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Geothermal Country Update Report for Slovenia, 2020-2022

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ABSTRACT

The most geothermally exploited region in Slovenia, the Mura-Zala basin, is in northeastern part and belongs to the Pannonian Basin. No significant progress with new deep drillings was achieved there in geothermal development in direct heat use of thermal water during the last three years. However, 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) sand aquifer with temperatures of 36 to 66 °C. No other new direct heat user from thermal water has appeared in the country. The installed capacity and annual energy use of 29 thermal water users amounted to 58.3 MWth and 551.9 TJ in 2022, with almost no influence of Covid pandemic period. Greater progress is achieved in shallow geothermal energy use with the ground-source heat pump (GSHP) technology, where some 16,135 GSHP units (predominantly of 12 kW rated power) are operational with capacity of 260.1 MWth, which used 1294.7 TJ/yr of heat from the shallow underground (Dec. 2022). The total numbers for all applications of geothermal direct heat uses are 318.4 MWth and 1846.6 TJ/yr, respectively. It is expected the trend of energetic renovation of older buildings (including apartment blocks in cities) will continue more intensively in future, also with installation of the GSHP units, as one of the obligations to reach the renewable energy targets set by the EU directives. Faster development in use of deep geothermal is expected in 2022-2024 as two projects, supported by EEA Grants, have started: INFO-GEOTHERMAL - Supporting Efficient Cascade Use of Geothermal Energy by Unlocking Official and Public Information and Si-Geo-Electricity - Pilot geothermal power plant on an existing gas well Pg-8. We also foresee new research in cooling capabilities of geothermal within a CRP project GeoCOOL FOOD - Cold food storage using shallow geothermal energy.

1. INTRODUCTION

Some geothermal resources in Slovenia were described in literature already before the 20th century. Their real systematic exploration, however, began much later in the 1970s after the first oil crisis. This paper presents the status of direct heat use and development in the last three years, 2020-2022. 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.

Only direct heat use of geothermal energy is effective in the country with emphasis on exploitation of low temperature resources for heating and cooling for buildings (individual space heating, district heating, air-conditioning, domestic hot water), health, recreation, and tourism (bathing & swimming with balneology), for agriculture and food processing (greenhouses) and other uses (snow melting). 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 northeastern part of the country (Rman, 2014; Rman, 2016; Rman et al., 2016, 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 geothermal heat pumps for the improvement in using the available heat in more efficient mode 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.

Due to the Covid-19 pandemic continuation in 2020-2021, the share of shallow geothermal energy (more correctly: utilization of the heat of the shallow underground or subsoil) in the total balance increased in 2021, as the annual withdrawal of thermal water from deep geothermal reservoirs in 2021 was 21.2% lower than in 2019 (before the pandemic) but in 2022 only 12% lower than in 2019. Therefore, the utilized geothermal energy from thermal water was lower in 2020 and 2021 than in 2019. The thermal water use and thermal energy use almost completely recovered in 2022. Regarding the use of thermal water in NE Slovenia, two users (Terme 3000 d.o.o. and Ocean Orchids d.o.o.) are planning to drill reinjection wells in the next years (Rajver et al., 2020; 2022). The installation of new doublets is also encouraged, especially for heating greenhouses. In 2022, initial research for the development of an innovative pilot geothermal power plant at the existing Pg-8 gas well (SI-Geo-Electricity project co-funded by EEA Grants) finally began.

Over the past years, biased competition between energy sources has been a greater limitation for the development of the use of shallow geothermal energy than natural conditions. The construction of devices for the use of shallow geothermal energy 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 that accumulates underground due to urbanization, industrialization, and climate change. This theoretical thermal potential is related to the distribution of underground heat load according to the natural environment and settlement. Analyzes so far already show that the possibility of recycling thermal energy should be considered in the transition to a low-carbon economy in a warmer world (Benz et al., 2022).

2. GEOTHERMAL RESOURCES AND POTENTIAL

A description of geology, geothermal field, resources and potential is given in the previous country updates (Rajver et al., 2020; 2022). 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, many 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., 2020 and references therein).

