Geothermal Energy Use, Country Update for Slovenia

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ABSTRACT

The most geothermally exploited region in Slovenia, the Mura-Zala basin in northeastern part, belongs to the Pannonian Basin. Three deep reinjection wells were drilled there in the last two years, one at Moravske Toplice and two at Dobrovnik, and are being tested. Better utilization schemes at several localities with introduction of heat exchangers and heat pumps of bigger rated power for improved geothermal heat use are in place. Most users there tap thermal water from the Mid- to Late Miocene (Pannonian-Pontian) sandy aquifer with temperatures of 38 to 70 °C. Several users utilize thermal water in a more efficient manner now. Nevertheless, the pumped volumes were higher in 2024 by 18.8% compared to year 2021. The total installed capacity and annual energy use (both deep and shallow geothermal) in 2024 are 389.04 MW_{th} and 2275.74 TJ/yr (632.15 GWh/yr), respectively. Installed capacity and energy use at all 31 users of thermal water from deep sources amounted to 56.53 MW_{th} and 581.68 TJ in 2024. Three new make-up geothermal wells, 101 m and 120 m deep at Laško (Thermana) in 2024, and 500 m deep at Podčetrtek (Terme Olimia) in 2023, were drilled for direct heat use of thermal water but are not yet in use. Shallow geothermal energy utilization shows greater progress, with the number of ground-source heat pump (GSHP) units reaching around 18'588 with 332.51 MW_{th} capacity and 1694.06 TJ/yr energy use (Dec. 2024). Faster development in use of deep geothermal is expected based on results of two projects, supported by EEA Grants: INFO-GEOTHERMAL - Supporting Efficient Cascade Use of Geothermal Energy by Unlocking Official and Public Information and SI-Geo-Electricity - Pilot geothermal power plant. New research on cooling potential with borehole heat exchangers (BHEs) is investigated within an ARIS-MKGP CRP project GeoCOOL FOOD - Cold food storage using shallow geothermal energy.

1. INTRODUCTION

Systematic explorations of geothermal resources in Slovenia began in 1974 after the first oil crisis. As a middle to high developed country, Slovenia (with population 2.12 mil. and area of 20'273 km^2) has a quite high electricity consumption (Table A), with 5.80 MWh per capita. This paper presents the status of direct heat use and development in the last three years, 2022-2024. Geothermal energy use in Slovenia 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. 2023), European Geothermal Congresses since 2013 (Rajver et al. 2022) and in the last 14 years for Ministry of the Environment, Climate and Energy (MOPE) and its predecessors (Rman et al. 2024).

Only direct use of geothermal energy (for heating and cooling) is effective in the country as of 2024, with emphasis on exploitation of low temperature resources for district and individual space heating, for greenhouses and thermal spas. During the last 23 years the direct use showed only slight and changing increase and recently just a slow increase. 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) was one of the problems being mostly resolved after 2020, but also some occasional technical difficulties and weak incentives for efficient use of the resources pose a threat to faster development. 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 more efficient manner. The GSHP sector utilizing the shallow geothermal energy is the only category showing a strong steady increase.

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 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. For the needs of such investments, GeoZS prepared 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 will be determined (Hozjan 2021). Yet, it's not expected that any electricity production from geothermal fluids in Slovenia could be realistic by 2030.

Regarding the use of thermal water in NE Slovenia, three deep reinjection wells were drilled lately, one in 2023 for Terme 3000 d.o.o. at Moravske Toplice, and two in 2024 at Dobrovnik for Ocean Orchids d.o.o. Namely, the installation of new doublets is encouraged, especially for heating greenhouses.

Since May 2022, research has been underway on the possibilities of producing electricity from geothermal energy in abandoned oil and gas wells, targeting the heat of the rocks at a suitable depth and its exploitation by conduction. As part of the EGP project SI-Geo-Electricity (funded by EEA Grants), a pilot geothermal power plant was built in Čentiba near Lendava, in 2023 on the abandoned gas well Pg-8. The project is based on an innovative method of producing electricity with a geothermal gravity heat pipe, which is protected by Slovenian patent SI 26426 A. The planned power of the power plant was 50 kW_{el}, and the final power will be known after the test run finishes (could be only ca 10 kW_{el}, Table A). Based on geological data, a 3D geological and geothermal model of the environment was created, with which simulations of temperature changes during thermal energy generation were performed. In addition, a mathematical model was developed to simulate heat and mass flow in a geothermal gravity heat pipe (Gselman et al., 2024). The project mapped all geothermally suitable abandoned oil and gas wells in Slovenia. Of the 62 wells that reached at least 100 ºC, 37 are permanently abandoned, some are producing thermal water or hydrocarbons, and we ultimately found that 13 showed significant potential for further development. Guidelines for the development of new projects have also been prepared, which include a development scheme for new projects and identify the biggest obstacles for investors, thereby addressing technical, procedural, legislative and operational challenges.

In recent years, biased competition between energy sources has been a constraint on the increased use of shallow geothermal energy. The construction of new devices was excluded in the areas of gas networks and district heating systems. Due to the reduced supply of gas from the Russian Federation, we expect that in the coming years the trend will most likely reverse and various sources, including shallow geothermal energy, will be combined into smart networks.

Shallow geothermal energy has the unique advantage of being able to heat and cool at the same time. The most balanced use of heat and cold allows significantly lower investments and at the same time the smallest environmental impact. Balanced use is planned at the level of the building, or device, group of buildings, settlement, local community etc. (Prestor et al. 2018). Today, attention is also being paid to research into the feasibility of recycling thermal energy which accumulates underground due to urbanization, industrialization, and climate change.

2. GEOTHERMAL RESOURCES AND POTENTIAL

A complicated geologic and tectonic setting of Slovenia is subdivided into several tectonic units with different hydrogeological properties and geothermal conditions (Figure 1). A description of geology, geothermal field, resources and potential is given in the previous country updates (Rajver et al. 2022 and references therein). 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 geomanifestations. There the thermal water was discovered during the oil and gas drillings (Lapanje and Rman 2009). Geothermal resources in the Pannonian and Krško basins have been studied in more detail (see Rajver et al. 2022 and ref. therein, Rajver and Ravnik 2003; Rman et al. 2015, 2020).

