m^3/h with a traditional architecture).

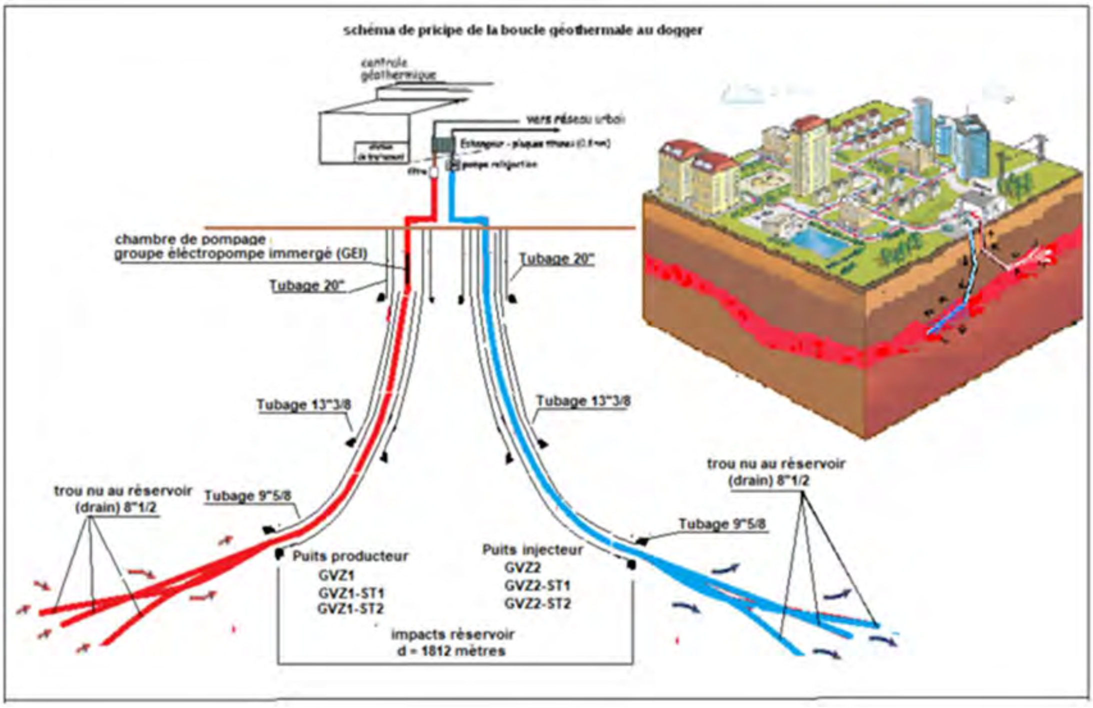


Figure 3: Presentation of Vélizy-Villacoublay project (source: ENGIE).

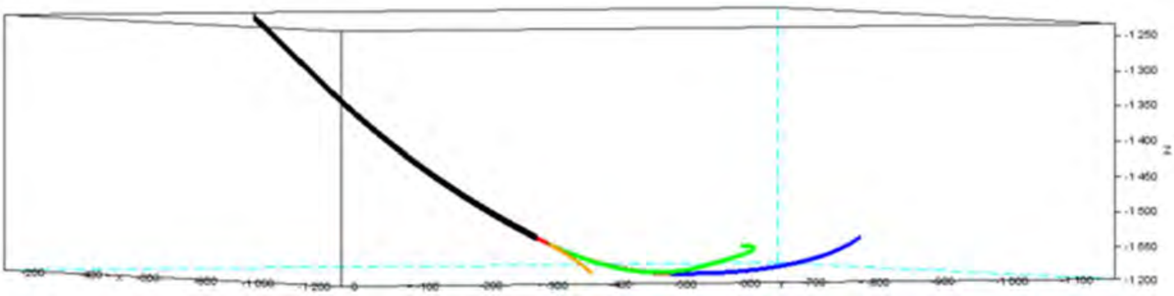


Figure 4: Multilateral well architecture, also called U-drains (source: ENGIE).

1.4 Perspectives

In the next years, deep geothermal operations are expected to quickly grow to reach the objectives formulated by the French government (PPE 2019). A dozen projects are planned to be drilled in the next 3 years and a dozen more, under studies, are foreseen in 3 to 6 years. A majority will be located in the Paris area and other will explore other basins (Aquitaine, South-East, Limagnes).

In the North of Alsace, several research licences (PER) have been attributed to the company *Lithium de France* to develop a project of heat and Lithium production in fractured reservoirs.

2. ELECTRICITY GENERATION

In terms of electricity production from deep geothermal resources, three thematical areas can be distinguished in France: electricity production in volcanic regions, from EGS reservoirs and from crustal faults.

2.1 State of the art in volcanic areas

For volcanic reservoirs, a single plant is currently in operation: the Bouillante geothermal plant located in Guadeloupe and operated by ORMAT. The capacity of the plant in 2021 is 15.5 MW_e. A magneto-telluric (MT) exploration campaign has been carried out over the geothermal field in order to understand the distribution of the resources in an attempt to extend the geothermal field in the coming years.

The plant is producing about 115 GWh per year of electricity, which corresponds to about 10 % of the Guadeloupe island needs. A project known as Bouillante 2 expects to drill two new geothermal wells at depth in between 1000 and 1600 m. The additional power expected is around 10 MW_e.

At the south of Bouillante (and at the South of the island), a new exploration licence has been attributed to *Albioma*. Additional exploration works are also going one in Martinique with a consortium of *Storengy* and *TLS Geothermics*. In La Réunion Island, a licence has been attributed to *ENGIE* to explore the Cafres-Palmiste area.

2.2 State of the art in EGS reservoirs

In France, and particularly in the Upper Rhine Graben, geothermal development takes place since decades thanks to the expertise developed for Enhanced Geothermal Systems, with the European pilot at Soultz-sous-Forêts (Vidal and Genter, 2018). The main geothermal projects running on the French side of the Upper Rhine Graben (Alsace) are the world-wide known Soultz-sous-Forêts power production plant and the most recent Rittershoffen heat plant. In parallel to electricity production of this site with an ORC, tests were performed using a mobile ORC to cool down the reinjection brine (H2020 MEET project).

Geothermal development around Strasbourg is in standby since the seismic crisis that occurred in 2020. The project of Vendenheim was stopped due to the links between the tests and these seismic events. The Illkirch site will probably restart in the next years. Moreover, a large exploration phase was performed by Electricity de Strasbourg with the acquisition of the first 3D seismic survey for deep geothermal energy in France (in Northern Alsace in summer 2018) (Richard et al., 2019).

The Soultz site has been successfully commissioned as industrial geothermal electricity site in 2016 thanks to a geothermal fluid at temperature higher than 150 °C. Since the geothermal water shows a high salinity (TDS around 100 g/l), the heat of the geothermal water is exploited via heat exchangers by an ORC (Organic Rankine Cycle) unit of 1.7 MW_e gross power (Figure 5). The brine is discharged at 150 °C on surface and then reinjected into the crystalline reservoir at 60-70 °C through two reinjection wells. The geothermal loop is composed of one production well GPK-2 and two reinjection wells GPK-3 and GPK-4. All three wells are 5 km deep and are cased to roughly 4.5 km in the granitic section. Below that depth, the reservoir is made of crystalline basement and underwent various kinds of hydraulic and chemical stimulations in the past and several periods of long-term circulations.

Figure 5: Aerial view of the Soultz-sous-Forêts binary plant (source: GEIE EMC).

Induced seismicity monitoring of this site is permanently performed through a network of seismological stations installed on surface (Maurer et al., 2017). It must be noticed that none of those events were felt. For both year 2017 and 2018, the availability of the Soultz-sous-Forêts geothermal plant reached 90 % of the time, including several weeks of planned maintenance stop.

Occurrence of micro-seismicity in the Upper Rhine graben has always been a subject followed closely. The seismic event of November 2019, situated at 5 km of the geothermal well of Vendenheim, has led to acceptability problems with the local population and in the whole territory (as well in new shallow geothermal projects as in deep geothermal projects in other geological contexts).

In October 2020, several seismic episodes were felt and are clearly linked with the tests carried out at the plant. In December 2020, the operator stopped all activities on site. Following these events, 3 working groups were etsablished: one with companies from AFPG (and EGEC), aiming at identifying good practices about these kinds of projects; one piloted by the Ministry of the Ecological Transition aiming at writing practical recommendations for both operators and public entities; and one piloted by the Prefecture of Strasbourg aiming at analysing the decisions taken on site.

2.3 State of the art in crustal faults system

Numerous exploration licences were attributed to a consortium of *Storengy* and *TLS geothermics* in the Massif-Central. The targeted reservoirs are crustal faults zones with expected hot fluids circulating through.

In April 2022, the first drilling operation licence was attributed to *Geopulse* for the drilling of two doublets at around 3500 m and 180 °C expected. The first megawatts of electricity could be produced in 2024-2025.

2.4 Generalities

In 2015, the geothermal cluster GEODEEP has been founded. It is made of large companies with experience in Research & Development, studies, project development, power plant equipment, operation and maintenance, engineering firms developers/integrators specialised in geothermal energy, ESCO's and the Geothermal French association of professionals. Apart from a strong common action to promote the French geothermal offer abroad, the cluster did achieve the creation of a risk mitigation fund.

A lithium cluster is currently under development. As for GEODEEP, the goal is to gather French companies working on the different parts of the value chain of lithium extraction, refining and utilization. Lithium is indeed naturally present in some geothermal brine (especially in the Rhine Graben). So, it represents the possibility of a low carbon lithium extraction, essential metal for the energy transition.

Finally, the feed in tariffs for geothermal energy have been abrogated. Only projects already approved by the Ministry will still benefit of the tariff of around 250 €/MWh close to the same amount in force in Germany. All other electric projects will benefit of the national tariff.

3. GEOTHERMAL HEAT PUMPS

The French geothermal heat pump market consists mainly on single-family home installations. The French geothermal actors estimate 205'000 geothermal heat pumps in operation in France in 2020, including 195'000 individual housing heat pumps. This trend could change in the coming years, the individual housing geothermal heat pump market being at a low level after a significant increase up to 2008 (Figure 6). The substantial decrease since 2009 could be stopped in the last 5 years, but the market which is facing the competition of air/water and air/air systems remained at a low level.

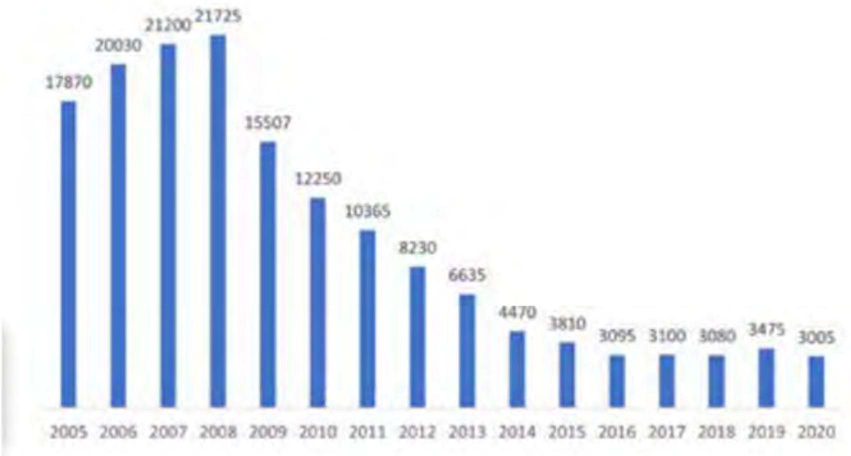


Figure 6: Sales evolution for geothermal HP (<30kW) in individual housing (2005-2020) (source: Observ'ER).

In contrast, the number of geothermal heat pumps dedicated to the collective housing and tertiary sectors is growing slowly. However, it should be noted that the collective housing geothermal heat pumps in operation is close to zero (2300 heat pumps).

In 2021, BRGM and AFPG, in liaison with ADEME, achieved a capitalization and dissemination of every geothermal heat pump systems through cartographical websites (https://www.geothermies.fr/viewer/). Figures 7 and 8 illustrate the geographical distribution of the systems (mainly vertical borehole heat exchangers and aquifer doublets) in coherence with the geological context, sedimentary basins being favorable for the aquifer systems deployment. Figures 7 and 8 do not represent the completeness of the operations for several reasons: data collection yet incomplete, difficulty to collect the data of very shallow ground heat exchanger operations (<10 m).

Horizontal loops are still representing a quarter of the geothermal market for individual housing and thermo-active foundations remain currently largely underdeveloped.

Individual housings can benefit from a state aid called "MaPrimeRénov" related to their revenue and if they undertake renovation projects in their home. The amount of this bonus is increased for the installation of a geothermal heat-pump. As higher incomes and new building are not considered in "MaPrimeRénov", the benefits on shallow geothermal heat pump sector are still not enough to revitalize that market.

For vertical borehole heat exchangers, Observ'ER determined distributions between installations in new building or renovation. For private housing installations, this is 18 % for new and 82 % for renovation. For collective installations, this is 40 % for new and 60 % for renovation.

For the collective buildings (housings, office, hospital, municipality buildings), a study published by Observ'ER (2020) estimates that there have been an additional 110 operations in the residential sector while we can count 445 new operations in the collective sector. This represents an additional 71 MW_{th} installed capacity for French residential and collective sectors in 2021.

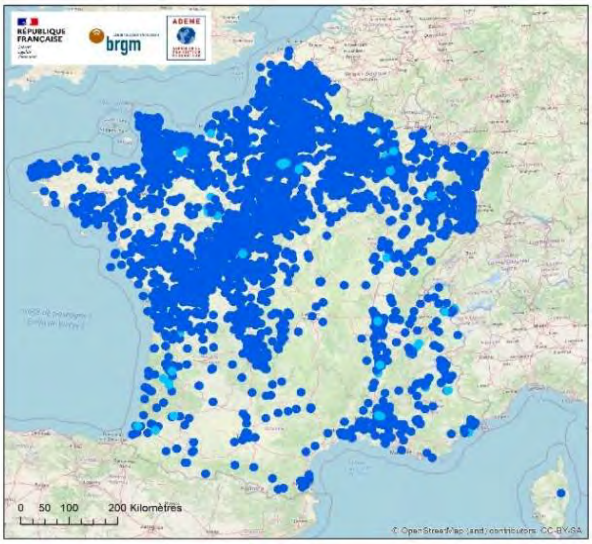


Figure 7: Geographical situation of the 6050 aquifer ground source heat pumps declared in April 2022.

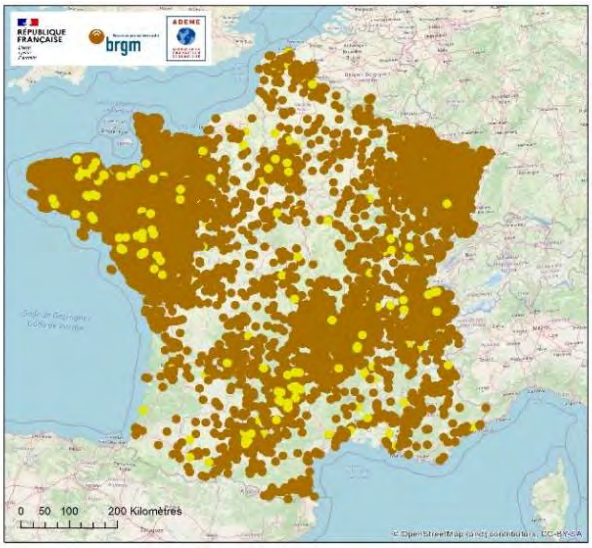


Figure 8: Geographical situation of the 22'447 borehole ground source heat pumps declared in April 2022.

New concepts and technologies could boost the ground source heat pump market in the coming years. The new concept of a low temperature geothermal loop delivering cold and heat energy is now in application in several towns with average installed power between 1 and 4 MW. New concepts of very shallow closed-loop heat exchangers such as helicoidal heat exchangers are also emerging. Since the beginning of 2022, ADEME Heat Funds also supports the installation of geothermal helicoidal heat exchanger.

3. GEOTHERMAL SECTOR DEVELOPPING STRUCTURES

3.1 Schemes to support the geothermal energy industry

France has developed different schemes to help the development of the geothermal sector. One of them is the **mitigation tool for geological risks**. This risk is linked to the fact that the exploitable geothermal energy resource can only be known after the drilling of the first borehole. This costly operation (more than 5 Million € at 2000 m geothermal target) which may result in failure (e.g. due for instance to a lack of resources, to insufficient temperature or exploitable flow rates in relation to the forecasts, or to the inability to exploit the geothermal fluid due to aggressive geothermal fluid for example). For deep aquifers used for heating production, the guarantee (SAF Environment) is existing since now 36 years and has proved is efficiency. In order to reach the target set up by the French Energy programming, i.e. a 4–5.2 TWh range by 2028, ADEME has launched works to reshape the "*Fonds SAF"* scheme to be in capacity to support financially and in the long run this volume of deep geothermal projects. The philosophy of the new Fund is based on an extension of the 90 % guarantee to all of France with a segmentation of zones according to their level of geological risks.

For shallow drilling ranging between surface and 200 m depth, there is the guarantee "Aquapac" (funded by ADEME, EDF and SAF), in place since 30 years, which covers the geological risk of the first drilling and the geothermal production during an exploitation period of 10 years. Furthermore, there is a financial supporting scheme even if the operation is a success. For heating production, the **Renewable Heat Fund** (*Fonds Chaleur Renouvelable* in French) was created in 2009 for collective housing, tertiary, industry and agriculture. At the end of 2020, 678 geothermal installations (for district heating and geothermal heat pump) have been subsidized by the Renewable Heat Fund:

- 361 vertical borehole heat exchanger operations: 37'500'000 € for 51.8 MW of installed capacity;
- 224 aquifer operations: 29'300'000 € for 104.6 MW of installed capacity;
- 19 operations on sea water: 12'600'000 € for 46.7 MW of installed capacity;
- 74 sewage operations: 26'600'000 € for 80.3 MW of installed capacity.

This represent a total amount of 106 M€ for the geothermal industry. In Figure 9, the repartition of these subsidies by regions is shown, as recorded by the number of facilities supported between 2009 and 2018.

3.2 French regulation

Geothermal energy is ruled by the French Mining Code and subject to declaration or authorization in accordance with Figure 10. Concerning the shallow thermal energy, a new law has been adopted on January 2015 and applications measures orders are now operational since July 2015.

- **general requirements** for shallow geothermal energy activities: conditions relating to the layout of an installation, measures to the implemented on performance, conditions of sale and exploitation as well as the terms of surveillance and maintenance of the installation.

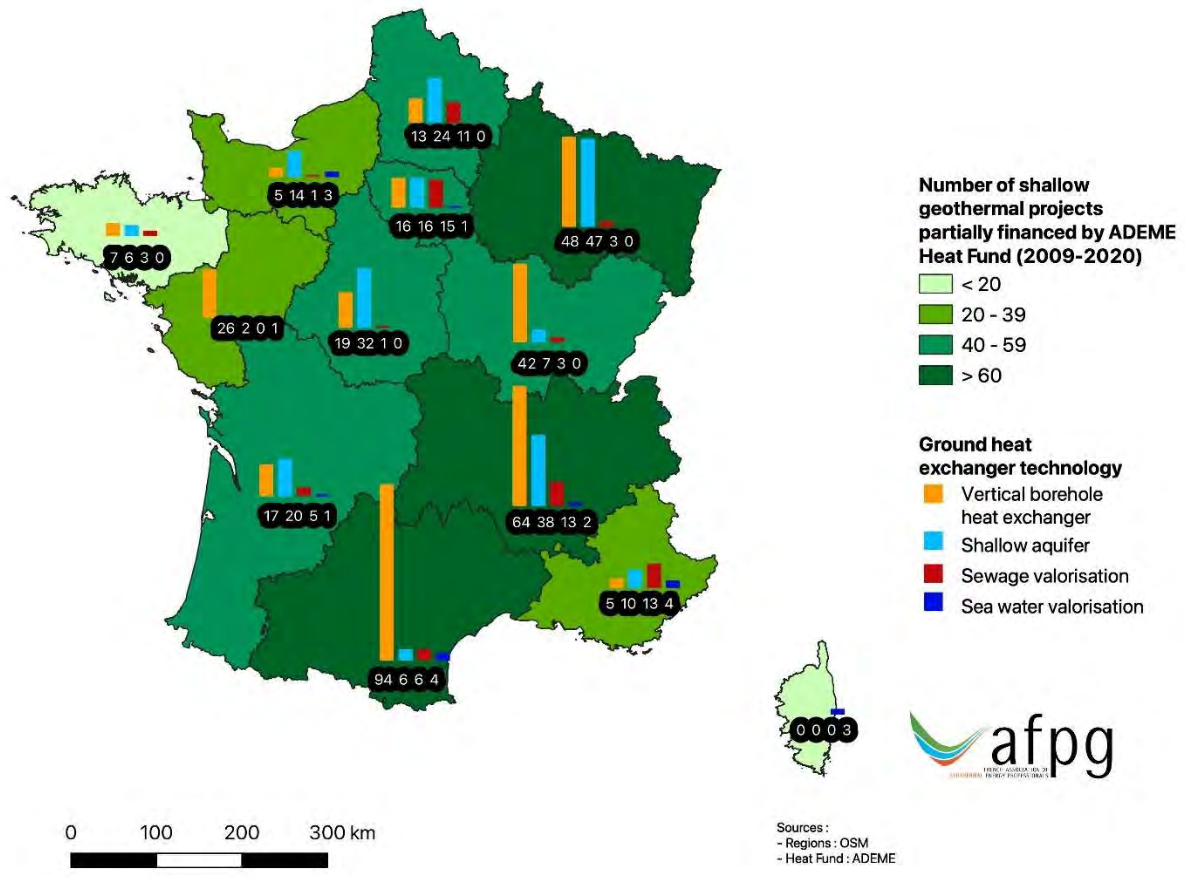


Figure 9: Total geothermal projects supported by ADEME Heat Fund between 2009 and 2020 (AFPG based on ADEME data).

- **qualification of drilling companies** working on shallow geothermal energy systems: obligation to perform drillings by qualified companies (RGE QualiForage).
- **cartography of statutory zones**. On a national scale, this relates to two maps, one for closed-loop exchangers and one for open-loop exchangers handling zone 10 at 200 m. These maps may be broken down, on a regional level, for 3 depth intervals: 10-50 m, 10-100 m and 10-200 m. They define 3 distinct statutory zones:

  - "green" zone: the declaration system applies;

  - "orange" zone: the declaration system applies whereby the bidder is required to provide a "certificate of compatibility" from an export to perform the project;

  - "red" zone: the geological risks shown on the cartography of the statutory zones exclude the benefit of the simplified administrative system for shallow thermal energy.
- **expert approval** for shallow geothermal energy systems: lays down the terms of approval of experts and the skills required.

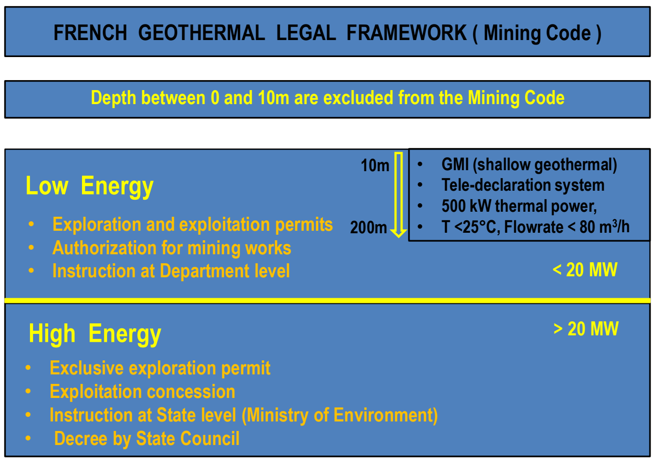


Figure 10: Synthesis of the French regulations for different geothermal exploitations.

4. SUPPORT FOR R&D AND INNOVATION

To boost innovation, the French government put in place the “Investments for the Future” program that funds several R&D actions. In 2011, it called for proposals to fund innovative deep geothermal heat and/or power generation demonstration projects. Among the proposals submitted in March 2012, only two about high-temperature geothermal developments were accepted, giving new opportunities to the French industry and opening new perspectives:

- the GEOTREF project in the "Vieux-Habitants area" in Guadeloupe (French overseas department, Lesser Antilles), with the Teranov company as leader.
- the FONGEOSEC project with Fonroche géothermie as leader

ADEME (the French Agency for Environment and Energy) launched in 2018, as part of "Investments for the Future", a new call for projects to accompany the development of renewable energies. Theme 4, focused on geothermal energy, deals with projects whose objective is to improve the competitiveness of the geothermal industry by:

- reduction and control of all the costs related to energy production (heat and / or electricity);
- increasing the potential of exploitable geothermal resources;
- better acceptance and territorial integration of geothermal projects.

The main part of the national R&D budget for geothermal energy is managed by ADEME. However, some funding can also be associated with a part of the upstream research funded by ANR (national agency for research) and technological innovation funded by FUI (fund for industrial clusters).

After two calls for projects on all research domains in France, 171 Laboratories of Excellence (LabEx) have been awarded. 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 receive an initial 3 M€ funding for a 9-year period. Nowadays, its annual funding is around 2 M€, sustained by national and European research projects, and from Electricité de Strasbourg, Strasbourg University - IDEX and CNRS. It illustrates and strengthens the industry-university partnership engaged in the framework of the "Investments for the Future" with new partners such as Total and Storengy (Engie group).

An Institute of Excellence for the use of the underground in the energy transition, called Géodénergies, has been also created in July 2015. Its aim is to support the development of the three industrial sectors: CO_2 storage, energy storage and geothermal energy (heat and electricity). This joint venture brings together industrial and public research organizations and benefits from 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 actors.

In order to promote the development of geothermal activities, Géodénergies has launched several research projects to bridge technological gaps (such as drilling hammer or pumps adapted to deep geothermal context, monitoring of reservoir cooling), develop methodologies (for microseismic measurements exploitation and conceptual reservoir models in grabens) and develop co-activities of exploitation (with Lithium production or with CO_2 storage).

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

- AVENIA, based in Nouvelle-Aquitaine region, deals notably with deep geothermal applications;
- SYNERGILE, based in Guadeloupe, aims at developing renewable energies in the overseas department;
- S2E2, based in Tours, deals with shallow geothermal energy and smart buildings.

In June 2014, GEODEEP, the French geothermal Cluster for heat and power, was officially launched. GEODEEP is a cluster of competences in the subsoil and energy sectors that complement each other to cover the entire value chain and develop full-cycle projects in France and internationally, from subsoil exploration and drilling to power plants and district heating systems, through distribution, training, maintenance and technological monitoring.

Carried by AFPG, the cluster comprises large companies with a worldwide presence, specialized companies with extensive experience in geothermal engineering services, power plant EPC, equipment manufacturing, drilling companies, societies proposing project financing solutions, specialized developers/integrators of geothermal projects and geothermal associations for professionals. Three markets are targeted:

- Geothermal heat and power production in the French mainland (hydrothermal EGS);
- Geothermal power production in the volcanic islands in French overseas territories;
- Geothermal power production in other volcanic regions in the world.

5. JOBS

According to In Numeri (2020, from ADEME data), global employment (direct and indirect jobs) has reached 3830 FTE (Full Time Equivalent) in 2020. The distribution for each sectors is presented as follow:

- to 660 FTE for shallow geothermal energy (residential sector) are estimated
- to 810 FTE for shallow geothermal energy (collective and tertiary sectors)
- to 2210 FTE for deep geothermal energy for heating applications
- to 150 FTE for deep geothermal energy for power generation

These are direct jobs associated with geothermal markets: manufacturing and installation (including preliminary studies) of equipment and operation, all types of maintenance (including production units).

These direct jobs correspond to the following activities: equipment manufacturing and installation, drilling, preliminary studies, operation-maintenance of production units and energy sales.

6. CONCLUSIONS

During the last years, the existing toolbox for geothermal energy deployment has been continuously improved, benefiting from a good cooperation between ADEME, BRGM, the French renewable energy syndicate (SER), the Ministry of Environment and *Caisse des Dépôts et Consignations*.

The announcement by the State of the end of oil heating in new buildings from the 1st January 2022 will open opportunities for geothermal applications as sustainable solutions in compliance with energy transition objectives. For GSHP, the industry is in favour of a remodelling of the administrative framework. And the sector still needs a strong boost in direction of individual housing installations to be competitive with air-air systems.

For direct uses, the development is continuing in Ile de France, but new ongoing projects are coming also in Aquitaine and Alsace. The sector will also benefit in the next five years from the numerous EGS cogeneration plants to be built in France onshore.

For the electricity generation sector, the work carried out by the professionals under the GEODEEP banner will allow to multiply by 4 the total installed power in the horizon to 2023. The creation of training schools and laboratories of Excellence focused on geothermal research is relatively new and will reinforce the high temperature sector deployment.

REFERENCES

ADEME: Marchés et emplois dans le domaine des énergies renouvelables. Situation 2013-2015 et perspectives à court terme. Report. 2017.

AFPG: Etude de filière de la géothermie en France. Report. 2021.

Baujard C., Genter A., Cuenot N., Mouchot J., Maurer V., Hehn R., Ravier G., Seibel O., Vidal J.: Experience from a successful soft stimulation and operational feedback after 2 years of geothermal power and heat production in Rittershoffen and Soultz-sous-Forêts plants (Alsace, France), Geothermal Resource Council, GRC2018, October 14-17, Reno, Nevada, USA, 2241-2252. 2018.

Boissavy C., Grière, O.: History and detailed results for the Short and Long term guarantee system for Geothermal Heating Operations using deep aquifers set up in France in the early 1980's- Report ADEME 48p. 2017.

Boissavy C. Brange C., Laplaige P., Rocher P.: Geothermal Energy use, Country Update for France- European Geothermal Energy Congress 2016 Strasbourg, 19-24 Sept 2016. 2016.

EurObserv'ER: The State of Renewable Energies in Europe, 2018 – 18th edition - 147 p. 2018.

Hamm, V., Maurel, C., Audouin, O. (CFG): BILAN GTH : Bilan de la filière géothermie profonde pour la production de chaleur sur la période 2007-2018. Rapport final BRGM/RP-69577-FR. 2020.

Hamm, V., Maurel, C.: Projet Sybase : synthèse de bancarisation et suivi des opérations de géothermie de basse température en France métropolitaine. Rapport final BRGM/RP-68601-FR. 2019.In Numeri : La géothermie. Report. 2021.

Maurer V., Cuenot N., Richard A., Grunberg M.: On-going seismic monitoring of the Rittershoffen and the Soultz EGS projects (Alsace, France). 2nd Induced Seismicity Workshop, 14-17 March 2017, Schatzalp, Switzerland. 2017.

Observ'ER: Suivi du marché et des prix du secteur des PAC individuelles. May 2018. 2018.

Richard A., Gillot E., Maurer V., Cuenot N., Klee J.: Upper Rhine Graben: the largest exploration by 3D seismic reflection, European Geothermal Congress, EGC 2019, 11-14 June 2019, The Hague, The Netherlands. 2019.

Ungemach P., Antics M., Davaux M.: Subhorizontal well architecture and geosteering navigation enhance well performance and reservoir evaluation- Proceedings, 44th Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 11-13, 2019. 2019.

Vidal J., Genter A.: Overview of naturally permeable fractured reservoirs in the Upper Rhine Graben: insights from geothermal wells, Geothermics 74, 57-73. 2018.

Acknowledgements

The authors are grateful to the GEIE Exploitation Minière de la Chaleur and ECOGI to access to the Soultz and Rittershoffen information respectively, the GPC IP Company for illustrations related to horizontal drilling in Cachan and composite casing experimentation in Bonneuil and ENGIE to access the data for multilateral wells.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	17.2 *	127 *	136,211 *	500,100 *	0,013 *	0,025 *
Under construction end of 2021	0	0				
Total projected by 2023	17,2	127				
Total expected by 2028	42.2	307				
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development: 2 Under investigation: 19	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Bouillante (Guadeloupe island, French West Indies)	Bouillante	1986 and 2004	2	O	1F + 2F	15.5 *	15,5 *	115 *
Soultz-sous-Forêts (Alsace region)	Soultz-sous-Forêts	2010	1	O	B-ORC	1,7 *	1,7 *	12 *
total						17.2 *	17.2 *	127 *

Key for status:		Key for type:			
O N R	Operating Not operating (temporarily) Retired / decommissioned	D 1F 2F	Dry Steam Single Flash Double Flash	B-ORC B-Kal O	Binary (ORC) Binary (Kalina) Other

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *		1 733 *		236 *		0		31 *
Under constru-ction end 2021		328		0		0		0
Total projected by 2023		2 061		236		0		31 *
Total expected by 2028	4 – 5.2 TWh_{th}/yr							

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cool ing ***	Geoth. capacity installed (MWth)	Total capacity installed (MWth)	2021 produc-tion * (MWhth/y)	Geoth. share in total prod. (%)
Occitanie	Blagnac 2 Ritouret	1976	N	N			14189*	
Nouvelle Aquitaine	Monte-de-Marsan	1976	N	N			13641*	
Ile-de-France	Montgeron	1981	N	N	9	13.1	11761*	68.6%
Nouvelle Aquitaine	Pessac-Saige Formanoir	1982	N	N	6.5	11.1	17000*	58.4%
Ile-de-France	La Courneuve Sud	1982	N	N	6.5	9.9	5660*	65.6%
Ile-de-France	Meaux Collinet	1982	N	N			12157*	
Nouvelle Aquitaine	Begles	1983	N	N			2272*	
Centre Val de Loire	Chateauroux	1983	N	N			Unknown	
Ile-de-France	La Courneuve Nord	1983	N	N	6.4	11.0	35804*	58.4%
Ile-de-France	Meaux Beauval 1	1983	N	N	15	22.9	37931*	65.6%
Ile-de-France	Meaux Hopital	1983	N	N	15	31.1	21571*	48.2%
Ile-de-France	Ris Orange	1983	N	N	11	11.0	23655*	100.0%
Nouvelle Aquitaine	Merignac - BA 106	1984	N	N	10	13.3	5968*	75.0%

Table D1: Existing geothermal district heating (DH) plants, individual sites (continued)

Locality	Plant Name	Year commis-sioned	CHP **	Cool ing ***	Geoth. capacity installed (MWth)	Total capacity installed (MWth)	2021 produc-tion * (MWhth/y)	Geoth. share in total prod. (%)
Ile-de-France	Epinay-sous-Senart	1984	N	N	15	22.9	35952*	65.6%
Ile-de-France	Meaux Beauval 2	1984	N	N			26212*	
Ile-de-France	Sucy-en-Brie	1984	N	N	15	15.3	27033*	98.3%
Nouvelle Aquitaine	Chasseloup-Laubat	1985	N	N	15	20.8	Unknown	72.0%
Ile-de-France	Champigny-sur-Marne	1985	N	N			53958*	
Ile-de-France	Chevilly-Larue	1985	N	N	14	20.7	49501*	67.6%
Ile-de-France	Creteil Mont Mesly	1985	N	N	20	61.0	59928*	32.8%
Ile-de-France	L'Hay-les-Roses	1985	N	N	14	20.7	49501*	67.6%
Ile-de-France	Maison Alfort 1	1985	N	N	11.8	20.0	38261*	59.0%
Ile-de-France	Villiers-le-Bel-Gonesse	1985	N	N	14	24.3	38435*	57.6%
Ile-de-France	Maison Alfort 2	1986	N	N	10.8	18.3	30062*	59.0%
Ile-de-France	Thiais	1986	N	N	11.6	12.3	34699*	94.0%
Ile-de-France	Alfortville	1987	N	N	14.8	16.5	42829*	89.9%
Ile-de-France	Fresnes	1987	N	N	10	16.6	47517*	60.2%
Ile-de-France	Villeneuve St-Georges	1987	N	N	17	33.9	15316*	50.2%
Ile-de-France	Melun l'Almont 2	1988	N	N	15	30.2	44728*	49.7%
Ile-de-France	Tour AGF Mirabeau	1990	N	O	1.03		13000*	
Ile-de-France	Orly 2 Le Nouvelet 2	2008	N	N	12.2	15.3	65530*	80.0%
Ile-de-France	Orly ADP	2011	N	N	12	50.6	15693*	23.7%
Ile-de-France	Coulommiers 2	2012	N	N	11.5	12.0	37501*	95.9%
Ile-de-France	Val-Maubuee	2012	N	N	11	12.6	48246*	87.3%
Ile-de-France	Aubervilliers	2013	N	N	11		2085*	
Ile-de-France	Chelles 2	2013	N	N	13.6	38.7	20959*	35.1%
Ile-de-France	Issy-les-Moulineaux	2013	N	N	3.48	6.8	10981*	51.0%
Ile-de-France	Le-Mee-sur-Seine 2	2013	N	N	11	16.6	53054*	66.1%

Table D1: Existing geothermal district heating (DH) plants, individual sites (continued)

Locality	Plant Name	Year commis-sioned	CHP **	Cool ing ***	Geoth. capacity installed (MWth)	Total capacity installed (MWth)	2021 produc-tion * (MWhth/y)	Geoth. share in total prod. (%)
Ile-de-France	Plessis Robinson	2013	N	O	5.35	25.5	8172*	21.0%
Ile-de-France	Neuilly-sur Marne	2015	N	N	11.8	19.7	43259*	60.0%
Occitanie	Mas Rouge - Galiere	2016	N	N	14.5	17.1	3500*	85.0%
Ile-de-France	Arcueil-Gentilly	2016	N	N	12.5	19.9	56832*	62.9%
Ile-de-France	Bagneux	2016	N	N	4.19		47867*	
Ile-de-France	Clichy-Batignolles	2016	N	N			17655*	
Ile-de-France	Rosny-sous-Bois	2016	N	N	10.5	12.8	51081*	82.0%
Ile-de-France	Tremblay-en-France 2	2016	N	N	11.8	14.8	39069*	79.6%
Ile-de-France	Villepinte	2016	N	N	14.6	18.3	37988*	79.8%
Ile-de-France	Bailly-Romainvilliers	2017	N	N	19.5	19.5	49073*	99.8%
Ile-de-France	Dammarie-les-Lys	2017	N	N	14.6	15.6	35111*	93.5%
Ile-de-France	Grigny II	2017	N	N	10.5	13.8	66676*	76.2%
Ile-de-France	Ivry-sur-Seine 2	2017	N	N	11.2	21.5	35660*	52.2%
Ile-de-France	Le Bland Mesnil 2	2017	N	N	10.8	18.8	23445*	57.4%
Ile-de-France	Villejuif	2017	N	N	15.5	22.9	49501*	67.6%
Nouvelle Aquitaine	Archachon (lycée)****	2018	N	N			Unknown	
Ile-de-France	Bonneuil-sur-Marne 2	2018	N	N	12.3	13.1	33518*	93.8%
Nouvelle Aquitaine	Teste de Buch****	2018	N	N			Unknown	
Ile-de-France	Vigneux-sur-Seine 2	2019	N	N	13.1	15.7	31141*	83.5%
Ile-de-France	Cachan 3	2020	N	N	12.5	17.5	41292*	71.5%
TOTAL					**569.45**		**1'733'000**	**68.2%**

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

**** Hydrocarbon and geothermal heat co-production plants

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MWth)	Total capacity installed (MWth)	2021 produc-tion * (MWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Nouvelle Aquitaine	Pessac-Stadium	1962	N			1082*		
Auvergne-Rhone-Alpes	Aigueperse	1979	N			11512*		
Occitanie	Lodeve St Fulcran	1979	N			586*		
Occitanie	Lodeve Grand Champ	1980	N			1744*		
Nouvelle Aquitaine	Mios Le Teich	1984	N			21440*		
Occitanie	Pezenas	1984	N			11576*		
Nouvelle Aquitaine	Gujan Mestra La Hume	1985	N			2004*		
Nouvelle Aquitaine	Hagetmau	1986	N			2793*		
Occitanie	Nogaro 2	1986	N			18494*		
Nouvelle Aquitaine	Bordeaux Meriadeck	1987	N			8025*		
Nouvelle Aquitaine	Saint-Paul-Les-Dax 1 (Lac de Christus)	1996	N			897*		
Nouvelle Aquitaine	Parentis****	2000	N			Unknown		
Nouvelle Aquitaine	Jonzac	2002	N			4463*		
Grand Est	Rittershoffen	2017	N			182000*		
TOTAL						**266’000**		

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	205’000*	3075*	4770*	4100*		
Of which networks **						
Projected total by 2023						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

There is currently no shallow geothermal UTES in France.

Table F: Investment and Employment in geothermal energy (2018)

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	70*	250*	100*	300*
Geothermal direct uses	50*	400*	50*	400*
Shallow geothermal	150*	1000*	200*	1200*
total	**270***	**1650***	**350***	**1900***

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include “jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration”. For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

Not applicable; some elements are already mentioned directly in the text (MePrimeRénov, Renewable Heat Fund, Fonds SAF…).

Geothermal Energy Use in Germany, Country Update 2019-2021

Josef Weber[1], Holger Born[2], Sandra Pester[3], Christopher Schifflechner[4] and Inga Moeck[1, 5]

[1] Georg August University Göttingen, Goldschmidtstr. 3, 37077 Göttingen, Germany

[2] Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems IEG, Am Hochschulcampus 1, D-44801 Bochum, Germany

[3] State Authority for Mining, Energy and Geology (LBEG), Stilleweg 2, D-30655 Hannover, Germany

[4] Technical University of Munich (Chair of Energy Systems), Boltzmannstr. 15 85747 Garching, Germany

[5] Leibniz Institute for Applied Geophysics, Stilleweg 2, 30655 Hannover, Germany

josef.weber@uni-goettingen.de

Keywords: Geothermal development, power production, direct use, ground source heat pumps, Germany.

ABSTRACT

This country report update gives an overview of the geothermal energy use in Germany. It covers geothermal power production, direct use applications as well as geothermal heat pump units for heating and cooling.

At the end of 2021, about 190 geothermal installations for direct use of geothermal energy were in operation in Germany. This number includes facilities for district heating and thermal spas, the latter often in combination with space heating.

The installed geothermal capacity of these facilities amounted to 406.9 MW_{th} with a geothermal heat production of 6183.7 TJ in 2020. District heating plants accounted for the largest portion of the geothermal capacity with 345.8 MW_{th} and a heat production of 4439.2 TJ.

Geothermal electricity generation in Germany is based on the use of binary systems (Kalina cycle or ORC). This allows power production even at temperatures of 100 °C. At the end of 2021, eleven geothermal plants with an installed capacity of 47.6 MW_{el} fed electricity into the German grid. The geothermal power production in 2020 summed up to a total of 190.6 GWh.

Due to favourable geological conditions, geothermal district heating and power plants are mainly located in the Molasse Basin in Southern Germany, in the North German Basin, or along the Upper Rhine Graben.

In addition to installations using "deep" geothermal energy, numerous small- and medium-sized decentralised geothermal heat pump units are in use for heating and cooling of individual houses and office buildings. In the last years, the sales figures of heat pumps have increased again. Over 150'000 heat pumps were sold in 2021, with a share of about 18 % (27'000) for geothermal systems (brine and water systems). At the end of 2021, 435'000 geothermal heat pumps were running successfully in Germany and supply renewable heat mostly for residential buildings. All installed geothermal heat pumps had a thermal output of about 4930 MW_{th} in total and provided 25'704 TJ of renewable heat in 2021.

1. INTRODUCTION

The majority of geothermal projects worldwide is located in geological systems with convection dominated heat transport such as magmatic arcs or large scale active faults (e.g. plate boundaries) (Moeck, 2014). Germany, with its conduction dominated heat transport systems, lacks natural steam reservoirs which can be used for a direct drive of turbines. Thus, geothermal power generation is based on the use of binary systems, which use a working fluid in a secondary cycle (ORC or Kalina cycle). Hydrothermal reservoirs with temperatures and hydraulic conductivities suitable for power generation can be expected and are already utilised particularly in the Upper Rhine Graben as an active, deeply rooting fault system, and the Alpine Molasse Basin as an orogenic foreland basin (Agemar et al., 2014a, b; Moeck, 2014).

However, the necessary implementation of the heat transition (referred to as *Wärmewende*) in Germany shifts the focus to geothermal heat production. In contrast to fossil fuels, geothermal heat in place can be used over a large depth and temperature range by a whole variety of technologies. Due to this scalability of geothermal applications, depending on the heat demand there is a huge potential for the development of geothermal utilisation. With the *Wärmewende* in Germany, we recognize the scalability of geothermal technology as the potential of geothermal use rather than individual geologic formations. Effectively, a broad range of the geothermal gradient from shallow to medium deep account for the installed geothermal capacity in Germany.

At the end of 2021, 30 geothermal plants for district heating and/or power generation were in operation in Germany and several new plants are under construction or in the planning phase. The discovery of deep hot aquifers has led to a vivid project development especially in Southern Germany. Current projects focus on the Bavarian part of the Alpine Molasse Basin, where karstified Upper Jurassic carbonates provide a suitable aquifer of several hundred meters thickness (Figure 1). Some projects are also in operation or under development in the Upper Rhine Graben, which is another region of elevated hydrothermal potential. Above-average geothermal gradients make this region especially interesting for the development of electricity projects.

This paper describes geothermal reservoirs and probable resources followed by the status of geothermal energy use in Germany. Different use categories such as district and space heating or thermal spas, as well as heat pumps and their contribution to the geothermal heat supply are allocated.

2. GEOTHERMAL RESOURCES

Geothermal resources applicable for geothermal power production and heat use in Germany were investigated in several studies and contributions to European geothermal atlases (Haenel and Staroste, 1988; Hurter and Haenel, 2002; Jung et al., 2002; Paschen et al., 2003).

In order to better understand the range of geologic settings hosting geothermal resources, subsurface data are collected, analysed, interpreted and provided by the Leibniz Institute for Applied Geophysics (LIAG) through the Geothermal Information System (GeotIS) since 2005 (Agemar et al., 2014a). GeotIS was funded by the German Government and the LIAG realised the project in close collaboration with several research partners.

The information system provides a variety of data collections on deep aquifers suitable for commercial geothermal exploitation. Furthermore, map and data compilations of regions with indicated hydrothermal resources and with inferred resources for enhanced geothermal systems (EGS) were published by Suchi et al. (2014) in a study about the competing use of the subsurface for geothermal energy and CO_2 storage. The resulting maps of that study are also available in GeotIS.

Besides the research focus, the practical relevance of GeotIS is to minimize the exploration risk of geothermal wells and to improve the quality of planning data for geothermal projects. GeotIS is designed as a digital information system which is available free of charge as an open-access data base (http://www.geotis.de).

Although a great theoretical potential for geothermal power generation is attributed to EGS (Paschen et al., 2003), the commercial project development to date focuses on hydrothermal resources in sedimentary systems. The most important geologic systems hosting proven geothermal reservoirs in a depth greater than 1000 m in Germany are the North German Basin, the South German Molasse Basin, and the Upper Rhine Graben (Figure 1).

More detailed information on this systems can be found in previous publications associated with earlier European or World Geothermal Congresses (e.g. Weber et al., 2019; Weber et al., 2020+1).

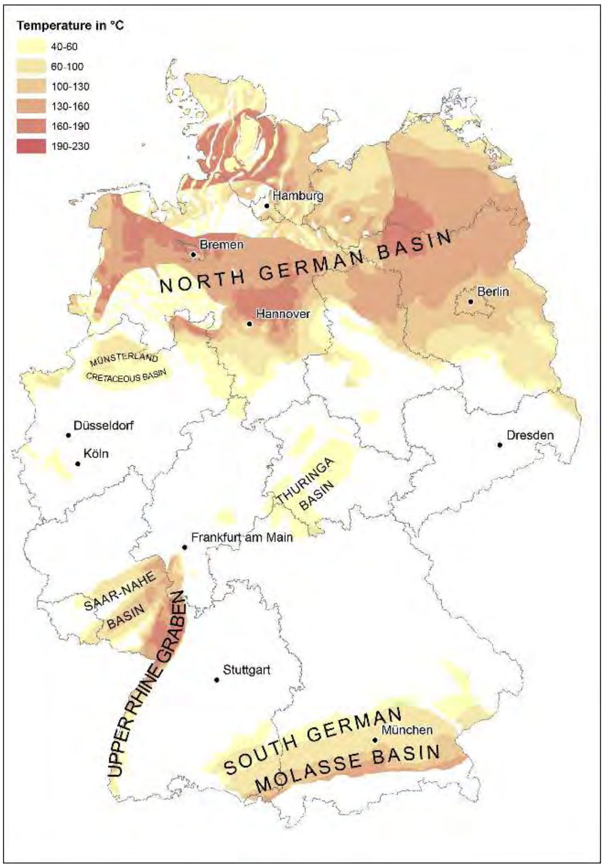


Figure 1: Regions with hydrothermal resources in Germany (inferred and indicated) and associated temperature ranges (map adapted from Suchi et al., 2014).

3. CURRENT TRENDS AT MEDIUM AND DEEP GEOTHERMAL PROJECTS

Before having a closer look on the installed geothermal capacities in Germany as described in Chapter 4, the following section provides a short summary about recent developments and trends for medium and deep geothermal projects being recently installed, currently under construction or are in the planning.

3.1 Large-scale high temperature heat pumps

The increasing availability of commercial high temperature heat pumps (HTPHs) with a deployable possible temperature level of up to 100 °C (Arpagus et al., 2018) is of high interest regarding medium and deep geothermal projects. Such HTHPs can play two potential roles regarding geothermal heating projects. Firstly, increasing the available thermal capacity of the geothermal project in case its capacity is (temporarily) lower than the heat demand of the district heating system (DHS). If this is the case, the HTHP can further cool down the return temperature of the DHS while providing additional heat to the DHS supply side. Due to the lowered DHS return temperature, the geothermal brine can now be further cooled down, resulting in a higher thermal load provided by the geothermal project. Secondly, enabling the integration of geothermal sources, even if the brine temperature is significantly lower than the required DHS supply temperature. Thus, by lifting the temperature of the heat source by e.g. 30 to 60 K, HTHPs enable the utilization of geothermal reservoirs with temperatures below the required DHS supply temperature (Schäfer et al., 2019).

A current commercial example for the application of such a large-scale HTHP system can be found in the geothermal heating project in Schwerin in the Northeast of Germany. The geothermal project utilizes a reservoir in a depth of 1200 m. The geothermal brine temperature of 55 °C is not feasible to supply the existing local DHS, which is characterized by an average supply and return temperature of 80 °C and 55 °C, respectively. The planned HTHP system cools down the geothermal brine from 55 °C to 20 °C, while heating up the DHS from 55 °C to 80 °C with an overall thermal capacity of 6.9 MW_{th}. A special technical feature of the project in Schwerin is the number of heat pumps installed. Instead of having one single heat pump with a high temperature lift, the overall temperature increase takes place in four serial heat pumps. Due to the lower temperature lifts in each of these heat pumps, a higher overall Coefficient of Performance (COP) can be achieved. While this solution increases the investment costs and plant complexity, the significant reduction of the required electrical power demand compared to one single HTHP is favourable considering the long-term operational costs (Mathes, 2022).

The Stadtwerke München (SWM) plan to install a large HTHP system with a capacity of 21–30 MW_{th} at their envisaged project *Michaelibad* in the East of Munich in order to increase the thermal capacity of the geothermal heating plant with a conventional capacity of 45 to 107 MW_{th} (SWM Services GmbH, 2021). Furthermore, future HTHPs may also be able to provide both process heat up to 200 °C and process steam for industrial consumers (Bracke et al., 2022). While such high temperature ranges cannot be supplied by commercially available HTHP systems today, there is a strong research activity in this area. For example, the current *Kabel ZERO* project investigates the supply of process steam for a paper factory by a geothermal reservoir with 130 °C and a HTHP.

3.2 Long-distance heat transmission pipelines

Regarding the utilization of geologically attractive regions, one limiting factor is that these regions are not always spatially overlapping with urban areas that have a high heat demand density. Thus, without heat transportation systems, rural geothermal heating projects might not be economic due to the low local heat demand. While transporting heat from geothermal sources over a long distance is currently not applied in Germany, such concepts can be found for example in Iceland (Erlingsson and Þorhallsson, 2008). However, it has gained also increasing interest in the German geothermal sector during the last years. E.g. in 2020, a study by the Geothermal Alliance Bavaria demonstrated the high potential of large-scale heat transmission systems in the Southeast of Germany. By installing long distance heat transmission pipelines, a high share of the biggest heat demand clusters in the region (Munich, Augsburg, Rosenheim, etc.) could be supplied by geothermal projects in geological attractive (but rural) regions in the South and Southeast of Munich (Loewer et al., 2020). The SWM plan to install a heat transmission pipeline from their central DHS to three existing geothermal power plants (Kirchstockach, Dürnhaar and Sauerlach) in order to have their thermal capacity of around 120 MW_{th} available for heating purposes if required (Cröniger, 2020; Kleinertz et al., 2021).

3.3 Cooling with deep geothermal energy by thermally driven absorption chillers

Against the background of the expected increasing cooling demand especially in urban areas, providing cooling will be a further relevant application case for geothermal energy next to heating and power generation. Currently, some buildings or district cooling systems (DCS) utilize shallow geothermal systems for this purpose (Epting et al., 2020). A further promising alternative are thermally driven ab- or adsorption chillers for cooling. Such sorption chillers can provide cooling by using heat as a main driving source for the cooling system, resulting in a significantly lower electricity demand compared to a conventional vapour compression cycle, which is currently the most common cooling technology. Depending on the required cooling temperature and the exact cycle configuration, sorption chillers can operate from a heat source level between 60 and 80 °C on. Thus, medium and deep geothermal energy might be utilized for cooling in two ways: Using the heat of a geothermally driven DHS at the consumer with cold demand or by driving a DCS supplied by a central geothermal driven sorption chiller.

In Unterföhring, the heat of the DHS is used to drive an absorption chiller with a cooling capacity of 200 kW in order to cool a large office building with more than 4500 m^2 since 2015 (Geovol, 2015). In Munich, the SWM are installing a large-scale absorption chiller at their geothermal project in Sendling. If the geothermal heat is not required completely for supplying the DHS during the summer months, it can be used for cooling purposes resulting in a higher overall annual utilization of the geothermal project. The cold will be transported to a DCS in the city centre by a 5 km long pipeline (SWM 2021). Thus, the current projects in Unterföhring and Munich highlight the technical feasibility and growth potential of environmentally friendly cooling. The recently published roadmap on deep geothermal energy in Germany by Bracke et al. (2022) suggests an installed capacity of 1 GW for cooling systems driven by deep geothermal energy after 2040.

3.4 Current trends in recently installed and planned power generation projects

During the last years, only a low number of geothermal power plants have been installed. The two main projects were both located in the South German Molasse Basin: Holzkirchen and Garching a.d. Alz. The combined heat and power generation (CHP) project in Holzkirchen utilizes a geothermal brine temperature of 155 °C, which is the highest temperature of all projects in the South German Molasse Basin so far. For power generation, a two-staged Organic Rankine Cycle (ORC) is installed. According to the manufacturer, their new two-staged ORC systems are utilizing an advanced four-staged turbine with two injection points on different pressure levels. Thus, the power generation of the two-staged ORC system can be realized within one turbine, resulting in a high efficiency also for low ORC mass flow rates during times with a high DHS heating demand (Duvia, 2020).

Also in Garching a.d. Alz, a CHP project is installed. In this project, the condensation system is a special feature. While the majority of the existing power plants are using air-cooled condensers, the project in Garching can use the cold water of an industrial channel next to the side for a water-cooled condenser (Friedlaender, 2020). Thus, especially during the summer period, higher ORC efficiencies can be achieved due to the lower condensation temperatures compared with air-cooled condenser systems. In addition, the water-cooled system reduces the required investment costs and auxiliary power demand and displays lower noise emissions. However, such cooling solutions are limited to very few potential locations due to strong ecological restriction in case of using water from natural rivers. In summary, both recently installed power projects are CHP projects and have an installed capacity of a few MW_{el}, following the main characteristics of the already existing geothermal power generation projects in Germany (Eyerer et al., 2020).

The geothermal project in Kirchweidach provides heat to local DHS and a greenhouse since several years. Currently, a large-scale ORC with around 4 MW_{el} is under construction (Duvia, 2020). In addition, several standardized modular ORC systems by the German ORC manufacturer Orcan Energy have been installed. Six modules with a capacity of up to 200 kW_{el} are installed, resulting in an overall capacity of around 1 MW_{el} (ITG, 2021). Thus, for the first time in Germany, such modular ORC systems have been installed at a geothermal project. While these modular systems display higher specific investment costs compared to an individually engineered large-scale ORC, they might enable an earlier starting of the power generation due to the significantly lower planning and construction times.

Regarding currently planned geothermal projects in the South German Molasse Basin, there is a certain trend towards larger projects consisting of four wells, instead of the currently common doublets. E.g. all three planned projects in Tengling, Palling and Traunstein want to realize four wells. Thus, these projects would have an installed power plant capacity of 10–15 MW_{el} each, while still planning to provide heat to local municipalities. Furthermore, around 10 projects are currently in a planning phase in the Upper Rhine Graben. Next to power generation and heat supply, some of these projects are focusing also on the extraction of Lithium from the geothermal brine. According to Sanjuan et al. (2022), the Upper Rhine Graben is the most promising area for geothermal Lithium extraction in Europe.

Another novel development is the current plan for the geothermal project in Geretsried, Bavaria. In 2018, the drilling for a conventional hydrothermal project was not successful due to a too low achievable brine flow rate. Currently it is planned to use the already existing well as a basis for realizing a deep closed-loop concept by a Canadian company, the so-called Eavor Loop concept. In Geretsried four such systems could be realized, resulting in a power capacity of around 9 MW_{el} (Gahr, 2022). The drilling might start in 2023. Realizing such a large-scale deep closed-loop system for the first time in Europe might be an interesting and promising development regarding the utilization of the tremendous geothermal potential not only in geologically favourable hydrothermal hotspot regions.

4. STATUS OF GEOTHERMAL ENERGY USE

The German Government supports the development of geothermal energy by project funding, market incentives, credit offers as well as offering a feed-in tariff for geothermal electricity. However, progress in the development of geothermal energy lags behind the development of other renewables although there are good conditions for heating plants and also for power production at several locations (Figure 1). For example, especially in southern Germany, a number of new projects have been realised and further developments are being planned.

Geothermal heat is utilised in about 190 larger installations using hydrothermal resources. Thermal spas are the most widespread form of deep geothermal heat utilisation. However, the number of larger district heating plants is growing continuously. They presently account for about 68 % of the deep geothermal heat production, with an upward tendency.

Besides deep geothermal utilisations, numerous geothermal heat pumps for heating and cooling office buildings and private houses contribute the major portion to geothermal heat use in Germany.

4.1 Geothermal Power Production

Since the last WGC country update in 2020 two new geothermal power plants were commissioned in Germany: the 4.9 MW_{el} plant in Garching a. d. Alz and the modular ORC systems in Kirchweidach (for details see paragraph 3.4). The installed geothermal capacity in Germany reached 47.6 MW_{el} end of 2021 (Tables A & B) and the electricity production amounted to 190.6 GWh in 2020.

4.2 Centralised Installations for Direct Use

In Germany, common deep geothermal utilisations for direct use are district heating plants or combined heat and power plants (CHP), thermal spas, and space heating. At present, about 190 geothermal installations of these types are in operation in Germany (Figure 2, Tables D1 & D2).

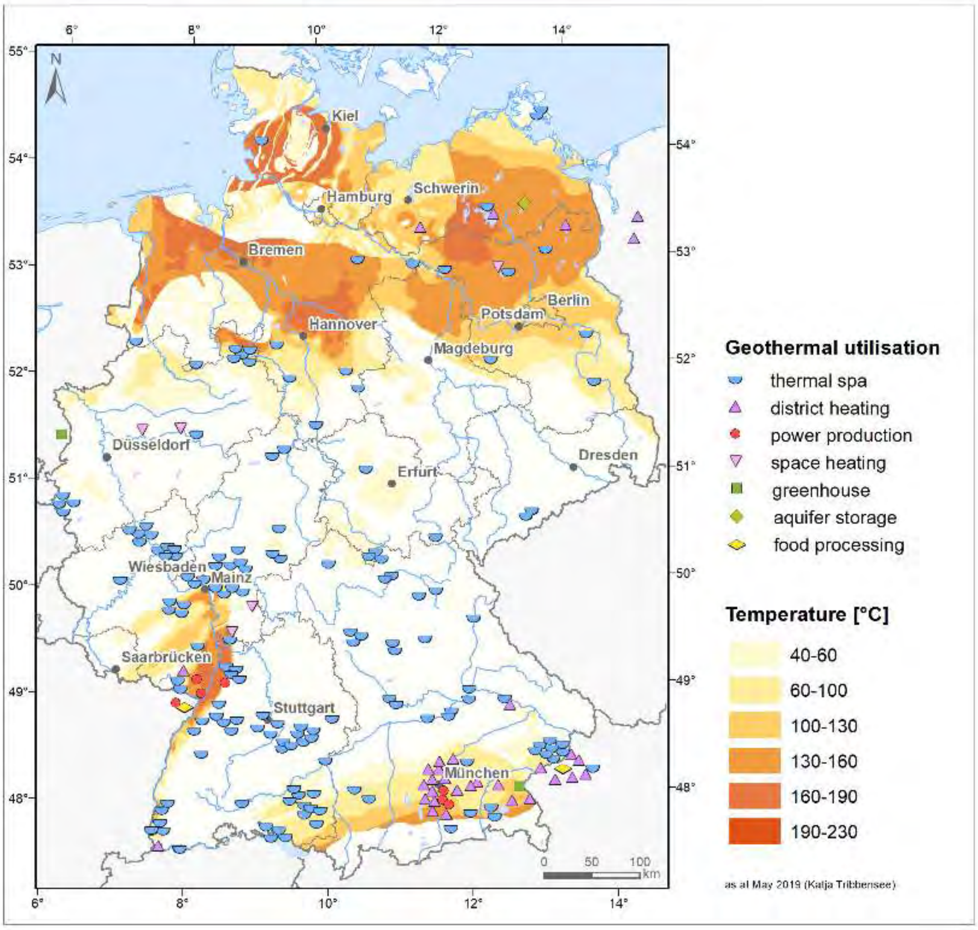


Figure 2: Sites of deep geothermal utilization in Germany and neighboring countries. The background colors represent predicted temperature ranges of the respectively deepest identified geothermal resources in sedimentary or volcanic rocks (map generated in GeotIS, 2019).

Furthermore, five deep borehole heat exchangers are in operation in Germany: Arnsberg with a total depth of 2835 m heating a spa, Prenzlau (2786 m, used for district heating), Heubach (773 m, providing heat for industry), Landau (800 m, for space heating) and Marl (700 m, for local heating). Also the use of mine water is becoming more and more interesting with regard to the heat transition in Germany.

At end of 2020, the geothermal installed capacity of direct heat use applications was 406.9 MW_{th} with a heat production of 6183.7 TJ in 2020. 26 district heating and combined heat and power plants accounted for the largest portion of the geothermal capacity with about 345.8 MW_{th} and a heat production of 4439.2 TJ (Tables C, D1 & D2). There was not much change since the last country report, however installed capacity as well as heat production will increase with the new heating plant of the Stadtwerke München at the Schäftlarnstraße being in full operation in 2022.

4.3 Geothermal Heat Pumps

Heat pumps are a technology that has been established and ready for the market for decades for the sustainable provision of heating and cooling in residential and non-residential buildings in Germany. After an initial small boom at the beginning of the 1980s, heat pumps have become increasingly established in the German heating market since the turn of the millennium. As Figure 3 shows, 2006 was the first year were more than 30’000 units were sold per year. Thereafter the sales and installation numbers rose to around 80'000 heat pumps annually in the mid-2010s and to over 150'000 heat pumps last year. There is a clear trend that the share of heat pumps sold is shifting from geothermal heat pumps to air-source heat pumps. While the percentage share of ground-source heat pumps was still more than 50 % until 2016, the sales figures for air-source heat pumps have increased significantly in the recent past, so that the share of ground-source heat pumps fell to below 20 %. These geothermal heat pumps use well systems, geothermal borehole heat exchangers (BHE) as well as geothermal collectors as a heat source.

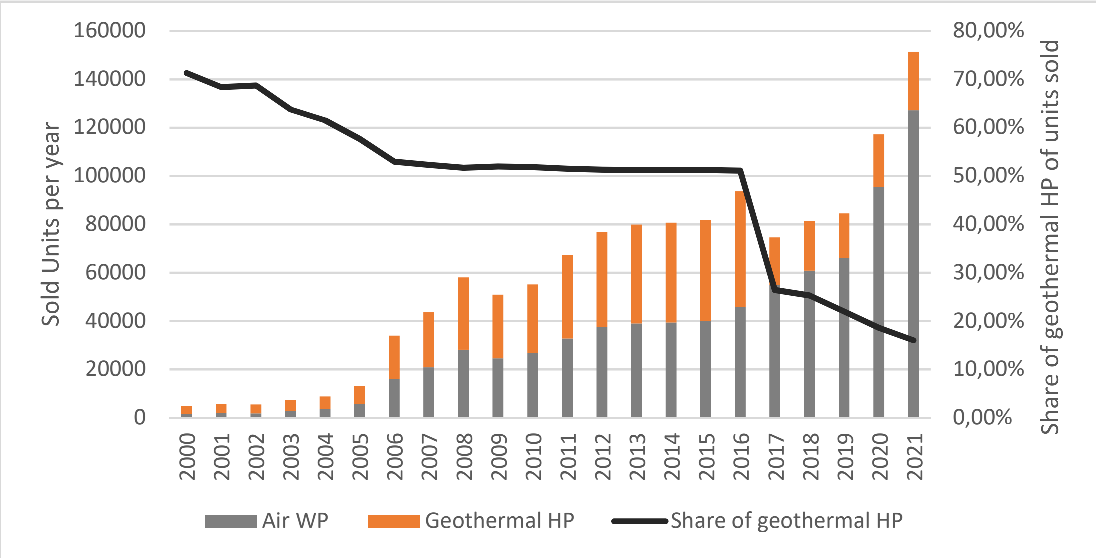


Figure 3: Development of sales figures for heat pumps in Germany (after annual data from BWP&BDH, 2013, 2017 & 2018, latest BWP&BDH, 2018).

Figure 4 shows the share of different heat sources - wells and BHEs/collectors - with geothermal BHEs being the dominant technology (Jensen and Pester, 2019). Well systems in particular have been declining in importance in the past, with a share of less than 5 % of systems sold in 2021. Nevertheless, well systems in hydrogeologically suitable areas make a contribution to the heating and cooling supply.

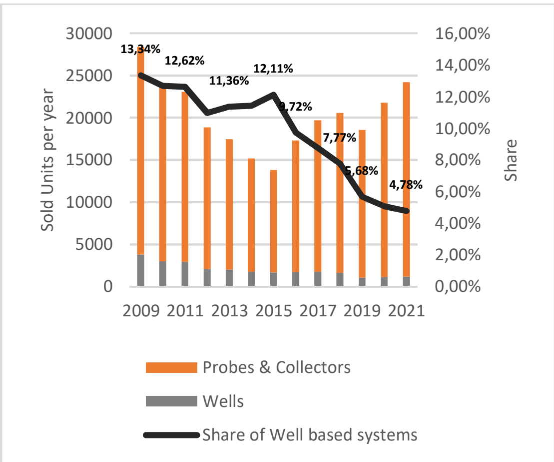


Figure 4: Share of different heat sources (after annual data from BWP&BDH, 2013, 2017 & 2018, latest BWP&BDH, 2018).

Furthermore, the trend can be observed that mainly geothermal heat pumps of relatively small output classes are sold (outputs of less than 20 kW), as shown in figure 5. This is mainly due to the fact that heat pumps are currently mainly used in smaller residential buildings, and here mainly in new buildings.

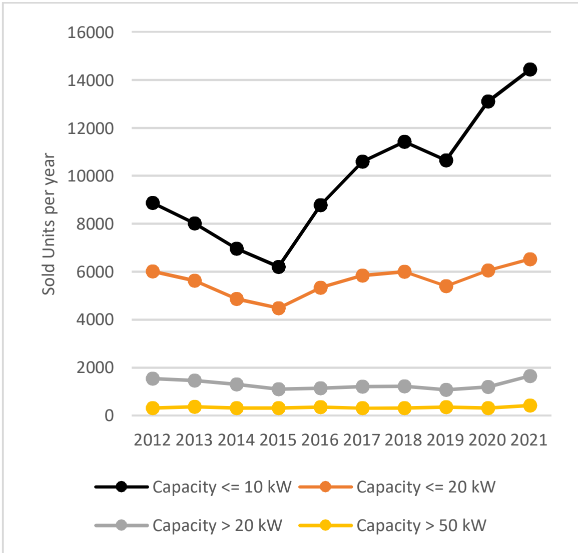


Figure 5: Capacity of sold geothermal heat pumps per year (after annual data from BWP&BDH, 2013, 2017 & 2018, latest BWP&BDH, 2018).

In 2020, heat pumps were installed in more than 50 % of new buildings (55’544 air-source heat pumps and 10’257 ground-source heat pumps) (Statistisches Bundesamt, 2021). In the same year, only 30’000 heat pumps were subsidised in existing buildings (BAFA, 2021). Nevertheless, much larger systems (several hundred kW) represent the top of the market. In sum there was a field inventory of 435’000 successfully installed geothermal heat pumps in Germany end of 2021, see table 1.

Table 1: Field inventory of geothermal heat pumps

Year	Geothermal heat pumps
2016	340.000
2017	362.000
2018	382.000
2021	**435.000**

4.3.1 Calculation of Capacity, Usable Heat and Renewable Energy

The renewable heat that is provided by geothermal heat pumps in Germany based on the number of heat pump systems in operation (the field inventory), the average seasonal performance factor (SPF) of the heat pumps (in correlation of the year on installation), the average full load hours per year and the average capacity. The derivation of the data is methodologically based on the study “Analysis of the German heat pump market” (Born et al., 2017). The methodology was described in detail in the last Country Update 2018 (Weber et al., 2019). A continuation to 31.12.2021 was made.

In result, the renewable heat that is provided by geothermal heat pumps in Germany is calculated in the following way.

The usable heat of all installed heat pumps is the product of the number of installed heat pumps multiplied by the average capacity and multiplied by the full load hours.

$$Q_{usable} = H_{HP} \cdot P_{rated}$$

where Q_{usable} is the estimated total usable heat delivered by heat pumps [GWh], H_{HP} are the equivalent full-load hours of operation [h] and P_{rated} is the capacity of heat pumps installed [GW]

$$P_{rated} = n_{hp} \cdot P_{avg}$$

where n_{hp} is the number of installed heat pumps and P_{avg} is the average capacity of all heat pumps [kW]

The renewable energy (E_{RES}, pure geothermal contribution) is the total useable heat minus the operating energy for the heat pump (electric energy) according to the average SPF.

$$E_{RES} = Q_{usable} \cdot (1 - \frac{1}{SPF})$$

Table 2 shows the calculated values for the total installed capacity of all heat pumps P_{rated}, the total usable heat Q_{usable} and the pure geothermal contribution E_{RES} for the years 2016 to 2018 and 2021.

Table 2: Installed capacity, usable heat and renewable energy provided by geothermal heat pumps

	2016	2017	2018	**2021**
P_{rated} [GW]	3,88	4,09	4,40	**4,93**
Q_{usable} [TWh]	7,95	8,38	9,03	**9,83**
E_{RES} [TWh]	5,80	6,15	6,60	**7,14**

435,000 geothermal heat pump systems in Germany provide around 10 TWh of heat annually, which corresponds to approx. 1.3% of Germany's energy demand for space heating and domestic hot water in 2021.

4.3.2 Outlook – Future market development

A large number of studies describe scenarios of how the stock of heat generators must change by 2030 or 2045 / 2050 in order to achieve Germany's climate policy goals. The unanimous tenor of the studies is that the heat pumps must play a central role in the future provision of heat.

The various scenarios, as shown in Figure 6, postulate an average (target path for expansion) of 6 million heat pumps in 2030 and 16 million in 2050 (Agora Energiewende, 2021; BDI, 2021; BWP, 2021, dena, 2017, Greenpeace, 2022). The most recent publication by Greenpeace (Greenpeace, 2022) even concludes that 12 million installed heat pumps are already possible in 2035. If these targets are compared with the trend scenario, which assumes a constant growth in the number of new installations as in the average from 2016 to 2021, it becomes clear that in just eight years there will be a shortfall of almost 5 million heat pumps, and in 2050 more than 8 million. In order to achieve the goals of the heat transition for society as a whole, enormous efforts are therefore necessary in the short and medium term to support change on the German heat generator market.

The decision for a geothermal heat pump systems in comparison to alternative fossil fuel heat generators is always also an economic decision. While the investment costs, especially for the drilling for heat source development, are still higher than for fossil heating systems, the developments for the operating costs, the electricity and gas prices, have been positive in the recent past. For the end customer, a kWh of electrical energy will only be ~3 times as expensive as a kWh of natural gas at the beginning of 2022, see Figure 7. Heat pumps with a seasonal performance factor of three are just as economical in operation as fossil heating systems.

In order to compensate for the higher investment costs, there is a nationwide subsidy for the installation of heat pumps in Germany via the Federal Subsidy for Efficient Buildings (BEG). The scope of the current subsidy range is 35% to 50% of the total investment costs (BAFA 2022).

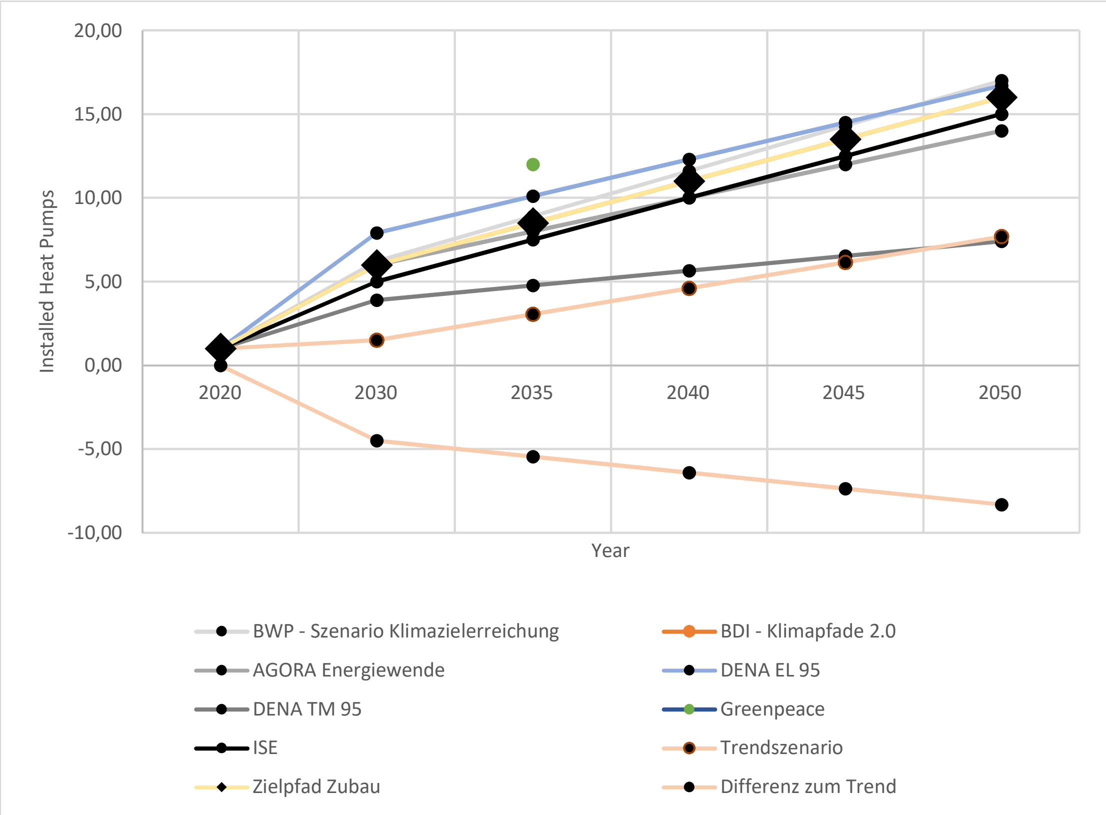


Figure 6: Scenarios for the Heat Pump field inventory by 2050 (Agora Energiewende 2021; BDI 2021; BWP 2021, dena 2017, Greenpeace 2022 and own calculations)

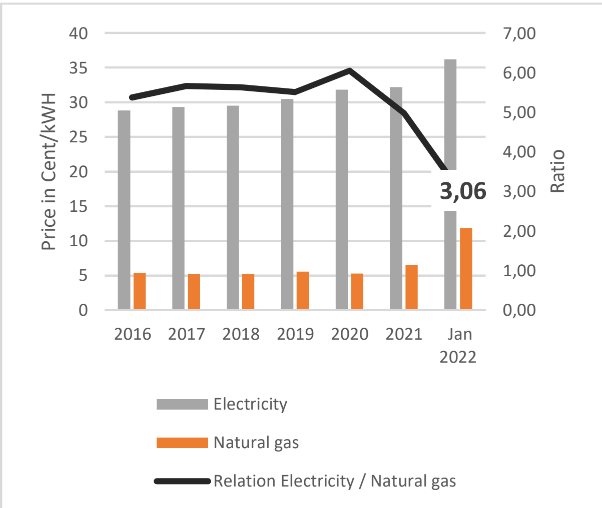


Figure 7: End customer price for electricity and natural gas in Germany (BDEW, 2022)

4.3.3 Data Collection on Shallow Geothermal Energy Utilization in Lower Saxony

Rather than depending on market sales of the heat pump producing industry, Lower Saxony, a federal state in Northwest Germany, is developing a database with the completed geothermal projects.

According to German law (Federal Mining Act, Geological Data Act and Federal Water Act) every drilling irrespective of its purpose has to be announced. Lower Saxony developed an online drilling-notification many years ago for the notification under mining law. The notifications required under water law were made in an analogous way at each water authority (53 in total in Lower Saxony). Since almost 100 % of the drillings are registered with this online application, the State Authority for Mining, Energy and Geology decided in 2012 to expand it to registering geothermal projects according to water law. Thus, the notification under mining law and water law were combined in one online tool for geothermal projects.

Up to now, data from about 14’400 of the known 21’400 installations in Lower Saxony are stored in this database. So now, not only the data of the drilling itself like location, depth and drilling method is collected, but also data about the geothermal project that are relevant for the license under water law. This includes the following data:

- Type of geothermal system (borehole heat exchanger, horizontal heat exchanger, open well systems, exploration well, thermally activated foundation pile)
- Depth of project
- Planned beginning

- Total number (e.g. total number of borehole heat exchangers)
- Heat output of the installation (output of the heat pump)
- Cooling output (in case of cooling)
- Seasonal performance factor
- Full load hours
- Further information on the geothermal system, e.g. borehole heat exchanger:
  - Total meters of borehole heat exchangers
  - Type of borehole heat exchanger (e.g. U-type)
  - Type of heat carrier fluid
  - Type of grouting material

These data allow the state authority and the water authorities easy access to statistics for the federal state and its administrative districts. Figure 8 shows an example of one of the different statistics available from the database for a larger administrative district in Lower Saxony. Here, the new geothermal installations broken down to the type of system are plotted for each year. In this case, the local authority can see a successive growth of the market, that borehole heat exchangers have a dominant market share and open well systems are rarely used.

It is not only possible to see the development of the market for shallow geothermal systems in Lower Saxony but also to detect trends in installation configuration. Furthermore, it allows an overview on used materials (heat carrier fluid and grouting material) and the possibility to select installations with specific properties.

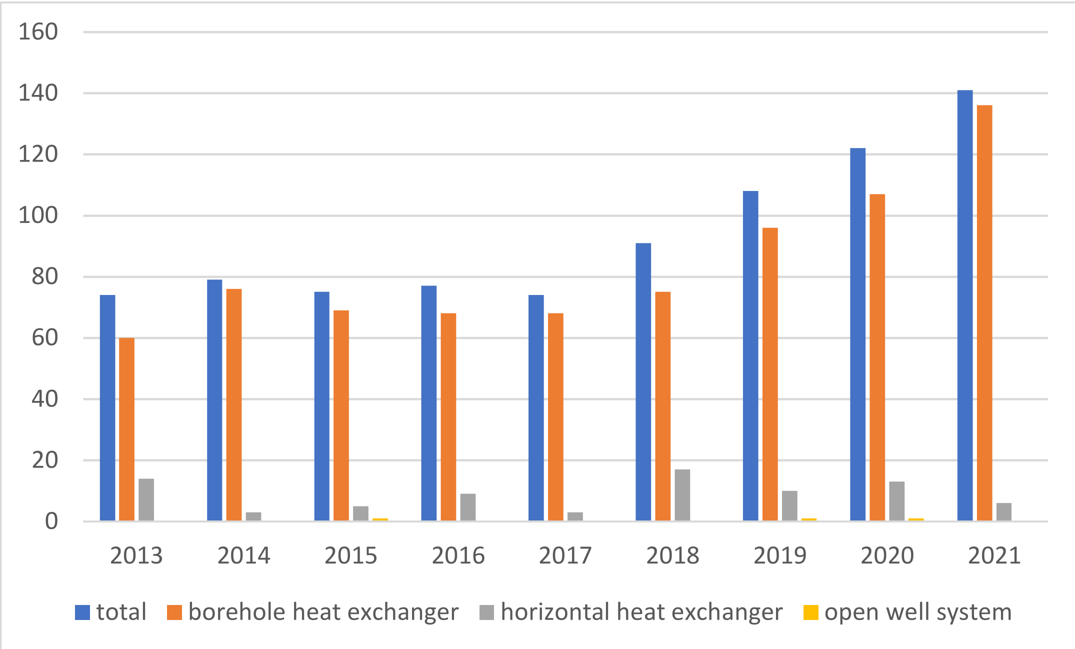


Figure 8: Number of new geothermal installations broken down to the type of heat pump system for a larger administrative district in Lower Saxony for the last nine years.

5. OUTLOOK

In Germany, about 75 % of the current heat supply for district/space heating and hot water are covered by the fossil fuels oil, natural gas and coal (BMWK, 2022).

In view of rising energy prices, geothermal energy, which has an enormous potential for expansion along with low land requirements, has to become a key pillar in German heat supply. The geothermal gradient can be used in all scales resulting in a whole variety of geothermal applications. In many areas of heat generation fossil fuels such as coal, oil and natural gas can be substituted by geothermal energy.

Besides deep geothermal energy utilisation there is also a large growth potential for shallow and medium-deep geothermal resources, through the utilisation of ground source heat pumps, especially for new buildings, or by using high temperature heat pumps, respectively.

In the case of shallow geothermal energy utilisation, it will be necessary above all to expand and strengthen human resources for all the steps required to set up a geothermal heat pump plant in order to be able to implement the enormous numbers of new plants that will be needed on the market in the coming years.

This includes the skilled trades of installers and drillers, who are already suffering from the increasing shortage of qualified workers in Germany, as well as the planning engineers and the licensing authorities. (BIBB, 2021; KOFA, 2021; prognos, 2018).

Furthermore, a change in the regulatory framework is urgently needed. In order to strengthen the use of geothermal heat pumps, a ban on the installation of new fossil heating systems in the short term and a ban on existing systems in the medium term would be an important step.

Geothermal heat pumps for heating and cooling purposes and for domestic hot water heating in individual buildings as well as in larger heating networks are an established technology for sustainable energy supply in Germany, whose extensive potential must be used much more extensively in the short term.

REFERENCES

Agemar, T., Alten, J.-A., Ganz, B., Kuder, J., Kühne, K., Schumacher, S. and Schulz, R: The Geothermal Information System for Germany – GeotIS, *German J. Geosci.*, 165 (2), (2014a), 129-144.

Agemar, T., Weber, J. and Schulz, R.: Deep Geothermal Energy Production in Germany, *Energies*, **7**, (2014b), 4397-4416.

Agora Energiewende: Prognos, Öko-Institut, Wuppertal-Institut: Klimaneutrales Deutschland 2045. Wie Deutschland seine Klimaziele schon vor 2050 erreichen kann Zusammenfassung im Auftrag von Stiftung Klimaneutralität, Agora Energiewende und Agora Verkehrswende, Berlin, Germany, (2021).

Arpagus, C., Bless, F., Uhlmann, M., Schiffmann, J. and Bertsch, S.F.: High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials. *Energy*, 152, (2018), 985 – 1010.

BAFA - Bundesamt für Wirtschaft und Ausfuhrkontrolle: Auswertung Förderanträge 2020, (2021).

BAFA - Bundesamt für Wirtschaft und Ausfuhrkontrolle: Bundesförderung für effiziente Gebäude (BEG), (2022).

BDEW - Bundesverband der Energie- und Wasserwirtschaft: Strompreisanalyse Januar 2022, Berlin, Germany, (2022).

BDH – Marktentwicklung Wärmeerzeuger Deutschland 2012-2020, (2021).

BDI - Bundesverband der Deutschen Industrie e. V.: Klimapfade für Deutschland, Berlin, Germany, (2021).

BIBB - Bundesinstitut für Berufsbildung: Statistik Brunnenbauer, (2021).

BMWK: Zahlen und Fakten: Energiedaten, BMWK, Stand 30.05.2022, https://www.bmwk.de/Redaktion/DE/Artikel/Energie/energiedaten-gesamtausgabe.html

Born, H., Schimpf-Willenbrink, S., Lange, H., Bussmann, G., and Bracke, R.: Analyse des deutschen Wärmepumpenmarktes - Bestandsaufnahme und Trends, Bochum, Germany (2017).

Bracke, R. et al.: Roadmap Tiefe Geothermie für Deutschland. (2022). https://doi.org/10.24406/ieg-n-645792

BWP-Bundesverband Wärmepumpe e.V.: BWP-Branchenstudie 2021, Berlin, Germany (2021).

BWP (Bundesverband Wärmepumpe – German Heat Pump Association): Press release on sales figures 2010 - 2018, Bundesverband Wärmepumpe e.V., Berlin, Germany (2018).

BWP-Bundesverband Wärmepumpe e.V: Absatzzahlen & Marktdaten zu Wärmepumpen, pers. comm. (2013, 2017, 2018 & 2021).

Cröniger, C.: Fernwärmevision der Stadtwerke München – Mit Tiefengeothermie zum Ziel. Fachtagung „Geothermie und geologische Wärmespeicherung“, (2020).

dena - Deutsche Energie-Agentur GmbH: Gebäudestudie – Szenarien für eine marktwirtschaftliche Klima- und Ressourcenschutzpolitik 2050 im Gebäudesektor, Berlin, Germany, (2017).

Duvia, D.: Project description and announcement of the 6th ORC plant, soon to be added to Turboden’s operating fleet in Bayern. Praxisforum Geothermie Bayern, (2020).

Epting, J. et al.: City-scale solutions for the energy use of shallow urban subsurface resources – Bridging the gap between theoretical and technical potentials. Renewable Energy, 147, (2020).

Erlingsson, T. and Porhallson, S.: Long distance transmission pipelines for geothermal water in Iceland (20-60 km). Workshop for Decision Makers on District heating - Use of Geothermal Resources in Asia, (2008).

Eyerer, S., Schifflechner, C., Hofbauer, S., Bauer, W., Wieland, C. and Spliethoff, H.: Combined heat and power from hydrothermal geothermal resources in Germany: An assessment of the potential. Renewable and Sustainable Energy Reviews, 120, (2020).

Fraunhofer ISE - Brandes, J., Haun, M., Wrede, D., Jürgens, P., Kost, C., Henning, H.: Wege zu einem klimaneutralen Energiesystem 2050, Freiburg, Germany (2020).

Friedlaender, O.: Entwicklung und Inbetriebnahme der Geothermieanlage Garching an der Alz. Praxisforum Geothermie Bayern, (2020).

Gahr, A.: Das Eavor-Loop-Erschließungskonzeptein geschlossener tiefengeothermischer Wärmetauscher. GAB Wissenstransfer 2022, (2022).

GeotIS (Geothermal Information System for Germany): Data on geothermal direct use and electricity, (2019), http://www.geotis.de.

GeotIS (Geothermal Information System for Germany): Data on geothermal direct use and electricity, (2022), http://www.geotis.de.

Geovol: Pressemitteilung: Erste geothermische Kälteanlage in Unterföhring im Betrieb. (2015).

Greenpeace: Heizen ohne Öl und Gas bis 2035, Hamburg, Germany, (2022).

Haenel, R. and Staroste, E. (Eds.): Atlas of Geothermal Resources in the European Community, Austria and Switzerland, Publishing company Th. Schaefer, Hannover, Germany, (1988).

Hurter, S. and Haenel, R. (Eds.): Atlas of Geothermal Resources in Europe, Office for Official Publications of the European Communities, Luxemburg, (2002).

ITG (Informationsportal Tiefe Geothermie): Geothermischer Strom von Orcan Energy Modulen, (2021). https://www.tiefegeothermie.de/news/geothermischer-strom-von-orcan-energy-modulen (last accessed on April 17, 2022).

Jensen, H. and Pester, S.: Potenziale für regenerative Wärme durch oberflächennahe Geothermie, Lecture notes, (2019).

Jung, R., Röhling, S., Ochmann, N., Rogge, S., Schellschmidt, R., Schulz, R. and Thielemann, T.: Abschätzung des technischen Potenzials der geothermischen Stromerzeugung und der geothermischen Kraft-Wärmekopplung (KWK) in Deutschland, Bericht für das Büro für Technikfolgenabschätzung beim Deutschen Bundestag, BGR/GGA, Archiv-Nr. 122 458, Hannover, (2002).

Kleinertz, B. et al.: Klimaneutrale Wärme München 2035. Ermittlung der Möglichkeiten zur Umsetzung von Lösungspfaden für eine klimaneutrale Wärmeversorgung in der Landeshauptstadt München. Gemeinsame Studie von FfE GmbH und Öko-Institut e. V, (2021).

KOFA - Kompetenzzentrum Fachkräftesicherung: Fachkräfteengpässe in Unternehmen – Fachkräftemangel und Nachwuchsqualifizierung im Handwerk, Köln, Germany, (2021).

Loewer, M., Keim, M., Molar-Cruz, A., Schifflechner, C., Zosseder, K. and Drews, M.: Ausbau der Tiefengeothermie in Bayern: Optimierung durch Wärmeverbundleitungen. Geothermische Energie, 97, (2020).

Mathes, R: Thermalwasserkreislauf und Wärmepumpenanlage im geothermischen Heizwerk Schwerin. Geothermische Energie, 101, (2022), 4-5.

Moeck; I.: Catalog of geothermal play types based on geologic controls, Renewable and Sustainable Energy Reviews, 37, (2014), 867-882.

Paschen, H., Oertel, D. and Grünwald, R.: Möglichkeiten geothermischer Stromerzeugung in Deutschland, TAB-Arbeitsbericht Nr. 84, Büro für Technikfolgenabschätzung beim Deutschen Bundestag (TAB), Berlin, (2003).

prognos im Auftrag des VdZ – Spitzenverband der Gebäudetechnik: Fachkräftebedarf für die Energiewende in Gebäuden, Berlin, Germany, (2018).

Sanjuan, B., Gourcerol, B., Millot, R., Rettenmaier, D., Jeandel, E. and Rombaut, A.: Lithium-rich geothermal brines in Europe: An up-date about geochemical characteristics and implications for potential Li resources. Geothermics, 101, (2022).

Schäfer, J., Reissner, F., Girbig, P. and Wenn. N.: Hochtemperaturwärmepumpen im Kontext geothermischer Wärmeversorgung. Berliner Energietage, (2019).

Statistisches Bundesamt: Bauen und Wohnen Baugenehmigungen / Baufertigstellungen von Wohn- und Nichtwohngebäuden (Neubau) nach Art der Beheizung und Art der verwendeten Heizenergie, Lange Reihen ab 1980, (2021).

Suchi, E., Dittmann, J., Knopf, S., Müller, C. and Schulz, R.: Geothermie-Atlas zur Darstellung möglicher Nutzungskonkurrenzen zwischen CO2-Einlagerung (CCS) und Tiefer Geothermie in Deutschland, German J. Geosci., 165 (3), (2014), 439-453.

SWM: Der neue Energiestandort Süd. (2022). https://www.swm.de/magazin/energie/energiestandort-sued (last accessed on April 17, 2022).

SWM Services GmbH: Geothermie Michaelibad, Wärmestation - Anlagenplanung Referenznummer der Bekanntmachung: SV-KWE-210721-003. (2021).

Weber, J., Born, H. and Moeck, I.: Geothermal Energy Use, Country Update for Germany 2016 – 2018. Proceedings European Geothermal Congress, (2019).

Weber, J., Born, H., Pester, S. and Moeck, I.: Geothermal Energy Use in Germany, Country Update 2015-2019. Proceedings World Geothermal Congress, (2020+1).

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	47.6	190.63*	232'500	573'600*	0.0002	0.0003
Under construction end of 2021						
Total projected by 2023						
Total expected by 2028						
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* 2020 numbers

Sources: BMWK (2022), GeotIS (2022)

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Bruchsal	Bruchsal	2010	1 (RI)	O	B-Kal	0.5	0.5	0*
Dürrnhaar	Dürrnhaar	2012	1 (RI)	O	B-ORC	5.5	5.5	34.4*
Garching a. d. Alz	Garching a. d. Alz	2021	1 (RI)	O	B-ORC	4.9	4.9	na
Grünwald/Laufzorn	Grünwald/Laufzorn	2014	1 (RI)	O	B-ORC	4.3	4.3	17.64*
Holzkirchen	Holzkirchen	2018	1 (RI)	O	B-ORC	3.6	3.6	24.04
Insheim	Insheim	2012	1 (RI)	O	B-ORC	4.8	4.8	21.0*
Kirchstockach	Kirchstockach	2013	1 (RI)	O	B-ORC	5.5	5.5	29.7*
Kirchweidach	Kirchweidach	2021		N		0.7	0	na
Landau	Landau	2007	1 (RI)	O	B-ORC	3.0	1.8	7,72*
Neustadt-Glewe	Neustadt-Glewe	2003	0	R	B-ORC	na	na	na
Sauerlach	Sauerlach	2013	1 (RI)	O	B-ORC	5.0	5.0	24.8*
Simbach-Braunau	Simbach-Braunau	2010	0	R	B-ORC	na	na	na

Table B: Existing geothermal power plants, individual sites (continued)

Locality	Plant Name	Year commissioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 production * (GWh_e/y)
Taufkirchen	Taufkirchen	2016	1 (RI)	O	B-Kal	4.3	4.3	na
Traunreut	Traunreut	2016	1 (RI)	O	B-ORC	5.5	5.5	31.33*
Unterhaching	Unterhaching	2009	0	R	B-Kal	na	na	na
total						47.6	45.7	190.63

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
R	Retired / decommissioned	2F	Double Flash	O	Other

* 2020 numbers

** (RI): re-injection

Source: GeotIS (2022)

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	345.8	1233.1*			4.28	10.0*	56.8 est.	474.6 est.
Under construction end 2021	90							
Total projected by 2023	440							
Total expected by 2028	500							

* 2020 numbers

Source: GeotIS (2022)

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Aschheim	Aschheim	2009	N	N (RI)	12.4	47.55	70.53[a]* 91.17[b]*	77.4
Bruchsal	Bruchsal	2009	Y	N (RI)	1.2	na	2.3[a]*	na
Erding	Erding	1998	N	N (RI)	10.2	48.8	18.69[a]* 91.12[b]*	20.5
Freiham	Freiham	2016	N	N (RI)	13.0	78.0	91.4[a]* 106.8[b]*	85.6
Garching	Garching	2012	N	N (RI)	7.95	27.95	37.06[a]* 49.65[b]*	74.6
Grünwald/Laufzorn	Grünwald/Laufzorn	2011	Y	N (RI)	40.0	73.0	51.67[a]* 268.29[b]*	19.3
Holzkirchen	Holzkirchen	2017	N	N (RI)	24.0	24.0	177.9[a]* 177.9[b]*	100.0
Ismaning	Ismaning	2013	N	N (RI)	7.2	37.0	45.0[a]* 59.0[a]*	76.3
Kirchweidach	Kirchweidach	2013	N	N (RI)	30.6	30.6	60.0[a]* 60.0[b]*	100.0
Landau	Landau	2011	Y	N (RI)	5.0	33.0	0.92[a]* na	na
München Riem	München Riem	2006	N	N (RI)	13.0	51.0	74.2[a]* 84.1[b]*	88.2
Neustadt-Glewe	Neustadt-Glewe	1994	N	N (RI)	4.0	14.0	15.36[a]* 20.22[b]*	76.0
Poing	Poing	2012	N	N (RI)	9.0	39.0	43.8[a]* 55.8[b]*	78.5
Prenzlau	Prenzlau	1994	N	N (BHE)	0.15	0.15	0.37[a]*	na
Pullach	Pullach	2005	N	N (RI)	16.5	33.5	69.0[a]* 75.0[b]*	92.0
Sauerlach	Sauerlach	2013	Y	N (RI)	4.0	4.0	8.5[a]* 8.5[b]*	100.0
Simbach-Braunau	Simbach-Braunau	2001	N	N (RI)	9.0	48.26	50.67[a]* 64.19[b]*	78.9
Straubing	Straubing	1996	N	N (RI)	2.1	7.3	2.9[a]*	na
Taufkirchen	Taufkirchen	2015	Y	N (RI)	40.0	40.0	92.0[a]* 92.0[b]*	100.0

Table D1: Existing geothermal district heating (DH) plants, individual sites (continued)

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Traunreut	Traunreut	2015	Y	N (RI)	13.9	12.0	30.06[a]* 43.65[b]*	68.9
Unterföhring	Unterföhring	2009	N	Y (RI)	10.0	30.0	32.4[a]* 32.4[b]*	100.0
Unterföhring II	Unterföhring II	2015	N	N (RI)	11.3	31.3	27.8[a]* 27.8[b]*	100.0
Unterhaching	Unterhaching	2007	N	N (RI)	38.0	83.0	157.84[a]* 176.47[b]*	89.4
Unterschleißheim	Unterschleißheim	2003	N	N (RI)	8.0	35.0	36.21[a]* 64.2[b]*	56.4
Waldkraiburg	Waldkraiburg	2012	N	N (RI)	14.0	18.5	34.73[a]* 35.93[b]*	96.7
Waren	Waren	1984	N	N (RI)	1.3	10.74	1.79[a]* 9.43[b]*	19.0
total					345.8	857.65	1233.1[a]* 1700.1[b]*	72,5

* 2020 numbers
** CHP: Y (for yes); N (for no)
*** (RI): re-injection
[a] geothermal
[b] total
Source: GeotIS (2022)

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Arnsberg	Erlenbach 2	2012	N (BHE)	0.35	na	2.1*	na	
Bochum	Zeche Robert Müser	2012	N	0.4	2.89	1.2*	na	
Essen	Essen	2010	N	0.8				
Heubach	Heubach	2013	Y (BHE)	0.09	na	na	na	
Landau	Landau	2014	N (BHE)	0.08	na	na	na	
Marl	Marl	2010	N (BHE)	0.06	na	na	na	
Neuruppin	Neuruppin		N (RI)	1.4	2.1	1.04	na	
Weinheim	Miramar	2007	N (RI)	1.1	4	5.65*	na	
various	168 thermal spas			56.8 est.	na	474.6 est.		
total				61.08		484.6	na	

* 2020 numbers

** (RI): re-injection

Source: GeotIS (2022)

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021	435’000	4930	7140 [a] 9830 [b]	27’000	280	18
Of which networks						
Projected total by 2023						

[a] geothermal

[b] total

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	Yes	Yes	Yes
Financial Incentives – Investment			Yes
Financial Incentives – Operation/Production	FIT		No
Information activities – promotion for the public			Yes
Information activities – geological information			Yes
Education/Training – Academic			(Yes)
Education/Training – Vocational			(Yes)

Key for financial incentives:					
DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for Greece

Dimitrios Mendrinos[1], Constantine Karytsas[1], Markos Kapiris[1], Maria Papachristou[2], Paschalis Dalampakis[3], Apostolos Arvanitis[4], and Nikos Andritsos[5]

[1]Centre for Renewable Energy Sources and Saving, 19th km Marathonos ave., 19009 Pikermi, Greece

[2]Department of Geology, Aristotle University of Thessaloniki, GR-54124, Thessaloniki, Greece

[3]Soil and Water Resources Institute, Greek Agricultural Organization "DEMETER", 57400, Sindos, Greece

[4]Hellenic Survey of Geology and Mineral Exploration, 1 Sp. Louis str., 13677 Acharnae, Greece

[5]Department of Mechanical Engineering, University of Thessaly, Athinon & Sekeri str., 38334, Volos, Greece

dmendrin@cres.gr

Keywords: resources, exploration, direct uses, geothermal heat pumps, GSHP.

ABSTRACT

Geothermal exploitation in Greece comprises 43 MW_{th} of low enthalpy geothermal energy use for greenhouse heating and other agricultural applications, 43 MW_{th} of thermal spas and 191 MW_{th} of ground source heat pumps (GSHP). All three sectors are expected to enjoy high growth during the next years. Furthermore, new district heating systems are under development and the first geothermal pilot power plants exploiting high enthalpy resources are under investigation.

1. INTRODUCTION

Greece is characterized by considerable availability of geothermal resources. They are divided in three main groups: (a) low temperature (30-99 °C) identified in most cases in the vicinity of the numerous thermal springs found all over the country, (b) medium-high temperature (100-300 °C) inferred by geothermometers at the depths of basins/grabens of high heat flow and in formations of Miocene or more recent volcanism and (c) high temperature (>300 °C) identified by drilling exploration or active volcanism in the islands of the Aegean Volcanic Arc Nisyros, Santorini, and Milos (Mendrinos et al 2010, Papachristou et al 2014).

Geothermal activities during the years 2019-2022 are characterized by intensive exploration seeking low temperature resources, mainly by the Hellenic Survey of Geology & Mineral Exploration (HSGME), development of the large corporate geothermally heating greenhouses of SELECTA HELLAS and THRACE GREENHOUSES and further expansion of the GSHPs market. Investments for low enthalpy applications (excluding GSHP) amounted at around 6 million euro annually. In addition, the geothermal legislation has been streamlined removing some of the legal barriers of the previous framework. The new legislation effectively facilitates GSHPs development, as the temperature threshold below which no concessions are required has been increased to 30 °C. Other market segments, namely the small family-owned agricultural units, aquaculture and thermal spas remained stagnant at previous levels due to the financial crisis affecting the country and the COVID-19 pandemic, while there was no geothermal power generation (Papachristou et al 2020).

2. RECENT DEVELOPMENT

2.1 Power generation

The national plan for energy and climate foresees 100 MWe of install capacity of geothermal power plants in 2030. In this direction, PPC-R the subsidiary of Public Power Corporation of Greece focusing on renewable energy has shown renewed interest in geothermal development. PPC-R proceeded with strategic cooperation with ELECTOR SA for the development of geothermal power plants in the areas that PPC-R has acquired high enthalpy geothermal concessions, namely Milos-Kimolos isl., Lesvos isl., Methana peninsula and Nisyros isl. In each one of them a 5 MWe power plant is planned.

The cooperation will be implemented through the joint subsidiary "Geothermal Objective II" owned by 51% ELECTOR, and 49% PPC-R. PPC-R will complete the exploration for the identification and characterization of geothermal potential in these areas. The total investment plan amounts at 120 million euro, 70 million of which will be geothermal exploration and the other 50 million geothermal field and power plants development.

The national legislation has been completed by two Ministerial decrees, as follows. The first one is Ministerial decree No ΥΠΕΝ/ΔΑΠ/42138/552 published at government gazette 1960B on 21 May 2021, which regulates onsite geothermal works. The second one is Ministerial decree No ΥΠΕΝ/ΔΑΠ/25257/126, published at government gazette 1460B on 28.03.2022, which defines the terms and procedure for allocating concession rights for exploration, management and exploitation of geothermal resources of national interest (resource temperature above 90 °C), as well as geothermal exploration rights in unexplored areas.

2.2 Agricultural applications

The utilization of geothermal fields for agricultural applications in northern Greece is largely due to the positive attitude of local government and local communities, and the general perception that geothermal energy can be a source of economic and environmental benefits.

THRACE GREENHOUSES

Thrace Greenhouses is the flagship of low enthalpy geothermal development in Greece with a turnover of 8 million euro annually employing 210 persons. It exploits the geothermal resource of Neo Erasmio, in order to heat 18.5 hectares of hydroponic greenhouses producing 6000 tons of tomatoes plus 10000 tons of cucumbers for the Greek market. It utilizes 14.64 MW_{th} of geothermal fluids of 60-70 °C delivering 45.8 GWh_{th} annually of heat from 8 production wells, 210-330 m deep each. Additional wells and piping network are planned to be constructed in order to reach 36.7 MW_{th} of geothermal heat utilization. For this purpose, additional 13 hectares of greenhouses are under construction in Neo Erasmio, increasing production by 6000 tons and creating another 70 jobs. An investment of 14.66 million euro is foreseen for this purpose.

The company has also secured the concession of the northern part of the nearby geothermal field of Nea Kessani, in order to produce 12 MW_{th} of 73°C of geothermal fluids from 400-450 m deep wells, which will heat 13 ha greenhouses producing 10 thousand tons of vegetables (tomatoes and cucumber). The corresponding investment amounts at 12.6 million euro and will generate 90 job positions.

SELECTA HELLAS

Selecta Hellas is the second corporate-owned geothermal greenhouse complex in Greece, producing flowers for the export markets. It is located at the geothermal field of Eratino-Chrysoupoli, near Kavala airport. The greenhouses cover an area of 3.5 hectares (ha) and employ 120 persons. In collaboration with the Municipal Water Supply and Sewerage Company of Nestos, it exploits 2.38 MW_{th} of geothermal fluid produced at 69-77 °C from two 750 m deep well doublets. Company development plans are to expand the greenhouse area by 2.1 ha in the next years, and to drill 2 additional wells (doublet) 700 m deep, in order to reach 9.8 MW_{th} of installed geothermal capacity.