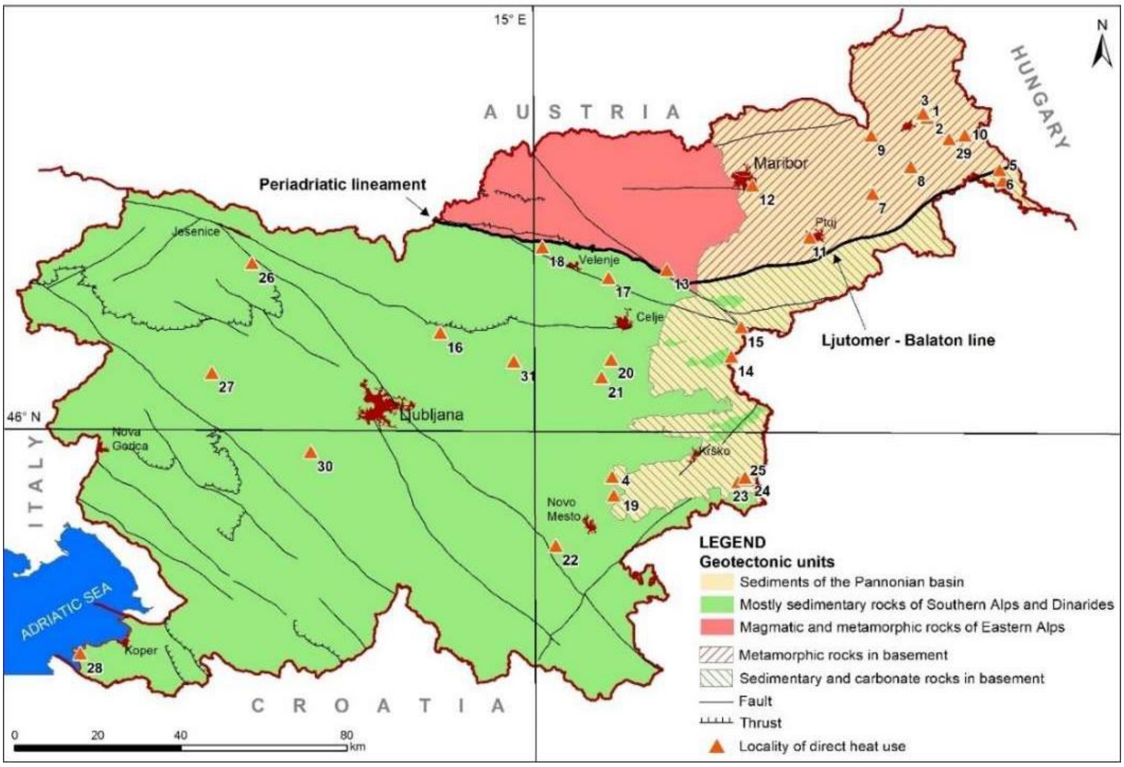

Figure 1: Generalized geological map of Slovenia with localities of direct heat use in 2021; in 2022 two users (12 and 25) were no longer operational (geology after Poljak, in Rajver et al., 2020).

2.1 Potential for geothermal power production

Natural steam reservoirs at relatively shallow depths haven't been detected yet with existing boreholes. In the E-SE part of the Pomurje (NE Slovenia) high temperature resources are unproven and only hypothetically expected in deeper fault zones in the Pre-Neogene basement. Focus should be more in 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. Geothermal and hydrogeological characteristics of the NE part of the country indicate potential geothermal resources, technically exploitable for electricity production, but only with restrictions (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 16 years within the European projects, the most recent being DARLINGe (Website 1) and GeoConnect3d (Website 2). The results give better insights in characteristics of the geothermal field and hydrogeological conditions of the geothermally most utilized Mura-Zala sedimentary basin. The NE part is characterized by elevated surface heat-flow density (HFD), above 0.10 W/m^2, with expected temperatures above 80 °C at 2 km depth east of the Maribor - Ptuj stretch, where maximum formation temperature may reach 150 °C at depths of 2.5 to 3 km (Rajver et al., 2012; Tóth et al., 2016). Efforts are put in promotion of more sustainable exploitation by applying new reinjection wells in the future based on materials prepared during the project activities. Most production wells tap thermal water from the Miocene sand aquifers, that is from the Mura Fm. with temperatures of 36 to 66 °C and from the Špilje Fm. with up to 77 °C. The only exceptions are the wells drilled in metamorphic rocks 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 MWth.

The most extensive Upper Pannonian geothermal sandy aquifers, which are widely utilized by Slovenia and Hungary, 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 therein 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. A problematic transboundary drawdown caused with thermal water production from the Upper Pannonian aquifers was proved by modelling within TRANSENERGY project (Tóth et al., 2016; more details also in Rajver et al., 2020), showing that this drawdown extended as far as 60 km in the neighbouring countries.

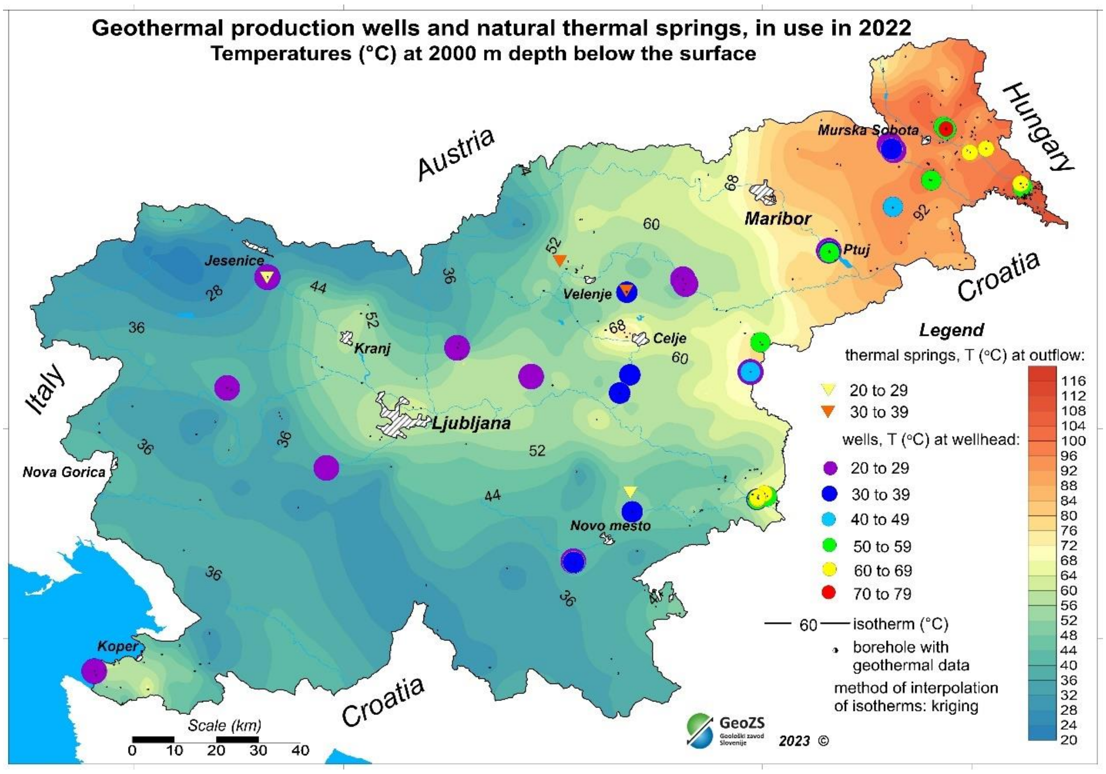

Figure 2: Production geothermal wells and natural thermal springs, in use in 2022 (status: Dec. 2022); isotherms show expected temperatures at 2000 m depth beneath the surface.