2.1 Potential for geothermal power production

Natural steam reservoirs at relatively shallow depths (3 to 4 km) are not expected. In the SE part of the Pomurje area (NE Slovenia) high temperature resources are hypothetically expected in deeper fault zones in the Pre-Neogene basement (for details see Rajver et al. 2016). In this area, south of the Ljutomer-Balaton fault (Figure 1), this 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, more than 4 km deep wells would be needed to reach at least the 150 °C isotherm.

The new Act on the Introduction of Installations for the Production of Electricity from Renewable Energy Sources (ZUNPEOVE) from 2023 supports “geothermal sandpits” for faster project development and exploration in areas where there is no data yet.

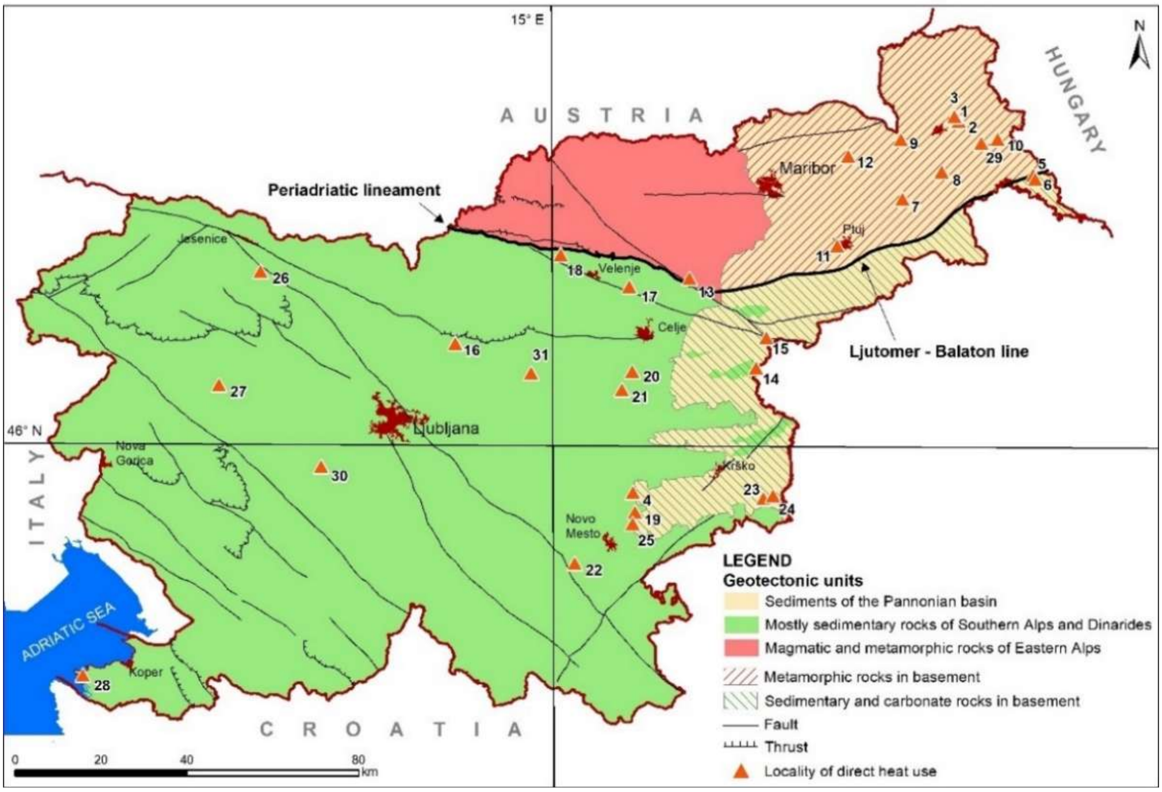

Figure 1: Generalized geological map of Slovenia with localities of direct heat use in 2024 (geology after Poljak, in Rajver et al. 2016).

2.2 Resources and potential for direct use

The northeastern and eastern Slovenia has been intensively investigated in the past 18 years within European projects, the most recent being DARLINGe[1], Cross-border, cross-thematic multiscale framework for combining geological models and data for resource appraisal and policy support (GeoConnect^{3}d) – GeoERA and INFO-GEOTHERMAL[2]. More sustainable exploitation is encouraged, including by applying new reinjection wells based on materials prepared during 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 Upper Miocene sand aquifers, that is from the Mura Fm. with temperatures of 54 to 66 °C and from the Badenian Špilje Fm. with up to 76 °C. The wells in Maribor were inactive since Dec. 31, 2021. Additionally, about 20 inactive and some 11 new potential wells in the country exhibit 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 1.45 km with temperatures from 50 to 70 °C (Nádor et al. 2012). These sandy lenses form 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, together with Tešanovci (2)), Ptuj (11), Radenci (9) and Renkovci (29). The best production wells have flow rates of up to 30 kg/s, however, the average flow rate barely exceeds 8 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 Fm sandstone aquifer discharges thermomineral water rich in CO_2 in Radenci (9) and with organic substances at temperatures up to 77 °C in Moravske Toplice. Two wells that were drilled in 2012-2013 and tested shortly thereafter for a doublet system for planned district heating of the Fazanerija Touristic center and some other facilities in the town of Murska Sobota, have been inactive since 2015.

[1] http://www.interreg-danube.eu/approved-projects/darlinge

[2] https://kdb.api.gic.geo-zs.si/api/v1/documents/138/pdf/DC%204_1%20Knjizica%20o%20energetsko%20ucinkoviti%20rabi%20geotermalnih%20virov%20in%20njihovem%20razvoju.pdf

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. The Čatež geothermal field in the eastern part of the 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 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 was described in the previous update report (Rajver et al. 2022). 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 of any existing today. 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. In fact, the first BTES system was installed in 2024 (Table E2; Borko et al. 2025).