FAMILY-OWNED GREENHOUSES

Having been the backbone of geothermal development in Greece until 2010, approximately 20 small family-owned geothermal agricultural businesses remain operational today. It has been a declining market during the past 10 years, mainly due to the financial crisis prevailing in the country and the COVID-19 pandemic. They are located in the geothermal fields of northern Greece, namely Nea Apollonia, Nigrita, Sidirokastro, Neo Erasmio and Myrodato, but also on the islands of Lesvos (Polychnitos) and Milos. They comprise greenhouses, soil heating and drying facilities, with small space heating applications in a few cases. Soil heating, space heating and aquaculture concern very limited applications, both in terms of installed capacity and number of facilities. Fish farming units do not operate any more. Estimated total geothermal utilization is around 24 MW_{th}.

2.3 District heating

During the last few years, the Municipality of Alexandroupolis started a new geothermal venture, in order to provide heat from the nearby geothermal field of Aristino to existing and new thermal energy users. Co-financed by regional structural funds, after 8 years of preparations and bureaucracy, in April 2020, a contract of 6.2 million € was signed for the construction of a 12 km long heat transfer and piping network. Its capacity is 10 MW_{th}, 9 MW_{th} of which will be utilized for agricultural use, namely heating 2 existing greenhouses of 1.5 ha total, plus new greenhouses totalling 3 ha, and 1 MW_{th} for district heating of nearby social housing complex of 5 buildings hosting children, plus 11 municipal buildings. The district heating network will be supplied by two geothermal doublets, 500 m deep. An additional amount of circa 1.2 million € was allocated recently for this purpose.

The project is now in its final phase and, according to the contractor, it is expected to be delivered by the end of August. At the time of writing of this paper (April 2022), drilling of the first re-injection borehole is under way, while drilling of the second one is expected to commence in May 2022. Next, consumers will be connected to the district heating network.

Future plans include expansion of the district heating network by additional wells and 6 more km piping to nearby villages, plus heating of a pellet-producing plant under construction. Allocated budget amounts at 14.7 million €. In April 2021, the Municipality expanded its geothermal concession rights to exploit fluids up to 99 °C, which are suitable for large scale district heating plus a small geothermal power plant. The Municipality initiated the necessary prefeasibility studies in this direction.

2.4 Thermal spas

In Greece there are more than 70 spa therapy centres and spa facilities as well as circa 25 outdoor pools operating with geothermal water. There are 100+ hot springs across the country, 80 of which are officially characterized as thermal, see Figure 1. The temperature of the hot springs ranges from 25 to 92+ °C, while the temperature of the hot waters in the spa treatment facilities does not exceed 39 ° C. Almost all traditional spa towns are open from June to October, while only a few remain open all year round. Geothermal fluids in these facilities are for thermal use only and are not used for heating of the spa areas or the hospitality of the guests, except in the case of the baths of Traianoupolis, located near Aristino geothermal field. The use of geothermal energy in spa units in Greece cannot be accurately calculated, as there is no systematic recording of the necessary data. A conservative estimation of installed capacity and energy use is 43 MW_{th} and 72 GWh_{th}/yr respectively.

In order to further develop the spa market in Greece, the Ministry of Tourism is setting up the public limited company "Thermal Springs of Greece" with initial share capital of 5 million €, in order to identify, manage and utilize the country's thermal springs according to existing investment plans. The "Thermal Springs of Greece" will utilize the natural thermal resources, their facilities and the surrounding area within a radius of 500 meters, which is the property of the State or local Authorities.

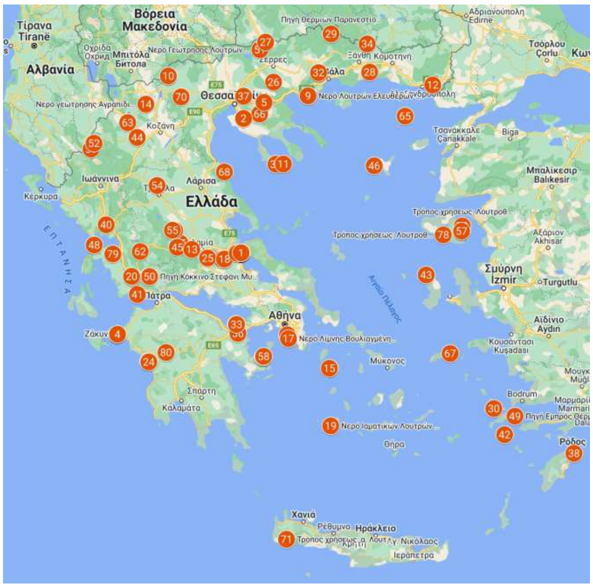


Figure 1: Map of thermal springs in Greece.

2.5 Ground Source Heat Pumps

The GSHP sector remains the most dynamic in the domestic geothermal market, for reasons that could summed up in the mature technology, their attractive financial performance, the simplified licensing procedures and most important the National commitment towards decarbonising the building sector, by incorporating the corresponding EU legislation towards nearly zero energy buildings in the national legal framework. They provide heating and cooling to residential, commercial, industrial and public buildings, also including one greenhouse heating application in Chrysoupoli. Although no exact figures are available, it is estimated that every year around 180 new installations take place of total capacity around 6.7 MW_{th}, corresponding to 2 % of new buildings. They are mainly large units of circa 47 kW_{th} installed capacity on average. Overall installed capacity of GSHPs exceeded 180 MW_{th} at the end of 2021, corresponding to circa 320 GWh_{th} of heating plus circa 160 GWh_c of cooling.

2.6 Dehydration of Agricultural Products

As has been described in previous updates and in Andritsos et al. (2003), a novel dehydration plant of agricultural products operates in Neo Erasmio (Xanthi, northern Greece) since 2001. The unit uses geothermal water of 60°C to heat atmospheric air to 55-58°C, which then is directed to series of drying channels. Although initially the plant was designed and constructed to dehydrate only tomatoes, in recent years the plant is used to dehydrate several other agricultural products, and the plant actually operates almost all year around. In 2021 the quantities of dehydrated products are as follows: tomatoes 6 tn (lower quantities than in early 2010s due to unavailability of fresh produce), citrus fruits (lemons, oranges, limes) 9 tn, peppers (yellow, green, chili) 8.5 tn, olives 4 tn and garlic 1 tn. Smaller quantities of several other products, such as apples, onions, mushrooms and zucchinis, have been also dehydrated during 2021.

3. ONGOING PROJECTS AND FUTURE PLANS

In addition to the above developments, the most important geothermal exploration and utilization projects in progress concern the following low enthalpy geothermal areas:

Akropotamos geothermal field: The Municipality of Paggaio has acquired the exploitation rights and field management and plans to invest around € 10 million in district heating networks and the distribution of thermal energy in semi-urban areas, greenhouses and spa facilities. The project is still in the early stages of prefeasibility studies.

Lithotopos geothermal field: The geothermal exploration rights of the field have been leased to the Municipality of Irakleia. The geothermal exploration assigned to I.G.M.E. (now HSGME, Hellenic Survey of Geology and Mining Exploration) was completed in 2019 and had relatively good results. The new production wells, 352.5-519.5 m deep, yield waters of 37.5-74.5 ºC. The flow rates range between 5 and 80 m^3/h depending on lithology, aquifer properties and screen depths. The total installed thermal capacity from the existing production wells is estimated to be 4.47 MW_{th} (Arvanitis et al., 2021). The Municipality has decided to utilize the geothermal energy in the area and is in the process of submitting feasibility studies for the development of the field in order to obtain the right to exploit and manage the geothermal potential.

Nigrita geothermal field: the Municipality of Visaltia extended their concession rights to exploit the geothermal field of Therma Nigritas for an additional 20 years. They own a production well delivering 2.5 MW_{th} of geothermal heat, which will be distributed to local farmers for greenhouse and soil heating.

Sidirokastro geothermal field: An ongoing geothermal drilling project is being performed by

HSGME (Hellenic Survey of Geology and Mineral Exploration) in the northern part of the Sidirokastro geothermal field. This project is included in the "Actions for the Rational and Sustainable Utilization of Geothermal Energy - GEOTHERM" and is funded by the Operational Program "Competitiveness, Entrepreneurship & Innovation" (EPAnEK) which is one of the Programs of the Partnership and Cooperation Agreement (NSRF) for the period 2014-2020. The first large diameter exploration well (Sd-18P) was completed in October 2021 and identified 75 °C fluid at 200 m depth. Geothermal exploration is ongoing in the area.

Eratino-Chrysoupoli geothermal field: The Municipality of Nestos, which owns the concession of the Eratino geothermal field and supplies geothermal fluid to Selecta Hellas via a small district heating network, also plans to further expand the district heating network towards heating the elementary school of Eratino and constructing a small farm heated by geothermal energy for agricultural research purposes in an area of 0.4 ha. The farm will comprise a pilot greenhouse growing hydroponic crops of vegetables and floating leafy vegetables, along with underfloor heating applications for asparagus, melons and watermelons. The greenhouse will be connected to existing district heating network. The project has already been designed and is in the final phase of funding.

Aristino geothermal field: A company named "THRACIAN ENERGY" plans to explore a part of the Aristino geothermal field covering an area of 7 km^2 and submitted binding investment proposal to the Decentralized Administration of Macedonia and Thrace in November 2021 in the frame of an open invitation. The proposed exploration program includes detailed geological and structural study, geoelectric surveys and drilling of two (2) exploration wells (500-600 m deep) aiming to find geothermal fluids of 90 °C with a flow rate of 200 m^3/h.

Polichnitos geothermal field: The Municipality of Western Lesvos has been interested in the exploitation of the Polichnitos geothermal field where temperatures of 30-90 °C are encountered at depths of 50-200 m and submitted binding investment proposal to the Decentralized Administration of the Aegean in November 2021 during an open tendering procedure for granting of exploitation and management rights.

Except for the exploration in the above-mentioned low enthalpy fields, some additional geothermal works and projects are currently carried out by the Hellenic Survey of Geology and Mineral Exploration (HSGME):

Diachronic (periodic and continuous) monitoring of selected low enthalpy geothermal fields and hot springs for their optimal use and ensuring their sustainability: Based on the new geothermal law (Law 4602/2019, article 21), the monitoring of the geothermal fields of the country is carried out by HSGME. For this purpose, the first geothermal telemetry stations for monitoring, recording and data transmission have been installed since October 2020 in the following geothermal areas: Neo Erasmio-Magana geothermal field, Nisyros island and Santorini island. Each geothermal telemetry station consists of the following main components: (a) temperature and hydraulic pressure sensors installed at specific depths in monitoring boreholes and contact thermometers at wellheads of production wells for water temperature measurements, (b) a box for collecting, recording and transmitting data containing the necessary equipment (data logger unit, radio modem, battery, charge controller) and (c) protected cables connecting sensors to the box. A telemetry station can be supplied either by photovoltaic panel or electricity grid. The installed telemetry stations use the "LoggerNet" support software for real-time access to data. All data is transmitted to the server of HSGME.

Management Plans of Low Temperature Geothermal Fields in Greece: This project has started since February 2020 and is funded by the Operational Program "Competitiveness, Entrepreneurship & Innovation" (EPAnEK) in the frame of NSRF 2014-2020. The aim of the Project is the creation of a pilot and synthetic study of management plans for geothermal fields of local interest (fluid temperature lower than 90 °C) and its pilot application in 2 selected geothermal fields (Neo Erasmio-Magana and Nea Apollonia). The first two technical reports entitled "Management plan specifications of low temperature geothermal field" and "Standard pilot implementation of a management plan in the Neo Erasmio-Magana geothermal field, Xanthi area" were completed and submitted to the Hellenic Ministry of Environment and Energy in November 2020 and August 2021 respectively.

Reconnaissance geothermal exploration in the Myrodato area: The geothermal exploration in the Myrodato area (Xanthi Regional Unit) included in the "Actions for the Rational and Sustainable Utilization of Geothermal Energy - GEOTHERM" (EPAneK, NSFR 2014-2020) aims at the probable identification of a new low temperature geothermal field. Collection and critical review of the existing geological, structural, and drilling data, registration of existing irrigation and drinking water wells, borehole and wellhead temperature measurements, water sample collection and chemical analyses have already been carried out.

Compilation and publication of a Guide on Geothermal Energy, in Greek and English - A Guide on Geothermal Energy: The aim of the Project funded by the Public Investment Program (National Funding) is to compile an investment guide for the use of geothermal energy in Greece, which will provide useful information on the geothermal situation, the fields and potential of the country, the existing legal framework and the available financial tools for investment projects.

Long-term monitoring, supervision and restoration of geothermal wells drilled by IGME (now HSGME) which have not been assigned to third parties: A large number of geothermal wells have been drilled by IGME (now HSGME) for exploration, identification and evaluation of the country's low enthalpy fields. Some of them have not been assigned to third parties. This project funded by the Public Investment Program (National Funding) includes the following activities: (a) registration of existing geothermal wells (location, history, lithology, geothermal and construction characteristics) which have not been assigned to third parties and their current condition, (b) systematic in situ supervision and monitoring of these wells, (c) preparation of emergency response plans in case of leak detection, well-construction failures etc and (d) problem management in collaboration with the Decentralized Administrations of Greece. At the end of this project, the usable wells will be assigned to the Decentralized Administrations.

Creation of a National Register for the Registration and Monitoring of Geothermal Points: This project has started in January 2022 and is included in the Act entitled “Reinforcing Entrepreneurship in the Domain of the Hellenic Survey of Geology and Mineral Exploration (H.S.G.M.E.)”. The implementation of the National Register for the Registration and Monitoring of Geothermal Points is provided for by article 17 of the new Geothermal Law (Law 4602/2019). This project is accompanied by Legal Implementation Support and Publicity of the Act.

4. CONCLUSIONS

The Greek geothermal market is divided in three main segments, as follows.

The first one corresponds to direct low enthalpy heat use for heating agricultural units, which is transforming from small, family-owned agricultural enterprises to large corporate owned greenhouse units. The market is based on the exploration performed by the state-owned Hellenic Survey of Geological and Mining Exploration (HSGME) and infrastructure developed by local Authorities utilizing regional structural funds. This market segment is expected to grow in the next years by the expansion of existing and the addition of new geothermally heated greenhouses.

The second one is the thermal spa market, which is fragmented but has been stable during the past few decades, and is currently under reform by the Ministry of Tourism, in order to stimulate further growth materializing existing investment plans.

The third and the healthiest market segment corresponds to ground source heat pumps, which during the past 15 years enjoys steady growth, aided by favourable legal framework and national policy towards decarbonization of the building stock.

In the next years, two new market segments will be developed, namely space heating, as soon as the Municipal district heating systems under construction and planned are completed, and geothermal power, when the first pilot plants are constructed.

REFERENCES

Administrator of Renewable Energy Sources and Guarantees of Origin (DAPEEP): Concise RES and Cogeneration Information Bulletin, (December 2021), 24 pp., in Greek.

Andritsos, N., Dalabakis, P., and Kolios, N.: Use of Geothermal Energy for Tomato Drying, GeoHeat Center Quarterly Bul., 24(1), (March 2003), 9-13.

Arvanitis, A., Kavouri, K., Vougioukalakis, G., Karmis, P., Xenakis, M., Koufogiannis, I., Somataridou, V., Vakalopoulos, P., and Exioglou, D. (2021), "Systematic and multidisciplinary exploration in the Lithotopos -Iraklia low enthalpy geothermal field (Macedonia, Northern Greece)", Proceedings World Geothermal Congress 2020+1, Reykjavik, Iceland, April - October 2021, 11p.

Hellenic Electricity Distribution Network Operator S.A. (HEDNO): Production Fact Sheet at Unconnected Islands for August 2021, (2021), 13 pp., in Greek.

Independent Power Transmission Operator (IPTO): Monthly Energy Report, (December 2021), 37 pp., in Greek.

Independent Power Transmission Operator (IPTO): Study of Power Sufficiency for the period 2020-2030, 62 pp., (2019), in Greek [https://www.admie.gr › sites › files › users › dssas].

Mendrinos, D, Choropanitis, I., Polyzou, O., and Karytsas, C.: Exploring for geothermal resources in Greece, *Geothermics*, 39, (2010), 124-137.

Papachristou, M., Dalampakis, P., Arvanitis, A., Mendrinos, D., Andritsos, N., (2020), “Geothermal developments in Greece-Country Update 2015-2020”, Proc. World Geothermal Congress 2020, Reykjavik, Iceland

Papachristou, M., Karakatsanis, S., Kyriakopoulos, K., D' Alessandro, (2014), Geological setting, geothermal conditions and hydrochemistry of south and southeastern Aegean geothermal systems. In: GEOTHERMAL SYSTEMS AND ENERGY RESOURCES – TURKEY AND GREECE (pp. 47-75) Chapter 4, CRC Press - Taylor & Francis. Group Editors: A. Baba, J. Bundschuh, D. Chandrasekaram.

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021	0	0	21846	53815	0	0
Under construction end of 2021	0	0	2630	-	0	0
Total projected by 2023	0	0	23160	55800	0	0
Total expected by 2028	23	160	28240	58900	0.1 %	0.3 %
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development: 0	
					Under investigation: 5	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

No geothermal power plants currently in Greece.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants[(1)]		Geothermal heat in agriculture and industry[(2)]		Geothermal heat for buildings		Geothermal heat in balneology and other	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021	17	52	24	76	2	5	43	72
Under constru-ction end 2021	65	198	-	-	-	-	-	-
Total projected by 2023	62	189	24	76	2	5	43	72
Total expected by 2028	90	275	29	89	2	5	43	72

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

(1) Includes stand-alone large Greenhouse complexes of Table D2 plus future district heating plants

(2) Small family-owned units

Table D1: Existing geothermal district heating (DH) plants, individual sites

No geothermal district heating plants currently in Greece.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021pro duc-tion (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Erateino - Chryssoupolis	SELECTA HELLAS	2017	N	2.38	2.38	6.7	100%	SELECTA HELLAS
Neo Erasmio - Maggana	THRACE GREENHOUSES	2014	N	14.64	14.64	45.8	100%	THRACE GREENHOUSES
total				17.02	17.02	52.5	100%	-

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g., by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021		
	Number	Capacity (MW_{th})	Production[(1)] (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021	3878	182	478	178	6.7	2
Of which networks **	0	0	0	0	0	0
Projected total by 2023	4234	195	513			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

(1) includes cooling

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No geothermal UTES installations currently in Greece.

Table F: Investment and Employment in geothermal energy

	in 2021		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	0	3	23	20
Geothermal direct uses	7	85	7	90
Shallow geothermal	16	65	16	65
total	**23**	**153**	**46**	**175**

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	no	no	no
Financial Incentives – Investment	no	DIS	DIS, LIL
Financial Incentives – Operation/Production	FIT	no	no
Information activities – promotion for the public	no	no	no
Information activities – geological information	no	no	no
Education/Training – Academic	no	yes	yes
Education/Training – Vocational	no	no	no

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

European Geothermal Congress 2022
Berlin, Germany | 17-21 October 2022
www.europeangeothermalcongress.eu

Geothermal Energy Use, Country Update for Hungary

Annamária Nádor[1], Attila Kujbus[2], Anikó Tóth[3]

[1] Szabályozott Tevékenységek Felügyeleti Hatósága (Supervisory Authority of Regulatory Affairs), H-1051 Budapest, Sas utca 20-22

[2] Geothermal Express Ltd. H-1223 Budapest, Hant utca 26/B

[3] University of Miskolc, Miskolc Egyetemváros, H-3515 Miskolc, Hungary

annamaria.nador@sztfh.hu

Keywords: Pannonian Basin, direct use, district- and town heating, agriculture, risk mitigation scheme

ABSTRACT

In Hungary geothermal district-heating and thermal-water heating cascade systems represent a major part of direct use available in 26 towns, which altogether represent an installed capacity of 235.29 MWth and 641.37 GWh_{th}/yr production. The major development happened in Szeged in the frame of an ongoing development, which aims to introduce geothermal energy into 9 of the existing 23 district heating circuits. So far 4 triplets (4 circuits) have been completed and are operating in a test mode. In addition, 2 smaller town-heating projects were completed.

Individual space heating (mostly associated with spas) is available at nearly 50 locations These represent altogether an installed capacity of 94.11 MWth and 163.39 GWh_{th}/yr production. The agriculture sector is still a key player in direct use, especially in the S-ern part of the Hungary, where heating of greenhouses and plastic tents have long traditions. These account for about 402 MW_{th} installed capacity and about 880 GWh_{th}/yr production. Balneology has historical traditions in Hungary, more than 270 wells yield thermal water, sometimes medicinal waters which represent a total installed capacity of about 263 MW_{th} with an annual use of about 778.5 GWh_{th}/yr.

There is still just one operating geothermal power plant in Tura, with a gross electric capacity of 2.3 MW_e.

The increase of GSHP numbers has continued over the last several years. In the family house market and in other official and industrial applications, air-based heat pumps represent a significant part. The majority of the new applications such as communal heating/cooling are installed in new buildings by new companies. Never-theless it is hard to quantify the real growth, as there are still no reliable GSHP registers available in Hungary, because the systems shallower than 20 metres do not require a license, not even a notification to the authorities.

1. INTRODUCTION

Due to the favourable geological situation, the Pannonian basin is one of the European areas with well-known positive geothermal anomaly. Hungary is lying in the central parts of this extensive hot sedimentary aquifer complex, where the rich geothermal resources have been utilized mainly for direct use purposes for a long time. This extensive use has put Hungary on the 3-4th on the European ranking list in terms of direct use during the past decades.

The last country update (Nádor et al., 2019) was based on data available until 2017 of about 900 active thermal water wells (those having outflow temperature higher than 30 °C). The past country updates were continuously challenged by the diverse and unharmonized datasets available at mining authorities, research institutes and water management organizations, where the different registers were tailored to the specific needs and purposes of the organizations mentioned above. In this respect, a major achievement was the establishment of Hungary's first digital online geothermal information platform (OGRE) in 2019-2020 (also fully available in English) which made it possible to make the present assessment based on a reliable and regularly updated national geothermal database (Nádor, 2022). The present paper is describing the development of the Hungarian geothermal sector based on assessing data from 2018 to 2021, which show a steady growth compared to the numbers of the previous country update reports (Nádor et al., 2016; Nádor et al., 2019).

The steady increase of new wells in each year (Table 1) is partly associated with the expansion of previous projects, partly related to new projects.

2. GEOTHERMAL POTENTIAL OF HUNGARY

A great number of papers have discussed the outstanding geothermal potential of the Pannonian Basin (e.g. Horváth and Royden 1981, Horváth et al. 2015, Lenkey et al. 2002, Lenkey et al. 2021, and references therein). The existence of the rich geothermal resources is due to the complimentary combination of the eminent heating sources and the regionally extended aquifers, where stored groundwater is heated up.

Table 1: New thermal water wells in Hungary drilled between 2018-2021

	2018	**2019**	**2020**	**2021**
balneology	4	5	8	2
agriculture	8	3	6	2
space and district heating	2	5	4	4
industry	2	0	4	1
reinjection	0	5	9	3
other	5	1	0	0
power production	0	0	1	0
total	**21**	**19**	**32**	**12**

The elevated heat flow density (50-130 mW/m^2) and high geothermal gradient of about 45 °C/km is resulting from the Miocene tectonic evolution of the basin (crustal extension and thinning), whilst the aquifers are represented by two main types:

(1) several thousand m thick sandy-clayey sediments deposited during the subsidence of the basin (porous reservoirs), and
(2) deep-lying fractured and karstified Mesozoic carbonates that form the basement rocks of the sedimentary basin.

According to the resource assessment calculations (Zilahi-Sebess et al., 2012) the realistically recoverable amount of deep geothermal energy is 127.6 PJ/year (58.2 PJ/year from the porous geothermal aquifers, and nearly 70 PJ/year from the basement reservoirs), which is about 10 times more than the current use (around 6 PJ/year), underpinning the great untapped potential.

3. NATIONAL GEOTHERMAL ENERGY POLICY AND REGULATORY FRAMEWORK

The regulatory and policy framework of deep geothermal have been summarized in the previous country updates (Nádor et al., 2016, Nádor et al., 2019), so in this paper we highlight only the most important changes since 2018.

Hungary published its renewed Energy Strategy and National Energy and Climate Plan in 2020. These documents highlight the role of geothermal energy especially in the heating (and cooling) sector (particularly greening the district heating) and in agriculture. Although the foreseen growth of geothermal in the heating-cooling sector is 58 % (84.6 ktoe – 2020, 116.6 ktoe – 2030), this will hardly increase the overall share of geothermal within the total RES, which will stay around 5 %. The Hungarian NECP foresees 59 MW_e installed capacity in geothermal power production, but only after 2040.

Since the introduction of the concessional system in 2010 (obligatory for the exploration and exploitation of geothermal energy at a depth below -2500 m), altogether 4 geothermal concessional contracts have been established. One has been annulled due to the non-realization of the project (Battonya-EGS), and another one has been terminated with non-satisfactory exploration results (despite the high temperature realized, the corrosive brines would make the operation too costly and risky). Nevertheless, on one area current production is happening from a designated protection zone, whilst on the 4th area exploration is still ongoing.

A major achievement of the reported period was the introduction of a national geothermal risk mitigation scheme, which was launched in June 2021. To foster geothermal project development, the Ministry of Innovation and Technology announced a Call to support geothermal heating via handling the geological risks of the first wells. The Call is supporting projects only with reinjection, i.e. drilling of doublets, or drilling only reinjection wells to complete already existing systems. The target depth is 1000-2500 m below the surface. The total budget is 6 billion Hungarian forints (approx. 16.6 million euros). The Call is open until December 31, 2023, the application is continuous. Individual projects may range between 100 million to 2 billion Hungarian forints (approx. 278’000 euros to 5.5 million euros). Eligible costs are related to drilling and testing. The reimbursement happens after the well tests are performed. The rate of success is determined by comparing actual flow rates and temperatures to those values pre-defined in the feasibility study submitted in the application. The reimbursement rate is 30 % in case of success, 40 % in case of partial success and 60 % in case of unsuccessful projects. Due to institutional reorganisations at the end of 2021, the former program operator (Mining and Geological Survey of Hungary) has been replaced by the Western Balkan Green Center, which caused a temporal pending of the application and evaluation procedures.

4. SHALLOW GEOTHERMAL

There are still no reliable GSHP registers available in Hungary, because the systems shallower than 20 metres do not require a license, not even a notification to the authorities. Therefore, the numbers reported in Table E are the best estimates of the authors.

The increase of GSHP numbers has continued over the last several years. In the family house market and in other official and industrial applications, air-based heat pumps represent a significant part. The majority of the new applications such as communal heating/cooling are installed in new buildings by new companies. The cooling function makes GSHPs more competitive in the greenfield constructions market.

According to the national geothermal potential assessment (Zilahi-Sebess et al., 2012) the GSHP potential of Hungary is as much as 23 PJ/year.

Currently there are two types of incentives:

- The eco tariff ("H tariff") provides a preferential tariff for the electricity consumption of heat pumps and other renewable energy heating equipment (e.g. thermal solar collectors, circulation pumps, etc.) used for the heat supply of buildings from renewable energy sources. This is a national and obligatory scheme, introduced in a ministerial decree (70/2009 (XII.4) KHEM) and is available for all consumers eligible to use the countrywide electricity service [Electricity Act Art. 3(7)]. The subsidized tariff is available only in the heating season.
- The voluntary preferential tariff ("B" GEO tariff) for heat pumps of COP higher than 3. This scheme is available only in those areas where the service provider introduced this system; it is however accessible for the whole year.

5. DEEP GEOTHERMAL

5.1. Power generation

There is one operating geothermal power plant at Tura, which is located in a well-explored former hydrocarbon block. The production well produces 2200 l/min of hot water at 108 °C from an uplifted Triassic carbonate block at a depth of 1500-1800 m, which is fully reinjected. The actual gross electricity capacity is 2.3 MW_e, of which nearly 1 MW_e is the electricity demand of the power plant. Thus, it is capable of 1.3 MW_e net.

There are some ongoing investigations on future geothermal power plant sites, but these are either in exploration phase, or in early conceptual stages.

5.2. Direct heat utilization

Geothermal "district" heating is available in 26 towns in Hungary in 2021 (Table D1), which altogether represent an installed capacity of 235.29 MW_{th} and 641.37 GWh_{th}/yr production. These are partly geo-DH systems, where geothermal energy contributes to the already existing district heating infrastructure (operated otherwise by gas) with a 30 to 100 % share, partly so called "thermal water heating cascade systems", where the gas-based heating of some public buildings (town halls, libraries, schools, hospitals, etc.) is replaced by geothermal. These local systems are commissioned on the basis of a water license and are often run by local municipalities, or municipality-owned service providers. This contrasts with the district-heating systems, where heat is provided by a trading company on a contract basis, regulated by the Hungarian Energy and Public Utility Regulatory Authority.

During the period reported, 6 new geoDH systems were commissioned. The largest development is still ongoing in Szeged, a city of nearly 163'000 habitants at the Hungarian-Serbian-Romanian border. The ambitious project started in 2018 with the aim to introduce geothermal energy into 9 of the existing 23 district heating circuits fed by imported gas, and supplying heat to 28'000 flats and 500 public buildings. A geothermal triplet is being drilled for each heating circuit with one production well (target reservoir at a depth between 1700-2000 m yielding thermal water of 90-95 °C) and two reinjection wells (target depth range between 1400-1700 m) into the porous basin fill reservoirs. Out of the 9 triplets, 4 have been completed during the past years and are operating in a test mode at present, while 5 triplets will be drilled and completed in the coming years. In the light of the Russian-Ukrainian war and its impacts on the security of gas supply, the results of this mega-project saving nearly 15 million m^3 import gas per year are outstanding. Once all 9 circuits are fed by geothermal, Szeged geothermal district heating system will be one of the largest ones in Europe.

A smaller town heating project was accomplished in Mátészalka is 2020, where a single production well supplies thermal water of 61 °C to 1365 flats and a few public buildings.

Another small town heating project at Létavértes was also completed in 2020, which applies reinjection, and 10 public buildings are being heated with the 64 °C thermal water.

Some new geothermal district heating projects are under construction. In Békéscsaba a new 5.3 MW system is being implemented: a 2450 m deep production well was completed in 2021 that provides 100 °C thermal water, the drilling of 2 reinjection wells have also been finished. The system will provide heat to public buildings.

In Lenti a new town heating system (heating of public buildings) is under construction: a production well with 68 °C outflow temperature was completed in 2021, 2 reinjection wells will be drilled in the coming period.

Some of the projects under preparation reported in 2019 are still in the implementation phase.

In Tótkomlós 2 production and 2 reinjection wells were drilled in 2019-2020 to supply a future town heating project and a greenhouse park. Although the wells were successful (providing outflow temperature of 120-130 °C from a depth of 1600-1800 m from Triassic carbonate) the project is pending, as connection pipelines haven't been built yet due to the unjustified heat demand and very high prices to connect the potential users to the grid. There is a plan to use this project for power generation.

A very similar situation happened at the Moson-magyaróvár geothermal district heating project, where both the production and reinjection wells were successfully completed, but due to the lack of the surface installations, the project is not complete yet.

Regarding the upcoming plans, the future geothermal district heating of Budapest has to be mentioned. Budapest has been known as a capital of thermal waters for many centuries. The deep lying buried Mesozoic carbonate blocks under the Pest plain store thermal water of 70-80 °C (also known from the famous Széchenyi spa), and its use for heating purposes has been on the table for many years. In 2021 the Budapest District Heating Plc (Főtáv) and the Icelandic Artic Green Energy signed a cooperation agreement on assessing the possibility of a future geoDH system in the capital of Hungary. The project is at a very early exploration phase at the moment, where potential future drilling sites are being assessed, which – together with the building of new pipelines – is a great and very costly challenge in the densely built-in environment.

In addition to district and thermal water town heating cascade systems, a significant number of individual space heating is existing, mostly associated with spas (Table D2). These represent altogether an installed capacity of 94.11 MW_{th} and 163.39 GWh_{th}/yr production.

In addition to the classical heating with thermal water, some new innovative solutions also emerged during the past years. The WeHeat project established the first closed-cycle geothermal heat plant from an abandoned oil well. Although the 0.5 MW_{th} heat producing system is capable of heating only some smaller spaces, it has a great future potential, as this technology enables the utilisation of out-of-use deep drillings without the extraction of the thermal water.

The other major sector for direct heat utilization in Hungary is still agriculture. Heating of greenhouses and plastic tents and other energy purposes (e.g. heating for animal husbandry) represents an installed capacity of ~402 MW_{th} and about 880 GWh_{th}/yr production. The major users are found in SE-Hungary. Between 2018 and 2021, altogether 19 new wells were drilled for agriculture purposes (mostly heating of greenhouses) at 17 locations.

Industrial applications have a growing importance, the total estimated installed capacity is around 27.5 MW_{th} and about 45 GWh_{th}/yr production.

A large proportion of the wells are used for balneological purposes. The outflow temperature typically ranges between 30 and 50 °C. The hottest ones are at Zalaegerszeg (SW-Transdanubia – 95 °C) and at Gyula (SE Hungary at the Romanian border – 89 °C). The estimated installed capacity of the wells used for balneology is about 263 MW_{th} with an annual use of about 778.5 GWh_{th}/yr (Table C). Between 2018 and 2021 altogether 19 new wells were drilled at 16 locations for balneological purposes, all at sites where thermal water is already used for balneological purposes. These are mostly replacing older wells, or expanding the sites.

In the "other" category (reported together with balneology in Table C), thermal water for "public water supply" is mostly considered to mean drinking water. "Drinking thermal water" is a concept specific to Hungary, where 90 % of the drinking water supply is provided from groundwater. In areas where the shallow aquifers are contaminated (such as SE-Hungary, where there is a naturally high arsenic content) lukewarm thermal waters with low TDS from slightly deeper confined aquifers are used.

6. RESEARCH AND INNOVATION, EDUCATION

Of late, Hungarian institutes, universities and companies have coordinated or participated in several research, development and innovation projects. The scope of these projects covers:

- reinjection of brines into sandstone reservoirs
- extraction of minerals from thermal water
- mitigation of technical risks in geothermal energy exploration and production (including operational problems, such as scaling)
- development of deep borehole heat exchangers (geothermal energy production in closed systems without thermal water abstraction)
- application of laser technologies for drilling operations and well-maintenance activities

The University of Miskolc has always been a pioneer in the field of geothermal research and education.

REFLECT is the university's ongoing international project. Its aim is to compile a geothermal atlas that collects all the critical data, physical and chemical parameters needed to make recommendations for the sustainable operation of geothermal systems in critical areas. Supported by the European Union's H2020 research and development program, the project is being carried out in collaboration with the German Heimholz Zentrum, the Potsdam Deutsches Geoforschung Zentrum (GFZ), and 13 other international partners in the field of deep-sea supercritical geothermal systems research.

The University of Miskolc offers 4 semesters postgraduate Geothermal Engineering programs, and has done so since 2008. This 4-semester program covers twenty curricula topics. Its students can receive the equivalent of a BSc or an MSc in Geothermal Engineering. Because of the Covid-19 pandemic the last and current geothermal course have been fully online. It can be confidently stated that these online courses can be very efficient, as they are convenient, flexible and use resources which are available anywhere and at any time. Furthermore, people who work full time find that web-based learning is often their only practical alternative. The downside is that all online learning is mostly theoretical, fairly non-specific and not always practical – for a full understanding of geothermal, field trips and outdoor training sessions are essential. Ideally, geothermal e-learning and personal, in-situ training in the field would complement each other to give a more complete educational experience.

7. CONCLUSIONS

Hungary shows a steady growth of geothermal energy use. Between 2018 and 2022, 84 new thermal water wells were drilled. Geothermal district-heating and thermal-water heating cascade systems represent a major part of direct use available in 26 towns, which altogether represent an installed capacity of 235.29 MW_{th} and 641 37 GWh_{th}/yr production. Individual space heating (mostly associated with spas) is available at nearly 50 locations These represent altogether an installed capacity of 94.11 MW_{th} and 163.39 GWh_{th}/yr production. The agriculture sector is still a key player in direct use, which account for about 402 MW_{th} installed capacity and about 880 GWh_{th}/yr production. Balneology has historical traditions in Hungary, which represent a total installed capacity of about 263 MW_{th} with an annual use of about 778.5 GWh_{th}/yr. There is still one operating geothermal power plant in Tura, with a gross electric capacity of 2.3 MWe.

REFERENCES

Horváth, F., Royden, L.H.: Mechanism for formation of the intra-Carpathian basins: A review, *Earth Evolutionary Sciences*, **1,** 307-316. (1981)

Horváth, F., Musitz, B., Balázs, A., Végh, A., Uhrin, A., Nádor, A., Koroknai, B., Pap, N., Tóth, T., Wórum, G.: Evolution of the Pannonian basin and its geothermal resources, *Geothermics* **53**, 328-352. (2015)

Lenkey, L., Dövényi, P., Horváth, F., Cloetingh, S.A.P.L.,: Geothermics of the Pannonian basin and its bearing on the neotectonics. *EGU Stephan Mueller Special Publications Series* **3,** 1–12. (2002)

Lenkey L., Mihályka J., Paróczi, P.: Magyarország geotermikus viszonyainak áttekintése, *Földtani Közlöny* **151/1,** 65-78. (2021)

Nádor, A., Tóth, A.N., Kujbus, A., Ádám, B.: Geothermal energy use, country update for Hungary. *Proceedings, European Geothermal Congress 2016*, Strasbourg, France (2016)

Nádor, A., Tóth, A.N., Kujbus, A., Ádám, B.: Geothermal energy use, country update for Hungary. *Proceedings, European Geothermal Congress 2019*, Den Haag, The Netherlands (2019)

Nádor, A. De-risking geothermal exploration by public data portals and financial incentives – good examples from Hungary. *Proceedings, European Geothermal Congress 2022*, Berlin, Germany (2022)

Zilahi-Sebess L., Merényi, L., Paszera, Gy., Tóth, Gy., Boda, E., Budai, T.: Nyersanyag készletek, A hazai ásványi nyersanyag-potenciál, 5. Geotermikus energia, (Háttértanulmány), Nemzeti Energiastratégia, Készletgazdálkodási és hasznosítási cselekvési terv, Manuscript, (2012), 84 p.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	2.3	2	6756	26’200	0.03	0.04
Under construction end of 2021	0	0	150	550	0	0
Total projected by 2023	11.3	52	450	1650	2.7	3.1
Total expected by 2028	20	95	1000	3800	2	2.5
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development: 1	
					Under investigation: 2	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Tura	Tura	2018	1 (RI)	operating	B-ORC	3.0*	2.3	2
total						3.0	2.3	0

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
R	Retired / decommissioned	2F	Double Flash	O	Other

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	235.29	641.37	429.5	925	86.11	163.39	263	778.5
Under constru-ction end 2021	11	30.03	8	18	4	7	3	9
Total projected by 2023	283	770	463	987	98	184	272	804
Total expected by 2028	340	921	505	1025	119	219	287	849

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 production * (GWh_{th}/y)	Geoth. share in total prod. (%)
Barcs	TH (town heating)	2014	No	No	2	2	5.8*	100
Bóly	TH	2002	No	No (RI)	2.5	2.5	4.3*	100
Cserkeszőlő	TH	2001	No	No	2	2	2.1*	100
Csongrád	DH (district heating)	2012	No	No	4.3	10	5.94*	43
Hódmezővásárhely	DH	1994	No	No (RI)	18.0	37.7	20.03*	47
Kistelek	TH	2005	No	No	3.39	3.39	9.4*	100
Gárdony	TH	2010	No	No (RI)	1.8	1.8	7.1*	100
Győr	DH	2015	No	No (RI)	52	476.8	199.56*	11
Létavértes	TH	2020	No	No (RI)	0.63	0.63	1.1	100
Makó	DH	2012	No	No (RI)	9.01	14.5	4.73*	62.1
Mátészalka	TH	2020	No	No	1.3	19.9	2.4	6.5
Mezőberény	TH	2014	No	No (RI)	1.6	1.6	0*	100
Miskolc	DH	2013	No	No (RI)	55	547.6	267.57*	10
Mórahalom	TH	2004	No	No	1.5	1.5	5.1*	100

Table D1 (continued): Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 production * (GWh_{th}/y)	Geoth. share in total prod. (%)
Szarvas	TH	n.a.	No	No	11.28	11.28	10.34*	100
Szeged	TH	2014	No	No (RI)	8.9	8.9	24.7*	100
Szeged (4 circuits)	DH	2020-21	No	No (RI)	10	224	0	4,5
Szentes	DH	1958	No	No	27.2	30.7	25.7*	88
Szentlőrinc	DH	2009	No	No (RI)	3.1	4.6	4.73*	67
Szigetvár	TH	n.a.	No	No	1.5	20.7	2.2*	7
Szolnok	TH	2012	No	No	1.2	72.8	4*	1,6
Tamási	TH	2015	No	No (RI)	1	1.42	2.26*	70
Törökszentmiklós	TH	2014	No	No (RI)	1.86	2.7	3.6*	n.a
Újszilvás	GSHP	2010	No	Yes	0.46	0.46	0.3*	100
Vasvár	DH	1975	No	No (RI)	1.76	7.1	2.04*	25
Veresegyház	TH	1993	No	No (RI)	12	12	31,1*	100
total					235,29		641.37*	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Alsópáhok	n.a.	n.a.	No	0.6	na.	0.1	n.a.	Kolping Hotel
Békés	n.a.	n.a.	No	0.6	na.	0.75	n.a.	Békés Gyógyászati Központ és Gyógyfürdő
Békéscsaba	n.a.	n.a.	No	0.7	n.a.	2.05	n.a.	Békéscsaba Vagyonkezelő Zrt.
Bogács	n.a.	n.a.	No	0.8	n.a.	0.91	n.a.	Bogácsi Thermálfürdő Kft.
Budapest		n.a.	No	8 (12 spas)	n.a.	14	n.a.	Budapest Gyógyfürdői és Hévizei Zrt.

Table D2 (continued): Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Bük	n.a.	n.a.	No	1.2	n.a.	4.34	n.a.	Büki Gyógyfürdő Zrt.
Cegléd	n.a.	n.a.	No	1.04	n.a.	3.66	n.a.	Ceglédi Termálfürdő, Ceglédi Vasutas SE
Debrecen	n.a.	n.a.	No	2	n.a.	3.2	n.a.	Debreceni Gyógyfürdő Kft.
Demjén	n.a.	n.a.	No	2	n.a.	5.09	n.a.	Demjén Termál Fürdő Kft.
Egerszalók	n.a.	n. a.	No	4.1	n.a.	8.75	n.a.	Egerszalóki Gyógyforrást Üzemeltető és Szolg. Kft.
Galambok	n.a.	n.a.	No	0.4	n.a.	0.23	n.a.	Zalakaros Castrum Termál
Gyöngyös	n.a.	n.a.	No	0.06	n.a.	0.05	n.a.	Gyöngyösi Sportfólió Nonprofit Kft.
Gyula	n.a.	n.a.	No	3	n.a.	9.08	n.a.	Gyulai Várfürdő Kft.
Hajdúnánás	n.a.	n.a.	No	2.4	n.a.	1.6	n.a.	Hajdúnánási Építő és Szolgáltató Kft.
Harkány	n.a.	n.a.	No	3.4	n.a.	7.93	n.a.	Harkányi Gyógyfürdő ZRt.
Hévíz	n.a.	n.a.	No	1.5	n.a.	5.39	n.a.	Hévízgyógyfürdő és Szent András reumakórház and Hunguest Hotels Zrt.
Igal	n.a.	n.a.	No	1.6	n.a.	2.99	n.a.	Igal-Fürdő Üzemeltető és Szolg. Kft.
Kaba	n.a.	n.a.	No	0.85	n.a.	0.35	n.a.	Municipality of Kaba
Karcag	n.a.	n.a.	No	4	n.a.	3.66	n.a.	Berek-Víz Kft., Nagykun Víz- és Csatornamű Kft.
Kiskunhalas	n.a.	n.a.	No	0.6	n.a.	1.25	n.a.	Halasthermál Fürdő és Idegenforgalmi Kft.
Kutas	n.a.	n.a.	No	1.4	n.a.	0.02	n.a.	Hertelendy kastélyszálló
Lakitelek	n.a.	n.a.	No	1	n.a.	0.09	n.a.	Népfőiskola
Lenti	n.a.	n.a.	No	1	n.a.	4.43	n.a.	Lenti Gyógyfürdő Kft.
Makó	n.a.	n.a.	No	0.7	n.a.	4.46	n.a.	Makói Gyógyfürdő

Table D2 (continued): Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Marcali	n.a.	n.a.	No	0.8	n.a.	0.41	n.a.	Marcali Városi Fürdő és Szabadidőközpont
Martfű	n.a.	n.a.	No	2	n.a.	3.22	n.a.	Tisza Joule Szolg.és Ker Kft.
Mátészalka	n.a.	n.a.	No	1.67	n.a.	2.67	n.a.	Mátészalkai Városgazda Nonprofit Kft.
Mezőkövesd	n.a.	n.a.	No	1.5	n.a.	5.84	n.a.	Zsóry Fürdő
Mezőtúr	n.a.	n.a.	No	1.6	n.a.	0.96	n.a.	Mezőtúri Intézményellátó és Ingatlankezelő Közhasznú Nonprofit Kft.
Miskolctapol-ca	n.a.	n.a.	No	6	n.a.	7.12	n.a.	MIVÍZ Kft
Mohács	n.a.	n.a.	No	0.6	n.a.	1.29	n.a.	Mohács Uszoda Kft.
Nádudvar	n.a	n.a.	No	0.3	n.a	0.39	n.a	Nádudvari Településfejl. és Városgazd. Kft.
Nagykanizsa	n.a.	n.a.	No	0.85	n.a.	0.67	n.a.	Kanizsa Uszoda Kft.
Nagykáta	n.a.	n.a.	No	2	n.a.	1.87	n.a.	Nagykátai Gyógyfürdő és Egyéb Szolgáltató Nonprofit Kft.
Nyirbátor	n.a.	n.a.	No	1.2	n.a.	1.91	n.a.	Nyírbátori Városfejlesztő és Működtető Kft.
Orosháza-Gyopárosfür-dő	n.a.	n.a.	No	1.3	n.a.	3.09	n.a.	Gyopáros Gyógy- és Élményfürdő
Poroszló	n.a.	n.a.	No	0.6	n.a.	0.85	n.a.	E+E ' 2006 Vendéglátó, Ker.és Szolg.Kft.
Sárospatak	n.a.	n.a.	No	2	n.a.	4.75	n.a.	PATAQUA Termálfürdő Kft.
Sárvár	n.a.	n.a.	No	0.5	n.a.	3.67	n.a.	Sárvári Gyógyfürdő Kft.
Szentes	n.a.	n.a.	No	3.34	n.a.	8.97	n.a.	Szentesi Sport és Üdülőközpont Nonprofit Kft.
Szigetvár	n.a.	n.a.	No	9.1	n.a.	4.13	n.a.	Szigetvári Gyógyfürdő Üzemeltető és Humán Szolgáltató Kft.

Table D2 (continued): Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Tiszaföldvár	n.a.	n.a.	No	1.6	n.a.	5.47	n.a.	Tiszaföldvári Városüzemeltető és Foglalkoztatási Kiemelten Közhasznú Nonprofit Kft.
Tiszaújváros	n.a.	n.a.	No	1.4	n.a.	3.86	n.a.	Tiszaszolg 2004 Kft.
Vácrátót	n.a.	n.a.	No	2	n.a.	5.1	n.a.	MTA Ökológiai Kutatóközpont
Vásárosna-mény	n.a.	n.a.	No	1.5	n.a.	1.33	n.a.	NUOVA -ATLANTIKA VÍZIVIDÁMPARK Kft.
Velence	n.a.	n.a.	No	0.8	n.a.	2.18	n.a.	VELENCE PLUS Kft. (strand)
Zalaegerszeg	n.a.	n.a.	No	3.5	n.a.	0.49	n.a.	SILVER SPA Szeleste Kft. K&B Kristály Patika Kft.
Zalakaros	n.a.	n.a.	No	5	n.a.	8.77	n.a.	Zalakarosi Fürdő Zrt
total				**94.11**		**163.39**		

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	7353	80.85	161	280	3,1	25
Of which networks **	400	30	60	15	1,1	25
Projected total by 2023	8213	87.05	221			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

	Aquifer Thermal Energy Storage (ATES)			Borehole Thermal Energy Storage (BTES)		
	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold
In operation end of 2021 *	3	H: 1.52 C: 1.47	H: 2.12 C: 2.09		H: C:	H: C:
New (additional) in 2021 *	0	H: C:	H: C:		H: C:	H: C:
Projected total by 2023	3	H: 2.1 C: 1.8	H: 2.4 C: 2.0		H: C:	H: C:

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	5	12	10	24
Geothermal direct uses	12	28	20	44
Shallow geothermal	2	14	3	20
total	**19**	**54**	**33**	**88**

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	O (National Research Fund)	O (National Research Fund)	O (National Research Fund)
Financial Incentives – Investment	A	DIS, RC	
Financial Incentives – Operation/Production			FIP (2 types of tariffs as reduced electricity price for GSHP-s)
Information activities – promotion for the public	in the frame of ongoing projects	in the frame of ongoing projects	in the frame of ongoing projects
Information activities – geological information	borehole data, interactive maps and reports, publications available at the website of the Mining and Geological Survey of Hungary https://map.mbfsz.gov.hu/ogre_en/		
Education/Training – Academic	Four semesters, academic engineering education at the University of Miskolc		
Education/Training – Vocational	Hungarian Chamber of Engineers hold courses		

Key for financial incentives:					
DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for Iceland

Árni Ragnarsson, Benedikt Steingrímsson, Sverrir Thorhallsson

Iceland GeoSurvey (ÍSOR), Urdarhvarf 8, 203 Kópavogur, Iceland

Keywords: Iceland, geothermal energy, power generation, direct use, space heating, district heating, country update.

ABSTRACT

Geothermal energy is used for both electricity generation and direct heat applications in Iceland. The share of geothermal energy in the nation's primary energy supply is 65 %. Eight geothermal power plants are in operation in the country with a total installed capacity of 755 MW_e. The annual electricity generation is about 6 TWh, which is around 30 % of the electricity produced in the country. Three of the geothermal power plants are co-generation plants that produce both electricity and heat for district heating. The largest power plant is at Hellisheidi (303 MW_e), which has been in operation since 2006, and the newest one is at Flúdir, 0.6 MW_e binary power plant. Space heating is the most important direct utilization of geothermal energy in Iceland, covering over 90 % of all energy used for house heating in the country. Other sectors of direct use are swimming pools, snow melting, industrial process heat, greenhouses, aquaculture and soil warming. The geothermal fluid is also a source of silica and salts for skin care products and liquid carbon dioxide (CO_2) for soft drinks, greenhouses and industry. In parallel with increased tourism several new geothermal spas have been established around the country. Also, a district heating system serving about 2500 people has recently been converted from a system based on electric boilers to a geothermal district heating system. The total direct use of geothermal energy in Iceland is estimated to be about 35'000 TJ annually.

1. INTRODUCTION

Iceland has a huge geothermal potential based on the location of the country on a hot spot on the Mid-Atlantic Ridge. The country is mountainous and volcanic, with much precipitation, making hydropower resources also abundant. The population of Iceland is about 375'000, of which almost two third live in the Reykjavik capital area. During the course of the 20th century, Iceland went from being one of Europe's poorest countries, dependent upon peat, dung and imported coal for its energy, to a country with a high standard of living where practically all stationary energy, and roughly 83 % of the primary energy supply comes from indigenous renewable sources (65 % geothermal (referenced to 15 °C), 18 % hydropower (generated electricity)). The rest comes from imported fossil fuel used for the transport sector and fishing fleet. Iceland's energy use per capita is among the highest in the world and the proportion provided by renewable energy sources exceeds most other countries.

The geothermal resources in Iceland are used for both electricity generation and direct uses. In the high-temperature (>200 °C) fields the geothermal steam fraction is utilized for electricity generation at seven sites. Heat from the turbine condenser and the brine fraction is used to heat freshwater for district heating in so-called co-generation plants at three of the sites. Thus, the energy efficiency is improved considerably. The low-temperature (<150 °C) fields are used mainly to supply hot water for district heating but also for power generation in one small binary power plant located in the south of Iceland. The current utilization of geothermal energy for heating and other direct uses is considered to be only a small fraction of what this resource can provide.

It has been the policy of the Government of Iceland to increase the utilization of renewable energy resources even further for power generation, direct uses and the transport sector. A broad consensus on conservation of valuable natural areas has been influenced by increased environmental awareness. Thus, there has been opposition against hydropower and some geothermal projects. The ownership of energy resources in Iceland is based on the ownership of land. However, exploration and utilization are subject to licensing.

A master plan assessing the economic feasibility and the environmental impact of selected power development projects was adopted by the Icelandic Parliament about 25 years ago. It is a tool to reconcile the often competing interests of nature conservation and energy utilization on a national scale and at the earliest planning stages. In June 2022 a parliamentary resolution for the third phase of the master plan was adopted by the Icelandic parliament and preparatory work on the fourth phase has already been ongoing for some years. (The Master Plan for Nature Protection and Energy Utilization, 2022).

2. OVERVIEW OF GEOTHERMAL UTILIZATION

Table 1 and Figure 1 show a breakdown of the utilization of geothermal energy in Iceland for 2020, both for direct uses and for power generation (Orkustofnun, 2022; Orkustofnun, 2021). Direct uses of geothermal energy were in total 35’052 terajoules (TJ), which corresponds to 9737 GWh_{th} of used energy. Calculation of the used energy is based on estimated inlet and outlet water temperature for each category (e.g. 35 °C outlet temperature for space heating) and the corresponding annual flow. In addition, electricity production by geothermal amounted to 21’458 terajoules or 5961 GWh_e. The 43.8 % share of space heating was the largest geothermal use sector while electricity production accounted for 38.0 %.

Table 1: Geothermal utilization in Iceland 2020

	Installed power	Energy consumption	
	MW	TJ/year	GWh/year
Space heating	1,720	24,751	6,875
Greenhouses	60	521	145
Fish farming	115	2,612	726
Industrial process heat	85	1,896	527
Snow melting	270	2,433	676
Swimming pools	220	2,839	788
Direct uses total	2,470	35,052	9,737
Elctricity generation	755	21,458	5,961
Geothermal utilization total	3,225	56,510	15,697

3. GEOLOCICAL BACKGROUND

Iceland is a geologically young country located in the North Atlantic astride the Mid-Atlantic Ridge, which is the boundary between the North American and Eurasian tectonic plates. The two plates are moving apart at a rate of about 2 cm every year. Geological and tectonic processes are extraordinary rapid and easily observed in Iceland. Some 20-30 volcanic eruptions occur every century on average, producing lava in the order of 45 km^3 every 1000 year.

Some 400 km of the Mid-Atlantic ridge are exposed, which makes it possible to observe on land a variety of tectonic processes such as volcanism and associated features. Numerous volcanoes and hot springs are found in the country and earthquakes are frequent. The volcanic zone crosses the island running from the southwest to the northeast. More than 200 volcanoes are located within this zone and at least 30 of them have erupted since the country was settled about 1150 years ago. Associated with the volcanoes are numerous geothermal systems, ranging from freshwater to saline in composition and from warm to supercritical in temperature. At least 25 high-temperature areas exist on land within the volcanic zones with temperatures reaching 200 °C above 1000 m depth and several HT-fields are expected to be (a few are known) in ocean ridges southwest and north of Iceland. About 250 separate low-temperature areas with temperatures not exceeding 150 °C in the uppermost 1000 m have been identified, mostly in the areas flanking the active volcanic zones. Over 600 hot spring areas (temperature over 20 °C) have been located (Figure 2).

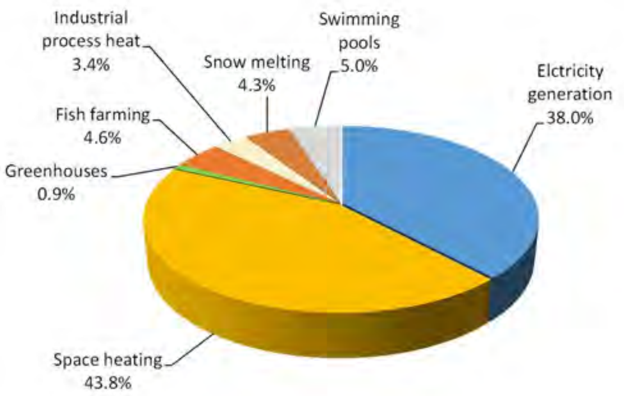


Figure 1: Sectoral share of geothermal utilization in Iceland 2020. Source of energy consumption: Orkustofnun, OS-2022 T002-01 and OS-2021 T014-01.

4. SPACE HEATING

Direct uses and especially space heating play a predominant role in the geothermal utilization in Iceland. The pioneer was a farmer at Sudur-Reykir in the vicinity of Reykjavík who started using geothermal water for heating his house in 1908 by transporting water from a hot spring through a pipeline over a distance of about 500 m. Utilization of geothermal energy for space heating on a large scale began with the laying of a 3 km long hot water pipeline from the hot springs of Laugardalur in Reykjavík in 1930. The formal establishment of Reykjavík Municipal District Heating Service (now Reykjavík Energy) was in 1946. Following the oil price hikes of the 1970s, the Government took the initiative in eliminating oil from district heating, replacing it with geothermal energy, with the result that the share of geothermal energy increased from 43 % in 1970 to the current level of over 90 %. Buildings outside geothermal regions have electric heating. This development is illustrated in Figure 3.

About 30 separate geothermal district heating systems are operated in towns and villages in the country and additionally some 200 small systems in rural areas. These smaller systems supply hot water to individual farms or a group of farms as well as summerhouses, greenhouses and other users. Geothermal space heating has enabled Iceland to import less fossil fuel and has resulted in a very low heating cost compared to most other countries. Using geothermal energy, which is classified as a renewable energy source, for space heating has also benefited the environment. Although most of the towns and villages in Iceland with the possibility of geothermal heating have already such a system in operation, exploration activities are ongoing with the aim to develop geothermal heating in new areas for the remaining villages and rural areas. The total geothermal energy used for space heating in Iceland in 2020 is estimated to be 24’751 TJ (Table 1).

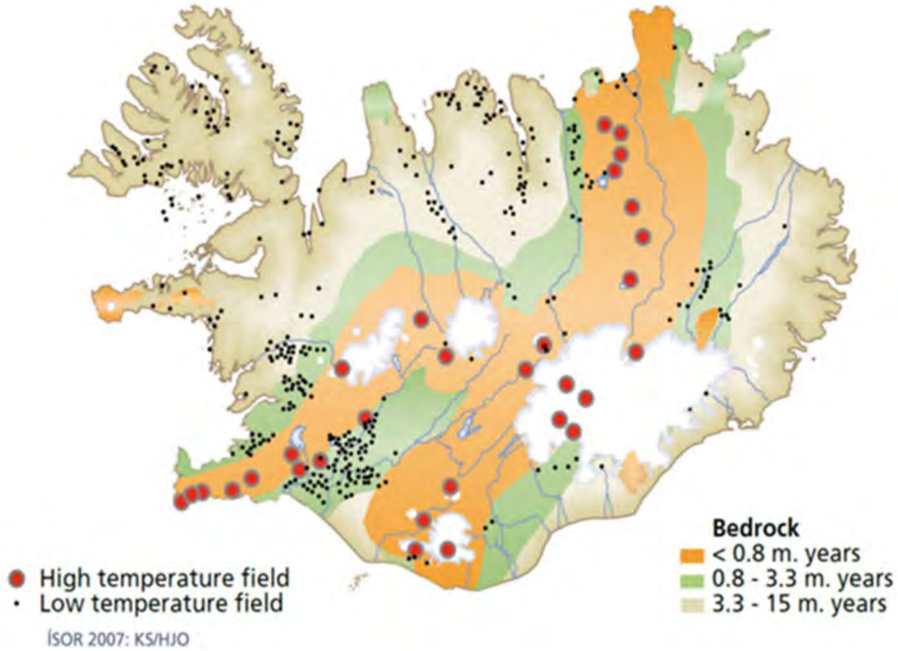


Figure 2: Volcanic zones and geothermal areas in Iceland.

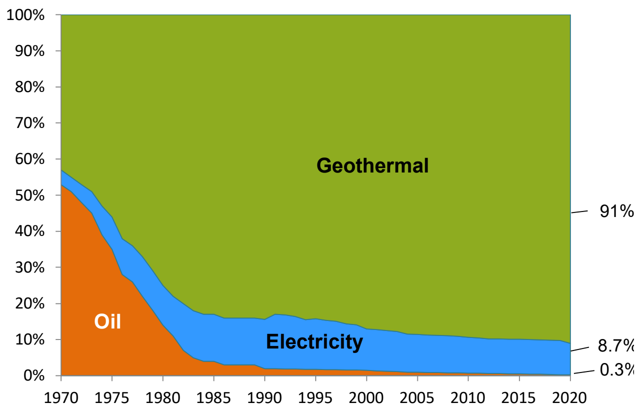


Figure 3: Energy sources used for space heating in Iceland 1970-2020.

A geothermal district heating system for the town Hofn (Hornafjordur) in south-eastern Iceland, which has about 2500 inhabitants, was commissioned in 2021 after many years of geothermal exploration in the area. The low-temperature geothermal water is transported to the town in a pipeline from the geothermal field at Hoffell about 20 km away. Before this new development the district heating system at Hofn had been operated for decades, based on ground water heated in electric boilers.

4.1 District heating in Reykjavík

Reykjavík Energy (Orkuveita Reykjavíkur) is a public utility responsible for production, distribution and sale of both hot water and electricity as well as the city's waterworks and sewage system and fibre optic cables. The principal owner is the City of Reykjavík, and since 2014 it provides its services through three subsidiaries; Veitur Utilities, ON Power and Reykjavík Fibre Network. The total number of employees is about 500 and the turnover in 2021 was about 52'000 million ISK (410 million US$ based on the average 2021 exchange rate). Reykjavík Energy is by far the largest geothermal district heating utility in Iceland. It serves in total about 240'000 people or about 65 % of the Icelandic population, the entire population of Reykjavík and neighbouring towns.

District heating in Reykjavík began in 1930 when some official buildings and about 70 private houses received hot water from geothermal wells, located close to the old thermal springs in Reykjavík. In 1943 delivery of hot water from the Reykir field, 18 km from the city, started. The district heating system was expanded gradually over the years to the whole greater Reykjavik area. Today Reykjavík Energy utilizes low-temperature areas within and in the vicinity of Reykjavík as well as the high-temperature fields at Nesjavellir, about 27 km away since 1990 and Hellisheidi since 2010. At Nesjavellir and Hellisheidi cold ground water is heated in co-generation power plants. In the past, a number of district heating systems were either bought or merged with Reykjavík Energy. Some are small systems in rural areas, but others are among the largest geothermal district heating systems in the country serving towns with population of several thousand people. The total installed capacity of Reykjavik Energy's district heating system is about 1250 MW_{th} and the total hot water production is about 90 million m^3 per year.

4.2 HS Orka and HS Veitur

Hitaveita Sudurnesja (Sudurnes Regional Heating) was a pioneer in building the co-generation power plant at Svartsengi in 1976. It is located about 50 km SW of Reykjavík. In 2000, the operation was privatized and following changes in electricity legislation in 2008 the company was divided up into HS Veitur hf. and HS Orka hf. The plant in Svartsengi utilizes 240 °C geothermal brine from the Svartsengi field to heat fresh water for district heating (190 MW_{th}), and to generate electricity (76.4 MW_e). HS Orka also has a 100 MW_e geothermal power plant on Reykjanes that was commissioned in 2006 for electricity generation only.

4.3 Nordurorka – District heating in Akureyri

Akureyri is a town of about 20’000 inhabitants located in the north of Iceland. It has been heated by geothermal energy since the end of the 1970s. Hot water is pumped to Akureyri from six different geothermal fields. In addition to this, two 1.9 MW_{th} heat pumps supplied a small part of the annual energy production after their installation in 1984, but their contribution has been insignificant for many years. In the past, several small geothermal district heating systems in neighbouring communities have merged with Nordurorka. Thus, the total number of people served is now about 24’000. The total installed capacity is 100 MW_{th} and the annual hot water consumption about 9 million m^3.

5. OTHER DIRECT UTILIZATION

5.1 Swimming and bathing

For centuries natural hot springs were mainly used for bathing in Iceland, but since early in the last century outdoor swimming pools as we know them today have been gaining popularity and they are now a part of the daily life all year round. There are about 170 recreational swimming centers in the country, 145 of which use geothermal heat to keep the water temperature at 28-30 °C. The combined surface area of the geothermally heated pools is about 35’000 m^2. Most of the swimming pools are open to the public throughout the year. They serve for recreational purposes and are also used for swimming lessons, which are compulsory in schools. Swimming is very popular in Iceland and swimming pool attendance has increased in recent years.

In the greater Reykjavík area alone there are fifteen public outdoor pools and a few indoor ones as well. The largest of these is Laugardalslaug with 1500 m^2 outdoor pools, 1250 m^2 indoor pool and five hot tubs where the tub temperature ranges from 35 to 42 °C. The number of people visiting Laugardalslaug annually is about 800 thousand. Among other balneological uses for geothermal energy are the Blue Lagoon, the bathing facility Mývatn Nature Bath (Jardbodin) at Bjarnarflag close to Lake Mývatn, the Laugarvatn Fontana geothermal baths, the Secret Lagoon at Flúdir and the NLFI Spa and Medical Clinic in Hveragerdi, comprising geothermal clay baths and water treatments. In recent years several new geothermal spas have been established like Vök baths at Urridavatn, Geosea-Geothermal Sea Baths at Húsavík, Krauma in Reykholtsdalur, Sky Lagoon in Kópavogur and Forest Lagoon in Eyjafjordur.

Typically, about 220 m^3 of geothermal water or 40’000 MJ of energy is needed annually for heating one m^2 of pool surface area. This means that a new, mid-sized (25 m long) outdoor swimming pool uses as much hot water as heating 80-100 single-family dwellings. The total geothermal energy used for heating swimming pools in Iceland in 2020 is estimated to be 2,839 TJ (Table 1).

The Blue Lagoon mentioned above is a 8700 m^2 surface pond that receives effluent brine from the Svartsengi power plant (42 l/s). At the start of operations of the power plant in 1976 the effluent water was discharged into the surrounding lava field, which was to absorb the water due to its high permeability. People started bathing in the pond and psoriasis patients discovered that the water had a beneficial effect on their skin. Later, showering facilities were added and in 1999 a man-made lagoon with a temperature of 37-39 °C was created along with improved facilities for visitors. The Blue Lagoon contains about 9 million liters of brine and the hydraulic retention time is about 40 hours. The salt content is 2.5 %, close to 70 % of seawater salinity. (Haraldsson and Cordero, 2014). In addition to the bathing facilities there are other important activities of the Blue Lagoon company. They operate a clinic for psoriasis patients that takes advantage of the therapeutic effects of the geothermal brine and produce a line of skin care products that contain unique natural ingredients, silica, minerals and algae. The number of Blue Lagoon visitors was around one million in 2019, making it one of Iceland’s most popular tourist attractions.

5.2 Snow melting

Geothermal water is used in Iceland to heat sidewalks and pavements to melt snow during the winter. These uses have been gradually increasing and today almost all new buildings in areas with geothermal heating have snow melting systems. Iceland’s total area of snow melting systems is around 1’200’000 m^2, mostly in the capital area. Spent water from the houses at about 35 °C is used for de-icing sidewalks and parking spaces. Most of the larger systems have the possibility to add water from the district heating system (80 °C) when the load is high. The main purpose is often to prevent icing or to make removal of the snow easier, rather than directly melt the snow. In downtown Reykjavík, a snow-melting system, consisting of loops of buried plastic pipes, has been installed under most sidewalks and some streets, covering an area of 70’000 m^2. This system is designed for a maximum heat output of 180 W/m^2 surface area and the annual energy consumption is estimated to be 430 kWh/m^2. About two thirds of that energy comes from spent water from the space heating systems and one third directly from hot supply water. The total geothermal energy used for snow melting in Iceland in 2020 is estimated to be 2433 TJ (Table 1).

5.3 Industrial uses

The largest industrial user of geothermal energy in Iceland is the seaweed drying plant Thorverk, located at Reykhólar in West Iceland. The company harvests seaweed found in the shallow sea waters of Breidafjordur bay using specially designed harvester crafts. Once landed, the seaweed is chopped and dried in a belt dryer that uses large quantities of air heated to 85 °C by geothermal water. The plant has been in operation since 1975 and produces about 4000 tonnes of rockweed and kelp meal annually. It uses 112 °C hot geothermal water that is cooled down to 45 °C in the drying process.

Since 1986, a facility at Haedarendi in Grímsnes, South Iceland, has produced commercial liquid carbon dioxide (CO_2) derived from the geothermal fluid of two gas rich wells. The Haedarendi geothermal field has an intermediate temperature (160 °C) and a very high gas content in the total flow (1.4 % by weight). The gas discharged by the wells is nearly pure carbon dioxide. Upon flashing, the fluid from the Haedarendi well would deposit large amounts of calcium carbonate scaling. Scaling in the well is, however, avoided by installing 250 m and 300 m long downhole heat exchangers made of two coaxial stainless steel pipes. Cold water is pumped down through the inner pipe and back up the annulus. Through this process, the geothermal fluid is cooled to arrest boiling and rapid degassing. The solubility of calcium carbonate increases sufficiently at lower temperatures to prevent scaling (inverse solubility). The plant extracts approximately 15 l/s of water from the wells and produces some 10’000 tonnes of CO_2 annually, which practically covers the needs of the Icelandic market. The production is used in greenhouses to enrich the atmosphere, for manufacturing carbonated beverages and in other food industries.

Geothermal energy has been used in Iceland for drying fish for about 40 years. The main application has been the drying of salted fish (bacalao), cod heads, fish bones, small fish, stockfish and other products. Cod heads were traditionally dried by hanging them on outdoor stock racks. Because of Iceland’s variable weather conditions, indoor drying is preferred. Hot air is blown over the fish in batch dryers. Today about 10 companies dry cod heads indoors and all of them use geothermal hot water. The annual export of dried cod heads is about 10-12’000 tonnes. The product is exported mainly to Nigeria where it is used for human consumption. Among the largest Icelandic producers of dried cod heads is the company Haustak. They buy about 1.3 kg/s of geothermal steam at 18 bar (210 °C) from the nearby Reykjanes power plant to produce annually 2500 tonnes of dried product from 12’000 tonnes of raw material. The steam is used to heat fresh water up to 70 °C for the drying process.

The Icelandic-American company Carbon Recycling International (CRI) has since 2012 operated a pilot plant that uses CO_2 emissions of non-condensable gas in the steam from the Svartsengi geothermal power plant of HS Orka to produce methanol to blend with gasoline to fuel cars. Hydrogen used in the process is produced locally by electrolysis of water. The current production capacity is 4000 tonnes of methanol per year from about 5500 tonnes of CO_2. Output from the plant is exported and used directly as a blend component for standard petrol or as a feedstock for biodiesel from esterified vegetable oil or animal fats.

Two small salt factories that utilize geothermal energy in their production have been established in Iceland in the last decade. The focus is on producing “gourmet” table salt. One of them is Nordursalt at Reykhólar in West Iceland, which has been in operation since 2013. They use over 100 °C hot geothermal water to boil seawater at 51 °C under sub-atmospheric conditions and to dry the salt. The other salt factory is Saltverk at Reykjanes in Northwestern Iceland. They started operation in 2011 and utilize about 10 l/s of 90-95 °C hot water from a geothermal well that is cooled down to 70 °C in the salt production process.

Several other industrial processes utilizing geothermal energy have been operated in Iceland in the past. Among them was the Kísilidjan diatomite plant at Lake Mývatn, which was among the largest industrial users of geothermal steam in the word. The plant used about 13 kg/s of steam at 180 °C (9 bar) and produced about 28’000 tonnes of diatomaceous earth filter aids for export annually. Kísilidjan was commissioned in 1968 and was operated until the plant was closed down in 2004 after 36 years of operation. Examples of other industrial applications that have been realized but are no longer in operation are: a salt production plant at the Reykjanes field utilizing geothermal brine and seawater, drying of imported hardwood in Húsavík by geothermal water, rethreading of car tires, and wool washing in Hveragerdi. Among smaller ongoing activities using geothermal energy are a hospital laundry and steam baking of bread at several locations and a plant for curing concrete blocks in a steam heated autoclave. The total geothermal energy used as process heat in industry in Iceland in 2020 is estimated to be 1896 TJ (Table 1).

The Icelandic company GeoSilica, which started as a university spin-off project, was founded in 2012. It produces silica health products from the mineral rich brine from the Hellisheidi power plant in cooperation with ON Power, the operator of the plant. The company's first product was released in late 2014, a liquid silica supplement made from 100 % natural silica. Today the product line consists of five different types of food supplements. GeoSilica has plans for expansion and export of their products.

5.4 Greenhouse heating

Heating of greenhouses is one of the oldest and most important uses of geothermal energy in Iceland after space heating. Naturally warm soil had been used for outdoor growing of potatoes and other vegetables for a long time when geothermal heating of greenhouses started in Iceland in 1924. The majority of the greenhouses are located in the south, and most are enclosed in glass. The heating installations are of unfinned steel pipes hung on the walls and over the plants. Under table or floor heating is also common. It is also common to use inert growing media (volcanic scoria, rhyolite pumice) on concrete floors with individual plant watering. By using electric lighting, the growing season is extended to year-round, which improves the utilization of the greenhouses and increases the annual production. Artificial lighting, which also produces heat, has contributed to a diminishing demand for hot water supply to greenhouses. As a consequence of the lengthening of the growing season the need for new constructions diminished. CO_2 enrichment in greenhouses is common, primarily by using CO_2 produced in the geothermal plant at Haedarendi (see Chapter 5.3). Outdoor growing at several locations is enhanced by soil heating with geothermal water, especially during early spring.

The total surface area of greenhouses in Iceland is about 200’000 m^2 including plastic tunnels for bedding and forest plants. Of this area, which has not changed much in the past few years, 50 % is used for growing vegetables (tomatoes, cucumbers, paprika etc.) and the rest mainly for growing cut flowers and potted plants. The total annual production of vegetables in Iceland is about 18’000 tonnes. The share of domestic production in the total consumption of tomatoes in Iceland is about 50 % and for cucumbers almost 100 %.

Most of the greenhouses in Iceland have automatic control of the indoor climate and thus, for example, the temperature can be adjusted to the optimum temperature for different kinds of crops, ranging from 10-15 °C in nurseries up to 20-25 °C for roses. Also, the temperature is commonly adjusted to follow the optimum daily variations. The main parameters that influence the heat loss from greenhouses and thereby the heating demand are the outdoor temperature, wind speed, greenhouse cover material, indoor temperature, artificial lighting, heating system arrangement and opening of the windows. A study made on energy consumption for heating a group of typical greenhouses in Iceland resulted in an average energy consumption of 3.67 GJ/m^2 per year in greenhouses with artificial lighting and 5.76 GJ/m^2 per year in greenhouses without artificial lighting (Haraldsson and Ketilsson, 2010). The total geothermal energy used in Icelandic greenhouses in 2020 is estimated to be 521 TJ (Table 1).

5.5 Aquaculture

Fish farming was a slowly growing sector in Iceland for a number of years but the growth has been very rapid the last few years. The total production reached about 53’000 tonnes in 2021, of that 46’000 tonnes salmon. Other main species are arctic char, trout and Senegalese sole. There are about 60 fish farms in Iceland and of these between 15 and 20 utilize geothermal water. Geothermal water, commonly 20-50 °C, is used to heat fresh water, either in heat exchangers or by direct mixing, typically from 5 to 12 °C for juvenile production. The main use of geothermal energy in the fish farming sector in Iceland is for juvenile’s production (char and salmon). Further rearing of salmon to full marketable size is made in sea cages where geothermal water is not used. However, in land-based char production geothermal energy is used for post-smolt rearing to marketable size. Geothermal utilization in the fish farming sector is expected to increase in the coming years. The total geothermal energy used in the fish farming sector in Iceland in 2020 is estimated to be 2612 TJ (Table 1).

A fish farm owned by the company Stolt Sea Farm started breeding warm-water Senegalese sole at Reykjanes peninsula, Iceland, in 2013. It is the first stage of a large indoor land-based operation that is planned. The 22’000 m^2 plant is located close to the 100 MW_e Reykjanes geothermal power plant owned by HS Orka. The power plant uses a large amount of sea water for the tubular power plant condensers, which is at the outlet at a temperature of 35 °C. From there the warm sea water flows by gravity to the sea and a part of it goes to the fish farm. There it is mixed with sea water that is pumped from shallow wells and used in the rearing tanks at about 21 °C, which is the optimum temperature for the fish. The juveniles are grown to about 500 g weight before the Senegalese sole is slaughtered and transported fresh to markets in Europe. The total production is about 400 tonnes per year.

6. ELECTRIC POWER GENERATION

Geothermal power accounts for a significant share of the electricity generation in Iceland. Table 2 gives an overview of the power plants and Figure 4 shows how the generation has developed during the period 1970-2020. The total installed capacity of geothermal generating plants is 755 MW_e. The total production in 2020 was 5961 GWh_e, which is 31.2 % of the total electricity production in the country (Table 1), (Orkustofnun, 2021).

The first geothermal power plant in Iceland is in Bjarnarflag where a 3,2 MW_e back pressure unit started operation in 1969. The turbine was bought second hand from a sugar refinery. It was later refurbished and operated successfully until early 2018 except for two periods when it was out of service, 1978-1980 due to damage of production wells caused by volcanic activity, the Krafla Fire, in the area, and 1985-1988 due to rehabilitation of the power plant. In 2018-2019 the plant was totally refurbished and the old turbine and generator replaced by a new 5 MW_e back pressure unit, which started full production in late 2019. The new turbine uses the same amount of steam as the old one. The Bjarnarflag plant is using steam from a well in the Námafjall geothermal field within the lake Mývatn area in North Iceland. The same field has been used to supply heat for industrial applications (Kísilidjan diatomite plant, closed down in 2004), district heating for the community and the Mývatn Nature Bath. Exploration drilling has been carried out in preparation of further development of the Námafjall field for a new 90 MW_e power plant in two stages.

The Krafla power plant is located near the lake Mývatn in North Iceland (about 10 km from the Bjarnarflag plant) and has been operating since 1978. Two 30 MW_e double flash condensing turbine units were purchased, but due to unexpected difficulties with steam supply the plant was run with only one installed turbine for the first 20 years. The shortfall of steam was due to volcanic activity, the Krafla Fire, that injected volcanic gases into the most productive part of the geothermal reservoir. Volcanic eruptions occurred only about two kilometers away from the power plant, posing a serious threat to its security. Initially, the power generation was only 8 MW_e, but reached 30 MW_e in 1984. The capacity of the Krafla power plant was expanded in 1997 from 30 to 60 MW_e by commissioning the second turbine, which reached full capacity in 1999. In total, about 40 wells have been drilled in the area. The plant uses 111 kg/s of 6.7 bar-g saturated high-pressure steam and 36 kg/s of 1.2 bar-g saturated low-pressure steam.

The Svartsengi co-generation power plant of HS Orka started operation in 1976 with hot water production only until electricity generation started two years later. The plant is located on the Reykjanes peninsula, 50 km from Reykjavík, and serves about 30’000 people. The reservoir fluid is a brine at 240 °C and with a salinity of about two thirds of sea water. The total production from the reservoir is about 450 kg/s. Of that about 60 % is reinjected. Geothermal heat is transferred to freshwater in several heat exchangers. After expanding the plant in several steps the total installed capacity in Svartsengi is now 190 MW_{th} for hot water production and 76.4 MW_e for electricity generation in several units (see Table 2). Of that 8.4 MW_e come from Ormat binary units using low-pressure exhaust steam. A part of the effluent brine from Svartsengi (42 l/s) goes to the Blue Lagoon (see Chapter 5.1), the rest is reinjected into the reservoir.

HS Orka started operation of a 100 MW_e geothermal power plant at Reykjanes in May 2006 (two 50 MW_e steam turbines with sea cooled condensers). The plant uses 160 kg/s of steam at 18 bar. Work has started on a 30 MW_e expansion of the plant by using flash-steam from the high-pressure separator brine, without increasing the fluid extraction from the geothermal reservoir.

Table 2: Geothermal power plants in Iceland 2020

Plant name	Plant size MW_e	Year	Unit size MW_e	No of units	Type	Temp. °C	Press. bar-g	Flow rate t/h	Estimated production GWh_e/yr
Krafla	60	1978	30	1	DF	172/122	6.7/1.2	400/130	480
		1997	30	1	DF				
Svartsengi	76.4	1978-1880	8	2	SF	155	4.5	124	611
		1989-1993	1.2	7	B	103	0.12	131	
		1999	30	1	SF	162	5.5	275	
		2007	30	1	DS	201	15	288	
Bjarnarflag	5	1969	5	1	SF	182	9.5	45	42
Nesjavellir	120	1998	30	2	SF	192	12	432	960
		2001	30	1	SF	192	12	198	
		2005	30	1	SF	192	12	198	
Reykjanes	100	2006	50	2	SF	210	18	576	800
Hellisheidi	303	2006	45	2	SF	178	8.5	600	2,400
		2007	33	1	SF	124	1.25	315	
		2008	45	2	SF	178	8.5	600	
		2011	45	2	SF	178	8.5	600	
Theistareykir	90	2017-2018	45	2	SF	178	8.5	560	738
Flúðir	0.6	2018	0.15	4	B	116		125	5
Total	**755**			**32**				**5,332**	**6,031**

SF: Single flash; DF: Double flash; DS: Dry steam; B: Binary

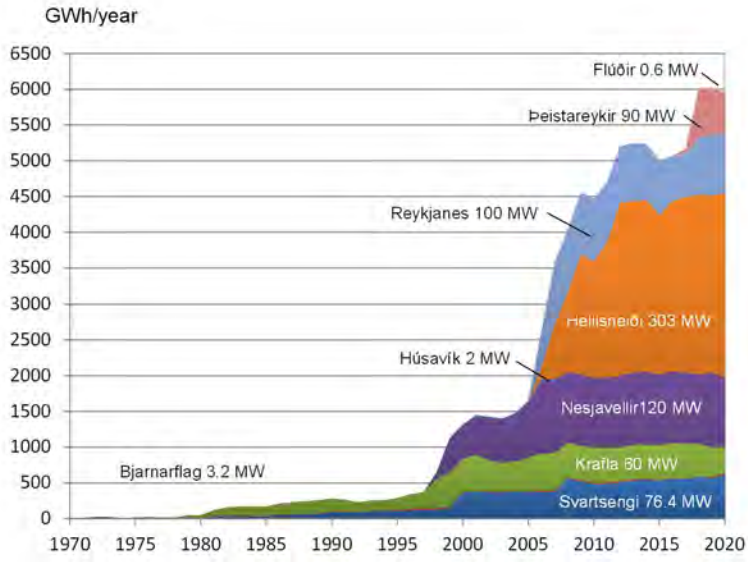


Figure 4: Electricity generation by geothermal energy in Iceland 1970-2020.

Reykjavík Energy has been operating a co-generation power plant at Nesjavellir high temperature field north of the Hengill volcano since 1990. A mixture of steam and geothermal water is transported from the wells to a central separator station at 192 °C and 12 bar-g. The primary purpose of the plant was to provide hot water for the Reykjavík area, 27 km away, and during the first eight years only the heating plant was in operation, heating fresh groundwater by geothermal steam and hot water in heat exchangers. After the electric plant was commissioned in 1998 the preheating of the freshwater is within the turbine condensers and thereafter by utilizing the water fraction from the separators. After deaeration, a small amount of geothermal steam containing hydrogen sulfide is injected into the water to remove any remaining oxygen and thereby preventing corrosion and scaling. The hot water is pumped from the power plant, which is at an elevation of 160 m a.s.l., to a large surge tank at an elevation of 400 m a.s.l. from where it flows by gravity to large storage tanks on the outskirt of Reykjavík before distribution. The capacity of the plant is about 300 MW_{th}, which corresponds to 1640 l/s of district heating water at 83 °C. The power plant started generating electricity in 1998 when two 30 MW_e steam turbines were put into operation. In 2001, a third turbine was installed, and the plant enlarged to a capacity of 90 MW_e, and finally to 120 MW_e in 2005 when the fourth turbine was installed (see Table 2).

Reykjavík Energy started operation of a new 90 MW_e geothermal power plant at Hellisheidi in the southern part of the Hengill area in October 2006. It was expanded by a 33 MW_e low pressure unit (bottoming plant) in 2007 and further by installing two 45 MW_e units in late 2008 and additionally two 45 MW_e units in 2011, increasing the total installed capacity of the plant to 303 MW_e. Hot water production for district heating in Reykjavík started at Hellisheidi in 2010. It has the capacity of 200 MW_{th}, which corresponds to 950 l/s of district heating water. Due to increased demand for steam, additional four wells drilled in a nearby area in the period 2006-2009 were connected to the plant at the end of 2015. Originally, these wells were planned for a new 90 MW_e power plant that was expected to be built in the area (Hverahlíd), but it was later decided to transport the steam over a distance of 5 km to maintain full generation in the Hellisheidi plant.

Reykjavík Energy, in cooperation with Icelandic and foreign scientists, has developed a process to capture CO_2 and other sour gases from geothermal power plants and permanently store it as rock in the subsurface. The process is based on dissolving the gases in water before injection into the bedrock where minerals will be formed in the same way as happens in the nature. After several years of research and pilot phases at Hellisheidi, Carbfix has been operated as a subsidiary of Reykjavik Energy since 2020. A hydrogen sulphide abatement unit is located at the Hellisheid power plant, which uses the Carbfix process to filter out 75 % of the hydrogen sulphide and 30 % of the carbon dioxide which is dissolved in the geothermal fluids and conducted into the re-injection system.

Landsvirkjun (The National Power Company) operates a 90 MW_e power plant at Theistareykir geothermal field in North Iceland, not far from the Krafla geothermal field. The construction work started in 2015 and the first 45 MW_e unit was commissioned in November 2017 and the second 45 MW_e in April 2018. The field had been under exploration since 1973. The first deep exploration well was drilled in 2002 and a total of 18 wells were drilled up to 2017 for production and reinjection. The main part of the power from the Theistareykir plant goes to a production plant for silicon metal in the nearby town Húsavík, which has a production capacity of 32’000 tonnes per year.

The project developer Varmaorka focuses on harnessing low-temperature geothermal resources for power generation. They have entered a collaboration with the Swedish binary plant supplier to deliver geothermal binary generation units. The modules are planned to be placed in several locations in Iceland. Their first project consists of four modules, 150 kW_e each, at Flúdir in southern Iceland, commissioned in June 2018. The binary units use geothermal water at 116 °C that is cooled down to 76 °C in the power generation process. The effluent water is planned to be used for district heating in the future. Varmaorka's second project was a 300 kW_e geothermal binary unit at Reykholt, Borgarfjordur. One additional small-scale geothermal binary plant that has recently been built is a 40 kW_e unit at the spa Krauma in Reykholtsdalur.

7. CONCLUSIONS

In general, Iceland's geothermal utilization story is a successful one. Over a few decades Iceland has become largely independent in regard to primary energy use by utilizing local energy sources. This has limited the need for importing fossil fuels so now Iceland is only using fossil fuels within the fishery fleet and transport sector. In the attempt to meet the international climate goals, Iceland is now focussing on eliminating the use of fossil fuels within the fishery sector and transport sector. To reach this goal, it is important to speed up the energy transition and focus on solutions like electric vehicles and liquid hydrogen for ships.

The main ongoing activity in the geothermal sector in Iceland is the 30 MW_e expansion of Reykjanes power plant. Although decisions have not been made regarding further development on a large scale, it is expected that increased demand in the future will require new developments for both electricity generation and direct uses of geothermal energy.

REFERENCES

Haraldsson, I.G. and Cordero, A.L.: Geothermal baths, swimming pools and spas: Examples from Ecuador and Iceland, Short Course VI on Utilization of Low- and Medium-Enthalpy Geothermal Resources and Financial Aspects of Utilization, organized by UNU-GTP and LaGeo, Santa Tecla, El Salvador, (2014), 14 pp.

Haraldsson, I.G. and Ketilsson, J.: Utilization of geothermal resources for electricity generation and direct applications, Orkustofnun (National Energy Authority, Iceland), report OS-2010/02, (2010) (in Icelandic), 62 pp.

Orkustofnun: OS-2022-T002-01: Final heat use in Iceland 2020 by district heating area. Orkustofnun, Reykjavík, (2022).

Orkustofnun: OS-2021-T014-01, Installed electrical capacity and electricity production in Icelandic power stations 2020, Orkustofnun, Reykjavík, (2021).

Ragnarsson, Á., Steingrímsson, B., Thorhallsson, S.: Geothermal development in Iceland 2015-2019, Proceedings, World Geothermal Congress 2020, Reykjavík, Iceland, October 24-27, 2021.

The Master Plan for Nature Protection and Energy Utilization, website 2022: http://www.ramma.is/english.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	755*	5,961*	2,936*	19,127*	25.7*	31.2*
Under construction end of 2021	30	260	30	260		
Total projected by 2023			3,200	21,090		
Total expected by 2028	960	7,700	3,300	21,690	29.1	35.5
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2020 pro-duction * (GWh_e/y)
Bjarnarflag	Bjarnarflag	1969/19	1	O	1F	5	5	29.8*
Krafla	Krafla	1978/97	2 (RI)	O	2F	60	60	359.5*
Svartsengi	Svartsengi	1978/07	11 (RI)	O	1F/B/D	76.4	76.4	609.0*
Nesjavellir	Nesjavellir	1998/05	4 (RI)	O	1F	120	120	973.9*
Hellisheidi	Hellisheidi	2006/11	7 (RI)	O	1F	303	303	2,573.4*
Reykjanes	Reykjanes	2006	2 (RI)	O	1F	100	100	829.4*
Theistakeykir	Theistareykir	2017/18	2 (RI)	O	1F	90	90	583.1*
Flúdir	Flúdir	2018	4	O	B-ORC	0.6	0.6	2.5*
Total						755	755	5961*

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
R	Retired / decommissioned	2F	Double Flash	O	Other

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2020 *	1,990*	7,551*	145*	672*			335*	1,514*
Under constru-ction end 2021								
Total projected by 2023								
Total expected by 2028								

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2020 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Reykjavík capital area	Veitur ohf.	1930	Y, partly	N (RI)	1,237		4,335	100
Akranes	Veitur ohf.	1980	N	N	34.9		122.2	100
Borgarnes	Veitur ohf.	1980	N	N	19.1		66.7	100
Hveragerði	Veitur ohf.	1947	N	N	15.3		53.7	100
Hvolsvöllur	Veitur ohf.	1982	N	N (RI)	6.8		24.0	100
Hella	Veitur ohf.	1982	N	N (RI)	10.4		36.5	100
Stykkishólmur	Veitur ohf.	1998	N	N (RI)	10.2		35.8	100
Þorlákshöfn	Veitur ohf.	1979	N	N	27.3		95.7	100
Rural areas	Veitur ohf.		N	N	57.5		201.0	100
Sudurnes	HS Veitur	1976	Y	N (RI)	205.8		721.1	100
Akureyri	Nordurorka	1977	N	N (RI)	121.1		424.4	100
Ólafsfjörður	Nordurorka	1944	N	N	10.3		36.0	100
Rural areas	Nordurorka		N	N	26.7		93.6	100

Table D1: Existing geothermal district heating (DH) plants, individual sites (continued)

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2020 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Mosfellsbær	Hitaveita Mosfellsbæjar	1929	N	N	69.8		244.7	100
Selfoss	Selfossveitur	1948	N	N	49.6		173.9	100
Rural areas	Selfossveitur		N	N	10.0		34.9	100
Sauðárkrókur	Skagafjarðarveitur	1953	N	N	28.0		98.0	100
Rural areas	Skagafjarðarveitur		N	N	23.1		80.8	100
Húsavík	Orkuveita Húsavíkur	1970	N	N	36.2		127.0	100
Rural areas	Orkuveita Húsavíkur		N	N	5.6		19.6	100
Blönduós	RARIK	1977	N	N	9.3		32.5	100
Dalabyggð	RARIK	1999	N	N	3.3		11.5	100
Siglufjörður	RARIK	1975	N	N	10.1		35.4	100
Skagaströnd	RARIK	2013	N	N	3.2		11.4	100
Rural areas	RARIK		N	N	2.3		8.2	100
Seltjarnarnes	Hitaveita Seltjarnarness	1971	N	N	39.0		136.7	100
Reykhólar	Orkubú Vestfjarða	1954	N	N	3.5		12.3	100
Suðureyri	Orkubú Vestfjarða	1977	N	N	4.8		16.7	100
Laugarás	Hitaveita Bláskógabyggðar	1964	N	N	12.8		44.7	100
Laugarvatn	Hitaveita Bláskógabyggðar	1955	N	N	4.0		13.8	100
Reykholt	Hitaveita Bláskógabyggðar	1969	N	N	5.6		19.6	100
Rural areas	Hitaveita Bláskógabyggðar		N	N	4.1		14.3	100
Egilsstaðir	HEF veitur	1979	N	N	21.7		75.9	100
Rural areas	HEF veitur		N	N	2.2		7.7	100
Dalvík	Hitaveita Dalvíkur	1969	N	N	16.8		59.0	100
Rural areas	Hitaveita Dalvíkur				3.3		11.6	100

Table D1: Existing geothermal district heating (DH) plants, individual sites (continued)

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2020 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Flúðir	Hitaveita Flúða	1929	N	N	18.5		64.7	100
Eskifjörður	Hitaveita Fjarðabyggðar	2005	N	N	9.0		31.4	100
Hvammstangi	Hitaveita Húnaþings vestra	1972	N	N	6.0		21.2	100
Rural areas	Hitaveita Húnaþings vestra		N	N	4.2		14.5	100
Rural areas	Kjósarveitur	2015	N	N	5.3		18.5	100
Rural areas	Other		N	N	137.0		480.5	100
total					2,331		8,167	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Reykjanes	Haustak	1999	N	44	44	271.0	100	
Reykjanes	Stolt Sea Farm	2013	N	54	54	331.5	100	
Svartsengi	Blue lagoon	1992	N	35	35	213.8	100	
Bjarnarflag	Jardbodin	2004	N	13	13	76.7	100	
Total				146	146	893.0	100	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2020 *	120*	1.2*	5*			
Of which networks **	2	1.9	0			
Projected total by 2023						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No shallow geothermal UTES currently exists in Iceland.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	30	120		
Geothermal direct uses	35	130		
Shallow geothermal				
total	**65**	**250**		

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	Yes	Yes	Yes
Financial Incentives – Investment	No	DIS	DIS
Financial Incentives – Operation/Production	No	No	No
Information activities – promotion for the public	Yes	Yes	Yes
Information activities – geological information	Yes	Yes	Yes
Education/Training – Academic	Yes	Yes	Yes
Education/Training – Vocational	Yes	Yes	Yes

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for Ireland

Riccardo Pasquali[1], Sarah Blake[2], Aoife K. Braiden[2,3], Niall McCormack[1]

[1] Geothermal Association of Ireland, c/o SLR Consulting, 7 Dundrum Business Park, D14 N2Y7, Ireland

[2] Geological Survey Ireland, Block 1, Booterstown Hall, Booterstown, Blackrock, Co Dublin, A94 N2R6, Ireland

[3] RML Ltd, Irishtown, Dublin, D04WP83, Ireland

rpasquali@geoservsolutions.com

Keywords: Ireland, country update, deep geothermal, shallow geothermal, ground source heat pumps, low enthalpy.

ABSTRACT

The exploitation of low enthalpy geothermal resources in Ireland using ground source heat pumps for heating and cooling applications continues to increase at an estimated rate of circa 3 % per annum. The number of heat pump units installed in Ireland since last reported at EGC2019 accounts for a total of 208 MW_{th} installed capacity with an increase in uptake during last two years of the current reporting period. The increase in growth rate is attributed to the setting of new targets for the deployments of heat pumps for heating and cooling and recent dedicated policy developments to support the deployment of geothermal technologies to substitute fossil fuel based technologies. The domestic heat pump market in Ireland remains dominated by the use of air source heat pumps (ASHP) with a reduced proportion of ca. 2.8 % of market share for ground source heat pumps (GSHP) in 2020 (EHPA, 2021). GSHP deployments have however increased as mostly larger-scale open and closed loop systems, where both heating and cooling applications are required. The increase in deployments is dominant in commercial building refurbishments in urban areas and in industrial applications.

Extensive research aimed at furthering the understanding of deep geothermal resources in different geological settings in Ireland is being undertaken by Geological Survey Ireland (GSI), and research organisations. This includes the development of a new National Geothermal Database that will include all relevant subsurface data (deep and shallow) to support the development of the geothermal sector in Ireland. Geological Survey Ireland has continued a programme of geothermal data collection with the completion of a test borehole at the Technological University of Dublin, Grangegorman campus in Dublin city. The test hole has confirmed the presence of promising geothermal reservoir temperatures at 998 m depth beneath the city with a temperature of 38 ºC recorded. This project is part of a wider ambition by Geological Survey Ireland to help realise the first geothermal district heating system for Ireland.

As the national Earth science agency, Geological Survey Ireland and researchers based in Ireland have benefitted from direct involvement in several pan-European research networks, including the GEOTHERMICA ERA-Net funding programme, the COST Action for District Heating and Cooling, the GeoERA MUSE (shallow geothermal energy) and GeoERA HotLime (carbonate geothermal targets) projects.

The Draft Policy Statement on Geothermal Energy for a Circular Economy published by the Dept. of the Environment, Climate and Communications (DECC, 2021) has raised significant awareness on the potential for utilisation of geothermal energy resources. The statement has been through an open public consultation process and a final draft is expected in late 2022. Work is ongoing to develop dedicated legislation and a new regulatory framework for geothermal energy resources. The expected timeline for this work is laid out in the document "Geothermal Energy in Ireland - A Roadmap for a Policy and Regulatory Framework" (DECC, 2020).

The publication of a new standard guideline document by the National Standards Authority of Ireland (NSAI) has set out standard recommendations for the design, installation and commissioning of ground source heat pump projects in Ireland (NSAI, 2021).

1. INTRODUCTION

The demand for heat energy was the largest source of energy use in 2021, accounting for 44 % of all primary energy usage. Despite the dramatic reduction in CO_2 emissions due to the travel restrictions and the COVID pandemic, CO_2 emissions from heat increased by 2.6 %, with the residential sector accounting for 53 % of total CO_2 emissions for heating. Renewable energy made up 6 % of final energy demand in the heat mode, with oil (44 %) remaining the largest fuel-type for the delivery of heat, followed closely by natural gas (40 %) The combined use ASHPs and GSHPs accounted for 19 % of renewable heat energy in 2020 (SEAI, 2021).

Ireland currently has the unenviable position of being last in the EU for RES-H contribution, far below the EU average of 23.1 % (Eurostat, 2022).

Ireland's National Energy and Climate Plan 2021-2030 (DECC, 2021a) sets out targets for the deployment of renewable energy technologies to meet the legally binding target of 32 % of overall renewable energy sources set out in the Renewable Energy Directive 2018/2001/EU. The plan set out clear objectives with respect to the understanding the potential for deployment of geothermal energy as part of the Just Transition and the development of a robust regulatory framework to support the sector. The National Development Plan (DPER, 2021) targets to retrofit 500,000 homes by 2030 and to install 680,000 heat pumps in existing and new buildings, underpin the targets set out in the Climate Action plant to reach and overall 34.1 % share of energy from renewable sources and a reduction of 51 % greenhouse gas emissions by 2030.

Ireland's Heat Plan (REI, 2021) was published by a multi-disciplinary industry organisation, with members working in the district heating, bioenergy, heat pumps, renewable gas and geothermal fields. The document presented roadmap to demonstrate how 40 % of Ireland's heat demand can be delivered from renewables by 2030. A key component of this plan is the role district heating networks can play in decarbonising heat in delivering large-scale renewable and low-carbon heat through such networks with few or no changes required from the consumer. This document outlines how the use of several renewable heat sources, including geothermal, could contribute to 10 % of Ireland's heating needs by 2030.

The recent National Heat Study (SEAI, 2022) highlights that existing policy measures are insufficient to meet our 2030 target of a 51 % reduction in emissions. The study sets out the need for rapid deployment of district heating in Ireland and recognises geothermal energy as a significant potential source for these networks, whilst also highlighting the following: "*Further work aimed at the complete characterisation of the suitability of the geothermal resource across Ireland will allow a better understanding of its potential for district heating at various locations*".

2. GEOTHERMAL RESOURCES IN IRELAND

Ireland is characterised by Precambrian to Lower Palaeozoic crystalline basement formations overlain for most of the central part of Ireland by Upper Palaeozoic formations of Upper Devonian and Lower Carboniferous age and comprising shales, limestones and sandstone lithologies (figure 1). Karstification of the Lower Carboniferous lithologies is extensive and for the most part buried due to a relatively thick Quaternary aged overburden cover (Holland, 2009).

The structural geological conditions in Ireland are controlled by the Caledonian and Variscan orogenies. These controlled the development and trend of the main fault structures of the Irish landmass. Cenozoic faulting, related to Alpine tectonics has also been shown to be present in Ireland (Cooper, 2012). The presence of 42 warm springs across Ireland is largely associated with the occurrence of these regional fault structures and with the presence of Lower Carboniferous aged lithologies.

Extensive research since the 1980s has recorded temperatures of between 13 °C and 25 °C at the warm springs. The warm spring occurrences appear to be related to the deep karstification of vertical or sub-vertical transmissive structures in limestone bedrock and exhibit non-linear discharge patterns characteristic of karst hydrogeology. Hydrochemical and isotopic studies have demonstrated that there is evidence of deep circulation of groundwater (Aldwell & Burden, 1986; Blake, 2016), however the precise locations of these deep circulation pathways in the subsurface remain enigmatic.

Geological Survey Ireland has produced a new suite of deep temperature maps for onshore Ireland. Six maps were produced using estimated temperature data from thermal models provided by the Dublin Institute for Advanced Studies (J. Fullea. G.O.THERM.3D Project *Providing a 3D Atlas of Temperature in Ireland's Subsurface*, funded by the Irish Research Council and Geological Survey Ireland). The models represent two dimensional slices through the crust at depths of 2 km, 2.5 km, 3 km, 3.5 km, 4 km and 5 km. These were produced as part of Geological Survey Ireland's National Geothermal Database project which is providing information to support the understanding of Ireland's geothermal resources, the development of Irish geothermal energy policy and the growth of the Irish geothermal industry (GSI, 2021a). The modelled temperatures are useful as an outreach tool for raising awareness of Ireland's deep geothermal potential. They also supersede overly pessimistic deep temperature maps from 2004. As they are based on a probabilistic model, Geological Survey Ireland has been careful to communicate that inherent uncertainty, particularly to non-technical users.

Irish shallow geothermal energy resources are relatively well understood and have been mapped by Geological Survey Ireland in a suite of geothermal suitability maps for open and closed loop systems (e.g., Figs. 2 and 3). Shallow geothermal energy resources are ubiquitous in Ireland and analysis of Geological Survey Ireland's maps shows that up to 94 % of Ireland's land mass has a 'suitable' or 'highly suitable' rating for at least one type of geothermal collector (SEAI, 2022). These shallow resources are favoured by a climate that is dominated by warm and mild maritime conditions. Relatively consistent, year-round soil temperatures and frequent rainfall keeping moisture in the ground maintains the soil as an excellent conductor, allowing heat to move towards a thermal collector system. These conditions are the reason the Irish subsurface is particularly suited to the installation of shallow closed loop systems (figure 2). The presence of gravel aquifers throughout Ireland and in particular in Cork, Dublin and Athlone, favours the use of open loop systems more commonly exploited for larger installations requiring heating and cooling (figure 3).

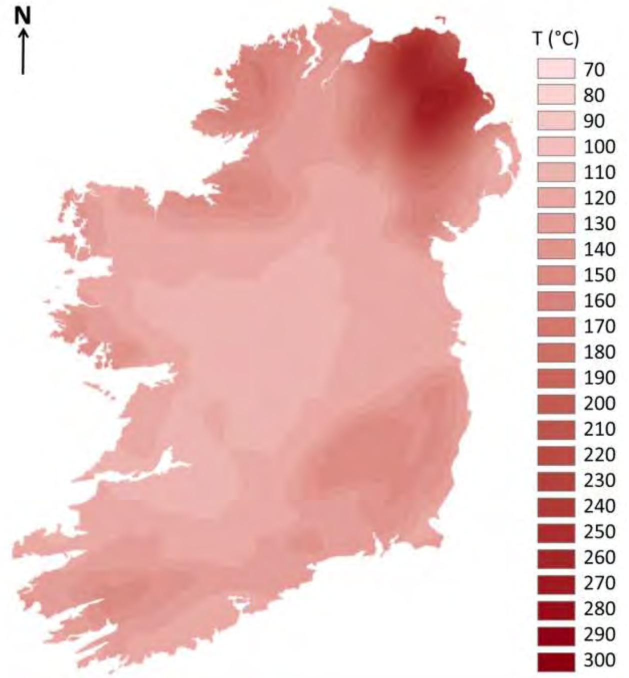


Figure 1: Deep temperature map at 3.5 km, temperatures in degrees Celsius, values range from 100 °C to 270 °C (GSI, 2021a).