In the SE part of the country the thermal water is mostly encountered in the Krško-Brežice sedimentary basin along its southern edge in the Mesozoic carbonate rocks. Its geometry was investigated within project HotLime (Website 3). A Čatež geothermal field in the eastern part of this basin is characterized by elevated geothermal gradient (>60 mK/m). The wells with maximum depth of 0.7 km produce thermal water from deep circulation in Triassic dolomites and older rocks with maximum 62 °C at the wellheads and annual average yields ranging from 1 to 14 kg/s (numbers 23, 24, 25 in Figure 1), while at Šmarješke Toplice (19) in the west up to 10 kg/s per well and maximum of 35 °C. The thermal water temperatures at wellhead of the production wells and at outflows of natural thermal springs are shown in Figure 2.

2.3 Potential for ground-source heat pumps

About 7% of the territory is covered by extensive and highly productive gravel and sand alluvial aquifers which are very favourable for wells and thus for open-loop GSHP systems. The major cities and towns are situated on these plains. The temperature of groundwater is characteristically between 10 and 15 °C. Clastic rocks and sediments cover over half of the Slovene territory, carbonate rocks about 40%, while pyroclastic, metamorphic, and crystalline rocks less than 8%. For horizontal heat exchangers more suitable is soil and sand or sandy clay, also soft flysch rocks such as sandy marls or loose sandstone, sandy claystone. For vertical heat exchangers the most suitable are dolomite, dolomitic limestone and limestone, most magmatic and metamorphic rocks, and flysch. The geological potential for closed-loop ground - water and open-loop water - water systems is already described in the previous update report (Rajver et al., 2020). 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

Today, only direct use of geothermal energy is implemented in Slovenia, with an emphasis on the use of low-temperature sources for heating and cooling for buildings including district heating (*sensu stricto*) in Lendava, for health, recreation and tourism and for agriculture and food processing (greenhouses heating). In the last 20 years, direct use has only increased slightly, while recently it has only varied or stagnated. The reasons depend on the individual location, and in 2020-2021 also on the consequences of the Covid-19 pandemic. One of the restrictions is the limitation of additional withdrawals of thermal water in the case of use without reinjection in some locations in the north and south-east of the country. Locally, technological problems due to the demanding chemical composition of water and weak incentives for investments in more efficient use of resources are also important.

Utilization of deep geothermal energy takes place only by direct use of heat from thermal water, which in 2022 did not feel the effects of the Covid-19 pandemic anymore. The pandemic limited the operation of spas and thermal baths in 2021, but less than in 2020. The use of heat from thermal water in 2022 was based on direct use from 50 production wells and 4 thermal springs, which took place at 29 locations (Figure 2). In Murska Sobota (Hotel Diana), which was reported for WGC 2020, geothermal energy is not used anymore as they stopped using thermal water for its heating system in autumn 2019. A very small user appeared in 2010 already at Klevevška Toplica (number 4 in Figure 1) which uses thermal water of 20.2 °C for space heating. No new direct heat users of thermal water emerged since the WGC 2020 report. The use of thermal water was followed by monitoring, which is supervised by the Agency of the Republic of Slovenia for the Environment (ARSO). In recent years, a more efficient use of thermal water in many places is noticed. This was helped by the introduction of heat exchangers, better insulation of buildings and other technological improvements, as well as the installation of heat pumps, usually of higher power, to raise the temperature of the thermal water to a higher level for further cascade use. This means that less heat of thermal water is released unused in the environment. Due to the continuation of the pandemic in 2021, the utilization of thermal water by some users was still a little lower than before the pandemic in 2019, so it is unrealistic to compare the utilized geothermal energy in 2021 with that in 2019. In addition, in recent years there have been minor changes in the technology of use with changes in the inflow and outflow temperature of thermal water in individual phases of use. In 2022 the situation was improving. The total average flow of thermal water and used geothermal energy for all users together were still lower in year-round use in 2022 than in 2019 and in the years before, without major changes in the installed capacity of wells (Figures 3 and 4). The impact of the pandemic was more felt in 2020 (Table 1a).

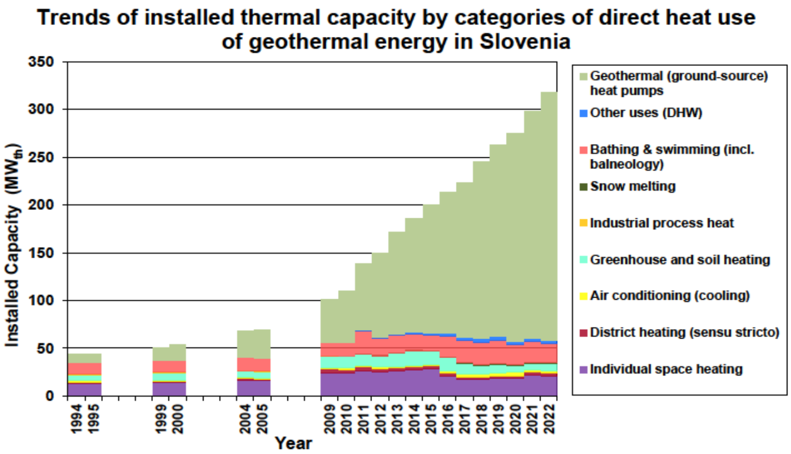

Figure 3: Trends of installed thermal capacity by types of direct heat use of geothermal energy in a period 1994-2022 (total capacity in 2022: 318.42 MW_t). Types of direct heat use are according to the previous WGC standard tables.

Some users, of course, improved the efficiency of use and, despite the lower annual withdrawal of thermal water compared to 2019, achieved an enviable level of used energy. Most users used slightly more geothermal energy, mainly because the total withdrawal of thermal water in 2022 (6,214,634 m^3) was 15.4% higher than in 2021 (Fig. 4). Only four users used less energy compared to 2021.

Table 1a: Total flow of thermal water for all users at maximum utilization and actual annual utilization, as well as capacity and annual geothermal energy use in the last seven years.