3. GEOTHERMAL UTILIZATION

There is no electricity generation from geothermal resources in Slovenia up to date. Geothermal utilization of thermal water heat in 2024 is based on direct use from 50 production wells plus 4 thermal springs, implemented at 31 localities (Figure 2). Geothermal energy from thermal water is no longer used in Murska Sobota (Komunala d.o.o. since 2016 and Hotel Diana d.o.o. since 2019) and in Dobova (AFP) since 2021. Therefore, since the EGC 2022 report no new direct heat users have emerged in Slovenia. Figure 3 shows the main utilization types for direct heat use from thermal water.

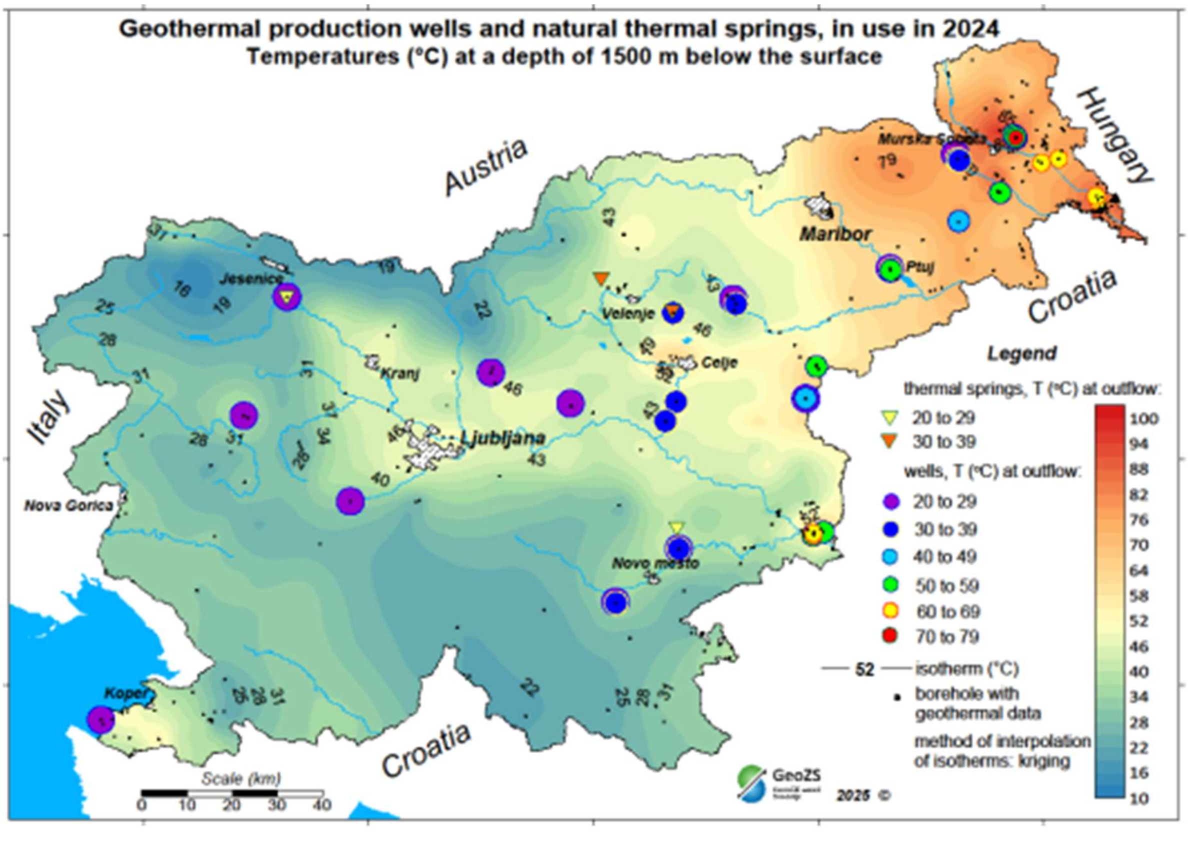

Figure 2: Production geothermal wells and natural thermal springs, in use in 2024 in Slovenia, with expected temperatures at 1500 m depth beneath the surface.

Geothermal energy currently delivers for direct heat uses and GSHP units at least 2275.74 TJ/yr (632.15 GWh/yr) of heat energy with corresponding installed capacity of 389.04 MW_{th}. Of these, direct use from thermal water is 56.53 MW_{th} and 581.68 TJ/yr (161.58 GWh/yr, by 23.2% more than in 2021), and the remainder, 332.51 MW_{th} and 1694.06 TJ/yr (470.57 GWh/yr, by 41.8% more than in 2021) are GSHPs (Table E1). 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).

3.1 Geothermal district heating

As regard to geothermal district heating (DH) *sensu stricto*, only one plant is considered in Slovenia at present (Table D1), in Lendava (number 5 in Figures 1 and 3), where several public buildings (schools, business complexes, theatre, shopping center, etc.) and blocks of flats (total 60'000 m^2) are heated under the Petrol d.d. authority with a doublet system. 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 space heating (at four users also cooling) and snow melting (at three users) are also 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 461.86 TJ/yr (128.305 GWh/yr). Of these (Table C), in 2024, the space heating itself took 184.76 TJ (51.33 GWh) of geothermal heat, DH *sensu stricto* (Lendava and Benedikt, Figure 3) 17.81 TJ (4.95 GWh), air conditioning 16.32 TJ (4.53 GWh), greenhouse 11.63 TJ (3.23 GWh), snow melting 11.55 TJ (3.21 GWh), bathing and swimming (incl. balneology) 178.31 TJ (49.54 GWh) and domestic hot water (DHW) heating 41.47 TJ (11.52 GWh). Six existing large systems for H and C uses other than DH are shown in Table D2.