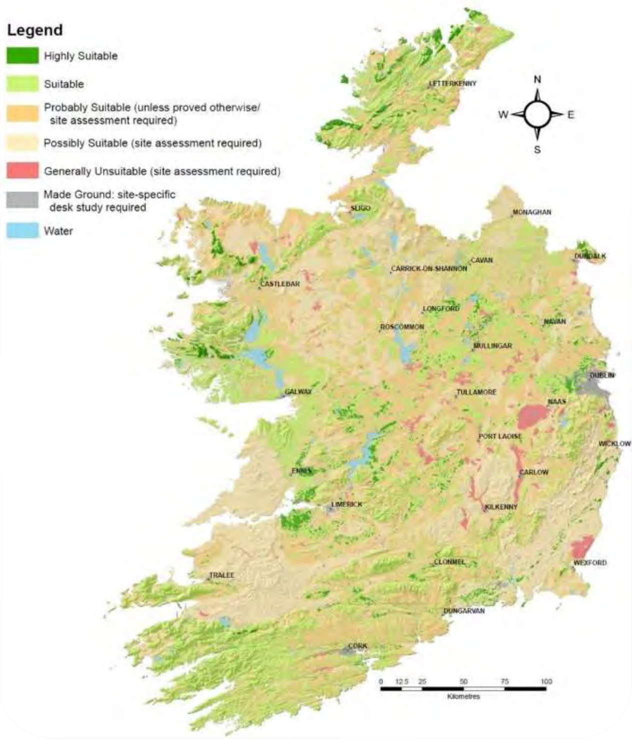


Figure 2: Vertical Closed Loop Collector Suitability Map (GSI, 2016).

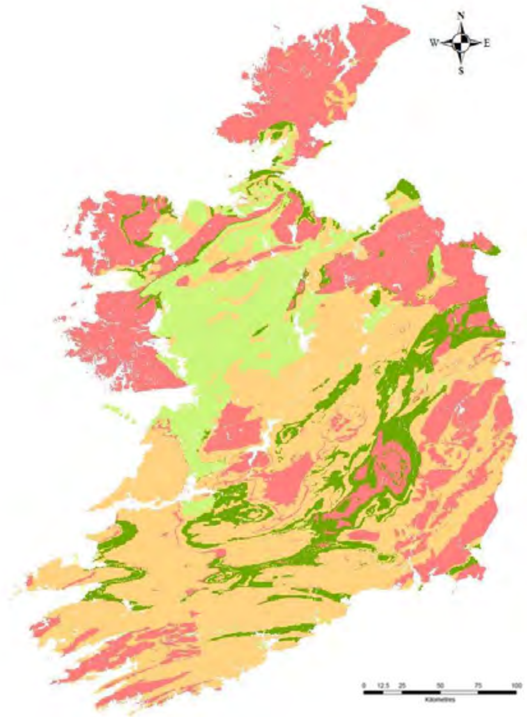


Figure 3: Open Loop Collector Suitability Map. Legend in figure 2 (GSI, 2016).

3. SHALLOW GEOTHERMAL ENERGY UTILISATION

The shallow geothermal energy utilisation in Ireland had a very high growth rate until 2009. The total estimated installed capacity for ground source heat pumps in 2021 is estimated at 208 MW_{th}, with a thermal energy produced for heating of 269 GWh and 10.3 GWh for cooling (Table E).

The lack of a dedicated database for reporting the number and characteristics for the installation of shallow geothermal energy systems in Ireland, has made it difficult to determine exactly both the market conditions in terms of the contribution of ground source heat pumps to renewable heating and cooling at a national level. Geothermal heating is estimated to contribute 1.2 % of total energy renewable energy contribution to thermal energy combined with air source heat pumps (figure 4).

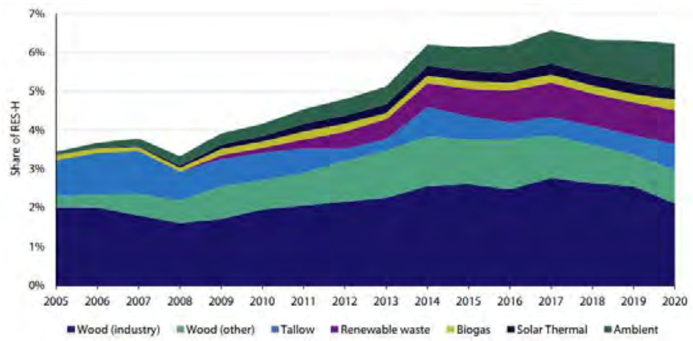


Figure 4: Renewable energy contribution to thermal energy (RES-H) in Ireland (SEAI, 2021).

Information on large scale commercial systems operating in Ireland is available through the Geothermal Association of Ireland (table 1), however, many installations (particularly new ones) remain poorly or not documented at all. The expected new regulatory framework for the deployment of GSHPs and the development of a new regulatory structure for geothermal resources may help to improve the future data collection and statistics related to GSHP installations by highlighting the installation of new large scale commercial systems and providing potential energy delivered data for the geothermal sector in Ireland allowing the geothermal sector contribution to be compared to other renewable technologies.

The shallow geothermal energy market in Ireland remains dominated by the installations in the residential sector (ca. 85 %) with lower uptake in the commercial and industrial processes sector (14 % and 4 % respectively) with systems of intermediate capacity between 10 kW and 24 kW the most widespread.

Large scale (60 to 250 kW), ground source systems are dominated by open loop collectors with an increased number of large scale closed loop collectors being developed as part of major space heating and cooling refurbishment projects. Examples of these include the Electricity Supply Board (ESB) headquarters in Dublin and the redevelopment of the Rubrics Building in Trinity College Dublin.

4. DEEP GEOTHERMAL ENERGY DEPLOYMENT

Deployment of deep geothermal energy resources on the island of Ireland has gathered renewed momentum. A geothermal exploration programme has been undertaken by Technological University of Dublin at the Grangegorman campus with Geological Survey Ireland to gather additional deep subsurface data and de-risk the development of deep geothermal resources in the Dublin Basin. Geological Survey Ireland successfully completed a deep exploratory borehole to a vertical depth of 998 m (figure 5) proving a temperature of 38 ^{o}C.

5. RESEARCH PROJECT

Geothermal research projects funded by SEAI and co-funded by Geological Survey Ireland are underway, such as the DIG project (De-risking Ireland's Geothermal Potential) led by the Dublin Institute for Advanced Studies. The project is investigating Ireland's geothermal potential using a wide range of geophysical and geological techniques at island-wide to local scales. The aims of the project include the determination of the regional geothermal gradient in Ireland, investigating the thermo-chemical crustal structure and secondary fracture porosity within the Munster Basin, as well as identifying and assessing the available low-enthalpy geothermal resources at reservoir scale in the Munster Basin.

Figure 5: Geological Survey Ireland's drilling rig completing an exploratory borehole at Technological University Dublin, Grangegorman (Photo credit: Sarah Blake).

Recently completed geothermal research projects include ShallowTHERM, led by GeoServ (jointly funded by SEAI and Geological Survey Ireland); a project that researched ground thermal property mapping to facilitate the design and installation of GSHP systems on a regional scale. The deployment of standing column well technology for larger scale heat pump system used for space heating is being demonstrated as part of the ThermoWell project, co-funded by SEAI and Geological Survey Ireland.

The recently completed G.O.THERM.3D project, led by the Dublin Institute for Advanced Studies, used a novel approach to quantify and map temperatures in Ireland's crust using an integrated approach that simultaneously accounted for multiple geophysical and petrological datasets. Based on this integrative approach new temperature models for Ireland's crust were created which provided an insight into the thermal regime within Ireland's deep subsurface, offering constraints on future modelling for deep geothermal prospects across the country. The outcomes of this project were aimed at assisting the development of public policy on geothermal energy exploration, mapping, planning and exploitation (Mather, 2018). The modelled temperature data were published as a suite of deep temperature maps by Geological Survey Ireland in 2021 and have already proven to be a useful outreach tool.

Table 1: Ground source heat pump installations in Ireland (domestic installations estimated in first row).

Locality	Ground or Water Temp.	Typical Heat Pump Rating or Capacity	Number of Units	Type	COP	Heating Equivalent Full Load	Energy Produced	Cooling Energy
	(°C)	(kW)				(hr/Year)	(GWh/yr)	(GWh/yr)
Domestic Installations Nationwide (Average Installed Capacity)	10	10.4	18653	H/W/V/O	3.5	1800	249.42	
Dolmen Centre, co. Donegal	10	45	1	H	3.5	1363	0.04	
Tralee Motor Tax Office, Co Kerry	10	120	1	H	3.5	1922	0.16	0.07
SHARE Hostel, Cork	15	120	1	W	3.5	1363	0.12	
UCC Glucksman Gallery, Cork	15	200	1	W	3.65	1922	0.28	0.11
Fexco HQ, Killorglin, Co Kerry	11	310	1	W	3.65	1922	0.43	0.17
Glenstal Abbey, Co Limerick	10	150	1	W	3.5	1363	0.15	
Musgrave HQ, Cork	10	160	1	V	3.65	1922	0.22	0.09
Killarney International Hotel, Co Kerry	11	60	1	W	3.5	1363	0.06	
Cork Co Council Environmental Labs	11	90	1	W	3.5	1363	0.09	
Cliffs of Moher Visitor Centre, Co. Clare	10	160	1	H	3.5	1363	0.16	
Killorglin Town Centre, Co Kerry	11	160	1	W	3.65	1922	0.22	0.09
Fermoy Leisure Centre, Co Cork	11	160	1	W	3.5	2725	0.31	
Tory Top Road Library, Cork	13	80	1	W	3.5	1363	0.08	
Coraville, Blackrock, Cork	13	36	1	W	3.5	1363	0.04	
Castleisland, Co Kerry	11	135	1	W	3.5	1363	0.13	
ESB Administration Offices, Cork	13	250	1	W	3.65	1922	0.35	0.14
Cork County Library, Cork	13	450	1	W	4	560	0.19	0.25
Swedish Ambassador’s Residence, Dublin	12	21	1	V	3.5	1363	0.02	
Cowper Care, Kilternan, Dublin	8	100	1	V	3.5	1363	0.10	
Cowper Care, Rathmines, Dublin	8	66	1	V	3.5	1363	0.06	
Cowper Care, Dublin	11	86	1	V	3.5	1363	0.08	
Vista Health Care, Naas, Co Kildare	10	400	1	W	3.65	1922	0.56	0.23
UCC Western Gateway IT Building, Cork	15	1000	1	W	3.65	1922	1.40	0.56
Athlone City Centre Retail Complex, Westmeath	10	2786	1	W	3.65	1922	3.89	1.56
Lifetime Lab, Cork	12	70	1	W	3.5	1363	0.07	
Bagenalstown Swimming Pool, Co. Carlow	11	18	1	W	3.5	1363	0.02	
Croi Anu Creative Centre, Co. Kildare	10	8	1	H	3.5	1363	0.01	
Rathmore Community Childcare, Co. Kerry	11	12	1	V	3.5	1363	0.01	
Treacys Hotel Co. Wexford	11	450	1	V	3.65	1922	0.63	0.25
Fairy Bush Childcare Centre, Co Roscommon	11	23.5	1	V	3.5	1363	0.02	
Tinnypark Nursing Home, Co. Kilkenny	10	32	1	H	3.5	1363	0.03	
Goretti Quinn Creche, Co. Kildare	11	12	1	V	3.5	1363	0.01	
CloCeardlann na gCnoc, Co. Donegal	10	18.3	1	H	3.5	1363	0.02	
St John's National School, Co. Mayo	10	14.2	1	H	3.5	1363	0.01	
Dubin Dockland Development Authority	12	17.5	1	H	3.5	1363	0.02	
Dunmore House Hotel, Co. Cork	11	18	1	W	3.5	1363	0.02	
Comhaltas Cosanta Gaeltachts Chuil Aodha, Cork	11	16	1	V	3.5	1363	0.02	
David Cuddy, Rathbranagh, Co. Limerick	11	11.5	1	V	3.5	1363	0.01	
Skeaghanore Farm Fresh Duck, Co. Cork	11	12	1	V	3.5	1363	0.01	
Kanturk Sheltered Housing, Co. Cork	11	8.3	1	V	3.5	1363	0.01	
Comhlacht Forbartha an Tearmainn, Co. Donegal	11	33.6	1	V	3.5	1363	0.03	
Feohanagh Special Needs Housing, Co Limerick	11	17	1	V	3.5	1363	0.02	
CLS Rosmuc, Co. Galway	10	19.8	1	H	3.5	1363	0.02	
Vicarious Golf, Co. Wicklow	10	13	1	H	3.5	1363	0.01	
Inis Oirr Health Centre, Co. Galway	10	12	1	H	3.5	1363	0.01	
Children's and Adults Respite Centres, Co. Galway	11	21	1	V	3.5	1363	0.02	
Kilcurry Community Development, Co. Louth	11	17	1	V	3.5	1363	0.02	
Ardara Community Childcare, Co. Donegal	11	22.1	1	W	3.5	1363	0.02	
Seawright Swimming School Co. Cork	11	31	1	W	3.5	1363	0.03	
Cope Foundation, Bandon, Co. Cork	11	30	1	V	3.5	1363	0.03	
Parklands Apartment Development, Co. Wicklow	11	40	1	V	3.5	1363	0.04	
Ballyconnell Central National School, Co. Cavan	11	12	1	V	3.5	1363	0.01	
James B Joyce & Co, Co. Galway	11	18.3	1	V	3.5	1363	0.02	
Poor Clare Monastery, Co. Louth	11	18	1	W	3.5	1363	0.02	
Tralee Community Nursing Unit, Co. Kerry	11	100	1	V	3.5	1363	0.10	
Brook Lodge Hotel, Co Wicklow	10	134	1	H	3.5	1363	0.13	
Hudson Bay Hotel, Athlone, Co. Westmeath	11	132	1	W	3.5	1363	0.13	
Hotel Europe, Killarney, Co. Kerry	10	110	1	W	3.5	1363	0.11	
Rathass Housing Estate, Tralee, Co. Kerry	8	70	1	H	3.5	1363	0.07	
Whites Hotel, Wexford	10	21	1	H	3.5	1363	0.02	
Belinter Hotel, Navan, Co. Meath	10	306	1	H	3.65	1922	0.43	0.17
Bellview Woods Childcare, Killarney, Kerry	8	30	1	H	3.65	1922	0.04	0.02

Table 1 (continued): Ground source heat pump installations in Ireland.

Locality	Ground or Water Temp.	Typical Heat Pump Rating or Capacity	Number of Units	Type	COP	Heating Equivalent Full Load	Energy Produced	Cooling Energy
	(^{o}C)	(kW)				(hr/Year)	(GWh/yr)	(GWh/yr)
D&G Electrinics Ltd, Castleisland, Co Kerry	8	21	1	H	3.5	1363	0.02	
Oilgate Nursing Home	8	100	1	V	3.5	1363	0.10	
Youghal Town Hall, Co Cork	8	21	1	V	3.5	1363	0.02	
Borris Nursing Home	14.65	74	1	W	3.8	3276	0.18	
Moyross Estate, Co. Limerick	9	140	1	V	4.1	1872	0.20	
Kilboy House, Tipperary	9	120	1	V	4.1	1872	0.17	
Vistakon Irleand, Limerick	12	890	1	W	5	4800	3.42	6.59
IKEA, Dublin	10	2000	1	V	3.5	1800	2.57	
Wonder Years Childcare Rossbrack, Manorcunningham Co. Donegal	8	43.6	1	H	4	1872	0.06	
Ballyroan Library, South Dublin	9.8	60	1	V	4.1	1872	0.08	
Cowper Care, Kilternan, Co Dublin	8	80	1	V	3.5	1872	0.11	
Mallow Swimming Pool, Co. Cork	15	100	1	W	3.5	4250	0.30	
Offaly Co. Council Ofices, Tullamore, Co. Offaly	10	105	1	W	3	1872	0.13	
Kelly's Showroom, Mountcharles, Co Donegal	8.4	38	1	V				
Lisdoonan Community Residential Scheme, Co. Monaghan		124	4 GSHP & 4 ASHP	H & ASHP				
UL Limerick Presidents House (estimated)		20	1	v	3	1800	0.02	
The Danes - Ashford Co. Wicklow (estiamte)		45	2	v	3.5	1800	0.12	
NUI Galway (estimated)		24	1	v	3	1800	0.03	
Mount St. Anne's Retreat and Conference Centre (est.)		80	1	v	3	1800	0.10	
Mount Juliet - Apartments (estimate)		125	1	v	3	1800	0.15	
Mount Juliet - Walled Garden Lodges (estimate)		30	1	v	3	1800	0.04	
Wexford Nursing Home (estimate)		75	1	v	3.5	1800	0.10	
Solas Chroi Spa & Health Centre, Brandon House Hotel (estimate)		50	1	v	3	1800	0.06	
Coolemore House & Gate Lodge Thomastown, Col. Kilkenny (estimate)		40	1	v	3	1800	0.05	
Queens University Belfast - School of Management	12.7	240	2	v		1200		
ESB HQ	11.6	210	1	v		1200		
TCD Rubrics	13.2	188	3	v		2000		
Offaly Co. Council Ofices, Tullamore, Co. Offaly	10	105	1	W	3	1872	0.13	
TOTAL		208244	18746				268.93	10.29

The Geo-URBAN project, led by Gavin & Doherty Geosolutions Ltd, evaluated novel geophysical exploration and modelling techniques for urban areas, which was applied to two test locations, Vallès, Catalonia, Spain and Dublin, Ireland. Geophysical data collected during GEO-URBAN supported a commercialisation strategy for the exploitation of deep geothermal resources in challenging urban environments. This drew upon existing knowledge and experience from partners in Denmark, where the deep geothermal heat industry is more established. Stakeholder involvement of local planning authorities and companies ensure that GEO-URBAN exploration activities align with local sustainable energy plans and district heating strategies. Furthermore, policy recommendations to assist the sustainable exploitation of deep geothermal energy resources in each region were outlined. The overall objective of the GEOURBAN project was to identify the geothermal resources available in two challenging urban locations and to demonstrate a commercialisation strategy for such an environment that has the potential to be adapted in other similar locations (Stafford, 2021).

The COSEISMIQ project, led by ETH Zurich and including the Dublin Institute for Advanced Studies, integrated seismic monitoring and imaging techniques, geomechanical models and risk analysis methods with the ultimate goal of implementing innovative tools to reduce geohazard risk for deep geothermal projects. These adaptive, data driven approaches for reservoir optimisation and for the control and management of induced seismicity represent a major contribution to safe and sustainable geothermal energy exploitation. COSEISMIQ demonstrated Real-Time Induced Seismicity Controller (RISC) in a commercial scale application in Iceland. Understanding how to prevent or reduce large induced earthquakes plays a pivotal role in the development of future, innovative, and clean forms of natural deep underground energy resources. The Dublin Institute for Advanced Studies is focusing of the development of the geomechanical models, the deployment of seismic monitoring stations and characterisation of seismicity and Hengill volcano test site in Iceland (Bean, 2018).

The GeoERA HotLime project, comprising several European partners including Geological Survey Ireland, assessed low-enthalpy deep limestone geothermal reservoirs. Hydrothermal systems in deep carbonate bedrock are among the most promising low-enthalpy geothermal plays across Europe. However, these prospects have received little attention, and are perceived as ‘tight’. The HotLime project improved mapping and assessment of geothermal plays in deep carbonate rocks in Europe in order to de-risk geothermal exploration in such plays. The project did this through identifying the generic structural and geological controls on fractures and karst conduit development in deep carbonate formation. This was achieved by comparing geological situations and their structural inventory, and through collating deep borehole data and their petro- and hydro-physical characteristics. The outcomes of the HotLime project included maps of geothermal reservoir distribution and volumetric resource assessments focussed on the Dublin Basin and the Lough Allen Basin. The HotLime reports can be accessed under: https://geoera.eu/projects/hotlime6/

A study by UCD Business School and the Irish Centre for Research in Applied Geosciences (iCRAG) included public acceptance and risk perception of Geothermal Energy in Ireland has highlighted public risk perceptions towards geothermal energy in the Irish context are lower in comparison to other energy sources. Based on a nationwide survey, public acceptance of geothermal energy was generally high with risk to the environment, society and the economy perceived as being low. Environmental and societal risks were deemed as the most important factors that influence overall public acceptance of geothermal energy in Ireland. The research also demonstrated the importance of communities being involved in the process of geothermal energy development from the beginning and are well communicated with in order to stabilise and generate acceptance (Hooks, 2018).

A number of projects funded by the European Horizon 2020 programme are being implemented with the aim of further developing the shallow geothermal energy sector. The development of innovative drilling, ground heat exchangers and heat pumps have been implemented and installed as part of the GEO4CIVHIC (led by CNR-ISAC including GeoServ) and GeoFIT (led by R2M and including National University of Ireland Galway) projects. These innovations demonstrate the potential for increasing the deployment of ground source heat pumps in complex urban settings as well as in the context of major retrofitting of buildings and the applicability of shallow geothermal in historical buildings.

The GEO4CIVHIC project aims to develop and demonstrate easier to install and more efficient ground source heat exchangers, using innovative compact drilling machines tailored for the built environment. The project also aims to develop or adapt heat pumps and other hybrid solutions in combination with renewable energy sources for retrofits through a holistic engineering and controls approach, for improving the return of investments. GEO4CIVHIC aims to accelerate the deployment of geothermal systems for heating and cooling in retrofitting existing and historical buildings based on the innovations developed by the project that consider both ground heat exchangers and hybrid heat pumps for high and low temperature terminals. A case study in Greystones in Ireland has successfully demonstrated during 2021 the use of a new drilling methodology, the installation of high efficiency coaxial borehole heat exchangers and the future operation of a cascade cycle high temperature heat pump (HTHP) in a historical residential building. (Bernardi at al., 2022, *in press*).

The GeoERA MUSE (Managing Urban Shallow geothermal Energy) project concluded in 2021 and provided tools and services to assist uptake and sustainable and efficient use of shallow geothermal energy in European urban areas. The MUSE project, including Geological Survey Ireland, identified, summarised and developed state-of-the-art methods for Shallow Geothermal Energy (SGE) assessment, management and monitoring; developed strategies for efficient and sustainable use in urban areas; and, transferred methods and integrated strategies into specific urban pilot areas including the city of Cork, Ireland (Hunter Williams, 2018).

Two research projects funded by Geothermica are focussing on research in deep geothermal energy systems. The DEEP project led by ETH Zurich and including the Dublin Institute for Advanced Studies, aims to build and test next generation sensors and develop new data analysis tools for induced seismicity monitoring including an Adaptive Traffic Light System (ATLS) as a decision-support tool providing operators with a reliable and up-to-date estimate of the risk of induced seismicity during reservoir operations at Enhanced Geothermal Energy sites (DEEP, 2021).

The RESULT project led by Netherlands Organisation for Applied Scientific Research (TNO) and including Gavin & Doherty Geosolutions will develop and test innovative well technology to lower the cost price, enhance lifetime and heat recovery of direct use geothermal heat production. This includes multi-lateral wells, and (progressively) adapting the well design by deploying the drill & learn paradigm originally developed in oil and gas. RESULT will develop, test, and validate the developed methods with reservoirs with extensive geographical extent and potential for urban geothermal development. These includes proof of concept and detailed design studies for the Rotliegend clastic reservoir (NL), Paleozoic carbonates of Carboniferous and Devonian age (IRE/NL) and volcanic reservoirs (ICE). A full-scale field demonstration of the (optimization) innovative multi-lateral geothermal well design and drill and learn approach will be performed in the Netherlands (source TNO).

6. LEGISLATIVE AND REGULATORY FRAMEWORK:

The Department of the Environment, Climate and Communications and Geological Survey Ireland are committed to overcoming existing barriers, encouraging the uptake of low-carbon geothermal energy and the development of a geothermal industry An Assessment of Geothermal Energy for District Heating in Ireland (GSI, 2020) highlighted the lack of legislation governing the use and ownership of geothermal energy in Ireland as a barrier to the development of the sector. Geothermal Energy in

Ireland - A Roadmap for a Policy and Regulatory Framework (DECC, 2020) was published shortly after this assessment and was followed by the Draft Policy Statement on Geothermal Energy for a Circular Economy (DECC, 2021). A public consultation period has now closed, and the final policy statement is expected in late 2022. It will set out the approach to regulating and licensing the exploration and development of geothermal energy as a natural resource. It will also set out the approach to be taken in engaging with the public, providing information, resources and gathering data and bridging gaps in knowledge. The policy statement will be finalised with the help of a Geothermal Energy Advisory Group. DECC will develop dedicated legislation and a regulatory framework for geothermal energy over the coming years.

7. FINANCIAL SUPPORT:

Existing financial support measures for GSHPs have remain available through the Sustainable Energy Authority of Ireland for both domestic and non-domestic applications.

The Heat Pump System grant provides home owners with € 3,500 towards the cost of a heat pump system (irrespective of the type) subject to adequate energy efficiency upgrades being implemented that reduce heat loss in the building fabric below 2 $W/K/m^2$.

The Support Scheme for Renewable Heat supports the adoption of renewable heating systems by commercial, industrial, agricultural, district heating, public sector and other non-domestic heat users not covered by the emissions trading system. The grant based scheme provides funding of up to 30 % of eligible costs to air source, ground source and water source heat pumps based on the buildings and heat using processes adhering to verified energy efficiency criteria, Building Regulations, Construction Products Regulations, EN Standards, efficiency, technology standards and air quality standards in relation to emissions. Under the same scheme an operational support tariff for high efficiency biomass CHP and biogas heating systems for a period of 15 years is offered.

The Renewable Electricity Support Scheme (RESS) makes provision for a renewable electricity (RES-E) ambition of up to a maximum of 55 % by 2030. This is to be achieved through a series of auctions throughout the scheme that begins in 2019 and that will promote the increasing technology diversity by broadening the renewable electricity technology mix allowing Ireland to achieve these ambitious goals. Deep geothermal energy could be considered as a future technology under this scheme when more data on available deep resources is established.

Geological Survey Ireland, SEAI, Science Foundation Ireland and international funds (e.g. Geothermica and the Clean Energy Transition Partnership) continue to support geothermal energy research in Ireland. Topics range from improving our understanding of subsurface resources, to geological modelling, reducing risk developing novel drilling techniques, and more efficient heating/cooling technologies. Research in the area of social acceptance and public policy is also key to including all stakeholders and strengthening the sector overall.

8. OUTREACH ACTIVITIES:

The Geothermal Association of Ireland has focussed on supporting the development of the geothermal sector. A geothermal webinar series hosted in conjunction with Queens University Belfast, The Geological Survey of Northern Ireland, Geological Survey Ireland and University of Aberdeen has been running over a 2 year period. The seminars are focussed on providing information to stakeholders actively in the development of geothermal policy, members of the public, government agencies on technology developments, market growth and application of geothermal technologies for heating, cooling and power production.

REFERENCES

Aldwell, C.R., and Burdon D.J.: Energy potential of Irish groundwaters, Quarterly Journal of Engineering Geology, London, (1986).19, 133-141.

Bean, C. COSEISMIQ: COntrol SEISmicity and Manage Induced earthQuakes. *Deep Geothermal in Ireland – Past, Present and Future*. Dublin, September 2018. http://www.coseismiq.ethz.ch/en/home/

Bernardi, A., De Carli, M. Pockelé, L., Poletto, F., Galgaro, A. Di Sipio, E.. Castelruiz, A., Urchueguía, J.F., Badenes, B., Pasquali, R., Bertermann, D., Mule'Stagno, L., Mendrinos, D., Vercruysse, J., Fedele. L. Menegazzo, D., Carnieletto, L., Contini, S. Mezzasalma, G., Cadelano, G., Bortolin, A., Sanner.B.: Shallow Geothermal Energy for existing buildings – overview and status of project GEO4CIVHIC. Proc. EGC 2022, *in press*.

Blake, S. IRETHERM Project An Overview. *Deep Geothermal in Ireland – Past, Present and Future*. Dublin, September 2018.

Cooper MR, Anderson H, Walsh JJ, Van Dam CL, Young ME, Earls G, Walker A (2012) Palaeogene Alpine tectonics and Icelandic plume related magmatism and deformation in Northern Ireland. *J Geol Soc Lond* 169:29–36

DECC, 2021a. Climate Action Plan 2021. Securing Our Future. *Department of the Environment, Climate and Communications*. Dublin, 2021.

DECC, 2021b. Consultation on the Draft Policy Statement on Geothermal Energy for a Circular Economy and associated SEA Environmental Report and AA Natura Impact Statement. Dublin, 2021.

DEEP, 2021. Innovation for de-risking Enhanced Geothermal Energy Projects. *DEEP website*. http://deepgeothermal.org/home (accessed 29th April 2022.)

DPER, 2021. National Development Plan 2021-2030. *Department of Public Expenditure and Reform*. Dublin, 2021.

European Heat Pump Association, 2021. Online Stats Tool. *European Heat Pump Association*. Brussels, 2021. http://www.stats.ehpa.org/hp_sales/country_cards/

Geological Survey Ireland, 2021a. Deep Temperature Maps for Ireland. *Geological Survey of Ireland.* Dublin, 2020. https://www.gsi.ie/documents/Deep_temperature_maps_for_Ireland_report.pdf

Geological Survey Ireland, 2021b. HotLime Project presentation. *Geological Survey of Ireland Geothermal Workshop*. Dublin, 2021.

Holland, C. H. Sanders, I. The Geology of Ireland. *Dunedin Academic*. Edinburgh, 2009.

Hooks, T, Schuitema, G. Moynihan, A. B. Public acceptance and risk perception of Geothermal Energy in Ireland. *Deep Geothermal in Ireland – Past, Present and Future*. Dublin, September 2018. http://spatial.dcenr.gov.ie/GSI_DOWNLOAD/Geoenergy/Other/Deep_Geothermal_in_Ireland_Workshop_Sept2018.pdf

Hunter Williams, N. Geothermal research at Geological Survey Ireland – past and current. *Deep Geothermal in Ireland – Past, Present and Future*. Dublin, September 2018.

King, J.: The proposed new Geothermal Energy Development Bill. Proceedings of the GAI Conference, Kilkenny, (2011). 18, 6-8.

Mather, B. G.O. Therm: Providing a 3D Atlas of Temperature in Ireland's Subsurface. *Deep Geothermal in Ireland – Past, Present and Future*. Dublin, September 2018.

National Standards Authority of Ireland (NSAI). 2021. S.R. 50-4:2021 Building services - Part 4: Heat pump systems in dwellings. *National Standards Authority of Ireland*. 2021

Raine, 2021. Geothermal Energy Potential in Northern Ireland. Summary & Recommendations for the Geothermal Advisory Committee. *GSNI*. Belfast, 2021.

Renewable Energy Ireland – REI, 2021. 40 By 30. *Renewable Energy Ireland.* Dublin, 2021.

SEAI (2021). Energy In Ireland – 2021 Report. Dublin, 2021.

SEAI (2022). National Heat Study – 2022 Report. Dublin, 2022.

Stafford, P. 2021. GeoUrban Project presentation. Geological Survey Ireland Geothermal Workshop. Dublin, 2020.

TNO, 2020. Enhancing Reservoirs in Urban development (RESULT) Public summary. TNO. https://projecten.topsectorenergie.nl/projecten/enhancing-reservoirs-in-urban-development-result-34600

TABLES A-G

Table A: Present and planned geothermal power plants, total numbers

No geothermal power plants currently in Ireland.

Table B: Existing geothermal power plants, individual sites

No geothermal power plants currently in Ireland.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *								
Under constru-ction end 2021								
Total projected by 2023	7	31.5			7	31.5		
Total expected by 2028	14	63	15	117	10	45		

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

*** Estimates based on current outline project developments

Table D1: Existing geothermal district heating (DH) plants, individual sites

No geothermal district heating currently in Ireland.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

No large geothermal heating systems currently in Ireland.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	18746***	209***	269***	460***	7.6***	25***
Of which networks **						
Projected total by 2023						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

*** Estimates

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No geothermal UTES currently in Ireland.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power				
Geothermal direct uses	1.5$^+$	15$^+$	15$^+$	65$^+$
Shallow geothermal	6.5$^+$	180$^+$	9.5$^+$	275$^+$
total	**8**$^+$	**180**$^+$	**24.5**$^+$	**340**$^+$

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

$^+$ Estimates

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	SEAI & Geological Survey Ireland Science Foundation Ireland and Geothermica research funding	SEAI, GSI, SFI and Geothermica research and outreach funding	SEAI, GSI, SFI and Geothermica research and outreach funding
Financial Incentives – Investment		Climate Action Fund for research and development of deep geothermal energy projects Interreg Peace Plus	Heat Pump System Grant - €3500 towards improved controls when a heat pump is installed Support Scheme for Renewable Heat – 30% grant funding for non-domestic applications Interreg Peace Plus
Financial Incentives – Operation/Production	N/A	N/A	N/A
Information activities – promotion for the public	Geological Survey Ireland, Geothermal Association of Ireland websites	Geological Survey Ireland, Geothermal Association of Ireland websites	Geological Survey Ireland, Geothermal Association of Ireland websites
Information activities – geological information		Geological Survey Ireland conferences and dissemination events Geothermal Association of Ireland Monthly webinar series	Geological Survey Ireland conferences and dissemination events Geothermal Association of Ireland Monthly webinar series
Education/Training – Academic	Undergraduate Courses on geothermal energy as an optional course in Engineering and sustainable energy	Undergraduate Courses on geothermal energy as an optional course in Engineering and sustainable energy	Undergraduate Courses on geothermal energy as an optional course in Engineering and sustainable energy
Education/Training – Vocational			Training and Certification for HP installers only – Carlow IT drilling course in collaboration with Geoscience Ireland and Geological Survey Ireland

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

European Geothermal Congress 2022
Berlin, Germany | 17-21 October 2022
www.europeangeothermalcongress.eu

Geothermal Energy Use, Country Update for Italy

Bruno Della Vedova[1], Ilaria Bottio[2], Maurizio Cei[3], Paolo Conti[1,*], Geoffrey Giudetti[3], Gianluca Gola[1,4], Lorenzo Spadoni[2], Maurizio Vaccaro[1], Luca Xodo[5]

[1] UGI – Italian Geothermal Union, c/o University of Pisa-DESTEC, Largo Lazzarino 2, 56122 Pisa, Italy

[2] AIRU – Italian District Heating Association

[3] Enel Green Power, via Andrea Pisano, 120, 56122 Pisa, Italy

[4] IGG-CNR – Inst. Geoscience and Earth Resources of National Research Council, Via Moruzzi 1, 56124 Pisa, Italy

[5] STEAM S.r.l., Via Ponte a Piglieri, 8, 56122 Pisa, Italy

paolo.conti@unipi.it

Keywords: Power sector, Heating & cooling sector, District Heating networks (DH), Ground Source Heat Pump (GSHP), Country update, Geothermal development.

ABSTRACT

This paper presents the development of geothermal applications in Italy in the 2017-2020 period for both the power and the heating & cooling sectors. Enel Green Power is the only geo-electricity producer in Italy. At the end of 2020, the installed geo-capacity was 915.8 MW_e, supported by 34 power plants and 37 generation units. In 2020, the gross electricity production reached about 6.03 thousand GWh. All the geo-power plants are in Tuscany Region. During the 2017 – 2020 period, no additional generation units have been installed; 13 new wells have been drilled between 2018-2021 for a total depth of 33.8 km approx.

Concerning the heating and cooling sector, the total installed capacity is about 1300 MW_{th}, with the corresponding thermal energy use of about 9700 TJ/yr (~2700 GWh/y). Compared with 2017 data, the H&C sector has experienced a reduction of about 11 % in terms of geo-heat use. The reduction is mainly due to the temporary closure of spa facilities imposed by the COVID-19 pandemic (-15 % in terms of heat delivery). On the contrary, the heating of buildings continues to grow at an average pace of 3 % per year, thanks to the continuous expansion of GSHPs and DH networks. Therefore, the heating of buildings confirms its leading position among the other sectors of applications (49 % of the total energy, 59 % of the overall installed capacity). The effects of the pandemic are expected to vanish in the coming year, but the historical data show an unsatisfactory standing trend for geothermal energy in Italy: the main drawbacks and possible boosting actions for a new growth phase of geothermal energy in Italy are presented and discussed for both power and H&C sectors.

1. INTRODUCTION: GEOTHERMAL ENERGY IN THE ITALIAN ENERGY SYSTEM

Italy is one of the main countries for geothermal resources worldwide. Thanks to a favourable geological context, the use of geothermal energy in Italy dates back to prehistoric times and developed intensively during the Roman Ages (3rd B.C. – 5th A.D.). Historical applications included: thermal baths, cooking, heating spa facilities in localities with active manifestations, and the use of hydrothermal minerals. All these uses declined notably from the 6th to the 12th century A.D., but they started growing again from the 13th century onward, making a substantial jump ahead in the 19th and early 20th centuries with the production of boron compounds (Ciardi and Cataldi, 2005).

During the 20th century, geothermal energy continued to expand. Besides the famous experiment by Prince Ginori Conti, Italy is also the Country of the first industrial power plant (250 kW_e) in the World that entered into operation in September 1913 in Larderello. At the end of World War II, installed capacity started to grow unceasingly for both power and heating&cooling applications (H&C). The evolution of the Italian geothermal development is briefly reviewed in Figures 1 and 2. Geo-power data have been constantly increasing both in terms of installed capacity and electricity production, reaching a maximum value of about 6.3 TWh/y in 2016 (Conti et al., 2016). The heating and cooling sector has experienced notable growth in the 2000s thanks to a new expansion phase related to space heating applications, namely district heating (DH) and ground-source heat pumps (Bargiacchi et al., 2020).

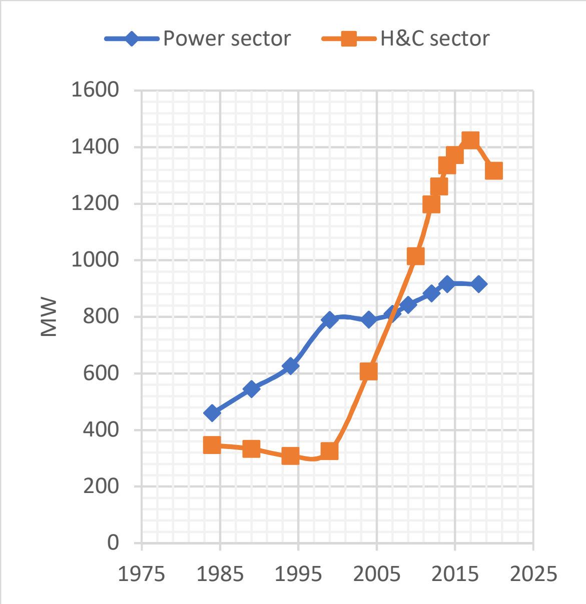


Figure 1: Evolution of geothermal capacity in Italy.

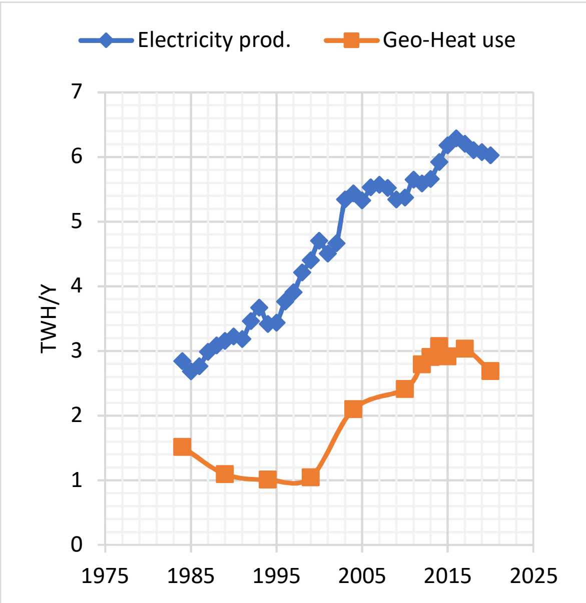


Figure 2: Evolution of geothermal energy use in Italy.

The variation of H&C statistics is also ascribed to the different data collection, processing methodology, and estimations made by the various authors of the Country Updates over the years. Geo-heat statistics have always suffered from a lack of official and robust datasets, especially for low-capacity Ground Source Heat Pump systems (GSHPs), fish farming, and thermal balneology. Due to the absence of official and complete catalogues, data are often the result of an educated guess, based on indirect information (e.g. market information).

Since 2010, the Italian geothermal union (UGI), in collaboration with the main geothermal-related association (e.g., AIRU – District Heating Association and ANIGHP – National Association of Geothermal Heat Pump), has started a systematic survey aimed at creating a database of all Italian direct uses (Conti et al. 2015). Additionally, large-capacity thermal application of geothermal energy in Italy is now monitored by the Italian authorities (GSE), improving the statistics on heating applications; nonetheless much work still remains to be undertaken because only a few operators can provide quantitative data and it is important to complete the final H&C statistics with estimations by CU authors (Conti et al. 2015, Bargiacchi et al., 2020).

To date, Italy is one of the top 10 countries for electricity generation (Hutter, 2020) and among the first 15 for heating and cooling applications (Lund and Toth, 2020). Despite its continuous development (see Figures 1 and 2), the contribution of geothermal energy to the overall Italian energy scenario has still notable room for improvement. In 2020 the gross final energy consumption in Italy amounted to 107.6 MTOE (~4500 PJ or ~1250 TWh), with a share of Renewable Energy Sources (RES) of 21.96 % (GSE, 2022). Due to the COVID-19 pandemic, final energy consumption in 2020 was lower than in previous years: for comparison, the same value in 2019 was 120.3 MTOE. However, the RES share is keeping up always around 21 % – 22 % since 2015.

In 2020, the share of the total electricity consumption covered by geothermal energy has been about 2 % (~6 TWh of the total electricity consumption of about 311 TWh). The same share (2 %) occurs in the thermal sector thanks to 81 kTOE provided by GSHPs, and 141 kTOE provided by other technologies, DH included (GSE, 2022).

This paper presents the geothermal development during the 2017 – 2020 period for both power and heating & cooling sectors. The section and data regarding electricity production were prepared by Enel Green Power (EGP), i.e., the Enel Group company that develops and manages energy generation from renewable sources at a global level, including all the 34 currently active geothermal power plants in Italy. Data regarding thermal applications are mainly derived from government statistics provided by Italian authorities (e.g. Italian Energy Services Manager (GSE), Ministry of Economic Development, and Ministry of Ecological Transition), together with datasets and information collected by UGI, AIRU, and ANIGHP.

2. GEOTHERMAL ELECTRICITY GENERATION

In the year 2020, the electricity needs in Italy reached 312.73 billion kWh (including the energy needed for auxiliary services), with a reduction of more than 6 % compared to 2018 due to the reduction in consumption linked to the COVID-19 pandemic. In 2020 the domestic contribution was about 89.7 %, while a relevant 10.3 % was imported (Terna, 2021). The estimated electricity generation capacity and production data from the geothermal source in Italy in 2020 are summarized in Table A. Of the 280.5 TWh of net domestic electricity generation, 65 % comes from thermal and 35 % from renewable sources (see Fig. 3). The latter percentage is almost equally distributed between hydro and wind plus solar and geothermal (Terna, 2021).

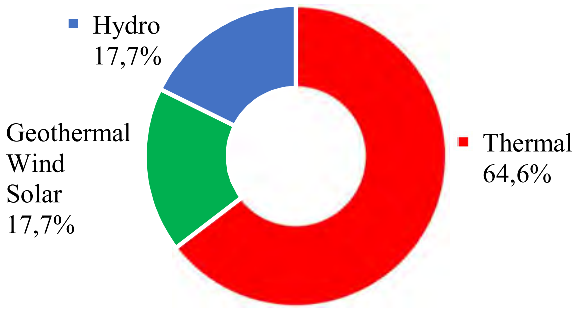


Figure 3: Electric domestic net generation in Italy (Terna, 2021).

The geothermal contribution only corresponds to 2.1 % of the whole Italian electricity generation, however, it covers over 30 % of the electricity needs in Tuscany, increasing the green energy share of the Region.

In 2020 the average market price of electricity was 3.98 Eurocent/kWh showing a significant decrease compared to previous years (GSE, 2021).

In 2021 the value of the GRIN tariff (Ex green certificates) for the plants that benefit from this type of incentive was 10.9 Eurocent/kWh in addition to the average market price of electricity. To this value, it must be applied the specific reduction coefficients foreseen for the type of technology and the type of intervention carried out (GSE, 2021). 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 MW_e installed Capacity), 9.8 Eurocent/kWh (for plants between 1 MW_e and 5 MW_e) and 8.4 Eurocent/kWh (over 5 MW_e installed Capacity). All these tariffs are inclusive of the average market price of electricity (D.M. 23/06/2016). A new FER2 Decree is expected before the end of 2022.

2.1 Geothermal power generation: current status and development

An updated historical trend of electricity generation from geothermal resources in Italy is given in Figs. 2 and 4, where two different increase phases are shown: the first one in the period from the 1930s to the mid-1970s, related to the development of shallow carbonatic reservoirs, with well depths up to about 1000 m. The second one from the beginning of the 1980s up to now, when the fluid production was increased thanks to the positive results of the deep drilling activity and the artificial recharge of the shallow reservoirs by means of the reinjection of water and condensed steam (Cei et al, 2020a).

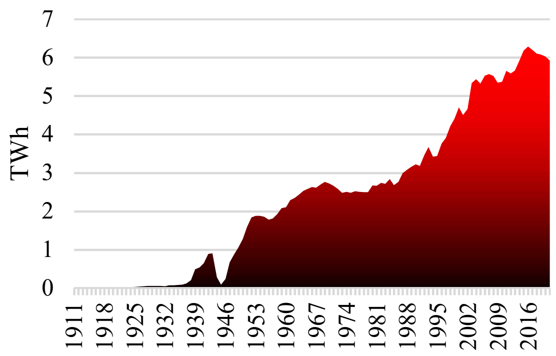


Figure 4: Historical trend of electricity generation from geothermal resources in Italy.

Despite the difficulties caused by the COVID-19 pandemic, EGP set up a new record in 2021 by building 5,120 MW of new renewable capacity with projects around the world, which includes 220 MW of batteries for the first time. In addition, EGP also set up a record in terms of energy from renewable sources produced in the year, with approximately 119 TWh, of which 55.4 TWh from wind and solar, 57 TWh from hydro, and 6 TWh from geothermal, avoiding million tons of CO_2 emissions per year.

EGP has cumulated an important multi-year experience in the management of geothermal fields that allowed the reaching of a record of electricity produced from the geothermal resource in Italy, with a gross electricity generation of about 6.3 GWh in 2016. During the year 2021, with an installed capacity of 915.8 MW_e, the electricity gross generation has picked up to 5.917 GWh. The complete list of the power plants in operation is given in Table B; taking into account the real operating conditions of the plants in the different areas (pressure, temperature, non-condensable gas content in the steam), the total running capacity (Reference Net Capacity) is 773.7 MW_e.

All 34 geothermal power plants in operation in Italy are equipped with AMIS (Abbattimento Mercurio e Idrogeno Solforato - mercury and hydrogen sulfide abatement) technology, with an average availability (hours of operation vs hours of operation of the associated power plant) that exceeded 90 % in the traditional area (Larderello and Travale-Radicondoli) and about 95 % in the Mount Amiata area in 2021. AMIS technology removes mercury and hydrogen sulfide present in the non-condensable gases of the geothermal fluid through a stage of catalytic oxidation for H_2S and specific sorbents for mercury (Sabatelli et al., 2009).

2.2 Geothermal fields

The four Italian geothermal fields under cultivation for electricity generation are all located in Tuscany (Fig. 5) and are the following: Larderello, Travale-Radicondoli, Bagnore, and Piancastagnaio (the two latter ones being located in Mount Amiata area).

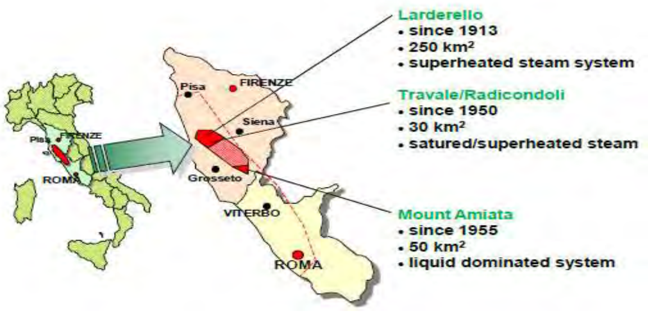


Figure 5: Location of the geothermal fields in Italy.

All geothermal power plants are remotely controlled and operated from a remote-control station located in Larderello, where 12 people work in round-the-clock shifts (24/7) ensuring continuous monitoring. In the remote control station, every operating parameter of each plant is monitored and analysed and every unit could be shut down and restarted. This solution allowed a more efficient and optimized plant operation, reducing dramatically operating costs.

The complex networks of steam pipelines, which often include many production wells with different thermodynamic and fluid-dynamic characteristics, are managed thanks to the use of innovative numerical modelling tools. This allows the optimization of production, evaluating in advance the best-operating conditions of the wells in order to manage the geothermal resource at its best performance during workovers or power plant shutdowns (Cei et al, 2020b).

The activities carried out by EGP over the last three years were concentrated mainly in the Larderello and Travale-Radicondoli areas and targeted at fields management optimization to reduce and contrast the natural decline by drilling new deep production wells. In the Mt. Amiata area, where the high potential deep reservoir could be further cultivated, no new drilling activities were put in place due to the excess of available resource compared to the installed power capacity in the area.

2.2.1 Larderello

In the explored area of Larderello, extending approx. 250 km^2, 200 wells produce superheated steam at a pressure between 2 and 15 bar and temperature ranging from 150 °C to 270 °C. The non-condensable gas (NCG) content ranges from 1 to 10 % by weight. The installed capacity is 594.8 MW_e, as of December 2021, with 22 units in operation. The area has been cultivated since the beginning of the 1900s and reservoir sustainability is ensured through two main strategies for its management: reinjection and deep drilling. Since the late 1970s, the condensed steam reinjection into the shallow carbonate reservoir formation has been highly beneficial, especially in the most depleted area (Valle Secolo), and made it possible to increase the reservoir pressure and, accordingly, the steam production (Cappetti et al., 1995 and Cei et al, 2020a). The deep exploration program showed the presence of permeable layers within the Metamorphic Basement, down to 3000–4000 m depth, with increasing reservoir pressure and temperature with depth up to 7 MPa and 350 °C, respectively (Barelli et al., 1995, 2000; Bertini et al., 1995; Cameli et al., 2000; Bertani et al., 2005).

In the period 2018 – 2021 the drilling activities in the Larderello area focused both on reinjection (especially in the central part of the geothermal field, where reservoir pressure is lower) and on new production wells in the peripheral area.

In 2018 EGP started the construction of the Monterotondo-2 geothermal power plant for additional 20 MW_e gross, on a new lease located SE of the traditional area, close to Lago Boracifero. Unfortunately, the drilling of the first commercial well did not confirm the expectations. Nevertheless, the Monterotondo-2 project was not abandoned, but its power capacity was reduced. The construction of a new 5 MW geothermal power plant is therefore expected by 2028.

2.2.2 Travale-Radicondoli

The explored area of Travale-Radicondoli extends for approx. 50 km^2. In this area, 42 wells produce superheated or saturated steam at a pressure ranging from 8 to 20 bars and a temperature of 190-250 °C. The non-condensable gas content is in the range of 5 – 6.5 % by weight. The installed capacity is 200 MW_e with 8 units in operation. The deep exploration, performed in previous years, showed also in this area the presence of permeable layers within the Metamorphic Basement, located at the same depths and with the same reservoir temperature and pressure as in the Larderello area. Moreover, some of the deep wells (at depths of about 4000 m) show the presence of productive layers also in the Granite underlying the Metamorphic Basement. It must be pointed out that the deep drilling activity proved that the two shallow fields of Larderello and Travale-Radicondoli represent the “outcropping” of a unique, wider, and deeper (3000-4000 m) geothermal system, with an extension of about 400 km^2. At a depth of about 3000 m, the same temperatures and reservoir pressures were found (300-350 °C and 6-7 MPa) both inside the fields and in the marginal areas (Bertani et al., 2005).

The drilling activities have continued during the last three years with 5 new production steam wells that reduced the natural decline of the field and with 7 workover activities on existing productive wells to recover their production. The new wells were located based on a joint accurate interpretation of the geophysical data, well data and 3D seismic surveys. No reinjection wells were drilled so far.

The intensive cultivation of the Travale-Radicondoli geothermal field caused a change in the thermodynamic properties of the fluid; in particular, the pressure lowering induced by fluid production has increased the superheating status of the fluid. Experimental tests carried out in recent years confirmed the possibility of using the reinjection strategy also in the deep geothermal system of Travale-Radicondoli in order to reduce the natural decline in reservoir pressure. For this purpose, a new important project is planned in the next few years to start the reinjection strategy, but no new production plants are planned until 2028.

2.2.3 Mount Amiata

Bagnore and Piancastagnaio are the two geothermal fields located in this area. They were discovered between the late 1950s and the early 1960s, with wells producing steam from the shallow carbonate reservoir. In the late 1970s, a deeper exploration program was initiated, with very successful results for both fields, revealing the presence of a fractured Metamorphic Basement, underlying the shallow carbonate reservoir, at depths ranging from 2500 to 4000 m. This deeper reservoir is liquid-dominated, with a pressure of around 200 bars and a temperature of 300-350 °C at 3000 m depth (Bertini et al., 1995). The produced fluid is a two-phase mixture that is separated at the wellhead at a pressure of 20 bar; the non-condensable gas content in the steam ranges from 5 to 8 % by weight.

At the end of 2021 the total installed capacity was 121 MW_e, with 7 units in operation. In the period 2018 – 2021 the drilling activity was mainly dedicated to the recovery of existing damaged wells, most of them for re-injection purposes.

The geothermal area of Mount Amiata is undoubtedly the most promising one for further development. EGP plans to build two new production units for a total of 60 MW by 2028 within the existing leases.

2.3 New development leases

The exploration activity carried out by EGP in previous years on the new research permits makes it possible to identify interesting new areas for the development of new projects for electric power production. In particular, EGP has acquired a new lease (called Roccalbegna), adjacent to the existing concessions in the Monte Amiata area. The construction of at least one new 20 MW production unit is planned in this new lease. Drilling activities will begin in the next 3 - 4 years, once the necessary environmental permits will be acquired.

2.4 Personnel and development

The number of professional personnel allocated to geothermal activities by EGP and the overall investments are shown in Table F. The manpower estimate considers EGP personnel only and it does not take into consideration the contribution of ancillary personnel working in local companies to support the geothermal activities of EGP. This contribution is difficult to quantify, but in any case, it is very important for the local economy.

2.5 Drilling

In the period 2018 – 2021, a total of 13 geothermal wells were drilled in Tuscany, for a total drilled depth of 33.8 km. Eight are make-up wells drilled in the Larderello field, six for production, and two for reinjection. Other five production wells were drilled in the Travale-Radicondoli fields to contrast the natural decline of geothermal production.

Heat mining activity also includes an important recovery and maintenance activity of the existing wells. A total of sixteen work-over jobs were carried out in the considered period, both on production and reinjection wells, and for plug and abandonment of old geothermal wells no longer exploitable.

3. GEOTHERMAL ENERGY USE FOR HEATING AND COOLING

While electricity from geothermal resources is produced only in Tuscany, heating and cooling applications are widespread all over the national territory. Among the main applications, we mention agriculture and food processing, industrial process heat, balneotherapy, recreation and tourism, space heating and cooling. H&C geothermal applications include individual ground-source heat pump systems (GSHPs), but also building blocks, DH networks, hot-water wells with direct use of the geothermal fluid, and cascade uses. Cooling applications are not considered in this report due to the lack of an established methodology for its quantification, though their development is expected to become significant in the next years.

Energy data are available only for large facilities, such as district heating systems (DHs), large greenhouses, and industrial applications. For those systems, the data source consists of the values declared by systems owners and analysed by AIRU (2021), UGI, and EGP. On the contrary, the data on small individual systems, thermal balneology, and aquaculture are based on the aggregated national data reported in GSE (2022). Finally, statistics on ground-source heat pumps (GSHPs) are based on the data reported in GSE (2022) and EurObserv'ER (2021).

All the collected data from different sources have been processed by the authors and presented in Tables 1 to 3 and Tables C and D1 at the end of this report. Tables and charts were produced using the same methodology presented and applied in previous Country Updates (Conti et al., 2015; Conti et al., 2016; Manzella et al., 2019) to allow a coherent comparison framework for the analysis of the historical evolution.

When it was not possible to obtain the source data, the statistics were performed according to available information, energy engineering considerations, suitable capacity factors (CF), and/or equivalent full load hours of operation (EOHs). For instance, there is no data on the capacity installed in agriculture, aquaculture, balneology, and industrial sectors. Therefore, we used the same CF values of previous country reports and the global average values suggested by Lund and Boyd (2016). For GSHP, reference EOH and seasonal coefficient of performance are based on the values suggested in Directive 2013/114/EU.

For this section, the following definitions apply:

- "Capacity" is the maximum instantaneous geothermal energy deliverable by the system under well-defined and declared operational conditions;
- "Energy" refers to the amount of geothermal energy delivered to the end-user systems (losses included) over the year of reference;
- "Capacity factor" (CF) is the ratio between the actual energy delivered by a system and the maximum theoretical output if operating at full capacity load were indefinitely possible.

3.1 Heating and cooling energy statistics

The reference year for all the statistics concerning the heating and cooling sector is 2020. At the end of the year, the installed capacity of geothermal energy for thermal use exceeds 1300 MW_{th}, with the corresponding total energy use of 9668 TJ/yr (Figs. 6 and 7, Tables 1 to 3). The main sector of utilization is space heating of the buildings, which accounts for 41 % and 49 % in terms of installed capacity and energy use, respectively. Health, recreation, and tourism is the second sector, representing 30 % of both energy use and installed capacity; the sum of agriculture, fish farming, and food processing accounts for 20 % of the total geo-heat utilization (1908 TJ/yr), and about 10 % of the overall installed capacity (133 MW_{th}). Heat utilization for industrial processes and minor uses amounts to less than 1 % of the total, with a capacity of 18 MW_{th} employing about 107 TJ/yr.

The average CF of all the H&C geothermal applications is 0.23 (see Section 3.3). This value is driven by the high equivalent working hours of fish farming (CF equal to 0.49) and agriculture (CF equal to 0.41), while the space heating CF is decreasing year by year, because of the globally increasing outdoor temperature and the increasingly restrictive Italian laws on building insulation.

3.1.1 Ground-source Heat Pumps

Regarding ground-source heat pumps, they account for 43% of the total installed capacity and some 36% in terms of energy. We recall that in this report we have referred to "Capacity" and "Energy" values as the power/energy delivered by the ground source, namely to the evaporator section, as it represents the actual geothermal contribution in heating mode. Other statistics on GSHPs in other reports might be referred to as the condenser output as the focus might also be the contribution of the technology to the heating service for the end-user system. In any case, attention shall be paid when different sources are used for GSHP aggregation. To prevent ambiguity, in Table E1, we have reported quantities at both evaporator and condenser (see Conti et al., 2015 and Conti et al., 2016 for further details on statistics processing methodology).

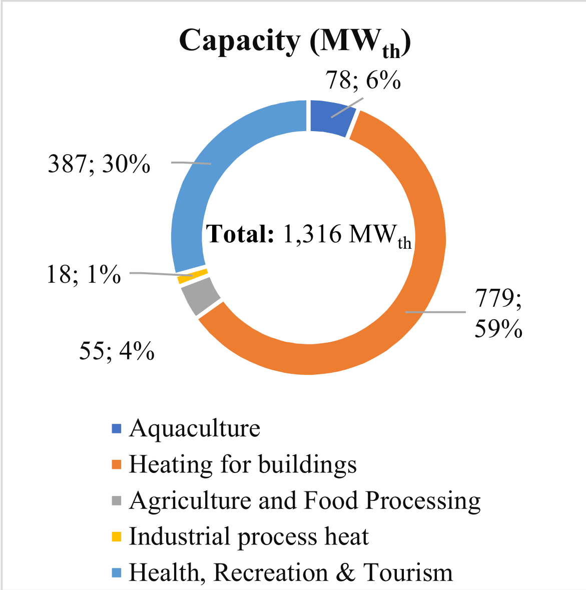


Figure 6: Share of geothermal installed capacity of H&C sector in Italy in 2020.

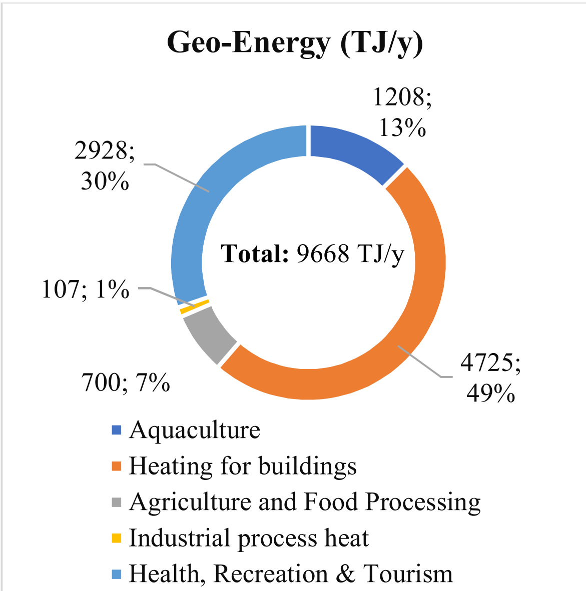


Figure 7: Share of geothermal geo-energy use of H&C sector in Italy in 2020.

3.1.2 District heating systems

District heating systems represent about 9 % of the total geothermal heat utilization (856 TJ/yr) with a total installed capacity of about 164 MW_{th}. The largest number of DH systems are in the Tuscany Region as cascade heat from the conventional geothermal power plants. The fluid used to feed the DH networks is indeed produced by the same deep wells and geothermal system feeding the power plants and is delivered to the heat exchanging sections depending on fluid characteristics.

Table 1: Summary of installed geothermal capacity in the H&C sector in Italy at the end of 2020 (values in MW_{th}).

	Total	GSHP	DH
Aquaculture	78		
Heating for buildings	779	555	161
Agriculture and Food Processing:	55	13	
Industrial process heat	18	4	3
Health, Recrea-tion & Tourism	387		
Total	1316	572	164

Table 2: Summary of geothermal energy use in 2020 in the H&C sector in Italy (values in TJ/y).

	Total	GSHP	DH
Aquaculture	1208		
Heating for buildings	4725	3404	844
Agriculture and Food Processing:	700	75	
Industrial process heat	107	25	11
Health, Recrea-tion & Tourism	2928		
Total	9668	3504	856

The other main Italian geothermal DH application is in Ferrara, where a system with 14 MW_{th} capacity and 2 production wells at about 2 km depth produces pressurized hot water at about 95 °C. The fluid is then totally reinjected in a third well. Two more systems worth to be mentioned are located in Milano, where two large GSHP units (18 MW_{th} and 15 MW_{th}) are used to deliver heat to two urban districts. Another district heating system, which uses a geothermal source, is that of Vicenza. The "Vicenza" geothermal well was drilled by the Saipem company in 1983 in the northern part of the city and within the area of Vicenza DH plant. It reaches the production area between 1500 m and 2150 m depth from ground level with a wellhead temperature of 68 °C at a flow rate of 100 m^3/h. The geothermal resource has been integrated into the DH system since 2013. A geothermal district heating system was realized in Grado (Gorizia), based on a producing well at 1200 m (up to 100 tons/h at 50 °C) and on a re-injection well about 1000 m deep at one km distance. It supplies 6 public buildings with a DH network of more than 3 km started in 2014, but it could not yet be completed. Currently it is not working, and it requires completion and a workover on the production well.

Table 3: Summary of the capacity factor in 2020 in the H&C sector in Italy.

	Total	GSHP	DH
Aquaculture	0.49		
Heating for buildings	0.19	0.19	0.17
Agriculture and Food Processing:	0.41	0.18	
Industrial process heat	0.19	0.20	0.10
Health, Recrea-tion & Tourism	0.24		
Average	0.23	0.19	0.17

3.3 Discussion on the evolution of the geothermal heating and cooling sector in the 2017-2020 period

Tables 4 to 6 and Figs. 8 and 9 show the evolution of the geothermal heating and cooling sector in the years 2017 – 2020.

- Installed capacity and heat use have both experienced a general reduction, i.e., -8 % and -11 %, respectively;
- Heating for buildings is one notable exception to the general reducing trend. The whole sector of application has increased from 739 MW_{th} to 779 MW_{th} (+5 %) in terms of installed capacity and from 4566 TJ/y to 4725 TH/y in terms of geo-heat used (+3%). During the considered 3-year period, the yearly average increase ratio has been about +1 %/yr and +2 %/yr for power and energy, respectively.
- The increase in the building sector was led by the GSHP market (+40 MW of installed geo-capacity[1] and +239 TJ/yr of geo-heat use). Additionally, the DH sector has increased its contribution with 12 MW of additional thermal capacity.

[1] As explained in Section 3.1.1, in this report the GSHP capacity is referred to the ground-coupled section of the HP device (i.e., the evaporator). The same statistic referred to the building section (i.e., the condenser) would be +52.5 MWth.

- As shown in Fig. 9, in 2020, the GSHP and the DH sectors account for 9 % and 36 % of the total geothermal energy in Italy. The same statistics in 2017 were 8 % and 29 %.
- Aquaculture variation is mainly ascribed to a different methodology and data source compared to the one used in the last CU. An estimation of the actual reduction between 2017 and 2020 is about -20 % in terms of both installed capacity and energy use.
- Statistics on the agriculture sector are affected by a similar statistical uncertainty due to the different data sources used in this report compared to the previous one. However, a reasonable analysis of the numbers suggests that the sector of application has not significantly changed its relevance in the 2017 – 2020 period, with a geo-heat use in the range of 650 – 700 TJ/yr.

Table 4: Development of geothermal capacity for H&C applications in Italy during the period 2017-2020 (values in MW_{th}).

	Total	GSHP	DH
Aquaculture[2]	-52 (-40 %)		
Heating for buildings	+40 (+5 %)	+40 (+8 %)	+12 (+8 %)
Agriculture and Food Processing:	-25 (-31 %)	-	
Industrial process heat	-2 (-10 %)	-	-
Health, Recreation & Tourism	-69 (-15 %)		
Total	-109 (-8 %)	+40 (+8 %)	+14 (+ 9%)

4. LEGISLATIVE FRAMEWORK AND SUPPORT MEASURES

Geothermal energy has been declared to be a strategic energy source for Italy (L. 134, 2012) having the potential to significantly accelerate the energy transition. The combined heat and power production and the great potential that Italy deserves for H&C, DH, and electric power generation clarify the great role and perspectives that this energy source will play in the future of the Country.

There is a great expectation for a significant improvement of the legislative framework and support measures since a few years for the three main sectors of geothermal applications in Italy, particularly after the publication of the recent RePower EU communication.

Table 5: Development of geothermal energy use for H&C applications in Italy during the period 2017-2020 (values in TJ/y).

	Total	GSHP	DH
Aquaculture[2]	-811 (-40 %)		
Heating for buildings	+159 (+3 %)	+239 (8 %)	-9 (-1 %)
Agriculture and Food Processing:	+44 (+7 %)	-	
Industrial process heat	- 67 (-39 %)	-	1 (10 %)
Health, Recreation & Tourism	-573 (-16 %)		
Total	-1248 (-11 %)	+239 (+7 %)	-7 (-1 %)

Table 6: Evolution of the capacity factor of geothermal H&C applications in Italy during the period 2017-2020.

	Total	GSHP	DH
Aquaculture[2]	-		
Heating for buildings	-0.01 (-5 %)	-	-0.02 (-11 %)
Agriculture and Food Processing:	+0.15 (+58 %)	-	
Industrial process heat	- 0.09 (-32 %)	-	-0.22 (-69 %)
Health, Recreation & Tourism	-		
Total	-0.01 (-4 %)	-	-0.02 (-11 %)

Law 34/2022 from end of April 2022, introduced urgent measures to control natural gas and energy costs, develop renewable energy sources, and relaunch industrial and energy policies. There is a clear endorsement for the development of the GSHP supported by both closed (BHE) and open loop heat exchangers. The corresponding national guideline and regulatory framework are due in two months following the publication of Law 34. The Italian Geothermal Platform[3] is contributing to the finalization of this

[2] Aquaculture variation is mainly ascribed to a different methodology and data source compared to the one used in the last CU.

[3] https://www.cngeologi.it/2022/06/24/convegno-webinar-gratuito-stati-generali-della-geotermia/

process which could start a great development of GSHP for H&C in single houses, as well as in blocks and cities to contribute to the decarbonization, energy saving and reduction of greenhouse gas emissions in urban areas, according to the EU directives and policies.

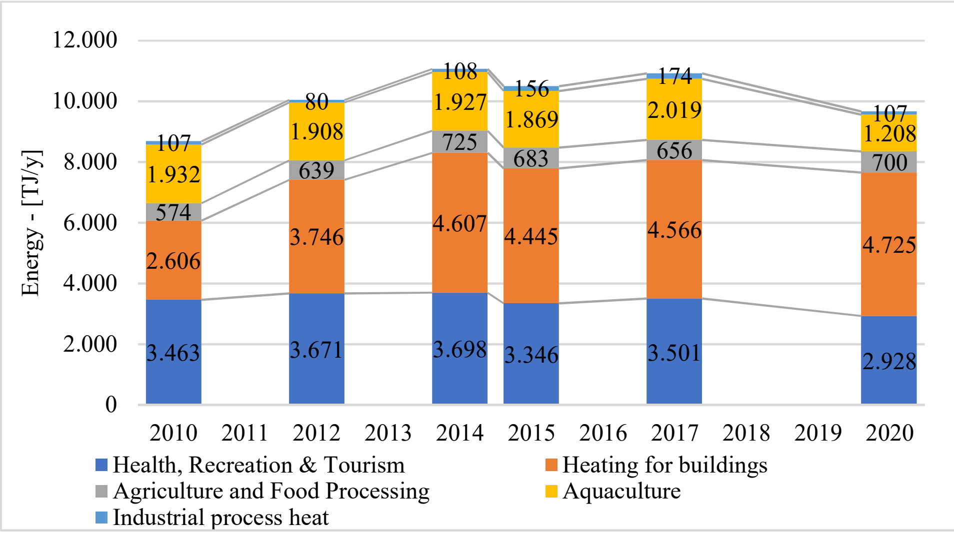


Figure 8: Development of the different sectors of direct uses in Italy (2010-2020).

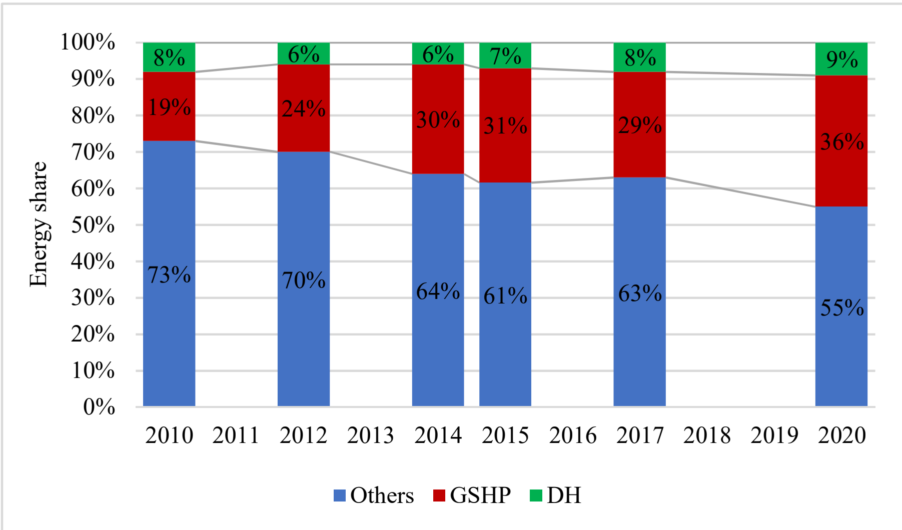


Figure 9: Development of geothermal DHs and GSHPs for space heating&cooling concerning the total geo-heat delivered in Italy (2010-2020).

On the DH side, the legislative framework is suffering because of the delay and lack of due legislative and regulatory instruments which are pending since a few years and prevent the development and deployment of DH systems fed by RES and waste heat locally available.

The electric power production sector is stagnant since about two decades and it is waiting for an adequate legislative framework and support measures, following the Decree n.22/2010 on the re-organization of the legislative framework on research and cultivation of geothermal resources.

The so-called “FER1 Decree” enacted in 2019 provides incentives to renewable energy plants in order to achieve the European targets by 2030 defined in the Integrated National Plan for Energy and Climate and to promote the effectiveness, efficiency, and sustainability of the sector, both in environmental and economic terms. Sources benefiting from the scheme include onshore wind, solar PV, hydroelectric, and sewage gases. The bad news was that geothermal was not included in this supportive scheme.

The FER2 scheme, announced long ago, is now under discussion and it is due quite soon by next fall. It includes traditional geothermal plants with innovation and innovative new “zero emission” geothermal plants.

UGI and AIRU, with the support of EGEC, settled the Tavolo Tecnico “Geotermia per la Transizione Energetica” (TTG) in February 2022. The agreed document has been signed by 10 operators of the heating sector and 14 from the geothermoelectric sector. UGI and AIRU will facilitate and coordinate the following sessions and activities. The target of this technical table is to underline and highlight the great potential contribution that geothermal energy can give to the energy transition in the Country, identifying the barriers that still prevent full development.

The TTG is supporting the decision makers in giving value to the extraordinary geothermal potential of the country for a quick, sustainable, secure, and low-impact energy transition. The TTG, in collaboration with the Italian Geothermal Platform, is contributing its expertise and entrepreneurship to policymakers for the improvement of the FER2 that should enable the development of innovative geothermal plants for the next five years.

5. R&D ACTIVITY IN GEOTHERMAL ENERGY TOPICS

Increasing accessibility of deep geothermal resources for low carbon heating and power generation is a fundamental requirement to accelerate the development of decarbonised and indigenous energy supplies in Europe. The achievement of the above-mentioned goal requires R&D activities in different, but complementary, Earth Sciences and Engineering topics. In this context, the advancement in drilling technology plays a key role in geothermal exploration and exploitation. The DeepU Project, funded by the European Union, seeks to achieve the deployment of geothermal anywhere and at providing a stable, uninterrupted, base load energy to meet global CO_2 emission reduction target. The overall aim of DeepU is to create a deep (>4 km), closed-loop, vitrified, waterproof, non-cracked U-tube heat exchanger by combining laser and cryogenic gas into a single technological drilling solution. The technology envisioned in this project will revolutionize the deep geothermal energy sector, offering a complementary approach and an alternative solution to traditional drilling approaches. The innovative, fast and effective drilling technology is tested at the laboratory scale in different rock types to verify its capacity to liquefy and vitrify the rocks, leaving the borehole ready for heat exchange immediately after drilling. The demonstration at the laboratory scale produces the information required for assessing the technological, environmental, and economic sustainability and defining the potential and commercial attractiveness of the proposed solution.

Besides, lowering emissions from geothermal power generation by capturing them for either re-use or storage is an important aspect. The GECO Project is an innovative EU-funded project which aims to provide clean, safe, and cost-efficient non-carbon and sulphur-emitting geothermal energy across Europe and the World. It builds upon the success of the recently completed CARBFIX project. This past project advanced considerably the ability to clean the exhaust gases emitted by geothermal power plants based on a novel water dissolution method in a dedicated scrubbing tower. By an industrial-scale demonstration, this new method has been demonstrated

1) to offer considerable cost savings compared to other approaches to capture and dispose of acidic carbon and sulphur-bearing gases;
2) to be far more environmentally friendly compared to other available technologies, and
3) to aid in the long-term viability of geothermal systems by enhancing the permeability of fluid injection wells.

The goal of the GECO Innovation Action is to adopt this approach, together with emission gas re-use schemes, to become a standard in the geothermal power industry worldwide through its application to three new sites across Europe. Moreover, the detailed monitoring and chemical modelling of this injection have provided novel insights into the reactions that occur in the subsurface in response to flowing fluids in geothermal systems. By consistently monitoring the reactions that occur in the four GECO field sites, each having distinct geology, we will be able to generalize these findings to create a tool for predicting the chemical behaviour of a large number of other systems before they are developed for geothermal energy. Such tools have the potential to decrease both the risk and the cost of future geothermal energy projects.

In addition to the above-mentioned projects, which focus on geothermal applications, the characterization, mapping, and understanding of the crustal thermal conditions need further improvements. The International Heat Flow Commission (IHFC) is developing and recommending standards and techniques for the determination of all parameters necessary for geothermal research, such as heat-flow density, thermal properties of geo-materials, underground temperatures, and quantification of geothermal energy resources. The IHFC oversees the Global Heat Flow database, which is under an extensive review and quality assessment.

6. EXPECTED DEVELOPMENTS

RePower EU, New Green Deal, Europe for 55, and other European Projects and Missions are making a great deal toward a secure, sustainable, and affordable energy supply for the near future, through a structural change of the economic and social development to meet climate ambitions.

Geothermal, together with the other RES, the waste heat locally available and the huge heat storage represented by the surface and groundwater masses and the coastal marine areas, has the potential to accelerate this change starting from the demand of H&C and hot water supply. AIRU estimated that the present 400 networks for DH distribute about 9.3 TWh/y (about 2.3 % of the national heat demand), but the potential for the deployment of DH systems is about 38 TWh.

The TTG highlighted the main barriers to a fully accomplished development, briefly listed here for district geothermal heating: leak of coherence in the legislative framework at the National level, need for stable rules and regulations, and need for complete planning at the Country level.

Electric power generation has a huge potential in Tuscany, Latium, Campania, and in parts of Sicily and Sardinia Island. Coastal areas and islands on the Tyrrhenian side are also excellent sites to consider for zero emission binary plants that could also be integrated with desalination infrastructures. The Geothermal Technical Table estimated that the realization of geothermal projects (by Enel GP and other operators of Rete Geotermica) presently under authorization, with permits in progress, or with lease just released, should be able to install about 240 new MW of electric capacity by 2030. The projects in pre-feasibility and feasibility phases could provide the installation of a further 120 MW capacity by 2035. Thus, a total of 360 MW (equivalent to about 3000 GWh) would represent an important contribution (3 %) to the total RES production capacity, foreseen by the Italian Government in about 100 TWh, mainly supplied by 70 GW installed capacity provided by wind and PV. In addition, geothermal shall be beneficial to the stabilization of the electric networks.

The main barriers identified by the TTG are the following: high initial capital costs, complex procedures and too long permitting timing for final authorization, leak of support, and incentives.

7. CONCLUSIONS

The paper has presented the development of geothermal applications in Italy during the 2017-2020 period, together with an updated status of R&D activities, and legislative framework and support measures (both ongoing and expected). The geo-power sector has maintained a good level with an installed capacity equal to 915.8 MW_e and an electricity production of 6.026 TWh without significant variations in the considered period. However, according to all the main industrial operators (EGP and Rete Geotermica), there is an unexploited potential in various Italian Regions (about 360 MW of electric capacity by 2035). The different operators are now working on several projects that are at different progress development (under authorization, permits in progress, permitting, pre-feasibility, and feasibility phases…). Concerning the heating and cooling sector, the total installed capacity is about 1300 MW_{th}, with the corresponding thermal energy use of about 9700 TJ/yr (~2700 GWh/y). Compared with 2017 data, the H&C sector has experienced a reduction of about 11 % in terms of geo-heat use, mainly due to the temporary closure of spa facilities imposed by the COVID-19 pandemic (-15 % in terms of heat delivery). On the contrary, the heating of buildings continues to grow at an average pace of 3 % per year, thanks to the continuous expansion of GSHPs and DH networks. Space heating confirms its leading position (49 % of the total geo-heat use) and the potential for the next years.

However, several actions must be undertaken, and several drawbacks must be overcome to support the geothermal development in Italy and the possible contribution to the ambitious targets of the energy transition, as declared by RePower EU, New Green Deal, Europe for 55, and other European Projects and Missions. Currently, the overall geothermal sector suffers from the lack of coherence in the legislative framework at the National and Regional levels, it needs for stable laws and regulations, together with comprehensive energy planning at the Country level. The current permitting phases are too complex and too long to be attractive for capital investments, and there is minor support and incentives for geothermal projects. UGI and AIRU, with the support of EGEC, settled the Tavolo Tecnico "Geotermia per la Transizione Energetica" (TTG) in February 2022 intending to coordinate and support all the geothermal stakeholders, investors, and decision-makers in giving value to the extraordinary geothermal potential of the country. In particular, TTG to act as a sound interface for policymakers, especially in the context of a new legislative and incentives framework (FER2) that should enable the development of innovative geothermal plants for the next five years.

REFERENCES

AIRU, Annuario 2021: sviluppo storico, situazione attuale e schede tecniche delle reti di riscaldamento urbano in Italia. *Edizioni Alkes*, Milano, (2022), pp. 404.

Bargiacchi E., Conti P., Manzella A., Vaccaro M., Cerutti P., Cesari G.: Thermal Uses of Geothermal Energy, Country Update for Italy, Proceedings of the World Geothermal Congress 2020, Reykjavik, Iceland. paper #001, 1-15. (2020).

Barelli, A., Cappetti, G. and Stefani, G.: Results of deep drilling in the Larderello- Travale-Radicondoli geothermal area. Proceedings of the World Geothermal Congress 1995, Florence, Italy, **2**, pp. 1275-1278, (1995).

Barelli, A., Bertini, G., Buonasorte, G., Cappetti, G. and Fiordelisi, A.: Recent deep exploration results at the margins of the Larderello Travale geothermal system. Proceedings of the World Geothermal Congress 2000, Kyushu-Tohoku, Japan, (2000).

Bertani, R., Bertini, G., Cappetti, G., Marocco, B.: An update of the Larderello-Travale-Radicondoli deep geothermal system. Proceedings of the World Geothermal Congress 2005, Antalia, Turkey, (2005).

Bertini, G., Cappetti, G., Dini, I. and Lovari, F.: Deep drilling results and updating of geothermal knowledge of the Monte Amiata area. Proceedings of the World Geothermal Congress 1995, Florence, Italy, **2**, pp. 1283-1286, (1995).

Cappetti, G., Parisi, L., Ridolfi, A. and Stefani, G.: Fifteen years of reinjection in the Larderello - Valle Secolo area: Analysis of the production data. Proceedings of the World Geothermal Congress 2000, Florence, Italy, **3**, pp. 1797-2000, (1995).

Cameli, G.M., Ceccarelli, A., Dini, I. and Mazzotti, A.: Contribution of seismic reflection method to the location of deep fractured levels in the geothermal fields of Southern Tuscany (Italy), Proceedings of the World Geothermal Congress 2000, Kyushu-Tohoku, Japan, (2000).

Cei, M., Montomoli, S. and Sartori, F.: Innovative Reservoir Management in Superheated Steam Geothermal System: Micro-reinjection and Push&Pull Production, Proceedings of the World Geothermal Congress 2020, Reykjavik, Iceland, (2020a).

Cei, M. and Lupi, M.: Numerical Simulation of a Steam Pipeline Network Using Dymola, Proceedings of the World Geothermal Congress 2020, Reykjavik, Iceland, (2020b).

Ciardi, M., Cataldi, R.: Il Calore della Terra, Edizioni ETS, Pisa, pp. 344. (2005).

Conti, P., Cei, M., and Razzano, F.: Geothermal Energy Use, Country Update for Italy (2010-2015), Proceedings of the European Geothermal Congress 2016, Strasbourg, France, paper #CU-17, 1-17. (2016).

Conti, P., Grassi, W., Passaleva, G., and Cataldi, R.: Geothermal Direct Uses in Italy: Country Update for WGC2015, Proceedings of the World Geothermal Congress 2015, Melbourne, Australia. #CUR-18b, 1-10. (2015).

EurObserv'ER: Heat Pumps Barometer, Brussels, (2021), pp. 7.

European Parliament and Council of the European Union, European decision 2013/114/EU: e establishing the guidelines for Member States on calculating renewable energy from heat pumps from different heat pump technologies pursuant to Article 5 of Directive 2009/28/EC of the European Parliament and of the Council, Official Journal of the European Union, 56, Brussels, (2013).

GSE – Gestore dei Servizi Energetici: Rapporto statistico 2020: Energia da fonti rinnovabili in Italia, Ed. GSE, Roma, (2022), pp. 176. Available at: https://www.gse.it/documenti_site/Documenti%20GSE/Rapporti%20statistici/Rapporto%20Statistico%20GSE%20-%20FER%202020.pdf

GSE: Tariffa incentivante ex Certificati Verdi, pubblicato il valore del parametro Re valido per l'incentivo 2021 (2021), Available at https://www.gse.it/servizi-per-te/news/tariffa-incentivante-ex-certificati-verdi-pubblicato-il-valore-del-parametro-re-valido-per-l-incentivo-2021

Huttrer, G.: Geothermal Power Generation in the World 2015-2020 Update Report, Proceedings of the World Geothermal Congress 2020, Reykjavik, Iceland. paper #001, 1-6. (2020).

Lund, J.W. and Toth, A.N.: Direct utilization of geothermal energy 2020 worldwide review, Geothermics, 90, (2021), 101915.

Manzella, A., Serra, D., Cesari, 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, The Hauge, Netherlands, #CU-16, pp 1-17. (2019).

Sabatelli, F., Mannari, M., Parri, R.: Hydrogen sulphide and mercury abatement: development and successful operation of AMIS technology, GRC Transactions, (2009).

Terna: Dati Statistici sull'Energia Elettrica in Italia - anno 2020 (2021), sez. Dati Storici, Available at https://www.terna.it/it/sistema-elettrico/statistiche/pubblicazioni-statistiche

TABLES A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	915.8 (915.8*)	5,917 (6,026*)	119,109*	280,531*	0.77*	2.1*
Under construction end of 2021						
Total projected by 2023						
Total expected by 2028						
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					In operation:	8
					Under development:	1
					Under investigation:	1

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Larderello	Valle Secolo	1991	2 (RI)	O	D	120.0	108.9	915.7
Larderello	Farinello	1995	1 (RI)	O	D	60.0	52.8	434.8
Larderello	Nuova Larderello	2005	1 (RI)	O	D	20.0	16.0	126.6
Larderello	Nuova Gabbro	2002	1 (RI)	O	D	20.0	18.2	153.9
Larderello	Nuova Castelnuovo	2000	1 (RI)	O	D	14.8	14.1	127.5
Larderello	Nuova Serrazzano	2002	1 (RI)	O	D	60.0	43.4	342.6
Larderello	Nuova Sasso	1996	1 (RI)	O	D	20.0	13.1	112.5
Larderello	Sasso 2	2009	1 (RI)	O	D	20.0	16.0	112.5
Larderello	Le Prata	1996	1 (RI)	O	D	20.0	18.4	122.8
Larderello	Nuova Monterotondo	2002	1 (RI)	O	D	10.0	7.5	53.3

Table B: Existing geothermal power plants, individual sites (continued)

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Larderello	Nuova San Martino	2005	1 (RI)	O	D	40.0	34.3	225.5
Larderello	Nuova Lago	2002	1 (RI)	O	D	10.0	10.1	64.8
Larderello	Nuova Lagoni Rossi	2009	1 (RI)	O	D	20.0	11.8	89.7
Larderello	Cornia 2	1994	1 (RI)	O	D	20.0	11.1	156.4
Larderello	Nuova Molinetto	2002	1 (RI)	O	D	20.0	13.4	118.6
Larderello	Carboli 1	1998	1 (RI)	O	D	20.0	15.3	131.3
Larderello	Carboli 2	1997	1 (RI)	O	D	20.0	15.3	136.4
Larderello	Selva	1997	1 (RI)	O	D	20.0	17.4	97.7
Larderello	Monteverdi 1	1997	1 (RI)	O	D	20.0	17.5	98.1
Larderello	Monteverdi 2	1997	1 (RI)	O	D	20.0	15.3	121.2
Larderello	Sesta	2002	1 (RI)	O	D	20.0	13.0	101.2
Travale-Radicondoli	Nuova Radicondoli Gr.1	2002	1 (RI)	O	D	40.0	36.4	222.1
Travale-Radicondoli	Nuova Radicondoli Gr.2	2010	1 (RI)	O	D	20.0	18.5	117.7
Travale-Radicondoli	Pianacce	1987	1 (RI)	O	D	20.0	13.0	72.2
Travale-Radicondoli	Rancia	1986	1 (RI)	O	D	20.0	18.2	124.7
Travale-Radicondoli	Rancia 2	1988	1 (RI)	O	D	20.0	18.2	117.1
Travale-Radicondoli	Travale 3	2000	1 (RI)	O	D	20.0	15.3	23.2
Travale-Radicondoli	Travale 4	2002	1 (RI)	O	D	40.0	36.6	212.1
Travale-Radicondoli	Chiusdino 1	2010	1 (RI)	O	D	20.0	18.5	141.9
Mount Amiata	Bagnore 3	1998	1 (RI)	O	1F	20.0	19.4	171.0
Mount Amiata	Gruppo Binario Bagnore3	2013	1 (RI)	O	B-OCR	1.0	1.0	4.3
Mount Amiata	Bagnore 4	2014	2 (RI)	O	1F	40.0	38.0	354.9
Mount Amiata	Piancastagnaio 3	1990	1 (RI)	O	1F	20.0	19.2	171.5

Table B: Existing geothermal power plants, individual sites (continued)

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Mount Amiata	Piancastagnaio 4	1991	1 (RI)	O	1F	20.0	19.2	169.7
Mount Amiata	Piancastagnaio 5	1994	1 (RI)	O	1F	20.0	19.2	171.5
total						**915.8**	**773.7**	**5917**

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
R	Retired / decommissioned	2F	Double Flash	O	Other

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units (in Italy, the listed plants reinject the liquid phase after the condensation section; some even apply the so-called "total re-injection", i.e. non-condensable gas included).

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	164*	238*	147*	221*	618*	1078*	387*	813*
Under constru-ction end 2021								
Total projected by 2023								
Total expected by 2028								

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Emilia Romagna	Bagno di Romagna (FC)	1983			1.4*	7.6*	2.5*	11%*
Toscana	Castelnuovo V.C. (PI)	1985 – 2015			12.0*	12.0*	32.9*	100%*
Toscana	Chiusdino (SI)	2019			12.0*	12.0*	1.7*	100%*
Toscana	Monterotondo M.mo (GR)	1995			6.4*	6.4*	6.4*	100%*
Toscana	Monteverdi M.mo (PI)	2015			6.0*	6.0*	6.3*	100%*
Toscana	Montieri (GR)	2014			6.0*	6.0*	3.9*	100%*
Toscana	Larderello (PI)	1996			5.0*	5.0*	6.5*	100%*
Toscana	Lustignano (PI)	1996			2.0*	2.0*	1.7*	100%*
Toscana	Montecerboli – San Ippolito (PI)	1996			5.5*	5.5*	9.8*	100%*
Toscana	Pomarance (PI)	2002			37.0*	37.0*	41.5*	100%*
Toscana	San Dalmazio (PI)	2002			1.5*	1.5*	1.7*	100%*
Toscana	Serrazzano – I Fani (PI)	1996			2.5*	2.5*	5.4*	100%*
Toscana	Radicondoli (SI)	2019			10.0*	10.0*	2.5*	100%*
Toscana	Santa Fiora (GR)	2006			17.2*	17.2*	21.4*	100%*
Toscana	Piancastagniaio (SI)	2017			2.4	2.4	0.5	100%
Emilia Romagna	Ferrara	1987			14.0*	153*	75.4*	34%*
Friuli Venezia Giulia	Grado (GO)	2016			2.3*	2.3*	0*	100%*
Lombardia	Milano	2010 – 2011			20*	938.2*	17.5*	1%*
Veneto	Vicenza	2013			1.0*	37.7*	0.05*	0%*
Total					**164.2***	**1264.3***	**237.7***	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

No data

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	16145*	807*/555*	1375*/946*	1242*	4*/3*	
Of which networks **						
Projected total by 2023						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

Capacity and Production values refer to both condenser and evaporator (COND/EVA). Only heating mode has been considered.

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

There are currently no shallow geothermal UTES plants in Italy.

Table F: Investment and Employment in geothermal energy Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	166.6	695	n.a.	n.a.
Geothermal direct uses				
Shallow geothermal				
total				

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	No	No	No
Financial Incentives – Investment	No (new incentive is expected in 2022-2023)	No	No
Financial Incentives – Operation/Production	No	No (only Tax relief, tax credit for increased efficiency in buildings)	No (only Tax relief, tax credit for increased efficiency)
Information activities – promotion for the public	Yes, in the Tuscany areas and by associations	Yes, in the Tuscany areas and by associations	Yes, from research projects and by associations
Information activities – geological information	Yes, in the Tuscany areas	Yes, in the Tuscany areas	
Education/Training – Academic	Yes, (in a few universities)	Yes (in a few universities)	Yes (in a few universities)
Education/Training – Vocational	No (only short courses organized by association)	No (only short courses organized by association)	No (only short courses organized by association)

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for Lithuania

Feliksas Zinevicius

Kaunas Regional Energy Agency, Breslaujos 3B, LT-44403, Kaunas, Lithuania

info@krea.lt

Keywords: geothermal resources, Klaipeda geothermal plant, radial water jetting, ground-source heat pumps.

SUMMARY

There is no new Country Update Report for Lithuania for EGC 2022, just some numbers updated. The report given for WGC 2020 (Zinevicius et al., 2020) is still valid and a short summary given here.

The main legal basis for geothermal energy growth is the new act "*National Energy Independence Strategy of the Republic of Lithuania*" (approved by the Seimas of the Republic of Lithuania on 21 June 2018).

Lithuania is situated in the western periphery of the East European Craton (EEC) that was consolidated during the Archean and Proterozoic eons. This type of geotectonic structure is characterized by a low intensity geothermal field owing primarily to a low tectonic activity. There is an exceptional high heat flow anomaly mapped in west Lithuania that is the most intense in the EEC. The heat flow is as high as 70-95 mW/m^2, while the background value of the craton is assessed at about 40 mW/m^2. The origin of the anomaly is related to the Middle Proterozoic hot granites hosted by the Lower Proterozoic metamorphic rocks composing the basement of the Baltic sedimentary basin. Some activity is also suggested below the Earth's crust of west Lithuania at the mantle level.

There are several large geothermal aquifers identified in the sedimentary pile of the basin. The Middle Cambrian and the Lower Devonian sandstones (Figure 1) are considered as the most prospective low enthalpy geothermal reservoirs. The temperatures reach 70-95 °C and 35-45 °C in the Cambrian and Devonian aquifers, respectively, with depths respectively about 2 km and 1 km. Also, the Middle Devonian reservoir (30-35 °C) is considered as a prospective body when combined to the balneological applications.

The information on the situation of Klaipeda geothermal demonstration plant (KGDP, Figure 1) is presented in detail in Zinevicius et al. (2020), with a short summary below. The growth of installed capacity of ground-source heat pump (GSHP) systems was also presented in that paper, complemented by two case studies representing good practice examples of Lithuania (logistics centre of SANITEX in Riga, 700 kW heat pump ground source system with a field of 77 borehole heat exchangers each 150 m deep under the building, and the first re-circulating marine aquaculture system for shrimp cultivation with eight tanks of 38 m^3 total water volume). The GSHP development is also summarised below.

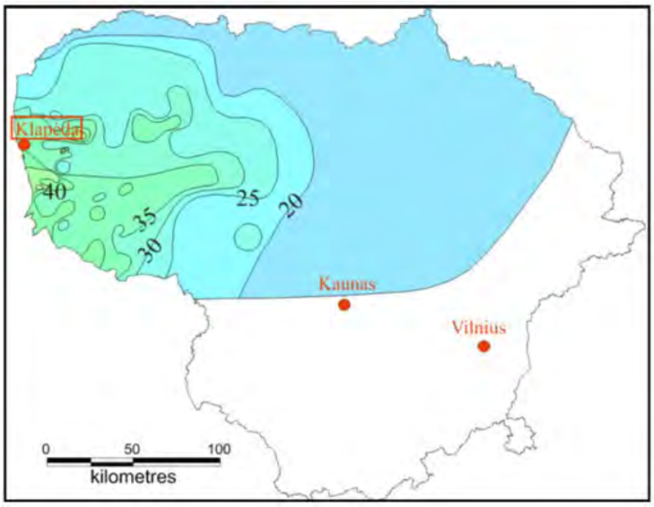


Figure 1: Temperatures of the Lower Devonian geothermal aquifer (with location of the Klaipeda geothermal plant shown in the red box).

Klaipeda Geothermal Demonstration Plant (KGDP)

Usage of geothermal resources for district heating started in Klaipeda in 2000. The absorption heat pumps use lithium bromide (LiBr) solution. Low-temperature geothermal heat is extracted from geothermal water of the Devonian aquifer. Plant capacity is confirmed by the State Commission to 35 MW$_{th}$ (13.6 MW$_{th}$ for the geothermal part). KGDP allowed to work on solutions for the difficulties of injection, but at the same time was struggling on the market. As a result, operation in the period from 2013 to 2017 was only during the heating season. Due to an unfavourable economic environment and ongoing problems with injection of used geothermal water, the operation of Klaipeda geothermal plant was stopped in the year 2017 (Figure 2). We hope that the problems faced by this plant will be solved and this pioneering installation will resume operation, serving for research and education purposes.

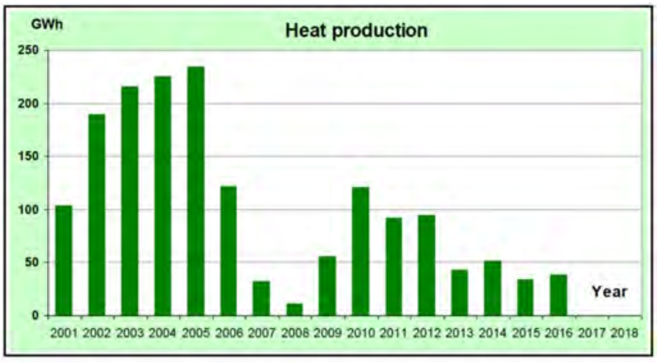


Figure 2: Heat production of KGDP in the period from 2000 to 2018.

Small-Scale Ground Source Heat Pumps (GSHP)

The number of small-scale ground source heat pump systems in Lithuania is growing. At present, there are nearly 11'000 installations thanks to such private enterprises as UAB Ekoklima, UAB "Naujos idejos", UAB "Tenko Baltic", UAB "EES", UAB "Vilpra", UAB "Ekokodas", UAB "Steltronika", UAB "Geoterminis sildymas", UAB "Ardega", UAB "Kauno hidrogeologija". The Lithuanian Geothermal Association is proud of its corporate members, like UAB "Donasta". The total installed capacity is now almost 140 MW (Figure 3).

Figure 3: Total capacity of installed small-scale GSHP systems.

REFERENCES

Zinevicius, F., Sliaupa, S., Mazintas, A., Nika, N.: Geothermal Energy Country Update - Lithuania. Proc. WGC 2020, 12p, Reykjavik, Iceland (2020). https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01069.pdf

Tables A-G

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *								
Under constru-ction end 2021								
Total projected by 2023								
Total expected by 2028	18	50						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

NB: The reopening of Klaipeda geothermal plant is expected.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	10’647	138.2	314.3			
Of which networks **						
Projected total by end of 2023	12’153	160.0	360.0			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power				
Geothermal direct uses		1		
Shallow geothermal	5.06	188		
total	5.06	189		

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D			
Financial Incentives – Investment			DIS (%) *
Financial Incentives – Operation/Production			
Information activities – promotion for the public	Yes	Yes	Yes
Information activities – geological information	Yes	Yes	Yes
Education/Training – Academic	Yes	Yes	Yes
Education/Training – Vocational	No	No	Yes

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

* In the frame of the Program "*Replacing outdated and worn-out boilers with new and efficient biofuel-powered boilers*", in the period from year 2019 to 2022 the sum of 4'540'670 EUR is allocated for 745 geothermal heat pump installation with total capacity 9321 kW.

Geothermal Energy Use, Country Update for The Netherlands

Melanie Provoost[1] and Frank Agterberg[2]

[1] Geothermie Nederland, Anna van Buerenplein 41, 2595 DA, Den Haag, The Netherlands

[2] Branchevereniging bodemenergie, Gooimeer 4-15, 1411 DC, Naarden, The Netherlands

melanie.provoost@geothermie.nl , info@bodemenergie.nl

Keywords: Geothermal energy, geothermal heat, underground energy storage, aquifer thermal energy storage (ATES), bore hole thermal energy storage (BTES), ground sourced heat pumps (GSHP), deep geothermal, high temperature storage.

ABSTRACT

This article deals with the Dutch market and policy developments in the domain of geothermal energy. It includes deep geothermal energy (DGE) and shallow geothermal energy (SGE), including underground thermal energy storage (UTES) and ground source heat pumps (GSHP). There are currently 31 DGE project locations, with an approximate total capacity of 6.4 PJ. UTES totalling some 3000 ATES and 65’000 BTES systems contributed some 5.3 PJ to renewable heating in 2020, growing at 7-8 % annually (CBS, 2020 and Vereniging Warmtepompen, 2020). The majority of SGE-systems comply with legal environmental requirements to not exceed 25 °C. However, the interest in medium-temperature (MT-) and high-temperature (HT-) ATES (30 – 90 °C) is growing and new pilots are in progress. By January 2023 a new Mining Act will be implemented for DGE projects, whereby policy and law is better suited to geothermal activities. Despite legally required protocols and a certification scheme for SGE-systems, regional and local governments distrust compliance and increasingly apply more stringent and thus limiting requirements such as depth restrictions and/or circulation fluid criteria.

1. INTRODUCTION

This article deals with the geological background of the Netherlands, Dutch developments, status quo and policies in the domain of geothermal energy. It includes deep geothermal energy (DGE) and shallow geothermal (SGE) (including underground storage (UTES) and ground source heat pumps (GHPS)). Section 2 of this article deals with the status 2019 and 2020, i.e. the actual figures for shallow geothermal energy (SGE)-installations and an overview of the field of stakeholders. Section 3 briefly presents the history and policy backgrounds, while Section 4 attempts to forecast some developments and funding. Each section will discuss the developments for direct use geothermal and shallow geothermal in separate subsections.

2. STATUS GEOTHERMAL ENERGY 2021

2.1 Deep geothermal energy

Geological Background

Due to a long history of oil and gas production, a lot of information is available on the subsurface, and yet still a lot is unknown, especially on the potential of geothermal energy. The ministry of Economic Affairs and Climate financed a seismic survey of “blanks spots” carried out by EBN in partnership with TNO, to map the subsurface where there is still uncertainty, prioritized based on areas with the highest demand for heat and developed into an updated, public and easily-accessible database (ThermoGIS) by TNO. This project is called SCAN (Seismic Campaign for Geothermal Energy in the Netherlands) and the figure below (Figure 1) shows which data is already available and where the “blank spots” are located. (EBN, TNO, 2019).

Projects

In 2021, 31 deep geothermal project locations are operational and are saving 342’000 tonnes of CO_2 and 181 million m^3 gas. A lot of geothermal projects are under development and working on a financial closure and seeking potential heat consumers. Though, in different phases of development over 70 projects are in development towards 2030, in both the horticulture sector and the built environment. Of these projects, 19 new projects already have a Stimulation of Sustainable Energy Production and Climate Transition (SDE++) subsidy or a predecessor and working towards the start of heat production.

There is an increasing interest in DGE in the built environment, but there are still political, financial, and social barriers that prevent these projects from developing. Public acceptance is increasingly becoming a more important topic to address. Most projects are operational between 2000 and 3000 m deep (Geothermie Nederland, 2022). One shallow geothermal project (27 °C, 600 – 700 m-bs) has been realised at Zevenbergen (IF Technology, 2019). This is the first project using horizontal wells drilled by Geothermal Directional Drilling technique.

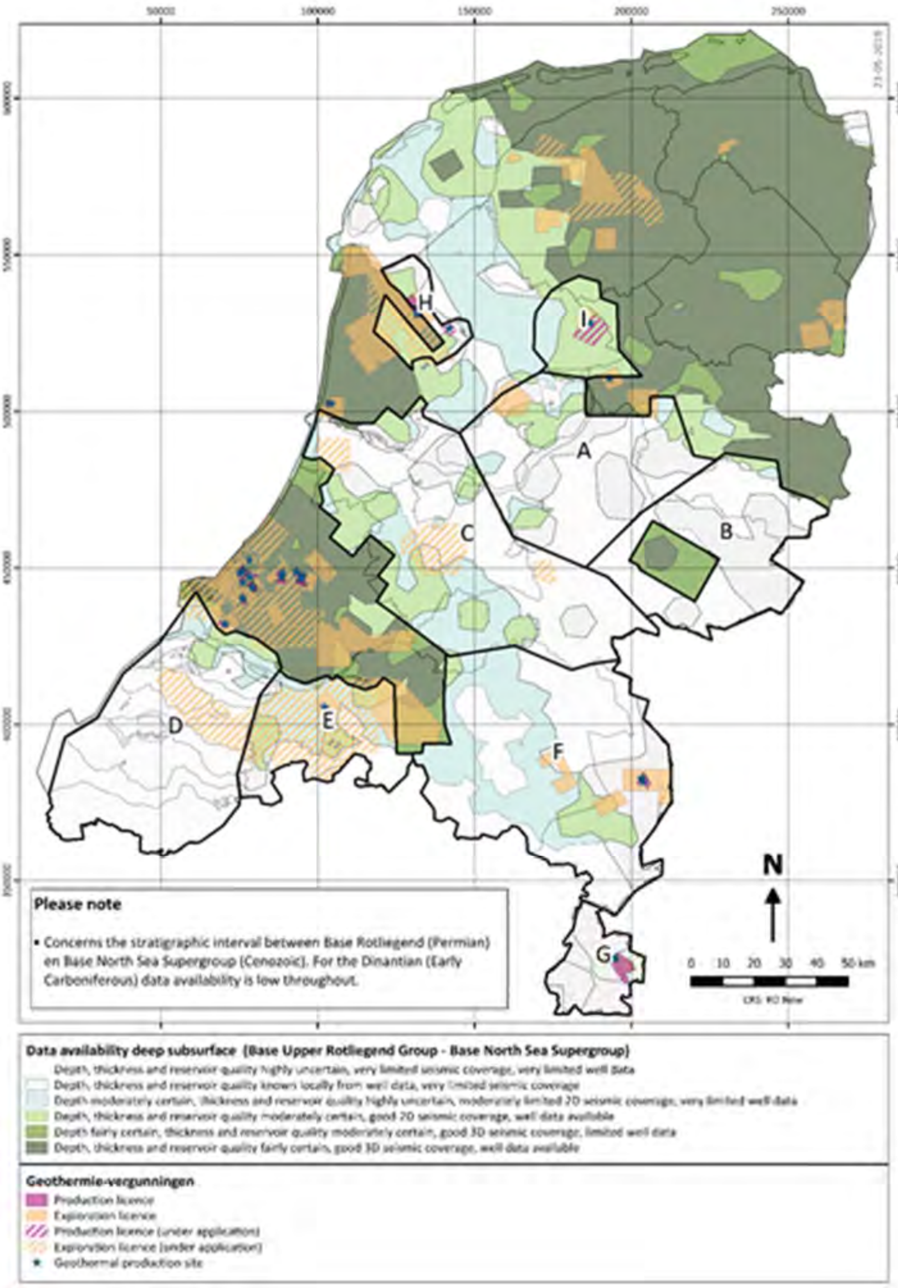


Figure 1: Seismic data for The Netherlands.