Year	Total flow rate (kg/s) at maximum utilization	Installed capacity (MW_t)	Total average flow rate (kg/s) at annual utilization	Annual energy use (TJ/yr)
2016	756.4	66.02	210.0	506.42
2017	694.7	61.87	236.25	604.37
2018	658.6	59.79	223.60	589.73
2019	667.5	62.07	215.2	599.69
2020	588.7	56.62	150.75	456.61
2021	625.3	60.27	164.74	472.10
2022	609.5	58.31	189.17	551.86

On the other hand, the following users used more geothermal energy in 2022 compared to the previous year, mostly due to higher flow rate and partly due to more efficient energy extraction: Terme 3000 and Terme Vivat at Moravske Toplice, Terme Lendava, Terme Radenci, Terme Ptuj, Terme Olimia, Terme Snovik, Terme Dobrna, Šmarješke Toplice, Dolenjske Toplice, Terme Paradiso Dobova, Hotel Cerkno, Terme Čatež (the highest increase) and Home for senior citizens (DSO) at Izlake (Figure 5), and slightly more energy also at Ocean Orchids Dobrovnik, Tešanovci greenhouse, Terme Topolšica, Thermana Laško and Hotels at Bled. In the case of other users (e.g. BioTerme Mala Nedelja, Terme Banovci, district heating in Lendava under Petrol Geo l.l.c., Renkovci greenhouse), the annual withdrawal of thermal water was not significantly changed, and thus the geothermal energy used was also not significantly changed.

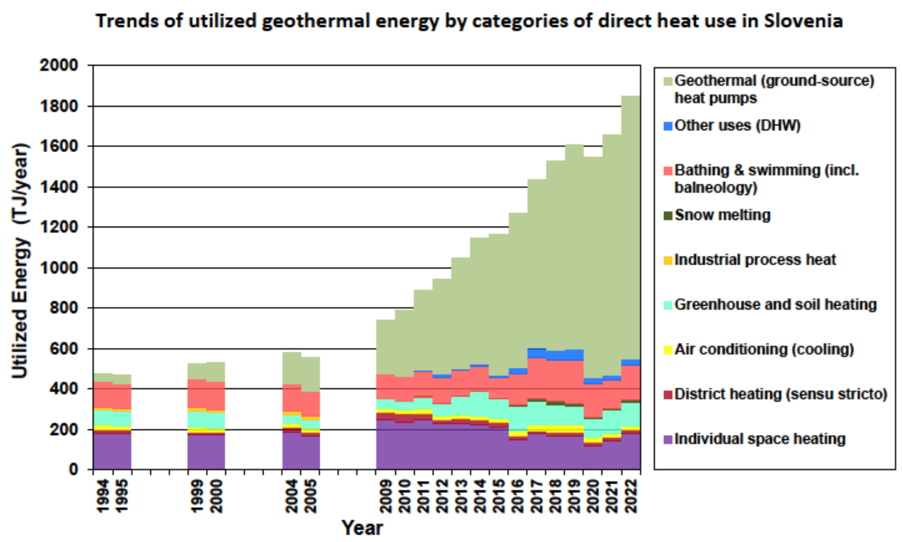

Figure 4: Trends of utilized geothermal energy by categories of direct heat use in Slovenia in a period 1994-2022 (total energy used in 2022: 1846.58 TJ). Types of direct heat use are according to the previous WGC standard tables.

Temperatures of thermal water at the wellhead of production geothermal wells and at the outflow of four natural thermal springs did not change significantly in 2022 compared to previous years (Figure 2). Most of the production wells in northeastern Slovenia pump water from the Mura-Zala sedimentary basin, more precisely from the Mura formation (Fm), with a water temperature of 36 °C to 66 °C, and from the Špilje Fm, with a water temperature of up to 77 °C, if looked by individual wells. The details of geothermal energy use according to geothermal applications given in Table 3 (Summary of Geothermal Heating & Cooling installations) follow below.

3.1 Agriculture and food processing

The *greenhouse and soil heating* as the type of direct heat use from the previous WGC standard tables belongs under this application. The greenhouse heating using geothermal water began in 1962 at Čatež (number 23 in Fig. 1, 5 and 6). It was performed there by the Cvetje Čatež Co. on 4.5 ha for cultivation of flowers for domestic market. 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 (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 2022 in three greenhouses (14 ha) was 122.481 TJ (34.023 GWh) from capacity of 7.358 MWth. The greenhouse Tešanovci is included in Table 4 as part of the Terme 3000 district system in Moravske Toplice.

3.2 Health, recreation, and tourism

This application of direct heat use of thermal water is implemented at 22 different locations (with exactly so many installations). The *bathing and swimming (incl. balneology)* as the type of direct heat use from the previous WGC tables belongs under this application, which includes the direct use in most cases of cooled thermal water in pools and/or reheating of pool water through heat exchangers or heat pumps and in few cases heating of communal water with thermal water with the help of geothermal heat pumps (GHPs). There are 14 thermal spas and health resorts, and additional 8 recreation swimming and sport centers (7 of them as part of the hotel accommodations) where water of swimming pools with a surface area of at least 50,530 m^2 and volume of 65,850 m^3 is heated directly or indirectly through heat exchangers and GHPs. The water temperatures at wellheads of the wells in thermal spas range from 20.2 in Bled to 59.4 °C in Čatež, however, inflow temperatures in lower range are utilized. From the capacity of 20.35 MWth the total geothermal energy used for this application amounted to 174.60 TJ/yr (48,50 GWh/yr, in Table 3 it is 39.01 GWh for 2021) in comparison with too high (and incorrect) value of 215.4 TJ/yr in 2019. Several users improved the temperature range utilization, such as at and Rogaška Slatina, Dobrna, Topolšica, Šmarješke Toplice and Laško (numbers 15 and 17 to 20 in Fig. 1, 5 and 6) with the heat exchangers introduced, while at Šmarješke Toplice, Laško and Terme Lendava (number 5 in Fig. 1 and 5) using the GHPs.