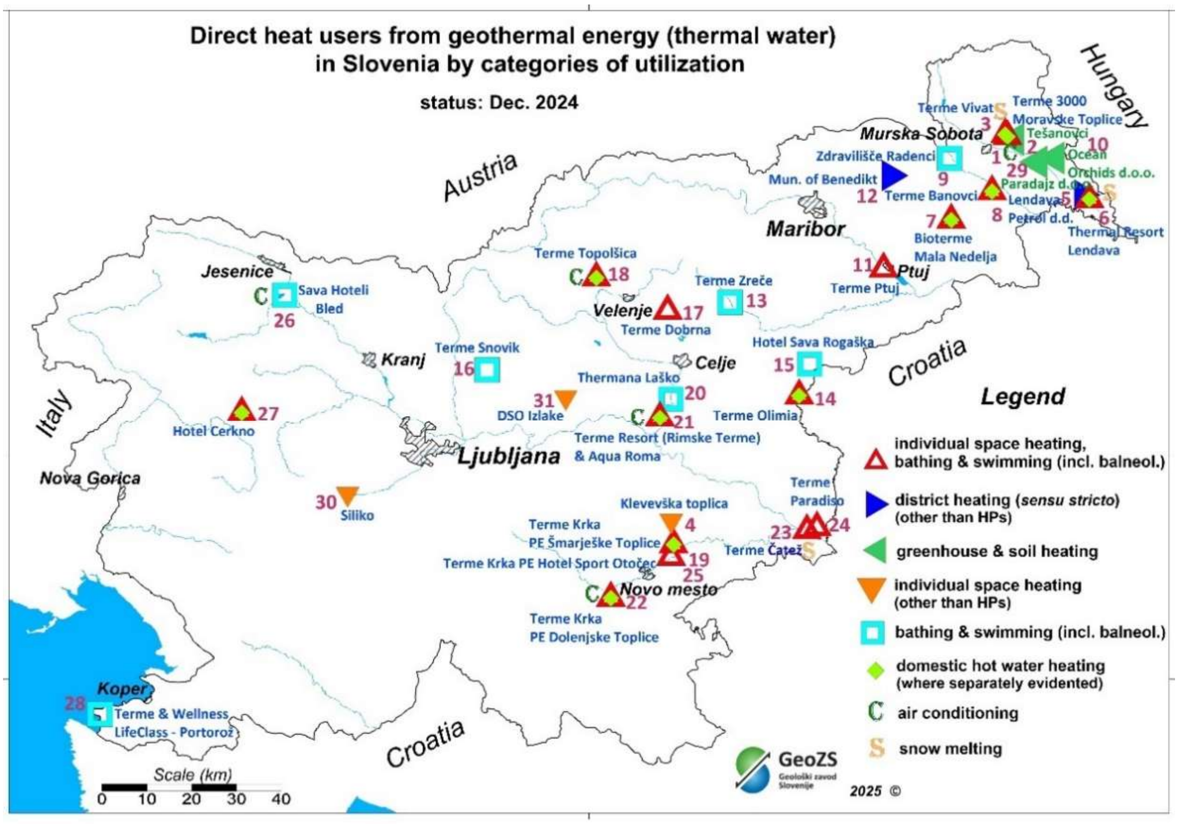

Figure 3: Main utilization types for direct heat use of geothermal energy (thermal water) in Slovenia (status: Dec. 2024); numbers are the same as in Fig. 1.

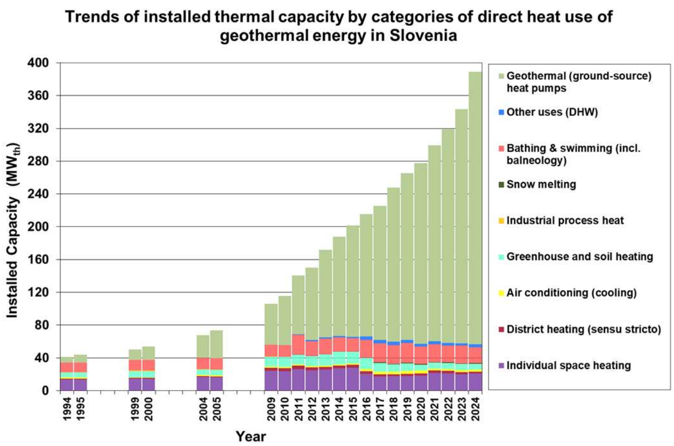

Figure 4: Geothermal direct use applications in a period 1994-2024 (total capacity in 2024: 389.04 MWth).

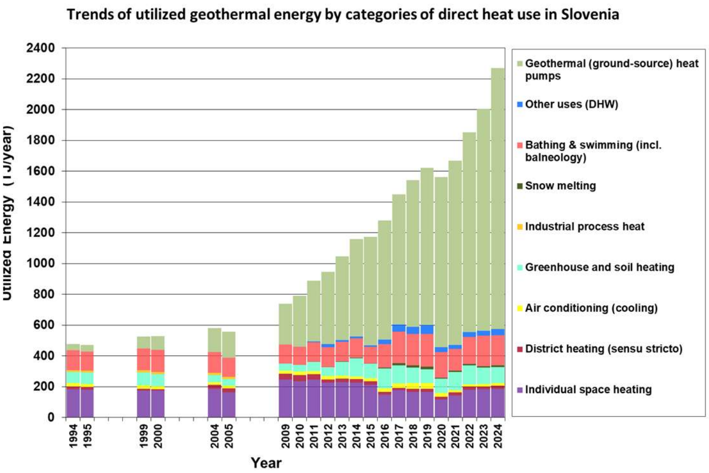

Figure 5: Geothermal direct use applications in a period 1994-2024 (total energy used in 2024: 2275.74 TJ).

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 due to economic reasons the Terme Čatež d.d. stopped operating their greenhouse by the end of 2019, 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 2024 in greenhouses (14 ha) was 109.58 TJ (30.44 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 97.94 TJ (27.208 GWh) (Table C). Total value is lower by 10.6% than in 2021, due to lower annual thermal water use at Dobrovnik and lower dT at both sites.

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 HEx (e.g. Moravske Toplice, Banovci, Lendava, Ptuj, Mala Nedelja, Čatež, Dobova etc.) or geothermal HPs (e.g. Mala Nedelja, 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 2024 was 187.37 TJ (52.048 GWh). Without 17 users, already accounted for as “DH plants”, geothermal energy used at other four localities (Klevevška Toplica, Otočec, Vrhnika and Izlake, numbers 4, 25, 30 and 31, resp. in Figure 1) for space heating amounted to 2.608 TJ (0.725 GWh) (Table C). Total value is lower compared to 1.582 GWh in 2021. DHW heating is included in these values at one locality (Izlake, number 31), while for the other 17 users the DHW heating is already included as part of DH plants’ network. For 11 users it is possible to calculate separately geothermal energy used for DHW heating, giving some 41.471 TJ in 2024 (11.520 GWh), while at other five 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 for bathing and swimming (incl. balneology) was implemented in 2024 at 15 thermal spas and health resorts, and additionally at 8 recreation centers where swimming pools with a surface area of about 50’726 m^2 and volume of 66’147 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, however, inflow temperatures in a lower range are utilized. The total geothermal energy used for bathing and swimming amounted to 195.50 TJ in 2024 (54.306 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), Zreče (13), Rogaška Slatina (15), Snovik (16), Laško (20), Bled (26), Portorož (28) and Otočec (25). Of total values, the used geothermal heat there amounted to 19.27 TJ (5.353 GWh) in 2024.