2.2 Shallow Geothermal energy

Shallow geothermal energy systems use Underground Thermal Energy Storage (UTES) as source of ‘free’ environmental thermal energy and use ground-based Heat Pumps (GSHP) to increase ambient temperatures to temperatures enabling heating of the indoor climate and/or domestic hot water (DHW). UTES systems are ‘charged’ by cooling buildings and storing the ‘collected luke-warm heat’ in open (aquifer thermal energy storage (ATES)) or closed-loop (borehole thermal energy storage (BTES)) systems. Typical temperature ranges for storing energy in open systems are between 5 and 17 °C. The lower end of this temperature range can be used for direct (passive) cooling, the higher temperature will be used as thermal source for heat pumps to increase the temperature to 40-60 °C to be used for heating purposes.

Figure 2 shows the development of deep and shallow geothermal heat and cold which is yearly abstracted from 1990 to 2019. In the first 20 years, the heat and cold supply were almost in balance. Most of the systems were applied for buildings like offices, hospitals and shopping malls. These buildings need heat and cold. The strong increase of the heat delivery by SGE systems from 2006 on can be explained by the use of this technology in residential areas, where almost only heat is required.

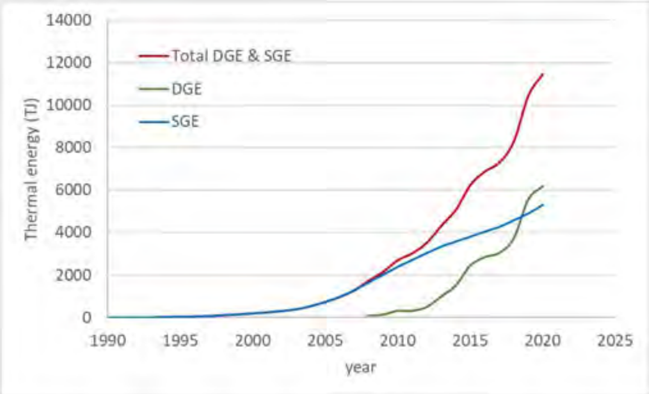


Figure 2: Total thermal energy from deep and shallow systems in use.

Fast growth in ATES- and BTES-systems is expected to continue due to their much needed contribution to reach climate policy objectives, but also because it is an economically attractive alternative to traditional heating and cooling techniques.

Figure 3 shows the annually added thermal energy of SGE (ground-based heat pump systems) in the internal climate regulation of buildings.

Currently the SGE share is 25 % and, whilst growing rapidly, is competing with other, mainly air-sourced, heat pump systems taking a larger share of growth. Figure 4 shows some detailed developments within ground-based systems' growth.

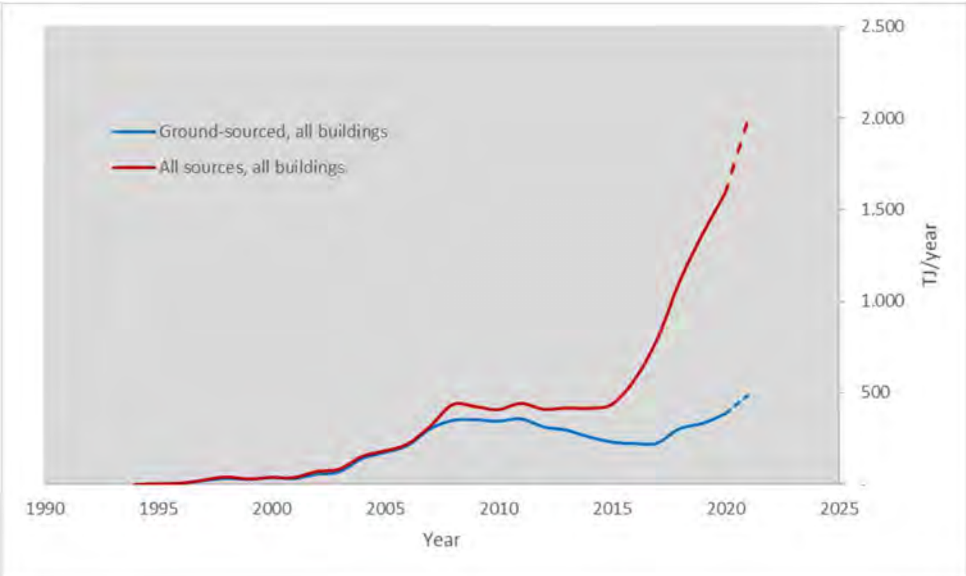


Figure 3: Annual addition of contribution from SGE systems.

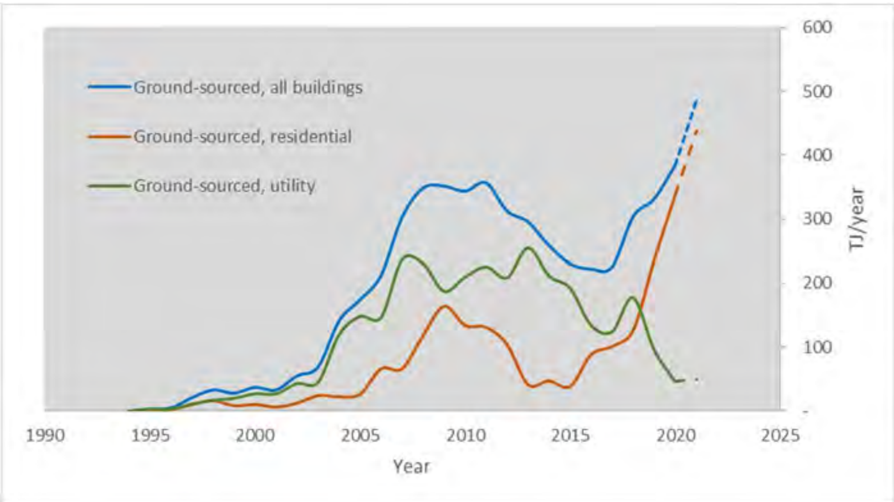


Figure 4: Annual addition of contribution from SGE systems in residential and utility buildings.

Two relatively recent policy measures and a societal trend have led to a boost in new ATES- and BTES-systems. The policy measure with largest impact was the releasing of mandatory connection to the public gas-grid for all new buildings from July 2018 to instrumentalize an overall policy of phasing-out the extraction and use of natural gas. A second measure was an Investment Subsidy for Individual sustainable energy measures (ISDE) which included GSHP. The subsidy scheme was introduced in 2016 which clearly boosted the residential market (see also section 3.2 below). Extraction of natural gas from the Dutch Groningen site was limited due to increasing earth quakes resulting from gas-mining; reduction of the use of natural gas is being limited to reduce climate change and thereby contribute to the Dutch share of the Paris' agreement. This has given rise to huge market opportunities in the geothermal market. UTES systems with heat pumps are regarded as a suitable alternative for gas-fired boilers. And their ability for passive, i.e. for free, cooling is very attractive from both an economic as well as a comfort perspective. The societal trend stimulating UTES is the increasing need for cooling for safety and comfort in increasingly well insulated – thus hot – buildings. Figures 3 and 4 show the resulting additional growth following these measures and trends.

Medium- and High-temperature thermal energy storage - MT/HT-ATES

There is an ever-increasing interest for higher-than 'normal' UTES, i.e. medium and high-temperature storage (MT/HT-ATES). High temperature storage is a storage technique, comparable with ATES, but the storage temperature varies from 30 to 90 °C. High temperature storage is suitable at locations with excess heat or an expected high demand for heat. It is often combined in cascading high-temperature heat from deep geothermal wells, where the HT-ATES is charged with geothermal heat during summer time and able to add additional heat capacity in winter time. HT-ATES is also often combined with solar heat collectors. HT-ATES is increasingly seen as an opportunity for residential or horticultural purposes. However, the legal framework still formally does not allow for temperature storage over 25 °C. Necessarily all projects are full-scale demonstration projects to investigate the impact of high temperatures on aquifers. Dutch participation in the European HEATSTORE project will help to develop technical improvements in the high temperature storage technique and to develop a suitable legal framework to both allow for higher temperatures as well as protect the subsoil environment.

HT-ATES with storage temperatures >30 °C has only been implemented in a few projects in the past. The first relevant HT-UTES project in the Netherlands was installed in the Beijum district in Groningen (1985: storage of 60 °C solar heat using BTES). The first HT-ATES projects were made at Utrecht University (1991: storage of 90 °C heat from a CHP installation using ATES) and a health care institution in Zwammerdam in the late nineties (storage of 90 °C heat from a CHP installation using ATES). Furthermore, four medium (<50 °C) temperature storage systems were built in the last 15 years.

The measured recovery efficiency for all the HT-ATES is often lower than designed. The main reason is that the storage temperatures (warm well, cold well and cut-off temperatures) have in many cases not been well fitted to the building system or the other way around: the heating system in the building was not adapted to the extraction temperatures from the heat store (Bakema et al, 2019). Besides better system integration, HT-ATES should have a storage volume of at least 250'000 m^3 to obtain a thermal efficiency of 70 %.

Despite the low interest in HT-ATES systems in the past, the interest is growing rapidly at the moment. Actual HT-ATES systems are running at Koppert-Cress (Monster) and at the NIOO institute in Wageningen. In 2020 a new HT-ATES (storage temperature 90 °C) was constructed at ECW Middenmeer and was taken into operation in the second quarter of 2021. This project stores surplus heat of geothermal wells to be used for heating greenhouses in winter time (IF Technology, 2018; Drijver et al. 2020).

For 2021 and beyond, new HT-ATES projects are planned. One of these projects is the HT-ATES Bergenden project in Lingewaard, where in 2020 a test drilling has been done.

3. POLICY DEVELOPMENT

3.1 Policy Developments for deep geothermal energy

The main trends in geothermal energy policy in recent years were a) a new Mining Act, b) an adjusted subsidy scheme with more and different opportunities for geothermal energy in 2022 and 2023, c) publication of a report on the acceleration of geothermal energy in the built environment.

The Mining Act will be effective from 2023 onwards. With the adjustments in the Mining Act, this law and regulations are better suited for geothermal activities. The Minister of Economic Affairs and Climate has given EBN (Energie Beheer Nederland: a state-owned company focussing on underground activities) the option to voluntarily participate in geothermal projects until the entry into force of the Mining Act in 2023. When the Mining Act comes into force, EBN can financially participate for 20 to 40 % in geothermal energy projects as a non-operating partner. The role of EBN will be evaluated within three years after the implementation of the Mining Act (Behandeling Mijnbouwwet, 2022). EBN will become a knowledge partner for the geothermal sector in order for the sector to grow based on data gathering and knowledge sharing.

The main policy instrument for deep geothermal in the Netherlands is the SDE++ (Stimulation of Sustainable Energy Production and Climate Transition (SDE++) subsidy, a Feed-in-premium instrument based on technologies competing on the basis of avoiding CO_2 and successor of the SDE+). The SDE++ conditions gradually improved in recent years, both in terms of the contribution per kWh, diversity in categories and in terms of scope of the regulation (to include triplets and 'dual play' wells - gas and geothermal). The policy instruments certainly encouraged increases in capacity and production levels of new plants. However, the main goal was to increase the number of new projects from roughly two doublets per year to five to ten. These efforts were frustrated by financing difficulties, the upcoming Mining Act, regional energy developments and slow permitting.

The ministry of Economic Affairs and Climate initiated a so-called acceleration trajectory with the geothermal sector to identify the main issues for growth in the urban environment and develop a call for action on three themes: business case, public acceptance and governance. The geothermal sector and the ministry are working together to develop actions and goals on the three themes. The report offers a realistic position for geothermal by aiming at removing the bottlenecks in legislation and regulations and by focussing more on public acceptance in the built environment.

The Green Deal Ultra Deep Geothermal Energy has ended. The consortium partners are investigating the possibility for a pilot drilling (Green Deals, 2018).

3.2 Policy Developments Shallow Geothermal energy 2015-2021

ATES is economically feasible for the medium to large utility buildings' sector (RVO, 2016) and besides some tax advantages (an Energy Investment tax deduction scheme) has no subsidies. To promote SGE in the housing sector, a new subsidy scheme for heat pumps was introduced in 2016 as was described in section 2.2. above. The main policy instrument for SGE, mostly BTES-sourced, in the Netherlands thus remains the ISDE. As of 2022 subsidies have increased 1.5-fold to speed up the energy transition. It was mentioned already that air-source heat pumps are competing fiercely with GSHP.

Dutch government had already set a target at zero CO_2 emission in 2050 for the heating of residential and utility buildings. In addition to the 'wijkenaanpak' to renovate all 14'000 districts of the current Dutch 344 municipalities, a more individual and step-wise approach was added to allow for individual initiatives. One initiative is to promote hybrid heat pump systems for base-load heating combined with a natural gas-powered boiler for peak capacities and for domestic hot water which may hinder GSHP roll out. Generally it may be expected that in renovation of existing buildings air-source heat pumps will be favoured over GSHP. The latter should continue to fight their market share.

Furthermore, the government invests in research in the field of high temperature storage. The current policy limits the maximum ground storage temperature to 25 °C, but storing at higher temperatures would offer an increased capacity for heat storage in SGE systems, thus also allowing cascading heat from higher temperature sources such as DGE. Besides the international program HEATSTORE a national program WINDOW is running. The WINDOW project includes the realisation of two or three additional HT-ATES projects and a new legal framework for HT-ATES.

A critical note needs to be made, unfortunately. Despite legally required protocols and a certification scheme for SGE-systems aimed at securing their performance as well as protecting the subsoil and groundwater, regional and local governments distrust compliance and increasingly apply more stringent, thus limiting, requirements such as drilling depth restrictions and/or circulation fluid criteria. However understandable from an environmental protection point-of-view, such measures counteract stimulation measures and thus yield serious barriers to scale up. The uncertainties prevent UTES companies from investing in their production capacity.

4. FUTURE POLICY DEVELOPMENTS >2022

A future policy development for the geothermal sector is, among others, the Environment and Planning Act – a simplification of all environmental and planning legislation in a single Act. The Act will replace 15 existing laws, including the Water Act, the Crisis and Recovery Act and the Spatial Planning Act. The Act will take effect in 2023.

After years of work the Mining Act is adopted by the house of representatives. Currently, lower regulations are developed together with a practical translation of policy and law. The Mining Act will take effect in 2023.

The Heating Act was for consultation in 2020 and aims to facilitate the anticipated greater role of heat networks in the Dutch heat supply and to set criteria to the sustainability of heat networks. The Act is still under construction.

National and local governments will work on regional energy strategies, a partnership for spatial integration of the energy transition in 30 Dutch regions. This includes a translation of the Agreement on Energy for Sustainable Growth and the over 600 measures of the Climate Agreement. This is expected to accelerate the increase of geothermal projects and combinations with high temperature storage and aqua thermal energy.

5. CONCLUSIONS

As this country update illustrates, geothermal energy in the Netherlands sees conducive developments within the national energy and climate policies. The total capacity of DGE projects and SGE installations is increasing at a steadily high pace. Research and innovation is being executed to advance the field including standardization for scaling up at a pace required to meet policy targets in 2030 and beyond.

Both the horticulture sector and the built environment are upping their case in deep and shallow geothermal energy as well as in medium- and high-temperature thermal energy storage for cascading heat. Research will indicate the ecological impact of high temperature groundwater in high temperature storage systems and should lead to a new legal framework conducive for MT- and HT-ATES.

Future policy developments are necessary to provide the geothermal energy sector with clear policy rules to make the estimated growth of projects possible. Geothermal heat as an alternative for natural gas is growing and a recurring topic in regional energy strategies of municipalities and regions.

The total number of UTES systems in the Netherlands is growing at some 8 % annually, in which the residential market dominates the utility sector. High temperature storage would be particularly interesting as heat buffer in a district heating or DGE networks for large scale heating purposes as residential areas or horticultural areas.

REFERENCES

CBS: Statline, Geothermal energy and energy storage (Aardwarmte en bodemenergie). https://opendata.cbs.nl/statline. (2022).

Geothermie Nederland, 2021: project data DGE projects, February 2022.

Energiebeheer Nederland (EBN).: Onderzoek mogelijkheden Ultradiepe aardwarmte in Nederland gaat van start, (2018).
Retrieved December 2018 from www.ebn.nl.

Netherlands Enterprise Agency.: Stimulation of Sustainable Energy Production (SDE+), (2018).
Retrieved January 2019 from www.rvo.nl.

Dutch Association Geothermal Operators, Stichting Platform Geothermie, Stichting Warmte-netwerken, Energiebeheer Nederland.: Masterplan Aardwarmte in Nederland.
Retrieved June 2019 from www.geothermie.nl.

Rijksoverheid: Aardgasvrije wijken, October 2018. retrieved January 2019 from: www.rijksoverheid.nl.

Rijksoverheid: Environment and Planning Act / Omgevingswet, (2019).
Retrieved April 2022 from: https://www.rijksoverheid.nl/onderwerpen/omgevingswet.

Netherlands Enterprise Agency: Startdocument Roadmap Bodemenergie, (2016).
https://www.rvo.nl/sites/default/files/2017/04/2016%20Startdocument%20RM%20BE_vertaald_def.pdf

Netherlands Enterprise Agency: geothermieproductie 2019,
retrieved June 2019 www.rvo.nl.

Tables

The standard tables as in the template for the EGC 2022 country update reports could not be provided, thus a set of similar tables is provided here.

Table 1: Summary table of Geothermal Direct Heat Uses as of 31st December 2019

Use	Installed Capacity [MW_{th}]	Annual Energy Use [TJ/yr = 10^{12} J/yr]	Capacity Factor
Individual Space Heating			
District Heating			
Air Conditioning (Cooling)			
Greenhouse Heating	230	5564	
Fish Farming			
Animal Farming			
Agricultural Drying			
Industrial Process Heat			
Snow Melting			
Bathing and Swimming			
Other Uses (specify)			
Subtotal			
Geothermal Heat Pumps	1600	4870	
Total	**1830**	**10’434**	

Table 2: Utilisation of Geothermal Energy for Direct Heat as of 31st December 2019 (other than heat pumps)

Locality	Type	Maximum Utilization						Annual Utilization		
		Flow Rate [kg/s]	Temperature [ºC]		Enthalpy [kJ/kg]		Capacity [MW$_{th}$]	Ave. Flow [kg/s]	Energy [TJ/yr]	Capacity Factor
			Inlet	Outlet	Inlet	Outlet				
Heerlen	D						3.15		?	
A&G van den Bosch I Lansingerland	G						6.1		194.4	
A&G van den Bosch II Lansingerland	G						4.3		151.2	
Venlo/Grubbenvorst	G						11.2		162	
Pijnacker Ammerlaan	G						6.9		0	
The Hague / Aardwarmte Den Haag	G						0		0	
Green Well Westland	G						11.4		162	
Koekoekspolder / Kampen	G						7.4		0	
Pijnacker Duijvestijn	G						8		0	
Floricultura Heemskerk	G						5.5		0	
ECW I Agriport Middenmeer	G		91	35			16		403	
ECW II Agriport Middenmeer	G		91	35			9		227	
ECW III Agriport Middenmeer	G		91	35			16		403	
VoF Geothermie De Lier	G						16		478.8	
Vierpolders	G						15.7		0	
Venlo/Grubbenvorst	G						10.6		0	
Aardwarmte Vogelaer	G						10.2		424.8	
Maasland Geopower Exploitatie B.V.	G						13.2		0	
Bergschenhoek Wayland Energy	G						9.9		97.2	
Kwintsheul Nature's Heat B.V.	G						17		0	
ECW III Agriport Middenmeer	G						14.9		82.8	
Hoogweg Aardwarmte Luttelgeest	G						30.3		0	
Greenbrothers Zevenbergen	G						8.2		0	
ECW Geo Andijk I	G		81	35			15		378	
ECW Geo Andijk II	G		81	35			15		378	
Trias Westland	G						20			
Total							**300.95**		**3542.2**	

D: District Heating G: Greenhouses

Table 3: Wells drilled for Electrical, Direct and Combined Use of Geothermal Resources from 1st January 2015 to 31st December 2019 (excluding heat pump wells)

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other	
Exploration	(all)					
Production	>150 °C					
	150-100 °C					
	<100 °C		20			50
Injection	(all)		20			50
Total			**40**			**100**

Table 4: Total Investment in Geothermal in US$ (2019 value)

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999						
2000-2004						
2005-2009						
2010-2014			200			
2015-2019			300			

European Geothermal Congress 2022
Berlin, Germany | 17-21 October 2022
www.europeangeothermalcongress.eu

Geothermal Energy Use, Country Update for North Macedonia

Sanja Popovska-Vasilevska[1], Sevde Stavreva[1]

[1] St.Kliment Ohridski, Faculty of Technical Sciences-Bitola, Makedonska falanga 37, 7000 Bitola, N. MACEDONIA

sanja.popovska-vasilevska@tfb.uklo.edu.mk

Keywords: geothermal energy, country update.

ABSTRACT

North Macedonia is characterized with low-temperature geothermal energy utilization, while the medium and high-temperature potentials are still not explored. Nevertheless, even the present available resources are by far underutilized.

This paper gives a summary of the geothermal status in North Macedonia comprising the geological background, known hydro-geothermal resources and their potential, present state of geothermal surveys & utilization and main projects' characteristics, with identification and comments on the negatively influencing factors. At the end, prospects of the expected / possible development are summarized.

1. INTRODUCTION

The overall geothermal status in N. Macedonia has not changed during the last three years. Even though not formally registered, the interest and interventions in obtaining and using the benefits of geothermal resources are obvious. Power generation from geothermal energy is not yet present, but there are indications of foreign interest to explore and utilize such potential. Concerning legislation and regulative on promotion, exploration, development and protection of geothermal resources, no any progress can be observed.

2. GEOLOGICAL BACKGROUND

2.1 Geological Framework and Tectonic Settings of Macedonia (Micevski, 2003)

In the territory of Macedonia rocks of different age occur, beginning with Precambrian to Quaternary ones. Almost all lithological types are represented. The oldest, Precambrian rocks consist of gneiss, micaschists, marble and orthometamorphites. The rocks of Paleozoic age mostly belong to the type of green schists, and the Mesozoic ones are represented by marble limestones, acid, basic and ultrabasic magmatic rocks. The Tertiary sediments consist of flysch and lacustrine sediments, sandstones, lime-stones, clays and sands.

Figure 1: Geological settings and geothermal regions in Macedonia (Arsovski, 1997).

With respect to the structural relations the territory can be divided into six geotectonic units (Fig. 1): The Cukali-Krasta zone, Western-Macedonian zone, Pelagonian horst-anticlinorium, Vardar zone, Serbo-Macedonian massif and the Kraisthide zone. This tectonic setting is based on actual terrain and geological data without using the geotectonic hypothesis (Arsovski, 1997). First four tectonic units are parts of Dinarides, Serbo-Macedonian mass is part of Rodopes and the Kraisthide zone is part of Karpato- Balkanides distinguished on the Balkan peninsula as geotectonic units of first stage.

2.1 Geothermal Background (Georgieva, 2002)

The territory of the Republic of N. Macedonia belongs to the Alpine-Himalayan zone, with the Alpine sub-zone having no contemporary volcanic activity. This part starts from Hungary, across Serbia, Macedonia and North Greece and stretches to Turkey. Several geothermal regions have been distinguished including the Macedonian region, which is connected to the Vardar tectonic unit. This region shows positive geothermal anomalies and is hosting different geothermal systems. The hydro-geothermal systems, at the moment, are the only ones worth exploration and exploitation.

There are 18 known geothermal fields in the country (Fig.2) represented with more than 50 thermal springs, boreholes and wells with hot water, having discharge of about 1000 l/s with temperatures between 20-79 ºC. Hot waters are mostly of hydrocarbonate nature, according to their dominant anion, and mixed with equal presence of Na, Ca and Mg. The dissolved minerals range from 0.5 to 3.7 g/l.

All thermal waters in Macedonia are of meteoric origin. Heat source is the regional heat flow, whose value in the Vardar zone is approximately 100 mW/m^2 and crust thickness is 32 km.

3. GEOTHERMAL RESOURCES AND POTENTIAL

Out of the seven geothermal fields identified in the east and northeast part of the country, four have been found to be very promising and three have been explored to the stage of possible practical use. Except the springs in Debarska banja and Kosovrasti, positioned in the West Bosnian-Serbian-Macedonian geothermal zone, all the others are located in the Central Serbian-Macedonian Geothermal Massif, Central and Eastern Macedonia (Figure 2).

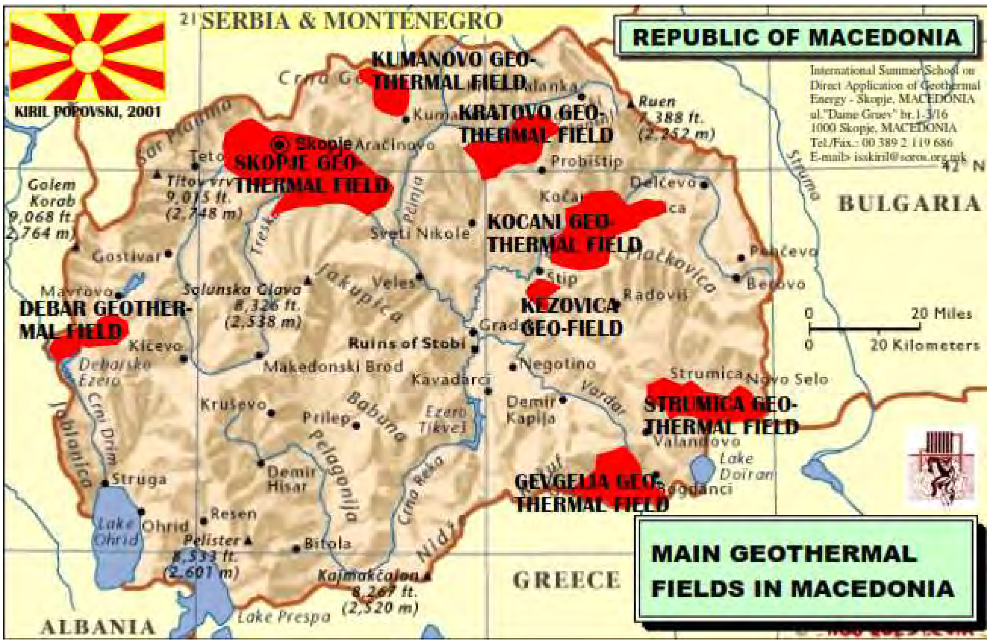


Figure 2: Main geothermal fields in N. Macedonia (Popovski, 2001).

It should be emphasized that the total available flow of the exploitable sources is 922.74 l/s, which is less than the estimated 1000 l/s 7 years ago, and differs from the previous values (1397 l/s) that are the maximum measured short-lasting flows. The difference is due to the more precise data for long lasting capacities of all the flows, after many years of exploitation and measurements.

Temperatures of the flows vary in the range of 24-27 °C (Gornicet, Volkovo and Rzanovo) up to 70-78 °C (Bansko and Dolni Podlog). Total average temperature is 59.77 °C. The biggest potential is in the Kocani geothermal field, with a total maximal flow of up to 350 l/s and temperatures of 65 °C (Istibanja) and 75-78 °C (Dolni Podlog). Next is the Gevgelija geothermal field, with about 200 l/s and temperatures of 50 °C (Negorci) and 65 °C (Smokvica). The list of the others is: Debar geothermal field with 160 l/s and temperatures of 40 °C (Debarska banja) and 48 °C (Kosovrasti), Strumica geothermal field with 50 l/s and 70 °C and Kratovo/Kumanovo geothermal field with 71 l/s and temperatures of 31 °C (Kumanovska banja) and 48 °C (Kratovo).

The real energy potential of the geothermal resource in Macedonia is in direct correlation with the technical/technological feasibility of its application, in accordance to the newest know-how in the country and in the world. A simulation, according to different outlet temperature, is made for all the exploitable geothermal resources in Macedonia. A total available maximum heat power of 173 MW is obtained, which suggests the possibility of annual maximum production of 1.52 TWh/year. This is only a theoretical indication considering that each project has different range of exploited temperature. In any case this maximum potential cannot be fully exploited, since it is strongly dependent on the utilization factor and the type of application. For instance, the geothermal system in Dolni Podlog (Kocani) has a maximum flow of about 300-350 l/s with temperature of 75 °C. If a maximal use of the source could be reached (i.e. effluent water of 15 °C), its heat power could increase up to 75-85 MW. However, the applied technical solutions by the users result with temperatures of the effluent water of 40-45 °C during the (winter) heating season. These in turn decreases the heat power of the source to 37.7-44.0 MW, i.e. 40-50 % of the maximally possible one. For the same geothermal system and composition of users, it is technically and economically feasible to obtain lower temperature of the effluent water of 30 °C during the first phase of development (Popovski, 1991), and 25 °C during the second phase of development. Such optimization would enable reduction of the losses for 25 % and 17 % respectively, which is in the acceptable limits even for the countries with longer experience in geothermal energy application. Therefore, depending on the achieved average outlet temperature of projects using available geothermal resources, the following orientation figures for total heat power could be taken: 172.9 MW for 15 ºC, 153.7 MW for 20 ºC, 134.3 MW for 25 ºC, 115.6 MW for 30 ºC, 97.2 MW for 35 ºC, 78.9 MW for 40 ºC and 68.2 MW for 45 ºC. According to the presently applied solutions, average outlet temperatures between 30 and 40 ºC are taken as representative.

4. GEOTHERMAL FIELDS IN MACEDONIA

There are 18 localities where geothermal fields occur and geothermal energy is in use for different proposes. The most known areas are listed below:

- *Kocani valley* (Popovski, 2002): The main characteristics of the Kocani valley geothermal system are: presence of two geothermal fields, Podlog and Istibanja, without hydraulic connection between them. The primary reservoir is built by Precambrian gneiss and Paleozoic carbonated schists, where by drilling the highest measured temperature in Macedonia of 79 ºC had been obtained. Predicted maximum reservoir temperature is about 100 ºC (Gorgieva, 1989). Kocani geothermal system is the best explored system in Macedonia. There are more than 25 boreholes and wells with depths of 100-1170 m. (Popovski, 2009)

- *Strumica valley* (Popovski, 2002): The main characteristics of this field are: the recharge and discharge zone occur in the same lithological formation - granites; there are springs and boreholes with different temperature at small distances; maximum measured temperature is 73 ºC; the predicted maximum temperature is 120 ºC (Gorgieva, 1989); the reservoir in the granites lies under thick Tertiary sediments. Bansko geothermal system has not been examined in detail apart the drilling of several boreholes with depths of 100-600 m. (Gorgieva, 2002)

- *Gevgelija valley* (Popovski, 2002): There are two geothermal fields in the Gevgelija valley: Negorci spa and Smokvica. The discharge zones in both geothermal fields are fault zones in Jurassic diabases and spilites. These two fields are separated by several km and there is no hydraulic connection between them, despite intensive pumping of thermal waters. The maximum temperature is 54 ºC, and the predicted reservoir temperature is 75-100 ºC (Gorgieva, 1989). Geothermal system in the Gevgelija valley has been well studied by 15 boreholes with depths between 100-800 m. (Gorgieva, 2002).

Figure 3: Location of geothermal projects in Macedonia.

- *Skopje valley* (Popovski, 2002): There are two geothermal fields in the Skopje valley: Volkovo and Katlanovo spa. There is no hydraulic connection between them. The main characteristics of the Skopje hydro-geothermal system are: maximum measured temperature of 54.4 ºC and predicted reservoir temperature (by chemical geothermometers) of 80-115 ºC (Gorgieva, 1989); the primary reservoir is composed of Precambrian and Paleozoic marbles; big masses of travertine deposited during Pliocene and Quaternary period along the valley margins. There are only five boreholes with depths of 86 m in Katlanovo spa, 186 and 350 m in Volkovo and 1654 and 2000 m in the middle part of the valley. The last two boreholes are without geothermal anomaly and thermal waters because of their locations in Tertiary sediments with thickness up to 3.800 m. (Gorgieva, 2002)

5. GEOTHERMAL UTILIZATION

The utilization of thermal waters consists of 7 geothermal projects and 6 spas. All of them had been completed before and during the 1980s. The present state of the projects is as follows:

- *Istibanja (Vinica) Geothermal Project*: Heating of 6 ha greenhouse complex in combination with a heavy oil boiler for peak loadings. It has been one of the worst completed projects before the crisis, however after the privatization in 2000 yr. it has been reconstructed and optimized with Austrian and Dutch grants and now properly covers the heat requirements of the roses' production for export. The owners are interested to continue with explorations in order to enable geothermal heating of additional 6 ha of greenhouses, but so far cannot achieve common interest with the municipality as owner of the concession rights.

- *Kocani (Podlog) Geothermal Project* ("Geoterma"): At present the largest geothermal project in Macedonia, composed of 18 ha greenhouse complex heating, and space heating of public buildings in the center of the town. Due to the economic circumstances, paper industry, vehicle parts industry and rice drying unit have been lost as heat consumers during the last 12 years. Nevertheless, by two Austrian grants, three additional boreholes have been drilled, partial injection of effluent water has been completed and monitoring system has been introduced in the system. Nowadays, there are activities in direction to finalize the completion of the reinjection and connection of public buildings in the center of the town. Project operates as a public and its organizational structure is well covered by the existing team. The only problem in operation is the price of supplied heat, which is kept very low by the State Energy Regulatory Commission, not including the costs of the necessary maintenance, service and development of the system.

- *Bansko Geothermal Project*: The bankruptcy of ZIK "Strumica" and the slow process of its privatization resulted in the collapse of the organizational structure and proper use of the system. Due to increased number of consumers and failure in covering the peak loadings, in order to enable proper operation, it is necessary to introduce centralized managing system and new exploitation boreholes, as well as considerable technical reconstructions and optimizations. Currently the exploitation concession is owned by one company to heat their greenhouses, but due to unsolved energy managing rules there are other consumers, too. Those are the hotel Car Samuil, Spiro Zakov (rest house, rehabilitation facilities for children), other plastic-houses, rest house Jugotutun, rest house ZIK Strumica, experimental and private plastic-houses.

- *Smokvica (Gevgelia) Geothermal System*: Once the largest geothermal system in Macedonia, covering the heating requirements of 22.5 ha glasshouses and of about 10 ha plastic-houses, nowadays is out of operation. At present, only 3 wells out of 7 are exploited with total flow of 90 l/s and temperatures between 63,9-68,5 ºC, to heat 10 ha greenhouses of which 6 ha glasshouses and 4 ha plastic-houses. When outside temperatures are very low back-up heavy oil boiler is used.

- *Negorci (Gevgelija) Spa*: Reconstruction of the heating installations has been finalized and now all the hotel and therapeutic facilities are heated with geothermal energy. Project is in a process of continual step by step modernization.

- *Other Spas in Macedonia*: Even planned, reconstruction of heating systems and their orientation towards geothermal energy use in Macedonian spas has not been realized due to their undefined property and the absence of funds. Now, when the process is finalized, activities to find possible investors are in progress in Katlanovo Spa, Kezovica Spa and Bansko Spa. However, it is not possible to expect quick results, due to the absence of capital in the country and real interest of foreign investors.

6. CONCLUSIONS

"Energy Development Strategy for Republic of Macedonia up to 2030" and "Strategy for Exploitation of Renewable Energy Sources in Republic of Macedonia up to 2020" do not include any foreseen geothermal development as a prospective energy source for Macedonia. Despite the formal attitude, some private initiatives exist, which will probably influence changes in this sector in the near future. Most important among them are: the renewal of the Smokvica geothermal system, reconstruction and expanding of the Bansko geothermal system and foundation of a new one in Dojran. Final completion of the injection system in Kocani is expected to be realized during the next two-three years. It is also expected that majority of spas would undergo reconstructions with intention to use geothermal energy for heating of the accommodation capacities, but so far there are no such information. Up to now, there is no any progress concerning the very prospective geothermal fields Kratovo-Zletovo, Skopje and Kumanovo regions.

Nevertheless, there are many improvements which should be done with the existing legislation in order to facilitate geothermal explorations and application, to enable sustainable exploitation and consider the environmental issues. Those are: definition of sustainable outflows, rights over single geothermal field, obligation to inject the used geothermal water, treatment of the geothermal water as mineral resource instead as energy resource too, calculation methodology for feasible and motivating price for geothermal heat, creation of subsurface register, incentives etc. (Panov, 2011)

The geothermal development in Macedonia is in stagnation for already 30 years, hopefully the situation will change along with the contemporary energy trends and initiatives in the country.

REFERENCES

Action plan for RES of RM up to 2025 with vision to 2030, Official Gazette of RM, no.207 from 24.11.2015 yr.

Arsovski M. (1997): Tektonika na Makedonija, Stip Dimitrov K., Gorgieva M. and Popovski K.: Geothermal Energy Resources and their Use in the Republic of Macedonia, Proceedings of the World Geothermal Congress 2000 Kyushu – Tohoku, Japan, May 28 –June 10, 2000

Energy December 2021, press release, State Statistical Office of Republic of North Macedonia, 25.02.2022

Energy balance of Republic of North Macedonia for 2021 yr., Official Gazette of RM, no.14 from 20.01.2021

Georgieva M.: Summary of Fundamentals for Evaluation of the Geothermal Potential of the Vardarian Zone and Serbian-Macedonian Massif at the Teritorry of the Republic of Macedonia, Annual Workshop of MAGA, Ohrid 2003

Georgieva M., Gorgiev D., Popovski K., Dimitrov K., Manasov S.: Inferred Section of the Main (Low-temperature) Geothermal Systems in the Republic of Macedonia, Proceedings World Geothermal Congress 2000 Kyushu - Tohoku, Japan, May 28 – June 10, 2000

Gorgieva M., Popovski K., Gorgiev D.: Geothermal Energy in Macedonia, State-of-the-Art and Perspectives, International Geothermal Days of ISS “Greece 2002”, Proceedings, Skopje 2002

Macedonian Academy of Science and Arts, Energy Development Strategy for Republic of Macedonia for the period 2008-2020 with vision up to 2030, Skopje, 2009

Macedonian Academy of Science and Arts, Strategy for Exploitation of Renewable Energy Sources in Republic of Macedonia up to 2020, Skopje, 2010

Micevski E.: Geotermalen potencijal na jugo-zapadniot del na Makedonija, Annual Workshop of MAGA, Ohrid 2003

Popovski K.: Feasibility Study on Possible Investments in Geothermal Projects in Macedonia, WB Study, Skopje 2002

Popovski K.: Geothermal Energy Use in Macedonia, International Conference GEAIA, Athens 2004.

Popovski K., Micevski E., Popovska-Vasilevska S.: Macedonia – Country Update 2004, Proceedings World Geothermal Congress, Antalya, Turkey, 24-27 April 2005

Panov Z., Gulev G., Ilievski A., Analysis of the Regulation for Exploration, Exploitation and Utilization of the Geothermal Water in the Republic of Macedonia, Kocani, 2011

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	0	0	2087.8	5498.3	0	0
Under construction end of 2021	0	0	NA	NA	0	0
Total projected by 2023	0	0	NA	NA	0	0
Total expected by 2028	0	0	NA	NA	0	0
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Less produced power due to major failure in the main TPP.

Table B: Existing geothermal power plants, individual sites

No geothermal power plants currently in North Macedonia

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	42.55	106	2.8	12.5	-	-	-	-
Under constru-ction end 2021	-	-	-	-	-	-	-	-
Total projected by 2023	-	-	-	-	-	-	-	-
Total expected by 2028	-	-	-	-	-	-	-	-

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

According the Energy Balance of RNMacedonia, for years, only the production of Kocani geothermal system (Geoterma) is reported, which is about 1.5-1.6 million m^3 per year or 5.5 ktoe or 64 GWh.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Bansko	Bansko		No	No	8.65	8.65	~21.55	100%
Kocani	Zelena kuka		No	No	33.90	33.9	~84.45	100%
total					42.55	42.55	106.00	100%

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

No geothermal large systems for heating and cooling uses other than DH currently in North Macedonia.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	>1000	2.50	21	NA	NA	NA
Of which networks **	NA	NA	NA	NA	NA	NA
Projected total by 2023	NA	NA	NA			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

Geothermal heat pumps are not recorded by any means, the figures given are just an assumption.

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No geothermal UTES currently in North Macedonia.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	0	0	0	0
Geothermal direct uses	NA	NA	NA	NA
Shallow geothermal	NA	NA	NA	NA
total				

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	0	0	0
Financial Incentives – Investment	0	0	LIL
Financial Incentives – Operation/Production	0	0	0
Information activities – promotion for the public	No	No	No
Information activities – geological information	Yes	Yes	No
Education/Training – Academic	Yes In frame of higher education	Yes In frame of higher education	Yes In frame of higher education
Education/Training – Vocational	No	Yes In frame of trainings for EE in buildings, build-up skills	Yes In frame of trainings for EE in buildings, build-up skills

Key for financial incentives:					
DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for Poland, 2019–2021

Beata Kepinska[1], Marek Hajto[2]

[1] Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, Wybickiego 7A Str., 31-261 Kraków, Poland; Polish Geothermal Society, Mickiewicza 30 Bvd, 30-059 Kraków, Poland

[2] AGH – University of Science and Technology, Mickiewicza 30 Bvd, 30-059 Kraków, Poland; Polish Geothermal Society, Mickiewicza 30 Bvd, 30-059 Kraków, Poland

bkepinska@interia.pl

Keywords: geothermal energy use, report, Poland, 2019–2021

ABSTRACT

The paper updates the status of geothermal energy use development in Poland in 2019–2021. It follows similar report for the EGC 2019 (Kępińska, 2019).

At the end of 2021 six geothermal district heating plants were operating . Their total installed geothermal capacity was 137.5 MW (74.6 in 2018) and geothermal heat production 281.49 GWh (250.4 in 2018). In individual cases the shares in total heat production were around 35–100 %. The development in geothermal recreation sector was continued: in 2021 at least 16 big centres were operating including one of the biggest in Europe opened in Central Poland (Wrecza) in 2020. Ten health resorts applied geothermal water for curative treatments. Among other single geothermal uses was an atlantic salmon farming; wood drying; heating up a football pitch and walking paths; CO_2 and bath salts extraction; food processing; biotechnology (R&D scale).

In case of shallow geothermal sector, its development was also continuing and the progress of GSHPs was a part of the progres in the whole heat pumps sector's development.

In 2019–2021 about 16 new geothermal wells were drilled (depths 1.5–3.9 km). They encountered ca. 42–84 ºC waters for geo-DHs or recreation), In addition, drillings of dozen or so boreholes or other investments were started. They were funded from state support programs for geothermal heating development that had been introduced since 2015/2016. Therefore, in the coming years one may expect some more DHs with geothermal share in the country.

1. INTRODUCTION

The paper updates the status of geothermal energy uses in Poland in 2019–2021. It follows a similar report presented at the European Geothermal Congress 2019 (Kępińska, 2019).

It gives a review of direct geothermal uses, with a focus on district heating, than recreation, balneotherapy and some other applications.

The paper lists also, among others, ongoing geothermal investments in various stages of realisation.

It is worth to pay attention to several public priority programs to support and boost geothermal development in Poland, specially for heating – introduced gradually since 2015/2016 and available in 2019–2021. These are the biggest programs so far taking into account the budgets allocated (for grants, loans) and the scope of investments that can be funded Information on first of these programs was given in an update for EGC 2019, in the current one next programs are listed. They have already resulted in many new wells and other investments (completed, in progress). Therefore it is expected that soon geothermal will be introduced to next several district heating systems in the country.

2. GEOTHERMAL ENERGY POTENTIAL

Geothermal energy resources in Poland are hosted mainly by Mesozoic sedimentary formations in the Polish Lowlands, and the Inner Carpathians. Some prospects are connected with selected areas and locations in the Outer Carpathians, the Carpathian Foredeep (sedimentary reservoirs) and in the Sudetes region (fractured parts in crystalline and metamorphic formations).

The outflow water temperatures recorded so far vary from about 20 to 97 °C (depths of aquifers up to ca. 3.7 km). The proven geothermal water reserves amount from several l/s up to 150 l/s. Water mineralisation (TDS) varies from 0.4 to 156 g/l.

3. OVERVIEW OF GEOTHERMAL USES

The chapter gives an insight into geothermal energy applications in Poland at the end of 2018. Their location is shown on Figure 1. Main data on geothermal installations are given in Tables A–G.

3.1 District heating

In 2021, six geothermal district heating plants were operational: in the Podhale region, in the municipalities of Pyrzyce, Mszczonów, Poddębice, Uniejów, Stargard (same as reported in 2019).

The Podhale region.

The geo-DH system has been operating since 1993. The total maximum artesian water flow rate produced by 3 wells is ca. 297 l/s of 82–86 °C water. In 2021 the installed geothermal capacity was 70 MW (total ca. 110 MW) while geothermal heat production amounted to 172.4 GWh, ca. 90 % of total production (M. Pelczarska – pers. communication). In 2021 ca. 1700 receivers were connected to geo-DH (mostly in Zakopane – the main city of that region; geo-DH met ca. 35 % of its heat demand). Part of spent geothermal water is injected back by 3 wells (one of them was added into the system in 2021) while another part supplies 2 recreation centres. The Podhale system is among the biggest geo-DHs in continental Europe. In 2019-2021 further optimization and extension of that system were ongoing.

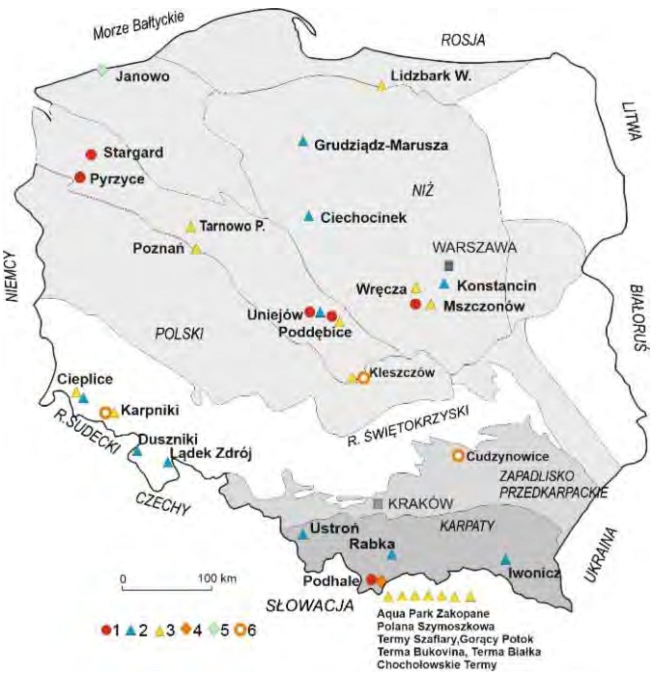


Figure 1. Poland: geothermal direct uses, 2021: 1. district heating plants, 2. health resorts, 3. recreation centers, 4. wood drying, 5. Fish farming, 6. Individual heating systems

NIŻ POLSKI – Polish Lowlands, KARPATY – the Carpathians, ZAPADLISKO PRZEDKARPACKIE – the Carpathian Lowlands, R. SUDECKI – the Sudetes region.

Not marked are localities where investments focused on district heating, recreation, etc. were in progress or in which new geothermal wells were drilled in recent years

Pyrzyce.

The geo-DH plant has been operating since 1996. Since 2017/2018 the maximum water flow rate of water discharged by one production well is ca. 55 l/s of 65 °C water (spent water is injected back by four wells). The plant's maximum installed capacity is 22 MW including 6 MW geothermal. It supplies heat and domestic warm water to over 90 % users of the whole town's population (13'000) and meets ca. 60 % of total heat demand. In 2021 geothermal heat production was 14.6 GWh (B. Zieliński – pers. communication).

Mszczonów.

The geo-DH has been operating since 2000. Maximum geothermal water flow rate is ca. 16.6 l/s of 42.5 °C, and mineralization 0.5 g/l. Water is discharged by a single well (no injection). In 2021 geothermal capacity was 3.7 MW while the total one was 8.3 MW (including also gas boilers, absorption heat pump, and compressor heat pump). In 2021 geothermal heat production was 4.5 GWh, total around 12 GWh (M. Balcer, B. Dajek – pers. communication). After cooling water is used for drinking. Part of water flow rate is sent to recreation centre. Since 2020 part of geothermal water and heat has supplied one of the deepest diving pools in the world (ca. 45 m deep). Some new projects on more efficient geothermal energy and water management were ongoing in that municipality.

Uniejów.

The geo-DH has been operating since 2001. The maximum discharge from one production well is 33.4 l/s is of 68 ºC water and mineralisation is ca. 6–8 g/l. The geothermal installed capacity is 3.2 MW (total 7.4 MW, including also biomass boiler and reserve fuel oil peak boilers). In 2021, 80 % of all buildings in that town were supplied by the geo-DH. Geothermal heat production was 2.5 GWh, ca. 60 % of total production (J. Kurpik – pers. communication). Part of geothermal water flow has been used for spa and recreation centre, which is also heated by geothermal energy. Some amount of spent water is used to heat up a football pitch and walking paths. Uniejów has a status of health resort (since 2012). Besides geo-DH, in 2021 some other uses were at various stages of project realization and preparation.

Poddębice.

The geoDH has been operating since 2013. It has a 10 MW geothermal capacity based on 68 ºC water (average flow rate 32.2 l/s, mineralization 0.4 g/l). The plant supplies several public buildings, school, hospital (and submits water to its rehabilitation part), multi-family houses. In 2021 geothermal heat production was 19.2 GWh, i.e. 97 % of total production. Some part of water stream is sent to swimming pools. Next types of geothermal uses were at various stages of project realization and planning in the reported period 2019-2021 (A. Karska, A. Peraj – pers. communication). Among them was a project of using geothermal for rehabilitation and removing barriers for disable persons (opened in May 2022).

Stargard.

The geothermal plant has been operating since 2012 (after renovation). It is based on several production and injection wells (four of them were drilled in 2018–2020 and included (test stage) into the existing system). In 2021 maximum water production was over 50 l/s of 87 ºC water. The geothermal capacity was 44.6 MW and heat production 68.3 GWh, entirely sold to the municipal district heating plant (A. Biedulski – pers. communication). That district heating system has been supplied mainly by a fossil-fuel–based plant (total capacity of 116 MW, serving 75 % of the population (75'000)). In the future, thanks to four new geothermal wells drilled in 2018–2020, increased total water flow rate (up to ca. 160 l/s) and some next investments, it will be possible to cover by geothermal 90 % of heat demand in Stargard.

To sum up the geothermal district heating in Poland: in 2021 the installed total geothermal capacity of six geo-DHs was 137.5 MW and geothermal heat production 281.5 GWh.

In addition to geo-DHs, in several recreation centers geothermal waters were used both for filling the pools, spa treatments and for heating their objects. Moreover, some single buildings started to be heated by geothermal energy.

3.2 Health resorts

In 2019–2021 in ten health resorts geothermal waters were used for various treatments. The exploitation resources of geothermal waters in these localities range from approx. 2 to 200 m^3/h, while the maximum temperatures at the outflows ranged from 18 to 70 °C.

3.3. Recreation, balneotherapy (balneology)

In 2021 there were over a dozen centers that use geothermal water in the recreation sector. Among them, there are seven centers in Podhale region, as well as several in the Polish Lowlands, and in the Sudetes region. The newest of these is the center in Wręcza near Mszczonów opened at the beginning of 2020, the largest center of this type in Poland and one of the largest in Europe. Some of these centers do not have their own wells and apply a part of geothermal water streams extracted by other enterprises mainly for heating purposes. In the coming years, further development of this very attractive sector is expected, which is of great importance both for the users of its services and for local economic development.

3.4. Aquaculture

In the reported period one farm in Poland applied geothermal water and heat for fish farming – a large Atlantic salmon farm launched in 2015 (http://www.lososjurajski.pl). In 2018 an experimental algae cultivation based on geothermal water was initiated in Poddębice (A. Karska – pers. communication).

3.5. Other uses

Other geothermal applications (usually in single cases and on a small scale so far) were:

- wood drying (one facility),
- heating up of a football pitch and waking paths,
- cosmetics production,
- agri-food processing,
- pilot algae cultivation,
- use of geothermal water for drinking purposes,
- extraction of bath salts,
- carbon dioxide extraction.

3.6. Shallow geothermal – heat pumps

In 2019–2021 further development of shallow geothermal (ground source heat pumps, GSHPs) was continued, as a part of the dynamic development of the whole heat pump sector (specially air/water types). According to the Polish Organisation of Heat Pumps Technology Development, in 2019–2021 the GSHPs' sales was 17'100 units (www.portpc.pl). Taking these numbers into account and data evaluated for the previous periods one may estimate that at the end of 2021 the total number of GSHP could reach ca. 78'480 units. This was around 40 % more than in 2018 (56'000 units; Kępińska, 2019). Their total capacity can be roughly estimated for at least 900 MW and heat production for at least 1200 GWh, assuming the linear trend of power and heat growth in previous years. However, taking into account the faster growth in recent years, in 2021 it could have been as much as 2 GW[1] and therefore more heat. In 2021–2022, discussions continued on assessing capacity and heat production by GSHPs, some corrections in the total number of GSHPs can be expected (more accurate figures on annual market sales available in several last years vs. difficulties in precise estimations for many previous years).

GSHPs are installed for individual heating, as well as for heating large-capacity facilities. They are also installed in some geothermal heating plants and recreation centers (some are large heat pumps, 1–1.5 MW). Increasingly, they work in both heating and cooling modes. An example of a large facility heated and cooled by GSHPs is, among others, the St. John Paul II Centre "Don't Be Afraid!" in Kraków completed in 2017. The installation is based on 139 borehole heat exchangers, with a total length of 23 km. Heat pumps of the system are also used as a cold source for air conditioning systems. In the cooling mode, the heat received during cooling process by the heat pumps from the cooling water is used for the preparation of domestic hot water. More information about large GSHPs installations can be

[1] https://globenergia.pl/comments/brakuje-danych-w-statystykach-dotyczacych-gruntowych-pomp-ciepla/ https://portpc.pl/pdf/10Kongres/5.2_Ryzynski_Grzegorz.pdf

found in the Annexes of the EGEC Geothermal Market Report (2022).

The highest increases in heat pump sales are achieved in the segment of air/water heat pumps. For example: in 2021, 79’300 such heat pump units were sold and it was an increase of 88 % compared to the sales in 2020, while in case of GSHP that increase was 7.4 % (from 5260 in 2020 to 5650 units in 2021 (GE, 2021).

An increase in interest in heat pumps was caused by the greater intensity of public financial support for heat pumps in the "Clean Air" program available from May 2020 and the thermal modernization relief (see also chapter on support programs).

The program statistics show that in March 2022 for the first time since the program started heat pump installations overtook gas boilers. Moreover, in April 2022 the “Clean Air” program received almost two times more applications for heat pumps than for gas boilers! Out of 12’441 applications for co-financing the replacement of a heat source with a heat pump, 5893, i.e. 47 %, concerned heat pumps (https:// czystepowietrze.gov.pl).

It is worth noting that the sales of heat pumps (all types) per capita in Poland in 2021 were higher than in the two key heat pump markets in Europe – Germany and the United Kingdom.

Market development forecast scenarios based on the PORT PC Market Report statistics for ground heat pumps until 2030 – depending on the scenario – may amount to 1.9–5.3 GW of installed thermal capacity (Ryżyński, 2022).

These values fit nicely in the panorama of renewable energy sources that should be implemented in Poland to increase the share of RES in the national energy mix according to the *Polish Energy Policy until 2040* (https://www.gov.pl/web/climate/energy-policy-of-poland-until-2040-epp2040).

According to the “Multiannual Program for the Development of the Use of Geothermal Resources” GSHP market will grow to 2030 with ca. 5.5 thousands of units each year which assumes an additional increase in total capacity installations to ca. 65 MW by 2030 (https://www.gov.pl/web/ klimat/mapa-drogowa-rozwoju-geotermii-w-polsce).

information in this sub-chapter is generally based on: https://portpc.pl/port-pc-wzrost-o-80-sprzedazy-pomp-ciepla-do-ogrzewania-budynkow-w-2021-r/; https://portpc.pl/rynek-pomp-ciepla-w-polsce-w-2019-roku-i-w-perspektywie-do-roku-2030/; https://globenergia.pl/rynek-i-sprzedaz-pomp-ciepla-w-2021-roku-zobacz-najnowsze-dane/)

4. GEOTHERMAL SHARE IN 2020 RES MIX

According to the Central Statistical Office (data source: GUS, 2021; [2]) in 2020 the RES share in total primary energy acquisition was estimated for 16.3 % (499’338 TJ), than given by Eurostat as 16.1 % [3]. The contributions of particular RES were as follows: solid biofuels 71.61 %, wind 10.85 %, liquid biofuels 7.79 %, biogas 2.58 %, heat pumps 2.38 %, solar 1.99 %, municipal wastes 1.15 %, geothermal 0.20 % (2021 data were not yet available while preparation of this paper).

According to international, EU- and state documents, the RES’ share in final gross energy consumption in Poland should reach 15 % by 2020 while in fact it was around 16 %, as given above.

In the coming years one may expect that the geothermal share in RES mix, including RES heat will increase somehow – thanks to increased geothermal heat production and sales both by already existing as well as several expected next district heating systems with geothermal components (in various stages of implementation in 2019–2021).

5. GEOTHERMAL DRILLINGS

In 2019–2021 at least 16 geothermal wells were drilled which had been funded mostly by various public support programmes oriented for geothermal space heating (energetic uses). Those programmes have been gradually launched from 2015/2016 and are listed further in the text (first of them were mentioned in former 2016–2018 Update). In the group of wells drilled in 2019–2021 were: 8 exploration wells – 6 positive, 2 negative (2 next exploration wells were approved for drilling); 8 production or injection wells (including 4 next wells for Stargard plant and 4 wells in other locations).

The depths of particular wells are in the range of 1.5–3.9 km, water wellhead temperatures 42–84 ºC, flow rates 80–260 m^3/h, mineralization 0.5-130 g/dm^3.

Thus, the expectations given in the previous 2016-2018 Update as regards the number of drilling new geothermal wells during 2019–2021 were confirmed or even exceeded: at least 10 wells were foreseen, while at least 16 boreholes were actually made.

Furthermore, positive decisions were issued in 2019–2022 on funding about 30 geothermal exploitation wells by various support programs. Their drillings are expected to start in 2022 and following years. In a positive scenario, several further wells could be decided for public funding as a result of next calls opened in the course of 2022.

[2] https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/energia-ze-zrodel-odnawialnych-w-2020-roku,10,4.html

[3] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_ind_ren

Those wells will be implemented as part of wider investment projects focused on connecting geothermal to some of the existing district heating systems, their modernization, increasing energy efficiency, etc. (in accordance with the objectives of the programs under which they will be implemented).

It is also worth to mention that the project of an extra deep well (ca. 7 km) in the Podhale region was granted public funds. It has several drilling objectives, including recognition of potential deep geothermal aquifers and feasibility of their exploitation for energy production. Start of drilling was expected in 2022.

6. WORKS IN PROGRESS AND PLANNED

In addition to drilling works, in 2019–2021 other geothermal investments were in progress. They were oriented mostly for heating, several for recreation. Some are listed below:

- Investments aimed at increasing geothermal capacities, efficient heat extraction and connecting new consumers to operating geo-DHs. It is worth pointing out four new exploitation wells drilled in Stargard plant – making possible to significantly increase geothermal heat production and sales to municipal district heating company (as mentioned in chapter 3.1); .
- Continuation or starting the investments oriented for several new geo-DHs (based on wells drilled thanks to public support programs). In that group was e.g. construction of a geothermal plant in Toruń and inclusion of geothermal as one of the element in municipal heating system (in May 2022 the operator of that network signed a long-term heat sales agreement with Geotermia Toruń [4]);
- Further investments in recreation and balneotherapy: e.g. the construction and opening (February 2020) of a huge center in Wręcza near Mszczonów (Central Poland). Another large recreation and multi-functional center (intended for people with disabilities – Land without barriers) was ongoing in Poddębice town (opened in May 2022);
- Several pre-investment works and feasibility studies related to various sites in the country meeting the interest shown by various stakeholders.

Along with the investment works, many feasibility studies, preinvestment works, as well as research and R+D+I activities were conducted in 2019-2021, e.g.:

- R+D+I on various topics related to geothermal uses; theoretical items; deep borehole heat exchangers; UTES; water desalination; agriculture; biotechnologies; shallow geothermal, etc.;
- Next projects funded by the EEA FM and NFM performed by teams from Poland, Iceland, Norway (first such projects were in 2016–2017);
- Participation in selected important EU projects by some Polish teams (eg., GEORISK (www.georisk-project.eu).

7. PROFESSIONAL PERSONNEL ALLOCATION

The number of professional full-time (and also part-time) personnel employed at various geothermal activities (scientific and research entities, geo-DHs, some other installations, servicing, consulting companies, geological survey) can be roughly estimated to ca. 200 persons as for the end 2021 (similar as for former reported period). Furthermore, significant number of technical personnel (services, treatment, management, etc.) has been working in recreation centres (depending on its size) and in health resorts (not included into total estimation here).

8. PROGRAMS TO SUPPORT GEOTHERMAL DEVELOPMENT

8.1. Deep geothermal

In 2019–2021, several public priority programs were available to support (as grants or loans) the geothermal development for heating (energy sector). Those programs had been gradually introduced since 2015/2016. Thanks to them, in 2019–2021 at least 16 geothermal wells were drilled, and decisions were issued regarding the financing the drillings of a dozen or so next wells (in 2022 and in the following years). The first programs launched in 2015/2016 concerned exploration / research wells, while the next focused on the energy use extracted from the identified geothermal resources, development of the necessary infrastructure, etc. These were and are the following priority programs initiated and operated by the Ministry of Climate & Environment, and the National Fund for Environment Protection & Water Management (more details, e.g.: www.klimat.gov.pl; www.nfosigw.gov.pl):

- *Geology and mining part I* (2016–2018) and *Recognition the geological structure of the country* (2019) – funding the drilling of 11 geothermal wells (total PLN 268.3). The programs supported the exploration and recognition of geothermal reservoirs to use them for energy production. In 2019-2021, five of those wells were drilled and the exploitation water reserves were determined;
- *Accessing geothermal waters in Poland* (since 2020) – supporting the exploration and recognition of geothermal reservoirs in order to tap them and include geothermal into the existing and planned district heating systems. The beneficiaries are local governments or their associations. These are grants up to 100 % of eligible costs. The budget of the program is PLN 300 million. In the first call (2020), 15 wells were recommended for co-financing (total of ca. PLN 230 million). Drillings

[4] https://pgeenergiaciepla.pl/aktualnosci/wszystkie/produkcja-ciepla-dla-torunia-z-wykorzystaniem-geotermii

will start mostly in 2022. After identifying geothermal reservoirs, funding for the project continuation can be obtained, e.g., from the Polska Geotermia Plus priority program;

- *Polska Geotermia Plus* (2019–2020) – the program aims to increase the use of geothermal resources in the country. PLN 600 million were allocated (PLN 300 million in grants up to 40–50 % of eligible costs, PLN 300 million of loans up to 100 % of eligible costs). 50 % co-financing can also be counted on in the case of the first research well verifying the feasibility of building a new geothermal heating plant, CHP plant / power plant, or extending the existing energy generation sources with a heating plant, CHP plant or geothermal plant. The program is addressed to the entrepreneurs. It indicates three obligatory tasks, the fulfillment of which determines the possibility of obtaining support. The first call for proposals ended in December 2020. Agreements were concluded for co-financing of 6 projects (including drilling several wells). In course of 2022, five more applications were being processed. The next call in this program was expected in the second quarter of 2022;
- *County Heating* (since 2021) – program aimed at local governments, towns below 100'000 residents (total PLN 500 million, returnable and non-returnable support) to co-finance modernization projects, heating networks' expansion and, among others, energetic use of geothermal resources [5];
- *The EEA FM Environment, Energy and Climate Change program, Energy program area* (2014–2021) – the expected result of the support is to increase the energy production from renewable sources. The call was announced, among others, for the construction of heat sources using deep geothermal energy. Under this program, it is possible to cooperate with the partners from Poland and Iceland – one of the Donor States, the European Economic Area Financial Mechanism (EEA MF). Co-financing is in the form of a subsidy (up to 100 % of eligible costs of the project). The allocation is EUR 7 million (PLN 31.6 million). The beneficiaries may be local government units or their associations, small, medium and large enterprises. Two projects have been approved for funding. They can then take advantage of the priority program *Co-financing of projects implemented under the EEA FM 2014–2021,* which is complementary in the form of a loan of own contribution for eligible expenditure. The continuous recruitment of this Program lasts until the end of 2024. The projects can include educational and training activities – this is a case of a predefined project *Capacity building of key stakeholders in the area of geothermal energy* that has been conducted since 2020 by the Mineral & Energy Economy Research Institute PAS (Poland) and the National Energy Authority (Iceland) (www.keygeothermal.pl);
- *Sub-activity 1.1.1 Supporting investments related to the production of energy from renewable sources together with their connection to the distribution / transmission grid, priority axis I of the Operational Program Infrastructure and Environment 2014–2020.* The support covers the construction or reconstruction of RES generation units, including geothermal energy (above 2 MW_{th}). In 2016–2021 funding was granted, inter alia, to 8 geothermal entities (including drilling several wells) for the amount of PLN 237 million. The program will be continued within the European Funds for Infrastructure, Climate and Environment Program in next years.

8.2. Shallow geothermal

Since May 2022 the "Clean Air" program has been available to support, among others, heat pumps development in the country. It has resulted in increased interest in this sector. Some other programs have facilitated that development, as well as thermal modernization relief.

The program statistics show that in March 2022 for the first time since the program started heat pump installations overtook gas boilers. Moreover, in April 2022 the "Clean Air" program received almost two times more applications for heat pumps than for gas boilers! Out of 12'441 applications for co-financing the replacement of a heat source with a heat pump, 5893, i.e. 47 %, concerning heat pumps (https:// czystepowietrze.gov.pl).

9. INVESTMENTS IN GEOTHERMAL SECTOR (HEATING)

The budget allocated for the investments in geothermal heating / energy sector – taking into account the sums granted as subsidies and loans from several public programs in 2019–2021 (listed in chapter 8) – can be roughly estimated for at least 240 million Euro (drillings, related works and equipment, surface infrastructure, etc.). Part of those investments will be continued in 2022 and beyond, using the sources granted by 2021.These numbers are given on a basis of publicly available information provided by programs' operators (National Fund for Environment Protection and Water Management, Ministry of Climate and Environment). The investments in recreation and other sectors (funded by various sources) are not mentioned here (however, they were also significant, specially that some very big centers were constructed and launched in the reported years).

Investments in shallow geothermal in reported years may be tentatively estimated to ca. 75 million Euro (i.e. similar to former reported years).

[5] https://www.cire.pl/artykuly/serwis-informacyjny-cire-24/155698-nfosigw-chce-teraz-rozwijac-programy-wsparcia-geotermii,-biogazowni-i-przydomowych-magazynow-energii

10. LEGAL BACKGROUND, STRATEGIC DOCUMENTS

As in former reported years 2016–2018, the references and provisions related to geothermal energy and investments were made in various key national legal acts and other documents, i.e . Geological and Mining Law; RED II; Energy Law; Building Law; Environmental Law; Public Aid Law; some other.

Among the state strategic documents related to energy introduced in recent years, several refer in general to geothermal energy development, eg.:

- The National Plan for Energy and Climate 2030,
- Energy Policy of Poland until 2040,
- National Plan for Reconstruction and Resilience.

In details, geothermal energy development is a subject of the following documents elaborated in recent years:

- “Multiannual Program for the Development of the Use of Geothermal Resources” for Poland until 2040, with a perspective until 2050 – initiated by the Ministry of Climate and Environment, elaborated in 2021 (announced in 2022). It is based on three pillars: 1. Research, 2. Execution and implementation of pilot installations, 3. Implementation, education and promotion (https://www.gov.pl/web/klimat/mapa-drogowa-rozwoju-geotermii-w-polsce);
- The Strategy for Responsible Development by 2020 with 2030 perspective (www.gov.pl/ documents/33377/436740/SOR.pdf). As a part of this Strategy, the Ministry of Climate and Environment conducts activities to support the development of geothermal use in Poland, e.g. strategic project *Development and use of geothermal potential in Poland*. It aims to create conditions for the promotion and development of renewable energy based on geothermal and to use their resources’ potential. The project includes the implementation of: Tasks of the state geological survey in the field of geothermal energy; Geothermal tasks performed in cooperation with foreign experts on the basis of EEA FM and NMF funds; Promotional and information activities for the development of geothermal energy. The project will run until June 2024. The Ministry also initiates and finances some geothermal research (carried out mainly by the Polish Geological Institute – State Research Institute; https:// www.gov.pl/web/klimat/geotermia). One shall point out that many important research, R+D+I works have been constantly carried out for many years by scientific and research entities leading geothermal sector in the country, like AGH–University of Science and Technology, MEERI PAS, some other;
- With the reference to the information in 2016–2018 Update: it is reported that works on State Raw Materials' Policy had been ongoing (Kępińska, 2019) and one of its executive programs, i.e. on Earths' heat had been under preparation (with significant input of the Polish Geothermal Society and cooperating entities). Instead, Multiannual Program for the Development of the Use of Geothermal Resources was elaborated and announced.

Geothermal heating can be supported also by various programs addressing thermal retrofitting, energy efficiency increase, air quality improvement, etc.

11. CLOSING REMARKS

The last few years, including 2019– 2021, have brought many activities aimed at increasing the geothermal uses in Poland, primarily in low-emission heating. This was in the form of the implementation of another dozen or so wells and other investments. It was possible mainly thanks to big public support programs, introduced gradually from 2015/2016 and available in the reporting period 2019–2021. Therefore, it should be expected that soon geothermal components will be included into a few more district heating networks in the country (so far, six geo-DHs have been in operation). The geothermal recreation and spa sector was also in development (with the difficulties in 2020 and 2021 due to the pandemic), some other single uses were also implemented.

Another argument for the wider geothermal uses development in Poland is, inter alia, the needs to decarbonize the heating sector, to increase local energy uses, to assure affordable prices and the security of supply. Geothermal in Poland has the potential to meet these challenges, the more so as the arguments in this regard are provided by various positive effects of already operating installations, relatively high level of social acceptance, increasing competitiveness of geothermal heat in comparison with other sources, availability of public support programs introduced in recent years.

In the view of above, in coming years one may expect more installations with geothermal share in Poland, specially as far as heating sector is concerned.

ACKNOWLEDGEMENTS

All persons who kindly contributed to this Report by providing basic data and informarmation are greatly appreciated: B. Dajek, M. Balcer (Geotermia Mazowiecka S.A.), A. Karska, A. Peraj (Geotermia Poddębice Sp. z o.o.), M. Pelczarska (PEC Geotermia Podhalańska S.A.), B. Zieliński (Geotermia Pyrzyce Sp. z o.o.), A. Biedulski (G–Term Energy Sp. z o.o.), J. Kurpik (Geotermia Uniejów Sp. z o.o.), W. Bujakowski (MEERI PAS).

REFERENCES

EGEC: EGEC Geothermal Market Report 2021. Annexes. Available for the EGEC Members. https://www.egec.org/the-european-geothermal-sector-emerges-stronger-from-the-covid-19-slowdown/. (2022).

GE: Rynek i sprzedaż pomp ciepła w 2021 roku – zobacz najnowsze dane! (2021). https://globenergia.pl/rynek-i-sprzedaz-pomp-ciepla-w-2021-roku-zobacz-najnowsze-dane/

Kępińska B.: Geothermal energy use – Country update for Poland, 2016-2018. Proceedings of the European Geothermal Congress 2019, Den Haag, The Netherlands, paper # CUR-21-Poland, 1-9. (2019).

The Geological and Mining Law. Unified text of the act. Law Gazette 2017, item 2126, (2017).

Ryżyński G.: Aktualne działania PIG –PIB w zakresie oceny potencjału geotermii niskotemperaturowej w Polsce. X Kongres PORT PC, 2 czerwca 2022 r., Kraków (2022). https://globenergia.pl/comments/brakuje-danych-w-statystykach-dotyczacych-gruntowych-pomp-ciepla/ https://portpc.pl/pdf/10Kongres/5.2_Ryzynski_Grzegorz.pdf.

http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_ind_ren (access June 2022)

https:// czystepowietrze.gov.pl (access June 2022) https://globenergia.pl/comments/brakuje-danych-w-statystykach-dotyczacych-gruntowych-pomp-ciepla (access June 2022)

https://globenergia.pl/rynek-i-sprzedaz-pomp-ciepla-w-2021-roku-zobacz-najnowsze-dane (access June 2022)

https://portpc.pl/port-pc-wzrost-o-80-sprzedazy-pomp-ciepla-do-ogrzewania-budynkow-w-2021-r/) (access June 2022)

https://pgeenergiaciepla.pl/aktualnosci/wszystkie/produkcja-ciepla-dla-torunia-z-wykorzystaniem-geotermii (access June 2022)

https://portpc.pl/pdf/10Kongres/5.2_Ryzynski_Grzegorz.pdf (access June 2022)

https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/energia-ze-zrodel-odnawialnych-w-2020-roku,10,4.html (access April 2022)

https://www.gov.pl/ attachment/5a0775b2 a5bb4dbb a6ae 87af1ac98dd4) (access 2022)

https://www.gov.pl/web/klimat/mapa-drogowa-rozwoju-geotermii-w-polsce (access June 2022)

www.cire.pl/artykuly/serwis-informacyjny-cire-24/155698-nfosigw-chce-teraz-rozwijac-programy-wsparcia-geotermii,-biogazowni-i-przydomowych-magazynow-energii (access June 2022)

www.gov.pl/documents/33377/436740/SOR.pdf (access June 2022)

www.georisk-project.eu (access June 2022)

www.gov.pl/web/klimat/geotermia (access June 2022)

www.keygeothermal.pl (access May 2022)

www.klimat.gov.pl (access May 2022)

www.lososjurajski.pl (access June 2022)

www.nfosigw.gov.pl (access June 2022)

Personal communications:

M. Balcer, B. Dajek (January 2021); A. Biedulski (January 2021); M. Pelczarska (February 2021); A. Karska, A. Peraj (February 2021); B. Zieliński (February 2021); J. Kurpik (January 2021)

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

There are currently no geothermal power plants existing in Poland.

Table B: Existing geothermal power plants, individual sites

There are currently no geothermal power plants existing in Poland.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers *(rough information)*

	Geothermal DH plants		Geothermal heat in agriculture and industry[1]		Geothermal heat for buildings[2]		Geothermal heat in balneology and other **, [3]	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	137,5	281,5						
Under constru-ction end 2021	~ 20	~ 40						
Total projected by 2023	190	~ 380						
Total expected by 2028	> 230	> 460						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

[1], [2], [3] These types of geothermal heat uses took place in Poland 2021 (specially balneology / recreation) however, due to various objectives reasons, data requested for this Report, were not surveyed or not updated (if given in former reports, e.g. for EGC 2019)

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Podhale Region	PEC Geotermia Podhalańska	1993	-	-	70	110	172,44	~ 90
Pyrzyce	Geotermia Pyrzyce	1996	-	-	6	22	14,58	~ 75
Mszczonów	Geotermia Mazowiecka	2000	-	-	3,7	8.3	4,51	37
Uniejów	Geotermia Uniejów	2006	-	-	3,2	7.4	2,50	< 40
Poddębice	Geotermia Podddębice	2013	-	-	10	10	19,16	100 [1)]
Stargard [1)]	Geotermia Stargard	2006/2020	-	-	44,6	44.6	68,3	100 [1)]
total					137,5	202.3	281,49	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N

1) Peak boilers in places other than geothermal plant itself

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Remark: several heating systems other than DH were operating in 2021 (individual buildings and H&C systems in recreation centers – however, usually less than <5 MW_{th} each).

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number [1)]	Capacity[1)] (MW_{th})	Production[1)] (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	78400	> 900 – 2000 (see text)	>1200 – 2500 (? See text)	5650	Ca. 70	No data available yet
Of which networks **	?	?	?			
Projected total by 2023	additions ca. 5500/yr	Ca. 70 additions/yr	?			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

1) The numbers given were estimated assuming the linear trend of capacity and heat production growth in previous years. However, taking into account the faster growth in recent years, in 2021 it could have been as much as 2 GW (Ryżyński, 2022) and therefore more heat (approx. 2500 GWh?). In 2021-2022, discussions continued on how to clarify the method of assessing power and heat production by GSHPs. Also, some corrections in a total number of GSHPs can be expected (more accurate figures on annual market sales available in last years and difficulties in precise estimations for many previous years).

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

	Aquifer Thermal Energy Storage (ATES)			Borehole Thermal Energy Storage (BTES)		
	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold
In operation end of 2021 *	0	H: C:	H: C:	0	H: C:	H: C:
New (additional) in 2021 *	0	H: C:	H: C:	0	H: C:	H: C:
Projected total by 2023	1–2 R&D stage	H: ? C: ?	H: ? C: ?	1 (R&D stage)	H: ? C: ?	H: ? C: ?

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	0	0	0	0
Geothermal direct uses (2019-2021)	~ 240 [1]	~ 200 [2]	~ 50 [3]	~ 200-250 [2]
Shallow geothermal	Data not available yet	No exact data		
total				

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include “jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration”. For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

1) Granted in 2019-2021 for investments oriented for geo-DH projects. Part of that sum will be spent also in 2022 and beyond (see the text). Expenditures in other sectors not included

2) Full-time (and part-time) personnel employed at various geothermal activities (see the text)

3) Tentative

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling (more: chapters in the main text)	Shallow geothermal
Financial Incentives – R&D	Some for CHP	yes	no
Financial Incentives – Investment	Some for CHP	yes	yes
Financial Incentives – Operation/Production	No	no	Yes (for electricity)
Information activities – promotion for the public	No	Occasionally so far. No broader systematic public campaign as for some other RES	Occasionally so far. No broader systematic public campaign as for some other RES
Information activities – geological information	Yes – as for deep geothermal H&C	Yes	Gradually – yes (elaboration of relevant information started in recent years)
Education/Training – Academic	Yes (CHP), at single universities – part of education / training on deep geothermal	Yes, at single universities	Yes, at single universities
Education/Training – Vocational	No	Yes – but occasionally – short wkps, study visits etc. as activities within various projects / national, EU-, EEA FM – funded	Yes - but /occasionally

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for Portugal

João Carlos Nunes[1*], Luís Coelho[2], José Martins Carvalho[3] and Maria do Rosário Carvalho[4]

[1] INOVA- Instituto de Inovação Tecnológica dos Açores, Rua S. Gonçalo s/n, 9504-540 Ponta Delgada, Açores & Universidade dos Açores, Rua Mãe de Deus, 9501-801 Ponta Delgada, Açores, Portugal

[2] Instituto Politécnico de Setúbal (EST/IPS), Escola Superior de Tecnologia de Setúbal, Campus do IPS, Estefanilha, 2910-761 Setúbal & CINEA-IPS, Centro de Investigação em Energia e Ambiente – IPS, Setúbal, Portugal

[3]Laboratório de Cartografia e Geologia Aplicada, Instituto Superior de Engenharia (ISEP), Politécnico do Porto, Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto & GeoBioTec, Universidade de Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal

[4]Departamento de Geologia, Faculdade de Ciências, Universidade de Lisboa & Instituto D. Luiz, Campo Grande, Edifício C6, 3º Piso, 1749-016 Lisboa, Portugal

* jcnunes@inovacores.pt

Keywords: Portugal 2021, power generation, thermal baths, shallow geothermal energy.

ABSTRACT

The presence of high-temperature geothermal resources, and the production of electricity from geothermal resources in Portugal, are restricted to the volcanic islands of the Azores Archipelago located in the North Atlantic Ocean.

Three geothermal binary power plants are installed and running normally in the islands of S. Miguel and Terceira, the most economically developed, with a total capacity running of 26 MW_e and an average production of about 200 GWh/year. The total production of those power plants in 2021 represented about 20 % of the total demand of the Azores archipelago. New nine vertical and directional wells were drilled in 2021 in both islands to increase the total running capacity of power plants, or at least saturate them, especially the Pico Alto geothermal power plant, Terceira Island.

Following the call released in 2018 for geothermal projects, sponsored by the FAI – "Fundo de Apoio à Inovação", to promote the use of geothermal resources in Portugal, namely the low enthalpy resources associated with Thermal Baths/Spas facilities, two district heating networks for hotels and public buildings are under completion: (i) Chaves (74 ºC, 25 l/s) and (ii) S. Pedro do Sul (67 ºC, 19.4 l/s).

Furthermore, in Chaves, an independent small operation (110 kW_{th}) was open in January 2022 in an emblematic museum located over an impressive former Roman Thermal Bath with innovations regarding the environmental management of the geothermal fluid and its disposal.

Concerning GSHPs, the potential is huge and continues to be exploited, with new projects ongoing and new specific regulations are expected to be approved shortly. There are a few installations registered until now, but the technical data of the operations are scarce and do not represent the totality of what is installed in Portugal.

1. INTRODUCTION

There are many thermal occurrences in Portugal known and used for balneotherapy since the second century. Their use as geothermal resources was first boosted in the 1970s. The geothermal uses for electricity production started in the Azores archipelago with the exploitation of the high enthalpy geothermal field on the island of S. Miguel. However, the increasing need to use renewable energy resources has led to an increase in the exploitation of high and low enthalpy geothermal resources in Portugal, including shallow geothermal with the use of heat pumps.

The high enthalpy geothermal resources, in Portugal, are restricted to the volcanic islands of the Azores Archipelago (Figure 1), associated with active tectonic and volcanic systems. Considering the abundant surface manifestations of hydrothermal activity, it is reasonable to consider that the geothermal potential of the Azores Archipelago is significant and, on at least several of the islands, there is potentially exploitable geothermal energy for power generation. The geothermal sources have been used for power production since 1980, at the Ribeira Grande Geothermal Field (RGGF) in S. Miguel Island, and since 2017 at the Pico Alto Geothermal Field (PAGF) in Terceira Island. Extensive exploration studies for the evaluation of geothermal resources potential are limited to these two islands, where the technical-economic feasibility of geothermal power projects is easily demonstrated (Carvalho, 1996; Carvalho et al., 2005; Ponte, 2012). Further investigations in other areas, including a variety of surface studies and drilling activities, are required for a complete and accurate assessment of the capacity for power generation (and direct uses) on the islands of the Azores.

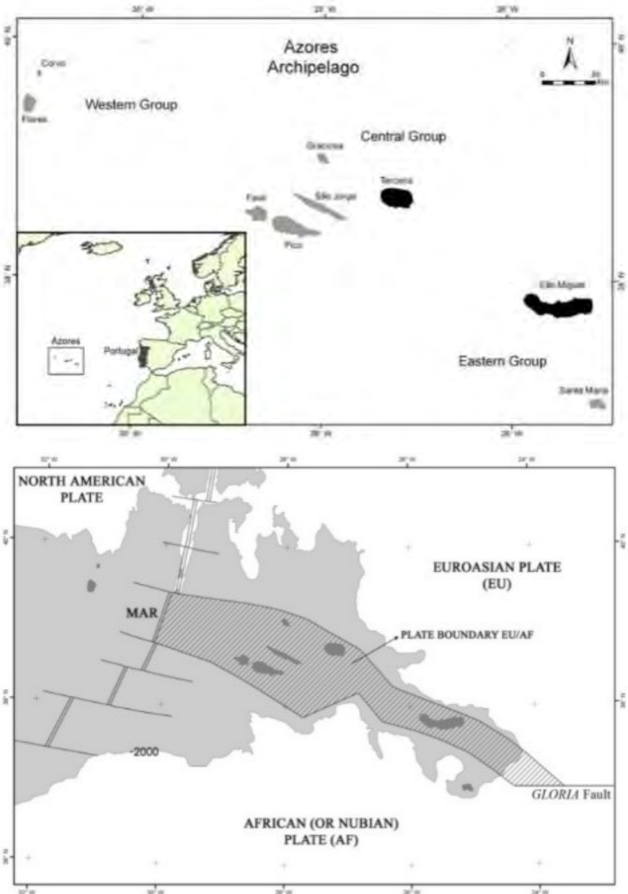


Figure 1: Location of Portugal Mainland, the Azores Archipelago and S. Miguel and Terceira islands (top) and the Azores Triple Junction area (bottom). MAR: Mid Atlantic Ridge. Shaded area represents the "Azores Plateau" (in: Nunes et al., 2016).

The low enthalpy resources are very well represented in Mainland Portugal, where classical geothermal resources, generally associated with the active faulting in the Variscan basement and diapirism in the sedimentary borders, are used at thermal spas and in a few cases in several small direct use operations (heating of hotels and swimming-pools) beside the thermal spa installations. Previous geothermal installations for fish-farming, green-houses and a VALOREN geothermal project supported by a 1500 m deep well in Lisbon are no more operational.

In the Azores islands, the low enthalpy resources are directly related to the high enthalpy systems. A few thermal springs with temperatures up to 92 ºC occur in almost all the islands, but the existing thermal spas are restricted to the islands of S. Miguel, Graciosa, and Faial. An Azorean governmental strategy to evaluate and value those resources and other hot spots revealed by groundwater prospecting wells, aiming for balneological and direct uses, was implemented since 2004 by INOVA – "Instituto de Inovação Tecnológica dos Açores", the local agency for innovation (Nunes et al., 2007).

The relatively mild weather in the Azores does not favour the use of geothermal energy for HVAC, however, GSHP may be seen technically as an adequate solution for cooling, and even dual purposes, in the country.

2. GEOTHERMAL FIELDS

2.1 High Enthalpy Fields

The Azores Archipelago is in the North Atlantic Ocean, associated with the triple junction of the North American, Eurasian, and African (or Nubian) plates (Figure 1). The nine islands that form the archipelago are spread over 600 km, along with a WNW-ESE trend, and emerge from the designated "Azores Plateau", which is defined by the bathymetric line of 2000 m. The Azores display intense seismic and volcanic activity. Since the discovery and settlement of the islands, in the early 15th century, 26 eruptions were recorded inland and onshore. Volcanic and seismotectonic activity are more concentrated in the Central Group islands and in the S. Miguel island, those at the plate boundary between the Eurasian and African plates (Figure 1).

On the island of S. Miguel, there are three active poly-genetic volcanoes with caldera that produced mostly explosive trachytic *s.l.* eruptions in recent times: Sete Cidades, Furnas, and Fogo volcanoes. A fourth silicic polygenetic volcano with caldera (e.g. Povoação volcano) and two Basaltic Fissural Areas (e.g. the Picos and Nordeste Complexes) complete the volcanic systems of S. Miguel island (Figure 2).

The Ribeira Grande Geothermal Field is located on the northern slopes of the Fogo central volcano (Figures 2 and 3) and this liquid-dominated high enthalpy system reaches maximum temperatures of about 245 ºC in depth.

Figure 2: Volcanological map of S. Miguel Island (Nunes, 2004). The RGGF- Ribeira Grande geothermal field concession area is outlined.

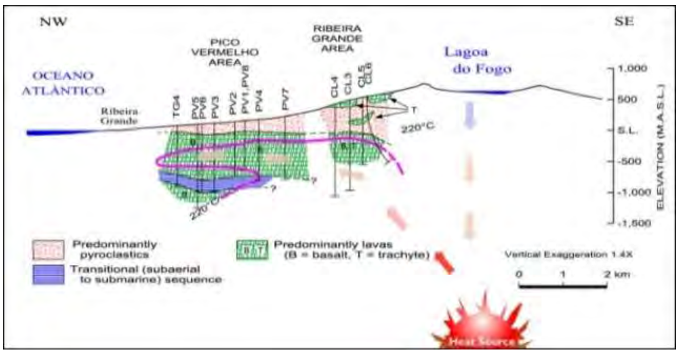


Figure 3: Generalized cross-section of the RGGF (adapted from GeothermEx, 2008).

Surface geothermal manifestations are spread on those three active central volcanoes of S. Miguel Island, which are particularly impressive at Furnas volcano caldera, with the presence of about 30 thermal springs and fumaroles.

On Terceira Island, which has a complex tectonic setting, there are four central volcanoes with caldera (Cinco Picos, Guilherme Moniz, Santa Bárbara, and Pico Alto – in decreasing age sequence) and the Fissural Basaltic Zone, in the central and SE part of the island (Figure 4 - Nunes, 2000). The Pico Alto volcano (the younger polygenetic volcano) is dominated by siliceous formations of pyroclasts, domes and *coulées* of trachytic to pantelleritic nature.

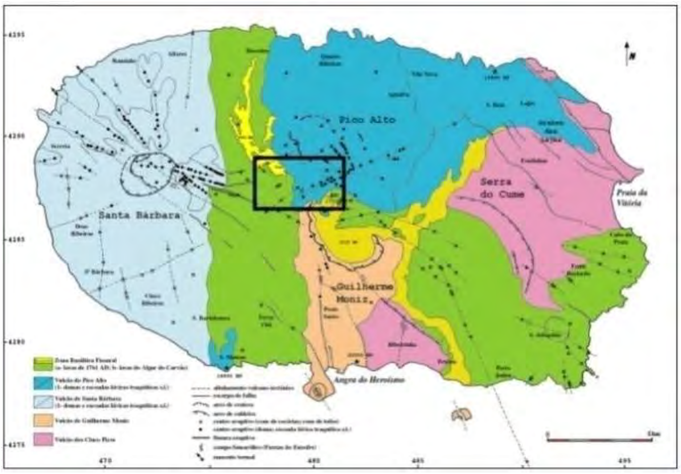


Figure 4: Volcanological map of Terceira Island (Nunes, 2000); The PAGF- Pico Alto geo-thermal field concession area is outlined.

At surface, the Pico Alto Geothermal Field encompasses mostly Pico Alto volcano and the Fissural Basaltic Zone formations (Figure 5), but the geothermal systems develop in a complex volcanological setting, that encompasses the interference of the Pico Alto (PA), Guilherme Moniz (GM) and even Santa Bárbara central volcanoes formations. This high enthalpy system reaches temperatures of about 300 ºC in depth.

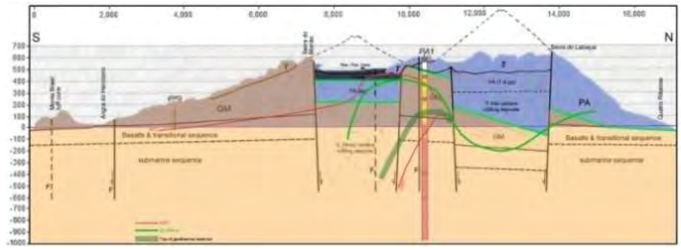


Figure 5: General N-S cross-section of Terceira Island, including the PAGF (adapted from TARH & ÍSOR, 2016).

2.2 Low Enthalpy Resources Occurrences

The low enthalpy geothermal resources, in Portugal, can be found in the Azores Archipelago, in the dependency on the high enthalpy resources, and on the mainland.

In the Azores Islands, surface geothermal manifestations are reported in all islands but Corvo and Santa Maria islands. In total, 48 surface geothermal occurrences of low enthalpy (with temperatures between 22 and 98 °C) have been identified, most of them (25 cases) in the Furnas Volcano in S. Miguel Island (DGEG, 2017).

Presently four Thermal Baths/Spas using geothermal resources are installed in Graciosa and S. Miguel islands (e.g., Carapacho, Furnas Boutique Hotel, Banhos da Coroa/Caldeiras da Ribeira Grande and Ferraria). At Furnas Volcano, in S. Miguel Island, in addition to the use of thermal water in swimming pools and other recreational infrastructures, the Quenturas spring is abstracted for use in the Furnas Boutique Hotel Thermal & Spa: Figure 6 shows the conceptual model of this exploited aquifer.

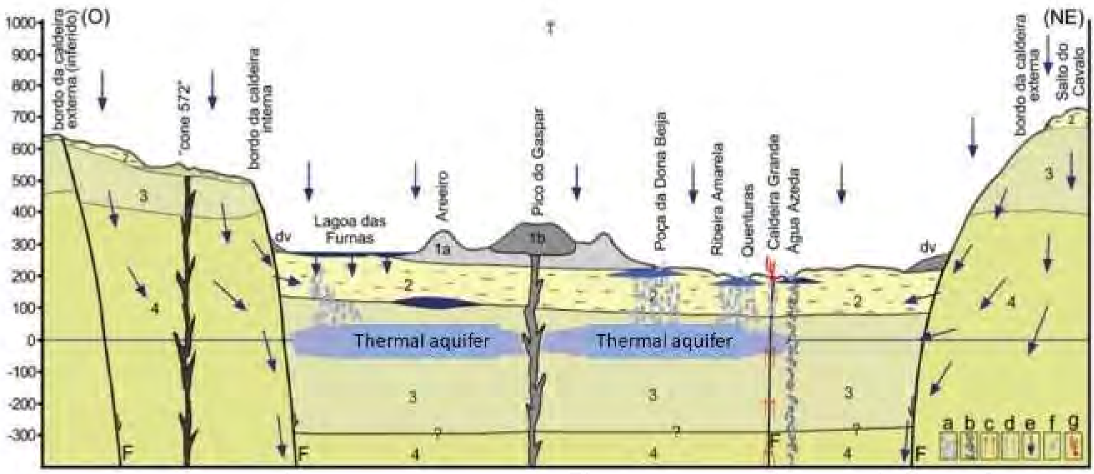


Figure 6. Conceptual model of Quenturas spring aquifer (Furnas volcano):
1a) and 1b) historical eruption, 15th century; 2) "Upper Furnas Group" formations; 3) "Middle Furnas Group" Formations; 4) "Lower Furnas Group" formations; dv slope deposits; F) fault/fracture.
Legend at lower right: a) steam (steam + gases); b) volcanic gases; c) deep geothermal water; d) thermal water; e) aquifer recharge; f) thermal and/or mineral springs; g) fumarole. Adapted from Freitas et al. (2020).

As represented in Figure 7, the Portuguese mainland is composed of the following geological units: (i) PreMesozoic Variscan basement, (ii) Western and Southern Meso-Cenozoic borders, and (iii) Ceno Antropozoic basins of Tejo and Sado rivers.

The following geotectonic zones are generally considered part of the Variscan Massif: (i) Central Iberian zone including the Middle Galicia-Trás os Montes domain, (ii) Ossa-Morena zone, and (iii) South-Portuguese zone.

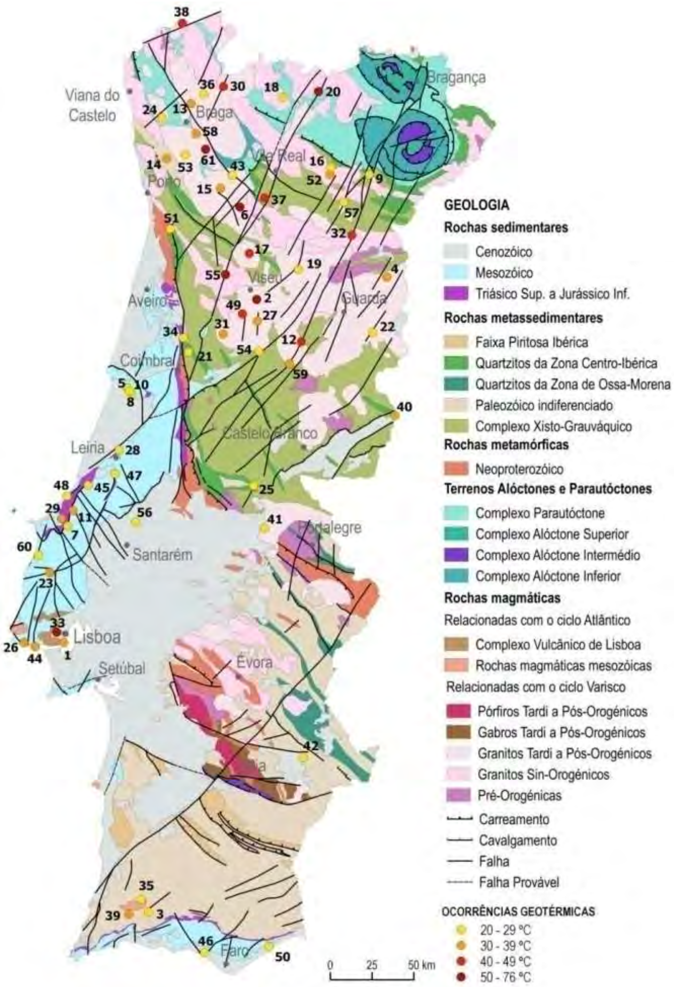


Figure 7: Geological map of Portugal Mainland and thermal occurrences (in: DGEG, 2017).

From the lithological point of view, the main rocks are granites of the Variscan orogeny and metasediments pre and post-orogenic. Weathering is quite irregular, depending on tectonics and present and past climates: average reported depths to found rock massifs range from 0 to 60 m, but in the vicinity of the main tectonic axis it is not infrequent to drill up to 300 m of weathered rock.

Most Portuguese thermo-mineral water of hard rock origin comes from the Central Iberian Zone. As pointed out by Ribeiro and Almeida (1981), this could not be a simple inheritance of the geological history, and another factor plays an important role in the productivity and distribution of springs: the recharge conditions which are largely higher in the northwestern area of Portugal.

The average annual rainfall (P) reaches 1811 mm in this area, but this figure decreases to less than 600 mm in some eastern and southern regions, the average annual rainfall for the entire country being 917 mm. About 55 % of precipitation is lost by evapotranspiration. The average air temperature is about 15 ºC, but the winter season is severe in the northern areas.

The recharge has an average value in the range of 223 mm, varying from 50 to 350 mm (LABCARGA, 2017). In the Central Iberian Zone, where most thermal manifestations are present, the average Rate of Infiltration ranges from 10 % to 15 % (LABCARGA, 2017) which seems satisfactory for recharge conditions for the existing thermal spring facilities. However, this is not enough to ensure sustainability for future geothermal operations dealing with higher extraction rates.

As expected, tectonics (and particularly active structures, for thermal waters, in a geological sense) is closely related to the occurrence of thermal springs. The distribution of mainland users of geothermal energy (thermal baths) is superimposed in Figure 7 with tectonic data from Cabral (1995; in: DGEG, 2017). Thermal anomalies follow axis trending NNE, NW, and ENE along the main active faults.

Naturally available discharging flows from former exploitation systems range from a few cubic meters/day to 864 m^3/day. In general, with new-drilled wells, it has been possible to increase former production. However, for the running exploitation, and considering real needs and/or environmental constraints, exploited yield is normally under the maximum permitted by the hydrodynamics of the aquifer and wells.

The temperature of occurrences, nowadays tube wells and boreholes, goes up to 77 ºC. Among Portuguese mineral waters, twenty-eight discharges with temperatures higher than 25 ºC are used for balneological purposes. Ten of those springs reach over 50 ºC. Other thermal springs occur all over the Northern area of Portugal Mainland and at the sedimentary basins. Examples of those exploited thermal aquifers are in Figures 8 (Chaves) and 9 (Vimeiro), respectively.

The Portuguese government through the FAI – "Fundo de Apoio à Inovação", developed in 2021 (DGEG et al., 2021) a national plan to demonstrate the feasibility of using natural mineral water in existing spas as geothermal resources for heating purposes, to replicate several direct use operations in due course since the 1980s. Those resources were evaluated at about 184 GWh/year on mainland and 9 GWh/year in the Azores mineral waters (DGEG et al., 2021). Those figures are only indicative of the existing potential and have a limitation: local resources were evaluated from an administrative point of view.

3. GEOTHERMAL UTILIZATION

Geothermal energy in Portugal is used for electricity production, for direct use associated with thermal baths/spas, and in Ground Source Heat Pumps. Tables

A to G at the end of this paper present the characterization of the geothermal uses in Portugal, in general terms as of December 2021.

3.1 Electric Power Installation and Generation

The geothermal sources have been used for power production since 1980, at the Ribeira Grande Geothermal Field (RGGF) in S. Miguel Island, and since 2017 at the Pico Alto Geothermal Field (PAGF) in Terceira Island.

The geothermal policy in Azores issued by the Azores Government is developed in the field by the regional electric utility EDA – Electricidade dos Açores S.A., through its affiliated company EDA RENOVÁVEIS S.A. (a joint of formers SOGEO - Sociedade Geotérmica dos Açores S.A. and GeoTerceira - Sociedade Geoeléctrica da Terceira S.A. companies).

At the RGGF two geothermal power plants – Ribeira Grande and Pico Vermelho – are in operation with a combined installed capacity of 27.8 MW (Table B). Both plants are based on ORC binary systems. A 4 MW geothermal pilot power plant was installed in the PAGF and operates since August 2017.

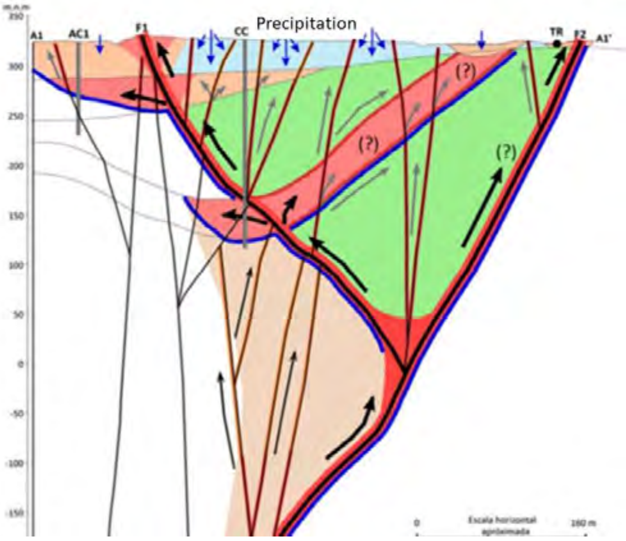


Figure 8: Conceptual model of the Chaves thermal aquifer, close to the exploitation wells (Freitas, 2015; in: DGEG et al., 2021).

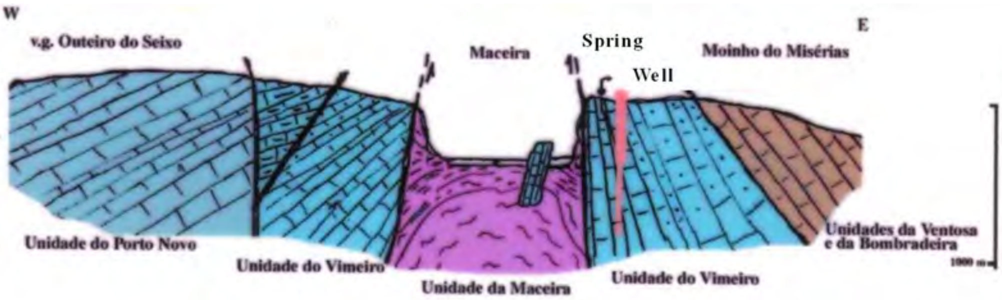


Figure 9: Conceptual model of the Vimeiro thermal aquifer (adapted from Chaminé et al., 2004).

The last years were extremely relevant for high enthalpy geothermal resources in the Azores, as previously documented (e.g., Carvalho et al., 2015; Nunes et al., 2016; 2019; 2021). In the RGGF (S. Miguel Island) the development of geothermal resources has been very successful, with an annual average contribution of about 40 % of the electricity produced on the island since 2013. Nevertheless, in 2021 the production in the RGGF was only 133 GWh/year (Table B) - about 30 % of the total production of electricity on the island - due to a failure on the Pico Vermelho power plant alternator (EDA, 2021). During 2021 six deep wells were drilled to increase the total running capacity up to 30 MW_e.

The total generation capacity of the PAGF Power Plant is 4 MW, following the evaluation tests carried out during 2013/2014, but is not still saturated with the existing production wells in this geothermal field (PAGF). Thus, in 2021 three deep wells were drilled to ensure the saturation of the existing power plant, and if possible, to increase the installed capacity in Terceira Island. In 2021 the production in the PAGF was about 26 GWh/year (Table B), 13,4% of the total production of electricity on the island (EDA, 2021)

3.2 Direct Heat Uses

Direct use application in the mainland and the Azores is restricted to small district heating operations and mainly balneological applications. The situation was reported recently, namely by Carvalho et al. (2015), Lourenço (2016), DGEG (2017), Nunes et al. (2019), DGEG et al. (2021), and no significant changes are to be mentioned.

Portugal, like other Mediterranean countries, has more levelled heating and cooling needs than Nordic countries. Therefore, in Portugal GSHPs are usually reversible, providing heating and cooling. The equilibrium between heating and cooling in a dwelling is important to maintain the temperature stability of the ground over the years.

In the residential sector, heating needs are higher than cooling needs, which can lead to a ground temperature decrease. However, that problem is smaller than in northern and central European countries. Commercial buildings can have more cooling needs, a function of the activity developed in the building, so special attention must be paid to geothermal borehole heat exchangers (BHE) design to avoid the ground temperature increase.

The Portuguese government is developing a national plan to demonstrate the feasibility of using natural mineral water in existing Spas as geothermal resources for heating purposes. The consortium SYNEGE/EST (IPS) has just run a Project to be carried out in the mainland and Azores (DGEG et al. 2021).