3.3 Heating and cooling for buildings

This application combines several types of direct heat use according to former WGC standard tables: (1) individual space heating with domestic hot water heating, (2) district heating (*sensu stricto*), (3) air conditioning and (4) shallow geothermal energy use with GSHP technology for heating and cooling for predominantly individual houses.

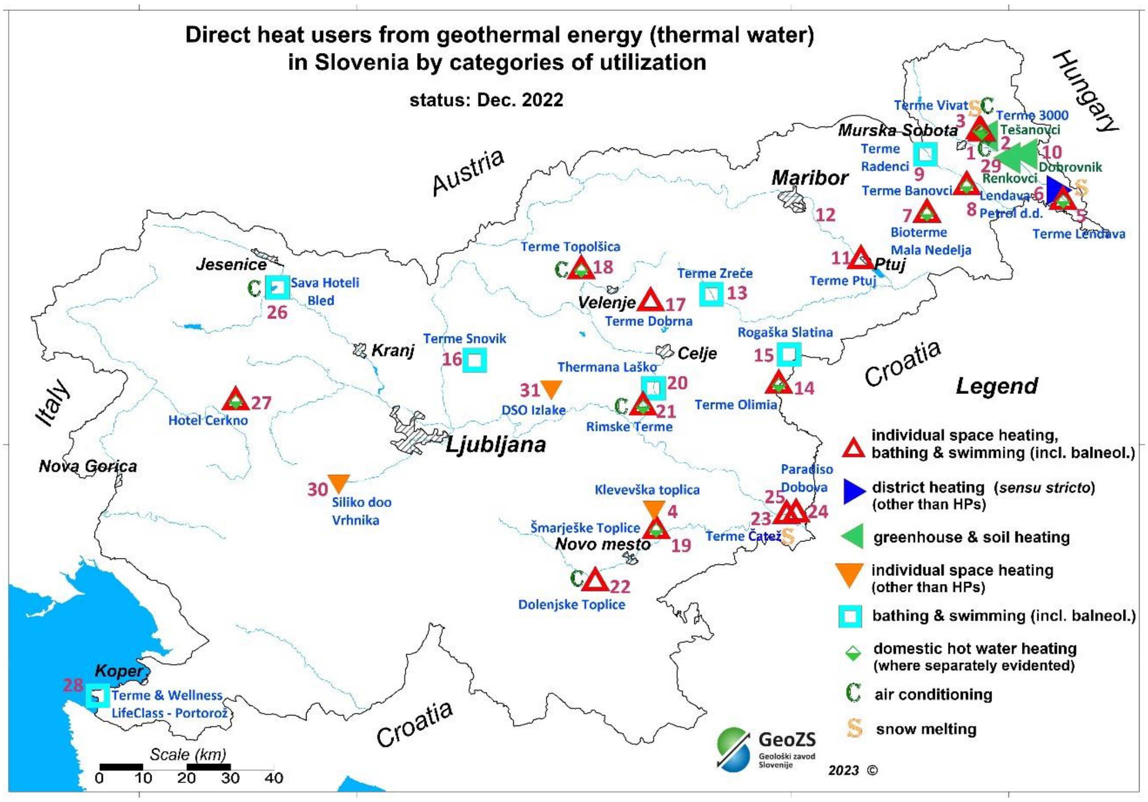

Figure 5: Direct heat users of geothermal energy in Slovenia, classified by types of direct heat use according to the previous WGC standard tables (status Dec. 2022). The user numbers are the same as in Fig. 1.

3.3.1 Individual space heating with domestic hot water (DHW) heating

Individual space heating, as type of heat use from the previous standard tables, is implemented at 18 locations (Figure 5), predominantly thermal spas and resorts, mostly through heat exchangers (e.g. Terme 3000 and Terme Vivat at Moravske Toplice, Banovci, Lendava, Ptuj, Mala Nedelja, Rimske Terme, Čatež, etc.) or geothermal HPs (e.g. Olimia, Dobrna, Topolšica, Šmarješke Toplice, Dolenjske Toplice, Rimske Terme, Cerkno, Izlake, Vrhnika, Dobova Paradiso, Čatež etc.). The GHP units usually of bigger capacity are somewhere installed in case of too low thermal water temperature for this type of use. The total geothermal energy used for space heating in 2022 was 179.889 TJ (49.969 GWh). This value is lower compared with 46.509 GWh in 2019, owing to more efficient thermal energy use, less energy needed and more correct calculation. At five locations the DHW heating is included in the space heating values and couldn't be evaluated separately (Dobrna, Dolenjske Toplice, Terme Čatež, Dobova Paradiso and Izlake). For other ten users (both users at Moravske Toplice, Terme Lendava, Mala Nedelja, Banovci, Olimia, Topolšica, Rimske Terme, Šmarješke Toplice and Cerkno) geothermal energy used for DHW heating was calculated separately, giving some 31.867 TJ (8.852 GWh) in 2022. The space heating together with DHW heating gives in total 211.756 TJ (58.821 GWh) of used energy.

3.3.2 District heating (*sensu stricto*)

Only one geothermal district heating (DH) system (*sensu stricto*) is operational in Slovenia at present. In Murska Sobota and at Benedikt the DH systems are not heated geothermally anymore since they both switched to fossil fuel few years ago. The future of geothermal DH there remains uncertain. Only in Lendava town (number 6 in Fig. 1, 5 and 6) some 20 public buildings (schools, kindergarten, theatres, business and shopping centers, hotels, etc.) and ca 610 apartments in blocks (total 60,000 m^2) are heated under the Petrol Geo d.o.o. authority (under project operator Petrol d.d.). The connection of the first users to the district system began in 2007. The total geothermal energy used for district heating in 2022 was 19.733 TJ/yr (5.481 GWh/yr), for 9.9 % higher compared with 17.96 TJ/yr in 2019.