Snow melting of the sidewalks from utilized thermal water was applied within the doublet system in Lendava (number 5 in Figure 1), with about 0.14 TJ in 2024. Snow melting was more applied under two football grounds at Hotel Vivat at Moravske Toplice (number 3) with 3.097 TJ, and under three football grounds at Čatež (number 23) with 8.313 TJ. Altogether the used geothermal heat is 11.55 TJ (3.208 GWh), included within DH plants, compared to 6.94 TJ in 2021.

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), in few hotels at Bled (26), Dolenjske Toplice (22), Topolšica (18) and Rimske Terme (21), contributing about 18.395 TJ in 2024 (5.110 GWh), compared to 14.808 TJ in 2021. Only Bled is the locality not included already within the DH plant networks, and geothermal heat for AC was there 2.079 TJ (0.578 GWh) in 2024.

3.5 Geothermal heat pumps

At 12 health or spa resorts, already belonging to the DH plant networks, plus in Lendava DH system and in hotels at Radenci, Snovik, Laško, Bled, Otočec and Izlake retirement home (numbers 9, 16, 20, 26, 25, 31) and at industrial company Siliko Vrhnika (number 30), the GHPs of bigger capacity (19.50 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 is becoming more popular and widespread. In the last 5 years, there has been a growing interest in installing higher-power GSHPs for public buildings, industrial buildings, and even for several buildings together. The market boom on a larger scale began during the last 18 years after a period of low interest in GSHPs in the early 1990's. 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 GSHPs. This is also backed by support programs from utilities and from the government through subsidies or credits (Table G).

We are sure the numbers of GSHP units presently installed, 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. 2024, there are about 17'198 operational small GSHP units (typical 10 to 15 kW_{th}) that extracted 1031.78 TJ of geothermal heat in 2024. Of these, 43.0% are open-loop systems that extracted 506.48 TJ from shallow groundwater, 31.2% are horizontal closed-loop (with 283.39 TJ), and 25.8% are vertical closed-loop systems (with 241.91 TJ). Small closed-loop units together extracted 525.30 TJ/yr from the ground. There are also 1390 bigger capacity GSHP units (>20 kW) installed in public, industrial and other buildings, which extracted 662.28 TJ in 2024. It is discovered year by year that not all of them are operational. Of them, 979 units are open-loop water-water type (70.4%), 348 units are vertical closed-loop (25.0%) and 63 (4.5%) are horizontal closed-loop systems (thermal baskets included). With total 18'588 GSHP units some 1694.06 TJ (470.57 GWh) of heat was extracted in 2024 (Table E1), while ca. 544 TJ/yr of heat was rejected to the ground in the cooling mode. Capacity factor for all GSHP units is app. 16.2 %, 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. Figures 8 and 9 present the trends in the number of GSHP units and their shallow geothermal energy extraction. An increase in the capacity was noticeable in the last two years, mainly due to the installation of several GSHPs with a capacity of over 0.5 or even 1 MW_{th}, all in an open-loop configuration.

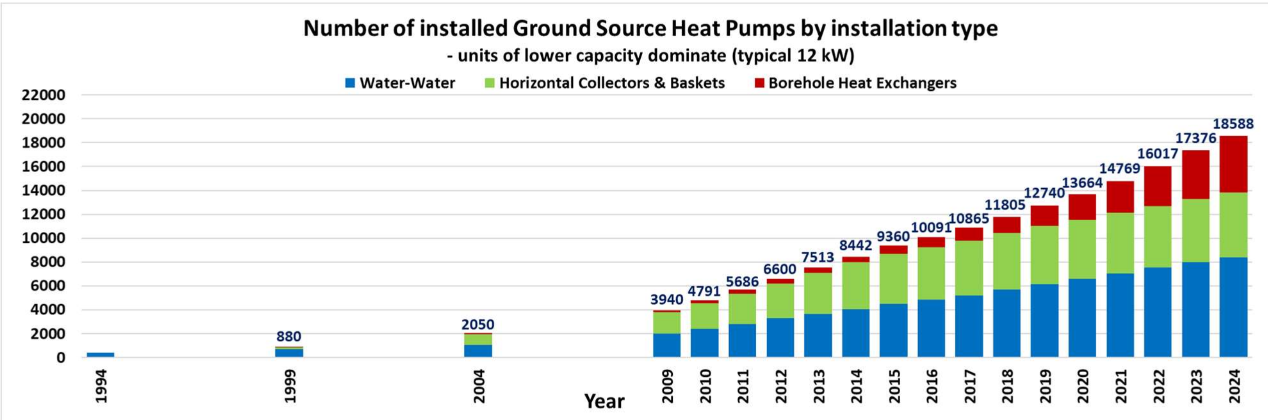

Figure 6: Number of installed GSHP units by installation type since the start of statistics in 1994 until 2024. For the situation in 1994, our estimate is around 400 installed GSHPs (all water-water).