3.2.1 District Heating

Two main operations are running normally in thermal baths:

- Chaves, Northern Portugal: a dedicated well, 150 m deep, 76 ºC, TDS of 2500 mg/l, 5 l/s capacity, in metamorphic slates with quartz veins, is used in a small district heating network (swimming pool and hotel). Another well (208 m deep, 74 ºC, TDS of 2500 mg/l, 10 l/s capacity), taped hot water in metamorphic slates with quartz veins and feeds the Thermal Bath as well as the district heating network. A third well (100 m deep, 68 ºC) is maintained as a backup well. Furthermore, in Chaves, an independent small operation (110 kW_{th}) was open in January 2022 in an emblematic museum located over an impressive former Roman Bath with innovations regarding the environmental management of the geothermal fluid and its disposal.
- S. Pedro do Sul, central Portugal, the main Portuguese Spa: one inclined well, 500 m deep, 69 ºC, 350 mg/l TDS, 10 l/s with artesian flow, in fractured granite, supplies the Thermal Bath and is in use in a small heating operation, financed by the Thermie Program, in two hotels, and inside the Spa. The total available production (classical spring and well AC1) is 17 l/s.

Several minor district heating operations are running in Caldas de Monção, Termas da Longroiva and Alcafache thermal baths in Mainland, and at Furnas hotels, in S. Miguel Island, Azores.

3.2.2 Bathing and Swimming

Balneological activities using thermo-mineral waters are quite popular in Portugal for the cure and touristic purposes. About 30 Thermal Baths are operating within a legal framework (cf. DGEG, 2017). Several of them are open only in summer, but some are normally operating all over the year. All the balneological activity inside the baths is carried out under strict medical control.

Since 2004 the INOVA Institute and the Azores Government undertake several initiatives and studies allowing the exploitation and valuing of the Azorean low-temperature geothermal resources for direct use, including touristic activities and balneology (Nunes et al., 2015). Associated with these activities new shallow wells were carried out in Ferraria (S. Miguel), Varadouro (Faial) and Carapacho (Graciosa).

3.3 Ground Source Heat Pumps

According to the latest data recorded by EHPA, European Heat Pump Association, there were no new sales of GSHP in Portugal in 2014. The aggregated sales until 2014 were about 54 units with an installed capacity of 0.65 MW. Considering typical values, the average installed capacity was 12 kW, with an operating hours value of 1340 and a typical Seasonal Performance Factor (SPF) of 3.425. For the years after 2014, it was not possible to obtain data. Thus, it is difficult to follow the evolution of new projects concerning GSHP, since Portugal still doesn´t have legislation to oblige the registration of this kind of projects, especially concerning the residential sector. Therefore, it is possible that a greater number of small installations are performed each year, but are not registered.

With a view to increase the knowledge in this area and inherently promote the dissemination and proper use of GSHP, four national entities (DGEG, LNEG, APG, and ADENE) established a collaboration protocol concerning the creation of a baseline study, analysis, and dissemination of geothermal use through GSHP. The Portuguese Platform of Shallow Geothermal Energy (PPGS) was created in 2013 with the mission to disseminate the best practices involving GSHP, promote the dialogue on the geothermal community, collaborate on new legislation, spread knowledge of technical standards and procedures, contribute to the training of the agents involved and to promote the development of new projects. However, due to the weak interest in the application of shallow geothermal energy in Portugal, this platform ended its activity in 2017.

One of the gaps in Portugal for the development of shallow geothermal energy is the lack of a legal framework. A new legislative framework concerning shallow geothermal purposes began to be prepared about 8 years ago. The latest version from the working group was finalized in 2019 and the document was passed to the Portuguese parliament to be approved. Unfortunately, the document has not yet been approved, which continues to limit the progress of the implementation of GSHP installations. The proposed legislative framework imposes the obligation to register the installed GSHPs. Therefore, another important progress after the proposed legislation is approved, will be to have the registration of all the systems installed, from then on, which will allow to have statistical data on new installations in the future.

Despite the lack of registration, there is some information about GSHP projects developed in Portugal (e.g., Edifícios e Energia, 2013, Cardoso and Lapa, 2015a; 2015b, Ferreira, 2019), that was presented in more detail on previous reports (see also Carvalho et al., 2015; Nunes et al., 2016; 2021) and is summarized below:

- Brigantia Ecopark in Bragança: it is equipped with three GSHP, one just for domestic hot water (DHW) heating and two for building acclimatization. To dissipate the heat generated by the GSHP, 45 boreholes with a depth of 120 m were performed. Regarding GSHP for DHW, only heat is produced, and the system is interconnected with DHW reservoir. Concerning the other two GSHP, for acclimatization, heat and cool is produced and the system is connected to a buffer tank of 9000 l.
- Aveiro University: the university has 5 buildings (ECORR, ESAN, CCI, CICFANO, and ESSUA buildings) acclimatized with GSHP and has been also collaborating with "Chama Energia" company in other projects.
- Superior School of Technology of Setúbal (EST Setúbal): the Polytechnic Institute of Setubal, which was a partner in the GROUNDHIT European Project (6th Framework Program), has a demonstration site for high energy efficiency GSHPs. Two GSHPs of 15 KW_{th} for heating and 12 KW_{th} for cooling each, were installed to acclimatize 7 office rooms and 2 classrooms. The project aimed at monitoring the prototype of improved energy efficiency heat pumps (COP higher than 5.5) in real conditions in a Mediterranean climate, and test two different Boreholes Heat Exchangers (BHE) types: double-U pipes and coaxial pipes. The demo site results showed that the GSHPs COP is according to the expected ones during the design phase (COP of 5.19 for cooling and 6.05 for heating in real conditions), with a good performance in the terminal units (fan-coils, secondary circuit), boreholes (primary circuit) and GSHP.
- Regional authority administration building in Coimbra: under the scope of the GROUNDMED European Project (7th Framework Program) an installation was set on a regional authority building with offices and laboratories, located in Coimbra city. One GSHP with a heating capacity of 56 kW_{th} and cooling capacity of 61 kW_{th} (Eurovent conditions) serves the building's 3rd-floor offices. The GSHP is coupled to seven double U, 125 m vertical borehole heat exchangers. The heating/cooling distribution system consists of 33 ceilings Coanda effect fan coil units with high-efficiency permanent magnet EC motors, installed in 22 offices, with a total area of 600 m^2. Since all systems were designed to function with moderated temperatures, the real cooling capacity is 63.5 kW_{th} and the real heating capacity is 70.4 kW_{th}, resulting in increased performance. The results showed good results with a GSHP COP of 5.65 and an EER of 6.19.
- Sines Tecnopolo: this complex, which includes heating, cooling, and DHW production, has an existing renewed building with 251 m^2, a laboratory building with 534 m^2 and an office building with 1286 m^2, all served by GSHPs. The existing renewed building is served by one GSHP with a heating capacity of 24.5 kW_{th} and cooling capacity of 18.4 kW_{th}, coupled with 2 simple U, 150 m vertical borehole heat exchangers;
- Ombria Resort, Algarve: this resort (with one golf course, the clubhouse, one hotel, one spa, and some villas) represents the largest installation of shallow geothermal energy in Portugal. The total needed capacity based on GSHP is about 2370 kW of heating and 1100 kW of cooling. The clubhouse has an area of 1260 m^2 and the hotel, spa, and villas have an area of 15'940 m^2. For the clubhouse, 40 BHE with 100 m depth each were installed, for the hotel 60 BHE with 125 m depth each, and for the spa and villas, 144 BHE with 115 m depth each. A total of 108 solar collectors (vacuum type) for the clubhouse, and 48 solar collectors for the hotel was installed, for DHW, hot water for the swimming pools, and also to inject heat into the ground through the BHE to equilibrate the balance of energy injected and extracted by the GSHP throughout the year.

In addition to the mentioned installations, only a few small installations, essentially in houses, have been implemented. However, in the recent future, interest in GSHP installations seems to be growing again. New projects are planned, namely an installation in a tourist resort in the south of Portugal. It is estimated a total capacity of around 675 kW_{th}. Also, an installation is planned in a residential building in Lisbon, for heating and cooling with a total capacity of around 800 kW_{th}. Some installations are also foreseen for individual houses and for an industry.

4. CONCLUSIONS

In Portugal, the presence of high-temperature geothermal resources and the production of electricity from geothermal resources are restricted to the active volcanic systems in the islands of the Azores Archipelago.

Presently EDA RENOVÁVEIS S.A. has a total installed generation capacity in S. Miguel Island Azores of 27.8 MW net in two geothermal power plants. Those power plants ensured the production in 2021 of 133 GWh_e in S. Miguel Island, which represents 30 % of the total production of electricity on the island (about 443 GWh). During 2021 six deep wells were drilled to increase the total running capacity of the Ribeira Grande and Pico Vermelho power plants up to 30 MW_e.

On Terceira Island, three new deep wells were drilled with the main goal to support the existing 4 MW Pico Alto power plant (that started operating in August 2017), and if possible, to increase the installed capacity in the island. In 2021 the energy production was about 26 GWh_e, which represents 13.4 % of the electrical production of the island (194 GWh).

Low-temperature geothermal resources in Mainland Portugal are exploited for direct uses in balneotherapy and small district heating systems.

Concerning GSHPs there are a few installations registered until 2014, but the registration data of the installations is scarce and do not represent the totality of what is installed in Portugal. However, this tends to change due to the preparation of new legislation for regulating shallow geothermal operations.

The Ombria Resort installation, the largest shallow geothermal energy in Portugal is located in the Algarve and represents an interesting case study about the use of this renewable energy source to promote and disseminate this technology in Portugal.

In fact, a new legislation draft on GSHPs was already prepared by the Directorate-General for Energy and Geology (DGEG) – the Portuguese authority for those geological resources – that will contribute not only to ameliorating the quality of the operations but also to allow future statistical data to be more realistic. However, its approval in the Portuguese parliament has taken a long time. Approval is expected to be forthcoming but there is no certainty.

In addition, in 2018 a call for geothermal projects was released, sponsored by the FAI – "Fundo de Apoio à Inovação", to promote the use of geothermal resources in Portugal, namely the low enthalpy resources associated with Thermal Baths/Spas facilities. An assessment was carried out grouping the hydromineral and geothermal resources in 4 geographic zones by their location: North Zone; North Central Zone; Central South and South Zone; Azores archipelago. The results of this project have been published (DGEG et al., 2021) and allow for a more in-depth understanding of the potential for exploitation of hydromineral and geothermal resources and their use at temperatures above 25 °C, with the aim of stimulating the use of these resources in the future. It was identified that for installations with a resource temperature below 35 ºC, the most advantageous scenario is the preheating of DHW with the support of GSHPs, since for any application it is always necessary to use the thermal support system.

REFERENCES

Cardoso, C. and Lapa, J.: A geotermia na sustentabilidade de campi universitários: os casos de estudo do edifício CICFANO e da escola superior de saúde, *PPGS Newsletter* **3**, (2015a), 6-9.

Cardoso, C. and Lapa, J.: A geotermia na sustentabilidade de campi universitários: os casos de estudo dos edifícios de comunicações óticas, da escola superior Aveiro Norte comunicações rádio e robótica e do complexo do departamento de comunicação e arte, *PPGS Newsletter* **4**, (2015b), 8-10.

Carvalho, J.M.: Portuguese geothermal operations: a review. *European Federation of Geologists Magazine* **3-4**, (1996), 21-26.

Carvalho, J.M., Monteiro da Silva, J.M., Bicudo da Ponte, C.A. and Cabeças, R.M.: Portugal country geothermal update. *Proceedings of the World Geothermal Congress 2005*, Antalya, Turkey, (2005), paper #0170, 11 pp.

Carvalho, J.M., Coelho, L., Nunes, J.C., Carvalho, M.R., Garcia, J. and Cerdeira, R.: Portugal Country update 2015, *Proceedings of the World Geothermal Congress 2015,* Melbourne, Australia, (2015), paper #01065, 11 pp.

Chaminé, H.I., Fonseca, P.E., Carvalho, J.M., Azevedo, M., Gomes, A. and Teixeira, J.: Geometria, cinemática e dinâmica diapírica da morfoestrutura do Vimeiro (Torres Vedras, Portugal Central): implicação para um modelo hidrogeológico. *Caderno Lab. Xeolóxico de Laxe* **29**, (2004), 9-30.

DGEG: *Geotermia - Energia Renovável em Portugal*. DGEG - Direção Geral de Energia e Geologia, (2017), Electronic Edition, 54 pp., ISBN: 978-972-8268-44-2.

DGEG/FAI/SYNEGE/IPS/AREAL/AÇORGEO: *Avaliação do potencial de exploração dos recursos hidrominerais e geotérmicos e da sua utilização para temperaturas superiores a 25ºC*. DGEG/FAI/SYNEGE Edition, (2021), 191 pp.

EDA, Electricidade dos Açores: *Procura e Oferta de Energia Eléctrica – Dezembro*, (2021), 30 pp. (Electronic Edition).

Edifícios e Energia Magazine: Issue Nov./Dec., (2013).

Ferreira, G.: Geotermia aplicada aos sistemas de climatização do Ombria Resort. *Curso de Formação "Introdução aos sistemas geotérmicos* superficiais", VIII Jornadas APG, Lisboa, Portugal (2019), 20-21 February, ppt presentation.

Freitas, A, Sá, H., Carvalho, M.R. and Nunes, J.C: Conceptual model of the Quenturas hydromineral resource (Furnas Volcano, S. Miguel Island): A contribution. *Comunicações Geológicas* **107**, (2020), 97-98. ISSN 1647-581X.

GeothermEx: Update of the conceptual and numerical model of the Ribeira Grande Geothermal Reservoir, São Miguel, Açores. *Sociedade Geotérmica dos Açores S.A. Internal Report*, (2008), 190 pp.

LABCARGA: Desenvolvimento de métodos específicos para a avaliação da recarga das massas de água subterrâneas, para melhorar a avaliação do estado quantitativo. Relatório final. *Laboratório de Cartografia e Geologia Aplicada*, Porto, (2017), 141 pp.

Lourenço, C.: Geothermal resources, natural mineral and spring waters: an overview, *PIMBIS 2016– Portugal International Mining Business & Investment Summit*, Lisbon, April 12th-14th, (2016), pdf pps presentation.

Nunes, J.C.: Notas sobre a geologia da Ilha Terceira (Açores), *Açoreana* **9 (2)**, (2000), 205-215.

Nunes, J.C.: Geologia, in: Atlas Básico dos Açores, Forjaz, V.H. (Ed.), 60-62, *Observatório Vulcanológico e Geotérmico dos Açores*, Ponta Delgada, (2004).

Nunes, J.C., Carvalho, J.M., Carvalho, M.R., Cruz, J.V., Freire, P. and Amaral, J.L.: Aproveitamento e valorização de águas termais no Arquipélago dos Açores, in: *O Valor Acrescentado das Ciências da Terra no Termalismo e no Engarrafamento da Água*. II Fórum Ibérico de Águas Engarrafadas e Termalismo, Chaminé, H.I. and Carvalho, J.M. (Eds.), Departamento de Engenharia Geotécnica/Laboratório de Cartografia e Geologia Aplicada (LABCARGA), Instituto Superior de Engenharia do Porto, (2007), 209-230, ISBN: 978-989-20-0892-9.

Nunes, J.C., Carvalho, J.M. and Olivera, L.C.: Águas termais dos Açores: passado, presente e futuro, *Balnea* **10**, (2015), 279-288. ISBN: 978-84-606-9368-0.

Nunes, J.C., Coelho, L., Carvalho, M.R., Garcia, J., Cerdeira, R. and Carvalho, J.M.: Geothermal energy use, country update for Portugal. *Proceedings of the European Geothermal Congress 2016,* Strasbourg, France, (2016), 11 pp. (Electronic Edition).

Nunes, J.C., Coelho, L., Carvalho, J.M., Carvalho, M.R. and Garcia, J.: Geothermal Energy Use, Country Update for Portugal. *Proceedings of the European Geothermal Congress 2019,* Den Haag, The Netherlands, (2019), 11 pp. (Electronic Edition).

Nunes, J.C., Coelho, L., Carvalho, J.M., Carvalho, M.R. and Garcia, J.: Portugal Country Update 2020. *Proceedings of the* World *Geothermal Congress 2020,* Reykjavik, Iceland, (2021), 12 pp. (Electronic Edition).

Ponte, C.B.: Aproveitamento de recursos geotérmicos para a produção de electricidade nos Açores, *Ingenium*, Set/Out, (2012), 64-67.

Ribeiro, A. and Almeida, F.M.: Geotermia de baixa entalpia em Portugal Continental. *Geonovas* **1 (2)**, (1981), 60-71.

TARH & ÍSOR: Conceptual model of the Pico Alto Geothermal Field, Terceira Island, Azores, Final Report. *EDA RENOVÁVEIS S.A. Internal Report*, (2016), 73 pp.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	26	158.9	22’421	53’054	0.12	0.3
Under construction end of 2021	0	0	not available	not available	not available	not available
Total projected by 2023	0	0	not available	not available	not available	not available
Total expected by 2028	40	310	not available	not available	not available	not available
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development: 2	
					Under investigation:	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Ribeira Grande (S. Miguel Island, Azores)	Pico Vermelho	2006	1 (RI)	O	B-ORC	13.0	13	68.3
Ribeira Grande (S. Miguel Island, Azores)	Ribeira Grande	1994/ 1998	4 (RI)	O	B-ORC	14.8	10	64.7
Pico Alto (Terceira Island, Azores)	Pico Alto	2017	1 (RI)	O	B-ORC	4	3	25.9
total						31.8	26	158.9

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
R	Retired / decommissioned	2F	Double Flash	O	Other

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	2.1*	12.3*	0	0	2.0*	3.2*	17.1*	125*
Under constru-ction end 2021	4	0	0	0	0	0	0	0
Total projected by 2023	5	30	Not available	Not available	Not available	Not available	Not available	Not available
Total expected by 2028	5	30	Not available	Not available	Not available	Not available	Not available	Not available

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Chaves	Chaves	1982/ 2015	N	N	0.9	Not available	7.4*	Not available
S. Pedro do Sul	S. Pedro do Sul	2000/ 2015	N	N	1.2	Not available	4.82*	Not available
total					2.1*		12.3*	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Monção			N	Not available	Not available	Not available		
Vizela			N	Not available	Not available	Not available		
Alcafache			N	Not available	Not available	Not available		
Longroiva			N	Not available	Not available	Not available		
Carvalhal			N	Not available	Not available	Not available		
Caldas S. Paulo			N	Not available	Not available	Not available		
Furnas (Azores)		2016	N	Not available	Not available	Not available		
total				2*		3.1*		

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	Not available	Not available	Not available	Not available	Not available	Not available
Of which networks **						
Projected total by 2023	Not available	Not available	Not available			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

There are no shallow geothermal UTES installations currently existing in Portugal.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	EDA RENOVÁVEIS S.A.	EDA RENOVÁVEIS S.A.	EDA RENOVÁVEIS S.A.	EDA RENOVÁVEIS S.A.
Geothermal direct uses	not available	not available	not available	not available
Shallow geothermal	not available	not available	not available	not available
total				

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include “jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration”. For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	Portugal 2020-30 and Horizon 2020-30 (EU)	Portugal 2020-30 and Horizon 2020-30 (EU)	Portugal 2020-30 and Horizon 2020-30 (EU)
Financial Incentives – Investment			
Financial Incentives – Operation/Production			
Information activities – promotion for the public	Some punctual information activities	Some punctual information activities	Some punctual information activities
Information activities – geological information	Some punctual information activities	Some punctual information activities	Some punctual information activities
Education/Training – Academic	A few academic courses/workshops	A few academic courses/workshops	A few academic courses/workshops
Education/Training – Vocational	A few short courses	A few short courses	A few short courses

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for Romania

Robert Gavriliuc[1], Marcel Rosca[2], Doinita Iuliana Cucueteanu[1]

[1] Romanian Geoexchange Society, 66 Pache Protopopescu Blvd., 021414, Bucharest 2 – Romania

[2] University of Oradea, 1 Universitatii Street, 410087, Oradea, Romania

robertgavriliuc@yahoo.com, mrosca@uoradea.ro, doinacucueteanu@gmail.com

Keywords: geothermal energy, Romania, deep geothermal, shallow geothermal, ground-source heat pumps, country update.

ABSTRACT

This country update regarding the geothermal energy use in Romania deals with both deep and shallow geothermal energy. The document presents the latest developments in this field, such as:

- the promotion of six new deep-geothermal projects, financed by the Operational Program for Large Investments (POIM);
- the further development of the deep geothermal project from Balotesti (belonging to the geothermal reservoir located North of Bucharest);
- several representative shallow geothermal projects providing heating and cooling for large office and apartment buildings, and for greenhouses.

The report also presents the latest up-dated information on the energy consumption of the GSHP system from ELI NP Magurele, near Bucharest, which has been running from 2016 onwards.

1. DEEP GEOTHERMAL ENERGY RESOURCES AND EXPLOITATION

1.1 Nufarul District, Oradea City

The City of Oradea, on the western border of Romania, has a population of about 200’000 inhabitants, and is located on top of the Oradea geothermal reservoir of Triassic limestone and dolomite layers at a depth between 2000 and 3000 m (Gavriliuc et al., 2016).

At present, the geothermal reservoir is exploited by 13 production wells with line shaft pumps, and 2 wells are used for reinjection. One production and one reinjection well are situated on the western side of the Iosia district. The 70 °C geothermal water is used to prepare domestic hot water and is then reinjected. From the geothermal heat plant, the domestic hot water is pumped to a high school and many blocks of flats, some of them located hundreds of meters away. Space heating is provided from the district heating system supplied by a co-generation power plant with a gas turbine and two hot water boilers fired by natural gas. The system is in operation for more than 40 years, and is of course very inefficient, as the water cools down inside the pipes during periods of low consumption.

The new project in the Nufarul district is currently in the final design stage. The planned activities are:

- drilling a new production well;
- construction of a new geothermal heat plant provided with heat exchangers and heat pumps to extract more heat from the available heat flow of geothermal water;
- abandon the existing sub-stations of the district heating system and replace them with fully automated modules to be placed in the basement of the consumers;
- connect the modules that will provide space heating and domestic hot water to the geothermal heat plant;
- connect the geothermal heat plant to three production wells, one currently used for the hot tap water system, one existing but not used yet, and the new one, to be drilled in the near future;
- drill a new reinjection well;
- connect the geothermal heat plant to the two reinjection wells (existing and new);
- connect the geothermal heat plant to a main transportation pipeline of the district heating system (for peak loads and back-up).

The new system will have a significantly higher efficiency as compared to the present one, will have an installed capacity of 12.85 MW_{th} of geothermal energy, and will reduce the emissions by about 13’000 tons CO_2 equivalent per year.

1.2 Beius City

The City of Beius is about 60 km south-east of Oradea on the foothills of the Western Carpathians, has a population of about 11’000 inhabitants, and is located on top of the Beius geothermal reservoir of Triassic limestone and dolomite layers at a depth between 2000 and 3000 m (Gavriliuc et al., 2016).

The geothermal reservoir is currently exploited by two production wells with about 80 °C wellhead temperature, and part of the heat depleted geothermal water is reinjected through another well. The geothermal water is sent to 5 heating plants that provide space heating and hot tap water in areas with a large heat demand density (blocks of flats, schools, hospitals, etc.). In areas with low heat demand density (individual family house), the geothermal water is transported through pipes to the small modules that provide space heating and domestic hot water to one or two houses. The heat depleted geothermal water is drained into the pluvial sewage system. This way, the investment cost is much lower and the system is economically reliable at an affordable heat cost for the consumers. As the mineralisation of the geothermal water is very low, below 1 g/l, it causes no pollution when drained into the river that flows through the city. The total installed capacity of the existing system is about 20 MW_{th}.

The new project plans to drill a new production well and connect it to the main geothermal water distribution pipeline. This will allow to supply space heating and hot tap water to more than 500 flats that decided to connect to the geothermal district heating network. This project will add 12.35 MW_{th}. to the installed capacity of the geothermal district heating system and will reduce the emissions by 2’109 tons of CO_2 equivalent.

1.3 The Pannonian aquifer

Four new projects will be developed to use geothermal water from the Pannonian sandstone described in detail by Antics (1997). All these projects have basically the same plan: drilling one production and one reinjection well, building a geothermal heat plant and a district heating system to provide space heating and hot tap water to public buildings (schools, hospitals, City Hall, social institutions, etc.). The most delicate part will be the design and completion of the new wells, mainly the reinjection ones, as injection at high flow rates in sandstone is not as easy as it is in fractured reservoirs. Due to the chemical composition of the geothermal water (mainly due to the phenolic compounds), the reinjection is mandatory, as the heat depleted water cannot be disposed of on surface.

Salonta, Bihor County

Salonta is a city located about 30 km south of Oradea, in the Bihor County, with a population of about 19’000 inhabitants. It currently has no district heating system, using natural gas or wood stoves for space heating.

The new geothermal district heating system will have a target installed capacity of 2.3 MW_{th} and will reduce the emissions by 849 tons of CO_2 equivalent. Based on data available from the two existing geothermal wells (not used at present), the depth of the two new wells is estimated at 1700 m, with a well head temperature of about 90 °C.

Pecica, Arad County

Pecica is a town in Arad County (south of Bihor), with a population of about 13’000 inhabitants, and with no district heating system. The heat sources used at present are natural gas and fire wood.

Based on data available from other geothermal wells in the area, the expected depth of the two new wells in Pecica should not be below 2000 m, with an expected wellhead temperature of up to 80 °C. The planned installed capacity of the geothermal heat plant is 1,5 MW_{th} and will reduce the emissions by 158 tons of CO_2 equivalent per year. The geothermal district heating system will supply space heating and hot tap water to all public buildings in the town.

Sandra, Timis County

Sandra is a village in the Timis County (Western Romania), close to the Hungarian and Serbian borders, and with a population of about 2’300 inhabitants. Sandra has no district heating system, the main heat source being natural gas and biomass.

Based on data from geological research in the area, the expected depth of the two new wells is 1,700 m, with a wellhead temperature of about 65 °C. The installed capacity of the geothermal power plant will be 1 MW_{th}. It will supply space heating and domestic hot water to 11 public buildings in the village, and will reduce the emissions by 185 tons of CO_2 equivalent per year.

Dudestii Vechi, Timis County

Dudestii Vechi is another village in Timis County, some 40 km from Sandra, even closer to the Serbian and Hungarian borders. It has a population of about 4’200 inhabitants, no district heating system, the main heat source being natural gas and biomass.

Based on data from geological research and other wells in the region, the expected depth of the two new wells is 1700-1900 m, with a wellhead temperature of between 75 and 90 °C. The installed capacity of the geothermal power plant will be 1.5 MW_{th}. It will supply space heating and hot tap water to 16 public buildings in the village and will reduce the emissions by 373 tons of CO_2 equivalent per year.

1.4. Therme Balotesti

The borehole now in operation was designed and authorized for a 90 m^3/h flowrate. Presently, the extracted flowrate is maximum 54 m^3/h, and the water temperature is 75-77 °C. The obtained heat flow - by decreasing the water temperature from 75 °C down to 25 °C is around 3 MW. The resulting annual energy extracted from the borehole is around 27’000 MWh/year.

In the near future, the spa will expand by one extra building. In order to cover the heating needs, it is required to increase the flowrate provided by the borehole up to 90 m^3/h, value for which it was initially designed and authorized. Considering this assumption, the extracted water will be hotter, reaching about 80 °C. Under these conditions, the heat flow provided will reach 5.2 MW, and the annual extracted energy will be around 45’000 MWh/year.

2. SHALLOW GEOTHERMAL ENERGY RESOURCES AND EXPLOITATION

2.1. ELI-NP Extreme Light Infra-structure

ELI-NP Extreme Light Infra- structure - built in Bucharest-Magurele – is the most important shallow geothermal application from Romania.

ELI-NP is the first pan-European research facility built in Eastern Europe which is oriented on high-level research on ultra-high intensity laser. The heating and cooling output is in the range of 5.4 MW, for a total air-conditioned area of 27’000 m². The ground source heat exchanger consists of 1080 boreholes at 125 m depth, the whole borehole length is 135’000 m.

The total investment cost of about 356 million € was paid mainly from Romania’s allocation of EU structural funds.

The results of monitoring this project for the 2017 year are presented in Gavriliuc et al. (2019).

The total electricity consumption from commissioning to the end of 2021 was 31,000 MWh. The diagram (figure 1) shows that in the last four years of the monitoring period the consumption was relatively constant, with small variations due to environmental factors or the volume of works and tests carried out in the buildings. This amount includes all the consumptions, meaning: heating, cooling and ventilation of the laboratories and of all the support buildings, hot water, electricity for lighting and office equipment, electricity for the data rooms, electricity consumed to running and cooling the research equipment, exterior lighting of the entire side and the adjacent road. Two-thirds of the electricity consumed comes from the HVAC system together with the technological cooling (figure 2), both needs being covered by the shallow ground source heat pump system.

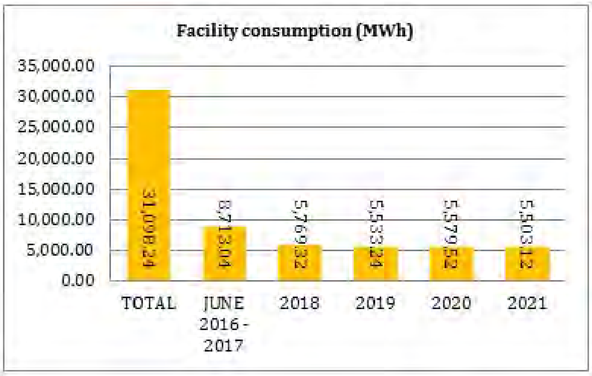


Figure 1: Power consumption since 2016 until 2021

For the operating year 2021, which was considered as the basis for future optimization of the energy consumption, the pattern shows, as expected, that the maximum consumption is recorded in the summer months and in the winter months, when the need of cooling or heating is high (figure 3).

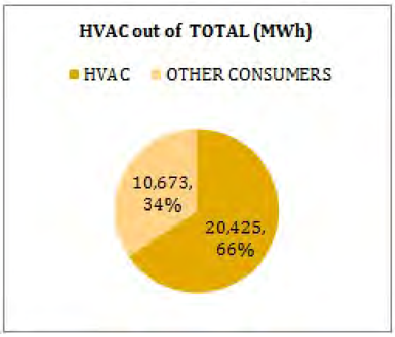


Figure 2: Power consumption fraction for HVAC

Figure 3: Total facility power consumption in 2021

Studies indicate that scientific research is more energy intensive than other disciplines, therefore the interest in benchmarking the research laboratories in terms of energy performance has grown in recent years to improve the metrics or key performance indicators that score the research facilities. However, the lack of data on similar infrastructures makes difficult the assessment of the ELI-NP energy performance.

The rooms that host the main research equipment are single volume halls, having large areas and considerable heights (maximum height around 16 m), being similar in this respect to event halls and sports facilities. Therefore, comparison with similar size infrastructures is not relevant due to the fact that research activity comes with high-energy consumption. Comparison with other geothermal systems is also of small relevance due to the fact that there are few geothermal systems of this size.

To achieve the assessment purpose in terms of energy consumption, a comparison of the energy performance of the ELI-NP facility with research facilities in the United States was considered. The most used key metric to benchmark buildings in terms of energy performance according to EPA (US Environmental Protection Energy) is the Energy Use Intensity (EUI) expressed as energy per square foot per year and calculated by dividing the total energy consumed by the building in one year (measured in kBtu or GJ) by the total gross floor area of the building (measured in square feet or square meters).

Values of source EUI for US research facilities and ELI-NP have been compared. The conversion factor for electricity (grid purchase) of the site energy to source energy according to the Romanian regulations is 2,62. The published median value of EUI for Technology/Science laboratories in the USA is 318,2 kBTU/ft^2/y, meaning 1004 kWh/ m^2/y whereas the EUI of ELI-NP, computed as previously mentioned, is 509.16 kWh/ m^2/y.

It comes out that the ELI-NP research facility has the EUI half of the median value of the EUI for research laboratories assessed and scored in the United States. To be noted that the consumption of the technological cooling is not separated from the HVAC, both needs being covered by the shallow ground source heat pump system.

2.2. Botanical Garden Greenhouse in the "Drumul Taberei" Park - Bucharest District 6

In 2017 – 2018 the City Hall of the 6th District of Bucharest implemented in a large park a Botanical Garden Greenhouse using mostly European funding. The total cost of the GSHP HVAC system was around 2 million Euro. The greenhouses have 7 large pavilions, in the form of a circuit, each with a vegetation specific to a geographical area.

The initial design drafted in 2012 included a HVAC solution based on electric energy. This initial design was changed in 2016 because the operation and maintenance costs would have been huge – around 6 million EUR / year. Finally, the HVAC solution that has been implemented was the GSHP one and it forced the investor to completely modify the initial design. The general arrangement of the park was also modified due to the 224 drillings that had to be made. The thermal energy supplied by the ground source heat exchanger covers 100 % the thermal request for heating and for cooling and allows to maintain the optimum temperature and humidity in greenhouses, but also to keep the costs for operation and maintenance in an efficient range.

Figure 4: Drilling works in the vicinity of the greenhouse

The heating and cooling water is provided by a fully automated thermal power station located in the vicinity of the greenhouses.

The thermal station provides hot water at 50/40 °C and chilled water at 7/12 °C for the heating and cooling coils of the air treatment plants that serve the 7 greenhouses. The capacity of the thermal station is 1048 kW for heating and 874 kW for cooling, taking into account the simultaneous consumption, thermal loads of equipment, installation efficiencies, heat loss on pipes, as well as the specific rigorous comfort category in which consumers are included.

The thermal station has 16 ground-to-water heat pumps with a thermal power of 65.5 kW on heating and 54.6 on cooling each. The 16 heat pumps are organized in 3 cascades (1x6 pumps and 2x5 pumps). They are equipped with safety valves and an electrical control panel ensuring full automatic control of the system.

The GSHP system enables high energy performance and low operating costs, thus proving to be a desirable solution for investments done by local authorities.

2.3. Oregon Park Office Complex

Oregon Park Office Complex is located in Bucharest, offering excellent road links to the city center. The complex consists of 3 buildings - BREEAM certified - which proves that great attention was given to numerous parameters, such as: health and well-being of workers, energy efficiency, transport, use of water, waste treatment.

The buildings have been designed in accordance with the highest office construction standards and incorporate open spaces which improve the current streetscape. This ensemble has set as a long-term strategic goal, the implementation of a package of solutions to increase efficiency and optimize consumption.

Figure 5: Oregon Park office buildings

Building B of the Oregon Park Ensemble is equipped with a cooling / heating plant provided with ground-to-water heat pumps, located in a dedicated technical room from 2nd basement floor. The plant consists of two ground-water reversible heat pump / refrigeration units that operate in the energy dissipation regime released by the I.T., each providing 214 kW for cooling (7/12 °C) and 219 kW for heating (50/55 °C). In recovery functioning mode, the plant provides 174 kW for cooling, and 239 kW for heating.

During the transition periods, the GSHP system operates in dual way, using the recovery of the heat released from the cooling of the I.T. or the building as the case may be. As long as the heat pumps produce cooling fluid for the I.T. building, with the help of the heat recovery system, they will also produce a 50/55 °C heating fluid

The BMS [Building Management System] system permanently monitors the thermal energy meters related to the GSHP system (thermal energy used for I.T. for the main cooling and heating system of the building, respectively) in order to ensure the maximum and balanced use of geothermal potential, according to consumption. of energy specified in the EED (Earth Energy Designer) simulation.

2.4. "One Peninsula" Complex for residential buildings

One Peninsula Complex is the first exclusive residential complex in Bucharest provided with a geothermal heat pumps system. The complex is located in an exclusive, quiet and green area, and includes several other facilities, such as a semi-olympic swimming pool, a Pilates room and a gym.

The complex consists of 125 apartments arranged in 17 low-rise blocks of flats, between three and 10 apartments per block, and eight villas. The total built area is about 8500 m^2. The overall energy needs of the complex are 2.55 MW for heating and 1.22 MW for cooling. These loads are partially covered by the GSHPs system, and partially (2.2 MW) by a high efficiency (over 90 %) gas based thermal plant.

Three reversible ground-water heat pump units with mechanical compression, covering 600 kW each, provide 45/40 °C heating water in wintertime and 8/13 °C cooling water in summertime, working with EER_{min} = 4.5.

The heat pumps are connected to 360 BHEs drilled down to 120 m. The BHEs' hydraulic circuit contains a 25 % water-propylene-glycol solution, working in a temperature regime 8/5.5 °C in wintertime, 27/29.5 °C in summertime.

The GSHPs system offers multiple advantages to those who live there: total autonomy for heating in winter and autonomy on refrigerant for air conditioning in summer, as well as reduction of annual heating and cooling costs by 50% compared to conventional solutions.

Figure 6: One Peninsula Complex residential buildings

2.5. Aspects regarding the custom codes for heat pumps, including geothermal / ground source heat pumps

Customs coding of equipment is regulated by **Commission Implementing Regulation (EU) 2020/1369** of 29 September 2020 amending Annex I to Council Regulation (EEC) No 2658/87 on the tariff and statistical nomenclature and on the Common Customs Tariff. The European custom coding regulation is coherent with the World Customs Organization Harmonized System Database that also includes the nomenclature and classification of goods at international level.

In the World/European customs coding regulation, the heat pumps are included in **Chapter 84 - Nuclear reactors, boilers, machinery and mechanical appliances; parts thereof.**

Romania is not a geothermal heat pumps manufacturer, therefore the GSHP units included in HVAC applications are 100 % imported. In Europe, the goods nomenclature called the "combined nomenclature" (abbreviated 'cn'), was established to meet both the requirements of the common customs tariff and the external trade statistics of the European Union. Unfortunately, even if this situation could facilitate the access to a complete, correct and coherent synthetic information regarding the geothermal heat pumps imported / mounted in applications in a unit of time, in reality this does not happen, mainly because of import codes reasons and the inconsistencies generated by the customs coding system / definition itself.

According the international / European customs coding regulations mentioned above, in Romania the imported heat pumps are classified (and have been classified for import) in two different 'cn" codes, namely:

– "**8415** - Air-conditioning machines, comprising a motor-driven fan and elements for changing the temperature and humidity, including those machines in which the humidity cannot be separately regulated – subclass:
  8415.81.00 - Air conditioning machines and apparatus, having their own motor fan and their own temperature and humidity changing devices, including those for which the humidity cannot be adjusted separately: - With cooling device and thermal cycle reversing valve (reversible heat pumps)";
– "**8418** - Refrigerators, freezers and other refrigerating or freezing equipment, electric or other; heat pumps other than air-conditioning machines of heading 8415 – subclass:
  8418.61.00 - Refrigerators, freezers and other refrigeration equipment, electric or not; heat pumps other than machines and apparatus for air conditioning of heading 8415".

As can be seen from the definition in English language of the two families (8415 and 8418) and subclasses of equipment (8415.81.00 and respectively 8418.61.00), expressions taken literally in the translation of the document into Romanian, neither from the definition of the subclasses nor from the definition of the class of equipment, it is not perfectly clear what kind of heat pumps covers each class / subclass of custom code.

At our request for clarification on customs codes, a request mediated by EGEC, DG TAXUD argued in detail stating in conclusion that "**the heat pumps covered by heading 8415 are the reversible heat pumps and those covered by heading 8418 are the non-reversible heat pumps**".

So far, most of the importers of geothermal heat pumps in Romania have used the seemingly correct solution, considering that the heading 8415 covers air source heat pumps and the heading 8418 covers the water / geothermal heat pumps.

DG TAXUD's recent response is not likely to clarify whether heat pumps with air source and geothermal heat pumps fall into the same class and if, at least at the sub-sub-class level, one can individualize only geothermal heat pumps (not mixed with other types of equipment). There are, for example, clear / trackable situations in which importers, not finding the subclass / heading explicitly suitable for imported geothermal heat pumps (reversible or non-reversible) simply classified them in the heading "Other" meaning 8418 69, although the respective imported geothermal heat pumps were reversible heat pumps.

This lack of taxonomic clarity of the custom code definitions leaves room for arbitrariness in the classification of imports in one or another of the classes.

Moreover, assuming that unintentional wrong assignments of geothermal heat pumps in the wrong class by a Romanian importer may happen, there would still be a reason for an intentional incorrect classification, namely the different values of the conventional rate of duty: 2.7% in the first category and 2.2% in the second category, respectively. This could lead to the temptation of importers to register the heat pumps from the first category in the second one, just to reduce by almost 20% the customs duties for imports from outside the European Community.

Due to this, the inclusion of heat pumps in the 2 custom headings is not a sure criterion in the inventory of geothermal heat pumps. For this reason, as well as due to the fact that in none of the custom codes the classification is not unambiguous as far as each class includes also other equipment that are not heat pumps, no coherent data can be obtained from the Romanian National Institute of Statistics on this matter, regarding the imports and installation of geothermal heat pumps in Romania in the last 12-14 years.

In the situation described above, the only potential source of evidence remains the statement of the importing companies. Unfortunately, most importing companies do not openly declare to a state authority, on their web pages or upon request, the number, COP and capacity of imported pumps each year. There are exceptions, but summing up their statements would not provide a correct figure for actual GSHP imports in Romania.

The lack of quantification possibilities described above also affects the traceability on all applications in the field. It is added that in Romania there is no mechanism for reporting the results of RES applications, all respondents stating that they do not report and were not asked to report GSHP imports or HVAC GSHP applications in which the imported pumps were included.

For the same reason, no accurate statistical data can be presented regarding the capacities of the pumps used, their real COP, and their real prices. The prices that sometimes appear on the web pages of distribution companies are sometimes catalogue prices, sometimes market prices.

As in the EU there are three main EU institutions responsible for customs administration:
(a) the Directorate-General for Taxation and Customs Union (DG TAXUD),
(b) the Directorate-General for Budget (DG BUDGET) and
(c) the European Anti-Fraud Office (OLAF),
we propose a rigorous revision of the definitions / names of customs classes and subclasses / headings in order to eliminate any confusing and equivocal situations in which certain equipment - in our case geothermal heat pumps - is not classified in the correct category, unambiguously, without being mixed with other equipment. In that way, the "reversible or non-reversible geothermal heat pumps" should be included in 2 headings of a single class without being mixed with other equipment.

3. CONCLUSIONS

The geothermal energy has a great potential for development in Romania. This potential can be exploited only through a wise national strategy in investments and professional training.

REFERENCES

Antics M. A.: Computer Simulation of the Oradea Geothermal Reservoir, Proceedings of the 22nd Workshop on Geothermal Reservoir Engineering, Stanford, California, (1997), 491-495.

Bendea, C., Antal, C., Rosca M.: Geothermal Energy in Romania: Country Update 2010-2014, *Proceedings,* WGC 2015, Melbourne, Australia (2015).

Gavriliuc, R., Roşca, M., Polizu, R., Cucueţeanu, D.: Geothermal Energy Use, Country Update for Romania, European Geothermal Congress, Strasbourg, France (2016).

Gavriliuc, R., Stefan, R., Cucueteanu D.-I., ELI-NP Magurele Romania – The largest shallow geothermal system in Europe – Operation data from 2017, European Geothermal Congress, The Hague, Netherlands (2019).

Gavriliuc R., Rosca M., Cucueteanu D., Geothermal Energy Use, Country Update for Romania, European Geothermal Congress, The Hague, The Netherlands (2019).

Acknowledgements

The authors acknowledge the important contribution to this paper of:

- Mr. Horia Ban (General Manager of Termoline Company Oradea);
- Dr. Razvan Stefan (Facility Manager ELI-NP Magurele);
- Mr. Florin Gavrila (Therme Bucharest Company);
- Management team of the Operational Program Large Investment (POIM);
- City Council of District 6 Bucharest;
- Portland Trust Bucharest,

who provided or confirmed part of the information presented in this report.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	0.1	0.8	7069	61931	0.0014	0.0013
Under construction end of 2021	-	-	-	-	-	-
Total projected by 2023	-	-	-	-	-	-
Total expected by 2028	-	-	-	-	-	-
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Explanation: The available temperature levels of deep geothermal resources in Romania do not allow power generation under reasonable technical efficiency and economic costs.

The data from this table are consistent with the information provided by Gavriliuc et al (2016, 2019).

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Oradea	CE Iosia Nord	nov.2012	1	O	B-ORC	0.05	0.05	0.4
Beius	Beius	2014	1	O	B-ORC	0.05	0.05	0.4
total						0.10	0.10	0.8

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
R	Retired / decommissioned	2F	Double Flash	O	Other

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units

The data from this table are consistent with the information provided by Gavriliuc et al (2016, 2019).

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	160	305.2	8	50			10	12
Under constru-ction end 2021[Note]	31.5						5.2	
Total projected by 2023								
Total expected by 2028								

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Note: The facilities “Under construction end 2021” are the projects mentioned in this report, in the section dedicated to “Deep geothermal energy resources and exploitation”. The figures presented in the cell dedicated to “Geothermal heat in balneology and other” refer to Therme Balotesti project.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Oradea	Iosia Nord	2005	No	No	19	24.2	25	78.5
Oradea	Nufarul	1992	No	No	5	5	10	100
Oradea	Calea Aradului	2002	No	No	1.6	1.6	3.9	100
Beius	Beius	2001	No	No	21	21	25.6	100
Sannicolau	Sannicolau	1980's	No	No	2.7	2.7	3.3	100
Saravale	Saravale	1980's	No	No	1.34	1.34	2.21	100
Lovrin	Lovrin	1980's	No	No	1.44	1.44	2.16	100
Jimbolia	Jimbolia	1980's	No	No	1.44	1.44	2.85	100
Teremia	Teremia	1980's	No	No	1.88	1.88	3.45	100
Calimanesti	Calimanesti	1980's	No	No	10.73	10.73	18.7	100
Otopeni (x)	*Otopeni*	*1980's*	No	No	*0.0*	*0.0*	*0.0*	*0*
Moara Vlasiei	Moara Vlasiei	1980's	No	No	29.9	29.9	33.5	100
radea	Borehole "Workers' Park" (AQUAPARK NYMPHAEA)	2017	No		3.2 (1)	2.2	4.8	100
1 Mai	Hotel&Wellness PERLA	2020	No		1.2 (2)	1.2	3.1	100
Oradea	Borehole University (Smart Campus)	2022	No	RI	4.5 (3)	4.5	*9.2* (5)	100
Oradea	Borehole ONCEA (Municip. Hospital)	2022	No	RI	4.9 (4)	4.9	*10.0* (5)	100
total					108.83	114.03	157.77	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

(x) Otopeni City has replaced its geothermal DH system by a gas-boilers based DH system!

(1) 2.2 MW deep geothermal water + 0.9 MW GSHP on heat recovery from the geothermal waste water

(2) 0.9 MW geothermal water + 0.3 MW GSHP on heat recovery from the geothermal waste water

(3) 3.4 MW deep geothermal water + 1.1MW GSHP on heat recovery from the geothermal waste water

(4) 4.2 MW deep geothermal water + 0.7 MW GSHP on heat recovery from the geothermal waste water

(5) estimated for 2022

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Tulcea	Hotel DELTA	2013	Y	0.42	0.42	1.02	100	Termoline Company
Timisoara	HELLA FACTORY	2015	Y	0.3	1.7	3.5	18	Termoline Company
Oradea	Business Center ROGERIUS	2015	Y	0.42	0.42	0.92	100	Termoline Company
Bucuresti	VICTORIEI PLAZZA	2015	Y	0.11	0.75	1.5	15	Termoline Company
Salonta	HIGHSCHOOL ARANY JANOS	2016	Y	0.15	0.8	1.6	19	Termoline Company
Oradea	EMERGENCY UNIT HOSPITAL	2020	Y	0.35	0.35	0.85	100	Termoline Company
Alimani Constanta	ALIRA Winery	2021	Y	0.16	0.4	0.85	40	Termoline Company
Oradea	County Hospital	2021	Y	0.63	0.63	*1.2* (1)	100	Termoline Company
Giurgiu	Hotel GIURGIU	2021	Y	0.14	0.14	*0.32* (1)	100	Termoline Company
total				2.68	5.61			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

(1) estimated for 2022

The data from this table are consistent with the information provided by Gavriliuc et al (2016, 2019).

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	600	40	100	N/A	N/A	N/A
Of which networks **	4	3	6,5	N/A	N/A	N/A
Projected total by 2023	6	5	11			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

<u>NB:</u> As presented in paragraph 2.5. “Aspects regarding the custom codes for heat pumps, including geothermal / ground source heat pumps”, for Romania it is very difficult to state accurately the real number of GSHP systems imported and in operation, due to ambiguities in the customs code (on the one hand), and due to lack of willingness from companies to declare their projects (on the other hand). There are no custom taxes among the EU countries, however, there are still customs codes mentioned when equipment is brought/imported/exported from one country to another, even inside the EU. The only information available with regard to the heat pumps installed is the one posted on the companies’ websites. The Romanian Geoexchange Society has officially required from the Romanian National Institute for Economic Statistics (INSSE) the situation of heat pumps’ equipment imported in 2021, as support of this report. The puzzling answer of INSSE provided the number of kilograms (!!!) of imported such equipment, which does not give any information – at least! - on the number of imported units, yet on their capacity. In 2021, the financial value of these imports was around 32 million euros.
For an accurate statistical situation with regard to the shallow geothermal heat pumps installed in Romania, there is only one feasible solution, namely: clear customs classification/codes at EU level, which should clearly separate the “heat pumps equipment” from any other type of equipment, and to separate the “water source heat pumps” from the “air source heat pumps”.

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No geothermal UTES currently in Romania.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	-	-	-	-
Geothermal direct uses	37 (x)	Info not available	Info not available	Info not available
Shallow geothermal	Info not available	Info not available	Info not available	Info not available
total				

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include “jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration”. For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

(x) The 37 million euros represent the funding awarded for the deep geothermal energy projects presented in paragraph 1, covered partly from the state budget, partly from European funds.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	N/A	National Res. Plan II, by competition	National Res. Plan II, by competition
Financial Incentives – Investment	N/A	Operational Plan Large Investments (POIM)	DIS - “Green House” Program (approx. 1350Eur/application)
Financial Incentives – Operation/Production	Green Certificates (not operational, yet)	N/A	N/A
Information activities – promotion for the public	Media information (not on regular basis)	Media information	Website of the Romanian Geoexchange Society Training courses for different stakeholders organized in European funded projects
Information activities – geological information	No	No	No
Education/Training – Academic	YES, BSc, MSc and PhDin Renewable Energies atthe University of Oradea	YES, BSc, MSc and PhD in Renewable Energies at the University of Oradea	Courses on RES (including geothermal) in Master studies in all construction and polytechnic universities in the country. Doctoral studies in some of them (UPB, TUCEB and UOR).
Education/Training – Vocational	NO	NO	The 2 involved specialties (GSHP installers and BHE installers) are included in the National Occupations Code (COR). The occupational standards are also in course of elaboration. The specialization courses are not recognized and endorsed by the Education Ministry if the respective specializations are not included in the National Occupations Code (COR).

Key for financial incentives:					
DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

The data from this table are consistent with the information provided by Gavriliuc et al (2016, 2019).

Geothermal Energy Use, Country Update for Russia 2022

Valentina Svalova

IEG RAS, Ulansky per., 13, Moscow, 101000, Russia

v-svalova@mail.ru

Keywords: Geothermal resources, electric power generation, direct use, Russia.

ABSTRACT

Russia possesses unique reserves of geothermal energy for production of electricity, provision of district heating systems for industrial and agricultural needs. Exploitation of geothermal resources, implementation of drilling operations for geothermal fluid production has been carried out in Russia and former Soviet Union for more than 60 years. Today, almost all territories in the country has been well investigated. It was found that numerous regions have reserves of hot geothermal fluid with temperatures ranging from 50 up to 200 °C at depth from 200 to 3,000 m. These areas are located in the European part of Russia: Central region; Northern Caucasus; Dagestan; in Siberia: Baikal rift area, Krasnoyarsk region, Chukotka, Sakhalin. Kamchatka Peninsula and the Kuril Islands have the richest resources of geothermal power available for the production of up to 2,000 MW of electricity and for more than 3,000 MW of heat for district heating system. Utilization of geothermal resources in Russia is especially important for heat supply to northern territories of our country. In Russia more than 45 % of total energy resources are used for heat supply of cities, settlements and industrial complexes. Up to 30 % of those energy resources can be provided using geothermal heat. Utilization of geothermal heat is planned in the following regions of Russia: Krasnodar Region (heat supply of Labinsk town as well as complex geothermal use in Rozoviy town), Kaliningrad Region and Kamchatka (heat supply of Yelizovo and construction of Pauzhetsky binary power plant of 2.5 MW capacity and extension of the existing Mutnovsky GeoPP (50 MW) utilize secondary steam for the production up to 12 MW of electricity.

1. INTRODUCTION

The economic and political changes that have taken place in Russia greatly influence the way the power industry is developing. Power and heat generation in Russia mainly is based on fossil fuel utilization and operation of nuclear and hydro power plants. Nowadays the contribution of geothermal energy is comparatively modest, although the country possesses significant geothermal resources. Contemporary economic situation in Russia depends on development of its energy potential. Difficulties with fuel transportation aggravate the problem of power supply, particularly in northern and eastern regions of the country. Under these circumstances, it is natural that the regions should strive to use their own energy resources and develop renewable sources of energy. In the Far Eastern regions, Sakhalin, the Kuril Islands, and, particularly, in Kamchatka, utilization of the Earth's thermal energy is coming to be a subject of great importance. Figure 1 illustrates the main territories of Russia possessing geothermal power resources for industrial utilization.

Figure 1: Promising geothermal areas of Russia.

1 - space heating by heat pumps, 2 – direct use, 3 - power generation. 1 – Northern Caucasus (Alpine area), 2 – Northern Caucasus (platform area), 3 – West Siberia, 4 – Baikal adjacent area, 5 - Kuril-Kamchatka region, 6 –Primorje, 7-8 – Okhotsko-Chukotsky volcanic belt

There are 8 main regions promising for "direct" utilization (heat supply to residential and industrial buildings, heating of greenhouses and soils, in the cattle breeding industry, fish farming, in industrial manufacture, for chemical elements extraction, for increase of a reservoir recovery, for frozen rocks melting, in balneology etc.), as well as for heat generation with application of heat pumps and power production at binary cycle geothermal power plants (GeoPP). One of them, region 5 (Kamchatka and the Kuril Islands), is region of active volcanoes being most promising for "direct" utilization of geothermal heat and construction of single and double flash GeoPP. So far 66 thermal water and steam-and-hydrothermal fields have been explored in Russia. Half of them is in operation providing approximately 1.5 million Gkal (1740 $GWht_h$) of heat annually, which is equal to the annual replacement of almost 300'000 tons of conventional fuel (Vartanjan and Komjagina, 1999).

2. SOUTHERN PART OF RUSSIA

Dagestan Republic at the Northern Caucasus is one of the biggest area for the development of geothermal energy. The total amount of resources at the depth of 0.5-5.5 km allows to obtain approximately 4 million m^3/day of geothermal fluid. At present, more than 7.5 million m^3/year of hot water 50-110 °C is used in Dagestan. Among them, 17 % as hot water; 43 % for district heating; 20 % for greenhouses and 3 % for balneology and mineral water production. Totally in Dagestan about 180 wells have been drilled at a depth from 200 to 5,500 m. The regions of such towns as Kizlyar, Tarumovka and Jushnosukhokumsk, possess unique reserves of hot water. For instance, Tarumovskoye deposit has the reserves of geothermal water of high salinity (200 g/l) with temperature up to 195 °C. Six wells have been drilled to depths of about 5,500 m, the deepest geothermal wells in Russia. Tests indicate high reservoir permeability with wells producing between 7,500 and 11,000 m^3/day at wellhead pressures of 140-150 bars (Magamedov et. al., 1999).

In Caucasia and Ciscaucasia thermal waters make multilayer artesian basins in sediments of Mesozoic and Cenozoic era. Mineralization and temperature of these waters vary significantly: in fore deeps at depths of 1-2 km - from 0,5 to 65 g/kg and from 70 to 100 °C respectively, while on the Scythian platform at depths of 4-5 km – from 1 to 200 g/kg and from 50 °C to 170 °C also respectively (Kononov et al., 2000). In Dagestan, the total amount of explored thermal water reserves makes 278'000 m^3/day with flowing operation, and with used water reinjection – 400'000 m^3/day, the heat potential therein being equivalent to the annual replacement of 600'000 tons of conventional fuel. Main explored thermal water resources with temperature between 40-107 °C and mineralization between 1.5-27 g/l are located in Northern Dagestan. For the last 40 years, 12 major thermal water fields have been discovered and 130 wells have been drilled and prepared for exploitation in this region (Figure 2). However, presently only 15 % of the potential of known thermal water reserves is used (Aliev et al., 2002). Krasnodar region also possesses significant reserves of geothermal heat. It has wide experience of geothermal energy source utilization. Thus, 50 geothermal wells are in service, which produce water in the amount of up to 10 million m^3 having temperature between 75-110 °C. Region wide-scale utilization of geothermal energy use in Krasnodar region will allow providing by 2020 up to 10 % of all heat demand and up to 3 % of all energy demand of the region. Geothermal energy has big perspectives in Krasnodar region. The aggregate heating capacity of geothermal fields being in service makes 238 MW.

Figure 2: Geothermal resources of the Southern part of Russia in Krasnodar and Stavropol regions, Dagestan and Chechen Republics

3. CENTRAL PART AND SIBERIA

Besides the economic viability of widely located low potential geothermal resources, utilization for heat and power generation is becoming more and more evident; such resources are mostly available in mineralized water fields with temperatures between 30-800 °C (sometimes even up to 1000 °C) at depths between 1-2 km. Such resources are located in the central part of the Middle-Russian basin (Moscow syneclise) comprising 8 regions: Vologodsky, Ivanovsky, Kostromskoy, Moskovsky, Nizhegorodsky, Novgorodsky, Tverskoy and Yaroslavsky. There are also promising opportunities to efficiently utilize thermal waters in Saint Petersburg and especially Kaliningrad regions. Efficiency of their utilization can be provided through application of heat pumps and binary circulating systems. Broad use of geothermal heat is possible in the centre of the European part of Russia. Siberia also possesses geothermal heat reserves, which can be used for heat supply and agriculture (Figure 1). Thermal waters of the West Siberia platform form a big artesian basin in the platform cover with an extent of almost 3 million km^2 in area. At depths down to 3 km resources of thermal water with temperatures between 35 and 75 °C and mineralization between 1 and 25 g/kg are evaluated at 180 m^3/s. Injection of high mineralized thermal waters and brines requires their reinjection after using their heat potential to prevent pollution of the environment. Utilization of even 5 % of their reserves will allow generating 834 million Gkal/year (967’440 GWh$_{th}$), which will save 119 million tons of conventional fuel. In Baikal adjacent area there are numerous thermal resources, flow rate of which may often reach many thousands of cubic meters a day with temperature varying between 30 and 80 °C and higher. Usually mineralization of such waters does not exceed 0,6 g/l. Considering the chemical content of thermal waters, they are mostly alkaline, sulfate or sodium bicarbonate. The majority of these resources is located in Tunkinsky and Barguzinsky cavities and along the coastline of lake Baikal (Kononov and Povarov, 2005; Svalova and Povarov, 2013; Svalova and Povarov, 2021). There are also thermal water resources in Primorje and Okhotsko-Chukotsky volcanic belt.

4. KAMCHATKA AND KURIL ISLANDS

However, the richest geothermal heat reserves are in the Far East part of Russia. In particular, Kamchatka and the Kuril Islands (Figure 3) have the richest resources, with a generating power capacity of up to 2,000 MW and of heat capacity no less than 3,000 MW utilizing a steam water mixture and hot water. Since the middle of 1950’s systematic geophysical surveys and drilling have been carried out in Kamchatka geothermal field. To date 385 wells have been drilled to depths of 170 to 1800 m including 44 wells producing a two-phase fluid at an emergence temperature of more than 160 °C. In 1966, Pauzhetskaya geothermal power plant was commissioned in the south of Kamchatka; at present it is under successful operation generating the cheapest electricity in that region. The estimated potential of this geothermal field is about 50 MW (for up to 30 years) (Povarov, 2000).

Figure 3: Kamchatka and Kuril Islands – active volcanoes zones

Practically all territory of Kamchatka has geothermal heat available in the form of hot water, two-phase fluid and steam. In the south of Kamchatka near the Pauzhetskaya GeoPP, exploration of the Koshelevskaya geothermal system has discovered resources sufficient for GeoPP, with a capacity of about 350 MW. North of Mutnovskaya GeoPP there are resources available for the generation of 180-200 MW. The eastern part of Kamchatka is estimated rich of high temperature geothermal water resources, for a power capacity of about 250 MW. In the central and northern part of Kamchatka the estimated power capacity of the geothermal resources with temperatures above 150 °C is 550 MW, and the estimated heat capacity of the geothermal resources with temperatures below 150 °C is up to 600 MW. Nowadays there are 5 geothermal power plants (GeoPP) in Kamchatka and the Kuril Islands under successful operation and 2 more under construction (Figure 4). Main high potential (steam and hydrothermal) systems of Kamchatka are: Mutnovsky, Pauzhetsky, Koshelevsky, Bolshebanny and Kireunsky fields.

At present power and heat supply of Kuril Islands is mostly fulfilled from diesel electricity generators and heating boiler-houses operating on imported coal. At the same time, Kuril Islands are rich with geothermal resources. Their expected capacity reaches 300 MW.

Geothermal power and heat plants of required capacity can be constructed in the vicinity of each large settlement, operating or planned facilities of Kuril Islands - on Kunashir, Iturup, Paramushir islands, etc. Several geothermal reservoirs were explored and several geothermal manifestations were detected at the mentioned islands. For example, at Kunashir Island, according to exploration works data, the expected reserves of the geothermal reservoir "Goryachy Plyazh - Mendeleyevskoye" are estimated at 52 MW. The expected reserves of the northernmost island of the Kuril ridge, Paramushir, calculated by various methods, can support operation of a geothermal power plant with capacity of 15-100 MW. A similar geothermal power complex is under construction at Iturup Island. It will permit supplying electricity for Kurilsk city. Construction of a geothermal power plant is implemented on site at the foot of Baransky volcano, 21 km away from Kurilsk city. Two power modules were installed on two sites, with total capacity of 3.6 MW. In 2006 start-up complex with capacity of 1.8 MW was commissioned. Reserves of fluid for Okeansky reservoir, "Kipyashchy" area, show a geothermal power plant’s capacity of 5.0 MW. Geothermal heat supply of Kurilsk city is not planned due to the complexity of the terrain relief.

Figure 4: Location of existing geothermal power plants in Kamchatka and Kuril Islands

5. LOCAL GEOTHERMAL DISTRICT HEATING AND POWER SUPPLY SYSTEMS

Direct use of geothermal resources is mostly developed in Kuril-Kamchatka region, Dagestan and Krasnodar region, for heat supply and greenhouses heating. Development of geothermal resources is also very promising in such regions as West Siberia, Baikal adjacent area, Chukotka, Primorje, Sakhalin. Besides the economic viability of utilizing widely available, low potential geothermal resources (located in mineralized water with temperature between 30 and 80 °C and up to 100 °C) fields at depths of 1-2 km for heat and power supply is quite evident. Such resources can be found in the central part of the Middle Russian basin. There are also promising opportunities to utilize thermal water in Saint Petersburg and especially in Kaliningrad regions. In line with construction of series of traditional single flash or double flash geothermal power plants and geothermal binary cycle power plants in Kamchatka and Kuril Islands, there are other promising projects in Russia at different stages of development as follow:

- District heating and electricity supply systems for Labinsk City, Krasnodar region;
- Complex utilization of geothermal resources in Stavropol region;
- District heating and electricity supply of Svetly town, Kaliningrad region.

Construction of new high efficient binary cycle power plants, application of heat pumps and new technologies for dwelling and industrial facilities heating would radically improve the energy supply balance of Russia.

6. CONCLUSIONS

Russia possesses unique natural resources. Fossil fuel reserves are huge in this country, and the following is the breakdown of energy sources: 35 % for gas, 33 % for wood, 12 % for oil. At the same time, however, it possesses enormous reserves of geothermal heat, the energy potential of which exceeds 8-12 times all hydrocarbon fuel energy potential. This could radically change the energy balance. Summarizing the situation with geothermal energy utilization in Russia, we should mention once again that in Kamchatka three geothermal power plants are in successful operation: 12 MW and 50 MW on Verkhne-Mutnovsky and Mutnovsky fields respectively and 11 MW on Pauzhetsky field (Povarov, 2000). On Kuril Islands (Kunashir and Iturup) there are two small GeoPP with capacities of 3.6 MW, which are also in successful operation. Utilization of geothermal heat is planned in the following regions of Russia: Krasnodar region (heat supply of Ust-Labinsk and Labinsk towns as well as complex geothermal use in Mostovskoy Region), Kaliningrad region (energy and heat supply of Svetly town), Kamchatka region (heat supply of Yelizovo district and construction of Pauzhetsky binary power plant 2.5 MW capacity and extension of existing Mutnovsky GeoPP).

REFERENCES

Aliev, R.M., Palamarchuk, V.S., Badavov, G.B.: Issues of geothermal district heating on the territory of North Dagestan. Proceedings, Geothermal heat power engineering. FED RAS, Makhachkala, (2002), 25 – 35.

Kononov, V.I., Polyak, B.G., Kozlov, B.M.: Geothermal development in Russia: Country update report 1995-1999, Proceedings, World Geothermal Congress, (2000), Hyushu – Tohoku, Japan. May 28 – June 10, 201–206.

Kononov, V.I., Povarov, O.A.: Geothermal development in Russia: Country update report 2000-2004, Proceedings, World Geothermal Congress, (2005), Antalya, Turkey, 24-25 April.

Magamedov, K.M., Alkhasov, A.V., Aliyev, R.M. Geothermal energy prospects in Dagestan, IGA News, No. 36, (1999), 3-4.

Svalova, V.B., Povarov, K.O.: Geothermal energy use in Russia. Country update for 2007-2012. Proceedings, European Geothermal Congress 2013, Italy (2013).

Svalova, V.B., Povarov, K.O.: Geothermal Resources and Energy Use in Russia. Proceedings, World Geothermal Congress 2020-2021, Iceland, 2021.

Povarov, O.A.: Geothermal power engineering in Russia today, Proceedings, World Geothermal Congress (2000), Hyushu – Tohoku, Japan. May 28 – June 10. Vol 1. 207-212.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	81.9	440.7	246,868		< 1	< 1
Under construction end of 2021						
Total projected by 2023						
Total expected by 2028						
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Kamchatka	Pauzhetskaya	1966	3	O	1F	14.5.	8	59.5
Kamchatka	Verkhne-Mutnovskaya	1999	3	O	1F	12	12	58.3
Kamchatka	Mutnovskaya	2002	2	O	1F	50	50	322.9
Kunashir	Mendeleevskaya	2007	1	O	1F	1.8.	1.8.	n/a
Iturup	Okeanskaya	2007	2	O	1F	3.6.	3.6.	n/a
total						81.9	75.4	440.7

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
R	Retired / decommissioned	2F	Double Flash	O	Other

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	110	600	200	1000	110	600	4	18
Under constru-ction end 2021								
Total projected by 2023								
Total expected by 2028								

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Kamchatka			N		122		750	
Kunashir			N		20		90	
Krasnodar			N		77		407	
Stavropol			N		18		93	
Adygeya			N		10		45	
Kabardino-Balkarija			N		2		9.2	
Dagestan			N		71		372	
Karachaevo-Cherkessja			N		4		16	
North Osetja			N		3		11.4	
Chechnja			N		10		45	
total					337		1838.6	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

No geothermal large systems for heating and cooling uses other than DH currently in Russia.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	1200	60	270	200	10	
Of which networks **						
Projected total by 2023	1500	75	337.5			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No geothermal UTES currently in Russia.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	1	300	1	300
Geothermal direct uses	1	500	1	700
Shallow geothermal	1	200	1	300
total	**3**	**1000**	**3**	**1300**

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include “jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration”. For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	DIS	DIS	DIS
Financial Incentives – Investment	DIS	DIS	DIS
Financial Incentives – Operation/Production	DIS	DIS	DIS
Information activities – promotion for the public	Yes, wide	yes	yes
Information activities – geological information	yes	yes	yes
Education/Training – Academic	yes	yes	yes
Education/Training – Vocational	yes	yes	yes

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for Serbia

Sibela Oudech[1], Ivan Djokic[1]

[1] Geco-inzenjering, Vardarska 14, Belgrade, Serbia

geco.ing@gmail.com

Keywords: Serbia, geothermal energy, hydrogeothermal systems, renewable energy resources.

ABSTRACT

The territory of Serbia has favourable geothermal characteristics. There are more than eighty hydrogeothermal systems within four geothermal provinces. According to the recent data in Serbia in 2021 546.27 GW_{th} was produced from geothermal sources with a total capacity of 161.85 MW_{th}, where 429.38 GW_{th} was in geothermal direct use with a thermal capacity of 109.26 MW_{th}, and 116.91 GW_{th} from shallow geothermal systems using heat pumps of total capacity 52.59 MW_{th}. The most ommon use of geothermal energy in Serbia is the traditional ones: balneology and recreation. The use of geothermal energy from shallow systems is expanding, whith the number of residential and office buildings using heat pumps for heating, air-conditioning and cooling, and sanitary hot water is rising on a monthly basis. However, Serbia did not meet its 2020 renewable energy target of 27 % of gross final energy consumption set by EU, yet it is intensively working on new regulations and projects to attract investors and provide funds to increase the total share of all renewable energy sources in gross final energy consumption.

1. INTRODUCTION

Serbia is situated in the central part of the Balkan Peninsula (Fig 1) and covers the surface of 88361 km^2. Systematic geothermal investigations in Serbia began in 1974, after the first world oil crises. Until 1990 numerous deep geothermal drill holes had been constructed and put into operation. In the Pannonian basin, as the most prospective region, 24 hydrogeothermal systems had been constructed and put in operation before 1990, when the highest production was reached of about 1.6 million m^3 of thermal water, that was used for heating, balneology, agriculture and industrial processes.

Nowadays the situation is different, hydrogeothermal systems in use are mainly those constructed before 1990, and most of them are not fully operational. However, Serbia is experiencing an expansion of energy production from shallow gethermal systems using heat pumps. Almost every state-of-the-art residential or business building is using heat pumps for heating, air-conditioning and cooling, and sanitary hot water.

Figure 1: Geographical location of Serbia.

2. GEOLOGICAL BACKGROUND

In the territory of Serbia rocks of different age occur, from Precambrian to Quaternary age, and of all types regarding their lithology. There are 5 great geotectonic units (Fig 2): Dinarides, Serbian-Macedonian massif, Carpatho-Balkanides and Pannonian Basin, and very small part at far east of the country that belongs to Mesian Platform (Grubic, 1980).

The Dinarides occupy the large part of Serbia and they are made of Mesozoic rocks, mainly limestones and dolomite of Triassic age, then of ophiolite melange of Jurassic age and Cretaceous flysch.

The Serbian-Macedonian massif occupies the central part of Serbia and it is made of Proterozoic metamorphic rocks: gneisses, various schists, marbles, quartzites, as well as magmatic, or intrusive-granitoide and volcanic rocks of Tertiary age.

The Carpatho-Balkanides extend over the eastern part of Serbia and this unit is mainly made of limestones of Triassic, Jurassic, and Cretaceous age. At north, Serbia belongs to the great unit that extends far beyond the Serbian borders, the Pannonian basin that consists of Palaeogene, Neogene and Quaternary sediments with a total maximal thickness of about 4000 meters.

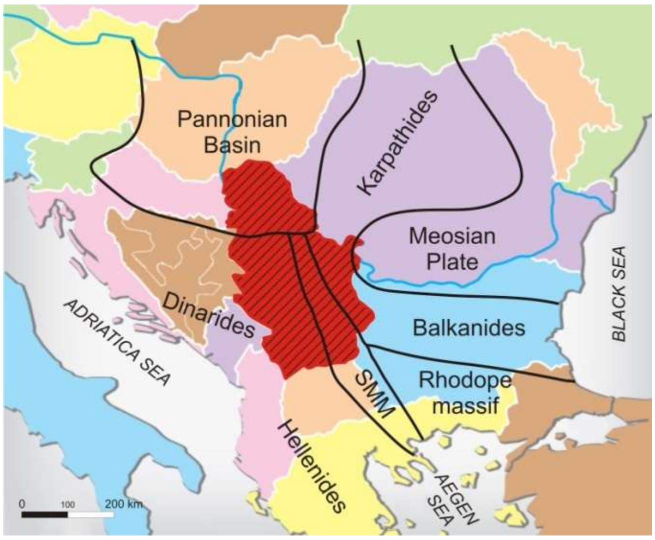


Figure 2: Tectonic map of Balkan Peninsula (Martinovic and Milivojevic, 2010)

3. GEOTHERMAL RESOURCES AND POTENTIAL

The territory of Serbia features greater geothermal potential than is in use nowadays. According to Milivojevic (1989), there are 4 geothermal provinces within the 4 great geotectonic units.

Excluding the Pannonian basin, there are 159 natural springs of thermal water with temperature above 15 °C. The thermal springs with the highest temperature are in Vranjska spa (96 °C), then Josanicka Spa (78 °C), Sijarinska Spa (76 °C), Kursumlijska Spa (68 °C) and Novopazarska Spa (54 °C). The total flow of all natural springs is about 4000 l/s. The thermal springs with highest flow are draining the karstified limestones of Triassic age, and the next highest are those from Tertiary granitoides and volcanic rocks. Most of the thermal springs occur in the Dinarides, followed by the Carpatho-Macedonian Massif.

In the Pannonian basin there are 83 hydrogeothermal drill holes with total average flow of about 700 l/s, and water temperature that ranges from 21 °C to 82 °C.

There are 60 convective hydrogeothermal systems in Serbia. Of this number, 25 are in the Dinarides, 20 in the Carpatho-Balkanides, 5 in the Serbian-Macedonian Massif, and 5 in the Pannonian Basin under Tertiary sediments (Fig 3). Conductive hydrogeothermal systems are developed in basins filled with Paleogene and Neogene sedimentary and as such they mainly occur in the Pannonian Basin in Vojvodina, northern Serbia (Martinovic and Milivojevic, 2010).

3. GEOTHERMAL UTILIZATION

In Serbia nowadays at over 50 locations, thermal water is being used for balneology, sport and recreation. Geothermal energy utilization for heating, as well as in agriculture and industrial processes is present, but only in few locations. Geothermal energy utilization for heating is usually connected with systems used for spas and balneology, while district heating systems based on geothermal energy are rather rare. Those are old systems, working only partially. However, there is a growing interest in using the geothermal energy from shallow systems using heat pumps for individual commercial and residential buildings heating, air-conditioning and cooling and sanitary hot water.

Total energy production from geothermal sources in Serbia in 2021 was 546.27 GW_{th}, where 116.91 GW_{th} was from shallow geothermal systems using heat pumps.

There are 130 hydrogeothermal drill holes, of which 83 are in the Pannonian basin and 47 in other provinces. The total heat capacity of all hydrogeothermal drill holes in Serbia is about 200 MW_{th}, where 82.5 MW_{th} is in the Pannonian basin. In 2021, 22 hydrogeothermal drill holes in the Pannonian basin were in operation with a total thermal capacity of 30 MW_{th}.

In other geothermal provinces in Serbia, Macva region is considered one of the highest prospects for multipurpose use of geothermal energy. The total heat capacity of hydrogeothermal drill holes in Mačva is over 30 MW_{th} while in 2021 in use was 16.35 MW_{th}.

Heat pumps use in Serbia became popular in the last several years along with the use of solar panels. There are about 2900 heat pumps installed throughout Serbia with a total capacity of 52.59 MW_{th} that produced 116.91 GW_{th} in 2021. Most are used for heating commercial and residential buildings in cities in Serbia like Belgrade, Novi Sad and Nis. In the last 4 years over 10 Projects of geothermal energy use for heating have been started in the mountain resorts and commercial and residential buildings in the cities, where the latest was started in Belgrade in 2021 with 180 probes of 2.15 MW_{th} thermal capacity for heating and 2.1 MW_{th} for cooling.

We must emphasize that the use of geothermal energy, especially from shallow geothermal installations, for small greenhouses and individual buildings is difficult to follow in the exact number, which is growing very quickly where users are not always following procedures proscribed by Serbian regulations.

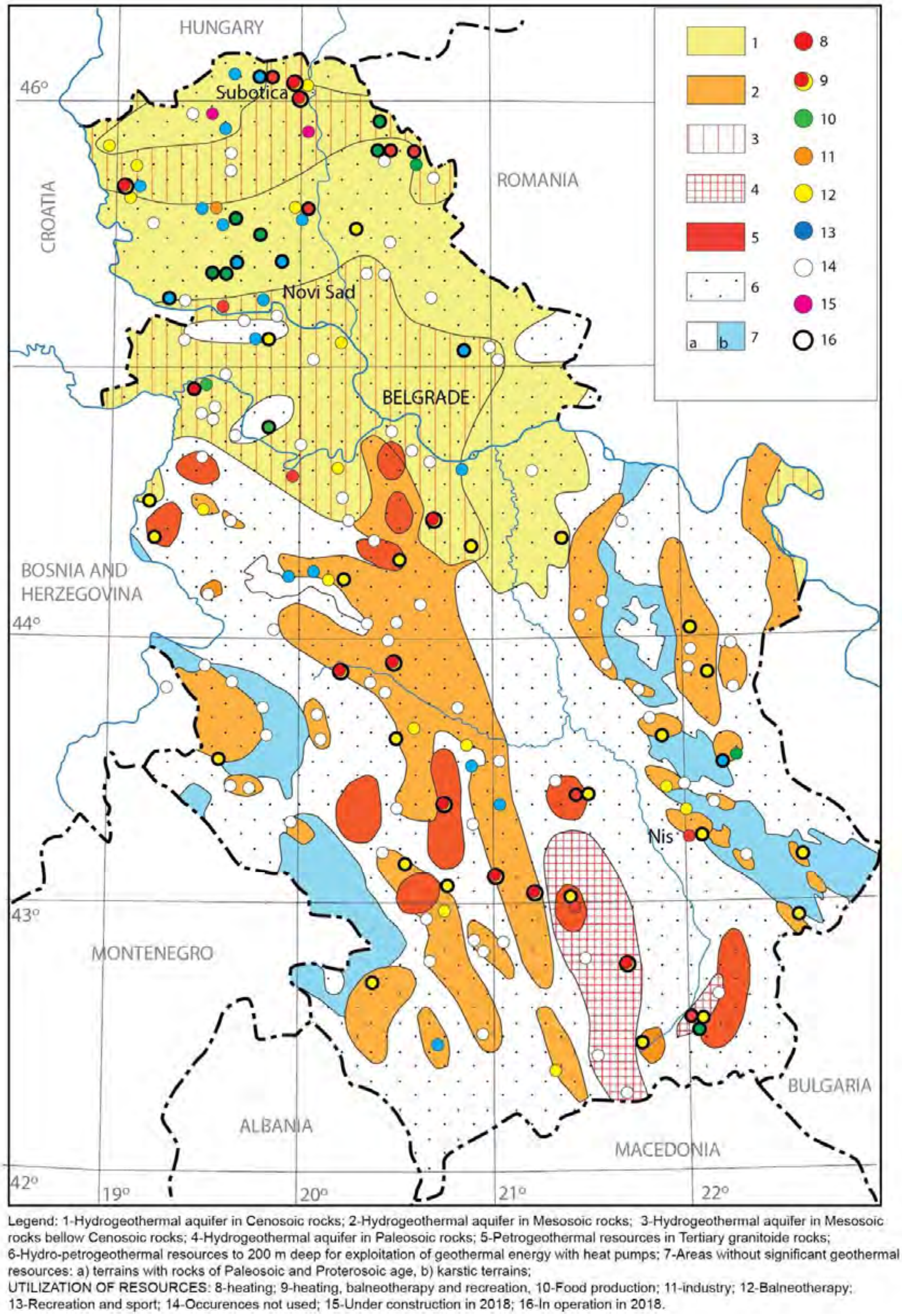


Figure 3: Map of geothermal resources of Serbia (background: Geothermal resources map, Milivojevic, 2001).

4. DISCUSSION

The highest interest in Serbia is in geothermal utilization for aqua parks and wellness centres, where the investors start recognizing the benefits of using the thermal water not only for recreational purposes but for heating the premises and sanitary hot water as well.

The government, for its part, is trying to help investors with incentives, but still, when it comes to deep systems, mainly due to the high cost of constructing the new heating systems or adapting the existing ones, projects stop after the hydrogeothermal drill holes are completed.

In the last decade, six hydrogeothermal drill holes were constructed in Vojvodina (Pannonian basin) and all were planned to be used for heating and recreational and wellness centres, yet only one was put into operation. Projected hydrothermal systems planned to be operational by 2022 are still on hold. This was only partially due to the pandemic of COVID-19 and more due to a lack of funds and serious investors.

Serbia did not meet the goal of 27 % renewable energy sources in gross final energy consumption by the end of 2020 in accordance with Directive 2009/28/EC. In 2019 its share was 21.4 % (Report on the Implementation of the National Renewable Energy Action Plan of the Republic of Serbia for 2018 and 2019).

Based on the current trend, it can be concluded that it takes time for the new system of incentives to come to life, and then to gain investors' confidence in the functioning of the system, as well as to prepare appropriate projects, especially projects for the construction of large power plants.

To improve investors' interest in renewable energy sources, in 2021 the Serbian Government has come up with three improved laws about energy, mining and renewable energy sources that intend to shorten the procedure for obtaining licences and encourage investors to choose renewable energy sources.

5. FUTURE DEVELOPMENT AND INSTALLATIONS

For now, geothermal energy in Serbia is used only in the amount of 109.26 MW_{th} and an additional amount of 52.59 MW_{th} out of shallow geothermal systems. This can be considered as pretty low having in mind its potential.

The most significant use of geothermal energy in Serbia could be for district heating of settlements and agriculture development, more precisely food production following the ecological standards and in near future for electric power production.

There are 6 geothermal systems awaiting realisation, 5 in the Pannonian basin for heating and recreational purposes with a total capacity of 14.68 MW_{th} and one from reservoirs in karstified limestone beneath the Neogene sediments in Macva province for use in agriculture with a thermal capacity of 8.49 MW_{th}.

The great interest in Belgrade is in using heat pumps for heating the large state-of-the-art residential buildings, hotels and shopping centres where reservoirs of interest are in alluvial sediments of Sava and Danube and Neogene sediments beneath. In addition, the prospects for use of heat pumps on pumped groundwater from alluvial deposits along all major rivers are significant.

At the very end of 2021, a new project commenced. United Nations Development Programme in partnership with the Ministry of Mining and Energy of the Republic of Serbia and the Council of Europe Development Bank and in close cooperation with the Administration for Joint Services of the Republic Bodies will implement this project intended for preparatory activities for the Programme: “Energy Efficiency in Central Government Buildings”.

The envisaged multiannual programme is aimed at energy efficiency renovation of central government buildings as per Article 5 of the Energy Efficiency Directive (2012/27/EU). The Programme should result in 30 % of primary energy consumption reduction, 20 % of CO_2 reduction and 29 % savings in operational cost for energy, within the 27 specified buildings. The first step shall be to determine the locally available hydrogeothermal, and petrogeothermal potential from which it is possible to generate the required energy for building systems sustainably and acceptably, regarding the status and significance of the buildings.

6. CONCLUSIONS

It is certain that Serbia has a great potential in hydrogeothermal energy for direct use and that this kind of energy is used to a very small amount. Recent explorations displayed that many sources were closed and out of operation and that many data were outdated. The great interest in geothermal energy utilization has been revoked and unfortunately lost after facing many obstacles.

On the other hand, the share of low enthalpy systems in total energy production from geothermal resources is 25 % and rising.

We hope that the new laws from 2021, which move Serbia to a market-based support scheme, would speed up geothermal energy utilization projects.

REFERENCES

Martinovic M and Milivojevic M.: Serbia Country Update, *Proceedings World Geothermal Congress 2010* Bali, Indonesia (2010).

Milivojevic, M.: Assessment of Geothermal Resources of Serbia Excluding Autonomous Provinces (Doctor thesis), *University of Belgrade*, Belgrade (1989), p 458 (in Serbian).

Milivojevic, M.: Geothermal map, Geological atlas of Serbia 1 : 2.000.000, No.11, *Ministry of mining and energetics Republic of Serbia,* Belgrade, (2001).

Report on the Implementation of the National Renewable Energy Action Plan of the Republic of Serbia for 2018 and 2019, *Ministry of energetics, development and environmental protection, republic of Serbia,* Belgrade, (2020).

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021	-	-	7855	34896	0	0
Under construction end of 2021	-	-	505	4905	-	-
Total projected by 2023	-	-	505	4905	0	0
Total expected by 2028	1	5	9500	45000	1	1
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development: 11 (exploitation) 5 (exploration)	
					Under investigation: 15	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

No geothermal power plants currently in Serbia.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021	47.674	113.858	11.626	61.713	14.497	71.122	35.467	182.674
Under constru-ction end 2021	7.427	65.034	8.494	74.377	7.766	55.691	3.079	20.371
Total projected by 2023***	7.427	65.034	8.494	74.377	7.766	55.691	3.079	20.371
Total expected by 2028	55.100	219.509	20.120	136.090	22.263	126.813	38.546	203.018

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

*** The projected systems, if different from those under construction, are in early phases and data is not available.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Junaković spa	Pb-1/H, Pb-3/H	1984	N	N	5.145	5.145	11.263	100
Kanjiža spa	Kž-1/H, Kž-2/H, Kž-3/H	1981	N	N	5.412	5.412	8.764	100
Ribarska Spa	Rb-4	1988	N	N	0.795	0.795	4.177	100
Lukovska Spa			N	N	1.607	1.607	14.069	100
Sijarinska Spa	B-4	1990	N	N	4.268	4.268	4.597	100
Niška Spa			N	N	3.012	3.012	15.608	100
Debrc-1	IEDc-1	1990	N	N	2.310	2.310	10.112	100
Debrc-2	Debrc-2	1990	N	N	7.113	7.113	24.914	100
Vranjska Spa	WG-2, WG-3	1989	N	N	15.397	15.397	13.483	100
Bogatić	BB-1	2018	N	N	2.615	2.615	6.870	100
total					47.674	47.674	113.858	100

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

No geothermal large systems for heating and cooling other than DH currently in Serbia.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	*est. 2850*	52.590	116.906	*est. 1000*	20.000	70
Of which networks **						
Projected total by 2023	n/a	n/a	n/a			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	-	-	-	-
Geothermal direct uses	*est.* 1.0	*est.* 125	*est.* 1.5	*est.* 135
Shallow geothermal	*est.* 0.8	*est.* 220	*est.* 2.8	*est.* 290
total	*est.* 1.8	*est.* 345	*est.* 4.3	*est.* 425

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D			
Financial Incentives – Investment	-	*est* 0.2 million € - DIS *est* 0.7 million € - LIL	*est* 2.8 million € - LIL
Financial Incentives – Operation/Production	FIT	FIT & LIL	FIT & LIL
Information activities – promotion for the public	yes, through media	yes, through media	yes, through media
Information activities – geological information	yes, through articles and media	yes through public media	yes, through public media
Education/Training – Academic	yes, through MSc studies	yes, through MSc studies	yes, through MSc studies
Education/Training – Vocational	yes, through workshops and conferences	yes, through workshops and conferences	yes, through workshops and conferences

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

European Geothermal Congress 2022
Berlin, Germany | 17-21 October 2022
www.europeangeothermalcongress.eu

Geothermal Energy Use, Country Update for Slovakia

Branislav Fričovský[1], Daniel Marcin[1], Katarína Benková[1], Radovan Černák[1],
Klement Fordinál[2], Ondrej Pelech[3]

[1] Dept. of Hydrogeology and Geothermal Energy, Dionýz Štúr State institute of Geology,
Mlynská dolina 1, 817 04 Bratislava, Slovakia

[2] Dept. of Geology of younger geological units, Dionýz Štúr State institute of Geology,
Mlynská dolina 1, 817 04 Bratislava, Slovakia

[3] Dept. of Geology of older geological units, Dionýz Štúr State institute of Geology,
Mlynská dolina 1, 817 04 Bratislava, Slovakia

branislav.fricovsky@geology.sk

Keywords: geothermal energy, direct use, resources and reserves, legislation, Slovakia.

ABSTRACT

As part of the Western Carpathians realm, partially consolidated and off any recent volcanic activity, the territory is of a moderate geothermic activity, as mean geothermal gradient is of app. 30 °C·km^{-1} and mean surface heat flow density reaches 82.1 mW·m^{-2}. Low to moderate enthalpy resources have been successfully sampled, prevailing with a water phase at a reservoir or a wellhead, with only a few observing saturated steam (wet-steam) at reservoir conditions and degassing in wells. Thermodynamic quality of sampled resources is, though, low to moderate-low.

Geothermal resources contribute on a exclusively direct use only in Slovakia. Previous national assessments reported 6,233 MW$_{th}$ of probable geothermal potential, with 436 MW$_{th}$ already proven by 282 wells, including those producing geothermal waters for curative purposes in spas.

The process of complete datasets and national database reconstruction is under way, beginning in 2017, explaining rise in number of wells and proven resources when compared to previous updates. Recently, 121 wells are in active service at 76 localities. A nameplate online capacity is 230 MW$_{th}$. According to data from private operators submitted to the Water Research Institute (most recent as of 2020), the yearly production reached 1,684 TJ of heat and a 470 GW$_{th}$h of geothermal energy. However, this does not include heat production of small to large scale GSHPs and BHEs, suffering lack of relevant data.

Recreation still prevails in utilization of geothermal energy in Slovakia, reflecting a decades-long tradition, with 48 wells reported online at 41 sites, yet only if this is a primary use, not including cases where the geothermal resource is cascaded to heating pools after use in other first-stage purposes.

Since last country update, three new wells at Bruty (the Levice Block) have been commissioned, however, reports are restricted for the public up to 2023. Recently, a new well in Kežmarok (Levoča Basin, S and W part) is under construction, as well as drilling in Čižatice (the Košická kotlina Basin) was finished in April 2022, expecting preliminary spontaneous free-flow tests soon. No official projects are in process of licensing, considering geothermal power production in the country.

1. INTRODUCTION

According to IEA public data, Slovakia is still an economy oriented towards fossil fuels, where RES contribute with roughly 29 % on heat production, whilst geothermal energy yields only a 2 % share. In power production, while fossil fuels count for a 21 % share, and pushing renewables (including small to large hydro) over 25 %, nuclear prevails. There is no geothermal power plant in the country.

Tradition in use of geothermal resources dates beyond Medieval owing to dozens thermal springs, later caught and cumulated in multiple spas. Yet systematic research has been launched in 70's, responding to global oil and gas concerns and crisis.

Previous reports and hydrogeothermal evaluations reported 6,233 MW$_{th}$ of probable reserves, as potential of perspective geothermal areas (GPAs). Concerns of conceptual methodology of previously carried evaluation triggered a pilot, tentative probabilistic booking of geothermal reserves as submitted to WGC2020 (Fričovský et al., 2020a). Yielded rate of probable reserves counted 6,716 MW$_{th}$ for short-term (40 years) and 2,686 MW$_{th}$ for long-term (100 years) production period, the latter reflecting discussions on sustainable reservoir production duration (e.g. Axelsson et al., 2001). Applying a reserve capacity ratio method, sustainable thermal potential of 31 geothermal water bodies of Slovakia was assessed for 2,972 MW$_{th}$ for short and 1,416 MW$_{th}$ for long period respectively.

In total, 31 geothermal water bodies, responding The Water Framework Directive No. 2000/60/EC of the EU Parliament and the Council are delineated recently (e.g. Fričovský et al., 2020b). Geothermal resources have already been proven by 282 wells among 30 out of 31 geothermal water bodies (GWBs), proving 436 MW_{th} of reserves. Following global trends, heat pump installations and use of shallow geothermal energy potential grow rapidly in the country, with realistic capacity data inaccessible.

2. GEOLOGY AND REGIONAL GEOTHERMICS

2.1 Review on regional geology

Regional geological structure of Slovakia reflects its geotectonic evolution and recent position, forming the northern branch of the European Alpine mountain chain (Schmid et al., 2008, Plašienka, 2018) as part of the Western Carpathians (WCs) formed in Variscan to Alpine orogeny (Jurewicz, 2005). The bedrock comprises of crystalline thick-skinned and Mesozoic sedimentary thin-skinned nappe series formed during Jurassic to Cretaceous collision. Subsequently the Central Carpathian Paleogene Basin (siliciclastics) covered the pre-Tertiary formations transgressively. The Miocene-Quaternary sediments of the Pannonian basin system reach particularly high thickness in the Vienna, Danube and East Slovak basins. Neovolcanites of Miocene - Pliocene age are substantial to Miocene extension, producing volcanoclastics and flow products as part of Neogene basin fill in the Inner Western Carpathians. The External Western Carpathians consist of thin-skinned nappes, where Carpathian Flysch Belt prevail in volume, recording syn-orogenic mass transport deposits formations. The Pieniny Klippen Belt is a complex shear zone dividing the External WCs and Internal WCs, composed of a "core" dominated by Mesozoic carbonates, and a Tertiary envelope of siliciclastics.

2.2 Regional hydrogeothermics, origin and chemistry of geothermal waters

Geothermal resources associate with conduction-dominated orogenic belt / foreland basin play types (Moeck, 2014). A single exception is the Beša-Čičarovce buried volcano structure within the Neogene sedimentary fill of the Trebišov Basin, few kilometers thick, assuming the magmatic intrusion type (Moeck and Beardsmore, 2014). However, it has not been subjected to a hydrogeothermal evaluation yet.

For EGC2019 (Fričovský et al., 2019a) a few concepts of sub-types have already been presented supporting the play-type classification (Moeck, 2014; Moeck and Beardsmore, 2014):

- Structures associated with intramountain depressions: usually hydrogeologically open, with petrogenic type of chemistry; natural recharge at hydrogeological massifs at periphery; reservoirs in Mid Triassic; basin-constriction, fault-plane, lateral-leakage and bedrock-high systems (e.g. Liptov Basin, Levoča Basin – S,W part)
- Structures associated with embayments of Neogene sedimentary basins: typically open to closed; petrogenic to mixed type of chemistry; natural recharge at hydrogeological massifs at periphery or through lateral inflow; reservoirs in Mid Triassic carbonates, Paleogene detritic carbonates and conglomerates, Neogene sands and sandstones; stratified-reservoirs, lateral-leakage, and bedrock-high systems; (e.g. Piešťany Embayment)
- Structures at footslopes of Neogene volcanic mountains: open to semi-open type; petrogenic type of chemistry; natural recharge at slopes of volcanic systems; reservoirs in Neogene volcanoclastics and sedimentary formations, primary reservoirs most probably in Mesozoic carbonates; fault-plane and lateral-leakage systems; (e.g. Žiar Basin)
- Structures associated with Neogene sedimentary basins: open to close, petrogenic to mixed chemistry; natural leakage (if any) at regional peripheries; stratified-reservoirs and basin-constriction types; reservoirs in Neogene siliciclastics or Mesozoic carbonates; (e.g. CDDP, Rimava Basin, Lúčenec Basin)

Outline of geothermic activity in the Western Carpathians follows: add 1: different structure and depths of neotectonic block with a manifest in overall crustal thickness; add 2: non-uniform mantle propagation; add 3: spatial distribution of Neogene - Quaternary volcanism; add 4: local and regional hydrogeological conditions; add 5: course and depth-seating of major crustal fault systems (Fendek et al., 1999; Franko and Melioris, 1999).

The surface heat flow density varies 50-120 $mW \cdot m^{-2}$, with a mean of 82.1 ± 20 $mW \cdot m^{-2}$ (Bodiš et al., 2018). Highest geothermic activity is documented within Eastern Slovakian Neogene Basin (90-130 $mW \cdot m^{-2}$) and CDPP (> 90 $mW \cdot m^{-2}$), decreasing in tertiary intramountain depressions (40-70 $mW \cdot m^{-2}$), whilst minima (30-50 $mW \cdot m^{-2}$) are recorded from the Flysch Belt (Marcin et al., 2014; Majcin et al., 2017).

2.3 Geothermal waters, origin and quality

Geothermal resources of 20-150 °C (Černák et al., 2014) have been sampled in wells, screening inflow intervals at depths of tens to 3,600 m. Geothermal models, however, assume extending of a reservoir dry-rock temperatures at 4,000-6,000 m up to 180-240 °C with rare maxima of 270 °C. This corresponds to low to moderate-low thermodynamic quality at both, the reservoir and wellhead conditions.

The geothermal waters are principially of marinogenic (originally seawater, or degraded), petrogenic (originally meteoric with various degree of vertical circulation) and mixed origin (Bodiš et al., 2018). The TDS extends widely between 0.4-90 $g \cdot l^{-1}$ (Marcin et al., 2014).

3. LEGISLATIVE CONTROLS ON GEOTHERMAL ENERGY RESEARCH, DEVELOPMENT, USE AND PROMOTION IN SLOVAKIA

Any research and prospection of geothermal resources follows the Act No. 569/2007 Coll. (Act on geology) as amended by the Act No. 311/2013 Coll., applying a provision on licensing withdrawals of geothermal waters in category B, and setting an obligation for approval by the Ministry of the Environment as based on long-term pumping tests on wells, and estimation of hydraulic properties, and physical-chemical properties of water, including monitoring of qualitative and quantitative monitoring (Fendek et al., 2016). The permitting of geothermal water withdrawals and payment for those is regulated by Act No. 364/2004 Coll. (Act on water) with later amendments, i.e. 306/2012 Coll. (Fendek and Fendeková, 2015).

Promotion of RES into national PEM is legislatively regulated through amendments of Act No. 309/2009 Coll. (Act on promotion of renewable energy sources and high efficiency combined production (latest 377/2018 Coll.) that follows goals as set by the Directive 2009/28/EC of the European Parliament and the Council on the promotion of the use of energy from renewable sources.

Relevant national strategies and plans useful in regulation and setting targets and roads to follow are:

- 2014 Energy Policy
- 2010 National Renewable Energy Action Plan
- 2017 National Energy Efficiency Action Plan
- 2018 Integrated National Energy and Climate Plan

Geothermal waters with proven curative composition are regulated according the "Spa Act", i.e. Act No. 538/2005 Coll. with onward amendments.

4. GEOTHERMAL ENERGY USE IN SLOVAKIA: REPORTING

4.1 List of previous country updates

Below is a list of country updates compiled for Slovakia since is break-up of former Czechoslovakia, tracking both, development of geothermal energy in the country, as well as changes in reporting and passporting procedures:

- 1995: Remšík, A. and Fendek, M.: Geothermal Country Update for Slovakia, Proceedings World Geothermal Congress 1995, Florence, Italy, 1-5
- 2000: Fendek, M. and Franko, J.: Country Update for the Slovak Republic, Proceedings World Geothermal Congress 2000, Kyushu-Tohoku, Japan, 1-7
- 2005: Fendek, M. and Fendeková, M.: Country Update of the Slovak Republic, Proceedings World Geothermal Congress 2005, Antalya, Turkey, 1-9
- 2010: Fendek, M. and Fendeková, M.: Country Update of the Slovak Republic, Proceedings World Geothermal Congress 2010, Bali, Indonesia, 1-10
- 2015: Fendek, M. and Fendeková, M.: Country Update of the Slovak Republic, Proceedings World Geothermal Congress 2015, Melbourne, Australia, 1-8
- 2016: Fendek, M., Fendeková, M., Fričovský, B. and Blanárová, V.: Geothermal Energy Use, Country Update for Slovak Republic, Proceedings European Geothermal Congress 2016, Strasbourg, France, 1-11
- 2019: Fričovský, B., Černák, R., Marcin, D., Blanárová, V., Benková, K., Pelech, O., Fendek, M.: Geothermal Energy Use, Country Update for Slovakia, Proceedings European Geothermal Congress 2019, Den Haag, Neetherlands, 1-15
- 2020: Fričovský, B., Černák R., Marcin, D., Blanárová, V., Benková, K., Pelech, O., Fordinál, K., Bodiš, D., Fendek, M.: Geothermal energy use – country update for Slovakia, Proceedings World geothermal Congress 2020, Reykjavik, Iceland, 1-19

4.2 Actual changes in passporting geothermal potential and utilization data on national scale

In country updates towards EGC2019 and WGC2020, actions aiming on a national database of geothermal wells have been described in details. This is still in a progress, so that major changes in number of wells, proven and installed capacity is due to adding wells to the database proving geothermal resources, however, due to various reasons, not listed in previous datasets. Moreover, we keep on listing wells producing curative mineral thermal waters under authority of Spa and Thermal-springs Inspectorate by Ministry of Health of the Slovak Republic, formerly eliminated from previous country update reports.

Data on actual geothermal waters production are provided to the Dionýz Štúr State institute of Geology by the Water Research Institute, authorized for collection by the Act on water. The most recent and completed list is, however, as of the year 2020.

4.3 State-of-art in probable and proven reserves assessment

A transition towards Water Framework Directive resulted in change of national geothermal potential evaluation, as already 31 geothermal water bodies (GWBs) have already been delineated as presented at WGC2020. Discussion presented in last two country updates on previous evaluations, resulted in a tentative, pilot probabilistic booking of geothermal reserves on a national scale, modeling all 31 GWBs using Monte Carlo simulation of USGS volume method (Garg and Combs, 2015); and effective reservoir volume (e.g. Sanyal and Buttler, 2005; Williams, 2007) or production efficiency (e.g. Ungemach et al., 2005) methods to asses locally scaled recovery factor R0 for both, reservoirs with and without reinjection. The probabilistic booking model was, however, based on "best-guess" and analogy when defining simulation distribution of variables. Though a rate of probable reserves has been assessed for:

- R_{pb} = 6,716 MW_{th} for 40 years of production
- R_{pb} = 2,686 MW_{th} for 100 years of production.

Applying a concept of reserve capacity ratio (Bjarnadottir, 2010; Fričovský et al., 2019b), that defines a critical sustainable capacity at r_{cap} = 0.5 or half of probable reserves, the sustainable geothermal potential was assumed for 2,972 MW_{th} for short and 1,416 MW_{th} for long period respectively.

Recently, the Dionýz Štúr State institute of Geology is working on a calibrated probabilistic reserves booking model as based on 2D to 3D geological and geothermic models. Release of the results is due by 2024.

Up to April 2022, 282 geothermal wells are enlisted in a database, proving 436 MW_{th} of geothermal reserves. Compared to results of tentative probabilistic booking, this should represent up to 6 % on short and 16 % of probables on long time scale. When compared to a sustainable potential, the proven reserves represent as much as 15 % and 31 % respectively, still counting a solid potential to prove and install in the country.

5. GEOTHERMAL ENERGY USE IN SLOVAKIA: QUANTITATIVE UPDATE

5.1 Recent use of geothermal energy – geothermal water bodies

There is at least one (e.g. Trnava embayment) up to 49 (Danube Basin Central Depression) in 30 out of 31 delineated GWBs in Slovakia (Figure 1). Records show 120 wells online in 22 GWBs (Table 1), i.e. 43 % of those ever drilled. Almost 23 % of all online wells are obviously in Danube Basin Central Depression (CDPP). Installed thermal capacity for online wells only increased to roughly 230 MW_{th} compared to EGC2019, i.e. 53 % of already proven reserves.

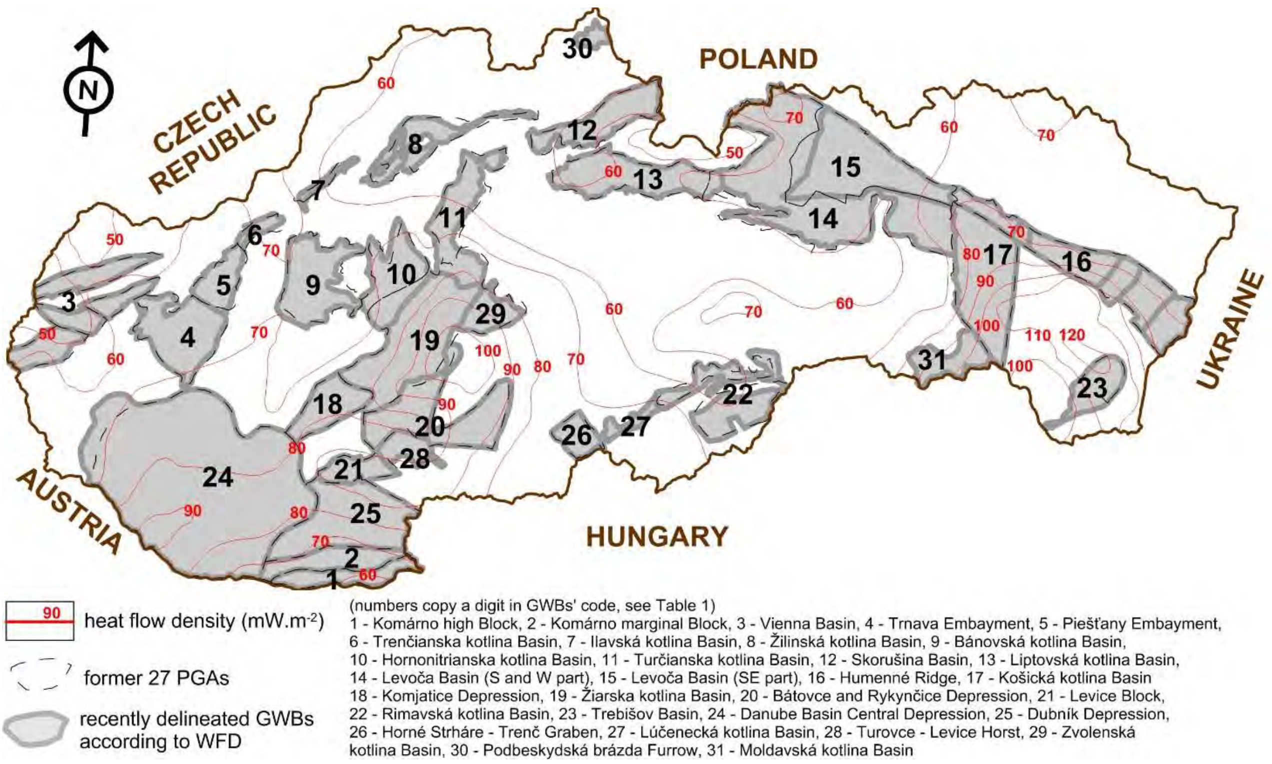


Figure 1: Delineated geothermal water bodies in Slovakia according to the Water Framework Directive at a surface heat flow density map background

According to most recent production data, a mean thermal output of all online wells is 57 MW_{th} for 2020, i.e. 25 % of installed capacity. Substantially, this projects to relatively low capacity and load factors calculated per separate wells, owing to:

- thermal waters with curative effects in spas are typically produced 365 days a year, yet withdrawals are rather low to avoid depletion and changes in a resource chemistry
- use of cascaded systems or by-pass is rare, so withdrawals for individual and district heating (or agriculture) vary rapidly in seasons
- some localities, especially producing geothermal waters to heat pools suffered of restrictions related to COVID-19, dropping a visit rate during an autumn and winter season mainly
- except the well OZ-2 Oravice (Skorušiná Basin), a typical scheme is one well – one operator – one locality in the country.