3.3.3 Air conditioning

Air conditioning (AC or cooling) of the hotels' spaces using geothermal heat with the help of GHPs is maybe not well documented. To our knowledge it is operational only at five locations: Moravske Toplice Terme 3000 (number 1 in Figs. 1, 5 and 6), in few hotels at Bled (26), Dolenjske Toplice (22), Topolšica (18) and Rimske Terme (21), contributing about 14.703 TJ in 2022 (4.084 GWh), compared to 10.91 GWh at six locations in 2019.

3.3.4 Heating and cooling with GSHP systems (use of shallow geothermal)

Shallow geothermal energy use for space heating, especially with small HP units, is becoming more popular and widespread in Slovenia. The market boom in larger scale began obviously some 12 years ago following a period of slow rise in the early 1990's, when there was low interest in GSHPs owing to high initial costs, high price of electricity and low prices of oil and gas. The number of installed operating GSHP units, their capacity and other necessary data are obtained every year through our inquiry from all manufacturers and main dealers of heat pumps, both domestic and foreign brands, present on the Slovenian market. Since no national statistics are available, in this manner fairly realistic figures on operating units and their annual trend are gained.

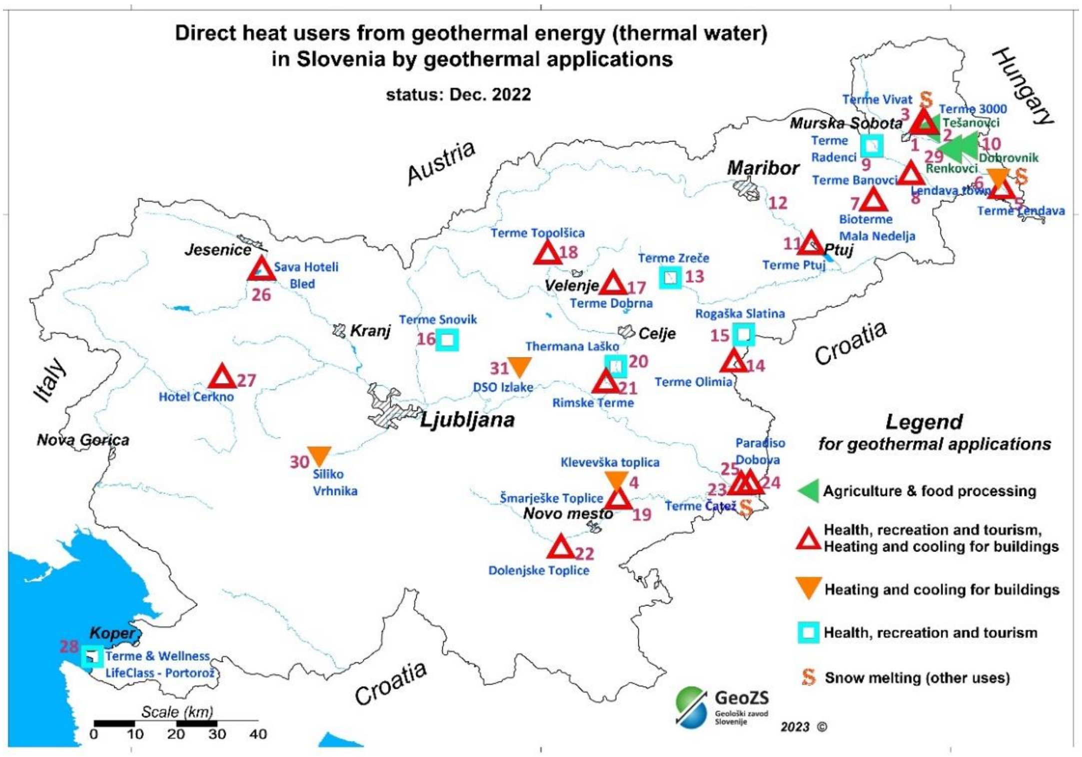

Figure 6: Direct heat users of geothermal energy in Slovenia, classified by geothermal applications given in Table 3 (Summary of H & C installations) (status Dec. 2022). The user numbers are the same as in Fig. 1 and 5.

As of the end of December 2022, some 15,099 operational small-capacity GSHP units (usually 11 to 12 kW) with a total rated power of 184.01 MWth are in the country, which in 2022 recovered 912.64 TJ (253.51 GWh) of shallow geothermal heat. Of these, about 45.5% are connected to open-loop water-water systems, which obtained 469.88 TJ from shallow groundwater, 33.9% are with closed-loop horizontal collectors with 271.17 TJ of obtained energy, and 20.6% with closed-loop vertical collectors (borehole heat exchangers or BHEs) with 171.6 TJ of obtained energy. In 2022, small closed-loop units recovered a total of 442.77 TJ of thermal energy from the shallow underground. The number of large-capacity GSHPs (with ≥ 20 kW) has been increasing in the last fifteen years. Around 1036 such units with a total of 76.1 MWth have already been sold and most of them also installed in the country, predominantly for heating or heating and cooling in public buildings (kindergartens, schools, cultural institutions, sports facilities, etc.), industrial, tourist and office buildings. In 2022, they obtained 382.08 TJ (106.13 GWh) of heat from the underground. Of these, 757 units are connected to an open water-water system (73.1%), 245 units have BHEs (23.6%) and 34 (3.3%) have horizontal collectors. Of the total of 16,135 GSHP units, 7626 units (47.3%) are connected to open-loop systems, which obtained around 780.93 TJ of underground thermal energy, 5152 units (31.9%) are coupled to closed-loop horizontal collectors (with 277.63 TJ of recovered heat) and 3357 units (20.8%) are coupled to BHEs (with 236.16 TJ of recovered heat). Therefore, approximately 1294.73 TJ (359.65 GWh) of heat was recovered in 2022 in the heating mode with the GSHP technology, which is by 18.8% more than in 2020 (Table 2a), while in the cooling mode, according to our estimate, at least 300 TJ/year of heat was rejected to the ground or water. The shallow geothermal energy sector contributed 70.1% of all net energy extracted from underground, compared to 62.7% in 2019. The number of GSHP units is the best possible estimate of the state of sold units. Presumably, the number of installed units is approximately equal to the number of operating units (Figure 8), and we assume, similar to experience in Switzerland (Rybach, personal comm.), that no more than 5% of all units sold are non-operating.