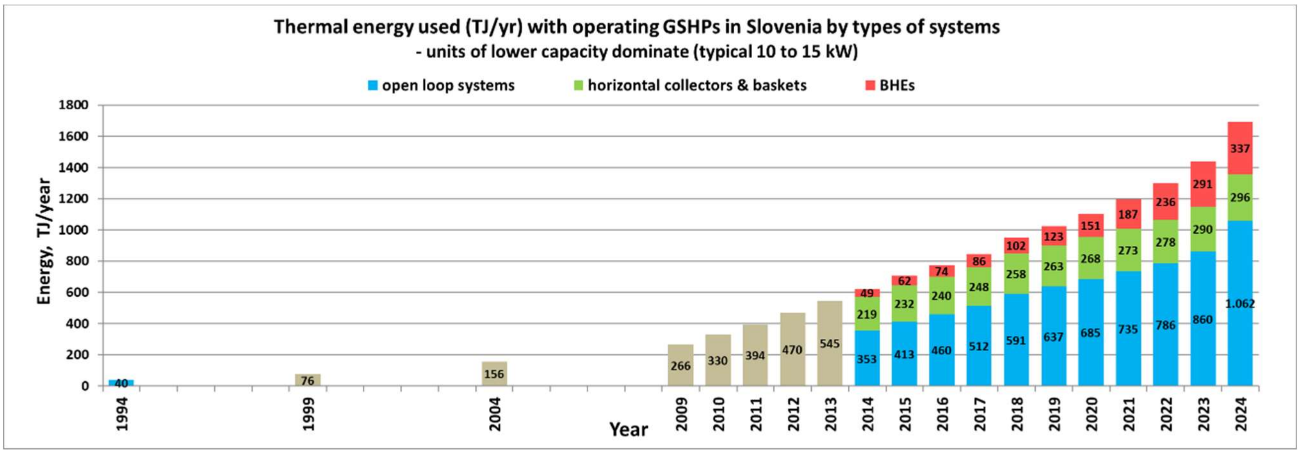

Figure 7: Extracted shallow geothermal energy with operating GSHP units since the start of statistics and by unit installation type; for the years 1995 - 2013 there is no exact data on the share of installation types.

4. DISCUSSION, RECENT DEVELOPMENTS AND FUTURE PROSPECTS

The distribution of capacity and annual energy use for various direct use applications (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 56.53 MW_{th}, including GHPs at thermal spas. The total abstraction of thermal water in 2024 amounted to 6'459'099 m^3, which is 6.2 % less than in 2019 (before the pandemic) but by 5.9% higher than in 2023. The annual energy use at 31 localities amounted to 581.68 TJ (161.58 GWh), which is by 23.2% more than in 2021

(472.10 TJ) and by 3.0% less than in 2019 (600 TJ). The impact of pandemic Covid period, which led to a prolonged closure of a significant number of thermal spas and resorts, has not been felt in 2023 and 2024 (Figure 5). Annual energy use (Figures 5 and 8) is now higher for individual space heating, air conditioning, bathing with balneology, snow melting and DHW heating, and a bit lower for greenhouse heating and DH *sensu stricto* in comparison with the situation in 2021. However, the GSHP sector exhibits the largest share (74.4 %) in direct use, compared to 71.7 % in 2021. With Figure 9, which shows the shares of all categories of direct heat use, excluding the GSHP sector, the three dominant categories differ more clearly (individual space heating, bathing and swimming and greenhouse heating).

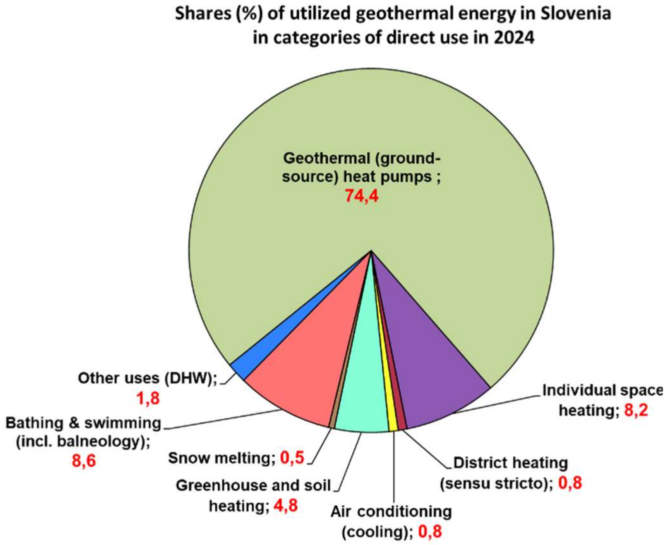

Figure 8: Shares of geothermal energy used in Slovenia in categories of direct use in 2024 (status Dec. 2024).

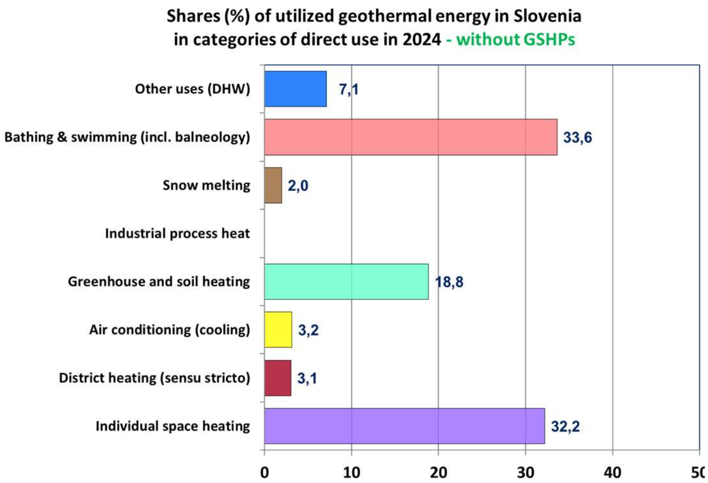

Figure 9: Shares of geothermal energy used in Slovenia in categories of direct use in 2024, without GSHP sector (status Dec. 2024).

The investments in geothermal (Table F) are only the best approximation and incomplete since many direct users and those of shallow geothermal do not report such data. A small number of new buildings and swimming pools was constructed at thermal resorts or spas.

Since 2021 no geothermal gradient boreholes have been drilled, but several T-z profiles have been measured in existing boreholes, which were drilled for other purposes, all with a goal to improve geothermal maps. In 2024, temperature logging was done in two deep inactive wells, up to 1.3 km in MD-1/05 at Mislinjska Dobrava and up to 1.5 km deep Or-1g/05 near Ormož.