Table 1: Geothermal water bodies: geothermal energy production statistics as of 2020

Code	Geothermal water body	Wells	Online wells	Sites	Rpv (MWt)	Pth_in (MWt)	Pth_act (MWt)	Qpv (kg/s)	Qcum (m3/rok)	ETH-ideal (GWh,th)	ETH-actual (GWh,th)	EQ (TJ)
Code	**Geothermal water body**	11	7	3	19	16	2	258	1.26	138	13	47
SK300010FK	**Komárno high Block**	5	0	0	3	0	0	19	0	0	0	0
SK300020FK	**Komárno marginal Block**	2	0	0	9	0	0	35	0	0	0	0
SK300030FK	**Vienna Basin**	1	1	1	1	1	0	14	0.06	5	1	1
SK300040FK	**Trnava Embayment**	16	6	1	20	16	3	120	0.64	138	30	107
SK300050FK	**Piešťany Embayment**	0	0	0	0	0	0	0	0	0	0	0
SK300060FK	**Trenčianska kotlina Basin**	12	6	1	3	2	1	45	0.55	18	12	42
SK300070FK	**Ilavská kotlina Basin**	13	9	4	7	4	1	95	0.5	31	6	23
SK300080FK	**Žilinská kotlina Basin**	8	3	3	5	3	1	62	0.25	25	5	20
SK300090FK	**Bánovská kotlina Basin**	18	10	4	15	10	3	115	0.83	85	21	76
SK300100FK	**Hornonitrianska kotlina Basin**	16	6	3	11	2	1	92	0.24	13	4	15
SK300110FK	**Turčianska kotlina Basin**	2	1	2	18	16	0	128	0.09	143	3	10
SK300120FK	**Skorušina Basin**	22	8	5	30	23	9	282	2.34	201	70	253
SK300130FK	**Liptovská kotlina Basin**	20	6	6	36	25	7	268	1.7	223	59	215
SK300140FK	**Levoča Basin (W and S part)**	5	0	0	5	0	0	22	0	0	0	0
SK300150FK	**Levoča Basin (NE part)**	4	1	1	1	0	0	12	0.07	4	1	5
SK300160FK	**Humenné Ridge**	4	0	0	73	0	0	173	0	0	0	0
SK300170FK	**Košická kotlina Basin**	1	0	0	3	0	0	11	0	0	0	0
SK300180FK	**Komjatice Depression**	18	15	4	10	8	4	85	1.14	73	36	130
SK300190FK	**Žiarska kotlina Basin**	1	0	0	2	0	0	12	0	0	0	0
SK300200FK	**Bátovce and Rykynčice Depression**	5	1	1	28	14	2	114	0.37	119	19	67
SK300210FK	**Levice Block**	4	1	1	2	1	0	59	0.08	7	1	5
SK300220FK	**Rimavská kotlina Basin**	10	1	1	3	1	0	27	0.16	5	2	8
SK300230FP	**Trebišov Basin**	49	27	25	104	78	20	507	3.25	680	165	580
SK300240PF	**Danube Basin Central Depression**	4	1	1	5	4	2	34	0.24	31	14	49
SK300250PF	**Dubník Depression**	8	2	2	7	1	0	89	0.12	5	1	6
SK3002600P	**Horné Strháre – Trenč Graben**	1	1	1	1	1	0	11	0.06	9	1	4
SK30027FKP	**Lučenecká kotlina Basin**	9	4	3	4	3	1	84	0.2	23	2	6
SK30028FKP	**Turovce - Levice Horst**	7	3	3	14	4	1	139	0.16	38	4	15
SK300290FK	**Zvolenská kotlina Basin**	1	0	0	1	0	0	0	0	0	0	0
SK300300FP	**Podbeskydská brázda Furrow**	5	0	0	1	0	0	45	0	0	0	0
SK300310FP	Moldavská kotlina Basin	0	0	0	0	0	0	0	0	0	0	0

The reservoir media in conditions of the Western Carpathians is a geothermal water, associated mostly with Mesozoic - Mid Triassic carbonates (e.g. Liptov Basin, Žilina Basin, Piešťany Embayment) or Neogene sands, sandstones or conglomerates (e.g. CDDB). Only several wells hit thermal waters in Neogene volcanosedimentary complexes (see Figure 1 sketching major reservoir host rocks).

Proven deliverability of wells sampling geothermal waters is 2,955 kg·s^{-1}, although carried free-flow and pumping tests are of various degree of certainty. Following the Act on water, each installation is subjected to apply for a license, yet the allowance may vary compared to proven flow rate, and is typically lower. This would represent a total amount of app. 95·10^{6} m^{3} of total geothermal waters withdrawn if produced at a full rate. Through 2020, a cumulative waters produced reached 14.3·10^{6} m^{3}, i.e. 15 % of that proven. Highest cumulative production rates were recorded in the CDPP (3.25·10^{6} m^{3}), Liptov Basin (2.3·10^{6} m^{3}) and the western and southern part of the Levoča Basin (1.7·10^{6} m^{3}). While in the first case, the rank is due to enormous amount of production wells, in the latter, the productivity is due to both, the energy demand and generally high deliverability of Mid Triassic carbonates forming a stratified reservoir with lateral and vertical inflows there.

An average heat production per well ranged 0.01 to 120 TJ·yr^{-1}, with maxima at the ZGL-1 Bešeňová well (Liptov Basin) serving for recreation mostly. When referring to geothermal water bodies, the highest heat per well ratio is calculated for the Levice Block (1 well, Podhájska site, recreation): 67.5 TJ·yr^{-1} and the Dubník depression (1 well, Bruty site, agriculture): 49 TJ·yr^{-1}.

5.2 Utilization of geothermal energy

There are 76 localities producing geothermal energy from geothermal water in 2020 – yet the number has not increased up to 2022. This includes spas dedicated for curative and medical purposes, not distinguished from recreation in updates until 2019. Although use of cascaded systems is rather rare, there are few to combine district heating with recreation (Veľký Meder), space heating with recreation (Bešeňová), or use by-pass systems, such is Podhájska site (agriculture with recreation, however, recreation prevails in this case).

Recreation - heating outdoor (e.g. Vinica, Kurinec, Chalmová, Bešeňová) and/or indoor (e.g. Patince, Poprad, Rajecké Teplice) pools still prevails in utilization, with 49 wells online at 41 sites and overall nameplate capacity of 102 MW$_{th}$. Only six sites use more than 1 well, i.e. Virt (3), Štúrovo (3), Vyhne (3), Chalmová (2), Kalinčiakovo (2) and Bojnice (2). A cumulative mean yearly thermal output counts app

22 MW_{th}, i.e. 37 % share on total. This is due to cumulative production of app $6 \cdot 10^6$ m^3 geothermal waters. A mean load factor is 0.20, while a mean capacity factor 0.25; meaning both as lowest among all direct-use purposes in the country. Reasons are already described above, as not every site produces 365 days a year and withdrawals differ off that proven or licensed as based on a dynamic demand and/or capacity of pools at a respective site.

Agriculture covers both, heating greenhouses and, thus, planting (e.g. Topoľníky, Bruty, Nesvady), and fish-farming (Vrbov). Typically, the scheme is 1 well per 1 site, exception is the Horná Potôň site, operating 2 wells. The geothermal energy for this purpose is produced through 12 wells at 11 sites. A total installed capacity is 45 MW_{th} (20 % of total). A mean cumulative yearly thermal output counts 18 MW_{th} (20 %). During 2020, cumulative amount of geothermal waters produced for agriculture was $1.72 \cdot 10^6$ m^3, i.e. 12 % share on total. Mean load factor for agriculture / aquaculture is 0.26, with a mean capacity factor of 0.31. This is due to seasonality in use of geothermal waters (Čiližská Radvaň, Ňárar, Nesvady, Topoľníky), however, other sites prefer a year-long production (e.g. Zemné, Dunajská Streda, Zlatná na Ostrove).

Balneotherapy is served through 46 wells at 11 sites. Typically, most spas use more than one well for curative and healing procedures (e.g. Sklené Teplice – 10, Piešťany – 6, Rajecké Teplice – 6, Trenčianske Teplice – 6), however, few spas use only a single-well resource, such is the Dudince or Sliač, otherwise produce “cold” mineral waters. The overall installed capacity is app 37 MW_{th} (16 % share), while cumulative mean yearly output reached app 10 MW_{th} in 2020 (18 %). A total yearly withdrawal reported is $2.9 \cdot 10^6$ m^3, sharing 20 % on cumulative production of geothermal waters. Load (0.34) and capacity (0.36) factors are higher compared to recreation and agriculture, yet due to a 365 days a year operation. According to calculations, app. 310 TJ of heat were produced for therapeutical purposes.

Together 10 wells at 10 sites provide heat of a geothermal resource for individual heating of administration buildings or resorts. Overall installed capacity is 33.4 MW_{th}, i.e. the nameplate rate is app 3.4 MW_{th} per single well. Cumulative mean thermal output for 2020 counts 9.8 MW_{th}, i.e. 0.9 MW_{th} per well, a second highest among direct use. This is a result of cumulative production of $2.34 \cdot 10^6$ m^3 of geothermal waters (16 % share), generating app 289 TJ of heat in this year. Load (0.34) and capacity (0.37) factors reflect generally a year-long demand at sites.

Four DH plants exist in Slovakia, and their number has not changes since EGC2019 yet – the Sereď, Šaľa, Veľký Meder and Galanta. The Galanta site is, however, the only operating two wells for the geothermal DH scheme. Well reports on each are already published (Takács and Grell, 2005; Halás, 2015). Each is, however, a hybrid system, combining geothermal energy supporting natural gas boilers. Installed capacity is 20.6 MW_{th} (9 %) to rate 4.1 MW_{th} per well. Cumulative mean yearly thermal output of geothermal DH systems reached 7.54 MW_{th} (13 %), as a result of cumulative amount $1.1 \cdot 10^6$ m^3 of geothermal waters produced. Load (0.38) and capacity (0.39) factors are by far the highest among direct uses of geothermal energy, owing to relatively stable and a year-long production of geothermal waters.

Distribution of sites in Slovakia is fairly uneven. While agriculture prevails rather in the southern part, i.e. the CDPP and the Dubník Depression (only Vrbov for fish-farming is in the north), and geothermal DH systems are exclusively within the CDPP, recreation purposes are quite dispersed through the country. Mineral-thermal waters produced for curative purposes in balneotherapeutical spas are produced exclusively from Mid Triassic carbonates, i.e. are located in intramountain depressions oriented northwards, reflecting historical commissioning dated centuries back, tapping healing springs first.

5.3 Shallow geothermal resources and ground source heat pumps

Reflecting the global acceleration of shallow geothermal energy resources, the growth of the sector is rapid in Slovakia. Dozens of small-scale installations (ground-source heat pumps, heat exchangers) are installed yearly, however, official numbers are not available.

Large-scale installations are reported from Podhájská, Bojnice, Vyšné Ružbachy, Gbelany, Rajecké Teplice, Piešťany, Senec, Čilistov and Rabča (Fendek and Fendeková, 2015), with heat rating capacity of 1.6 MW_{th}. In addition, Fendek et al. (2016) assume the net heat rating capacity of all heat pumps of 78.1 MW_{th}, expecting it to grow continuously. If so, the segment of shallow geothermal energy resources would instantly become the second largest amongst geothermal energy use in the country.

Unfortunately, no representative numbers are available to sum small to large scale geothermal heat pumps installations. A pilot project on assessment of shallow geothermal energy potential, the GeoPLASMA-CE, has already been published for the WGC2020 (e.g. Goetzl et al., 2020; Švasta et al., 2020).

5.4 New and close-future installations

Since the EGC2019 and WGC2020, no geothermal well has been commissioned and tested, neither put into operation in Slovakia. However, there are localities expected to progress in a few months / years. Many delays are, obviously, due to the COVID-19 situation in the last years.

The GTP-1 well in Piešťany (Piešťany Embayment) obtained provisions on geothermal waters withdrawal by Ministry of Environment of the Slovak Republics, so is ready to supply rising aqua center in town, with plans for individual space and pool water heating.

The M-2 well in Komárno underwent a reconstruction, planned to serve the municipal pool resort in cascaded, individual space heating and consequent heating of pools.

The Lipany-2 well was recommissioned and took actualized pumping tests, yet the plan is to provide geothermal waters for local thermal park, as at a first site (Lipany) in the Levoča Basin – NE part GWB.

Discussions on geothermal DH system installation for the city of Košice, as the second largest in the country, has already taken place, concerning the nearby Ďurkov depression hydrogeothermal structure (Vranovská et al., 2000; Beňovský et al., 2000; Halás et al., 2015; Fričovský et al., 2019b), yet since commissioning in 1999 and few pumping tests carried, no action followed. Recently, Ministry of Economy decided to support financially the site, aiming to trigger the construction of the geothermal DH system and the connection to the town of Košice. As based on recent demand and heat production in the city, it would be able to cover 10 - 20 % of actually delivered heat.

Two new pumping tests and application of withdrawal provisions for geothermal waters have already been submitted to Ministry of Environment of the Slovak Republic, at Veľká Lomnica and Veľký Slavkov, turning ready for production. Moreover, a new well in the town of Kežmarok is recently being drilled, planned for geothermal DH installation. All three wells are part of the Levoča Basin south and west part.

A new well, GTČ-1 Čižatice has successfully been drilled at the Čižatice site nearby the town of Košice (the Košice Basin GWB), as a result of several years of geological research and modeling (e.g. Jacko et al., 2014, Jacko et al., 2021). Here, the Košice self-governing region takes cooperation with the Technical University of Košice and the Rotaqua consortium, with the Dionýz Štúr State institute of Geology contributing on hydrogeothermal evaluation of the well. Recently, the final depth is reached at approx. 2,700 m in April 2022, a borehole influx temperature is 120 – 128 °C (Figure 2). Mobile phase is geothermal water in reservoir or a wet steam, separating within the well under atmospherical pressure, yet observed thermal water temperature at the wellhead was 96 to 98 °C at free-low, recording a mean deliverability of 14 $l \cdot s^{-1}$. Still, serious qualitative and quantitative measures must be taken before decision on a purpose of a resource use.

Meanwhile, there is a continuous plan for a first binary plant unit installation in the Lovča area, the Žiar Basin GWB, where geophysical prospection and interpretation of the hydrogeothermal system took place, drilling has, however, not started yet.

6. REMARKS

Some comments must be given to numbers presented in the report. Number of sites and wells must be taken with care and may differ compared to official records, as due to legislation, subjects are not obliged to submit geothermal water withdrawals in case their mean production does not reach 0.5 $l \cdot s^{-1}$. This may be a case of small pools or greenhouses, although most of the wells are technically registered in official archives operated by Dionýz Štúr State institute of Geology. Compared to previous country update reports, installed (nameplate) capacities were recalculated to 15 °C reference temperature, erasing previous concerns.

Figure 2: Drilling at the Čižatice site, free-flow with spontaneous steam separation. Photo: Dr. Zuzana Kollová, Dionýz Štúr State institute of Geology – division Košice

Still, reconstruction of a geothermal database keeps under process, so numbers may differ in future as long as this is not finished. For that reason, we also recommend the reader to check for a country update in submission towards WGC2023 in Beijing.

7. CONCLUSIONS

The geothermal energy is used exclusively for direct applications in Slovakia by 2020 (data records) or 2022 respectively. Although a calibrated model of national-scale probabilistic geothermal booking is still in a process, pilot model submitted towards WGC2020 estimated 2,686 MW_{th} of probable reserves when balanced for 100 years, turning to almost 1,420 MW_{th} of sustainable thermal potential of geothermal waters applying reserve capacity ratio.

Recently, 122 online wells operate in 76 sites in 22 out of 31 delineated geothermal water bodies (GWBs). Recreation keeps a decades long tradition and prevails in all considered aspects except mean load and capacity factor. While total proven reserves represent 436 MW_{th}, actual installed thermal output of online wells is roughly 230 MW_{th}, though cumulative yearly mean thermal output of online wells drops rapidly to app. 57 MW_{th}, resulting in considerably low load and capacity factors of both, individual wells and sites in all aspects of an evaluated direct use. Geothermal waters produced 470 $GW_{th}h$ of geothermal energy and 1,684 TJ of geothermal heat, as a result of their operation characteristics, plus cumulative deliverability reaching up to $14.3 \cdot 10^6$ m^3 in 2020.

Compared to EGC2019, there are few wells under construction (Kežmarok, Čižatice), with some others applying or receiving withdrawal provisions (e.g. Veľký Slavkov, Veľká Lomnica, Bardoňovo, Piešťany). This, obviously, means geothermal district heating and individual space heating cascaded down for recreation will increase in the country. As long as government will stand its word, district heating related to the Ďurkov site will also be on a list in a close future. Nearby progress is also expected concerning plans on a binary unit in Lovča.

Table 2: Distribution of geothermal energy use / utilization in Slovakia by segment (year 2020)

Direct use	sites	wells	Pth_installed	Pth_actual	Eth_actual	EQ
	(-)	(-)	(MWt)	(MWt)	(GWh,th)	(TJ)
district heating / cooling	5	4	20.6	1.5	64.2	220.5
individual heating / cooling	10	10	33.4	1	80.2	288.7
agriculture / aquaculture	12	11	41.2	0.8	81.3	292.6
recreation	49	41	96.5	0.4	158.6	572.1
balneotherapy	46	11	37.7	0.2	86.4	310.2

REFERENCES

Beňovský, V., Drozd, V., Halas, O., Vrana, O., and Vranovská, A.: Investigation of the Ďurkov geothermal structure for utilization of geothermal energy, *Bulletin d'Hydrogeologie*, 17, (2001), 1-11.

Bjarnadottir, R.: Sustainability evaluation of geothermal systems in Iceland. Indicators for sustainable production [manuscript – Master's Thesis], Reykjavik Energy Graduate School of Sustainable Systems, Reykjavik, (2010).

Bodiš, D., Remšík, A., Černák, R., Marcin, D., Ženišová, Z. and Fľaková, R.: Geothermal and hydrogeological conditions, geochemical properties and uses of geothermal waters in Slovakia. In: Bundschuh J. – Tomaszewska B. (EDs.), Geothermal Water Management, , 41-69, *Taylor & Francis*, (2018).

Černák, R., Remšík A. and Nador A.: Geothermal energy research in Slovakia and cooperation on geothermal transboundarz project Transenergy, *Slovak Geological Magazine*, 14 (2), (2014), 5-16.

Fendek, M., Remšík, A. and Král, M.: The nature of geothermal resources in Slovak Republic, *Slovak Geological Magazine*, 5 (1-2), (1999), 121-130.

Fendek, M. and Fendeková, M.: Country Update of the Slovak Republic, *Proceedings World Geothermal Congress 2015*, Melbourne, Australia, (2015), 1-8.

Fendek, M., Fendeková, M., Fričovský, B. and Blanárová, V.: Geothermal Energy Use, Country Update for Slovak Republic, *Proceedings European Geothermal Congress 2016*, Strasbourg, France, (2016) 1-11.

Franko, O. and Melioris, L.: Condition for formation and extension of mineral and thermal waters in the Western Carpathians, *Slovak Geological Magazine*, 5 (1-2), (1999), 93-107.

Fričovský, B., Vizi, L., Fordinál, K., Surový, M. and Marcin, D.: A reviewed hydrogeothermal evaluation of the Ďurkov depression hydrogeothermal structure: insights from probabilistic assessment and sustainable production optimization, *Proceedings 44th Workshop on Geothermal Reservoir Engineering*, Stanford University, CA, USA, (2019), 1-14.

Fričovský, B., Černák, R., Marcin, D., Benková, K., Blanárová, V., Pelech, O., Fordinál, K. and Fendek, M.: Geothermal energy use – country update for Slovakia, *Proceedings World Geothermal Congress 2020*, Reykjavik, (2020a), 1-19.

Fričovský, B., Černák, R., Marcin, D., Benková, K., Bodiš, D. and Blanárová, V.: Geothermal energy utilization in Slovakia – first insights from sustainability prospective, *Proceedings World Geothermal Congress 2020*, Reykjavik, (2020b), 1-14.

Garg, S.K. and Combs, J.: A reformulation of USGS volumetric „heat in place" resource estimation method. *Geothermics*, 55, (2015), 150-158.

Goetzl, G., Dilger, G., Grimm, R., Hoffmann, K., Holeček, J., Černák, R., Janza, M., Kozdrój, W., Klonowski, M.R., Hajto, M., Gabriel, P., Gregorin, S.: Strategies for fostering the use of shallow geothermal energy for heating and cooling in Central Europe – Results from the Interreg Central Europe Project GeoPLASMA-CE, *Proceedings World Geothermal Congress 2020*, Reykjavik, Iceland, 1-17

Halás, O.: Geothermal district heating systems in Slovakia – current status and plans, *Proceedings World Geothermal Congress 2015*, Melbourne, Ausralia, (2015), 1-5.

Jacko, S., Fričovský, B., Pachocká, K., Vranovská, A. 2014: Reverse stationary temperature modeling and geothermal resource callibration for the Košice depression (eastern Slovakia). *Geological exploration technology, geothermics, sustainable development*, 1 (2014), 3 – 25

Jacko, S., Farkašovský, R., Ďuriška, I., Ščerbáková, B., Bátorová, K.: Critical tectonic limits for geothermal aquifer use: Case study from the East Slovakian Basin Rim, *Resources*, 10 (31), (2021), 1-15

Jurewycz, E.: Geodynamic evolution of the Tatra Mts. and the Pieniny Klippen Belt (Western Carpathians): problems and comments, *Acta Geologica Polonica*, 55 (3), (2005), 295-338.

Majcin, D., Král, M., Bilčík, D., Šujan, M. and Vranovská, A.: Deep geothermal sources for electricity production in Slovakia: thermal conditions, *Contributions to Geophysics and Geodesy*, 47 (1), (2017), 1-22.

Marcin, D., Remšík, A. and Benková, K.: Geothermal water utilization in Slovakia, *Slovak Geological Magazine*, 14 (2), (2014), 69-79.

Moeck, I.S.: Catalog of geothermal play types based on geologic controls, *Geothermics*, 37, (2014), 867-882.

Moeck, I.S. and Beardsmore, G.: A new "Geothermal Play Type" catalog: streamlining exploration decision making, *Proceedins 39th Workshop on Geothermal Reservoir Engineering*, Stanford University, CA, USA, (2014), 1-10.

Plašienka, D.: Continuity and episodicity in the early Alpine tectonic evolution of the Western Carpathians: How large-scale processes are expressed by the orogenic architecture and rock record data, *Tectonics*, 37 (1), (2018), 1-51.

Sanyal, S.K. and Butler, S.J.: An analysis of power generation prospects from Enhanced Geothermal Systems, *Geothermal Resource Council Transactions*, 29, (2005), 131-137.

Schmid, S. M., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M. and Ustaszewski, K.: The Alpine-Carpathian-Dinaridic orogenic system: correlation and evolution of tectonic units. *Swiss Journal of Geosciences*, 101 (1), (2008), 139-183.

Švasta, J., Goetzl, G., Černák, R., Steiner, C., Fuchsluger, M., Porpaczy, C., Rupprecht, D., Fričovský, B.: Shallow geothermal energy potential in transboundary region between Austria and Slovakia (Results from the GeoPLASMA-CE Project), *Proceedings World Geothermal Congress 2020*, Reykjavik, Iceland, 1-9

Takacs, J. and Grell, S.: Use of geothermal water for district heating in Galanta, *Mineralia Slovaca*, 37 (2005), 152-156.

Ungemach, P., Antics, M. and Papachristou, M.: Sustainable geothermal reservoir management, *Proceedings World Geothermal Congress 2005*, Antalya, Turkey, (2005).

Williams, C.F.: Updated methods for estimating recovery factors for geothermal resources, *Proceedings 32nd Workshop on Geothermal Reservoir Engineering*, Stanford University, CA, (2007).

Vranovská, A., Beňovský, V., Drozd, V., Halas, O. and Váňa, O.: Investigation for geothermal energy utilization in the town Košice, Slovak Republic, *Proceedings World Geothermal Congress 2000*, Kyushu-Tohoku, Japan (2000).

Williams, C.F., Reed, M.J. and Anderson, A.F.: Updating the classification of geothermal resources, *Proceedings, 36th Workshop on Geothermal Reservoir Engineering*, Stanford University, Stanford, California, (2011), 1-10.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	n/a	n/a	6 413	27.92	n/a	n/a
Under construction end of 2021	n/a	n/a	n/a	n/a	n/a	n/a
Total projected by 2023	n/a	n/a	n/a	n/a	n/a	n/a
Total expected by 2028	20	n/a	n/a	n/a	n/a	n/a
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development: 0	
					Under investigation: 1	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

No geothermal power plants currently in Slowakia.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2020	20.64	64.22	41.24	81.3	33.39	80.16	134.2	245
Under constru-ction end 2020	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Total projected by 2020	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Total expected by 2020	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Galanta	Galantaterm Ltd.	1996	N	N	10.9	13.1	27.7	94.5
Šaľa	MeT Šaľa Ltd.	2011	N	N	3.4	20.7	16.2	27.6
Veľký Meder	Veľký Meder	2017	N	N	3.28	15	16.7	22
Sereď	Energetika Sereď Ltd.	2012	N	N	1.9	8.7	3.5	37.7
total					19.5	57.5	64.2	-

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Čiližská Radvaň	Čiližská Radvaň	n/a	N	1.58	1.58	1.58	100
Dunajská Streda	Dunajská Streda	n/a	N	4.51	4.51	4.51	100
Horná Potôň	Horná Potôň	n/a	N	8.85	8.85	8.85	100
Ňárad - Baloň	Ňárad - Baloň	n/a	N	3.39	3.39	3.39	100
Nesvady	Nesvady	n/a	N	0.48	0.48	0.48	100
Vrbov	Vrbov	n/a	N	4.61	4.61	11.91	100
Kolárovo	Kolárovo	n/a	N	5.15	5.15	10.77	100
Nováky - Laskár	Nováky - Laskár	n/a	N	3.84	3.84	8.06	100
Čalovo	Čalovo	n/a	N	2.51	2.51	7.18	100
Galanta (Vincov Les)	Galanta (Vincov Les)	n/a	N	2.01	2.01	6.92	100
Bánovce nad Bebravou	Bánovce nad Bebravou	n/a	N	1.7	1.7	4.03	100
Liptovský Ján	Liptovský Ján	n/a	N	1.21	1.21	3.59	100
Poľný Kesov	Poľný Kesov	n/a	N	2.44	2.44	2.46	100

Table D2 (continued): Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Oravice	Oravice	n/a	N	11.39	11.39	2.11	100
Rajecké Teplice	Rajecké Teplice	n/a	N	0.36	0.36	2.01	100
Nové Zámky	Nové Zámky	n/a	N	0.78	0.78	2.35	100
Sklenné Teplice	Sklenné Teplice	n/a	N	0.36	0.36	1.66	100
Dolná Strehová	Dolná Strehová	n/a	N	0.32	0.32	1.12	100
Kaluža	Kaluža	n/a	N	0.4	0.4	1.4	100
Malé Bielice	Malé Bielice	n/a	N	0.85	0.85	1.4	100
Zelená voda	Zelená voda	n/a	N	0.76	0.76	1.36	100
Rapovce	Rapovce	n/a	N	1.03	1.03	1.05	100
Patince	Patince	n/a	N	2.17	2.17	0.79	100
Oravice	Oravice	n/a	N	4.88	4.88	0.76	100
Stráňanvy	Stráňanvy	n/a	N	0.8	0.8	0.7	100
Santovka	Santovka	n/a	N	0.69	0.69	0.41	100
Diakovce	Diakovce	n/a	N	0.37	0.37	0.35	100
Komárno	Komárno	n/a	N	0.48	0.48	0.35	100
Koplotovce	Koplotovce	n/a	N	0.53	0.53	0.53	100
Rajec	Rajec	n/a	N	0.98	0.98	0.18	100
Gánovce	Gánovce	n/a	N	0.09	0.09	0.09	100
Vinica	Vinica	n/a	N	0.24	0.24	0.26	100
Turčianske Teplice	Turčianske Teplice	n/a	N	0.17	0.17	0.11	100
Mošovce-Drienok	Mošovce-Drienok	n/a	N	0.06	0.06	0.09	100
Sielnica	Sielnica	n/a	N	0.22	0.22	0.09	100
Partizánske	Partizánske	n/a	N	0.26	0.26	0.008	100
Čalovo	Čalovo	n/a	N	3.03	3.03	11.13	100
Diakovce	Diakovce	n/a	N	2.51	2.51	10.42	100
Dunajská Streda	Dunajská Streda	n/a	N	3.65	3.65	2.89	100

Table D2 (continued): Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Poľný Kesov	Poľný Kesov	n/a	N	0.54	0.54	1.99	100
Senec	Senec	n/a	N	1.63	1.63	5.78	100
Veľká Lomnica	Veľká Lomnica	n/a	N	6.51	6.51	1.4	100
Bešeňová	Bešeňová	n/a	N	6.45	6.45	15.19	100
Borša	Borša	n/a	N	0.58	0.58	2.19	100
Kremnica	Kremnica	n/a	N	2.96	2.96	13.93	100
total							

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	10	1.6	14.2	n/a	n/a	n/a
Of which networks **	n/a	n/a	n/a	n/a	n/a	n/a
Projected total by 2023	n/a	n/a	n/a			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No geothermal UTES currently in Slowakia.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	Realistic data not available	Realistic data not available	Realistic data not available	Realistic data not available
Geothermal direct uses	Realistic data not available	Realistic data not available	Realistic data not available	Realistic data not available
Shallow geothermal	Realistic data not available	Realistic data not available	Realistic data not available	Realistic data not available
total	Realistic data not available	Realistic data not available	Realistic data not available	Realistic data not available

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	Realistic data not available	Realistic data not available	Realistic data not available
Financial Incentives – Investment	Realistic data not available	Realistic data not available	Realistic data not available
Financial Incentives – Operation/Production	Realistic data not available	Realistic data not available	Realistic data not available
Information activities – promotion for the public	Yes, several presentations provided by individuals or in cope with professional organizations, such as Slovak Association of hydrogeologists, Slovak Geological Society, Slovak environmental technologies society etc.		
Information activities – geological information	Web service of Dionýz Štúr state institute of Geology		
Education/Training – Academic	Courses on hydrogeology and geothermal energy, renewable energy sources, alternative energy sources at technical universities in Košice, Žilina and Bratislava, and Faculty of Natural Sciences, Commenius University in Bratislava - no study programme on geothermal electricity production		
Education/Training – Vocational	Domestic and international conferences held in Slovakia, e.g. Renewable Energy Sources, Hydrogeology, Geochemistry, Heating		

European Geothermal Congress 2022
Berlin, Germany | 17-21 October 2022
www.europeangeothermalcongress.eu

Geothermal Energy Use, Country Update for Slovenia

Dušan Rajver[1], Andrej Lapanje[1], Nina Rman[1], Joerg Prestor[1]

[1] Geological Survey of Slovenia, Dimičeva 14, 1000 Ljubljana, Slovenia

dusan.rajver@geo-zs.si

Keywords: geothermal resources, direct uses, reinjection, ground-source heat pumps, development, Slovenia.

ABSTRACT

In Slovenia, geothermal energy has been used for about 50 years. The total installed capacity and annual energy use (both deep and shallow geothermics) in 2021 are 298.45 MW_{th} and 1,671.47 TJ/yr (464.30 GWh/yr), respectively. Installed capacity and energy use at all 31 users of thermal water from deep sources amounted to 60.70 MW_{th} and 486.13 TJ in 2021. More efficient use of thermal water is evident at several sites due to implementation of concession fees for thermal water utilization and requirement for 70 % thermal efficiency, which led to lower annual energy use in 2021 compared to years 2017-2019, owing to lower pumped volumes. The pandemic Covid period is still the main reason for lower thermal water production in 2021 compared to that in standard year of 2019. Low progress was achieved in geothermal development in terms of new wells for direct heat use of thermal water during the last three years with only one new production well for Terme Čatež. Three reinjection wells are planned in NE Slovenia. Greater progress is evident in shallow geothermal energy utilization, where the number of ground-source heat pump (GSHP) units reached around 14,818 with 237.75 MW_{th} capacity and 1185.3 TJ/yr energy use (Dec. 2021). It is expected that energy retrofitting of older buildings and installation of the GSHP units will continue in the future as one of the commitments to meet the renewable energy targets and to gradually replace most of gas and other hydrocarbon heating systems.

1 INTRODUCTION

Some geothermal resources in Slovenia were described in literature already before the 20th century. However, their real systematic explorations began much later in 1974 after the first oil crisis. This paper presents the status of direct heat use and development in the last three years, 2019-2021. Geothermal energy use in Slovenia (with surface of 20.273 km^2) has been statistically followed by Geological Survey of Slovenia (GeoZS) on regular basis since 1994 with country update reports at World Geothermal Congresses (Rajver et al., 2020 and ref. therein) and European Geothermal Congresses since 2013 (Rajver et al., 2019).

Suitable geothermal resources for electricity production in Slovenia have not (yet) been discovered, but research has already begun. Dravske elektrarne Maribor (Drava Electric PPs Maribor, DEM) of the HSE group has opened the project task "Study of the possibility of using existing wells for the construction of geothermal power plants" (Božič and Gregorc, 2020). The National Energy and Climate Plan (NEPN) envisages the construction of the first demonstration geothermal power plant by 2030 (Hozjan, 2021). For the needs of such investments, GeoZS will prepare a map with geothermal potential based on which the most suitable areas for the exploration-production well (probably several wells) and the construction of a geothermal power plant (Hozjan, 2021) will be determined. Yet, it’s not expected that any electricity production from geothermal in Slovenia could be realistic by 2025. Only binary technology is promising, but it is also geologically disputable.

So far only direct use of geothermal energy is effective in the country with emphasis on exploitation of low temperature resources for district and individual space heating, for greenhouses and thermal spas. During the last 20 years the direct use showed only slight and changing increase and recently just a stagnant state. The reasons depend on the locality. Overexploitation of geothermal resources in some localities of the north-eastern part of the country (Rman, 2014; Rman et al., 2012 and references therein) is one of the problems, but also some occasional technical difficulties, and weak incentives for efficient use of the resources. An increase of experience is evident at many direct heat users, notably with introduction of heat exchangers (HEx) and heat pumps for the improvement in using the available heat in a better way, and not to discharge it at a too high temperature. The ground-source heat pump (GSHP) sector utilizing the shallow geothermal energy is the only category showing a strong steady increase.

2 GEOTHERMAL RESOURCES AND POTENTIAL

A description of geology, geothermal field, resources and potential is given in the previous country updates (Rajver et al., 2019 and references therein). A complicated geologic and tectonic setting of Slovenia is subdivided into several tectonic units with different hydrogeological properties and geothermal conditions (Figure 1). Four thermal springs out of 24 (natural and captured, with constant temperature from 20 to 37 °C) are in use for direct heat utilization. However, several drilled localities exist with no previous surface thermal manifestations. There the thermal water was discovered during the oil and gas drillings (Lapanje and Rman, 2009). Also, geothermal resources in the Pannonian and Krško basins have been studied in more detail (see Rajver et al., 2019 and references therein; Rajver and Ravnik, 2003; Rman et al., 2015).

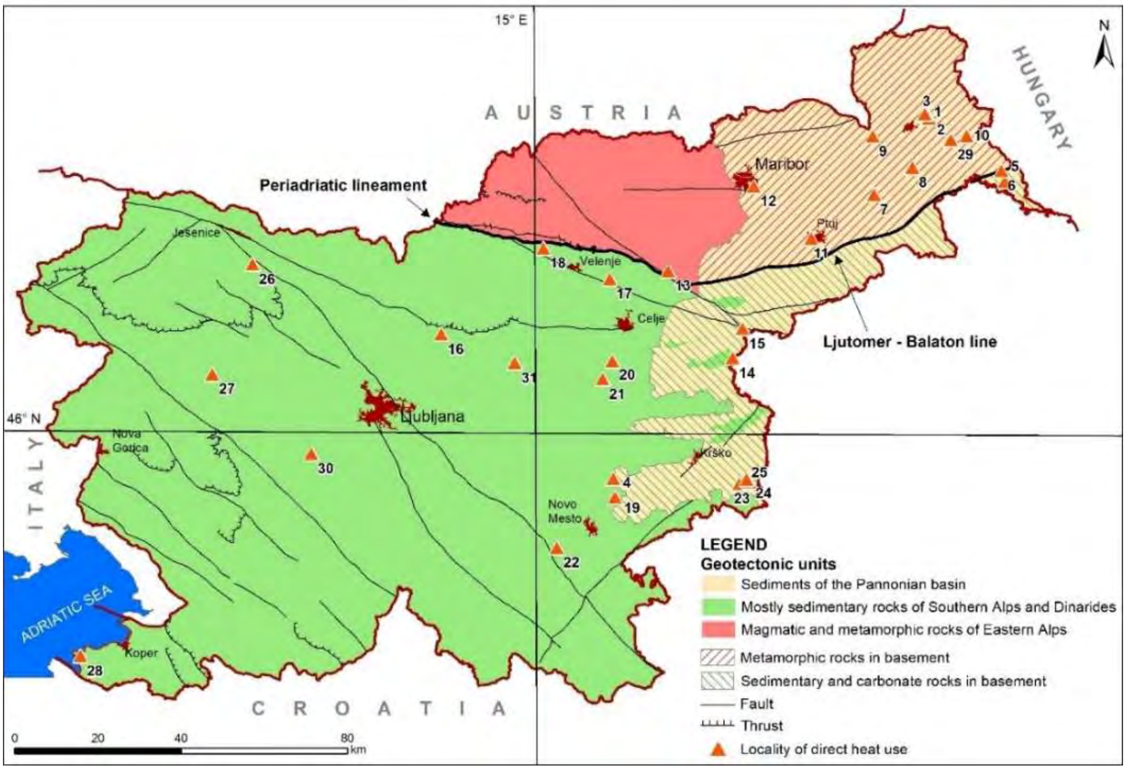


Figure 1: Generalized geological map of Slovenia with localities of direct heat use in 2021 (geology after Poljak, in Rajver et al., 2019).

2.1 Potential for geothermal power production

Natural steam reservoirs at relatively shallow depths (3 to 4 km) haven't been detected yet with existing boreholes. In the SE part of the Pomurje area (NE Slovenia) high temperature resources are unproven but hypothetically expected in deeper fault zones in the Pre-Neogene basement (for details see Rajver et al., 2016). It is the area south of the Ljutomer-Balaton fault (Figure 1) where the Pre-Neogene basement consists of clastic and carbonate rocks, expected to be more fractured in places for eventual exploitation of medium or high enthalpy geothermal resources (Rajver et al., 2012). New investigations and geothermal wells should be targeted on finding a geothermal aquifer with a wellhead fluid temperature above 100 °C and a yield above 25 kg/s which allows the binary cycle utilization. However, deeper wells would be needed to reach at least the 150 °C isotherm.

2.2 Resources and potential for direct use

The northeastern and eastern Slovenia has been intensively investigated in the past 15 years within the European projects, the most recent being DARLINGe (Website 1). Efforts are put also in promotion of more sustainable exploitation by applying new reinjection wells in the future based on materials prepared during the project activities. The NE part is characterized by elevated surface heat-flow density (HFD), above 100 mW/m^2, with expected temperatures above 80 °C at 2 km depth (Rman et al., 2012; Rajver et al., 2012). Most production wells tap thermal water from the Miocene sand aquifers, that is from the Mura Fm. with temperatures of 54 to 62 °C and from the Špilje Fm. with up to 76 °C. The only exceptions are the wells in Maribor (number 12, in Figure 1). Besides, about 20 inactive and some 11 new potential wells in the country exhibit the wellhead temperatures of 20 to 72 °C and have a total maximum yield of 281 kg/s, resulting in ideal thermal power of ca 24 MW$_{th}$.

The most extensive Upper Pannonian geothermal sandy aquifers, which are widely utilized by Hungary and Slovenia, are made of 50 to 300 m thick sand-prone units that are found in depth interval of about 0.7 to 1.4 km with temperatures from 50 to 70 °C (Nádor et al., 2012). These sandy lenses represent the best yielding low temperature geothermal aquifer in the sedimentary basin in Slovenia. It is utilized at Banovci (number 8 in Figure 1), Dobrovnik (10), Lendava (5 and 6), Mala Nedelja (7), Moravske Toplice (1, and 3), Tešanovci (2), Ptuj (11) and Renkovci (29). The best production wells have flow rates of up to 30 kg/s, however, the average flow rate barely exceeds 10 kg/s per well. Isolated turbiditic sandstone aquifers of the Middle and Upper Pannonian Lendava Fm. are exploited at Banovci, Lendava, Mala Nedelja, Moravske Toplice in depths of 0.8 to 1.6 km (Rman et al., 2012). The share of this water with temperature as high as 68 °C in the mixture produced from multiple – formations' screened wells is less than 5 % at most. A rather limited Badenian to Lower Pannonian Špilje formation sandstone aquifer discharges thermomineral water rich in CO_2 in Radenci (9) and with organic substances at temperatures up to 76 °C in Moravske Toplice. Two boreholes, drilled in 2012-2013 for a doublet system for the planned district heating of the Touristic center Fazanerija and some other buildings in Murska Sobota town are, after the testing done, still inactive since 2015.

In the SE part of the country the thermal water is mostly encountered in the Krško sedimentary basin along its southern edge in the Mesozoic carbonate rocks. A Čatež geothermal field in the eastern part of this basin is characterized by elevated geothermal gradient (>60 mK/m). The maximum depth of the wells is 0.7 km, and they produce thermal water from Triassic dolomite with annual average yields ranging from 1 to 14 kg/s (numbers 23, 24, 25 in Figure 1), while at Šmarješke Toplice (19) up to 10 kg/s per well.

2.3 Potential for ground-source heat pumps

The geological potential for closed-loop ground - water and open-loop water - water systems has been already described in the previous update report (Rajver et al., 2019). To our knowledge very few attempts were made to explore the possibility of aquifer thermal energy storage systems (ATES) in Slovenia up to date, and we are not aware they were exploited at all. According to the hydrogeological setting in Slovenia and pretentiousness of ATES technology, it is probable that borehole thermal energy storage (BTES) could be applied in higher extent than ATES but still in small quantity.

3 GEOTHERMAL UTILIZATION

There is no electricity generation from geothermal resources in Slovenia up to date. Geothermal utilization of thermal water heat in 2021 is based on direct use from 53 production wells plus 4 thermal springs, implemented at 31 localities (Figure 2). At one locality, which was reported for EGC 2019, geothermal energy is not used anymore. This is at Murska Sobota for Hotel Diana where they stopped operating and using thermal water for its heating system. One small user is included at Klevevška Toplica (number 4 in Figure 1) which uses thermal water of 20.2 °C for space heating. Therefore, since the EGC 2019 report no new direct heat users have emerged in Slovenia. Figure 3 shows main utilization types for direct heat use.

Geothermal energy currently supply for direct heat uses and GSHP units at least 1671.5 TJ/yr (464.3 GWh/yr) of heat energy with corresponding installed capacity of 298.45 MW_{th}. Of these values direct use is 60.70 MW_{th} and 486.13 TJ/yr (135.04 GWh/yr, by 17.6% less than in 2018), and the remainder, 237.75 MW_{th} and 1185.34 TJ/yr (329.26 GWh/yr, by 26.2% more than in 2018) are GSHPs (Table E). Since 2013 the GSHPs are the main application of use with more than 50 %, followed by geothermal "DH plants", geothermal heat in agriculture, then in balneology, individual space heating with DHW, air conditioning and snow melting at all those users not already included in the DH plants networks (Tables C and D1; Figures 4 and 5).

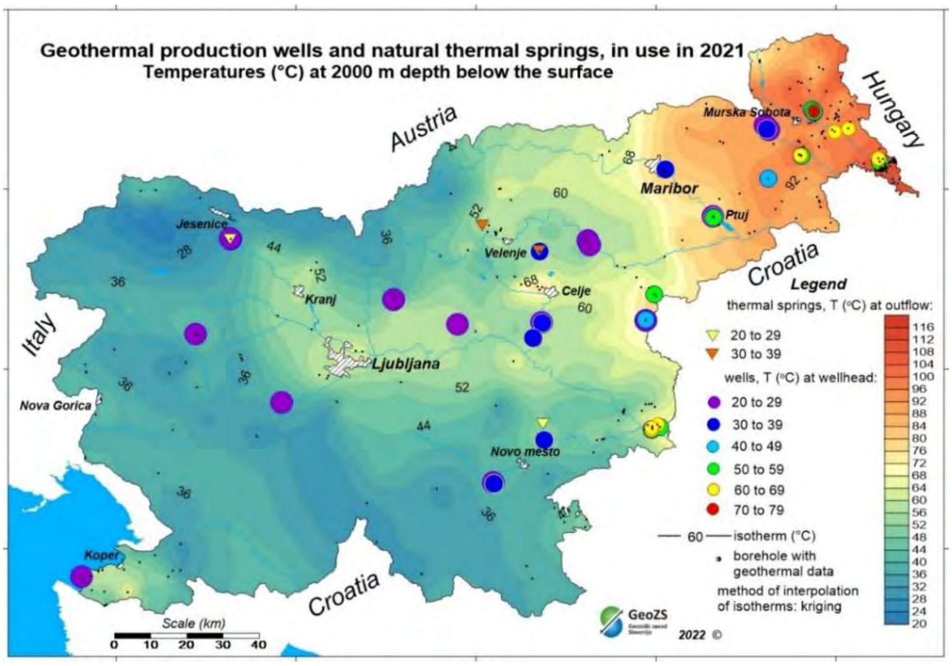


Figure 2: Production geothermal wells and natural thermal springs, in use in 2021 in Slovenia (status: Dec. 2021); Expected temperatures at 2000 m depth beneath the surface.

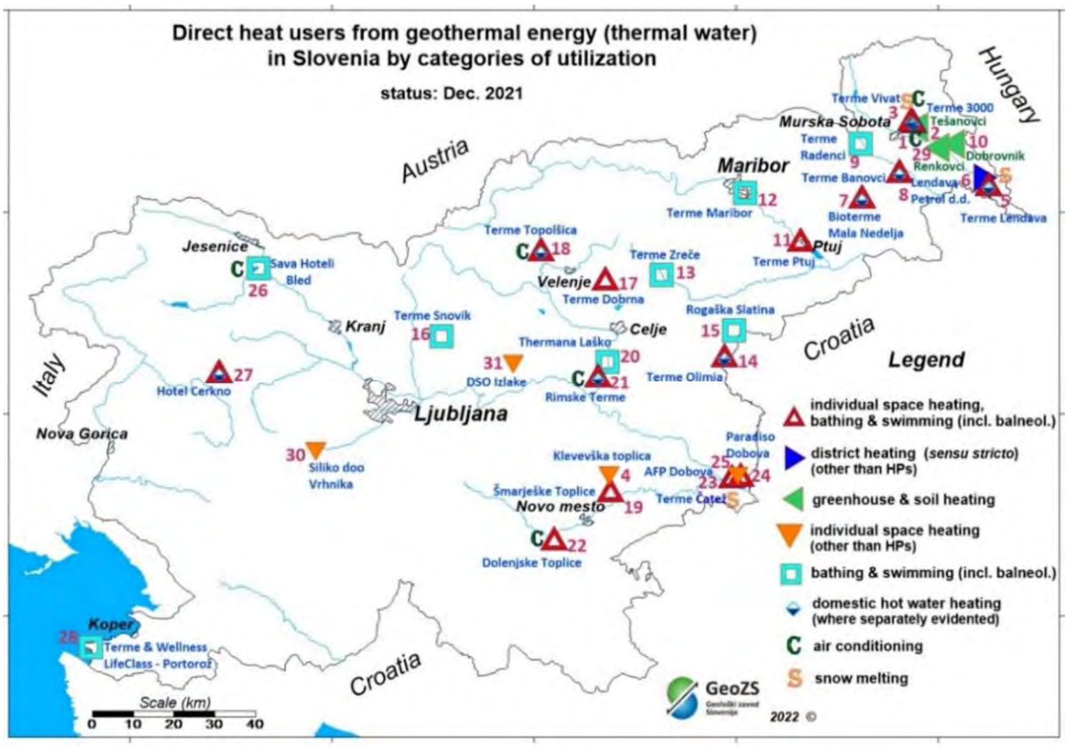


Figure 3: Main utilization types for direct heat use of geothermal energy (thermal water) in Slovenia (status: Dec. 2021); numbers are the same as in Fig. 1.

3.1 Geothermal district heating

When speaking about geothermal district heating (DH) *sensu stricto*, only one plant is considered in Slovenia at present (Table D1), in Lendava (number 6 in Figures 1 and 3), where several public buildings (schools, business complexes, theatre, shopping center, etc.) and blocks of flats (total 68,000 m^2) are heated under the Petrol Geo d.o.o. (subs. of Petrol d.d.) authority with a doublet system. The future of geothermal DH in Murska Sobota and Benedikt remains uncertain. However, following the explanations for Tables C and D1, there are 17 users with geothermal DH plant network. These are 15 spas and/or thermal resorts with bathing/swimming pools and balneology facilities, where also space heating (and at four users also cooling) and snow melting (at three users) are accounted for. A greenhouse in Tešanovci (number 2 in Figures 1 and 3, related to Terme 3000) and Lendava town DH (*sensu stricto*) complete the list of these 17 users. The total geothermal energy used for these DH plants is 356.73 TJ/yr (99.093 GWh/yr). Of these (Table C), in 2021, the space heating itself took 144.64 TJ (40.18 GWh) of geothermal heat, DH *sensu stricto* 20.074 TJ (5.576 GWh), air conditioning 12.142 TJ (3.373 GWh), greenhouse 9.332 TJ (2.592 GWh), snow melting 6.94 TJ (1.928 GWh), bathing and swimming (incl. balneology) 135.23 TJ (37.564 GWh) and domestic hot water (DHW) heating 28.381 TJ (7.884 GWh).

3.2 Agriculture (greenhouses) and industry

The heating of greenhouses using geothermal water began in 1962 in eastern Slovenia at Čatež (number 23 in Figure 1). It was performed there by the Flowers Čatež Co. on 4.5 ha for cultivation of flowers. But the Terme Čatež d.d. stopped operating their greenhouse by the end of 2019 due to economic reasons, when also hydroponic tomato production at Čatež was abolished and thus a long-standing tradition lost. At Tešanovci near Moravske Toplice (number 2) the Grede Agricultural Co. uses the already thermally spent water flowing from Moravske Toplice (Terme 3000, number 1) with 40 °C to heat 1 ha of greenhouse for tomato production. At Dobrovnik (number 10), the Ocean Orchids Co. greenhouse of 4 ha cultivates orchids and grows lettuce. At Renkovci (number 29), greenhouses of 9 ha are for tomato and exotic fruit cultivation. The total geothermal energy used in 2021 in greenhouses (14 ha) was 118.896 TJ (33.027 GWh). Without the greenhouse (1 ha) as part of a DH plant (Tešanovci, number 2), geothermal energy used at Dobrovnik and Renkovci greenhouses (total 13 ha) was 109.564 TJ (30.434 GWh) (Table C). Total value is higher compared with 25 GWh in 2018, due to improved temperature difference used at both users (numbers 2 and 10, resp.).

3.3 Individual space heating of buildings with domestic hot water heating

Space heating is implemented at 19 localities (Figure 3), predominantly thermal spas and resorts, mostly through heat exchangers (e.g. Moravske Toplice, Banovci, Lendava, Ptuj, Mala Nedelja, Čatež, Dobova etc.) or geothermal HPs (e.g. Cerkno, Izlake, Vrhnika, Dobova Paradiso, Čatež etc.). The GHP units usually of bigger capacity are installed in case of too low thermal water temperature for this type of use. The total geothermal energy used for space heating in 2021 was 150.33 TJ (41.758 GWh). Without 15 users, already accounted for as "DH plants" (and excluding Tešanovci greenhouse), geothermal energy used at other four localities (Klevevška Toplica, Dobova AFP, Vrhnika and Izlake, numbers 4, 25, 30 and 31, resp. in Figure 1) for space heating and DHW amounted to 5.694 TJ (1.582 GWh) (Table C). Total value is lower compared with 4.937 GWh in 2018. The DHW heating is included in these values at one locality (Izlake, number 31), while for the other 15 users the DHW heating is already included as part of DH plants' network. For nine users it is possible to calculate separately geothermal energy used for DHW heating, giving some 28.381 TJ in 2021 (7.884 GWh), while at other six users it is included in the space heating values and couldn't be evaluated separately.

3.4 Bathing and swimming pools with balneology, air conditioning and snow melting

Geothermal heat used for bathing and swimming (incl. balneology) was in the second place in 2021. There are 15 thermal spas and health resorts, and additional 8 recreation centers where swimming pools with a surface area of about 52,105 m^2 and volume of 67,755 m^3 are heated by geothermal water directly or more commonly indirectly through HEx or GHPs. Wellhead water temperatures in thermal spas range from 23 to 62 °C, of course, inflow temperatures in lower range are utilized. The total geothermal energy used for bathing and swimming amounted to 146.71 TJ in 2021 (40.752 GWh). At some localities improvements were achieved by better temperature range utilization with HEx, while at some others with GHPs. Apart from geothermal heat for bathing and swimming, already reported for 15 users within the DH plant networks, this category is also operational at other eight users: Radenci (number 9 in Figures 1 and 3), Maribor (12), Zreče (13), Rogaška Slatina (15), Snovik (16), Laško (20), Bled (26) and Portorož (28). Of total values, the used geothermal heat there amounted to 11.478 TJ (3.188 GWh) in 2021.

Snow melting of the sidewalks using geothermal heat from utilized thermal water was applied within the doublet system in Lendava (number 6 in Figure 1), with about 0.11 TJ in 2021. Snow melting was more applied under two football grounds at Hotel Vivat at Moravske Toplice (number 3) with 1.032 TJ, and under three football grounds at Čatež (number 23) with 5.798 TJ. Altogether the used geothermal heat is 6.940 TJ (1.928 GWh), included within DH plants, compared to 14.66 TJ in 2018.

Air conditioning (AC or cooling) of the hotels' spaces using geothermal heat is not well documented, being operational only at five localities: Moravske Toplice Terme 3000 (number 1 in Figure 1) and Hotel Vivat (3), in hotels at Bled (26), Dolenjske Toplice (22), Topolšica (18) and Rimske Terme (21), contributing about 14.808 TJ in 2021 (4.113 GWh), compared to 11.04 GWh in 2018. Only Bled is the site not included already within the DH plant networks, and geothermal heat for AC was there 2.665 TJ (0.740 GWh) in 2021.

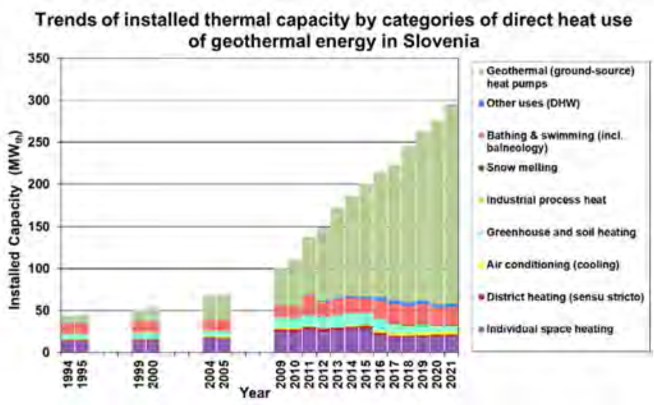


Figure 4: Geothermal direct use applications in a period 1994-2021 (total capacity in 2021: 298.45 MWt).

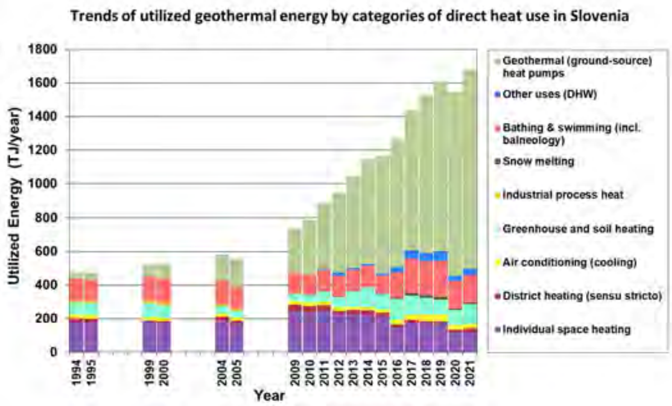


Figure 5: Geothermal direct use applications in a period 1994-2021 (total energy used in 2021: 1671.47 TJ).

3.5 Geothermal heat pumps

At 12 health or spa resorts, already belonging to the DH plant networks, plus at hotels at Radenci, Snovik, Laško, Bled and Izlake (numbers 9, 16, 20, 26, 31) and at industrial company Siliko Vrhnika (number 30), the GHPs of bigger capacity (14.4 MW_{th} altogether) are used in an open loop system for raising the thermal water temperature for further use in swimming pools and space heating or just to maintain the water temperature in swimming pools, and for DHW heating. Their contribution in used geothermal energy is already accounted for within other applications.

Geothermal energy use for space heating and cooling in decentralized small units in Slovenia is becoming more popular and widespread. The market boom in larger scale began during the last 15 years after some slow period in the early 1990's with low interest in GSHPs due to high initial costs, high price of electricity and low prices of oil and gas. Depending on local conditions the GSHP units consist of closed loop GCHPs (horizontal and vertical heat collectors) or open loop groundwater heat pumps (GWHP). Technical, environmental, and economic incentives can be considered advantageous for more rapid introduction of the GSHPs. This is also backed by support programs from utilities and from the government through subsidies or credits (Table G).

The number of GSHP units presently installed, and their capacity and energy supplied, are quite realistic despite no available national statistics exist. The HP sales from domestic producers and numerous merchant agents of imported units give practically all the quantity for their estimation. As of 31st Dec. 2021, there are about 13,925 operational small GSHP units (typical 12 kW) that extracted 845.61 TJ (234.89 GWh) of geothermal heat in 2021. Of these, 46.0 % are open-loop systems that extracted 438.95 TJ from shallow groundwater, 36.1 % are horizontal closed-loop (with 266.47 TJ), and 17.8 % are vertical closed-loop systems (with 140.2 TJ). Small closed-loop units together removed 406.66 TJ/yr from the ground. There are also bigger capacity GSHP units (>20 kW) installed within about 893 systems in public and other buildings, which extracted 339.73 TJ in 2021. It is discovered year by year that not all of them are operational. Of them, 677 units are open-loop water-water type (75.8 %), 182 units are vertical closed-loop (20.4 %) and 34 (3.8 %) are horizontal closed-loop systems. With total 14,818 GSHP units some 1185.34 TJ (329.26 GWh) of heat was extracted in 2021 (Table E1), while ca 240 TJ/yr of heat was rejected to the ground in the cooling mode. Capacity factor for all GSHP units is app. 16.0 %, the lowest among all the application types, reflecting that small and big units usually utilize a rather narrow temperature difference (< 4 K) and for individual heating also the shortest time of full load operating hours, which means in Slovenian climate conditions usually less than 2000 h/year.

4 DISCUSSION, RECENT DEVELOPMENTS AND FUTURE PROSPECTS

The distribution of capacity and annual energy use for various direct use applications as presented in Table C are practically all based on data from the users. The total thermal capacity currently installed for direct use of geothermal energy from thermal water amounts to roughly 60.70 MW_{th}, including GHPs at thermal spas. The total abstraction of thermal water in 2021 amounted to 5,391,131 m^3, which is by 21.2 % less than in 2019 (before the pandemic). The annual energy use at 31 localities amounted to 486.13 TJ (135.04 GWh), which is by 17.3 % less than in 2018 (587.73 TJ) and by 19 % less than in 2019 (600 TJ). This is due to the pandemic Covid period, which led to a prolonged closure of a significant number of thermal spas and resorts in 2021 and even more so in 2020. Annual energy use (Figures 5 and 6) is now lower for individual space heating, air conditioning, bathing with balneology, snow melting and DHW heating, and higher for greenhouse heating and DH *sensu stricto* in comparison with the situation in 2018. However, the GSHP sector exhibits the largest share (70.9 %) in direct use, compared to 61.4 % in 2018.

The investments in geothermal (Table F) are just approximate or incomplete since many direct users and those of shallow geothermal don't report such data. There was small number of new buildings and swimming pools constructed at thermal resorts or spas. Since 2018 no geothermal gradient boreholes have been drilled in Slovenia.

Three users (Moravske Toplice, Dobrovnik and Renkovci) in northeastern Slovenia do have plans to build new reinjection wells in the next five years. Dobrovnik has already been granted funding from the Ministry of Agriculture, Forestry and Food for this purpose. At Čatež geothermal field a new make-up well was drilled and one old liquidated. Several spa sites are investigating possibilities to revitalize inactive wells or drill new ones, but it all depends on available funds.

No new sites are underway for further geothermal direct use development. The wells at Janežovci near Ptuj, near Korovci, at Rimska Čarda and at Mislinjska Dobrava still wait for investment into development of the site.

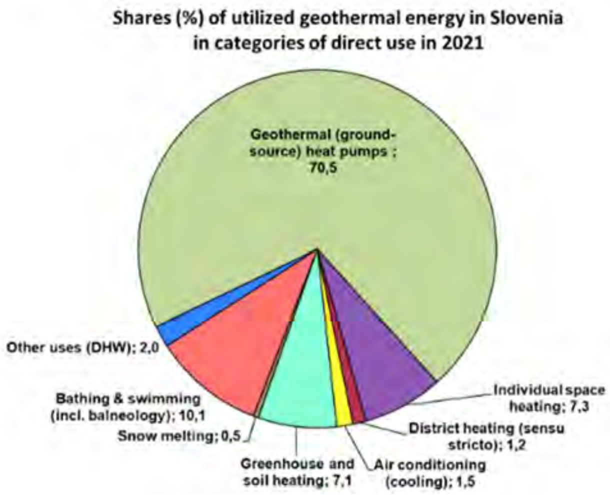


Figure 6: Shares of geothermal energy used in Slovenia in categories of direct use in 2021 (status 31st Dec. 2021).

Considerations on high enthalpy geothermal resources in Slovenia were initiated in previous years about the possibilities for electricity production in the north-eastern part where the highest temperatures at depths of 3.5 to 4.5 km are encountered or simulated at about 200 °C. The DEM and Petrol d.d. companies and GeoZS investigated the possibility for using deep wells, also existing ones such as Mg-6 (Murski gozd). To drill new deep exploration (wild cat) boreholes targeted geophysical (seismic, microseismic, microgravimetric, MT) investigations should be performed and currently several projects are in pre-feasibility phase.

Apart from standard approach, DEM is developing a pilot geothermal electricity plant at an inactive 3 km deep old gas well Pg-8 using a patented (No. SI 23618 A) geothermal gravitational heat pipe. Research work will start in 2022.

With the aim to provide attractive and clear business environment for medium to high geothermal resources we have planned a project Supporting efficient cascade use of geothermal energy by making available official and public information - INFO-GEOTHERMAL, presumably financed by the EEA and Norway Grants.

4.1 Thermal water direct use

A doublet scheme is operational only in Lendava. In NE Slovenia the localities are the most vulnerable to overexploitation of thermal water as most users capture water from the same aquifer. In this sense it is unfortunate that the Murska Sobota municipality has not completed the extension project for the DH system where reinjection well was also planned (Rman et al., 2012). Thermal capacity of the new doublet could reach 4 MW_{th} and geothermal energy use 8.8 GWh/year.

The Interreg project DARLINGe, running between 2016 and 2019, significantly contributed to a better resource assessment of eastern and northeastern Slovenia. A harmonized geological 3D model was extended to Croatia, a benchmarking assessment was performed at new sites and a numerical model focused on reinjection possibilities is being built (Rman et al., 2019). The effects of current thermal water abstraction on the hydraulic state of the Mura Fm. aquifer were simulated by a regional mathematical model of groundwater flow enabling calculation of different development scenarios, predictions and control of impacts (Nádor et al., 2012, Rman et al., 2015). Trends in geothermal are focused on enhancing the cascade direct use, lowering the outlet thermal water temperature, promoting higher efficiency of installed capacity for direct use, solutions for scaling and degassing, as well as performing new research for potential geothermal sites and implementation of doublets. Since 2016 the abstraction is strictly followed by an operating production monitoring, established at all thermal water users with concession. Therefore, resource assessment and state evaluation are very reliable. Reinjection should become nationally supported to preserve the existent capacities of thermal water, and many activities are now being taken also from the user's side to raise funds for its establishment.

The planned extension to about 7 geothermal DH systems (*sensu stricto*) in Slovenia by 2016 proved to be unrealistic, as the extensions at Murska Sobota and Benedikt and new plants at Turnišče and Ormož just did not happen. No major investments are planned so far in these communities.

For this sector, activities are carried out within the framework of several international projects: COST CA18219 Geothermal-DHC (Website 2), Horizon 2020 REFLECT and CROWDTHERMAL, PanAfGeo-2, IGCP636, HealingPlaces, Geothermical GeoFOOD, and individual applicative projects. The potential of thermal water in SE and NE Slovenia was researched by the projects of GeoERA programme HotLIME and GeoConnect3d, which both ended in 2021. Continuation started in 2022 as CSA WP3: Geo-energy.

4.2 Ground source heat pumps

Application of larger and more advanced systems is evident by good practices of GSHPs in the last decade. Since 2013 we made a systematic overview and inquiry for objects with installed GSHP units of rated power bigger than 20 kW. These plants are rarely included in any records because the owners (investors) do not obtain funds from financial incentives such as smaller individual plants. Industrial objects with such installations are therefore not in the records, but they represent a significant share in energy use and installed rated power. Figure 7 shows some 332 systems with GSHP units of bigger power with detailed data collected so far, with addition of 7 known hydrothermal HP units.

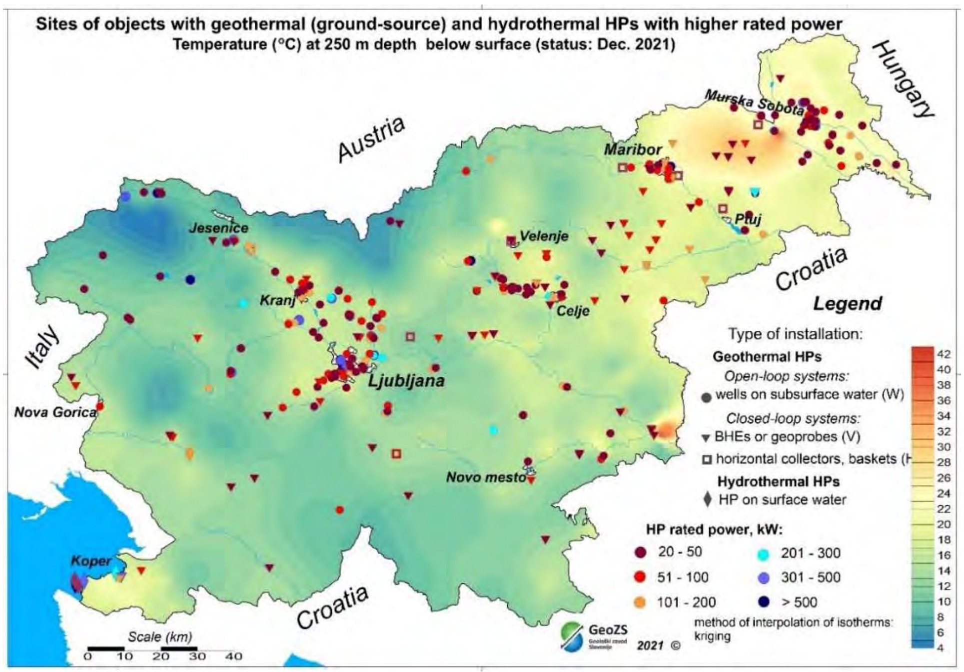


Figure 7: Distribution of 332 installations with collected detailed data on GSHP systems with rated power of at least 20 kW, by type of installation, and 7 known hydrothermal HP unit systems (data collected on a voluntary basis). The isotherms show temperature at 250 m depth.

Several bigger open-loop systems have 4 production and 4 reinjection wells or more. Similarly, the biggest closed-loop systems have more than 20, some of them app. 30 BHEs (with an average depth of 100, 120 or 150 m), mostly in eastern and northeastern regions. Another system in Koper has 58 BHEs (with depths of 18 to 32 m).

Great technological improvements are evident with air-water HP units. The HP producers state they sell at least 5-times more air-water HP units than geothermal HPs, and some of them claim this ratio is 10:1 in favor of air-water HPs.

5 CONCLUSIONS

Due to lower annual flow rates at different users, which is the evidence of delivered maximum allowed pumping quantities, and some technical difficulties, direct heat use from thermal water does not show any clear increase on yearly basis. The GSHP market is more predictable, as it was increasing for about 84.3 TJ (23.43 GWh) every year in the last 5-year period. Actual (Dec. 2021) contribution in direct heat use from deep geothermal energy reached 486.13 TJ and thermal energy used by all GSHP units so far reached 1185.34 TJ, all together 1671.47 TJ (464.30 GWh or 39.92 ktoe). Consequently, target values (Website 3) are still quite distant, and a lot of effort will be needed beyond 2022.

The lower annual energy use in 2021 compared to 2016-2019 is also a consequence of increased efficiency of geothermal energy use, and this is the most important achievement and significant step forward for the sustainability. It is a consequence of a huge joint effort made by the authorities and GeoZS, based on several activities: 1) setting up a numerical model of the most important transboundary reservoir in northeastern Slovenia, 2) benchmarking of management efficiency of all thermal water users, 3) implementing the most important indicators of efficient management in the concession decree, 4) joined evaluation of data from different authorities, 5) granting the decrees for the water users with requirements for monitoring programs and reporting templates. With continuation of these activities significant improvement on control of exploitation is expected also in following years. Guidelines for water reinjection and safe abandonment of geothermal wells were also elaborated.

Further development should open all available (digital) information, provide best practices of doublet technologies, monitoring, reporting and benchmarking, link geothermal users into thematic associations, connect various authorities into interdisciplinary working groups, and, eventually, establish a geothermal one-stop-shop in Slovenia.

REFERENCES

Božič, M. and Gregorc, B.: Examining the possibility of using existing wells for the construction of geothermal power plants (in Slovene). Dravske elektrarne Maribor d.o.o., HSE group, (2020), 5 p.

Hozjan, V.: By March 2023, appropriate bases must be prepared for the first demonstration geothermal power plant in Slovenia (in Slovene). Energetika.NET, (2021).

Lapanje, A. and Rman, N.: Thermal and thermomineral water, in: The geology of Slovenia, Pleničar, M., Ogorelec, B. and Novak, M. (Eds.), *Geological Survey of Slovenia*, Ljubljana, (2009), 553-560.

Nádor, A., Lapanje, A., Tóth, G., Rman, N., Szöcs, T., Prestor, J., Uhrin, A., Rajver, D., Fodor, L., Muráti, J. and Székely, E.: Transboundary geothermal resources of the Mura-Zala basin: a need for joint thermal aquifer management of Slovenia and Hungary, *Geologija*, 55/2, Ljubljana, (2012), 209-224. doi:10.5474/geologija.2012.013

Rajver, D., and Ravnik, D.: Geothermal characteristics of the Krško basin, Slovenia, based on geophysical research. *Phys. Chem. Earth*, 28, (2003), 443-455. doi:10.1016/S1474-7065(03)00064-0

Rajver, D., Lapanje, A. and Rman, A.: Possibilities for electricity production from geothermal energy in Slovenia in the next decade (in Slovene), *Geologija*, 55/1, Ljubljana, (2012), 117-140. doi:10.5474/geologija.2012.009

Rajver, D., Lapanje, A., Rman, N., Prestor, J.: Geothermal energy use, Country update for Slovenia. *Proc. of the European Geothermal Congress 2016*, Strasbourg, France (2016), 1-18.

Rajver, D., Lapanje, A., Rman, N., Prestor, J.: Geothermal energy use, Country update for Slovenia. *Proc. of the European Geothermal Congress 2019*, Den Haag, The Netherlands (2019), 1-17.

Rajver, D., Rman, N., Lapanje, A. and Prestor, J.: Geothermal country update report for Slovenia, 2015-2019. *Proc. of the World Geothermal Congress 2020+1*, Reykjavik, Iceland (2020), paper #1075, 1-16.

Rman, N.: Analysis of long-term thermal water abstraction and its impact on low-temperature intergranular geothermal aquifers in the Mura-Zala basin, NE Slovenia, *Geothermics*, 51, Amsterdam, (2014), 214-227. dx.doi.org/10.1016/j.geothermics.2014.01.011

Rman, N., Lapanje, A. and Rajver, D.: Analysis of thermal water utilization in the northeastern Slovenia, *Geologija*, 55/2, Ljubljana, (2012), 225-242. doi:10.5474/geologija.2012.014

Rman, N., Gál, N., Marcin, D., Weilbold, J., Schubert, G., Lapanje, A., Rajver, D., Benkova, K. and Nádor, A.: Potentials of transboundary thermal water resources in the western part of the Pannonian Basin, *Geothermics*, 66, (2015), 88-98. doi:10.1016/j.geothermics.2015.01.013

Rman, N., Vengust, A., Marković, T., Lapanje, A., Šram, D., Rajver, D., Kerčmar, J. and Nádor, A.: D.3.3.2 Excursion guide for the Slovenian-Hungarian-Croatian pilot area. Interreg Danube Transnational Programme DARLINGe (2019), 20 p.

Website 1: http://www.interreg-danube.eu/approved-projects/darlinge

Website 2: https://www.geothermal-dhc.eu/

Website 3: https://www.energetika-portal.si/fileadmin/dokumenti/publikacije/nepn/dokumenti/nepn_eng.pdf

Acknowledgements

The authors are grateful to all direct heat users who provided data on their direct heat use of geothermal energy, as well as to all heat pump producers who delivered data on GSHP units sold in the country, and to owners and managers of many installations for specific data on the GSHP units of bigger rated power. The authors appreciate help of Petra Meglič for preparing the Figure 1.

TABLES A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *			3666.1*	13315*		
Under construction end of 2021						
Total projected by 2023			4450	14822		
Total expected by 2028			4800	15988		
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development: 0	
					Under investigation: 0	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

All values: a 50 % share from the Nuclear PP is taken into account (because 50% of its capacity and production belongs to Croatia)

Production values: Net generation (transferred to the network)

Table B: Existing geothermal power plants, individual sites

No geothermal power plants currently in Slovenia.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	49.581	99.093	6.337	30.434	1.558	1.582	3.224	3.929
Under constru-ction end 2021								
Total projected by 2023								
Total expected by 2028								

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Banovci-Veržej	Terme Banovci	1990	N	N	2.838	4.8	3.540	99
Čatež	Terme Čatež	1979	N	N	12.881	15.51	19.317	90
Cerkno	Hotel Cerkno	1979/ 2000	N	N	0.571	0.7	1.204	94
Dobova	Dobova Paradiso	2010	N	N	1.427	1.5	0.433	93
Dobrna	Terme Dobrna	1855/ 1979	N	N	0.329	0.57	0.917	80
Dolenjske Toplice	Terme Dolenjske Toplice	2003	N	Y	2.347	4.26	3.397	53?
Lendava	Terme Lendava	1997	N	N	1.531	2.5	4.558	75
Lendava	Petrol dd/Petrol Geo d.o.o.	2007	N	N, RI	2.734	5.0	5.606	98
Mala Nedelja	BioTerme	2007	N	N	1.029	2.726	0.932	60
Moravske Toplice	Terme 3000	1986/ 1989	N	Y	10.582	15.0	20.124	98
Moravske Toplice	Terme Vivat	2006	N	Y	2.149	4.409	3.985	99
Podčetrtek	Terme Olimia	1988	N	N	2.089	2.3	10.399	88
Ptuj	Terme Ptuj	1980	N	N	1.477	3.1	4.770	50?
Rimske Toplice	Rimske Terme	2010	N	Y	1.582	2.384	6.129	96
Šmarješke Toplice	Terme Šmarješke Toplice	1987	N	N	3.019	4.0	4.965	98
Tešanovci	Grede	2002	N	N	0.736	0.753	2.592	100
Topolšica	Terme Topolšica	1982	N	Y	2.259	3.304	6.223	90?
total					49.581	72.816	99.093	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

No geothermal large systems for heating and cooling uses other than DH with >500 MW_{th} currently in Slovenia.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	14818	237.746	329.260	1164	19.578	7 ***
Of which networks **						
Projected total by 2023	16900	271.0	376.0			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

*** Jozef Stefan Institute, Energy Efficiency Center (M. Česen), Ljubljana. (incl. the Eco Fund data)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No geothermal UTES currently in Slovenia.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	0	0	est. 1	10
Geothermal direct uses	*est.* 2	35	*est.* 2	35
Shallow geothermal	*est.* 6	120	*est.* 7	130
total	**8**	**155**	**10**	**175**

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include “jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration”. For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D		GeoERA projects: HotLime, GeoConnect3d, HOVER, CROWDTHERMAL, REFLECT, COST Geothermal-DHC; Geothermica – GeoFOOD	GeoERA projects: MUSE; COST Geothermal-DHC DIS; ARRS-MKGP Target research programme for cooling in agriculture, Call for EEA and Norway Grants
Financial Incentives – Investment	DIS Call for EEA and Norway Grants – Pg-8	DIS: Project investment for agriculture - Reinjection well in Dobrovnik LIL: yes; RC: no	DIS, LIL
Financial Incentives – Operation/Production	No	O – reduced concession fee for a limited period of time	DIS - Eco Fund
Information activities – promotion for the public	Yes	Yes, through media	Scheme of Energy Advice (EnSVet), Brochures (Preinvestment analysis for shallow geothermal applications)
Information activities – geological information	Yes, articles and media	public reports (explanation)	Yes, through public media
Education/Training – Academic	No	Yes, through different studies & projects Thermogeology course at NTF (Geothermal-DHC summer school), several MSc, PhD	Yes, through different studies & projects Thermogeology course at NTF (Geothermal-DHC summer school)
Education/Training – Vocational	No	Yes, workshops (explanation)	Yes, Chamber of engineers (education); seminars

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium	O	Other (please explain)
RC	Risk coverage	REQ	Renewable Energy Quota		

Geothermal Energy Use, Country Update for Spain

Iñigo Arrizabalaga[1], Margarita de Gregorio[2], Celestino García de la Noceda[3], Paloma Pérez ,
Javier F.Urchueguía[5]

[1] Telur Geotermia y Agua, S.A., Aliendalde Auzunea, 6. Bizkaia

[2] GEOPLAT (Spanish Technology and Innovation Platform on Geothermal), Doctor Castelo 10. Madrid

[3] IGME (Instituto Geológico y Minero de España), Río Rosas 23. Madrid

[4] GEOPLAT (Spanish Technology and Innovation Platform on Geothermal), Doctor Castelo 10. Madrid

[5] Instituto Universitario de Aplicaciones de las Tecnologías de la Información y de las Comunicaciones Avanzadas.

Universitat Politècnica de València. Camino de Vera s/n. 46022 Valencia, España.

margadegregorio@geoplat.org ; pperez@geoplat.org

Keywords: Update, Spanish geothermal sector, geothermal resources, deep geothermal, shallow geothermal, geopower, geo-exchange, heat pumps, exchange systems, Spain, forecast, heating & cooling, geothermal training courses, GEOPLAT

ABSTRACT

In Spain, there are still no geothermal power plants and, until very recently, the capacity installed of heating and cooling geothermal systems was estimated according to several data sources of very different reliability. In 2021 the Institute for the Diversification and Energy Saving (IDAE) of the Ministry of Environmental Transition and Demographic Challenge published the official census on the geothermal direct use and ground source heat pump sector, which represents a relevant milestone ending a situation of 'invisibility' that hurts at time to design promotion policies and support instruments.

Furthermore, the recovery plan—Next Generation EU—will enable Spain to mobilize public and private investment to realign the productive model, promoting decarbonisation, energy efficiency, the deployment of renewable energies, offering opportunities for geothermal energy.

Also, especially relevant for the Spanish geothermal sector was the recent publication of the first professional training qualifications on geothermal heating and cooling systems in the State Agency for the Official State Gazette (BOE) in June of 2021.

1. INTRODUCTION

Spain has a high potential of geothermal resources from different types (high, medium and low temperature). This geothermal potential, if harnessed adequately through proper development initiatives, could decrease the existent gap in the level of use of these resources with respect to other European nations. To enable this development, it is essential that the sector counts on an adequate support framework to undergo a sustained technological evolution.

Spain's geothermal potential could enable the inexhaustible use of this renewable energy source to produce electricity as well as for residential use and services. This would also allow Spain to reduce its foreign energy dependency (above 75 %), one of the biggest among EU countries and shown by many authors to be one of the real burdens to increase the competitiveness of the domestic economy. As well as to reduce the consumption of non-renewable energy sources and contribute to ultimately guarantee a constant supply of indigenous and reliable energy that is independent of external factors.

Table 1 provides a summary of the assessed geothermal resources in Spain.

A description of the existing geothermal resources available in the Spanish subsurface is provided in chapter 2. This description includes the characteristics and potential of each resource, such as zones of interest, geological conditions, depth and temperature of the resource, fluid composition, etc.

The resources have been classified into the following groups to prepare such descriptions:

- Very Low-Temperature Resources (T < 30 ºC).
- Low-Temperature Resources (30 ºC < T < 100 ºC).
- Medium-Temperature Resources (100 ºC < T < 150 ºC).
- High-Temperature Resources (T > 150 ºC).
- Enhanced Geothermal Systems (EGS).

Table 1. Geothermal resource potential in Spain. (Source: Evaluation of the geothermal energy potential. 2011-2020 PER technical study).

Type of use	Type of reservoir	Recoverable stored heat (10^5 GWh)	Power (MW)
Thermal	Low temperature (total resources)	15'682	5'710'320 (MW_{th})
	Low temperature (usable)	160	57'563 (MW_{th})
Electric	Medium temperature (total resources)	541	17'000 (MW_e)
	Medium temperature (studied)	54	1695 (MW_e)
	High temperature (studied)	1.8	227 (MW_e)
	Enhanced geothermal systems (known areas)	60	745 (MW_e)

2. GEOTHERMAL RESOURCES IN SPAIN

2.1 Very low temperature (<30 ºC) – shallow – geothermal resources

Closed-loop geothermal systems.

These resources are available nationwide. There are two main groups depending on the average thermal conductivity and the physical and mechanical characteristics of the ground.

Consolidated formations extending over 60 % of the territory area. Formed by sedimentary, igneous or metamorphic rocks ranging from Palaeozoic to Mesozoic age, specific weight greater than 2.0 tm/m^3, the thermal conductivity in saturated conditions is over 2 W/mK and can be drilled without drilling mud or auxiliary casing except for a few top meters. These formations extend the entire periphery as well as the central mountain ranges. The conditions for implementing very low temperature geothermal systems are optimal, especially when they go hand in hand with continental type climatic conditions.

Unconsolidated formations occupy broad areas across the two plateaus and the eastern third of the country. Geological conditions are less favorable, increasing the installations cost. However, these areas frequently have continental climatic conditions, with a great and well-equalized heating and cooling demand, improving the attractiveness of shallow geothermal systems in terms of Levelized Cost of Heating/Cooling (LCoHC) and Pay-back of the investment.

Open-loop geothermal systems.

There is a wide use of groundwater, especially for urban and agricultural supply, in Spain. Many times, groundwater extraction involves deep aquifers often with high pumping heights, increasing the energy cost over the shallow systems redlines. Furthermore, complex regulations and hydrological stress in broad areas of the country do not facilitate their use for thermal energy applications. In practice, the greatest potential can be found in cascade applications, still scarcely developed, or more frequently in alluvial aquifers associated to Spanish main rivers such as the Ebro, Guadalquivir, Guadiana, etc. standing many of the country's main cities (Zaragoza, Seville, etc.). These aquifers, very transmissive (> 10^3 m^2/d), supply open-loop ground source heat pump systems of typically several hundreds of kW, just a few meters of drawdown.

In addition, several coastal areas of Spain (islands and mainland) stand a significant number of hotels where heating, HSW and cooling demand is being supplied by open loop systems using ground seawater.

According to the methodology provided by other sources (e.g. documents from the US Department of Energy such as "Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers. December 2008"), resources are not limited by ground conditions, but rather by demand configuration and our ability to harness the resources in a technically and economically viable way. In this sense Spain has many of the factors that favour geothermal heat pump-based systems such as broad climatic areas with important seasonal temperature variations, large numbers of dwellings or buildings in rural or semi-urban areas with sufficient surrounding land and difficult access to gas or other sources and a deeply rooted heating and cooling industry backed by broad experience.

2.2 Low temperature (30 – 100 ºC) geothermal resources

The Spanish subsurface has been classified into two main groups, for the purpose of analysing these resources:

1) large sedimentary basins and peripheral mountain ranges
2) the Iberian Hercynian Massif

The first group includes the Duero, Tajo-Mancha-Júcar, Guadalquivir, Ebro and North-Cantabrian basins. The second group includes the Bética Ranges in addition to the Pyrenees, the Catalan Coastal Ranges and the Iberian Hercynian Massif located in the west of the Iberian Peninsula. Within the areas that are included in the first group, there are numerous Mesozoic and Tertiary permeable formations that fill said basins, as described in studies prepared by IGME (Spanish Geological Survey) in the 1980s based on the information obtained from deep hydrocarbon exploration wells. Geothermal energy in the form of recoverable stored heat (geothermal reserves) in such formations has been estimated at a total of 15’126 x 10^5 GWh. When applying the calculation to zones of influence in key urban centres that have significant thermal demand, this figure increases to 150.3 x 10^5 GW, which is approximately 1 % of the total.

The areas included in the second group, which have been studied in detail by IGME from 1975, are characterized by significant regional fracturing coupled with a considerable vertical development of permeable formations that allow the proliferation of zones that host geothermal resources. Geothermal energy in the form of recoverable stored heat (geothermal reserves) in these zones has been estimated at 736 x 10^5 GWh. When applying the calculation to zones of influence in key urban centres that have significant thermal demand, this figure increases to 9.6 x 10^5 GW, which is approximately 1.3 % of the total in these areas.

In summary, low-temperature geothermal energy estimates in the form of recoverable stored heat in Spain’s subsurface (Figure 1) amount to a total of 15’862 x 10^5 GWh, of which 159.9 x 10^5 GWh are located proximal to areas that have significant demand levels of this energy for direct heat applications.

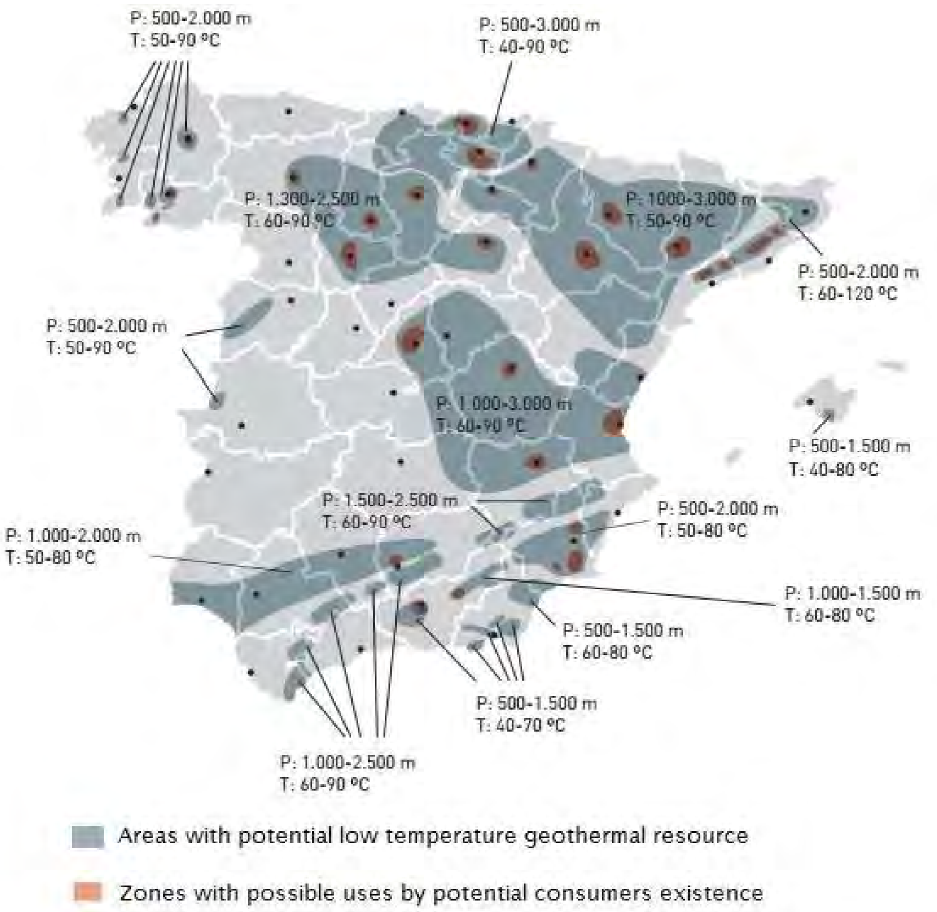


Figure 1. Map of low-temperature geothermal resources and zones with good potential for resource exploitation (Source: PER 2011-2020).

2.3 Medium temperature (150-180 ºC) geothermal resources

The great depths that characterize some geologic basins in Spain that normally host permeable formations at depths greater than 3500 m allows for the existence of medium temperature geothermal resources suitable to be used in binary cycles for the combined production of heat and power. At these depths, the temperature of water contained in permeable formations exceeds 100 ºC thanks to the geothermal gradient of the subsurface. In other zones, it is the considerable extent of regional fracturing that facilitates deep circulation of geothermal fluids. Thus, the areas located in the Cantabrian, Pre-Pyrenean, Tagus, Guadalquivir and Betic Range basins host deep permeable formations that contain fluids whose temperature exceeds 100 ºC.

In regions where granitic materials predominate, such as Cataluña and the Hercynian Massif (mainly in Galicia, northwestern Spain), regional fracturing favours the existence of these reservoirs thanks to the presence of fluids that circulate at depth. The studies carried out by IGME as well as hydrocarbon exploration conducted by oil companies have allowed recognizing or estimating areas that can potentially host geothermal resources. These areas include La Selva and Vallés depressions in Cataluña, the zone of Jaca-Serrablo in Aragón, the northern zone of the Madrid Basin, Lebrija in the Guadalquivir River Basin, a number of internal depressions in the Bética Ranges such as Lanjarón in Granada or Sierra Alhamilla in Almeria and some disperse areas in Galicia, Salamanca and Cáceres.

The gross potential of these resources in the form of recoverable stored heat in unexplored areas (Figure 2) amounts to 541 x 10^5 GWh, which is equal to an installed capacity of 17’000 MW_e. Geothermal resources in the form of recoverable stored heat in the abovementioned known or explored areas have been estimated at 54.23 x 10^5GWh. Up to 1695 MW_e could be installed in binary cycle plants when taking into account performance, renewability and operating load factors.

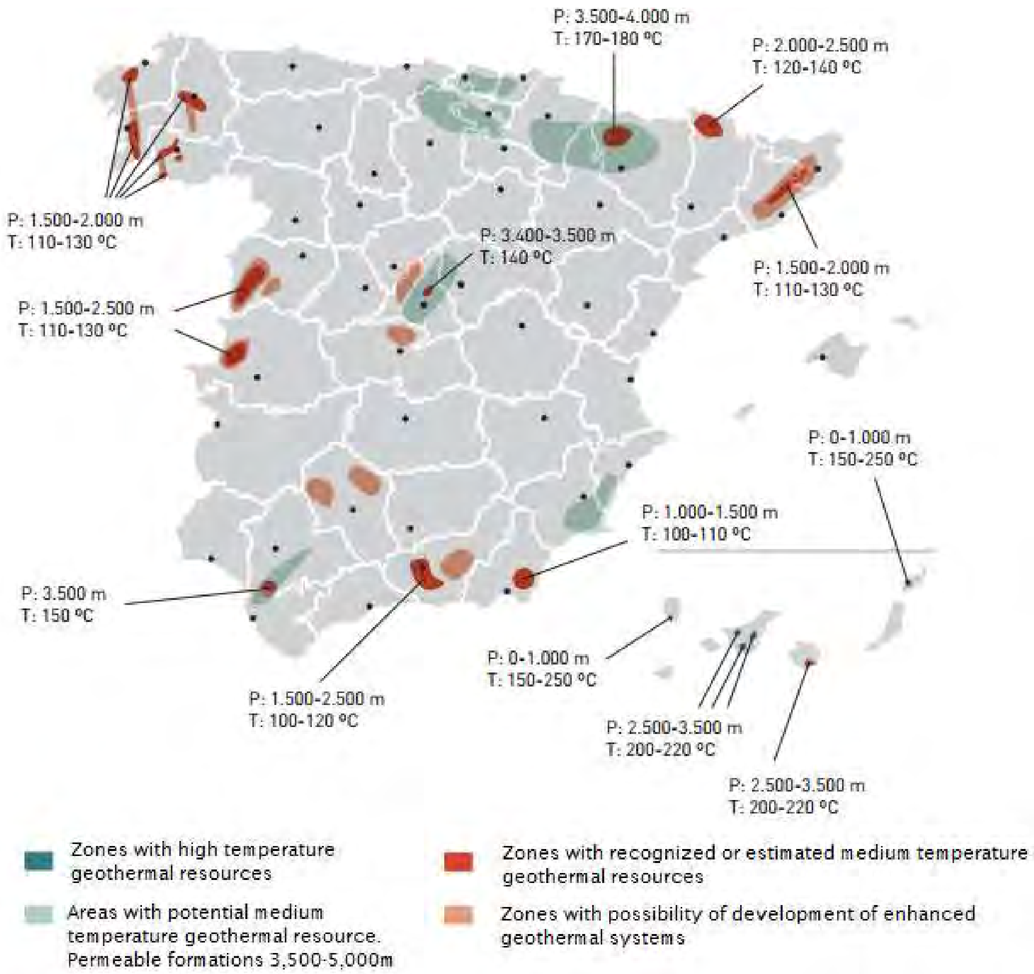


Figure 2. Map of medium and high-temperature geothermal resources and possible enhanced geothermal systems (Source: PER 2011-2020)

2.4 High temperature (> 150 ºC) geothermal resources

The conditions that enable the existence of high-temperature geothermal resources associated with active volcanism (a phenomenon which is also known as conventional geothermal energy) have been confirmed in Spain only in the Canary Islands. Previous investigations conducted by IGME and other entities have highlighted the possible existence of steam reservoirs or reservoirs involving a combination of steam and water in several areas of Tenerife (in the NW, E and S of the island). In other islands (Lanzarote and La Palma), several important thermal manifestations at the surface exist which, nonetheless, do not appear to indicate any possible storage of geothermal fluid.

In the three areas mentioned above on the island of Tenerife, the potential existence of geothermal storage zones has been estimated at depths between 2500 and 3500 m and temperatures in the range of 200-220 ºC. Geothermal energy in the form of recoverable stored heat in such zone has been estimated at 1.82 x 10^5 GWh. Up to 227 MW_e could be installed in conventional flash type plants when taking into account performance, renewability and operating load factors.

2.5 Enhanced Geothermal Systems (EGS)

The basic criteria used when selecting areas that have the potential for the development of EGS are:

1) the existence of a mass of hard granitic or metamorphic rock with low permeability at its matrix;

2) significant regional fracturing affecting this mass; and

3) a certain degree of geothermal anomaly.

In light of these criteria, a detailed review of the mainland geology has revealed a series of areas which, from a geological perspective, can allow the implementation of these enhanced geothermal systems (Figure 2). The areas considered are: the tectonic grabens of La Selva and Vallés in Cataluña, areas of deep fracturing in Galicia, the tectonic grabens in the SW of Salamanca (towns of Ciudad Rodrigo and Tormes), fractured areas west of Cáceres, the borders of the Tagus River depression, which are characterized by large-scale fractures that affect the Hercynian bedrock and lastly, areas in Andalucía where the granitic or Paleozoic bedrock is highly fractured, such as Sierra Morena or the more internal zone of the Bética Ranges in the vicinity of Sierra Nevada.

The geothermal energy that could be found in the form of recoverable stored heat in these areas has been estimated at 60 x 10^5 GWh, which would allow installing a total power capacity of 745 MW_e when taking into account the already mentioned performance, renewability and usage load factors.

3. SPANISH GEOTHERMAL SECTOR UPDATE

The Spanish geothermal sector is advancing step by step, establishing solid foundations to consolidate as a renewable, reliable, highly efficient and competitive alternative in all its uses. This decade will be key to getting it off the ground in Spain.

3.1 Integrated National Energy and Climate Plan 2021-2030

The Spanish Integrated National Energy and Climate Plan (NECP) 2021-2030[1], approved in March 2021, identifies the challenges and opportunities within the five dimensions of the Energy Union: decarbonization, including renewable energy; energy efficiency; energy security; the internal energy market; and research, innovation, and competitiveness. The Plan also gives the necessary signals to provide certainty and direction to all players while also bringing flexibility and manageability to the energy transition and the decarbonization of the economy.

The Plan sets a target of 80 MW for installed power in 2030 under the label 'other renewable energies' which consist of marine and geothermal energy. In the thermal field, the NECP sets a target of 34 % renewables in heating and cooling applications; a scenario in which geothermal energy could play a very relevant role in Spain.

The NECP 2021-2030 considers auctions to be the main tool for the development of these technologies, by EU Directive 2018/2001 on the promotion of the use of energy from renewable sources.

On 4 December 2020, Spain's Ministry for Ecological Transition and Demographic Challenge approved a new order regulating the first auction mechanism for the economic regime for renewable energy and establishing the indicative calendar for renewables auctions during the period 2020-2025. However, the first auction established a target quota of 3000 MW, of which at least 1000 MW for photovoltaic and another 1000 MW 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 the electricity renewable auctions, geothermal energy in Spain has continued to advance, fundamentally in its thermal uses, both on a domestic scale and an industrial scale, with installations for heating, cooling and domestic hot water through heat pump systems associated with a geothermal exchanger.

3.2 Publication of the official data on the Ground Source Heat Pumps (GSHP)

In March 2021, the Institute for the Diversification and Saving of Energy – IDAE, (a body assigned to the Ministry for the Ecological Transition through the Secretary of State for Energy) officially published, for the first time, the census, not a statistic, regarding the use of ground source heat pumps in Spain (Tables 2 and 3, Figure 3). The installed capacity for thermal uses (Heating, DHW and Bathing/Spa, etc.) amounts to 164 MW (in 2018), with the following regions having the greatest identified installed capacity for geothermal heating systems: Aragón (42 MW), Basque Country (25 MW) and Madrid (21 MW), followed by the Canary Islands (11 MW), Andalusia and Catalonia (with 10 MW each); while the installed capacity for use in refrigeration amounts to 143 MW. The publication of these official dataset regarding the penetration of the geothermal heating and cooling technology in Spain implied a significant milestone for the sector.

Although the census published by IDAE does not represent the totality of the installed capacity of direct use and GSHP systems in Spain (there is no specific centralized register of these technologies and many installations are not identified), they do constitute a good base starting point to continue updating it periodically and highlight the evolution of the geothermal sector in Spain.

3.3 Recovery, Transformation and Resilience Plan

In June 2021, the European Commission approved Spain's Recovery, Transformation and Resilience Plan[2]. The Plan is a national project defining the roadmap for the modernization of the Spanish

[1] https://www.miteco.gob.es/images/es/pnieccompleto_tcm30-508410.pdf

[2] https://www.lamoncloa.gob.es/temas/fondos-recuperacion/Documents/160621-Plan_Recuperacion_Transformacion_Resiliencia.pdf

economy, for the recovery of economic growth and job creation, for a robust, inclusive and resilient economic rebuilding after the Covid-19 crisis, and to respond to the challenges of the coming decade.

Table 2: Main installed capacity studies, 2018 (source: IDAE)

CCAA	nº de bombas de calor geot/hidr	Potencia *TOTAL (kW)	Potencia usos térmicos: Calef., ACS, Clim_piscinas (kW)	Potencia para uso Calefacción (kW)	Potencia para uso ACS (kW)	Potencia para Climatización de piscinas (kW)	Potencia para uso refrigeración (kW)
Andalucía	111	12.142	10.124	7.439	6.135	-	9.743
Aragón	251	57.997	42.162	40.213	5.083	-	52.802
C. Valenciana	33	4.753	4.753	4.650	1.023	61	4.356
Cantabria	58	1.115	1.115	975	787	79	116
Castilla La Mancha	196	4.105	4.105	4.075	1.296	-	3.676
Castilla y León	527	9.623	9.233	9.231	1.261	-	530
Cataluña	37	10.035	10.035	9.658	8.034	-	9.593
Comunidad de Madrid	443	20.798	20.798	19.509	18.130	-	18.808
Comunidad Foral Navarra	66	2.574	2.574	2.573	1.467	-	1.142
Extremadura	5	85	85	80	47	-	52
Galicia	353	4.934	4.934	4.818	2.264	70	754
Islas Baleares	25	8.186	7.876	4.376	391	-	7.359
Islas Canarias	32	21.611	11.306	10.254	9.595	518	21.621
La Rioja	22	1.472	1.472	1.445	244	25	384
País Vasco	673	25.361	25.361	24.874	8.651	200	8.491
Principado de Asturias	280	8.044	8.044	7.751	7.022	57	3.846
Región de Murcia	3	150	150	150	9	-	30
Total general	**3.115**	**192.986**	**164.129**	**152.070**	**71.440**	**1.010**	**143.303**

**incl. todos los usos*

*Potencia usos térmicos calef.+ACS+Clim_piscinas que contabiliza para la estadística EERR: **164.129 kW***

Potencia usos térmicos calef.+ACS+Clim_piscinas ≠ suma de cada uso → problema de doble contabilidad por usos compartidos

Table 3: Main results of the study of geothermal and hydrothermal heat pumps (source: IDAE)

CCAA	2018 Potencia TOTAL calor (kW)	2018 EREs CALOR (tep)	2020 Potencia TOTAL calor (kW)	2020 EREs CALOR (tep)
ANDALUCIA	10.178	1.000	10.500	1.032
ARAGON	42.108	4.635	42.108	4.635
CANARIAS	11.306	903	12.700	1.089
CANTABRIA	1.081	165	1.081	165
CASTILLA Y LEON	9.267	1.173	9.292	1.177
CASTILLA-LA MANCHA	4.105	423	4.193	431
CATALUÑA	10.035	1.239	10.035	1.239
COMUNIDAD DE MADRID	20.798	2.692	29.484	3.593
COMUNIDAD FORAL NAVARRA	2.574	641	2.603	645
COMUNIDAD VALENCIANA	4.753	410	5.763	483
EXTREMADURA	85	6	85	6
GALICIA	4.934	492	7.859	753
ISLAS BALEARES	7.876	422	7.876	422
LA RIOJA	1.472	186	1.472	186
PAIS VASCO	25.361	3.290	27.359	3.473
PRINCIPADO DE ASTURIAS	8.044	1.285	9.171	1.397
REGION DE MURCIA	150	9	150	9
Total general	**164.129**	**18.973**	**181.731**	**20.736**

EREs→ energía capturada por las bombas de calor

$$E_{RES} = Q_{usable} \times \left(1 - \frac{1}{SPF}\right)$$

donde:

Q_{usable}: calor útil total estimado proporcionado por la bomba de calor [GWh]; calculado según:

$$Q_{usable} = H_{HP} \times P_{rated}$$

con:

H_{HP}: horas equivalentes de funcionamiento a plena carga [h]; y

P_{rated}: potencia instalada de la bomba de calor, teniendo en cuenta la duración de los diferentes tipos de bombas de calor [GW];

SPF: factor de rendimiento medio estacional estimativo.