In recent years, we have noticed that all large-capacity GSHPs are not yet operational or have not even been installed. On the other hand, we are also not certain whether some lesser-known and less present foreign brands were omitted in the inquiry for sold units. Our effort to distinguish the GSHP units with rated power of >20 kW from the total number is quite tedious in finding appropriate objects with such installations. Figure 7 shows some 351 large-capacity units for which detailed data have been collected so far, reflecting their concentration in more inhabited and plain regions with favorable hydrogeological conditions for setting up the open-loop systems.

3.4 Other uses (snow melting)

Under this application only *snow melting* is included, which is implemented in 3 locations in winter. In Lendava the sidewalks are heated using geothermal heat from utilized thermal water within the doublet system (number 6 in Figures 1, 5 and 6), with about 0.095

TJ in 2022. 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 Terme Čatež (number 23) with 7.46 TJ. Altogether, from the total capacity of 0.87 MWth the used geothermal heat was 8.581 TJ (2.384 GWh), compared to 14.66 TJ in 2018.

4. DISCUSSION

The distribution of capacity and annual energy use for various direct heat use applications as presented in Table 2a are based on reported data from the users of thermal water and from the GSHP producers and sellers. The total utilized geothermal energy, both with the direct heat use from thermal water (deep wells and captured thermal springs) and with the use of heat from shallow underground with GSHPs, amounted in 2022 to at least 1846.58 TJ/year (512.94 GWh/year) of thermal energy with a corresponding capacity of 318.42 MWth. This is 11.4% more than in 2021 and 14.8% more than in 2019 (the last year before the pandemic), mostly thanks to the unstoppable growth of the GSHP sector, as the pandemic has had the biggest impact on the lower activity of our spas and health resorts and consequently to a significant reduction in the use of thermal water from deep wells, especially in 2020.

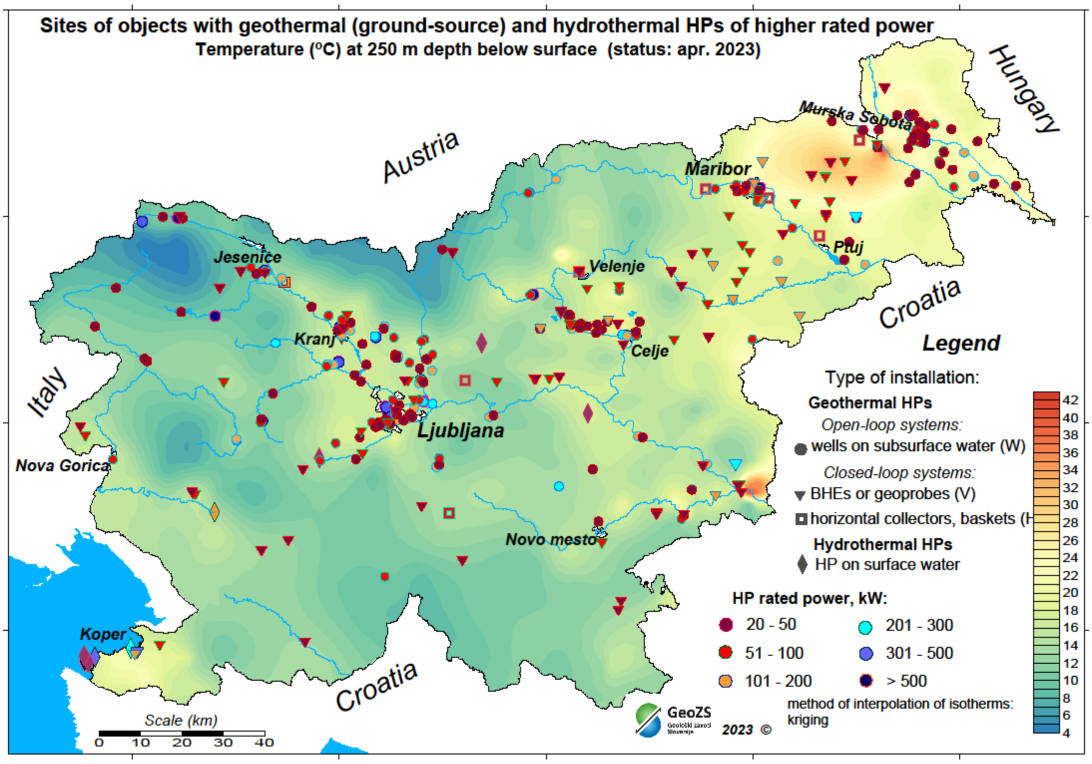

Figure 7: Distribution of 351 installations with collected detailed data on GSHP systems with rated power of at least 20 kW, by type of installation, and 10 known hydrothermal HP unit systems (data collected on a voluntary basis). The isotherms show temperature at 250 m depth.

Table 2a: Summary of installed capacity and geothermal energy used in 2022 by geothermal applications given in Table 3.