Two users (Terme 3000 at Moravske Toplice, Ocean Orchids at Dobrovnik) in northeastern Slovenia built new reinjection wells in 2023/2024, the latter one even 2 wells, as has been granted funding from the Ministry of Agriculture, Forestry and Food for this purpose. At Laško, two new shallow make-up wells were drilled in 2024 and one in Podčetrtek in 2023. Several spa sites investigate possibilities to revitalize inactive wells or drill new ones, but it all depends on available funds. Exploration for borehole design has been done for a new site in Dobrovnik-Žitkovci, for a new greenhouse heating system.

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 d.o.o. and Petrol d.d. companies and GeoZS investigated the possibility for using deep wells, also existing ones such as Mg-6 (Murski gozd)[3]. To drill new deep exploration (wild cat) boreholes targeted geophysical (seismic, microseismic, microgravimetric, MT) investigations should be performed and currently such projects are gaining needed permits.

In addition to the standard approach, DEM d.o.o. is in the final stages of developing a pilot geothermal power plant on an inactive 3 km deep old gas well Pg-8 using the patented (No. SI 23618 A) geothermal gravity heat pipe. Research work began in 2022, and the plant is now in the testing phase.

4.1 Thermal water direct use

A doublet scheme is operational only in Lendava but at least two others will soon be added at Moravske Toplice and Dobrovnik. In NE Slovenia the localities are the most vulnerable to overexploitation of thermal water as most users capture water from the same aquifer. After lengthy procedures for obtaining funds, these users realized that reinjection wells were urgently needed. In this sense it is unfortunate that the Murska Sobota municipality has not completed the extension project for the DH system where a reinjection well was also planned (Rman et al. 2012). Thermal capacity of

[3] https://si-geo-electricity.si/en/the-pilot-geothermal-power-plant-project-centiba-is-approaching-completion/

the new doublet could reach 4 MW_{th} and geothermal energy use 8.8 GWh/year.

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 new plants at Turnišče and Ormož just did not happen. No major investments are planned so far in these communities. The exception is the municipality of Benedikt, where in 2022 a DH system (for heating several buildings around) was established using heat from a deep BHE, which was installed in a previously active geothermal well drilled into metamorphic rocks.

For this sector, activities are carried out within the framework of several international projects: COST CA18219 Geothermal-DHC[4], Horizon 2020 REFLECT and CROWDTHERMAL, 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) usually do not obtain funds from financial incentives such for 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 10 shows some 477 systems with GSHP units of bigger power with detailed data collected so far, with 15 known hydrothermal HP units.

Several bigger open-loop systems have 4 production and 4 reinjection wells or more. Similarly, the biggest closed-loop systems have more than 30, some of them ca. 50 or over 100 BHEs (with average depth of 100 to 150 m), mostly in eastern and northeastern regions.

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.

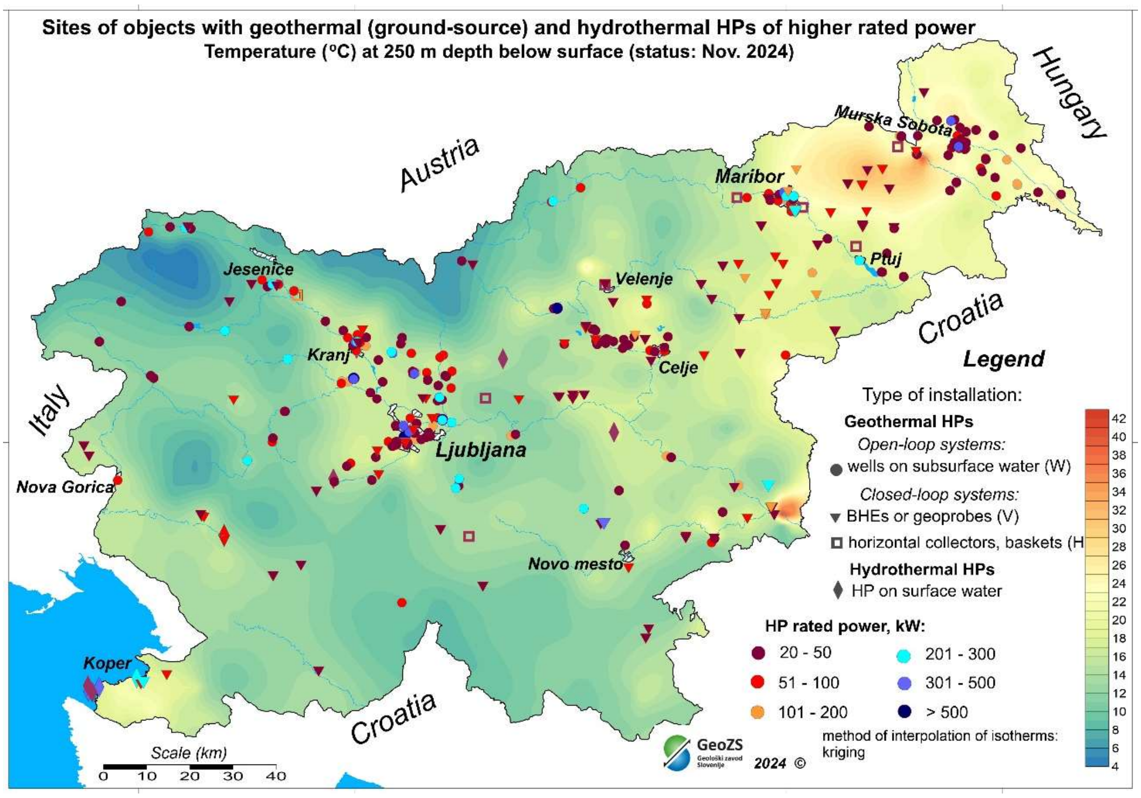

Figure 10: Distribution of 477 installations with a capacity of at least 20 kW by installation type for which the main technical data have been collected, together with at least 15 systems with a hydrothermal HP unit (all data collected on a voluntary basis). The isotherms show the expected temperatures at a depth of 250 m.