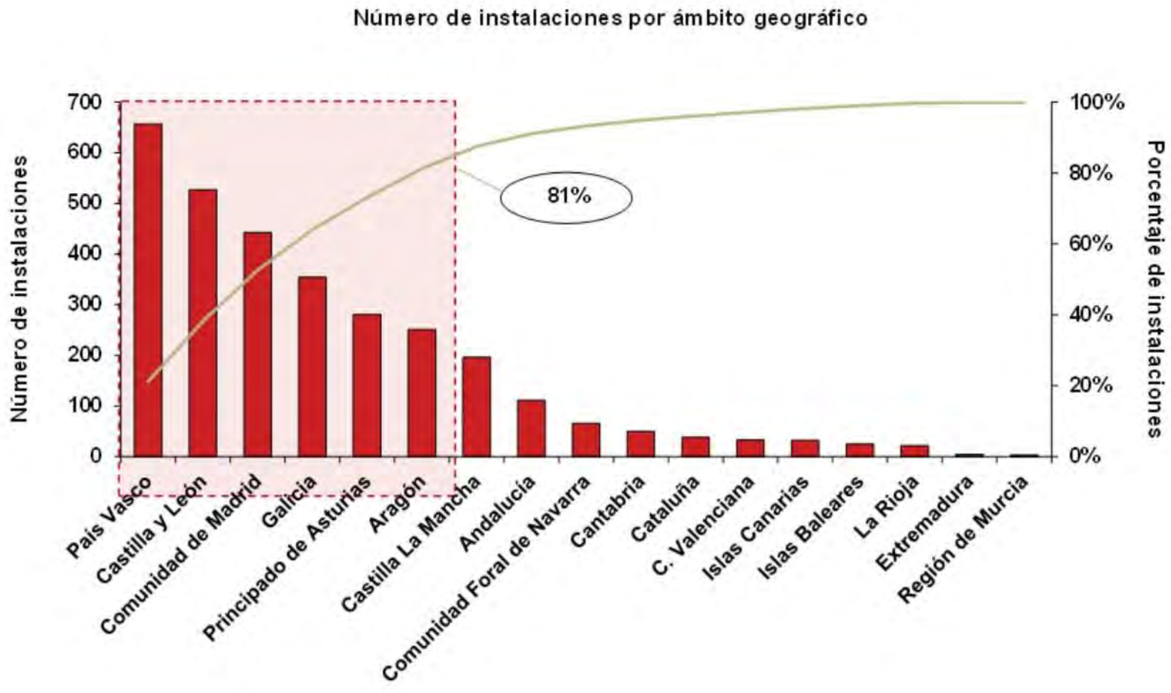


Figure 3: Facilities by autonomous community (source: IDAE)

This Recovery, Transformation and Resilience Plan will entail a significant volume of public and private investment in the coming years. This investment, necessary to relaunch the Spanish economy and accelerate the transformation of the production model towards sustainable and inclusive growth, will be financed by Next Generation EU, the European Recovery Fund.

The Plan is structured around four transversal axes that will provide the backbone for the transformation of the economy as a whole and which the Government has placed at the centre of its economic policy strategy from the outset: ecological transition, digital transformation, gender equality and social and territorial cohesion. These axes will guide the entire recovery process, inspiring the structural reforms and investments that will be implemented, with the ultimate goal of returning on the path to growth, promoting the creation of companies and accelerating the generation of employment.

The geothermal sector welcomed the growth opportunities represented by the aid that articulates the Recovery, Transformation and Resilience Plan thanks to the Next Generation EU. These funds are being channelled through different mechanisms whose objective is to cover the entire field of renewables for thermal uses in general and geothermal energy in particular.

The Council of Ministers approved Royal Decree 477/2021[3] approving the granting of aid for self-consumption and storage through renewable energy sources, as well as the implementation of renewable thermal systems in the residential sector, all within the framework of the Recovery, Transformation and Resilience Plan. The autonomous communities and the cities of Ceuta and Melilla must make the corresponding calls within a maximum period of 3 months from the entry into force of this Royal Decree, which will be in force until December 31, 2023.

The incentive programs are:

- Program 1. Self-consumption and storage in the service sector.
- Program 2. Self-consumption and storage in other productive sectors, such as industry or agriculture and livestock.
- Program 3. Incorporation of storage in existing renewable self-consumption in economic sectors.
- Program 4. Self-consumption and storage in the residential sector, the public sector and the third sector.
- Program 5. Incorporation of storage in renewable self-consumption in the residential sector, public sector and third sector.
- Program 6. Implementation of thermal renewable energy installations in the residential sector. The eligible actions within the incentive program 6 include geothermal energy for heating and cooling and/or domestic hot water in homes.

Furthermore, last December the Council of Ministers in Spain approved Royal Decree 1124/2021[4] for direct grants to regions for renewable heat projects

[3] https://www.boe.es/boe/dias/2021/06/30/pdfs/BOE-A-2021-10824.pdf

[4] https://www.boe.es/diario_boe/txt.php?id=BOE-A-2021-21106

implemented in different sectors of the economy, whose installed capacity exceeds 1 MW.

The incentive programs are:

- Program 1: Thermal renewable energy installations in the industrial, agricultural, services and other sectors of the economy, including the residential sector.
- Program 2: Thermal renewable energy installations in non-residential buildings, establishments and infrastructures of the public sector.

IDAE is responsible to coordinate the new budget line and has already allocated EUR 150 million. The regional administrations are responsible for publishing the respective calls.

And another Royal Decree is currently being prepared to promote the implementation of district air conditioning networks, which will allow aid to reach this type of system that allows centralized heating, cooling, and DHW to be provided in a highly energy-efficient manner.

4. UPDATE PROJECTS IN THE SPANISH GEOTHERMAL SECTOR

4.1 Geothermal District Heating Network Sourcing Heat from Abandoned Mine in Asturias

In March 2021, the construction of a geothermal district heating network from a geothermal well at Fondón, in the municipality of Langreo, in Asturias, a region in Northern Spain, concluded. It involved the construction of a heat network to satisfy the demand for heating and domestic hot water in buildings around located in the nearby city of Langreo (public health centre, a residential building, the Juan Carlos Beiro sports center, the Nuestra Señora del Fresno elderly residence and the Langrehotel building), through the geothermal use of the pumped mine water (Figure 4). In this first phase, the three shipments of the well shipment will be rehabilitated to house the geothermal generation plant, with a heating capacity of 1.5 MW thermal. The DH Pozo Fondón has the support of the European Union and the Government of the Principality of Asturias, that finance part of the project through Feder funds.

The works of the geothermal energy district heating network from the water that floods the Pozo Fondón represent the second geothermal project based on mine water promoted by Grupo Hunosa. In Mieres, the district heating network of Pozo Barredo provides geothermal heating and cooling to the Polytechnic School of Mieres (EPM), the secondary school Bernaldo de Quirós (IBQ) and a group of buildings, located in the Vasco-Mayacina area (Figure 4). The project was awarded in 2019 the Global District Energy Climate Award by the International Energy Agency (IEA), under the category "emerging markets".

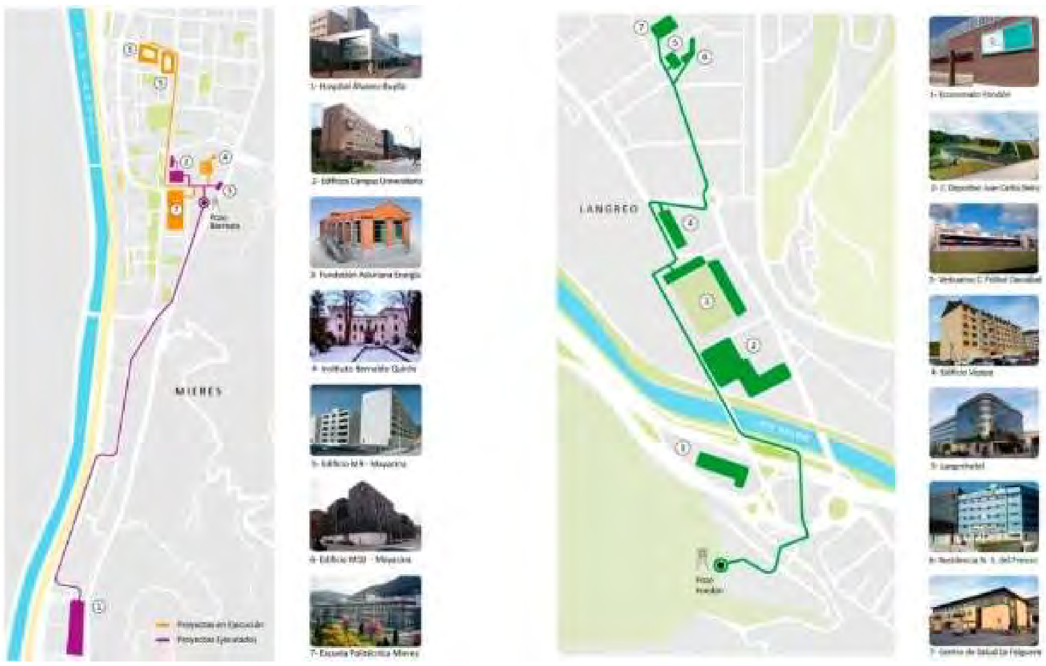


Figure 4: Extension of the geothermal networks of Pozo Barredo and Pozo Fondón (source: HUNOSA)

4.2 Geothermal heat project to greenhouse Andalusia

In 2021, a deep geothermal direct use project in Almeria, in Southeast Spain, was kicking off to use geothermal energy beneath the Níjar region to heat the greenhouses with grant funding under the Spanish Ministry for the Ecological Transition and the Demographic Challenge.

The project, headed by the company Cardial Recursos Alternativos, contemplates reaching depths of more than two thousand meters to take advantage of that heat to heat the interior of the greenhouses. The first exploitation was completed in Tristanes, in Campo de Níjar at 2000 meters borehole that reached a temperature in its lower zone of 105 ºC, which confirms the enormous geothermal potential hidden under the soil of Almeria. The drilling process for this well has also allowed acquiring valuable experience and knowledge to tackle the next wells, which will foreseeably reach a depth of 2500 meters. The future borehole network will allow Cardial to supply thermal energy to as many greenhouses as possible. This first survey is a decisive step for the implementation of deep geothermal energy in Spain.

4.3 Promotion of geothermal energy in the Canary Islands

In 2021, the Government of the Canary Islands worked on its Canary Islands Energy Transition Plan (PTECan). The preparation of PTECan was entrusted to the Canary Islands Technological Institute (ITC), to promote the development of a sustainable energy model in the 2030 horizon based on energy efficiency and renewable energies, and that contemplates the promotion of geothermal energy in the Islands.

In addition, the Geothermal Energy Strategy and Roadmap are published, the objective of which will be to identify the necessary actions to increase the use of low enthalpy geothermal energy and promote high enthalpy geothermal energy in the Archipelago.

5. GEOTHERMAL EDUCATION AND TRAINING IN SPAIN

GEOPLAT, jointly with the National Institute of Qualifications of the Spanish Ministry of Education (INCUAL), has worked, for five years ago, on the development of the basis for qualification of professionals to manage the installation and maintenance of geothermal heat exchange systems.

In June of 2021, the first professional training qualifications on geothermal heating and cooling systems were published in the State Agency for the Official State Gazette (BOE)[5]:

- 'Installations, commissioning and maintenance of closed-loop geothermal exchange facilities' (level 2)
- 'Organization and projects of closed-loop geothermal exchange facilities' (level 3)

This was a milestone being the first qualifications published both in Spain and in Europe on geothermal heating and cooling systems for buildings. Their publication 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.

A few months later, in September of 2021, ENAE06 'Installations, commissioning and maintenance of closed-loop geothermal exchange facilities' (level 2) was included in the Catalogue of Formative Specialities of the Spanish Public Service state employment (SEPE)[6]. This will allow any Spanish accredited training center to teach this program.

All this work will help to advance the professionalization of the sector, assisting to improve the quality of installations.

REFERENCES

APPA Renovables - Study of the Macroeconomic Impact of Renewable Energies in Spain 2020

GEOPLAT – Spanish Geothermal Technology and Innovation Platform (www.geoplat.org)

IDAE - The Spanish Institute for Energy Diversification and Saving (www.idae.es)

IDAE – Instituto para la Diversificación y Ahorro de Energía: Evaluación del potencial de energía geotérmica. Estudio Técnico PER 2011-2020.

IDAE - Heat pump statistics (https://estadisticas-bombasdecalor.idae.es/)

MITECO - Spanish Ministry for Ecological Transition and Demographic Challenge (https://www.miteco.gob.es/es/)

MITECO - Integrated National Energy and Climate Plan (NECP) 2021-2030

MITECO - Recovery, Transformation and Resilience Plan

MITECO – La energía en España 2019

Acknowledgements

This work wouldn't have been possible without the collaboration of Spanish geothermal stakeholders and the work of the secretariat of the Spanish Geothermal Technology and Innovation Platform -GEOPLAT.

[5] https://www.boe.es/diario_boe/txt.php?id=BOE-A-2021-8975

[6] https://sede.sepe.gob.es/es/portaltrabaja/resources/pdf/especialidades/ENAE06.pdf

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	0	0	109’970*	273’257*	0	0
Under construction end of 2021	0	0				
Total projected by 2023	0	0				
Total expected by 2028	15**	112.5**				
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation: - 466 km^2 (exploration permit Gran Canaria) - 4.5729 km^2 (exploitation permit Níjar (Almería))	

* If 2020 numbers need to be used, please identify such numbers using an asterisk
** Estimated under investigation

Table B: Existing geothermal power plants, individual sites

No geothermal power plants currently in Spain.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	2.6*	14.6*	14.9*	26.2*				
Under constru-ction end 2021			13.36					
Total projected by 2022	1.5	4.35	15.25					
Total projected by 2023			17.45					

* If 2020 numbers need to be used, please identify such numbers using an asterisk
** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Madrid	DH Arroyo Bodonal			Y	0.9			
Puerta de Pollenso (Balearic Islands)	DH&C Club Pollentia Resort			Y		8.5		
Olot (Girona)	DH Olot		Y [a)]	Y		0.97		
Las Palmas (Canary Islands)	DH Hotel Teguise							
Barcelona (Catalonia)	Plaza de Lleó							
Lérida (Catalonia)	DH Camping la Noguera		Y [a)]					
Álava (Basque Country)	DH Neiker – Tecnalia		Y [b)]	Y				
Mieres (Asturias)	DH Pozo Barredo (phase 1)	2014		Y	3.65 C / 4.67 H		7.12 (2.06 C / 5.06 C)	
Mieres (Asturias)	DH Pozo Barredo (phase 2)	2020			2		1.79	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

a) trigeneration: geothermal + biomass + natural gas

b) biomass / geothermal

Table E1: Shallow geothermal energy, Ground Source Heat Pump (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	4889***	270.176***				
Of which networks **						
Projected total by 2023						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

*** Data based on GEOPLAT’s internal estimation

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power		144*		
Geothermal direct uses				
Shallow geothermal		560*		
total		**704***		

* If 2020 numbers need to be used, please identify such numbers using an asterisk
** Expenditures in installation, operation and maintenance, decommissioning
*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	YES	YES	YES
Financial Incentives – Investment	NO	NO	Direct investment support, Low-interest loans
Financial Incentives – Operation/Production	NO	NO	Direct investment support, Low-interest loans
Information activities – promotion for the public	YES	YES	YES
Information activities – geological information	YES	YES	YES
Education/Training – Academic	YES	YES	YES
Education/Training – Vocational	NO	NO	YES

European Geothermal Congress 2022
Berlin, Germany | 17-21 October 2022
www.europeangeothermalcongress.eu

Geothermal Energy Use, Country Update for Sweden

Signhild Gehlin[1], Olof Andersson[2], Jan-Erik Rosberg[3]

[1] Swedish Geoenergy Center, P.O. Box 1127, SE-221 04 Lund, Sweden

[2] Geostrata HB, Kärrsångarvägen 14, SE-247 35, S Sandby, Sweden

[3] Engineering Geology, Lund University, P.O. Box 118, SE-221 00 Lund, Sweden

signhild.gehlin@geoenergicentrum.se

Keywords: Sweden, Country Update, Shallow geothermal energy, BTES, ATES, deep geothermal, ground source heat pumps

ABSTRACT

This paper presents the status of geothermal energy use and market in Sweden by the end of 2021. Geothermal energy use in Sweden is dominated by shallow geothermal energy systems, mostly vertical ground source heat pump systems (GSHP) but also horizontal loops. The vast majority of installed systems are for space heating and domestic hot water heating for single-family buildings. By the end of 2021, there were approximately 630’000 shallow geothermal energy systems installed in Sweden, with an increase of roughly 15’000 new systems per year. GSHP systems provided some 25.5 TWh of heating in Sweden of which approximately 18.5 TWh is renewable heat from the ground. The total installed GSHP heating capacity was 7.3 GW. These figures include the contribution of 68 GWh of geothermal heat produced by the Lund geothermal system plant connected to the district heating. In addition to the heat from the ground, at least 1 TWh is provided as ground source direct-cooling.

1. INTRODUCTION

The more than a half century history of geothermal energy utilization in Sweden was largely triggered by the oil crises in the 1970’s and 1980’s. At that time there were nationwide efforts to achieve an oil-independent energy system. This led to the promotion of heat pumps technology, and was further favoured by the national power production strategy based on nuclear power and hydropower. During the 1990’s the heat pump technology in general and ground source heat pump (GSHP) technology in particular, developed rapidly in Sweden, resulting in a world-leading role in the GSHP research and industry.

The geothermal market and development in Sweden is mostly focused on shallow geothermal systems. Activities related to deep geothermal resources have so far resulted in one geothermal district heating plant in the south of Sweden, established in the 1985 and still in operation (Aldenius, 2017). It has moderate depth and has an extraction temperature <25 °C, hence does not meet the criteria for the EGC definition of deep geothermal district heating system.

In the 2010, 2015 and 2020 world geothermal surveys (Lund et al. 2010, Lund and Boyd 2015, Lund and Toth 2020), Sweden is rated as top three world leading country in geothermal energy utilisation, in terms of installed capacity and extracted thermal energy.

1.1 Geology, hydrogeology and climate in Sweden

The Swedish geology is characterized by the massive Baltic shield and its diverse crystalline eruptive and metamorphic rocks. In the southern parts of the country, sedimentary rock formations of significant thickness are found, spot-wise containing porous sandstones at considerable depth and with very good hydraulic properties (Figure 1).

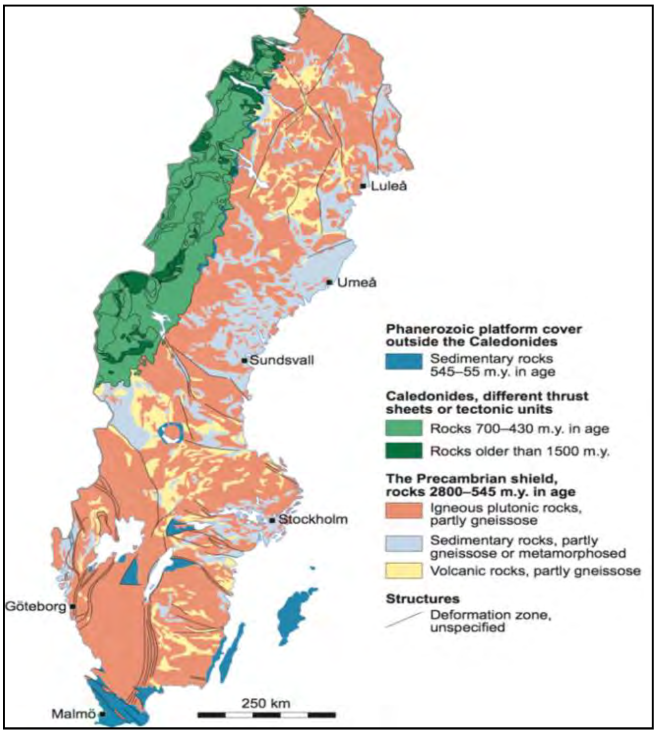


Figure 1: The bedrock geology of Sweden (© Swedish Geological Survey)

The geothermal gradient varies in the range of 15-25 °C/km. The higher value represents a geothermal well in the sedimentary basin in SW Sweden (Gustafson et al., 1979), while the lower values (15-19 °C/km) were found in deep boreholes in the Baltic shield region (Odén, 2013), see Figure 2.

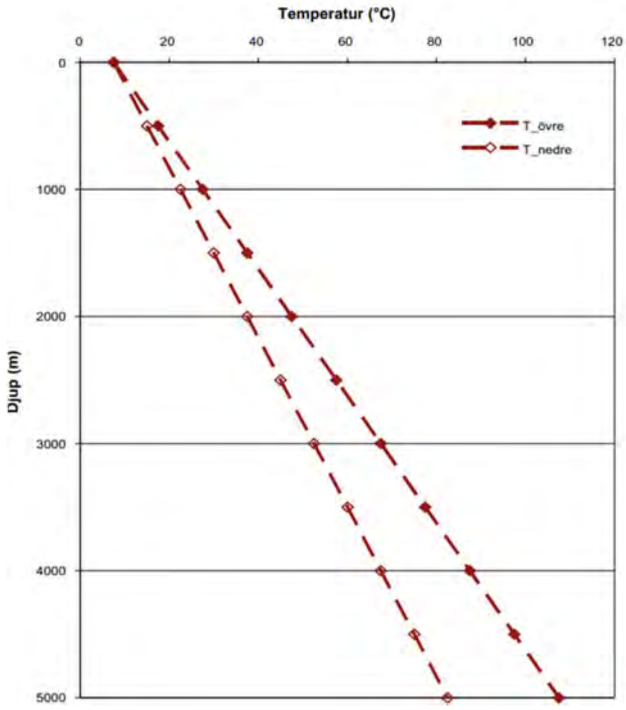


Figure 2: Upper and lower geothermal gradients in the Fennoscandian basement (Odén, 2013)

Rosberg and Erlström (2019 and 2021) presented gradients between 22-24 °C/km for two wells drilled through the sedimentary basin and further into the basement (3700 and 3330 m deep) in southernmost Sweden. Lorenz et al. (2015) presented a gradient of 20 °C/km for a deep well in the Swedish Caledonides.

The basement consists mainly of solid granites, and gneisses. It is favourable to drill with DTH hammer drilling, and has a generally low groundwater yield. Shallow geothermal boreholes are drilled to a depth up to 450-500 m without any major problems, though common depths are more in the range of 250-300 m.

Groundwater in the form of aquifers is mainly found in eskers. These are glaciofluvial deposits from the melting of the inland ice that covered Scandinavia some 10-20’000 years ago. The eskers with highly permeable gravel and sand deposits are located along the river valleys where also the population is dense. Apart from their use for drinking water supply, these eskers are also highly interesting for groundwater-based shallow geothermal systems for heat or cold extraction, as well as for thermal energy storage.

A limited number of large aquifers are also found in the sedimentary rock, mainly located in the southernmost part of Sweden. In particular it is the Mesozoic sandstones and limestones that are used for shallow geothermal systems.

Sweden has a climate that varies from north to south. The southern half is temperate continental while the northern half is continental. The variation in average high summer temperatures is small, with 21 °C in the south and 20 °C in the north. However, the variation during the winter season is more pronounced, with average temperatures varying from -3 °C in the south to -14 °C in the north (climatedata.eu 2019). The seasonal swing between summer and winter is favourable for underground seasonal storage systems. Ground temperatures at a depth of 100 m vary between +9 °C in the south and +2 °C in the north. The ground temperature features the annual mean temperature in the air at the location but is slightly higher in the north due to the insulating effect from snow cover in the winter.

2. DEEP GEOTHERMAL

In Sweden, the interest for using deep geothermal energy started during the 1970s (Bjelm et al., 1977; Eriksson et al., 1978, Bjelm et al., 1979, Bjelm et al., 1981). In southern Sweden the focus was to extract warm water from the sandstone aquifers and to apply the HDR-concept (Hot Dry Rocks) in other parts of Sweden dominated by Precambrian crystalline rock.

The first geothermal well (Höllviksnäs-1) was drilled and tested in 1977-78. It indicated a large potential in the Bunter sandstone at 1800-2000 m (Gustafson et al., 1979). In the next step a full-scale geothermal district heating plant was designed for a nearby village (Andersson, 1980) but was never realized in the end.

The initial exploration projects resulted in the Lund Geothermal Heat Production plant, which has been in operation since 1985 (see further section 2.1). Low-temperature, initially 22 °C, saline water is extracted from and later injected into a sandstone aquifer located between approximately 500 m and 800 m depth (e.g. Bjelm and Alm, 2010). At the same time an HDR-project was initiated in Fjällbacka, west Sweden, and a reservoir was created at around 450 m depth (e.g., Wallroth et al., 1999).

In 2002, Lund Energi AB (today Kraftringen AB) and the Department of Engineering Geology at the Lund University started a geothermal exploration project, with the aim of finding hot water in fractured crystalline bedrock associated to the Romeleåsen Fault Zone (e.g. Rosberg and Erlström, 2019). Two wells were drilled, the first one, DGE-1, was drilled to 3702 m depth, and penetrated the sedimentary succession before entering the crystalline basement at 1946 m depth. The drilling of the second well, DGE-2 was stopped at 1927 m depth after penetrating the sedimentary succession. Around that time Sydkraft (today E.ON) drilled two wells, FFC-1, 2110 m deep, and FFC-2, 2801 m MD or 2120 m TVD, for exploring the deep seated sandstone aquifers within the Mesozoic succession in Malmö (Tengborg and Erlström, 2007). An impact structure was investigated for geothermal purposes at Björkö in lake Mälaren, west of Stockholm at the same time

(Henkel et al., 2005). None of the projects were commercialised.

In 2016, around 10 years after the projects in Lund and Malmö were terminated, the interest for EGS (Enhanced Geothermal System) applications in the crystalline basement increased. The increased interest was driven by the EGS exploration project in Espoo, Finland with the focus on the Fennoscandian bedrock (e.g. Kukkonen and Pentti, 2021; Malin et al., 2021). E.ON (a large European electric utility company) initiated a geothermal exploration project to investigate the potential for applying EGS-plants in the city of Malmö, south Sweden. In 2020, after several years of feasibility studies, a decision was made to re-enter FFC-1, the well drilled in 2002 (see above). The aim with re-entering the well was to get increased knowledge about the crystalline basement below 2100 m depth as a part of planning for a full-scale EGS-plant. The only available information about the crystalline basement in southern Sweden was from the previous mentioned deep drilling, DGE-1, in Lund, around 20 km north-east of Malmö. The objectives with deepening the FFC-1 well were to obtain information such as drilling performance using air-percussion drilling, evaluate seismic monitoring during the drilling operation, obtain information about rock types, fracture intensity and characteristic, as well as information about hydraulic, mechanical, and thermal properties.

The initial plan was to deepen the well from about 2100 m depth to 4000 m depth using air-percussion drilling. The drilling method was only used for around 90 m of drilling and was found infeasible, due to too high inflow of formation fluid. The subsequent drilling was conducted with conventional rotary drilling using a solid-free salt polymer mud and it was used to the new target depth of 3133 m. The new target depth was set after changing drilling method. The drilling operation took about two months and valuable information from the upper one kilometre of the crystalline basement was obtained from the drilling. A logging operation was conducted by Weatherford three months after the drilling was terminated. The logging operation included surveys with the Gamma Ray, Spectral Gamma Ray, Photo-Density, Compact Cross Dipole (CXD), Slim Compact Micro-imager (SCMI) including multi-arm Caliper and borehole deviation tools (Badulescu and Ciuperca, 2021). Data from the crystalline basement section acquired during and after the drilling is compiled in Rosberg and Erlström (2021), as is an overview of the drilling operation. The bottom hole temperature in FFC-1 is of 84.1 °C and the calculated mean temperature gradient is 23.5 °C/km in the upper part of the crystalline basement, down to 2610 m depth and below 2880 m the calculated mean temperature gradient is 17.4 °C/km. The zone in between seems to be thermally disturbed. The lower gradient is more like gradients measured in other deep wells located in the Fennoscandian basement, see comparison in Rosberg and Erlström (2021). The EGS exploratory project in Malmö is for now put on hold.

During the last years a feasibility study to use EGS-plants for district heating production is ongoing in Gothenburg. The project is a cooperation between the energy company Göteborg Energi and Gothenburg University. In 2021, a borehole was drilled with continuous core drilling in crystalline bedrock to 1000 m depth and in 2022 a new core drilling operation was started. The target depth for the second borehole is 1300 m and the drilling is planned to target the intersection between two fracture valleys. Temperature and acoustic televiewer loggings have been conducted in the first borehole and are planned for the second borehole as well. The bottom hole temperature in the first borehole is 23.4 °C and the calculated mean temperature gradient is 15.1 °C/km.

Unfortunately, the 3702 m deep geothermal exploration well in Lund, the previously mentioned DGE-1, is now plugged and abandoned. The other mentioned deep wells in Lund, Malmö and Gothenburg are still open and available for additional in-situ measurements and, hydraulic and mechanical testing.

2.1 The Lund geothermal plant

There is no geothermal power production in Sweden, and the only geothermal plant in Sweden that meets some of the criteria for deep geothermal is the Lund geothermal heat pump plant. It has been operating since the mid 1980's. The geothermal resource at the well site Värpinge consists of a set of very porous sandstones at 400-800 m depth. The formation belongs to the Campanian of Upper Cretaceous located at the border zone of the Danish basin known as the Sorgenfrei Tornquist zone. The sandstone aquifer is highly permeable with a transmissivity of about 3 x 10^{-3} m^2/s.

Four production wells are pumped with a flowrate of 450 l/s (1620 m^3/h) at an average temperature of 21 °C. After heat extraction the water is reinjected into five injection wells normally at a temperature of 3 °C. The medium distance between the two well groups is in order of 2.1 km. The development of production temperature is shown in Figure 3, showing how the thermal break-through from the closest injection wells (VÄ-2 and VÄ-3) affect the temperature.

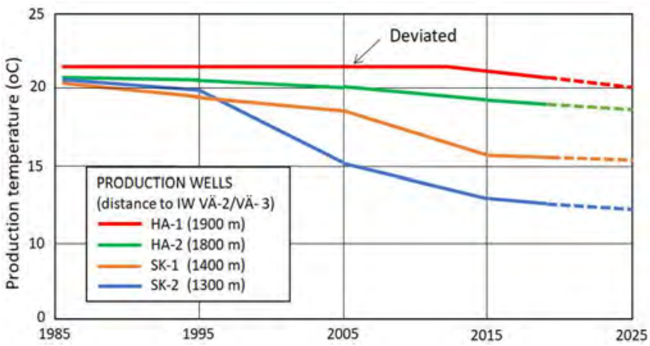


Figure 3: Production well temperatures from 1985-2019 with prognoses to 2025 (Bjelm and Andersson, 2018)

While the capacity of the production wells has been stable ever since the start, the gravel packs in the injection wells tend to clog by fine material. They have therefore been a subject to air-lift treatment at several occasions. In addition, hydro-jetting was introduced for treating the wells in 2011 and resulted in significantly improved injection capacity (Andersson and Bjelm, 2013).

The geothermal fluid is used as the heat source for two heat pumps. These heat pumps have a combined capacity of 47 MW. After 30 years run-time, the geothermal plant was evaluated by Aldenius (2017). At its peak in 1993, the plant produced 350 GWh of heat, providing 40 % of the energy in the Lund district heating network. Between 2015 and 2020 the heat production was between 100 and 140 GWh/year and in 2021 the production was 68 GWh. The decrease in production is mainly due to an increased amount of waste heat and co-generation heat production in other parts of the district heating system and is therefore not much related to the geothermal well capacity. In December 2021 the geothermal heat pumps were shut down due to the unusually high electricity price. So far (2021) the plant has produced approximately 8 TWh of heat, replacing some 800 000 m^3 of oil.

3. SHALLOW GEOTHERMAL

The typical shallow geothermal energy systems in Sweden is a vertical groundwater-filled borehole drilled in crystalline rock, connected to a ground source heat pump (GSHP) used for extraction of heat for space heating and domestic hot water (DHW) production in a single-family house. The heat pump is typically electrically driven.

Horizontal ground loops are used for heat extraction for heating and DHW in small buildings in Sweden. As they require larger surface areas these systems are mostly found on the countryside where enough space for the loops can be found more easily than in urban areas. In Sweden these systems are used only for heat extraction.

Shallow geothermal energy systems from larger buildings in Sweden occur both as GSHP systems and underground thermal energy storage (UTES). GSHP systems for larger residential buildings often require some kind of active recharge, such as waste heat from exhaust air or solar heat. Commercial buildings typically apply boreholes or aquifers for extraction and storage of both heating and cooling (see further section 4).

Vertical boreholes in rock and groundwater wells are also used for direct-cooling only. Such systems are mostly applied in the telecom and industrial sectors, but there are rare examples of low-temperature geothermal direct-heating and -cooling applications also for residential and commercial buildings. Skanska has developed an application with boreholes for direct-cooling and pre-heating of ventilation air where no heat pumps are used. They call their system Skanska Deep Green Cooling and an example of the application is described by Skanska (2014) and by Liu and Zhang (2020). The main heating source in those applications is district heating. The housing company HSB has also developed a pre-heating concept called Geo-FTX where boreholes are used for pre-heating of ventilation air in residential buildings (Kempe and Jonsson, 2015; Kempe et al., 2021).

Figures 4 and 5 show trends in sales for GSHP units in Sweden between 2010 and 2021. Sales volumes for smaller fluid-to-fluid heat pump units (<10 kW) have decreased with three fifths between 2010 and 2021. Improved energy efficiency in buildings, competition from air-source heat pumps and an ambition to minimize the need for supplementary heating while maximizing the heat pump use, are likely explanations to this development. Sales volumes for larger GSHP units with capacity >10 kW for single-family buildings, multi-family buildings and commercial buildings have been steadily growing and have almost tripled since 2013 (Figure 5). The biggest increase is seen for heat pump sales of units with a capacity between 11-25 kW for the single-family house market, which compensates largely for the decreased sales volume of smaller heat pump units. Larger heat pump units (>100 kW) are not always reported to the Heat Pump Association. Hence, many of the larger systems are missing in the statistics.

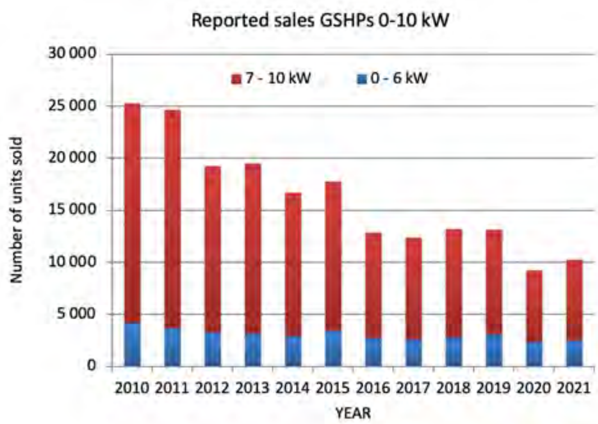


Figure 4: Reported sales of GSHPs up to 10 kW capacities in Sweden (SKVP 2022).

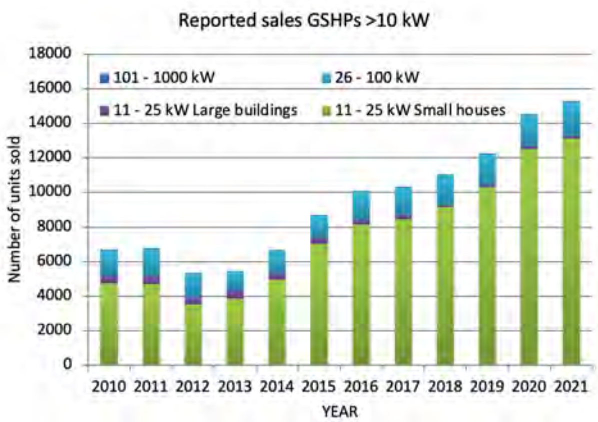


Figure 5: Reported sales of GSHPs >10 kW for large buildings in Sweden (SKVP 2022).

Figure 6 shows the amount of borehole meters drilled between 2010 and 2021. The figures for 2021 are under-estimated due to a delay in registration to the well database. The number of drilled meters per year has been relatively stable around 3.3 million meters per year.

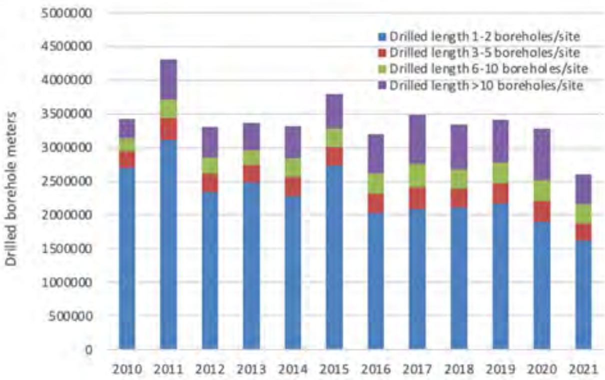


Figure 6: Reported annual number of drilled borehole meters for different system sizes. (SGU Well database 2022).

The trend with increasing borehole depth for GSHPs and BTES systems that started in the late 1990's when drill rig compressor capacity increased, as mentioned by Gehlin and Andersson (2013) and Gehlin and Andersson (2019), has continued (Figure 7). The preliminary overall average borehole depth in Sweden in 2021 was 200 m, as compared to 162 m in 2010 and 193 m in 2018, an increase with ~1-2 % per year.

The preliminary average borehole depth for the system size of one or two boreholes, i.e. single-family buildings, was 182 m in 2021, which is an increase with 24 m (15 %) since 2010, and with 4 m since 2018. For system size >10 boreholes, the average borehole depth has increased from 187 m in 2010 to 269 m in 2021, an increase with 82 m (44 %). The increase between 2018 and 2021 was 25 m (10 %).

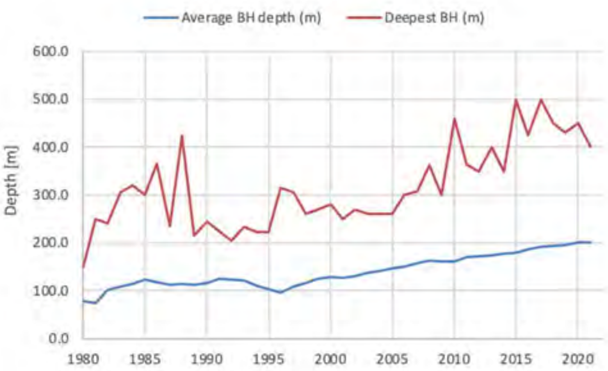


Figure 7: Average borehole depth and deepest borehole. (SGU Well database 2022).

Based on sales volumes for GSHP units reported to the Swedish Heat Pump Association around 630'000 ground source heat pumps were installed in Sweden by the end of 2021. Roughly 475'000 of these are vertical closed loop borehole systems while some 145'000 systems are estimated to be horizontal loops in soil and lake sediments. An estimate of 10'000 systems are open loop systems using groundwater or surface water as the heat source. This figure has been near constant over time with only a handful new registered systems per year. Since 2016 around 22'000 new ground source heat pump units in sizes ranging from 3 kW to 25 kW have been installed per annum. An increasing number of these heat pump units are replacement heat pumps for older heat pump units. In 2020 GSHP sales were slightly affected by the general financial decline due to the pandemic, but bounced back in 2021, even despite component shortage due to a temporary world-wide shortage of semi-conductors. The number of new installed larger GSHP units of >25 kW nominal capacity has increased from 1750 in 2018 to 2030 in 2021.

By the end of 2021 the calculated heating energy provided by GSHP systems in Sweden reached 25.5 TWh, with a total installed nominal capacity of 7.3 GW. The calculations are based on the assumption of an average heat pump running time of 3500 hours/year. In addition to this, ATES and BTES systems provide approximately 1-2 TWh direct cooling from the ground. The latter estimation is derived from an assumption that approximately 1000-2000 systems run with 1000-2000 full load hours of cooling on average. Commercial and institutional buildings often need cooling throughout the year and may reach 2 000 full-load hours. Within the residential sector the need for comfort cooling is approximately 500 full-load hours annually. A small number of ATES and BTES systems are used for cooling only and may reach 4000 full-load hours per year.

4. UNDERGROUND THERMAL ENERGY STORAGE

Underground thermal energy storage (UTES) systems that combine heating and cooling are common applications for larger buildings in Sweden, with the two commercial systems being Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES). A limited number of Cavern Thermal Energy Storage (CTES) systems, where heat or cold is stored in rock caverns, also exist in Sweden, and in recent years the interest for such applications has increased.

4.1 Aquifer thermal energy storage (ATES)

ATES systems use groundwater for carrying the thermal energy into and out of an aquifer. The wells are normally designed with a double function – both as production and injection wells. Energy is stored in the groundwater and in the grains (or rock mass) that form the aquifer. Between 10-15 % of the Swedish land area contains aquifers suitable for ATES, and approximately 25 % of the population lives in these areas (Andersson and Sellberg, 1992). The use of groundwater is strictly regulated, making the real potential for ATES systems considerably smaller.

An estimate of some 210 ATES plants with a capacity of 100 kW or more are installed in Sweden, as of 2021. This estimate is based on the number of boreholes that are classified as "energy wells" in the SGU well data base, and are not deep enough to belong to the closed system category. The larger systems (>1 MW) are fairly well known from engineering reports, articles etc.

Systems larger than 100 kW nominal capacity are estimated to represent a total of some 195 MW. These are mainly located in aquifers in eskers, sandstones and limestones (Table 1). In addition to these ATES plants, there is an estimate of approximately 320 installed groundwater-source heat pumps with an average capacity of 50 kW. Some of these may still be ATES applications, but the majority is probably used only for heat extraction within the residential sector.

Table 1: Estimated number and size distribution of ATES plants with a capacity > 100 kW

Capacity size (MW)	Number of units	Total capacity (MW)
0,1-0,49	125	40
0,5-0,99	50	40
1,0-5,0	30	75
>5,0	5	40
Sum	**210**	**195**

Typical ATES system storage temperature levels are 12-16 °C on the warm side and 4-8 °C on the cold side (Andersson, 2007).

One of the largest ATES systems in Sweden is the Stockholm Arlanda Airport ATES plant. An esker is used for seasonal storage of heat and cold. The cold is used for air conditioning of the airport buildings, while the heat is used for pre-heating of ventilation air and for snow melting at some airport gates. Cold is stored at 2-3 °C and heat at 20-25 °C. The system has been designed for a capacity of 10 MW and uses no heat pumps (Andersson, 2009). The system delivers 22 GWh of heat and cold annually (Arvidsson, 2016).

The very largest ATES plant in Sweden was designed in 1998 for short-term storage for cooling. It is connected to the district cooling system for Stockholm City, and was designed for a cooling capacity of 25 MW for peak shaving during hot summer days. Due to well problems it is working at approximately 15 MW capacity. The working temperature is +3/+14 °C and when fully charged it holds around 1000 MWh of cold (Andersson, 2007).

4.2 Borehole thermal energy storage (BTES)

Swedish BTES systems typically consist of multiple closely spaced groundwater-filled boreholes of 150-300 m depth in crystalline rock. Single or double U-pipe borehole heat exchangers (BHE) are most commonly used and the storage temperature typically ranges between +2 °C in the winter and +8 °C in the summer, though some systems with direct-cooling may reach +16 °C in the summers. BTES systems have been in use in Sweden since the 1970's and 1980's (Gehlin, 2016).

By the end of 2021 there were about 5200 GSHP and BTES systems with more than 1000 borehole meters and more than 2000 systems with 10 boreholes or more registered in the Swedish Geological Survey Well database (SGU Well database 2022).

The number of new large GSHP and BTES systems per year has been relatively stable over the past decade (Table 2 and Figure 8). Data for 2021 is incomplete due to delay in reporting to the well database. On average some 50 new systems with >20 boreholes have been registered in the well database annually since 2016. As can be seen in Figure 8 is GSHP and BTES systems with between 20 and 50 boreholes that account for the major part of these systems.

Table 2: Number of new BTES systems of various sizes reported in SGU Database *(SGU Well database 2022)*

Year	Units 1-2 holes	Units 3-5 holes	Units 6-10 holes	Units 11-19 holes	Units ≥20 holes
2000	5673	134	27	8	4
2001	7886	151	26	6	2
2002	12989	227	41	10	7
2003	14875	294	52	25	4
2004	18260	381	78	21	7
2005	18987	569	142	39	9
2006	20833	609	154	43	23
2007	14279	555	171	50	34
2008	10862	489	146	62	33
2009	13387	392	114	37	16
2010	15377	404	136	39	26
2011	17303	517	187	75	46
2012	12824	434	163	69	36
2013	13559	416	141	50	35
2014	12344	426	180	57	32
2015	14564	424	178	73	38
2016	10511	406	191	71	50
2017	10741	457	213	87	59
2018	10740	367	182	79	51
2019	10896	393	187	75	41
2020	9439	412	186	96	52
2021*	8029	336	156	58	26

** Data for 2021 is incomplete due to delay in reporting.*

The largest BTES system in Sweden is still the BTES system at the Volvo Powertrain plant in Köping, constructed in 2015-2016. The system has a total of 215 boreholes with average borehole depth of 270 m, and a total borehole length of 58'000 m (Svensk Geoenergi, 2017).

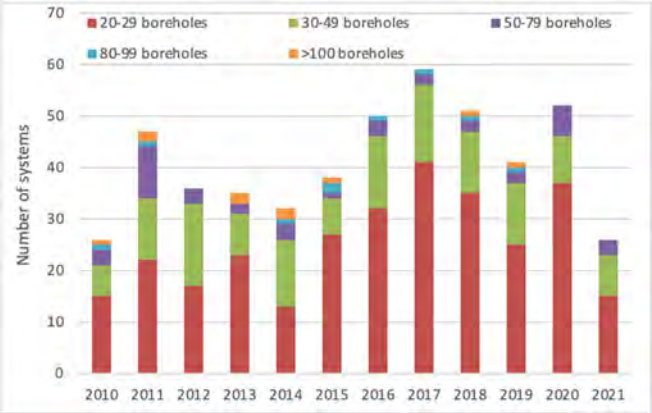


Figure 8: New large BTES systems 2010-2021 registered in the SGU Well Database. Data for 2021 is incomplete due to delay in reporting. (SGU Well database 2022).

Two high-temperature BTES systems are currently in operation in Sweden: The Anneberg residential plant and the Xylem Emmaboda HT-BTES plant. The Anneberg HT-BTES has been in use for seasonal storage of solar heat for residential heating of 50 houses since 2002. It uses no heat pumps and had a measured solar fraction of 40 % after 12 years in operation (Heier, 2013). Many of the system components (solar collectors and control system) are now reaching the end of their technical life span and in 2021 a process started in which the future of the HT-BTES will be decided. One of the considered options is to decrease the storage temperature, replace the solar collectors with PV panels and install heat pumps. A decision will be made in 2022.

The Emmaboda Xylem HT-BTES plant is used for seasonal storage of industrial waste heat, as well as for process cooling (Andersson and Rydell, 2012; Nordell et al., 2016; Andersson et al., 2021). Heat pumps were installed in 2018 and the storage temperature was decreased. The installation of heat pumps improved the system efficiency as was shown in the case study report from the IEA HPT Annex 52 project (Andersson et al., 2021). The first HT-BTES plant in Sweden, the Lulevärme project (Nordell, 1994), is no longer operating. It stored industrial waste heat from steel industry and was used for space heating of a university building in wintertime. It was an experimental plant that was operational during 1981-1989.

5. FUTURE AND TRENDS

The market for small residential building GSHPs has been relatively stable since the previous country update (Gehlin and Andersson, 2019) and the market for larger GSHPs and UTES applications is growing, despite uncertainties in material delivery, increased material cost and component shortage due to the pandemic in 2020-21 and the Ukraine war in 2022.

The on-going research program TERMO (Swedish Energy Agency, 2017) on heating and cooling technologies, run by the Swedish Energy Agency has funded and stimulated several R&D projects related to geothermal energy and thermal energy storage. The research program encourages development of geothermal and thermal storage applications combined with district heating and small to medium scale thermal networks. Several research and development projects related to geothermal energy have been initiated with funding from the TERMO program. These include studies of new high-temperature ground heat exchangers, and high-temperature underground thermal energy storage applications. One of the funded TERMO projects is the Swedish participation in the international collaboration project IEA HPT Annex 52 on long-term performance measurements of large GSHP systems. The project closed in 2021 and Sweden contributed with 14 case studies (IEA HPT Annex 52, 2022).

There has been a growing interest for EGS (Enhanced Geothermal Systems) placed in the crystalline basement over the last three years. This has been trigged by the deep drilling SP-project in Otaniemi (Espoo), Finland. In Sweden E.ON finalized a deep well in Malmö in 2020 and in 2021 exploration drilling started for an EGS project in Gothenburg (Rosberg and Erlström, 2021).

Sweden participates in two international collaboration projects related to geothermal energy. One of these projects is the IEA TCP ES Task 38 – Ground Source De-Icing and Snow Melting Systems for Infrastructure. The focus is set on geothermal systems for de-icing and snow-melting. The other project is the EU supported InterReg project CoolGeoHeat that is focused on the fifth generation (5G) district heating and cooling with integrated thermal energy storage.

6. CONCLUSIONS

Even if the pandemic has slowed down the growth to some extent, the market for GSHP and UTES systems has continued to grow. These systems are nowadays recognised as true commercial alternatives for any new, or retrofit, system for heating and cooling.

In the three latest geothermal energy utilization world overviews from World Geothermal Congress 2010-2020, Sweden has been rated number three world leading country in geothermal energy utilisation and is the leading geothermal energy market in Europe. The Swedish market is completely dominated by shallow geothermal energy, with no geothermal power production or deep geothermal energy within the definition of EGC.

Of great interest is that stakeholders are taking steps to go deeper into the Scandinavian crystalline bedrock in order to achieve higher temperatures. This effort seems to be partially linked to the development of the fifth generation of district heating and cooling.

The current energy prices in Sweden are remarkably high due to the war in Ukraine. The effect of this on the geothermal market is yet unclear. Shallow geothermal systems are dependent on moderate electricity prices for running the heat pumps. The cost of diesel also significantly affects the drilling cost, which in turn affects the willingness to invest in geothermal projects. If the current prices (April 2022) remain over a longer time this will be unfavorable for most shallow geothermal applications. Environmental benefits from geothermal still favor the future use of shallow geothermal.

REFERENCES

Aldenius, E.: Lunds Geotermisystem, en utvärdering av 30 års drift. Master's Thesis in geology. Lund University. (2017).

Andersson, O.: Geotermisk värme till fjärrvärmenät I Vellinge. Förstudie. Byggforskningsrådet (1980). Rapport R147:1980.

Andersson, O. Sellberg, B.: Swedish ATES Applications. Experiences after Ten Years of Development. *Proceedings of SAE International Engineering Conference*, San Diego, Aug. 3-7, (1992).

Andersson, O.: Aquifer Thermal Energy Storage (ATES). In Thermal energy storage for sustainable Energy Consumption, Chapter 6. *Springer*, 2007.

Andersson, O., and Bjelm, L.: Geothermal Energy Use, Country Update for Sweden. *Proceedings, European Geothermal Congress 2013*, Pisa, Italy, (2013).

Andersson, O., Rydell, L., Håkansson, N.: Case study report for the Xylem HT-BTES plant in Emmaboda, Sweden. Efficiency by using heat pumps for extraction of stored heat. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings. (2021). https://doi.org/10.23697/j2hk-4×61

Arvidsson, K.: Arlanda Energi AB. *Verbal information* from Kent Arvidsson, Nov. (2016).

Badulescu, C., Ciuperca, C. FFC-1 data interpretation report IAES Weatherford report, Internal E.ON FFC-1 project report. (2021).

Bjelm L., Persson P.-G.: Geotermisk energiutvinning i Skåne Slutrapport Etapp 4 (in Swedish), Department of Engineering Geology, Lund University report, (1981). LUTVDG, TVGL-3013, 1–52.

Bjelm L., Alm P.-G.: Reservoir Cooling After 25 Years of Heat Production in the Lund Geothermal Heat Pump Project. In: *Proceedings World Geothermal Congress*. Bali, Indonesia April 25–29, (2010).

Bjelm, L., Andersson, O.: Analyzes of well performance in the Värpinge Geothermal System. *Unpublished working material from Nov 2018.* (2018).

Climatedata.eu: Retrieved February 11, (2019), from https://www.climatedata.eu

Gehlin. S.: Chapter 11. Borehole Thermal Energy Storage. In S.J. Rees, *Advances in ground-source heat pump systems*. London: Woodhead Publishing. (2016).

Gehlin, S., Andersson, O.: Geothermal Energy Use, Country Update for Sweden. *Proceedings from European Geothermal Congress 2016*, Strasbourg, France, 19-24 September 2016. (2016).

Gehlin, S., Andersson, O.: Geothermal Energy Use, Country Update for Sweden. *Proceedings from European Geothermal Congress 2019*, Den Haag, the Netherlands, June 2019. (2019).

Gustafson, G., Andersson, O.: Uppborrning och provpumpning av Höllviksnäs-1. *Slutrapport NE-projekten 4560-061 och -061. Nämnden för Energiproduktionsforskning, Juni 1979.* (1979).

Heier, J.: Energy Efficiency through Thermal Energy Storage: Possibilities for the Swedish Building Stock. Licentiate thesis, KTH. (2013).

Henkel, H., Bäckström, A., Bergman, B., Stephansson, O., Lindström, M.: Geothermal Energy from Impact Craters? The Björkö Study, *Proceedings, World Geothermal Congress 2005*, Turkey, (2005), 5 pp.

IEA HPT Annex 52. April 2022. (2022). https://heatpumpingtechnologies.org/annex52/documents/

Kempe, P., Jonsson, R.: Nybyggt flerbostadshus med förvärmning med borrhålsvatten - HSB-FTX geoenergi utan värmepump. BeBo-utvärdering. (2015).

Kempe, P., Lindström, K., Persson, A., Karlsson, P.: Geotermisk förvärmning. Inventering, analys av mätdata vinter och sommar samt dimensioneringsråd. 2021:05. (2021).

Kukkonen, I.T., Pentti, M.: IOP Conf. Ser.: Earth Environ. Sci. 703, 012035. 17th *World Conference ACUUS 2020* Helsinki. (2021). doi:10.1088/1755-1315/703/1/012035.

Liu, H., Zhang, H.: Performance Evaluation of Ground Heating and Cooling Systems – Long-term performance measurements of two case buildings. MSc Thesis, Lund, Sweden (2020). University of Lund.

Lorenz, H., Rosberg, J.-E., Juhlin, C., Bjelm, L., Almqvist, B., Berthet, T., Conze, T., Gee, D., Klonowska, I., Pascal, C., Pedersen, K., Roberts, N., Tsang, C.-F.: *COSC-1-drilling of a subduction-related allochthon in the Palaeozoic Caledonide orogen of Scandinavia.* Sci Dril. (2015);19:1–11.

Lund, J.W., Boyd, T.L.: Direct Utilization of Geothermal Energy 2015 Worldwide Review. *Proceedings World Geothermal Congress 2015*, Melbourne, Australia (2015), 31 p.

Lund, J.W., Freestone, D.H., Boyd, T.L.: Direct Utilization of Geothermal Energy 2010 Worldwide Review. *Proceedings World Geothermal Congress 2010*, Bali, Indonesia (2010), 23 p.

Lund, J.W., Toth A.N.: Direct Utilization of Geothermal Energy 2020 Worldwide Review. *Proceedings World Geothermal Congress 2020*, Reykjavik, Iceland (2020), 39 p.

Malin, P., Saarno, T., Kwiatek, G., Kukkonen, I., Leary, P., Heikkinen, P.: Six Kilometers to Heat: Drilling, Characterizing & Stimulating the OTN-3 Well in Finland. In: *Proceedings World Geothermal Congress.* Reykjavik, Iceland. (2021).

Nordell, B.: Borehole Heat Store Design Optimization. PhD-thesis, 1994:137D. Division of Water Resources Engineering. Luleå University of Technology, Sweden. (1994)

Odén, A.: Förutsättningar för borrning av och deponering i djupa borrhål. *SKB, Rapport P-13-08. September 2013.* (2013).

Rosberg, J-E., Erlström, M.: Evaluation of deep geothermal exploration drillings in the crystalline basement of the Fennoscandian Shield Border Zone in south Sweden. Geothermal Energy 9:20. (2021). https://doi.org/10.1186/s40517-021-00203-1.

Rosberg, J-E. and Erlström, M. Evaluation of the Lund deep geothermal exploration project in the Romeleåsen Fault Zone, South Sweden: a case study. Geothermal Energy 7:10. (2019). https://doi.org/10.1186/s40517-019-0126-7.

SGU Well database: The Swedish Geological Survey Well Database, Data retrieved April, 2022. (2022).

SKVP: Annual sales figures received from the Swedish Heat Pump Association, received in January 2022. (2022).

SKANSKA: Entré Lindhagen, Sweden. Case Study 122. Skanska AB. April 2014. (2014).

Svensk Geoenergi, No. 2/2017, page 25. (2017). www.geoenergicentrum.se.

Swedish Energy Agency: Utlysning: TERMO – värme och kyla för framtidens energisystem. (Call: TERMO – heat and cold for the future energy system). Swedish Energy Agency. DNR 2017-009832. (2017).

Tengborg, P., Erlström, M.: Övergripande beskrivning av geotermiprojektet i Malmö, Dnr: 08-2133/2005, Swedish Geological Survey, (2007). p.1-36 (in Swedish).

Wallroth, T., Eliasson, T., Sundquist, U.: Hot dry rock research experiments at Fjällbacka, Sweden. Geothermics 28, (1999), 617–625.

Acknowledgements

The support from the authors' employers is gratefully acknowledged.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

There is no geothermal power production in Sweden.

Table B: Existing geothermal power plants, individual sites

There is no geothermal power production in Sweden.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

There is no present or planned deep geothermal DH plant in Sweden that meets the criteria of >25 °C.

Table D1: Existing geothermal district heating (DH) plants, individual sites

There is no existing deep existing geothermal DH plant, nor individual ones, in Sweden that meets the criteria of >25 °C

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

There are no existing large geothermal systems for heating and cooling in Sweden that meets the criteria >500 MW.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021	630’000	7’280	25’500	15’440	285	n/a
Of which networks **	n/a	n/a	n/a	n/a	n/a	n/a
Projected total by 2023	660’000	8’900	27’500			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

	Aquifer Thermal Energy Storage (ATES)			Borehole Thermal Energy Storage (BTES)		
	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold	Number	Capacity (MW_{th}) Heat / Cold	Production (GWh_{th}/yr) Heat / Cold
In operation end of 2021	210	H: 195 C: 240	H: 780 C: 660	800	H: 240 C: 280	H: 840 C: 400
New (additional) in 2021	10	H: 15 C: 17	H: 55 C: 40	50	H: 15 C: 18	H: 52 C: 27
Projected total by 2023	240	H: 225 C: 270	H: 960 C: 840	950	H: 285 C: 330	H: 1000 C: 495

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table F: Investment and Employment in geothermal energy

	in 2021		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	0	0	0	0
Geothermal direct uses	0	0	0	0
Shallow geothermal	> 3000	> 10'000	>3000	>10'000
total	> 3000	> 10'000	>3000	>10'000

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	none	none	The Swedish Energy Agency runs the research programme TERMO from which geothermal energy research may be partially funded.
Financial Incentives – Investment	none	none	New GSHP installations for private residential buildings are partly deductible from tax, as is the case for a number of other types of renovation work.
Financial Incentives – Operation/Production	none	none	none
Information activities – promotion for the public	none	none	The Swedish Geoenergy Center arranges courses, conferences/workshops, seminars, information activities, and issues the journal Svensk Geoenergi (Swedish Geoenergy).
Information activities – geological information	none	none	Open access well database administered by the Swedish geological Survey (SGU).
Education/Training – Academic	none	none	Short courses and lectures at universities
Education/Training – Vocational	none	none	Short courses in basic geothermal energy and EED training by the Swedish Geoenergy Center Two weeks education of new drillers once every year

Key for financial incentives:					
DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for Switzerland

Katharina Link[1] and Christian Minnig[2]

[1] Geothermie-Schweiz, Rebstrasse 3, CH-8500 Frauenfeld

[2] Swiss Federal Office of Energy (BFE), Pulverstrasse 13, CH-3063 Ittigen

Katharina.link@geothermie-schweiz.ch

Keywords: Switzerland, shallow geothermal, smart thermal grids, deep geothermal, EGS, geothermal heat pump systems, geothermal direct use, power production, heat storage, ATES, heat projects, power projects.

ABSTRACT

Shallow (near surface) geothermal projects are a success story in Switzerland with a wide range of applications. Beginning in the 1970s, this technology has grown enormously over the last 30 years. Switzerland is one of the leading international players in this geothermal energy technology, thanks to widespread geothermal heat pump installations and extensive know-how. Smart thermal grids, also known under the term *Anergienetze* (anergy grids), were first realised in Switzerland. These systems have now reached market maturity in Switzerland. The oldest utilisations of geothermal energy are highly popular thermal baths and natural spas. At 5.32 MW_{th} per 100 km^2, the density of installed thermal capacity per area is the highest worldwide (Lund and Toth, 2020)), dominated by GSHP installations.

To date, direct use of geothermal energy and power remain marginal – compared to the geothermal heat pump sector – 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.

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

In the field of research and development as well as pilot and demonstration projects, important work has also been carried out with the aim of developing and optimising innovative geothermal technologies. This includes the topics of subsurface exploration and development, seismic monitoring, drilling technologies and many more. The Bedretto rock laboratory of ETH Zurich offers an ideal infrastructure for carrying out national and international research projects.

In 2020, the total installed capacity of all heat pump systems was 2389.5 MW, of which 83.4 % (1993.4 MW) were installed in borehole heat exchangers, 13.9 % (331.4 MW) in groundwater systems, 1.2 % (29.6 MW) in geostructures, 0.3 % (6.3 MW) in deep aquifer systems, 0.2 % (3.9 MW) in tunnel water systems and less than 0.1 % (1.1 MW) in deep borehole heat exchangers.

The geothermal heat supply amounted to 4015.6 GWh (actual operating data) in 2020, with a geothermal and thus renewable energy part of 3006.1 GWh, dominated by geothermal heat pump systems for space heating (3823.6 GWh). Of this, about 85.1 % came from systems with borehole heat exchangers (3253.7 GWh). The remaining heat pump-based utilisation was made up by groundwater systems (482.7 GWh), geostructures (61.5 GWh), deep aquifers (17.5 GWh), tunnel water (5.9 GWh) and deep borehole heat exchangers (2.3 GWh). Direct geothermal heat use without heat pumps was applied mainly for thermal bathing (192.0 GWh) and a doublet system for district heating (4.8 GWh) in Riehen near Basel. At the Lötschberg and Gotthard base tunnels through the Alpine range a large part of the geothermal heat was used directly for fish farming.

1. INTRODUCTION

With an area of approximately 41’000 km^2, Switzerland is located in central Europe. Most of the 8.7 million inhabitants (in 2021) 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 in Switzerland. 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 2008 for geothermal power, and since 2018 for geothermal heat projects, respectively, to overcome this barrier.

2. SWISS ENERGY POLICIES

Switzerland has developed energy policies with an energy scenario for 2050 in mind (Figure 1). 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.

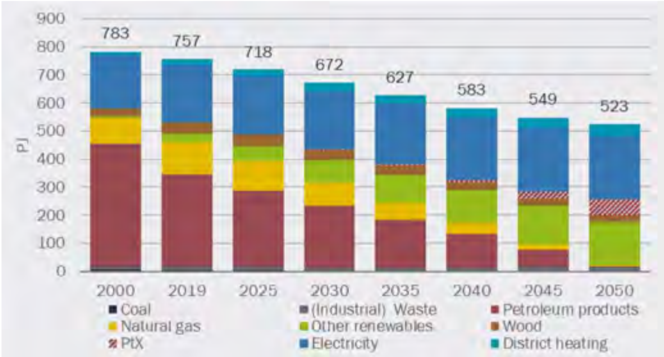


Figure 1: Final energy consumption in Switzerland: possible development from 2000 up to 2050 according to the Swiss “Energy Perspectives 2050+” (Bundesamt für Energie BFE, 2020).

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. 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 (20 % in 2020), power production from renewable energies has to grow at substantial rates. An increased deployment of renewable energy technologies is therefore a 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 about 2000 GWh$_e$ per year may be supplied by geothermal power plants

(Bundesamt für Energie BFE, 2020). In comparison, the current annual energy consumption in Switzerland is about 58’100 GWh_e (2021). Unlocking the potential of geothermal energy for power will also unlock vast amounts of geothermal heat for direct (and other) uses.

In addition to geothermal electricity production, direct geothermal heat supply has also come into focus in recent years. Today, about 40 % of the Swiss Energy consumption is used for heating. In 2021, only about 27 % of the heating energy was provided by renewable sources, the rest was provided by fossil energy sources. The potential for CO_2 reductions in the heating sector is therefore enormous. Consequently, the Swiss Federal Office of Energy is currently working on a national heating strategy to complement the electricity-focused national Energy strategy. In terms of sustainability and potential savings of CO_2 and other greenhouse gases, geothermal energy is very attractive and has high growth potential in the Swiss heating (and cooling) market. The urgency of developing local renewable energy sources as geothermal has increased massively since the war in Ukraine and the associated uncertainties regarding gas supplies.

It is expected that combined heat-and-power plants and direct use heating projects will be utilised to develop Switzerland’s geothermal energy potential. According to Geothermie-Schweiz to (the Swiss Geothermal Association),, geothermal energy can provide 17 TWh_{th} by 2050, or around a quarter of the annual heat demand (Geothermie-Schweiz, 2020). The Swiss vision of heat and power 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. At the federal level, important steps have been taken in recent years to accelerate market development. 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. In addition, the legal framework for the use of geothermal energy from deep underground has been created or optimised in a number of cantons.

3. GEOLOGICAL BACKGROUND

Switzerland is roughly divided into the Tabular and the Folded Jura in the West and North (blue units in Figure 2), the Swiss Molasse Basin (Swiss Midland, yellow unit) and the Alpine orogen in the central and southern parts (other colours, Figure 2).

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 2) 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 3).

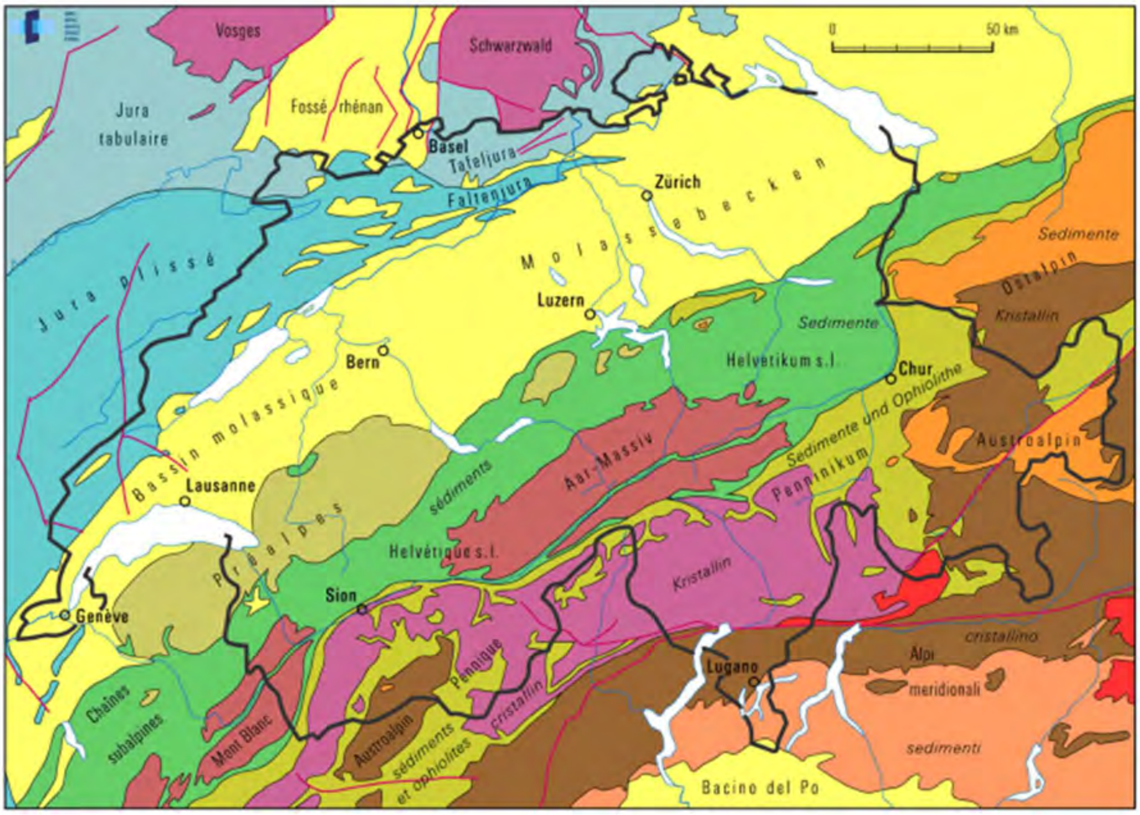


Figure 2: Geological classification of Switzerland (Source: Swiss Federal Office of Topography swisstopo).

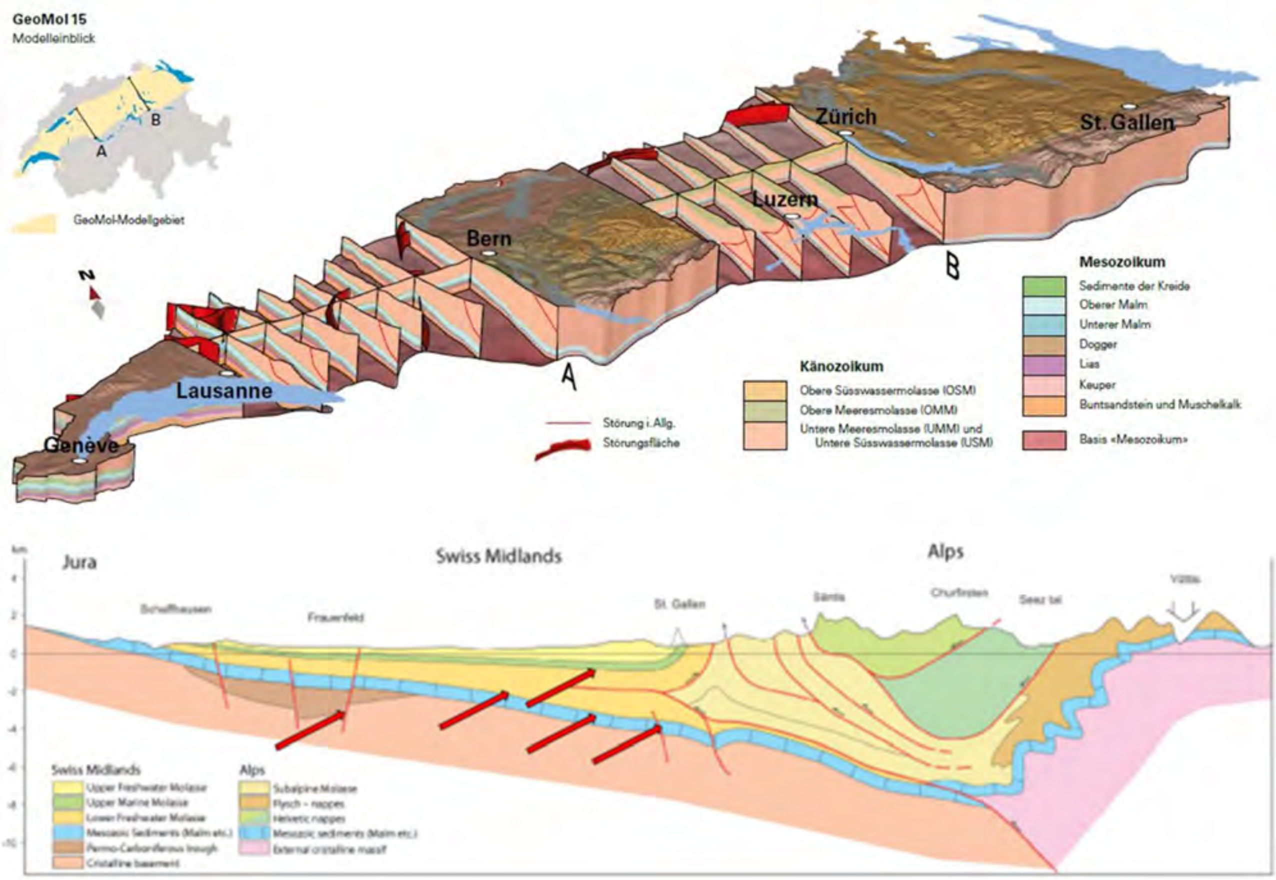


Figure 3: The Swiss Molasse basin and possible hydrothermal target horizons and/or target areas along fault zones (red arrows).

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

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 being 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 ("Oberer Malm", "Oberer Muschelkalk"), the top crystalline basement, and fault zones (Figure 3). 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, especially for power production. The local feasibility of heat and power production has to be evaluated by geophysical surveying and (possibly slim hole) exploration wells. In contrast, the potential of EGS is assumed to be large in Switzerland. 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 Swiss Federal Office of Topography swisstopo has created a 3D model of the deep underground in the Swiss Midland. This project "GeoMol CH" assessed the subsurface potentials of parts of the Swiss Molasse basin for sustainable planning and use of natural resources. "GeoMol CH" was part of the transnational project "GeoMol", covering also the Slovenian, Austrian, German, French and Italian parts of the alpine foreland basins. The GeoMol 3D Model is constantly being updated based on new data, and new local scale 3D models from third parties are being integrated after a quality assurance process. Currently swisstopo is modelling the adjacent area of the Jura mountain belt and moves towards progressing GeoMol towards a parametrised model.

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.

4. GEOTHERMAL UTILISATION

4.1 Electric power generation

No geothermal power plant has yet been built in Switzerland by 2022. However, a deep well is currently (2022) being drilled in the Rhone Valley for the AGEPP (*Alpine Geothermal Power Production*) hydrothermal project, which aims to produce electricity and heat. Work will also soon begin in Haute-Sorne (canton Jura) to create a drilling site for another power project. In this case, an EGS project is to be realised (Chap. 5).

4.2 Geothermal heat use

Different kinds of geothermal direct use applications have been realised in Switzerland (e.g., Figure 4 and Figure 5). Details regarding installed capacity, produced energy etc. are compiled and the individual figures and trends described in detail in the annually published Swiss geothermal energy statistics (e.g. Link, 2021).

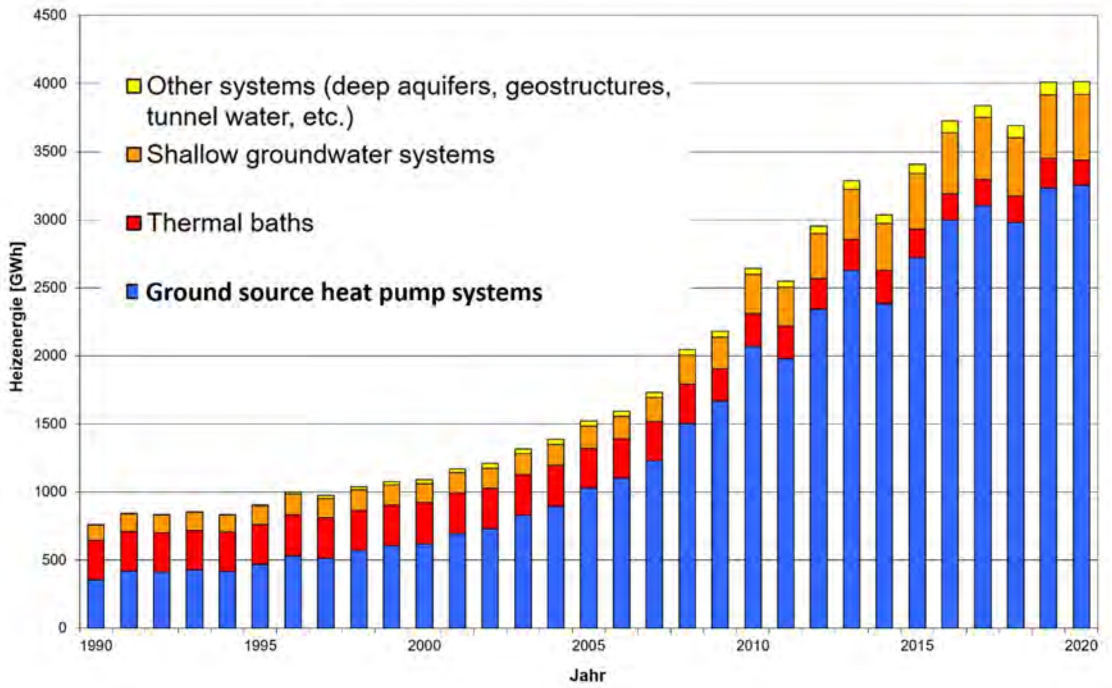


Figure 4: Annual geothermal heat production in Switzerland in GWh from 1990 to 2020 (after Link 2021). The data are based on the Swiss heat pump statistics (official sales figures) or on the reporting of the operator. The figures represent real operating data. The annual variations are due to the dependence on the heating degree days in a specific year.

The trends of the individual geothermal direct use applications show a steady increase in deployment, installed capacity and produced heat. By far, ground source heat pumps are still the most important application in Switzerland, followed by near-surface groundwater utilisations and balneology (Figure 4). Other systems including the use of deep aquifers have been of less relevance.

The decline in heat production in some years (e.g. 2011, 2014, 2018) is due to a warm winters and thus low number of heating degree days.

The total heating capacity of all geothermal systems in Switzerland in 2020 was 2389.5 MW. The total capacity of heat pump systems was 2365.7 MW (Figure 5). Of this total, 1993.4 MW (83.4 %) was attributable to ground source heat pump systems (predominantly borehole heat exchangers). Also contributing to Switzerland's geothermal heating output: Near-surface groundwater 331.4 MW (13.9 %), geostructures 29.6 MW (1.2 %), deep aquifers 6.3 MW (0.3 %), tunnel water uses 3.9 MW (0.2 %), thermal baths 22.3 MW (0.9 %), direct uses of deep aquifers 1.5 MW (0.1 %) and direct tunnel water uses (n/a). Compared to the previous year, the heating capacity in 2020 increased by 4.5 %.

The heating energy produced by geothermal systems amounted to 4015.6 GWh in 2020, with a share of geothermal and thus renewable energy of 3006.1 GWh (74.9 %). The other part of the heating energy produced represents the electricity share of the heat pump systems. The heating energy produced came mainly from heat pump systems with a share of 95.2 % (3823.6 GWh). Of this, 85.1 % was accounted for by borehole heat exchanger systems (3253.7 GWh). The other geothermal heat pump uses were divided into near-surface groundwater (12.6 %, 482.7 GWh), geostructures (1.6 %, 61.5 GWh), deep aquifer use (0.5 %, 17.5 GWh), tunnel water (0.2 %, 5.9 GWh) and deep borehole heat exchangers (0.1 %, 2.3 GWh).

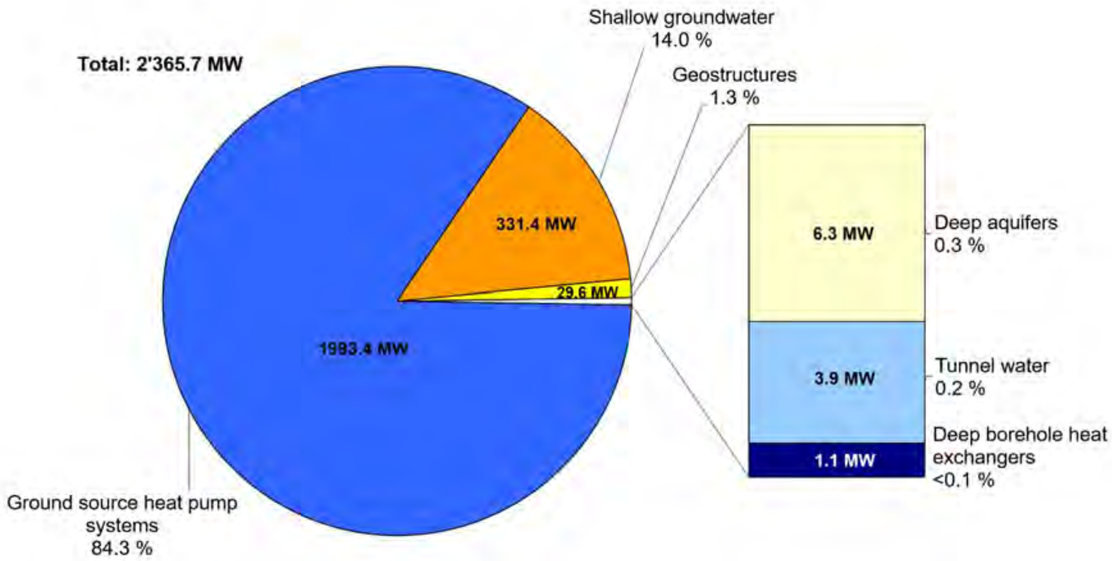


Figure 5: Installed capacity of heat pump systems in Switzerland in 2020 (after Link 2021).

With direct geothermal uses without heat pumps, a total of 192.0 GWh was produced in 2020, corresponding to 4.8 % of the total heating energy produced. Most of the direct use was via thermal baths (192.0 GWh). In addition, the Riehen system also supplied part of the deep aquifer use directly without a heat pump (4.8 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).

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. In order to maximize efficiency, after direct heat exchange to a secondary fluid, 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. In February 2022, a 3D seismic was carried out to gain more detailed knowledge about the deep underground and the potential to install a second doublet. The results of the investigations are expected to be available at the end of 2022 and a decision will be made on how the "Geo2Riehen " project will proceed.

4.2.2 Geothermal heat in agriculture and industry

The geothermal project "Grob" in Schlattingen (canton Thurgau) has been officially in operation since January 2022. As in Riehen, the plant also uses hot thermal water from the "Muschelkalk". However, the plant in Thurgau is used to heat greenhouses.

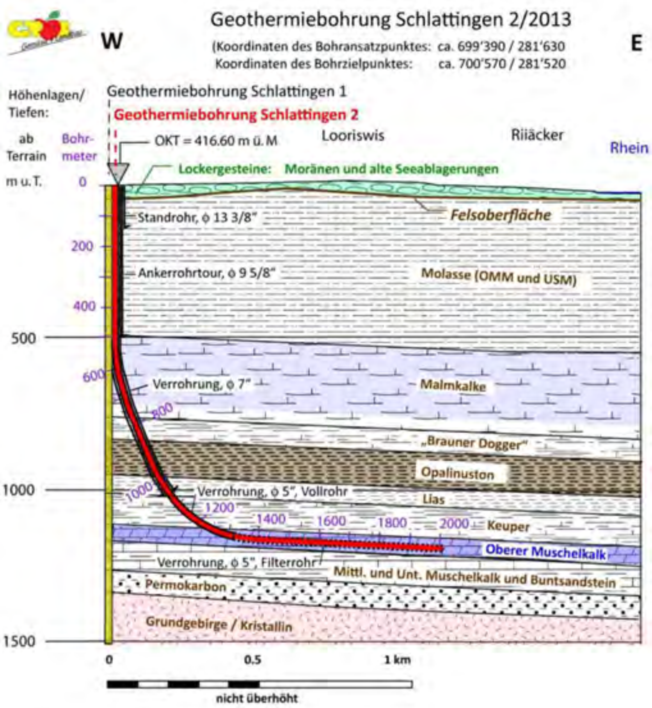


Figure 6: Geothermal project “Grob” in Schlattingen (canton Thurgau; source: Grob Gemüse).

One of the two boreholes drilled has a nearly 800 m long and almost horizontal section within the approx. 1.2 km deep aquifer. Both boreholes, the vertical one and the second deviated one, are designed as production wells. According to the concession, the plant operator is allowed to use 900 litres per minute of the thermal water, which has a temperature of around 65 °C. After heat extraction, the cooled water is discharged into a surface water body. The strict guidelines of Swiss water protection are adhered to here.

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. At 57 km, the Gotthard base tunnel is the longest railway tunnel in the world. 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 put to use in various applications: in Switzerland tunnel water is used for space heating, greenhouses, balneology, fish farming etc.

Figure 7: 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.

The potential of warm tunnel water has not yet been fully exploited in Switzerland. Extensive measurements are currently (2022) being taken at the Hauenstein tunnel in the Jura hills in order to expand thermal use in the district heating network.

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 "Anergienetze" (anergy grids) are now economically competitive and are implemented by private entities without national financial subsidies.

Numerous thermal grids with one or more borehole heat exchanger 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.

One example is the Greencity project in Zurich (Figure 8). In several stages, apartments for around 2000 people, office and commercial premises for 3000 workplaces, a hotel with 600 beds, a school for 250 children and several small shops will be built. Greencity is a certified 2000-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 borehole heat exchanger fields and the groundwater systems serve as energy sources for heating and cooling. The electricity for the heat pumps is provided partially by locally installed and proprietary photovoltaic systems.

Energie Wasser Bern (ewb) is also pursuing a very innovative project. A geo-heat storage project within 300-500 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 drilling site has been completed and drilling operations will start in October 2022.

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 and the associated risk of not finding a commercial resource.

However, the new incentive scheme introduced at the beginning of 2018 (see chapter 6.2) is having a strong impact. Nine projects have secured federal funding of cumulatively 170 Mio CHF so far. Five of them are in the prospection stage (identifying drilling targets through e.g. seismic data acquisition) and four projects are or will be using the subsidy for exploration drilling and, if successful, developing the resource. Three projects are looking for electricity grade geothermal resources and six projects are working towards direct heat utilisation. In addition to the projects that secured the subsidies already, five more projects have submitted a funding application and are being evaluated, and a handful of other projects are in the pipeline and are preparing a subsidy request. These two groups of projects also display a healthy mix of power and heating purpose, the majority is entering the prospection phase. It is expected that in the coming years a significant number of drilling projects will spawn from the strong prospection activity we are seeing today.

Below, a few running and planned projects are being highlighted.

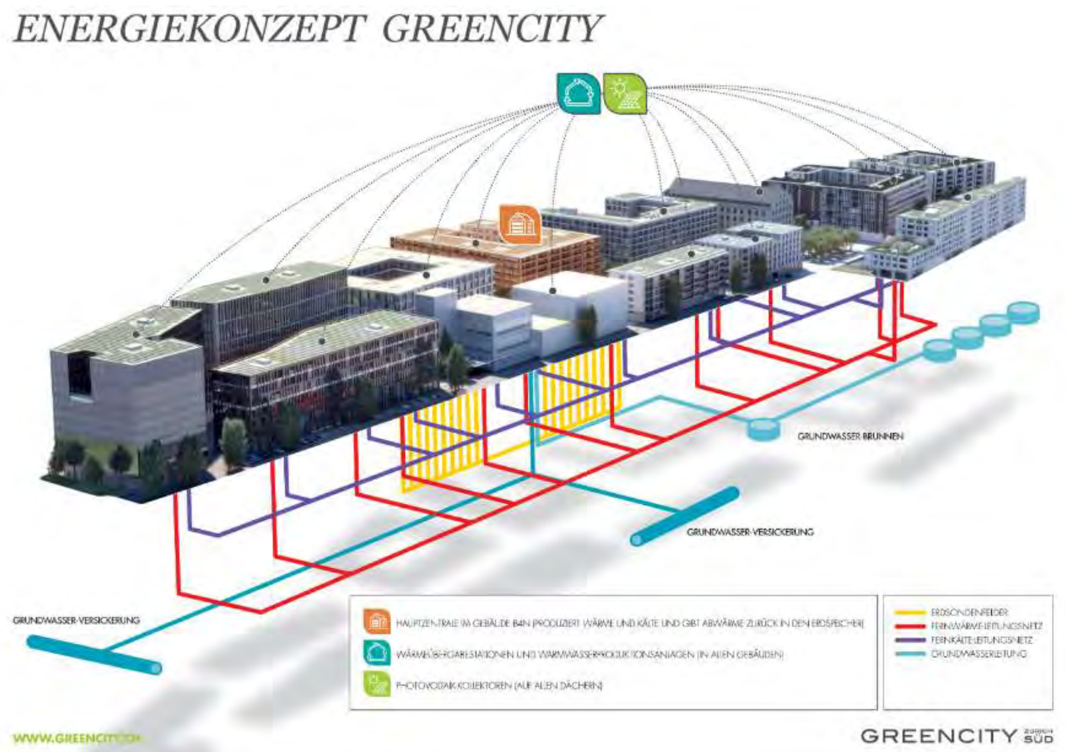


Figure 8: Energy concept for the Greencity district: 60% of the heating and cooling supply is based on borehole heat exchanger fields and 40% on thermal groundwater utilisation.

Programme GEothermies 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 resp. GEothermies. The programme aims to improve knowledge of the Geneva underground and to develop the institutional framework for the development of this energy. Led by the State of Geneva, this programme is financed and implemented by SIG. It is divided into three phases: prospecting, exploration by drilling and exploitation. The programme is currently in the phase of 3D prospecting and exploration of our underground.

Programme TEnU 2030

In the canton of Thurgau, the Geothermie Thurgau association has launched the project TEnU 2030 ("Thurgauer Energienutzung aus dem Untergrund 2030") that pursues comparable goals to the Geneva geothermal project. Here, too, underground knowledge of the entire canton is to be improved step by step through prospection and the geothermal potential is to be developed through exploratory drilling at the most suitable sites. The final decision on financial support for this project will be made in spring 2023 with a cantonal referendum.

Geo2Riehen Project

In the City of Riehen, the largest geothermal 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. A cross-border 3D seismic campaign (Figure 9) was carried out in early 2022 to evaluate the possibilities and potentials of a second doublet.

Figure 9: Prospection Area for the geo2riehen 3D seismic campaign (Source: www.erdwaermeriehen.ch).

EnergeÔ La Côte / Vinzel Project

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. At a later stage, additional aquifers expected at depths of about 5000 m will be targeted. A first seismic campaign was executed in 2021. Of the four potential sites under investigation by EnergeÔ La Côte, the area of Gland/Vinzel has been targeted as the first site for an exploration well (Figure 10). After the drilling work for the AGEPP project in the Rhone Valley has been completed, the drilling rig will be brought to Vinzel. The drilling site has already been built.

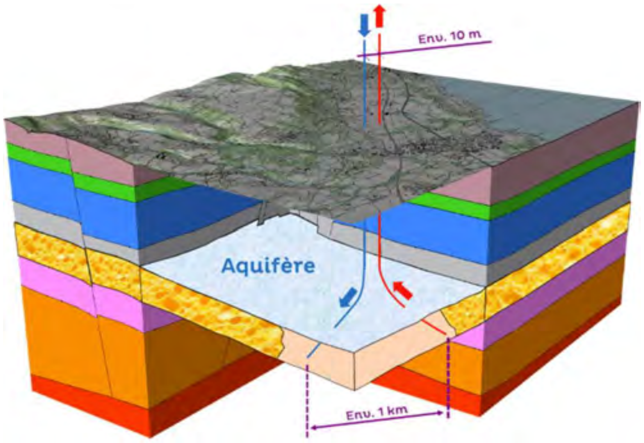


Figure 10: Planned geothermal project EnergeÔ Vinzel (source: EnergeÔ Vinzel).

Magglingen Project

The Federal Office for Buildings and Logistics FBL is planning a geothermal project to supply heat to the National Sports Centre in Magglingen (Canton Bern). For this purpose, an aquifer suspected to exist at a depth of around 1300 m is to be tapped and used. The FBL is therefore carrying out a seismic campaign for more detailed subsurface exploration (Figure 11). The results should be available in 2023. If the Federal Assembly approves the financing of the geothermal project, drilling work can probably begin in 2025.

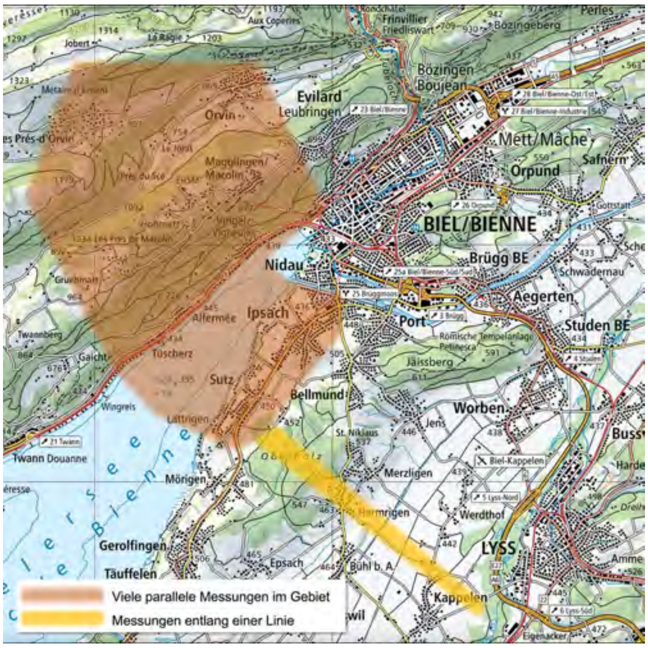


Figure 11: Area of the seismic campaign for the Magglingen project (Source: BBL).

AGEPP Project

The Alpine Geothermal Power Production (AGEPP) project (https://www.agepp.ch/) is located in the Rhône Valley (Swiss Alps) near Lavey-les-Bains, one of the best-known geothermal sites in Switzerland (Figure 12). The existence of a significant geothermal resource in the region has been known since the 19th century. The hottest springs in Switzerland, they are at the origin of the development of Lavey Spa.

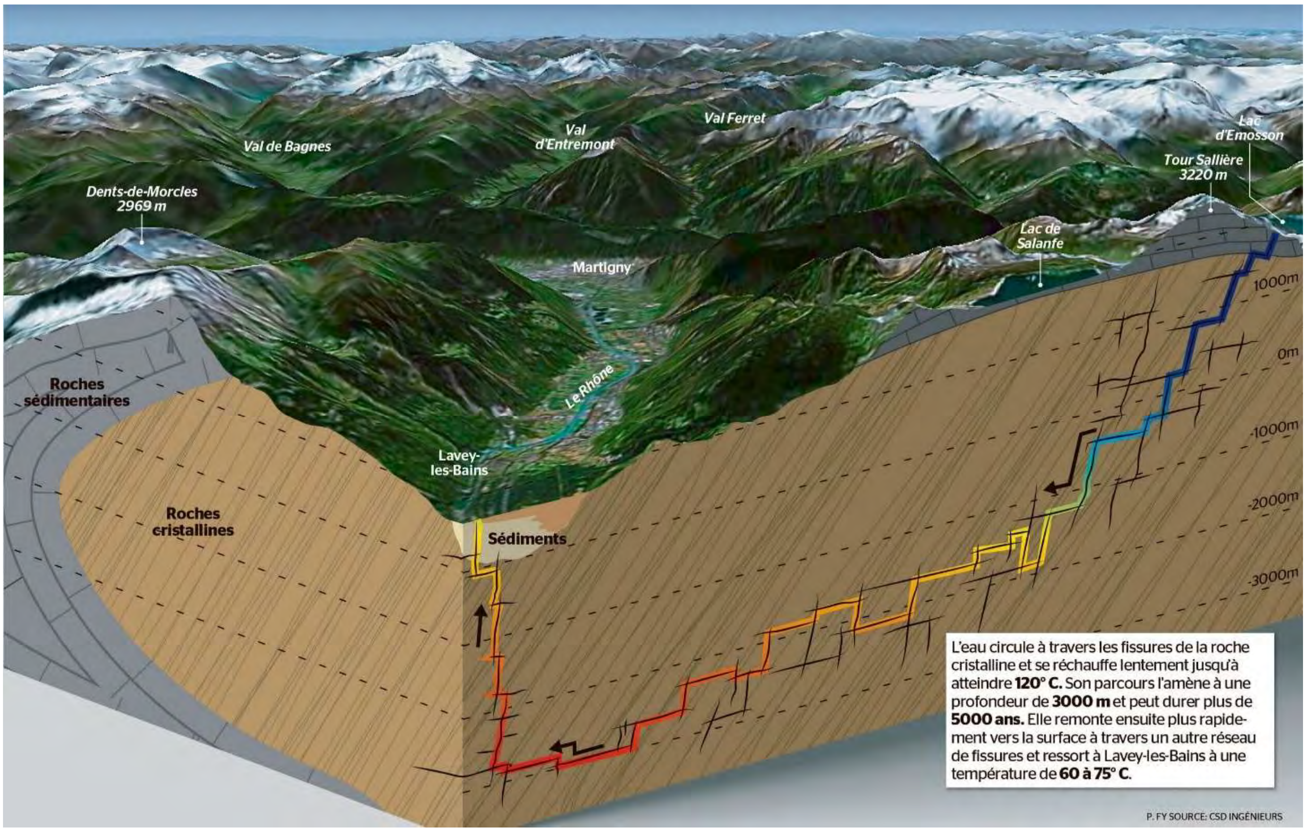


Figure 12: AGEPP project in the Western Swiss Alps (source: AGEPP SA).

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.

Drilling started in January 2022 and was completed in September 2022. First tests showed that while the temperature was as expected, the flow rate proved to be sub-commercial. Further evaluations are underway.

Irrespective of the commercial result of the project, it will provide a wealth of new subsurface data and contribute significantly to de-risking the geothermal resources of the Rhone Valley.

Gruyère Energie Project

The energy supply company "Gruyère Energie SA" is launching a campaign to explore geothermal resources at a depth of 3000-4000 m in the Gruyère region. Seismic measurements are expected to be carried out in summer 2023. The goal of the project is geothermal electricity and heat production.

Haute-Sorne Project

Geo-Energie Suisse AG pursues EGS technology to unlock the enormous potential of heat stored in solid rock for electricity and heat production. Based on lessons learnt from previous EGS projects, Geo-Energie Suisse has developed a multi-stage stimulation system where, instead of a large reservoir, a large number of smaller sections of a reservoir will be developed in sequential fashion (Figure 13). The multi-stage stimulation system can also be used to enhance the productivity of hydrothermal systems.

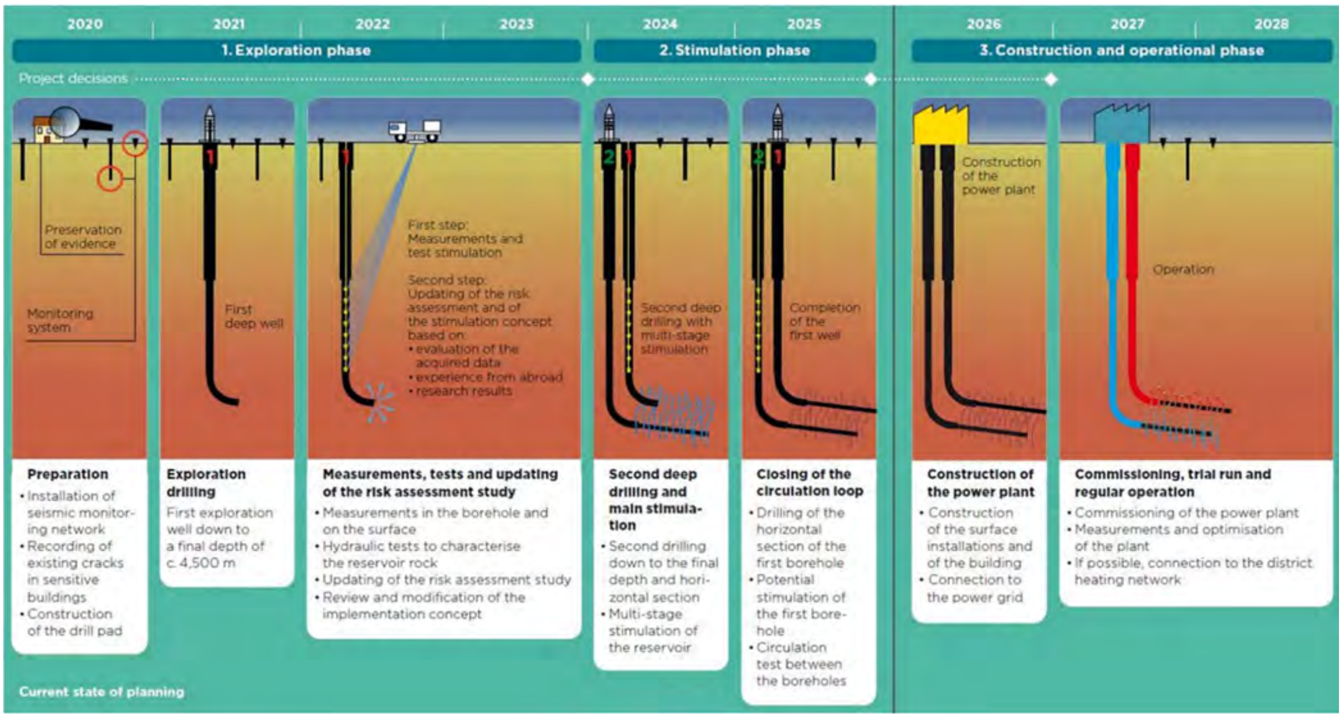


Figure 13: Haute-Sorne project: timeline of the individual project phases and overview of the technological steps to develop the reservoir (Source: Geo-Energie Suisse AG).

The Haute-Sorne EGS project (canton of Jura) is about to enter the execution phase. The Cantonal authorities have already granted approvals in June 2015. However, five neighbours opposed the decision of the Canton, took legal recourse and eventually appealed to Switzerland's highest court, the Federal Tribunal. In early 2019, the Federal Tribunal rejected the appeal and essentially gave the green light to the Haute-Sorne project. In spring 2022, the canton and Geo-Energie Suisse AG signed an agreement on comprehensive safety measures.

Other deep geothermal projects

Additional geothermal projects are being planned in Switzerland as mentioned further up. These are in the most diverse project phases and cannot all be presented here in more detail due to confidentiality reasons.

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. In addition, there are various options for obtaining financial support for carbon offset projects. These include, for example, the foundations "myclimate" or "Klik (Climate Protection and CO_2 Compensation Foundation)". Deep geothermal projects can in principle also apply for funding from these foundations.

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:
NB: 1 Swiss Franc (CHF) is about 1 US-$ or 1 €)

- 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.
- **Exploration subsidies for power projects**: Up to 60% of the cost of prospection and exploration drilling are covered by these subsidies since 2018. From 1.1.2023 on, also additional wells to fully develop the reservoir will be eligible, as it is already the case for heat projects. This risk mitigation scheme sets aside max CHF 50 million per year from the network surcharge fund. Under current legislation, the scheme runs until 31.12.2030. The parliament is discussing extending that to 31.12.2035.
- **Exploration subsidies for direct use heat projects:** Up to 60% of the cost of prospection and development (exploration and development drilling) are covered by these subsidies since 2018 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. Under current legislation, the scheme will not run out at a specific deadline.
- **Feed-in tariffs** for power production from hydrothermal and EGS plants. The feed-in tariff applies for a period of 15 years (instead of 20 years prior to 2018). The scheme will run out on 31.12.2022. From 1.1.2023 onwards, new geothermal power plants will no longer benefit from the feed-in tariff. However, from 1.1.2023 on, new geothermal power projects will be able to apply for **investment subsidies for surface installations** needed to convert geothermal energy to electric power. These investments will also be subsidised at max. 60% and - as the exploration subsidies for power projects - will run out on 31.12.2030, with the option of extension to 31.12.2035 currently discussed in parliament.
- Another recently initiated discussion in parliament is the introduction of a **moving market premium** for power production, from which also geothermal power plants could benefit. The power producer only receives financial contributions, when the electricity price on the market drops below his offered price. This measure – which is basically a re-introduction of the feed-in tariff - is in an early stage of discussion and shows the current dynamics in energy politics.

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 Swiss Federal Office of Energy also supports the cantonal authorities in developing favourable framework conditions for geothermal development. This includes establishing adequate regulatory procedures and competences. As an example serves the programme GEOBEST with which the cantonal authorities can get the support of independent experts to advice them with respect to monitoring and mitigating risks from geothermal operations, like e.g. seismic risks. GEOBEST is fully financed by the Swiss Federal Office of Energy but serves entirely the cantons.

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. The demand for shallow geothermal installations has remarkably increased following the current issues in the energy sector (gas delivery restrictions).

7.2 Deep geothermal energy

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 (chapter 6.2). Numerous projects have already been launched in the first four years (chapter 5.2). In addition to the new incentive schemes, human resources in the relevant federal offices have been increased. In recent years, a 3D model of the deep underground in the Swiss midlands has been created (see Chapter 3) and is now widely accepted by authorities and industry as a valid base for regional framework models for geothermal projects.

Some cantons have significantly improved their framework conditions for geothermal energy, like e.g. modern subsurface laws with favourable conditions for geothermal, hiring of technically skilled staff for permitting, licencing and oversight or the integration of geothermal energy in energy planning. An accelerated market development in these cantons can be seen as a result.

When the recent uptake of geothermal activity started with the new federal subsidy scheme in 2018, the market for medium-deep and deep geothermal energy was not mature in Switzerland. In the meantime, a few competent service providers and project developers have established themselves around regional hot spots of geothermal development activities. While these frontrunners are moving forward on the learning curve, they remain regional phenomenon that are not representative on a national scale.

Geothermie-Schweiz, the Swiss Geothermal Association, has defined a roadmap for establishing medium-deep and deep geothermal energy in Switzerland. The association is currently particularly active in the areas of knowledge transfer and information dissemination. Its numerous activities are in general financially supported by the Swiss Federal Office of Energy.

As a result of the numerous ongoing seismic campaigns, an increased interest in the Swiss market by seismic acquisition companies from abroad can be seen. This results in increasingly competitive bidding processes and cost reductions are expected. It is expected that with increasing market maturity, substantial further cost reductions will result – particularly needed 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 once all the ongoing and future prospection campaigns will lead to exploration drilling.

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

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.

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, had a focus on geothermal energy and particularly on technologies required to unlock Engineered Geothermal Systems. The SCCERs were set up along the lines of a public-private partnership with industry players encouraged to participate.

A highlight was research activities at the Bedretto Underground Laboratory for Geosciences and Geoenergies (Bedretto lab), an underground laboratory in the crystalline basement of the Alps. The new Bedretto Lab, inaugurated in May 2019, is located 1.5 km below surface in the middle of a 5.2 km long tunnel. The Bedretto Lab is a research infrastructure of ETH Zurich in which various groups conduct experimental research together with national and international partners. Equipped with state-of-the-art technology, the Bedretto Lab offers ideal conditions for research that deals with the behaviour of the deep underground. At the Bedretto Lab, researchers gain new scientific insights in areas such as geothermal energy, earthquake physics and the development of innovative techniques and sensors (Figures 14-15).

Switzerland is currently no fully associated member of the EU research framework program, Horizon 2020 resp. Horizon Europe. However, for some Horizon Europe research programmes, Swiss participants can apply for funding from the State Secretariat for Education, Research and Innovation (SERI).

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 lead the projects ZoDrEx and COSEISMIQ, and was a major contributor to HEATSTORE. All projects were successfully completed by the end of 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.

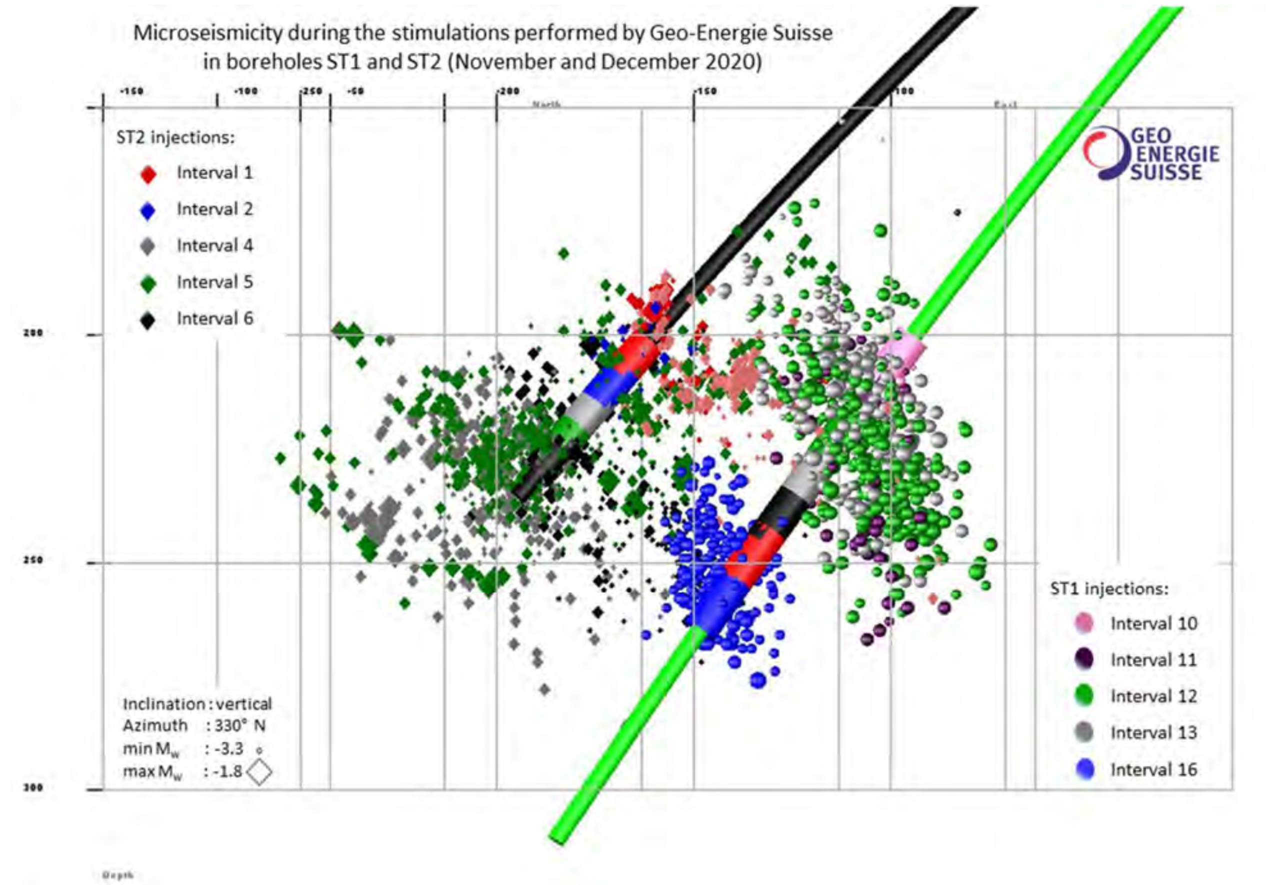


Figure 14: Microseismicity during successful stimulation in the Bedretto Lab (Source: Geo-Energie Suisse AG).

Figure 15: Construction of the new Bedretto Underground Laboratory for Geoenergies (Inauguration in May 2019).

Industry engages in geothermal development activities mostly in the areas of EGS, subsurface heat storage, and hydrothermal project development. Financial information is not available.

Geothermal research highlights are:

- The new Bedretto underground laboratory http://www.bedrettolab.ethz.ch/home/ ; (**Fehler! Verweisquelle konnte nicht gefunden werden.**)
- GEOTHERMICA ZoDrEx (Zonal Isolation, Drilling and Exploitation of EGS Projects)
- GEOTHERMICA HEATSTORE
- GEOTHERMICA COSEISMIQ
- Bedretto Reservoir Project
- VALTER Project (Validating of Technologies for Reservoir Engineering)
- MISS Project (Mitigating Induced Seismicity for Successful Geo-Resources Applications)
- FEAR Project (Fault Activation and Earthquake Rupture)
- SPINE Project (Stress Profiling in Enhanced Geothermal Systems)
- DEEP Project (Innovation for De-Risking Enhanced Geothermal Energy Projects)
- GEORISK Project (Deveoling geothermal projects by mitigating risks with financial instruments)

In addition to these projects, there were and are numerous other activities in the area of research and development.

9. 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 one of the leaders in the field of smart thermal grids. This type of application will play an increasingly important role in Switzerland. Contrary to this is the picture of medium-deep and deep geothermal energy for direct use and electricity production. Although there are some successful medium-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 financial subsidies have been granted for the exploration and development of geothermal resources including direct use heat projects. In addition, the Swiss Federal Office of Energy provides financial support to the geothermal association "Geothermie-Schweiz" for comprehensive information campaigns and knowledge transfer. These are fundamental elements for market development. The positive effects of this measures are remarkable; numerous new projects have been launched, both in the area of heat and electricity production.

REFERENCES

Baujard, C., Signorelli, S., and Kohl, T.: Atlas des ressources géothermiques de la Suisse Occidentale, Schweizerische Geophysikalische Kommission. Beiträge zur Geologie der Schweiz: Geophysik, Nr. 40. (2007).

Bundesamt für Energie BFE: Energieperspektiven 2050+ - Kurzbericht. (November 2020, updated 12th April 2022)

Hirschberg, S., Wiemer, S., and Burgherr, P. (eds.): Energy from the Earth – Deep Geothermal as a Resource for the Future?, TA-SWISS Study TA/CD 62/2015, vdf Hochschulverlag AG, 524 Seiten, ISBN 978-3-7281-3654-1 (Buch) / Download open access (TA 62/2015 e).

Link, K.: Statistik der geothermischen Nutzung in der Schweiz – Ausgabe 2020 (2021).

Link, K. and Zingg, O.: Geothermie für die Nah- und Fernwärmeversorgung – Überblick über die kantonalen und nationalen Geothermie-Potenzialstudien, Nutzungsmöglichkeiten und Anwendungsbeispiele (2017).

Lund, J. and Toth, A.: Direct Utilization of Geothermal Energy 2020 Worldwide Review, Proceedings World Geothermal Congress 2020+1, Reykjavik, Iceland, April - October 2021.

Signorelli, S., and Kohl, T.: Geothermischer Ressourcenatlas der Nordschweiz, Schweizerische Geophysikalische Kommission. Beiträge zur Geologie der Schweiz: Geophysik, Nr. 39. (2006).

Sommaruga, A., Eichenberger, U., and Marillier, F.: Seismic Atlas of the Swiss Molasse Basin, Schweizerische Geophysikalische Kommission. Beiträge zur Geologie der Schweiz: Geophysik, Nr. 44. (2012).

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *		0.0		58'100		
Under construction (test drilling) end of 2021		4.2				
Total projected by 2023		4.2				
Total expected by 2028	~ 5	25				
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

No geothermal power plants currently exist in Switzerland.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2020 *	11.7	30.1	-	-	1.1	2.3	22.3	185.3
Under constru-ction end 2021			3	26				
Total projected by 2023	11.7	30.1	3	26	1.1	2.3	24	200
Total expected by 2028	23	93	3	26	1.1	2.3	24	200

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2020 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Bassersdorf (ZH)	Bassersdorf				0.24		0.47	
Davos (GR)	Davos Arkaden				0.88		0.37	
Itingen (BL)	Itingen				0.08		0.18	
Kloten (ZH)	Kloten				0.24		0.98	
Riehen (BS)	Riehen				5.00		17.93	
Seon (AG)	Seon				1.35		2.36	
Oberwald (VS)	Furka Eisenbahntunnel				1.43		2.87	
Airolo (TI)	Gotthard Strassentunne				0.72		0.86	
Kaltbrunn (SG)	Ricken Bahntunnel				0.16		0.25	
Frutigen (BE)	Nahwärmeverbund Lötschbergbasis-tunnel, Nordportal				1.08		3.38	
Trimbach (SO)	Hauenstein Basis-Bahntunnel				0.37		0.38	
Minusio/Tenero (TI)	Mappo Morettina, Strassentunnel				0.1		0.08	
total					11.7		30.1	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2020 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2020 *	110’247	2354.5	3797.9	2738	79.8	
Of which networks **						
Projected total by 2023						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No shallow geothermal UTES plants currently exist in Switzerland.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power				
Geothermal direct uses				
Shallow geothermal				
total				

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include “jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration”. For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	DIS	DIS	DIS
Financial Incentives – Investment	DIS / RC	DIS	DIS (for replacing fossil fuel heating system; but stopped in some cantons due to economic competitiveness)
Financial Incentives – Operation/Production	FIT	-	-
Information activities – promotion for the public	Yes	Yes	Yes
Information activities – geological information	Yes	Yes	Yes
Education/Training – Academic	Yes	Yes	Yes
Education/Training – Vocational	Yes	Yes	Yes

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

European Geothermal Congress 2022
Berlin, Germany | 17-21 October 2022
www.europeangeothermalcongress.eu

EUROPEAN GEOTHERMAL CONGRESS 2022

Geothermal Energy Use, Country Update for Türkiye - 2022

Orhan Mertoglu[1], Sakir Simsek[1], Nilgun Basarir[1], Halime Paksoy[2], Aysegul Cetin[3],

[1] Turkish Geothermal Association, And Sokak 8/2, Cankaya/Ankara-TÜRKİYE

[2] Cukurova University, Chemistry Department, Balcali, Adana

[3]Energy Storage Heat Pump Committe-Turkish Society of HVAC and Sanitary Engineers (TTMD)

o.mertoglu20@gmail.com

Keywords: Türkiye, geothermal, electricity production, direct use, EGS.

ABSTRACT

The diversity in the geological structure, the recharge and discharge conditions, and the resources in the geothermal systems developed depending on the geodynamic processes are spread all over Türkiye in close relation with the young tectonism and volcanism. Volcanic activity together with fault and fracture systems are directly effective geological elements in the formation of geothermal resources in Türkiye. The geothermal research and investigations started in 1960's in Türkiye. As of April 2022, the explored geothermal fields has reached up to 460 with an discharge (surface manifestations) temperature of min. 30 °C.

The 1714 MW_e geothermal electricity production and geothermal direct use installed capacity of 5323 MW_{th} has been achieved. Total 1663 geothermal exploration licences and 1835 operation licenses belong to the private sector, local governorships and municipalities and companies. As the geothermal heat potential has been re-calculated to 107'000 MW_{th}, the technical and economical hydrothermal power potential is 9000 MW_e (72 billion kWh/year; 0-6 km; 11 US-cent/kWh and 10 years purchase guarantee) and the technical and economical EGS potential is 272'000 MW_e according to maximum 21 US-cent/kWh and 20 years purchase guarantee.

1. INTRODUCTION

Due to its complex geology and active tectonic properties, Türkiye has high geothermal (hydrothermal and EGS) potential distributed throughout the whole country with different temperature intervals. Due to the effect of extensional tectonics, the western part of Türkiye has the most abundant geothermal activity-(Figure 1).

Figure 1: Distribution of geothermal resources in Türkiye.

Up to 341 °C in Nigde province (Central Anatolia) has been measured at 3845 m depth recently. The deepest geothermal well has reached up to 4792 m at Denizli-Tekkehamam geothermal field. Faults accommodating the deep circulation of hydrothermal fluids of mostly meteoric origin are the primary means by which geothermal systems are controlled in this region. In the last 10-15 years, under the framework of energy resources diversification, the investment of geothermal energy applications rapidly increased. This can be seen especially in geothermal electricity production and geothermal greenhouse applications. Moreover, some small drying and cooling applications have been added into the geothermal utilisation range in the country. The number of the geothermal fields for different utilisation types are shown in Table 1.

Total 65 geothermal power plants are to date running in Türkiye. Some of the existing geothermal power plants in Türkiye provide exemplary investments and geothermal brine, heat supply for integrated uses. In Çanakkale-Babadere, Aydın-Ortaklar, Aydın-Germencik, Salavatlı and Denizli-Sarayköy, the geothermal fluid from the geothermal power plant is used in greenhouse heating and urban heating before reinjected back to the reservoir.

2. GEOTHERMAL APPLICATIONS IN TÜRKİYE

2.1 Current Status on Geothermal Electricity and Direct Use Applications in Türkiye

The geothermal electricity applications and the geothermal direct use applications (district city heating) started in 1986 in Türkiye. A list of geothermal district heating systems in cities is given as Table 2.

Table 1: The number of the geothermal fields for different utilisation types in Türkiye.

Utilisation type	Number	Percentage (%)
Geothermal electricity production	65	16
Geothermal Heating	151	36
Thermal Facilities, geothermal Spa, balneological use	226	48
Total*	**415**	**100**
*As in some of the fields more than one application can be realized the result can change accordingly.		

Table 2: Geothermal city heating systems in Türkiye.

City Name	Residences Equivalence (RE) heated (1 RE= 100 m^2)	Geothermal water temperature (°C)	Greenhouse heating ---------------- Thermal water supply for the spas	Distance between City and the geothermal field (km.)	Investor/Company
Balçova + Narlıdere	38500	140	+ ------------ +	3	Local Governorship and Municipality equal partnership Inc.
Gönen	3400	80	+ ------------ +	2	Mainly Municipality Inc.
Simav	18600	125	+ ------------ +	5	Municipality + Municipality Inc.
Kırşehir	1900	57	+ ------------ +	1	Mainly Governorship + Municipality Inc.
ılcahamam	2500	70	+ ---------- +	2	Mainly Municipality Inc.
Afyon	30000	95	+ ---------- +	15	Mainly Governorship + Municipality Inc.
Kozaklı	4100	90	+ ---------- +	2	Mainly Municipality Inc.
Sandıklı	30000	75	+ ---------- +	10	Mainly Municipality Inc.
Diyadin	970	70	+ ------------	5	Mainly Local Governorship Inc.
Salihli	10067	94	----------- +	6	Municipality
Sarayköy	5000	95		10	Mainly Municipality Inc. Private sector Inc. is the Investor and operator
Edremit	5500	60	+ ------------ +	4	Municipality+ Private Sector Inc.
Bigadiç	1500	96		18	Municipality
Güre	1400	98	------------ +		Gürcag Foundation +Municipality
Dikili	2000	125	+ ------------- +	10	Municipality Inc.
Bergama	850	70		8	Municipality Inc.
Sorgun	1500	80	+ ------------ +	2	Municipality
Sındırgı	4000	98	---------- +	12	Municipality + Private Sector Inc.

A geothermal pilot power plant started to run in 1974 with 0,5 MW_e capacity. The share of geothermal in electricity generation in Türkiye is between 3.2-3.6 % per year. The economic activity contribution created by geothermal to the Turkish National Economy with electricity generation, geothermal central heating, greenhouse heating, liquid carbon dioxide and dry ice production, thermal tourism and others has been calculated as approximately 91 Billion TL per year (5.3 Billion USD/year). The total (direct/indirect) employment in the sector is 240'000 people. The present geothermal application types and capacities can be seen in Table 3. In our study, the amount of CO_2 in geothermal power plants in Türkiye has decreased by 50-70 % in the last 15 years. Therefore, the use of downhole pumps, submersible pumps and pumps resistant to high temperatures has become mandatory.

Table 3: Present geothermal utilization in Türkiye

Utilization	Capacity
Geothermal District Heating (City, Residences)	158.000 Residences Equivalence (RE) (1528 MWt)
Greenhouse Heating	5293 Decare (1230 MWt) 146.600 RE
Geothermal heating of Thermal facilities, Thermal Hotels, etc.	68.000 RE (680 MWt)
Heat energy of thermal water used in Hotels, Spas and Thermal Facilits for balneological purposes	520 Thermal Facilities (1763 MWt) (23 Million People annually)
Vegetable/fruit drying	9,5 MWt
Cooling (by Abs.)	0,35 MWt
Geothermal Heat Pump (Ground Source)	112,3 MWt
Total Direct Use	**5323,15 MWt**
Total Electricity Production (Install Power)	**1714 MWe** (Aydin, Denizli, Manisa, Canakkale, Afyonkarahisar, Izmir)
Industrial liquid CO_2, Dry-Ice production	400.000 Tons/year

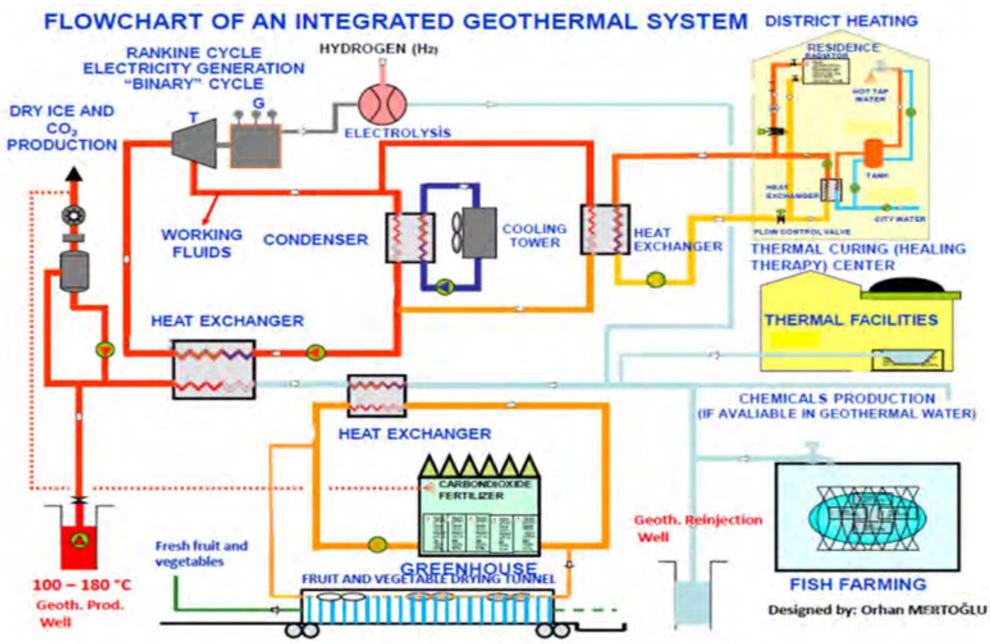


Figure 2: Flowchart of an integrated geothermal system (Mertoglu, O., 2022).

Some examples to low temperature applications in Türkiye: In Kırşehir, 1900 residences equivalence district heating has been realized with geothermal water at 57 °C since 1994. In Haymana, floor heating is applied at a mosque by using 42 °C geothermal water. Since 1992, Afyon-Oruçoglu Thermal Resort facilities have been heated by floor heating with 48 °C geothermal water. In addition, Bolu-Karacasu Thermal Facilities have been partially heated at 44 °C since 2001, Rize-Ayder Cure Center at 55 °C, Hatay-Kumlu Thermal Facilities at 3 7°C with floor heating, Sivas-Hot Çermik Thermal Springs at 46 °C and Samsun-Havza Thermal Facilities with geothermal water at 54 °C.

2.2 Current Status on Ground Source Heat Pump Applications in Türkiye

Ground source heat pump systems (GSHP) have been implemented in different types as horizontal, vertical, groundwater and sea source. Ground source systems started with horizontal applications in the early 2000's with a capacity of 586 kW. With the increasing interest in renewable energy in 2018, new applications in shopping centers, schools and public buildings were implemented. Cezeri Renewable Energy High School and Land Registry cadastre building are examples of applications in this period. The number of installed systems reached 161 in 2021 with total installed capacity of 112'321 MW_{th} (Figures 3 and 4).

In small house applications, borehole heat exchanger systems are in the first place in terms of both the number of applications and installed capacity. In office applications, although borehole heat exchangers have the highest number, they have the lowest capacity; groundwater-based applications, on the other hand, have the highest installed capacity despite their low number. In shopping mall applications, groundwater sourced systems take the first place. The number of school applications is very few and only borehole heat exchanger system is used in these systems. In hotel applications, sea source systems are in the first place in terms of both number and installed capacity (Table 4).

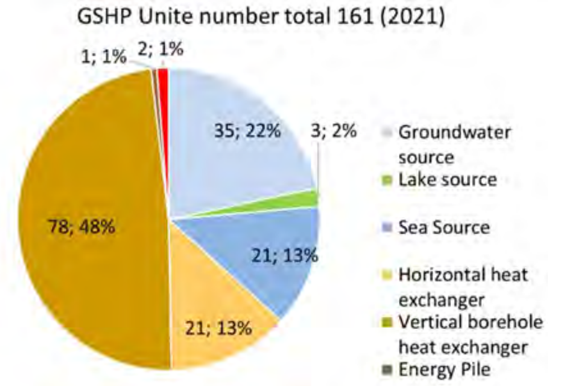


Figure 3: Distribution of GSHP types according to number of units.

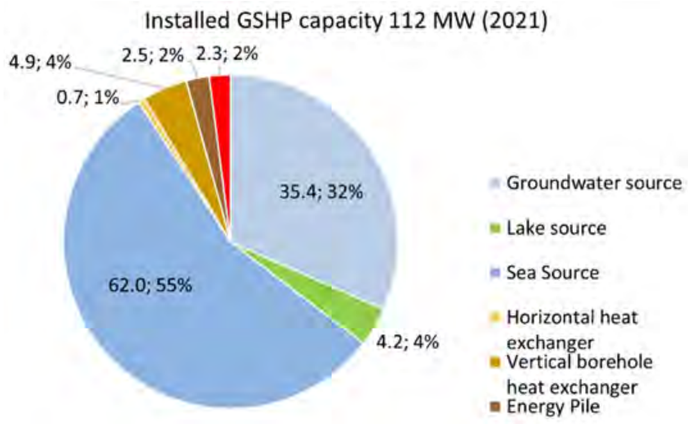


Figure 4: Distribution of GSHP types according to installed capacity of systems.

Table 4: Installed capacity of different GSHPs in different building types (Form Group et. al.)

Building Type	System Type	Unit Number	Installed Capacity (MW)	Unit Number (%)	Installed Capacity (%)
Small House	Borehole heat exchanger	57	2.24	2.57	54.28
	Horizontal	20	0.518	0.60	12.55
	Groundwater	10	1.369	1.57	33.17
	Subtotal	**87**	**4.127**	54.04	3.67
Office	Borehole heat exchanger	12	1.021	75	11.13
	Energy pile	1	2.5	6.25	27.26
	Sea	1	1.65	6.25	17.99
	Groundwater	2	4	12.5	43.62
	Subtotal	**16**	**9.171**	9.94	8.16
Shopping center	Vertical	2	1.15	25.00	4.65
	Groundwater	6	23.57	75.00	95.35
	Subtotal	**8**	**24.72**	4.97	22.01
School	Borehole heat exchanger	3	0.262	100.00	100.00
Industry	Groundwater	1	0.9	100.00	100.00
Hotel	Sea	20	60.38	43.48	82.55
	Borehole heat exchanger	4	0.409	8.70	0.56
	Lake	3	4.23	6.52	5.78
	Geothermal waste water	2	2.31	4.35	3.16
	Ground water	16	5.602	34.78	7.66
	Horizontal	1	0.21	2.17	0.29
	Subtotal	**46**	**73.141**	28.57	65.12
	TOTAL	**161**	**112.321**		

The installed capacity of applications on open systems including sea, lake, groundwater and geothermal wastewater sources is 104 MW_{th}. This corresponds to 92 % of the total capacity. Closed systems consisting of horizontal, vertical and energy pile applications have a total capacity of 8.3 MW_{th} and these constitute 7.4 % of the installed capacity (Figure 5).

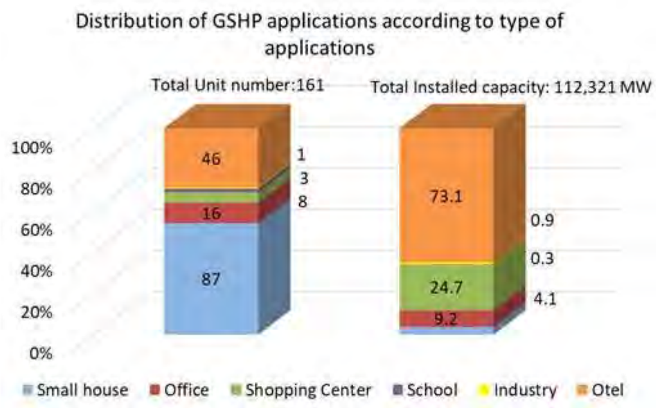


Figure 5: Distribution of GSHP applications according to type of applications.

3. SOCIAL EFFECTS

A significant part of the geothermal power plants in Türkiye became operational between 2005-2020. However, these power plants are located very near to the cities/villages and integrated use in these power plants is still low. Since there are very few integrated uses and the local people do not see directly the results of the concrete outputs of geothermal energy and smell the H_2S, there developed an opposition to geothermal both socially and environmentally in the regions where the power plants are located. Turkish Government has established rules for H_2S monitoring and measuring the emission. If necessary, H_2S abatement plant will be compulsory.

Direct use of geothermal energy through integrated use would provide a way to share the benefits of geothermal energy to improve the local economy and providing the needed services.

This situation reveals that it is important to determine the preferences of the local people for the development of geothermal energy and to shape the strategies and policies according to socio-cultural expectations.

4. INNOVATIVE APPROACHES

So far, the main usage areas of geothermal resources in Türkiye have been district heating (house heating, greenhouse, thermal facility, etc.), electricity generation, greenhouse heating and thermal health tourism. Geothermal resources are also used in chemical production (liquid carbon dioxide), dry ice, leather processing, agricultural drying, cooling and heat pump (ground source and well sourced) applications. Another important application, hybrid system for solar energy with geothermal, has started at power plant areas.

However, despite the significant potential, innovative applications have not become widespread yet. Liquid carbon dioxide production was first started in Denizli-Kızıldere field (1986) in our country and production is still continuing. The annual liquid CO_2 and dry ice production capacity of our country is 400’000 tons (Mertoglu et al., 2021). The use of geothermal CO_2 as an inhibitor in Türkiye started in the Tuzla geothermal field.

In some geothermal fields, the status of H_2S (Hydrogen Sulfide) depending on reservoir and the type and technology of the power plant gains importance in terms of the environment and the reaction of the public. H_2S level is not the same in all fields. It differs from field to field. There are techniques for the elimination of H_2S from power plants in geothermal fields. For the implementation of these techniques (which imposes an additional financial burden) the state has to give additional incentives, as in Italy.

The state strictly supervises the reinjection of the geothermal fluid.

We think that EGS/HDR projects will start in 2023 in Türkiye, depending on technological developments and incentive practices.

The risk insurance system (Risk Share Mechanism) planned by the World Bank and TKYB (Bank) was implemented and partially successful, against the geological risk (mining risk) that may arise during the drilling of deep wells that carry a great risk in geothermal exploration. Instead, an insurance system developed by insurance companies is needed. A large insurance company in Germany is working on this issue. In Türkiye, it seems beneficial for the state to direct and advise the relevant institutions regarding well risk insurance.

One of Europe's largest heat pump applications is located in Istanbul and one in Ankara. In addition, the heating and cooling of places such as shopping malls, villas, etc. in different regions of the country is done by heat pumps.

Some geothermal resources in Türkiye have high mineral content (such as lithium, boron, potassium, strontium). Studies on mineral recovery from these sources continue.

5. CURRENT GEOTHERMAL INCENTIVE SYSTEM

There is an incentive system implemented by the Ministry of Industry and Technology for geothermal investments of a certain size. Customs duty exemption, Value Added Tax (VAT) exemption, permission for credit allocation, etc. incentives are applied.

More than 15 countries in the world apply geothermal incentive (FIT-feed in description). The lowest incentive applied in the world is in Türkiye. As of July 2021, it is approximately 7.5-8.6 US-cents/kWh. 10 years purchase guarantee is applied by Ministry of Energy and EPDK (EMRA).

6. GEOTHERMAL POTENTIAL OF TÜRKIYE

a) Hydrothermal geothermal probable theoretical heat potential of Türkiye (Excluding EGS/HDR)
   - 107’000 MW_{th}

b) Total geothermal electricity potential of Türkiye (Hydrothermal resources) (0-4 km)
   - 9000 MWe (72 Billion kWh/Year) technical, economical potential (11 US-cent/kWh based on 10-year purchase guarantee)

c) Geothermal (Hydrothermal) electricity production target of Türkiye for 2030
   - 3000 MW_e (24 Billion kWh/Year), supported by the state (10.5 $cent/kWh based on 10-year purchase guarantee)

d) EGS/HDR (Enhanced Geothermal Systems/Hot Dry Rock) Electricity Generation (3-5 km);
   i) Technical Potential; Minimum 400’000 MW_e
   ii) Technical Economical Potential; 272’000 MW_e, supported by the state (up to 21 US-cent/kWh and 20 years purchase guarantee)
   iii) EGS/HDR geothermal electricity generation technical economical potential of Türkiye;
      - 40’000 MW_e (based on 14 US-cent/kWh and 15-year purchase guarantee)
      - 20’000 MW_e (based on 12 US-cents/kWh and 15-year purchase guarantee)

7. CONCLUSIONS

Since EGC2019, geothermal direct use applications have been increased by 53 % and geothermal electricity production increased by 33 %.

Today, geothermal district heating costs in heating applications in Türkiye are 60-70 % cheaper than natural gas. In other words, it is for the benefit of the people, and the natural gas to be saved should be used in electricity production and industry because our geothermal heat potential is around 107’000 MW_{th}, that is, it is large enough to potentially heat 13 million houses. Most of this geothermal potential fields are more suitable for heating as an aspect of technical and economical point of view that could result in 1 Million houses (100 m^2/house).

In order for the EGS/HDR potential to be partially put into production; The government of the Republic of Türkiye needs to make the first good example application and provide additional incentives (long-term and high feed in tariff purchase guarantee) for HDR/EGS applications.

One of Europe's largest heat pump applications is located in Istanbul and one in Ankara. In addition, the heating and cooling of places such as shopping malls, villas, etc. in different regions of the country is done by heat pumps. In the near future GSHP application will be extended.

Approximately 3.5 % of Turkey's electricity consumption was met from geothermal power plants. Therefore, geothermal resources, which are domestic, renewable and cheap, have made significant contributions to the country both in electricity generation and heating.

The risk insurance system (Risk Share Mechanism) is on line and partially successful. It was implemented by the World Bank and TKYB (Bank) and is intended to cover the geological risk (mining risk) that may arise during the drilling of deep wells that carry a great risk in geothermal exploration.

In some geothermal fields, the status of H_2S (Hydrogen Sulfide) depending on the type and technology of the power plant gains importance in terms of the environment and the reaction of the public. H_2S level is not the same in all fields. It differs from field to field. There are techniques for the elimination of H_2S from power plants in geothermal fields. For the implementation of these techniques the state has to procure additional incentives.

We expect that EGS/HDR projects will start in 2023 in Türkiye, depending on technological developments and incentive practices.

REFERENCES

TJD. Geothermal Energy Development Report., Turkish Geothermal Association (TJD).Ankara. (2022).

Mertoglu, O., Simsek, Ş., Basarir, N. Proceedings World Geothermal Congress 2020 Reykjavik, Iceland, April 26 – May 2, 2020. (2020).

Mertoglu, O., Simsek, S., Bakir, N., Dagistan, H., Gungor, N., Ozok, G., Bolat, M., Tuna, Y., Gok, H., Parlaktuna, M., Dilli, B., Karamanderesi, I., Akpınar, K., Akkus, I., Bulut, S., Durak, S. SPO (DPT) State Planning Organization, 9th Five Years (2007 – 2013) Development Programme Report on Geothermal Energy, (2006), (in Turkish).

MTA. Geothermal inventory in Turkey. MTA publication, (2005), (in Turkish).

Simsek, S. New Wide Development of Geothermal Power Production in Turkey, International Geothermal Days Slovakia 2009, Casta Papiernicka, Slovakia, (2009).

Form Group, Yesilenerji, Canovate, Toprak Enerji, Rehau, Bosch, Vaillant, Özbek Mühendislik, Üntes, Private comunications, (2022).

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	1714	11’046	98’788	3.29 x 10^5	1.7	3.36
Under construction end of 2021	50	332.11				
Total projected by 2023	1720	11’424	110’000	3.66 x 10^5	1.6	2.5
Total expected by 2030	2800	18’598				
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Denizli (Zorlu)	Kizildere	1984	1	O	F	15		
Denizli (Zorlu)	Kizildere-2	2013	3	O	B+2F	80		
Denizli (Zorlu)	Kizildere-3	2015	5+1	O	B+2F	165		
Manisa (Zorlu)	Alasehir	2015	2	O	B	45		
Manisa (Zorlu)	Alasehir -2	2019	1	O	B	18.6		
Aydin (Güris)	Galip Hoca Germencik	2009	1	O	2F	47.4		
Aydin (Güris)	Efeler	2014	6	O	B	162.6		
Aydin (Gürmat)	Efe-8	2020	2	O	B	50		
Aydin (Celikler)	Pamukören	2013	1	O	B	68		
Aydin (Celikler)	Pamukören2	2013	1	O	B	23		
Aydin (Celikler)	Pamukören3	2013	1	O	B	23		
Aydin (Celikler)	Pamukören4	2018	1	O	B	32		

Table B: Existing geothermal power plants, individual sites (continued)

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Aydin (Celikler)	Sultanhisar	2017	1	O	B	13.8		
Aydin (Celikler)	Sultanhisar2	2018	1	O	B	22.5		
Aydin (Celikler)	Pamukören5	2020	1	O	B	32		
Aydin (Kipas)	Mehmethan	2016	1	O	B	25		
Aydin (Kipas)	Deniz	2012	1	O	B	24		
Aydin (Kipas)	Ken Kipas	2015	1	O	B	24		
Aydin (Kipas)	Kerem	2014	1	O	B	24		
Aydin (Kipas)	Maren	2012	1	O	B	44		
Aydin (Kipas)	Melih	2018	1	O	B	33		
Aydin (Kipas)	Ken-3	2015	1	O	B	24.8		
Aydin (Kipas)	Nezihe :Beren	2020	1	O	B	20		
Aydin (Kipas)	Kiper Nazilli JES	2020	1	O	B	10		
Aydin (MB)	Dora-1	2006	1	O	B	7.95		
Aydin (MB)	Dora-2	2010	1	O	B	9.5		
Aydin (MB)	Dora-3	2014	1	O	B	34		
Aydin (MB)	Dora-4	2016	1	O	B	17		
Denizli (Greeneco)	Greeneco 1-2	2016	2	O	B	26		
Denizli (Greeneco)	Greeneco 3-4	2016	2	O	B	26		
Denizli (Greeneco)	Greeneco 5	2019	1	O	B	28		
Denizli (Greeneco)	Greeneco 6	2020	1	O	B	26		
Manisa (Türkerler)	Alaşehir-1	2014	1	O	B	24		
Manisa (Türkerler)	Alaşehir-2	2017	1	O	B	24		
Manisa (Türkerler)	Alaşehir-3	2018	2	O	B	30		
Aydın (Karadeniz)	Karkey Umurlu	2016	2	O	B	12		
Aydın (Karadeniz)	Karkey Umurlu-2	2018	1	O	B	12		
Manisa (Sanko)	Salihli-1	2017	1	O	B	15		
Manisa (Sanko)	Salihli-2	2019	1	N	B	24.5		
Manisa (Sanko)	Salihli-3	2019	1	O	B	30		

Table B: Existing geothermal power plants, individual sites (continued)

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Manisa (Sis)	Ozmen - 1	2017	1	O	B	23.5		
Manisa (Sis)	Ozmen - 3	2019	1	O	B	19		
Manisa (Maspo)	ALA-1	2018	1	O	B	10		
Manisa (Maspo)	ALA-2	2019	1	O	B	30		
Manisa (Soyak)	Mis-1	2018	1	O	B	12.3		
Manisa (Soyak)	Mis-3	2019	1	O	B	48		
Manisa (Enerjeo)	Kemaliye	2016	1	O	B	25		
Aydin (Cevik)	Kubilay	2016	1	N	1F	24		
Manisa (Akca)	Baklacı	2018	1	O	B	19.4		
Aydin (Turcas)	Kuyucak	2018	1	O	B	18		
Canakkale (MTN)	Babadere	2016	1	O	B	8		
Canakkale (Enda)	Tuzla	2010	1	O	B	7.5		
Denizli (Bereket)	Kizildere	2007	1	O	B	6.85		
Denizli (Akca)	Tosunlar	2015	1	O	B	3.81		
Afyonkarahisar (Afjet)	Afjet	2018	1	O	B	2.76		
Aydin (3S Kale)	3S Kale	2018	1	N	B	25		
Denizli (Jeoden)	Sarayköy	2014	1	O	B	2.52		
Aydin (Limgaz)	Buharkent	2018	1	O	B	13.8		
Aydin (BM)	Gumuskoy	2014	1	O	B	13.5		
Seferihisar (RSC Elektrik)	Seferihisar JES	2020	1	O	B	15		
Canakkale (Yerka)	JES	2020	1	O	B	10		
Canakkale (Transmark)	Ayvacik	2021	1	O	B	3.20		
Total						1714		

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
R	Retired / decommissioned	2F	Double Flash	O	Other

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	1528							
Under constru-ction end 2021								
Total projected by 2023								
Total expected by 2030	10’630	30’100	2800	7358	5000	15’330	2000	7008

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Izmir	Balcova-Narlidere	1983	N	Y	260			
Balikesir	Gonen	1987	N	N	19			
Kutahya	Simav	1991	N	N	141			
Kirsehir	Kirsehir	1994	N	N	20			
Ankara	Kizilcahamam	1995	N	N	28			
Afyonkarahisar	Afyonkarahisar	1996	Y	N	355			
Nevsehir	Kozakli	1996	N	N	45			
Afyonkarahisar	Sandikli	1998	N	N	305			
Agri	Diyadin	1999	N	N	114			
Manisa	Salihli	2002	N	N	70			
Denizli	Saraykoy	2002	N	N	43			
Balikesir	Edremit	2003	N	N	39			
Balikesir	Bigadic	2005	N	N	7			
Balikesir	Güre	2006	N	N	6			

Table D1: Existing geothermal district heating (DH) plants, individual sites (continued)

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Yozgat	Sorgun	2008	N	N	19			
Izmir	Dikili	2009	N	N	19			
Izmir	Bergama	2009	N	N	6			
Balikesir	Sindirgi	2014	N	N	32			
Total					1528			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

No information available

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	161	112	984	11	3002	6.9
Of which networks **	-	-	-			
Projected total by 2023	261	206	1834			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

No information available

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	n.a.	n.a.	n.a	n.a
Geothermal direct uses	n.a.	n.a.	n.a	n.a
Shallow geothermal	112	1288	94	800
total				

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D			
Financial Incentives – Investment			LIL (Denizbank)
Financial Incentives – Operation/Production			
Information activities – promotion for the public			Webinars
Information activities – geological information			
Education/Training – Academic			
Education/Training – Vocational			

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Country Update for United Kingdom

Corinna Abesser[1], Robin Curtis[2], Rob Raine[3], Hester Claridge [4]

[1] British Geological Survey, Maclean Building, Crowmarsh Gifford, Wallingford, OX10 8BB, UK

[2] GeoScience Ltd, Falmouth Business Park, Falmouth, Cornwall, TR11 4SZ, UK.

[3] GSNI, Dept for the Economy, Dundonald House, Upper Newtownards Road, Belfast, BT4 3SB

[4] TownRock Energy Ltd, East Woodlands House, Dyce, Aberdeen, Scotland, AB21 0HD

curtis@geoscience.co.uk

Keywords: Country update, United Kingdom, low enthalpy, direct use, GSHP, WSHP, minewater, EGS, HDR

ABSTRACT

The exploitation of medium to deep geothermal resources in the United Kingdom (UK) continues to be slow. There are no developed high temperature resources and limited development of low- and medium enthalpy resources. Currently, the main areas of exploitation are in shallow, and minewater based GSHP (Ground Source Heat Pump) and WSHP (Water Source Heat Pump) systems. In the reporting period 2019–2022, there has been a sustained resurgence of interest in all aspects of geothermal energy in the UK – particularly in the provision of decarbonised heat.

The most significant developments in deep geothermal have been the completion of the drilling phases of the United Downs Deep Geothermal Project (UDDGP), and the Eden Geothermal Project (EGP), both in Cornwall. At United Downs, the production borehole UD-1 was completed to a depth of 5.2 km MD, and injection borehole UD-2 to a depth of 2.5 km. At Eden the initial borehole has been completed to 5277 m MD – making it the longest geothermal well drilled in the UK. Both of these deep geothermal projects have encountered permeable structures at depth in radiogenic granites and have undergone a period of well testing to provide information on temperature and permeability of target zones and to enable characterisation of the geothermal resource to understand how the wells will perform and their expected outputs.

Utilisation of shallow geothermal via GSHPs has accelerated (from a low base) due to the positive impact of the domestic and non-domestic versions of the Renewable Heat Incentive (RHI) scheme in Great Britain (GB). The domestic scheme closed to new applicants in March 2022 and has been replaced by the Boiler Upgrade Scheme (BUS) which currently favours Air Source Heat Pumps (ASHPs). The non-domestic scheme closed to new applicants in March 2021. At time of writing (May 2022), there has been no announcements of new schemes to replace the non-domestic RHI. The Public Sector Decarbonisation Scheme (PSDS) remains the main funding route to install large GSHP on public buildings. A significant private minewater project has been completed in Gateshead and others are in development. Significant (multi-MW scale) Water-Source Heap Pumps (WSHPs) installations using rivers or wastewater treatment outfalls have also been commissioned. In addition to this, several deep aquifer projects, and other minewater projects, are at various stages of pre-drilling planning and investigation. Funding schemes for Decarbonisation of Public Sector buildings is also generating interest in various forms of geothermal energy to deliver low carbon heat.

The BGS has established a geothermal research site in Glasgow and is currently in the process of building a second site in Cheshire. The sites are open to the research community and industry to investigate aspects of minewater geothermal and of shallow, borehole related geothermal energy delivery, respectively.

1. INTRODUCTION

In a worldwide context, the exploitation of geothermal energy in the UK remains small. The geological and tectonic setting precludes the evolution of high enthalpy resources close to the surface and historically only low to moderate temperature fluids have been accessed by drilling in deep sedimentary basins in S England, NE England and in Northern Ireland (NI). Elevated temperature gradients and high heat flows have also been measured in and above some granitic intrusions, most notably in southwest England. These granites were previously the site of the UK Hot Dry Rock programme in Cornwall and are now where deep boreholes at the United Downs Deep Geothermal Project (UDDGP) and the Eden Geothermal Project (EDG) have confirmed the temperatures and temperature gradients at depths of ~ 5 km.

In the NE England, the drilling of the Eastgate and Newcastle boreholes that targeted the buried Weardale Granite also suggested higher than anticipated temperature gradients and hence increased focus on the possible application of geothermal heat in that region. Although not utilized after drilling, at the time of writing it is reported that the Newcastle borehole is to be resurrected by the NetZero GeoRDIE project as a research facility. A large scale thermal response test is currently out to tender for this borehole.

The comprehensive work by the British Geological Survey (reported by Downing and Gray, 1986) is still the definitive reference to the geothermal prospects of the UK. For a background to material provided here, readers are referred to earlier UK Country Updates provided for the GRC International Symposia on Geothermal Energy (Garnish, 1985; Batchelor, 1990) the IGA World Geothermal Congresses (Batchelor, 1995; Batchelor et al., 2005, 2010, 2015, 2020) and European Geothermal Congresses 2013, 2016, 2019 (Curtis et al., 2013, 2016, 2019). The most recent summary is provided in the IEA Geothermal UK Country Report (Abesser and Jans-Singh, 2022). The Renewable Energy Association and ARUP assessed the potential for UK deep geothermal resources to deliver decarbonisation. (REA, 2021), while Abesser and Walker (2022) have produced a comprehensive brief on geothermal energy for UK parliament.

2. POLICY / INSTITUTIONAL

In this reporting period, the UK has moved beyond the driver of the EU 20/20/20 RES Directive and is formulating its own renewable energy and decarbonization plans. The UK Climate Change Committee continues to provide the targets that the UK is legally obliged to meet – but until the time of writing there has been no coherent plan adopted by government to meet these targets. Events in Ukraine have now focused the UK government's mind and an energy strategy has been released (which mentions geothermal energy) to address the dual objectives of meeting CO_2 reduction targets whilst achieving national energy security.

The most significant policy driver for geothermal during this reporting period has been the final years of the RHI. Enabling legislation was passed in 2008 to allow for feed-in tariffs (FITs) for both small scale electricity generation and for renewable heat. The latter is the Renewable Heat Incentive (RHI) scheme which applies to biomass, solar thermal, and heat pump technologies. After four years of evolution and development, the RHI for domestic and non-domestic installations has been operating in this reporting period. The tariffs for biomass and borehole based GSHPs initially led to a disproportionate fraction of the non-domestic RHI being taken by biomass installations (>90%). This tariff imbalance was reviewed and addressed, resulting in a fall-off in the rate of biomass installs, and a significant increase in GSHP installs, particularly in larger installations in the non-domestic sector. During this reporting period the domestic scheme closed to new applicants in March 2022, but the non-domestic scheme has been extended by a year (for pre-registered non-domestic schemes only) to compensate for delays in completion caused by Covid-19.

To address the enormous challenge of decarbonizing heat in UK buildings a series of new policies have been announced.

The UK government's "Heat and Buildings strategy" was released in October 2021, which outlines "electrification of heat for buildings using hydronic (air-to-water or ground-to-water) heat pumps, heat networks and potentially switching the natural gas in the grid to low-carbon hydrogen" as the likely future for heating in the UK and sets a target of installing at least 600'000 hydronic heat pumps per year by 2028. (Deep) geothermal energy has been recognised in the strategy as a low-carbon source for heat networks that government "will continue to monitor … (to) assess whether the technology provides a cost-effective option to help to decarbonise heat."

A new scheme, the Boiler Upgrade Scheme (£450 million over three years), has been announced in the Government's Heat and Building Strategy for domestic and small non-domestic installations in England and Wales, starting in April 2022. The scheme offers capitals grants of £5000 for ASHPs and biomass boilers, and £6000 for GSHPs for schemes up to 45 kW, including shared ground loops for non-social housing projects. A maximum of 30'000 homes per year would be able to benefit from the scheme at the current level of funding, the same as current installation levels. Separate funding will be made available for social housing schemes.

The Electrification of Heat Demonstration Project (£14.6m) installed ca 750 innovative heat pump systems across a range of different housing types. The project will monitor these systems to demonstrate the feasibility of a large-scale roll-out of heat pumps. The system installation phase was completed in 2021, monitoring will be undertaken for two years, finishing in 2023. Early results indicate that heat pumps are suitable for all UK housing types.

A number of support schemes are available for heat networks. The Heat Network Delivery Unit (HNDU) provides support for local authorities in England and Wales for carrying out techno-economic feasibility studies and specialist consultancy work around provision of heat (including from geothermal sources) to heat networks. This fund was set up in 2013 and a total of £25.6m has been awarded to date.

In England and Wales, BEIS's Heat Network Investment Project (HNIP) invested £320m up to April 2022 to support the construction of heat networks and accelerate the growth of the market across England and Wales. Although now closed, this fund is referred to a number of times in this report as it provided the grants to the North East minewater geothermal schemes.

HNIP has been replaced by the £288m Green Heat Network Fund (GHNF) scheme in England, which started in March 2022. To assist in the transition between HNIP and GHNF, a £10 million transition scheme was launched in June 2021 (Green Heat Network Fund Transition Scheme) for networks with heat demands >2GWh/year (urban) or >100 connected dwellings (rural). These are more likely to be served by deep geothermal or mine energy sources instead of GSHPs. The Transition Scheme provided grant funding to support projects through the commercialisation phase of development so they would be ready to apply to the GHNF for construction funding when it opens.

GHNF is a capital grant fund that runs for three years from March 2022. The scheme supports all networks that meet its core eligibility criteria (which include metrics on technology carbon intensity and minimum heat demand supplied by the network) irrespective of technology. It covers commercialization and construction costs including geological surveys and exploratory investigations, Environmental Impact Assessment, contract negotiations for Energy Supply Arrangements as well as costs for accessing the heat source, low-carbon generation, primary heat network distribution and the upgrading of infrastructure in secondary distribution, respectively.

Legislation for deep geothermal development has been slow to catch up with the renewed level of interest in the sector. There is still no official licensing scheme for deep geothermal development in the UK. Geothermal power continued to be eligible to compete in the Contracts for Difference (CfD) under Pot 2 (less established technologies). CfD is a mechanism by which the government buys power from renewable technologies with 15-year contracts. They are “won” by developers of eligible technologies through a competitive auction. No geothermal projects have so far been successful.

Northern Ireland

The governance of energy in NI is almost entirely a devolved policy matter, but there are existing UK-wide agreements and legislation that influence energy policy in NI. The Department for the Economy (DfE) leads on energy policy and in December 2021 published the Northern Ireland Executive’s Energy Strategy - the Path to Net Zero Energy. The strategy and accompanying action plan set out plans to develop opportunities for heat networks and assess potential solutions to decarbonise existing heat networks. As part of this DfE will take forward heat network trials and demonstrators, using a range of energy sources including geothermal energy as outlined in Point 16 of the Energy Strategy Action Plan 2022.

To support the Energy Strategy, DfE set up a new Geothermal Advisory Committee (GAC) for Northern Ireland, chaired by the Geological Survey of Northern Ireland (GSNI). The GAC was established in July (2021) and brings together a group of experts from industry, academia, public sector and professional organisations based in UK and Ireland. This group will provide independent advice to DfE aimed at informing, supporting and developing public policy on geothermal energy for NI.

In Northern Ireland, interest in geothermal energy has seen a notable rise over the past few years. Following on from a successful international conference in December 2020 organised by GSNI and the Centre for Sustainability, Equality and Climate Action (SECA) at Queen's University Belfast (QUB), a series of monthly webinars have been organised by GSNI, QUB, Geothermal Association of Ireland (GAI) and Geological Survey Ireland (GSI) through 2021 and 2022. The GSNI produced a summary report on geothermal energy potential (Raine and Reay, 2021).

The cross-border EU PEACEPLUS Programme 2021–2027 comprises €1.1bn funding to support peace and prosperity across Northern Ireland and the border counties of Ireland, building upon the work of the previous PEACE and INTERREG Programmes. Theme 5.5 of the draft programme has EUR €20m allocated for a geothermal energy demonstration programme under Theme 5 and Investment Area 5.5 which aims to promote energy efficiency and reduce greenhouse gas emissions.

Scotland

In Scotland, several additional funding streams are available for geothermal energy technologies, including the Low Carbon Infrastructure Transition Programme (LCIPT) and the Community and Renewable Energy Scheme (CARES). Under the Scotland Act, heat policy, energy efficiency and building standards are devolved. In October 2021, Scottish Government published its “Heat in Buildings Strategy”, including a commitment to make available at least £1.8 billion for heat and energy efficiency projects across Scotland, £200 million of capital funding to support decarbonisation of social housing and £200 million to support the Scottish public sector estate to improve and reduce energy use and install zero emissions heating systems. The Heat Networks (Scotland) Act 2021 sets ambitious targets for the amount of heat to be supplied by heat networks - 2.6 Terawatt hours (TWh) by 2027 and 6 TWh by 2030. This was followed by the Heat Network Delivery Plan (published on 31 March 2022) that sets out how wider policy will contribute to increasing heat networks in Scotland.

3. GEOTHERMAL UTILISATION

3.1 Medium / Low Enthalpy Aquifer Projects

The City of Southampton Energy Scheme (Smith, 2000) still remains the only deep aquifer geothermal energy system in the UK. It is owned and operated by Cofely District Energy, now part of ENGIE. The scheme was started in the early 1980s when an aquifer in the Triassic Sandstone containing 76 °C fluid was identified at approximately 1800 m in the Wessex Basin. Construction of a district-heating scheme commenced in 1987 and this has since evolved and expanded to become a combined heat and power scheme for 3000 homes, 10 schools and numerous commercial buildings[1]. While gas fired CHP now supplies the majority of the district energy scheme's low-carbon heat, the geothermal well has saved 131’564 tonnes of CO_2 emissions since start of operation (ENGIE 2022, pers. comm). The geothermal well was taken offline in 2020 to install a new borehole pump. The well is presently not in operation due to a technical problem with another component of the district heating and cooling network unrelated to the geothermal system (ENGIE 2022, pers. comm).

The hot springs at Bath have long been a tourist attraction among the Roman architecture of the ancient city. After their extensive refurbishment they continue to be popular (http://www.thermaebathspa.com/). A recent development at Bath is that the cascaded underflow from the hot springs, as supplied to the baths, is being used to provide space heating, via heat pumps, for a new underfloor installation in the nearby Bath Abbey.

In 2018 work commenced on a geothermal borehole to supply the newly refurbished seawater lido pool at Penzance in Cornwall. The intention was that a 1700 m deep borehole would supply direct use heat to a partitioned sub-section of the larger seawater pool. In the event, there were difficulties with the drilling. The first borehole on the esplanade was abandoned at circa 100 m depth due to seawater ingress. A second hole was then attempted which reached a depth of ~400 m before encountering difficult drilling conditions. However, significant groundwater inflow was encountered at that depth at a temperature of ~25 °C. The project has been modified to be an open loop groundwater source heat pump system. The geothermal pool opened to the public in September 2020 and has proved to be a popular local attraction.

Other preliminary work on aquifer based geothermal heat schemes and deep coaxial projects was reported in the Country Update paper for the period 2013–16 (Curtis et al., 2016).

3.2 Deep Coaxial Projects

Following the demonstration of a deep coaxial heat exchanger in borehole RH15 at Rosemanowes, Cornwall in 2014 (Law et al., 2016), a number of proposals have been developed for similar projects in England and Scotland. Currently, the only active deep coaxial scheme is proposed for the Eden Geothermal Project. The first deep borehole (EG-1) is being prepared for installation of a co-axial completion, which will supply heat directly to the biomes at the adjacent Eden Project.

A review of the potential of deep coaxial technologies for accessing deep geothermal energy sources in the UK, mainly related to the potential for heat production, was presented at EGC 2019 (Watson et al., 2019).

3.3 EGS / HDR Projects

There are currently two significant EGS projects under development in the UK, both in Cornwall: the United Downs Deep Geothermal Project, and the Eden Geothermal Project.

The evolution of these projects has been reported on in earlier EGC, WGC, and IEA Geothermal UK Country update papers. Updates on both projects were reported at WGC 2020 (21), and papers will be presented at EGC 2022 (eg see Ledingham and Cotton, 2020), updated from the status at EGC 2019 (Law et al., 2019).

United Downs Deep Geothermal Power project

The United Downs Deep Geothermal Power project (UDDGPP), led by Geothermal Engineering Ltd (GEL), is the first commercial project in the UK to develop deep geothermal for power generation. The project aims to utilize the natural permeability of the Porthtowan Fault, a deep Variscan NW-SE striking, steeply dipping, strike-slip fault zone in the Carnmenellis granite in Cornwall. Drilling of two deviated wells started in November 2018 and was completed in 2019. The wells intersect the fault at two different depths in order to create a closed loop circulation system vertically along the fault. The first well, UD-1, has a drilled length of 5275 m (5057 m total vertical depth), encountering temperatures of nearly 200 °C, and is the production well (Figure 1). The second well, UD-2, has a drilled length of 2393 m (2214 m total vertical depth) and will act as the injection well.

Figure 1: HAS Innova drilling rig on Borehole UD1 at United Downs Cornwall, February 2019.

Limited hydrotesting of the wells took place in July 2021 on the basis of which a 5 MW_e gross air-cooled binary power plant has been ordered. There is a restriction on power export of ~3 MW_e due to local grid constraints. Installation of the power plant is expected to be complete in 2022. A contract for power supply has been signed with the green energy supplier Ecotricity Ltd. The project plans to supply 3 MW electricity to the grid and distribute 12 MW of heat to

[1] http://www.energiecites.org/db/southampton_140_en.pdf

a range of potential users (including a new housing estate, a tropical rum distillery and a direct lithium extraction plant). GEL has announced plans to develop four more projects in Cornwall by 2026. These four sites have been submitted for local planning approval at the time of writing.

In addition, GEL is planning a trial of a lithium extraction plant at the United Downs geothermal site, which was reported to have significant lithium concentrations (averaging around 220 mg/L) in the produced geothermal fluids. The pilot plant will use Direct Lithium Extraction (DLE) technology to recover lithium from the geothermal water.

Eden Geothermal Project

The second, deep geothermal project is at the Eden project in Cornwall. It 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 has funding of £9.9m from the European Regional Development Fund, £1.4m from Cornwall Council and £5.5m from institutional investors. The project is targeting a deep Variscan NNW-SSE striking, steeply dipping, strike-slip fault zone known as the Great Cross Course in the St Austell granite in Cornwall. Drilling of the well into the granite began in May 2021 and was completed in November 2021. The well, EG-1, has a vertical depth of 4871 m and its measured depth (actual drilled depth) is 5277 m, making it the longest geothermal well in the UK. High temperatures and early signs of potential permeability at depth have been recorded.

The initial phase of injection testing has now been completed. Further injection and production tests will be conducted at a later date following a period of further wireline logging. The results of the well testing will enable characterization of the geothermal resource to understand how the geothermal system will perform, and the expected outputs.

It is a requirement of the funding of this project that the first hole is initially used as a deep coaxial system to demonstrate its production capability. Preparations are underway to install the co-axial completion and associated pumps and pipework to deliver heat to the biomes (displacing gas fired boilers), greenhouses and other buildings at the adjacent Eden Project. The intention is to drill a second deep borehole in order to develop a doublet for ultimate power production. If this goes ahead, the coaxial installation will be decommissioned, and waste heat from the power plant will be used to supply the biomes instead.

A new assessment of the resource base for EGS systems in the UK was published in 2017 (Busby and Terrington, 2017). The GWatt project explores the potential for deep EGS systems based on fracture networks in the UK granites and was reported at WGC 2020 (Rochelle et al, 2020)

Deep Geothermal – Scotland and Northern Ireland

Deep Geothermal is still managing to elude Scotland, despite early government support (launched in 2015) for feasibility studies under the Geothermal Energy Challenge Fund as part of the Low Carbon Infrastructure Transition Programme (LCITP). Though some projects have made it to feasibility level they stalled for a variety of reasons (Townsend et al., 2020). The most advanced project yet, is planning to carry out an exploratory drilling programme starting in 2024. By identifying a heat customer and teamed with favourable geology, this project hopes to become the first deep geothermal project in Scotland, with a target to be operational by 2028. A useful pointer to geothermal activity in Scotland is provided here: Geothermal energy - Renewable and low carbon energy - gov.scot (www.gov.scot).

It is thought that the Paleoclimatic effect of the last glaciation period has resulted in heat flow being significantly underestimated in Scotland (Gosnold, 2005; Westaway and Younger, 2013), although more recently published heat flow data for Scotland (Busby et al., 2015) and resource estimates have been corrected for that effect (Busby and Terrington, 2017).

In Northern Ireland, whilst there are no commercial deep geothermal projects at the planning or feasibility stage, both the Energy Strategy Action Plan from DfE and the EU PEACEPLUS Programme make provision for progressing deep geothermal demonstration projects.

3.4 GSHP Activity

The background to GSHP activity in the UK up to 2019 and 2020 respectively is provided in earlier Country Update papers - eg for EGC 2019 (Curtis et al., 2013) and for WGC 2020 (Batchelor et al., 2020), and for IEA Geothermal (Abesser and Jans-Singh, 2022).

Along with installation activity, a number of parallel supporting activities have continued. The UK Ground Source Heat Pump Association (www.gshpa.org.uk) has held technical seminars and has continued to develop technical standards. In this reporting a new Drilling Standard for closed loop GSHPs has been developed with the MicroGeneration Certification Scheme (MCS) and the British Drilling Association[2]. All of the UK GSHPA standards are now available via the CIBSE website[3].

The GSHPA has ongoing discussions with both the BGS and the Environment Agency on regulatory issues related to open and closed loop GSHP / WSHP systems.

[2] https://mcscertified.com/wp-content/uploads/2022/02/The-MCS-Specification-for-Ground-Source-Closed-loop-Drilling-1.0.pdf

[3] https://www.cibse.org/knowledge/topic/energy,-sustainability,-climate-the-environment?knowledgesource=GSHPA.

To promote awareness of the significant carbon reduction potential of GSHPs in the UK, due to the rapid reduction in the carbon intensity of the UK electricity grid, the GSHPA supports an online app that provides real time, regionally based, CO_2 emissions for various heating systems[4]. This app has been adopted by the newly formed UK Heat Pump Federation at: https://www.hpf.org.uk/carbonwatch.

During this reporting period, the Renewable Heat Incentive (RHI) for both domestic and non-domestic heating installations (solar, biomass and heat pumps) finally began to have significant (positive) impact on the rate of GSHP installations, following a decline since 2010. A review by the government department responsible for energy (initially DECC which later became BEIS) of the relative RHI tariffs for heat pumps compared to other technologies led to revised tariffs and a subsequent acceleration in GSHP installations since spring of 2017. The RHI scheme closed to new applicants in March 2022 for domestic installations and has been extended for a further 12 months for pre-approved non-domestic installations. Taking advantage of the revised tariff, several large multi-MW open loop WSHP installations have been installed either using rivers or existing water treatment facilities.

In April 2019 the Climate Change Committee announced that they are recommending to UK Government that in 2025, all new housing will have to be fitted with low / zero carbon heating systems. At a local level, the Greater London Authority (GLA) has also recently announced revised carbon performance requirements for new and redeveloped buildings that fall within its region.

The challenge for the UK GSHP industry will be to manage the four year gap between the end of the RHI in 2022 and the requirement for low carbon domestic heating systems in 2025. The new Boiler Upgrade Scheme that has superceded the RHI provides grants for domestic heat pumps and currently favours ASHPs significantly.

The latest update (February 2022) from OFGEM on the RHI installation statistics for Domestic systems is published here:

https://www.ofgem.gov.uk/publications/domestic-renewable-heat-incentive-drhi-quarterly-report-issue-31

and for Non-Domestic systems (January 2022):

https://www.ofgem.gov.uk/publications/non-domestic-renewable-heat-incentive-rhi-quarterly-report-january-march-2022

4. MINEWATER GEOTHERMAL PROJECTS

The EGC 2016 UK Country Update reported on a significant awakening of interest in the possible use of flooded abandoned coal and metal mines in different regions of the UK, viz Scotland, England, Wales and Cornwall. A number of potential schemes were described and are not repeated here. In the interim there have been ongoing investigations. It is reported that the Coal Authority, who manage abandoned mines in the UK, are developing the heat resource from 16 existing minewater treatment schemes. In South Wales, following feasibility studies and reports, Bridgend Council have started drilling into old coal mines in the Llynfi Valley with the intention of heating a school and 70+ homes.

The UK Geoenergy Observatory (UKGEOS) in Glasgow, funded by the UK Government Plan for Growth Science & Innovation, commissioned by UKRI-NERC and run by the British Geological Survey, opened in 2021. It will enable research and innovation of minewater thermal energy across Scotland and the UK.

In June 2019 the D2GRIDS Project was launched as part of Interreg North West Europe. This will see five pilot minewater based sites initiated across Europe based on the successful minewater development at Heerlen in the Netherlands. The two sites in the UK will be in Glasgow and Nottingham.

There remain a number of technical barriers to putting the old mine workings back to work in sustainable developments to provide heating, hot water and cooling. In particular, issues of surface and subsurface ownership, licences for abstraction and discharge, the control of pollution and the potential claims of mineral owners still need resolution for any particular project.

The first large scale minewater project in the UK was commissioned in 2021 by Lanchester Wines in Gateshead. This comprises two minewater source WSHPs of 2.6 MW and 1.4 MW thermal capacity, delivering 4300 MWh/yr to two large wine warehouses. The project is described in a IEA Geothermal Case Study: https://drive.google.com/file/d/1ZpJaXjIgzKHzLzNToWDrB_J85Qou2uFb/view

TownRock Energy have taken on the operations & maintenance (O&M) and optimisation / improvements to Lanchester Wines since 2021. The opportunity is being taken to develop a minewater heat pump O&M handbook and programme, so that minewater projects have adequate technical and regulatory support through their entire lifecycle.

The IEA Geothermal TCP has launched an international minewater expert group. The group aims to build global collaborations between industry, research and regulators in the field of minewater energy (heating, cooling and storage) to encourage enhanced deployment of the technology whilst reducing some of the biggest barriers to widespread deployment – cost and risk. The group will be a voluntary, self-nominated grouping of interested people.

[4] https://planetcooler.pythonanywhere.com/static/CO2Reg0.html

The Coal Authority are currently developing the following minewater based systems:

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 MW_{th}, supporting a district heat network of 1500 new homes. The Dawdon green energy project will cost between £12 million and £15 million. It received £3.8m government support from the Heat Networks Investment Project (HNIP). It is hoped that the scheme will be a commercially viable sustainable energy demonstrator project that can be duplicated across UK coalfields.

Hebburn Minewater District Network

This development involves drilling into the former Hebburn colliery to extract heat for council owned buildings in the town. The Hebburn site, run by Dunelm Geotechnical, is currently drilling two 300-400 m deep boreholes, one abstraction well and one re-injection well, into the mine workings. Drilling was expected to complete in December 2021, with pumping tests scheduled for 2022.

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. A 6 MW water source heat pump will recover heat and distribute via the heat network to up to 1250 new private homes, a care home, Gateshead International Stadium and other Council-owned buildings. The development is being funded from a grant of £6m from the UK government's Heat Networks Investment Project (HNIP).

Minewater Geothermal projects in Scotland

There are a number of minewater projects across Scotland at various stages from feasibility to operational and maintenance. Scottish local councils have recently woken up to the heating potential beneath their feet, and are keen to see adoption of minewater heating systems for district heating networks and urban building decarbonisation. Two minewater geothermal projects with East Lothian Council, one with South Lanarkshire Council and one with the University of Strathclyde are currently in development.

TownRock Energy (TRE) completed the first commercial minewater exploratory drilling programme in Dollar, Clackmannanshire in December 2020, supported by researchers at the Universities of Glasgow and Strathclyde, and have since collected a 12 month hydrogeological dataset (Walls, 2022). The Dollar project, which aims to provide minewater heat to circa 150 new build houses, has recently obtained planning permission in principle.

5. DISTRICT HEATING NETWORKS USING GEOTHERMAL ENERGY.

District heating networks are not as common in the UK as in other European countries. However, there is an increasing recognition in the role these can play in reaching net zero targets. Consequently, government funding has been directed to these projects.

Swaffham Prior Community Heat Network

Funded with a £3.268m grant, sponsored by Cambridgeshire County Council in partnership with Swaffham Prior Community Land Trust, is intended to help a village of some 300 homes to transition from oil to low carbon heating and serve as a model for other rural communities. The network will combine ground source heat and air source heat pumps to provide heating to homes within the village. Construction will consist of drilling 130 boreholes to a depth of around 200 m to extract heat. The ground source pump will be supplemented by the air source one and both will be powered by solar panels.

Taff's Well Thermal Spring Heat Network Project

In South Wales, Rhondda Cynon Taf County Borough Council has announced the Taff's Well Thermal Spring Heat Network Project. The project plans to utilise Wales' only natural thermal spring, Taff's Well, as a source of low-carbon heat for the heating systems of the new school block and nearby pavilion. The spring emerges from the south Wales Coalfield and discharges to the river Taff at temperatures of 21-22 °C. The wider development is supported by a £1m investment from Welsh Government.

Social Housing

The use of common ground loop borehole arrays delivering to distributed heat pumps has gained significant traction in the social housing sector due to policy changes that allowed the use of deemed (non-metered) estimates of heating consumption. This unlocked a combination of RHI and other funding for these schemes and has allowed several City Councils to retrofit their apartment blocks or housing estates with these systems.

Thermal Storage

Recently the Scottish Government Low Carbon Infrastructure Transition Programme (LCITP) supported the development of the BODYHEAT Programme through a Green-Recovery from Covid-19 Pandemic. The BODYHEAT system harnesses thermal energy produced by dancers and stores it in shallow geothermal boreholes. The first pilot project is being built by TownRock Energy in SWG3 Events Venue, Glasgow.

6. MEETINGS AND PUBLICATIONS.

The level of interest in all things geothermal in the UK is reflected in recent symposia/meetings held on the subject and a number of generic papers on the subject.

In April 2022, the UK Parliamentary Office for Science and Technology (POST) published a briefing paper (POST brief) on Geothermal Energy (Abesser and Walker, 2022).

2022 Mine Water Geothermal Energy Symposium, organised by the BGS, Coal Authority and IEA Geothermal, 16-17 March 2022 (virtual): https://iea-gia.org/workshop-presentations/2022-mine-water-geothermal-energy-symposium/.
During the symposium, the new IEA Geothermal Minewater Group was announced. Anyone interested in joining can contact the group directly at: MineWaterThermal_IEA@bgs.ac.uk.

A Parliamentary Debate on Opportunities for geothermal energy extraction in the UK took place in the House of Commons on 15th September 2021. (Hinson and Sutherland, 2021)

The principal UK geothermal energy conference was the 8th London Geothermal Symposium held on 17th November 2021 at the Geological Society: https://www.geolsoc.org.uk/11-EG-Geothermal

Build Back Better: Geothermal Energy for Norther Ireland virtual conference (virtual) 11th December 2020: Conference-Agenda-Building-Back-Better-A-future-for-Geothermal-Energy-in-Northern-Ireland.pdf (qub.ac.uk)

2021 Mine Water Geothermal Energy Symposium: Mine Water Heating and Cooling – A 21st Century Resource for Decarbonisation (virtual), organised by the BGS, BEIS and IEA Geothermal, 12 -13 April 2021: https://iea-gia.org/workshop-presentations/2021-mine-water-geothermal-energy-symposium/.

The UK GSHPA continues to hold its Annual AGM and Seminar/Exhibition. The most recent one was held on 22nd October 2021 at Skipton, Yorkshire.

The UK section of WING (Women in Geothermal) has been formed and has been actively promoting a series of online webinars.

Because of the increasing interest in geothermal energy in the UK, the British Geological Survey led stakeholder consultations with industry and regulators and published a number of Briefing Papers and report on the topic (Abesser et al., 2020; Abesser, 2020; Abesser et al., 2018).

7. RESEARCH

In this reporting period there has been a significant expansion in the amount of geothermal related research activity.

7.1 Research Centres

A second research site is currently being developed by the UK Geoenergy Observatories, a £31m project funded by the 2014 UK Government Plan for Growth of Science and Innovation. The new site, UKGEOS Cheshire, will include infrastructure for research on GSHP systems and thermal storage in the Triassic Sherwood Sandstone and investigation of environmental impacts. A trial borehole has been drilled and the tender for the supply of the remaining boreholes and instrumentation has recently closed.

The first research site, UKGEOS Glasgow, is now operational and available to third party researchers. The infrastructure comprises 12 wells drilled into an abandoned mine system and 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.

7.2 Research Programmes

UK geothermal research is starting to broaden out, with an increasing number of funding calls supporting geothermal research. Overall, funding for geothermal research remains sparse with much research undertaken within / led by the Higher Education sector. A number of new projects have started in 2021.

A second call for an £14.6 NERC/EPSRC Programme to Decarbonise Heating and Cooling was issued in 2020. Eleven projects were funded under this call, including three geothermal projects:

- Geothermal Energy from Mines and Solar-geothermal heat (GEMS) (£1.4m), led by Durham University.
- Sustainable, Flexible and Efficient Ground-source heating and cooling systems (SaFEGround) (£1.5m), led by Imperial College.
- ATESHAC - Aquifer thermal energy storage for decarbonisation of heating and cooling: Overcoming technical, economic and societal barriers to UK deployment (£1.5m), led by Imperial College: https://www.imperial.ac.uk/earth-science/research/research-groups/ateshac/

The £8m UK Unconventional Hydrocarbons (UKUH) research programme (funded by NERC and ESRC) made £400K funding available to fund a series of projects that address new research themes, which have emerged as the result of the changes to the shale gas landscape in the UK. Projects that received funding included:

- Underground energy on-the-ground: risk perception, community engagement and lessons learned for geothermal energy in a post-shale energy landscape (£70K), led by Anglia Ruskin University which started in May 2021.
- Testing the limitations of empirical traffic light systems used to manage the hazard of fluid induced seismicity (£25K), led by Durham University.
- Baseline seismic monitoring survey for UKGEOS Glasgow geothermal production using Distributed

Acoustic Sensing (DAS) (£25K), led by University of Bristol.

- Public engagements with induced seismicity: lessons for geothermal energy in the UK's net-zero transition (£25K), led by University of Birmingham.
- Effective monitoring of the environment before, during and after sub-surface activities (£25K), led by the British Geological Survey.

In Northern Ireland, funding announced for an innovative new partnership between academia and industry will harness Northern Ireland's natural geothermal resources, thermal energy that comes from the sub-surface of the earth to encourage the most efficient use of energy by industrial users such as data centres. It is funded through Invest NI's Competence Centre Programme and the Centre for Advanced Sustainable Energy (CASE).

Funding Calls

Funding opportunities included Natural Environment Research Council (NERC) Highlight Topic F: Smart subsurface assessment and monitoring of urban geothermal resources: Funding for up to two projects that improve understanding of the technical and economic viability, environmental sustainability, and the ability to monitor and govern the use of the shallow subsurface for geothermal applications, each up to the value of £2.5 million (100 % full economic cost) and up to four years in duration. Submissions are currently being assessed.

International Collaborations

Collaboration of UK partners (Durham University, BGS) with the INTERREG NW Europe DGE-ROLLOUT project and publication of two new papers on the Carboniferous Limestone Geothermal Resource as part of a Special Publication in the Journal of the German Geological Society - *Zeitschrift der Deutschen Gesellschaft für Geo-wissenschaften* (Narayan et al., 2021; Pharaoh et al., 2021).

Less Conventional Resources

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 programmes, as follows:

- Exploiting the permeability of deep fracture systems as viable geothermal resources (Glasgow University).
- Exploring the extent of palaeokarst within the buried Carboniferous Limestone and its geothermal potential (Durham University). (Narayan et al., 2021)
- Quantifying the potential of the thermal resource within disused mine systems in the UK (Newcastle University, Glasgow University, British Geological Survey) (Gluyas et al., 2018).
- NERC funded GWatt project – Geothermal Power Generated from UK Granites – to increase knowledge of the geological conditions needed for deep fracture-controlled fluid flow within granitic rocks (University of Exeter, Camborne School of Mines, BGS, Heriott Watt): https://gtr.ukri.org/projects?ref=NE%2FS003886%2F1

7.3 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 increasingly offer modules on aspects of geothermal energy. There is also increased interest in renewable energy topics, including Geothermal Energy, in secondary school education. The 2021 Environmental Science Teacher Associations Annual General Meeting hosted a keynote lecture on Geothermal Energy in the UK (delivered by the BGS). A significant public outreach programme was developed as part of the United Downs Deep Geothermal Project. The GSHPA and others are currently developing training courses and material related to GSHP design and installation.

At COP26, a new education platform was launched: the UK Centre for Masters' Training in Energy Transition (CMT). The platform brings together UK universities with leading energy companies and industry training providers to facilitate access to resources and training for the next generation of geoscientists and engineers. Its remit covers a range of energy and renewable technologies, including geothermal energy and CCS. Further details are available on the CMT website at: https://www.energy-transition.ac.uk/

8. CONCLUSIONS

With the increasing pressure to develop secure, low carbon, sustainable energy sources for the delivery of both electricity and heating, there has been a revival of interest in geothermal energy in the UK. After a wait of over 30 years, real activity has restarted in Cornwall, with the United Downs Deep Geothermal Project and the Eden Geothermal Project. The outcomes of these significant deep geothermal projects will be closely followed, with interest already developing in future systems in South West England.

GSHP activity is on an upward curve once RHI tariffs were rebalanced between biomass GSHP systems. The requirement for low carbon heating systems should mean that there is a prospect of rapid growth in this sector.

The various deep geothermal heat projects that were reported for EGC 2016 are still taking considerable time and effort to bring to fruition. Hopefully the Bridgend minewater project should be realised and encourage the utilisation of other UK minewater resources in Glasgow and Nottingham through the D2GRIDS project.

REFERENCES

Abesser, C., Schofield, D., Busby, J., Bonsor, H.: Who Owns (Geothermal) Heat? British Geological Survey (Nov 2018). http://geoatlantic.eu/portfolio/wp-content/uploads/2019/01/whoOwnsGeothermalHeat.pdf

Abesser, C. Deep Impact: Unlocking the potential of geothermal energy for affordable, low-carbon heating in the UK. British Geological Survey Science Briefing Note, Sept 2020. https://www.bgs.ac.uk/download/science-briefing-note-deep-geothermal/

Abesser, C. et al. Unlocking the potential of geothermal energy in the UK. Open Report OR/20/049,22pp. (Nottingham, UK British Geological Survey) (2020). https://nora.nerc.ac.uk/id/eprint/528673/

Abesser, C; Jans-Singh, M. 2021 United Kingdom Country Report; IEA Geothermal (July 2022).

Abesser, C., Walker. Geothermal Energy, Parliamentary Office for Science and Technology (POST) researching briefing, POSTbrief 46, (2022). https://post.parliament.uk/research-briefings/post-pb-0046/

Batchelor, A.S.: Geothermal Resources of the UK - Country Update Report 1985-1990, International Symposium on Geothermal Energy, GRC International Volume, Hawaii, USA (1990).

Batchelor, A.S.: Geothermal Developments in the UK-Country Update Report 1990-1995, IGA WGC Proceedings, Florence Italy (1995).

Batchelor, A.S, Curtis, R.H, Ledingham, P.: Country Update for the United Kingdom, IGA WGC Proceedings, Antalya, Turkey (2005).

Batchelor, A.S, Curtis, R.H, Ledingham, P.: Country Update for the United Kingdom, IGA WGC Proceedings, Bali Indonesia (2010).

Batchelor, A.S, Curtis, R, Ledingham, P, Law, R.: Country Update for the United Kingdom, Proc World Geothermal Congress, Melbourne, Australia (2015).

Busby, J.P., Gillespie, M, Kender, S.: How hot are the Cairngorms? Scott J Geol. 2015; 51:105–15. (2015)

Busby J., Terrington, R.: Assessment of the Resource Base for Engineered Geothermal Systems in Great Britain. Geothermal Energy, pp18, DOI 10.1186 /s40517-017-0066-z. (2017)

Curtis, R., Ledingham, P, Law, R, Bennett, T: Geothermal Energy Use, Country Update for United Kingdom. European Geothermal Congress 2013, Pisa, Italy (2013).

Curtis, R., Law, R., Adams, C.: Geothermal Energy Use, Country Update for the United Kingdom. European Geothermal Congress 2016, Strasbourg, France (2016).

Curtis, R., Pine, T.: RHI – Incentive or Inhibitor to UK GSHP Growth? European Geothermal Congress 2016, Strasbourg, France (2016).

Downing, R.A., Gray, D.A.: Geothermal Energy The Potential in the United Kingdom, HMSO, ISBN 0 11 884366 4 (1986).

Garnish, J.D.: Geothermal Resources of the UK - Country Update Report, International Symposium on Geothermal Energy, Geothermal Resources Council, International Volume, ISBN 0-934412-88-X, Hawaii USA (1985).

Gluyas, J.G., Adams, C.A., Busby, J.P.: Keeping Warm: a review of deep geothermal potential of the UK. Proc Inst Mechanical Engineers, Part A: Journal of Power and Energy (2018).

Gosnold, W.D., Majorowicz, J., Safanda, J., Szewczyk, J.: Has northern hemisphere heat flow been underestimated? in AGU Spring Meeting Abstracts (Vol. 2005, pp. T43D-01) (2005).

Hinson, Sutherland. Opportunities for geothermal energy extraction. House of Commons Research Briefing (2021): https://commonslibrary.parliament.uk/research-briefings/cdp-2021-0143/

Jones, D. Unlocking the deep geothermal energy potential of the Carboniferous Limestone Supergroup - British Geological Survey Research highlight (2021). https://www.bgs.ac.uk/news/unlocking-the-deep-geothermal-energy-potential-of-the-carboniferous-limestone-supergroup/

Law, R., Chendorain, M., Free, M., Collins, M.: Development and Deployment of Deep Geothermal Single Wells in the UK. European Geothermal Congress 2016, Strasbourg, France (2016).

Law, R., Cotton, L., Ledingham, P.: The United Downs Deep Geothermal Power Project. Proc. European Geothermal Congress 2019, Den Haag, The Netherlands (2019).

Ledingham, P., Cotton, L.: The United Downs Deep Geothermal Power Project. Proc World Geothermal Congress, Reykjavik, Iceland (2020).

Narayan et al.: Karstified and fractured Lower Carboniferous (Mississippian) limestones of the UK – A cryptic geothermal reservoir, Zeitschrift der Deutschen Gesellschaft für Geowissenschaften; DOI: 10.1127/zdgg/2021/0288 (2021).

Pharaoh et al.: Early Carboniferous limestones of southern and central Britain: Characterisation and preliminary assessment of deep geothermal prospectivity; Zeitschrift der Deutschen Gesellschaft für Geowissenschaften; DOI: 10.1127/zdgg/2021/0282 (2021).

Raine, Reay: Geothermal energy potential in Northern Ireland: summary and recommendations for the Geothermal Advisory Committee. Geological Survey of Northern Ireland, 27pp. (2021). http://nora.nerc.ac.uk/id/eprint/530934/

REA, ARUP: Deep Geothermal Energy – Economic Decarbonisation Opportunities for the United Kingdon, Report by the Association for Renewable Energy and Clean Technology (REA) and Arup, (2021). https://www.r-e-a.net/wp content/uploads/2021/05/Deep-Geothermal-Energy-Opportunities-for-the-UK.pdf

Rees, S., Curtis, R.: National Deployment of Domestic Geothermal Heat Pump Technology: Observations of the UK Experience 1995 – 2013. Energies 2014, 7(8), 5460-5499 (2014). https://doi.org/10.3390/en7085460

Rochelle, C., Busby, J., Kilpatrick A., Shail, R., Yeomans, C., Eyre, M., den Hartog, S., Arnold, D., Geiger, S., Busch, A., Ledingham, P., Law, R., Carroll, C.: Geothermal Power Generated from UK Granites (GWatt), Proc. World Geothermal Congress 2020, Reykjavik, Iceland (2020)

Sinclair Knight Merz (SKM): Geothermal Energy Potential: Great Britain and Northern Ireland (May 2012).

Smith, M.: Southampton Energy Scheme. World Geothermal Congress, IGA, Kyushu - Tokyo Japan (2000)

Townsend, D.H., Naismith, J.D., Townsend, P.J., Milner, M.G., Fraser, U.T. 'On the Rocks'– Exploring Business Models for Geothermal Heat in the Land of Scotch. In Proceedings World Geothermal Congress 2020, Reykjavik, Iceland (2020). https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/08025.pdf

Walls, D.B.: Mine water geothermal resources of Scotland (Unpublished PhD thesis). University of Strathclyde, Glasgow (2022).

Watson, S.M., Westaway, R., Falcone, G.: A Review of Deep Geothermal Energy and Future Opportunities in the UK. Proc. European Geothermal Congress 2019, Den Haag, The Netherlands (2019).

Westaway, R., Younger, P.L.: Accounting for palaeoclimate and topography: a rigorous approach to correction of the British geothermal dataset. Geothermics, 48, pp.31-51. (2013).

ACKNOWLEDGEMENTS

The views expressed in this paper are those of the authors alone.

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	0	0	75'800*	330'000*	0	0
Under construction end of 2021	3	0	3200	0	0.0038	0
Total projected by 2023	3	21	75'800	340'000	0.0038	0.0062
Total expected by 2028		43	77'800	350'000	0.0077	0.012
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation:	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

There are no geothermal power plants currently existing in the UK.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *					1.7	20.14	~1	~9.4
Under constru-ction end 2021					0	0	0	0
Total projected by 2023					?	?	?	?
Total expected by 2028					?	?	?	?

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Southampton	Southampton DH		Y	N	1.7	1.7	20.14	100
Bath	Roman Baths		N	N	~1	~1	~9.4	100
Matlock Bath	New Bath Hotel & Spa		N	N	~0.2	~0.2	?	100
total					~2.9	~2.9		

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	43’700	787	1316	4000	99	<1 %
Of which networks **	?	?	?			
Projected total by 2023	48’000	903	1490			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings (“cold” DH, Geothermal DH 5.0 etc.)

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	5.0	10	10.0	20
Geothermal direct uses	0	20	???	30
Shallow geothermal	230	650	200	600
total				

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include “jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration”. For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D		Industrial Transition Energy fund	
Financial Incentives – Investment	Contracts for Difference	Public Sector Decarbonisation Fund; various funds for Heat Networks	
Financial Incentives – Operation/Production			Boiler Upgrade Scheme (BUS)
Information activities – promotion for the public	Information developed for UDDGP & Eden; Parliamentary briefing paper (POST brief) (Abesser and Walker, 2022)	Parliamentary briefing paper (POST brief) (Abesser and Walker, 2022)	Material developed by GSHPA GeoERA MUSE project factsheets and information material; https://geoera.eu/blog/new-muse-leaflet-about-shallow-geothermal-energy-published/ Parliamentary briefing paper (POST brief) (Abesser and Walker, 2022)
Information activities – geological information	No	Yes, BGS and Durham University have been reviewing mapping and resource estimates for some of the UK's deep targets for geothermal heating (e.g. Pharaoh et al., 2021; Narayan et al., 2021; Jones, 2021)	Cardiff Urban Observatory / GeoERA MUSE project https://geoera.eu/blog/muse-pilot-area-activities-results-7-cardiff/
Education/Training – Academic	UK Centre for Masters' Training in Energy Transition (CMT).		HP training Exeter University
Education/Training – Vocational	No	No	Apprentice training developed by GSHPA. GSHP Designer Training by GSHPA

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Geothermal Energy Use, Ukraine Update for 2021

Yurii Morozov, Anastasia Barylo and Oleh Lysak

Institute of Renewable Energy – National Academy of Sciences of Ukraine,
Hnat Khotkevych str., 20-a, Kyiv, Ukraine, 02094

E-mail: geotherm@ukr.net

Keywords: geothermal energy, geothermal uses, development state, update, Ukraine, 2019–2021, 2022.

ABSTRACT

This paper is written during the full-scale invasion of Russia with the support of Belarus. This full-scale invasion began on the 24th February 2022 and it is the part of the Russian invasion since 2014, when Russia has temporarily occupied the territories of Ukraine: the Crimean Peninsula and the parts of the Donetsk and Lugansk regions of Ukraine.

This paper analyses the development of geothermal energy in Ukraine. The most favourable conditions for the development of geothermal energy exist in the Transcarpathian and the Outer Subcarpathia artesian basins, the Black Sea artesian basin (especially the Crimean steppe and the Black Sea coast) and the Dnipro-Donetsk artesian basin. Substantial low-temperature geothermal resources are also available in Donetsk folded area. All mentioned territories correspond with the known territories of oil & gas extraction. Some of the depleted or abandoned oil & gas wells on those territories can be retrofitted to extract geothermal energy. Similar projects have already been done by other countries – and their experience can be used in Ukraine.

The history of geothermal energy in Ukraine begins with the geothermal use for heating purpose that was initiated in the 1970s. Since that time there is a steady rise in geothermal energy consumption in Ukraine. The last decade there was an especial rise of the development of geothermal energy resources for balneology and shallow geothermal heat pumps.

Ukraine provides governmental programs of financing research in the field of geothermal energy. Ukraine provides feed-in-tariff for electrical energy produced by geothermal electrical plants and feed-in-tariff can be increased if equipment made in Ukraine is used. Simultaneously, there are reduction in taxes for imported geothermal equipment in Ukraine too. However, currently there is no geothermal electrical production in Ukraine and all geothermal energy in Ukraine is limited to heating and balneology.

There is also a government support for conducting geothermal research in Ukraine. In particular, in 2018, an experimental installation for study of heat storage from renewable energy sources in the underground aquifer thermal energy system was created by the Institute of Renewable Energy of the National Academy of Sciences of Ukraine.

1. INTRODUCTION

Before the beginning of the analysis of the state of geothermal energy development in Ukraine, it is rather important to mention the current event in Ukraine which concerns Europe as well as the whole world.

It is the full-scale invasion of Russia with the support of Belarus. This invasion began on the 24th February 2022 and it is the part of the Russian invasion since 2014, when Russia has temporarily occupied the territories of Ukraine: the Crimean Peninsula and the parts of the Donetsk and Lugansk regions of Ukraine.

However, the lack of reaction to the initial Russian invasion in 2014 lead to even higher over-reliance on Russian fossil fuels in the world – and the money, earned by Russia through selling them, are now used for financing the Russian war against Ukraine.

Thus, reaching both the energy security of Ukraine and the phasing out Russian fossil fuels is the goal of all European countries. That should be done through both the implementation of energy efficiency measures and, in particular, by the development of renewable energy sources, including geothermal energy. Such development should lead to: increasing security of energy supply; reducing greenhouse gas emissions; increasing economic savings and improving quality of life.

This paper is about the current state of geothermal energy in Ukraine, describing of what has been done in that field in Ukraine and the analysis of what can be done further.

The paper presents the status of geothermal energy development in Ukraine in 2019–2021, which is the continuation of the previous update report submitted for the European Geothermal Congress 2019 (Morozov and Barylo, 2019), which shows the state of geothermal energy development in 2018. The most recent report to update the information on geothermal energy in Ukraine is the report for World Geothermal Congress 2020+1 (Morozov et al., 2021), which shows data as of 2019.

2. GEOTHERMAL ENERGY POTENTIAL

Ukraine has great potential for the development of geothermal energy (Figure 1). According to Gordienko et al. (2018, 2019), the most favourable conditions for the development of geothermal energy exist in the Transcarpathian and the Outer Subcarpathia artesian basins, the Black Sea artesian basin (especially the Crimean steppe and the Black Sea coast) and the Dnipro-Donetsk artesian basin. Substantial low-temperature geothermal resources are also available in Donetsk folded area (Gordienko et al., 2018, 2019). All mentioned territories correspond with the known territories of oil & gas extraction. Some of the depleted or abandoned oil & gas wells on those territories can be retrofitted to extract geothermal energy. Similar projects have already been done by other countries – and their experience can be used in Ukraine (Lysak, 2022).

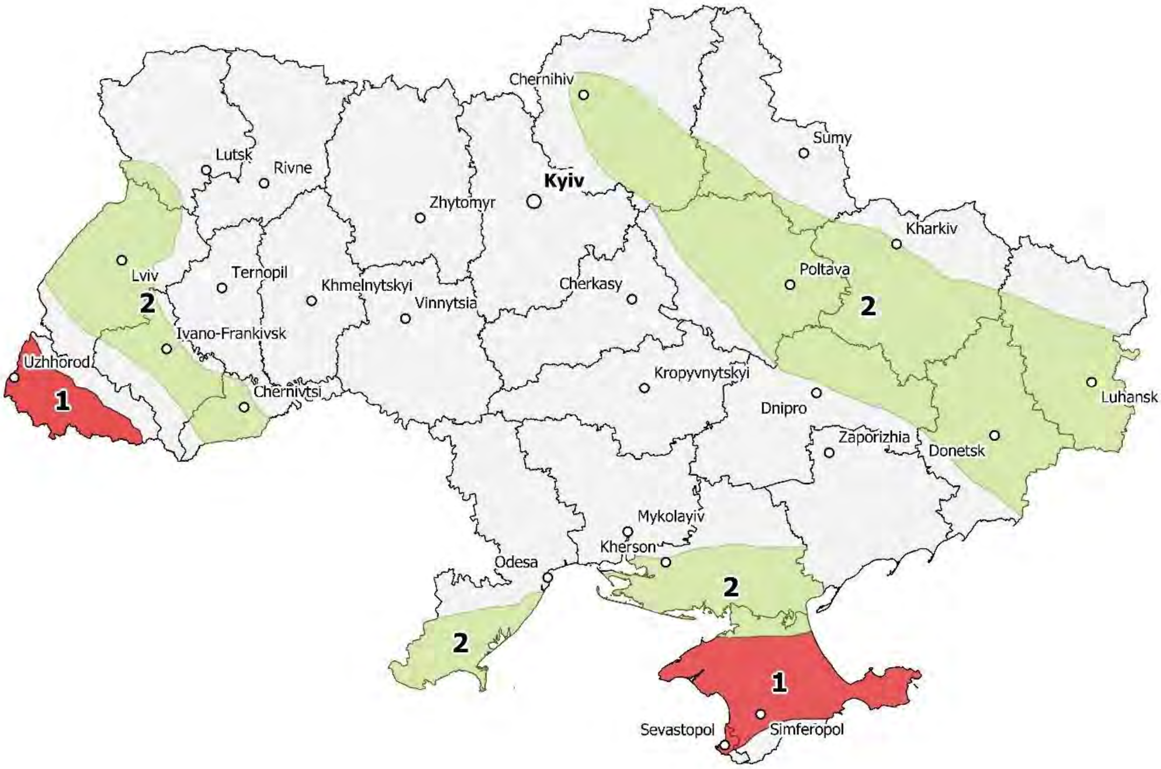


Figure 1: Ukrainian geothermal map zones based on their geothermal potential, 2019:
1 – the best zones to extract geothermal energy;
2 – the other zones to extract geothermal energy.

The following analysis of geothermal energy potential can be divided into three parts: hydrothermal resources, shallow geothermal resources, petrothermal resources.

Hydrothermal resources

The Institute of Renewable Energy of the National Academy of Sciences of Ukraine (IRE NASU) made the assessment of the energy potential from the geothermal fields with hydrothermal resources for heating and electricity generation in Ukraine. The assessment was based on the characteristics of more than 400 gas, gas condensate and oil wells. These wells are located within 102 hydrocarbon deposit fields, which represents 47 % of the total number of hydrocarbon fields in Ukraine (Barylo and Morozov, 2017).

From those wells were excluded wells without thermal water. It is about a half of those 400 wells. Then geothermal well with thermal water temperature below 60 °C were also excluded. Thus, only wells with thermal water temperature above 60 °C were taken into the further assessment.

The energy potential from those geothermal fields was determined on the basis of actual data from the selected wells by volumetric method. This assessment does not take into account the dynamic component resource, i.e., the amount of underground water which may enter the productive horizon of the adjacent horizons or influx of rock mass heat.

The assessment showed that those geothermal fields in Ukraine have a heating output of 60 million tons of coal equivalent per year (Barylo and Morozov, 2017).

The value of 1 kg coal equivalent corresponds to a value specified as 7000 kcal ~ 29.3 MJ ~ 8.141 kWh. The following conversion is applied: 1 ton of coal equivalent is 0.7 ton of oil equivalent (TOE). Thus, the potential of oil & gas wells for geothermal energy production in Ukraine is 42 million TOE per year. In order to evaluate those numbers, they should be compared with the level of heat consumption in Ukraine.

For example, in 2020 the companies whose activity is licensed by the National Energy and Utilities Regulatory Commission (NEURC) of Ukraine, have supplied 13.7 million Gkal for heating and ventilation; and 2.7 million Gkal for hot water heating ("Annual Report", 2021). This is 16.4 million Gkal which is 1.64 million TOE. Thus, theoretically, the identified geothermal fields have potential to cover the need for this type of heating in Ukraine.

The shown data on heat consumption do not represent the whole heat consumption in Ukraine as those licensed companies are limited to monopolies in heat generation while there is a trend in Ukraine to decrease the energy consumption from them but it shows the biggest district heating supply companies in Ukraine.

This assessment does also not include many factors like distribution of energy because energy consumers can be too far away from these sources of energy.

Another part of improvement of that assessment is through using the database which provides more wells with more precise characteristics. The actual number oil & gas wells are a way higher and the data on them are being constantly updated. At the current time there is already data for more than 800 oil & gas wells which is still just a small fraction of the total number of oil & gas wells in Ukraine.

When it comes to the possible installation of geothermal electrical power, those geothermal fields could generate 2080 MW_e. That capacity constitutes only about 4 % of the total installed electric generation capacity in Ukraine in 2020 ("Annual Report", 2020).

Shallow geothermal resources

The potential of the shallow geothermal resources at the depth of 300 m in the suburban area of the Ukrainian cities is estimated up to 26.8 million tons of coal equivalent per year, which is 18.76 million TOE per year (Basok and Dubovskoy, 2017; Morozov et al., 2018).

Petrothermal resources

The Institute of Geophysics of the National Academy of Sciences of Ukraine (IGPH NASU) in 2004 issued the "Geothermal Atlas of Ukraine" book which shows possible heat output at the depths of 3, 4.5 and 6 km. Heat output was calculated based on average geothermal gradient and thermal properties of rocks of estimated areas. There have been works which were made to improve and provide additional data for that estimation (Gordienko et al., 2018, 2019).

The current estimation of geothermal resources in Ukraine and possible investment projects

In 2020 IRE NASU published the maps of renewable energy resources and the prospects of their use for Ukrainian regions, including the field of geothermal energy and the possible investment projects for that matter (Kudria, 2020) that can be used as a guide into the future geothermal energy projects in Ukraine.

3. GEOTHERMAL USE

The history of geothermal energy in Ukraine begins with the geothermal use for heating purpose that was initiated in the 1970s. Since that time there is a steady rise in geothermal energy consumption in Ukraine. The last decade there was an especial rise of the development of geothermal energy resources for balneology and shallow geothermal heat pumps.

According to the research, the geothermal energy output in 2021 hasn't varied significantly compared to the report for the World Geothermal Congress 2020+1 (Morozov et al., 2021).

For 2021, the total capacity of large geothermal district system (for both district heating & cooling as well as other use) has been considered to be 6.96 MW_{th} with the energy production of 26.57 GWh_{th}/yr – but due to those facilities are sued for balneology, it is all counted as balneology (Table D2).

Also, the number of ground-source heat pump installations is considered to be circa 11'000, but the data for that has also been rather tentative (Table E1). In 2021 the total capacity of heat pumps is 1600 MW_{th} with the energy production of 1386 GWh_{th}/yr

4. LEGAL FRAMEWORK GEOTHERMAL ENERGY OF UKRAINE

In recent years, there was an improvement of the legal basis in Ukraine regarding the field of conservation, management, environmental protection and development of alternative and renewable energy sources, in particular geothermal waters. Among adopted legal documents there were: "On Subsoil" (from 27.07.94, number 132/94-VR), "Water Code" (from 06.06.95, number 213/95-VR), "On alternative energy sources" (from 20.02.03, № 555-IV) etc.

The procedure for the development of geothermal fields, providing requirements for special permits (licenses) is based on the Cabinet of Ministers of Ukraine № 615 of May 30, 2011 "On approval of special permits for subsoil use".

Ukraine provides feed-in-tariff for electrical energy produced by geothermal electrical plants and feed-in-tariff can be increased if equipment made in Ukraine is used. Simultaneously, there are reduced taxes for imported geothermal equipment in Ukraine too. However, currently there is no geothermal electrical production in Ukraine.

Besides that, IRE NASU has developed the three-state national standards in the field of geothermal energy: “Geothermal energy. Terms and definitions”, “Geothermal energy. Geothermal heat stations” and “Geothermal energy. Geothermal power stations”. These standards define the basic terms and concepts, as well as technical requirements for electrical and thermal geothermal stations.

In 2018, because of government support, an experimental installation for study of heat storage from renewable energy sources in the underground aquifer thermal energy system was created by the IRE NASU. The investments in the research of geothermal sector in 2019 consist of 4 million UAH (0.16 million USD).

CONCLUSION

Currently, the number of geothermal facilities in Ukraine hasn’t changed much. In the period of 2020-2021 it is caused by economic difficulties due to the COVID-19 pandemic.

It should be mentioned that due to the ongoing full-scale Russian invasion, some facilities have been destroyed while others have been damaged and, thus, decreased their output.

At the current moment, the fast development and installations of new geothermal systems is one of the possible solutions to decrease the gas consumption in Europe and to decrease the energy price pressure caused by the Russian aggression against Ukraine.

We also hope that Ukraine would have the assistance of other European countries in the future development of geothermal systems in Ukraine, using the existing recommendations on possible geothermal development in Ukraine.

REFERENCES

Annual Report for 2020 of the National Commission for State Energy and Public Utilities Regulation [in Ukrainian], 2021 https://www.nerc.gov.ua/storage/app/sites/1/Docs/Richny_zvity/Richnyi_zvit_NKREKP_2020.pdf

Barylo, A., Morozov, Y.. Evaluation of the energy potential of the individual geothermal deposits in Ukraine [in Ukrainian], *Vidnovliuvana Energetyka*, (2017), Is. 1, V. 48, 70–77.

Basok B., Dubovskoy S. Methodological features of estimation of the available power of heat pumps in Ukraine [in Russian]. *Nasosy i oborudovanie*. (2017), Is. 3, V. 104, 42-44.

Gordienko, I., Gordienko, V., Zavgorodnyaya, O. Geothermal resources of Ukraine. *Geofizicheskiy Zhurnal*, (2018), V. 40, 269–285. https://doi.org/10.24028/gzh.0203-3100.v40i5.2018.147494

Gordienko, V.V., Gordienko, I.V., Zavgorodnyaya, O.V., 2019. Geothermal resourses of Ukraine. IOP *Conf. Ser.: Earth Environ. Sci.*, (2019), V. 249, https://doi.org/10.1088/1755-1315/249/1/012008

Kudria, S. (ed.) Atlas of energy potential of renewable energy sources [in Ukrainian], *Interservis,* Kyiv, (2020).

Lysak, O.V. Analysis of the experience of the implementation of geothermal energy in Poland for the conditions of Ukraine [in Ukrainian], *International scientific conference “Features of innovative development in the field of technology: the comparative experience of Ukraine and the European Union”: conference proceedings*, August 5–6, 2022, Riga, Latvia, “Baltija Publishing”, (2022), 58-63, https://doi.org/10.30525/978-9934-26-230-2-15

Morozov, Y. and Barylo, A.: Geothermal Energy Use, Country Update for Ukraine. *Proceedings,* EGC 2019, The Hague, The Netherlands (2019).

Morozov, Y., Barylo, A., Lysak, O. Geothermal Energy Country Update Report from Ukraine, 2020. Proceedings World Geothermal Congress 2020+1, Reykjavik, Iceland, (2021).

Morozov, Y., Velychko, V., Kushnir, I., Evaluation of the heat potential of the upper layers of the earth on the territory of Ukraine [in Ukrainian], *Vidnovliuvana Energetyka*, (2018), Is. 4, V. 55, 84-92 https://doi.org/10.36296/1819-8058.2018.4(55).84-92

Tables A-G

Table A: Present and planned geothermal power plants, total numbers

Currently, there are no present or planned geothermal power plants in Ukraine.

Table B: Existing geothermal power plants, individual sites

Currently, there is no present or planned geothermal power plants in Ukraine.

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	–	–	–	–	–	–	6.96	26.57
Under constru-ction end 2021	–	–	–	–	–	–	–	–
Total projected by 2023	–	–	–	–	–	–	–	–
Total expected by 2028	–	–	–	–	–	–	–	–

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Note: Due the ongoing full-scale Russian invasion into Ukraine, there is the possibility that some facilities may be destroyed or lose their equipment. Due to being some parts of Ukraine are being temporarily occupied, the prognosis isn't made.

Table D1: Existing geothermal district heating (DH) plants, individual sites

As it is hard to distinguish geothermal district heating from other needs, all geothermal plants are shown for mixed use in Table D2.

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Dovhe, Irshava Raion, Zakarpattia Oblast	Borzhava	–	–	0.3	–	1.23	–	–
Nyzhnie Solotvyno, Uzhhorod Raion, Zakarpattia Oblast	Derenivska Kupil	–	–	0.36	–	2.07	–	–
Henicheska Hirka, Henichensk Raion, Kherson Oblast	Hariache Dzherelo	–	–	0.9	–	2.91	–	–
Koson, Berehovo Raion, Zakarpattia Oblast	Kosyno	–	–	1.2	–	5.45	–	–
Mukachevo, Mukachevo Raion, Zakarpattia Oblast	Latorytsia	–	–	0.2	–	0.65	–	–
Veliatyno, Khust Raion, Zakarpattia Oblast	Tepli Vody	–	–	0.6	–	2.25	–	–
Vynohradiv, Vynohradiv Raion, Zakarpattia Oblast	Teplytsia	–	–	0.43	–	2.25	–	–
Nyzhnie Solotvyno, Uzhhorod Raion, Zakarpattia Oblast	Termal Star	–	–	0.57	–	2.04	–	–
Berehovo, Berehovo Raion, Zakarpattia Oblast	Zhavoronok	–	–	0.45	–	2.16	–	–
Barvinok, Uzhhorod Raion, Zakarpattia Oblast	Zolota Hora	–	–	0.55	–	2.55	–	–
Small facilities in Ukraine		–	–	1.4	–	3.01	–	–
total				6.96	–	26.57	–	–

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2021 *	11000	1600	1 386	–	–	–
Of which networks **	–	–	–	–	–	–
Projected total by 2023	–	–	–			

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	–	–	–	–
Geothermal direct uses	–	–	–	–
Shallow geothermal	–	–	–	–
total	–	–	–	–

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	Yes	Yes	Yes
Financial Incentives – Investment	–	Yes	Yes
Financial Incentives – Operation/Production	Yes	–	–
Information activities – promotion for the public	Yes	Yes	Yes
Information activities – geological information	Yes	Yes	Yes
Education/Training – Academic	Yes	Yes	Yes
Education/Training – Vocational	–	Yes	Yes

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)