[4] https://www.geo-zs.si/PDF/Projekti/INFO-GEOTHERMAL/DC%204_1%20Knjizica%20o%20energetsko%20ucinkoviti%20rabi%20geotermalnih%20virov%20in%20njihovem%20razvoju.pdf

5. CONCLUSIONS

Some users have faced lower annual flow rates, which is the evidence of delivered maximum allowed pumping quantities, but nevertheless many of them, in spite of some technical difficulties, increased their direct heat use from thermal water in last two years. The GSHP market is more predictable, as it increased for about 118 TJ (32.78 GWh) every year in the last 5-year period. Actual (Dec. 2024) contribution in direct heat use from deep geothermal energy reached 581.68 TJ and thermal energy used by all GSHP units so far reached 1694.06 TJ, all together 2275.74 TJ (632.15 GWh or 53.41 ktoe). Consequently, target values[5] are still quite distant, and a lot of effort will be needed beyond 2025.

Increased efficiency of geothermal energy use 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) joint 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 years to follow. 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.

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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 2024 *			4446.6*	12’293.9*		
Under construction end of 2024	0.01					
Total projected by 2028			4800	15’988	negligible	negligible
Total expected by 2032						
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2024 (indicate exploration/exploitation if applicable):					Under development**:	
					Under investigation**:	

* If 2023 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

No operational geothermal power plants currently exist in Slovenia (in 2024).

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 2024	45.918	128.305	6.191	27.208	0.515	0.725	3.904	5.353
Under constru-ction end 2024								
Total projected by 2028								
Total expected by 2032								

* Note: spas and pools 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})	2024 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Banovci-Veržej	Terme Banovci d.o.o.	1990	N	N	1.585	4.80	4.391	72
Benedikt	Benedikt Municipality	2023	N	N	0.092	0.1	0.435	
Čatež	Terme Čatež d.d.	1979	N	N	12.955	15.51	34.156	88
Cerkno	Hotel Cerkno d.o.o.	1979 / 2000	N	N	1.297	2.98	1.582	100
Dobova	Paradiso Hotel d.o.o.	2010 / 2016	N	N	1.665	1.70	0.653	92
Dobrna	Terme Dobrna d.d.	1979 / 2015	N	N	0.854	1,45	0.883	60
Dolenjske Toplice	Zdravilišče Dolenjske Toplice d.o.o.	2003	N	Y	2.557	4,26	4,51	100
Lendava	Terme Lendava d.d.	1997	N	N	1.381	2.50	7.374	90
Lendava	Petrol d.d.	2007	N	N, RI	2.321	5.00	4.552	85
Mala Nedelja	BioTerme d.d.	2007	N	N	0.932	2.152	1.157	61
Mala Nedelja	BioTerme d.d.	2007	N	N	0.932	2.152	1.157	61

* 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 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})	2024 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Moravske Toplice	Naravni park Terme 3000 d.d.	1986 / 2002	N	Y	10.126	15.00	32.141	90
Moravske Toplice	Terme Sončni park Vivat d.d.	2006	N	N	2.297	4.409	8.30	100
Podčetrtek	Terme Olimia d.d.	1988	N	N	1.840	3.64	7.316	25
Ptuj	Terme Ptuj d.o.o.	1980	N	N	1.334	3.10	5.922	75
Rimske Toplice	Terme Resort d.o.o. & Aqua Roma	2010	N	Y	1.639	2.72	4.651	83
Šmarješke Toplice	Zdravilišče Šmarješke Toplice d.o.o.	1987	N	N	1.662	2.262	5.012	90
Topolšica	Terme Topolšica d.d.	1982	N	Y	1.381	2.476	5.272	70
total					**45.918**	**74.059**	**128.305**	

* 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})	2024 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Radenci	Zdravilišče Radenci d.o.o.	1989	N	0.686	?	0.385	20	Sava Turi-zem d.o.o.
Dobrovnik	Ocean Orchids d.o.o.	2006	N	2.568	5.9	12.897	90	Ocean Or-chids d.o.o.
Zreče	PE Terme Zreče d.o.o.	1878	N	0.81	?	1.106	62	Unitur d.o.o.
Snovik	Terme Snovik - Kamnik d.o.o.	1994	N	0.701	1.704	0.407	12	Zarja Kovis d.o.o.
Laško	Thermana & Zdravilišče Laško d.o.o.	1975 / 2008	N	0.597	0.35	2.430	20	Thermana d.d.
Renkovci	Paradajz d.o.o.	2012	N	3.623	3.623	14.311	100	Paradajz d.o.o.
total				**8.985**	>13?	**31.536**		

* 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 the year 2024		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2024	18’588	332.51	470.572	1212	46.893	7**
Of which networks *						
Projected total by 2028	23’810	404.8	581.0			

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

** Jožef Stefan Institute, Energy Efficiency Center, Ljubljana; (incl. the ECO Fund data)

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 2024		H: C:	H: C:	1	H: 0.20 C:	H: 0.080 C:
New (additional) in the year 2024		H: C:	H: C:	1	H: 0.20 C:	H: 0.080 C:
Projected total by 2028		H: C:	H: C:		H: C:	H: C:

Table F: Investment and Employment in geothermal energy

	in 2024		Expected in 2028	
	Expenditures* (million €)	Personnel ** (number)	Expenditures * (million €)	Personnel ** (number)
Geothermal electric power	0.438	2	?	3
Geothermal direct uses	4 (est.)	36	4 (est.)	36
Shallow geothermal	9 (est.)	140	10 (est.)	150
total	**>13**	**178**	**>14**	**189**

* 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	Yes[1)]	Yes[2)] DIS
Financial Incentives – Investment	Yes[3)] DIS	Yes[4)] DIS	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, course[5)], several MSc, PhD	Yes, through different studies & projects, course[5)]
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		
RC	Risk coverage	REQ	Renewable Energy Quota		
TC	Tax credits	O	Other (please explain)		

1) GeoERA projects: HotLime, GeoConnect3d, HOVER, CROWDTHERMAL, REFLECT, COST, Geothermal-DHC; Geothermica – GeoFOOD
2) GeoERA projects: MUSE; COST Geothermal-DHC, ARRS-MKGP Target research programme for cooling in agriculture, Call for EEA and Norway Grants
3) Call for EEA and Norway Grants – Pg-8
4) Project investment for agriculture - Reinjection wells: Dobrovnik
5) Thermogeology course at NTF (Geothermal-DHC summer school)