Geothermal application	Capacity	Annual energy use			Capacity factor	Share of energy
	MW_{th}	TJ/yr =	GWh/yr =	ktoe/yr		%
Agriculture and food processing:						
Greenhouse heating	7.36	122.48	34.02	3.05	0.53	6.6
Health, recreation and tourism:						
Bathing & swimming (incl. balneology)	20.35	174.60	48.50	4.34	0.27	9.5
Heating and cooling for buildings:						
Individual space heating 1)	21.10	179.89	49.97	4.48	0.27	9.7
District heating, *sensu stricto* 1)	2.82	19.73	5.48	0.49	0.22	1.1
Air conditioning (cooling)	2.53	14.70	4.08	0.37	0.18	0.8
DHW heating (when separately evidented)	3.29	31.87	8.85	0.79	0.31	1.7
GSHPs – small units, <20 kW	184.01	912.64	253.51	22.70	0.16	49.4
GSHPs – big units, >20 kW	76.10	382.08	106.13	9.51	0.16	20.7
Subtotal A: only GSHPs	**260.11**	**1294.72**	**359.65**	**32.21**	**0.16**	**70.1**
Other uses:						
Snow melting	0.87	8.58	2.38	0.21	0.31	0.5
Subtotal B: direct use from thermal water	**58.31**	**551.86**	**153.29**	**13.73**	**0.30**	**29.9**
TOTAL: A+B	**318.42**	**1,846.58**	**512.94**	**45.94**	**0.18**	**100.0**

1) Other than heat pumps

The total capacity of wells and springs for all 29 users (the Tešanovci greenhouse considered as a separate user in Moravske Toplice), amounted to 58.31 MWth in 2022 (Figure 3), and the annual geothermal energy used was 551.86 TJ (=153, 29 GWh), which is for 22.2 TJ (or 16.9%) more than the year before (Figure 4, subtotal B in Table 2a). In recent years, a larger share of utilized geothermal energy belongs increasingly to used shallow geothermal energy with GSHP technology. With an installed capacity of 260.11 MWth, this recovered 1294.73 TJ/year (359.65 GWh/year) of energy from the shallow underground (Figure 9), or 9.3% more than in 2021. Since 2013, the GSHPs have had a share of more than 50% in all heat obtained from geothermal energy, and this has only increased over the years. They are followed by other applications of use of geothermal energy from thermal water (Table 2a).

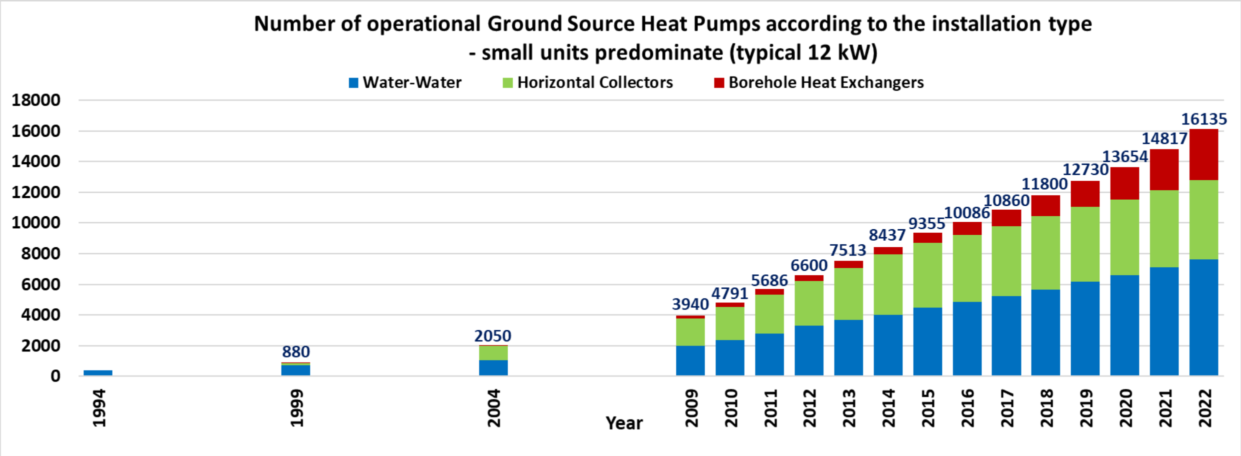

Figure 8: Trend of numbers of operational GSHP units (both small & big-rated capacity) since 1994 by type of installation.

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 over 20 kW. These plants are rarely included in any records because the owners (investors) rarely 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. Several bigger open-loop systems have 4 production and 4 reinjection wells or more. Similarly, the biggest closed-loop systems have more than 20, many of them over 30 BHEs or more (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).

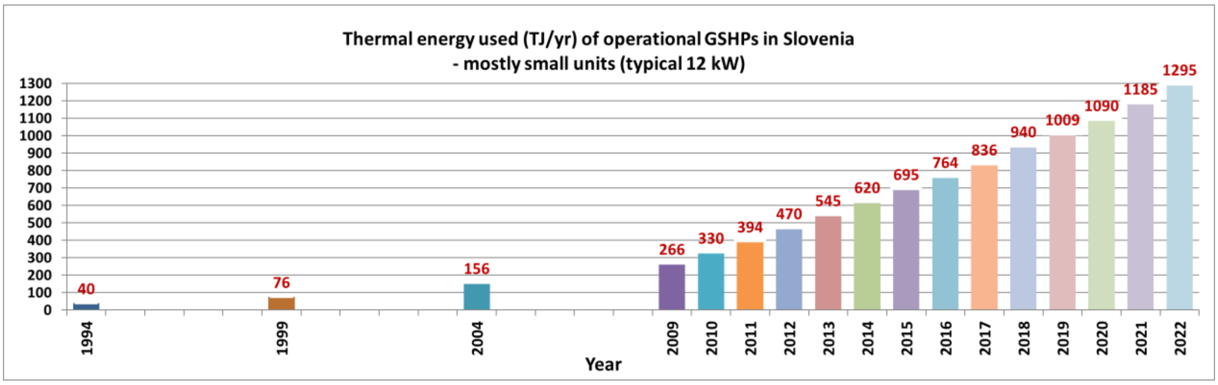

Figure 9: Trend of shallow geothermal energy used (TJ) by operational GSHP units (both small & big-rated cap.) since 1994.

The value of geothermal energy has already been recognized by the Ministry of Agriculture, Forestry and Food, for which in 2021-2022 the task “Assessment of the possibility of using geothermal energy in agriculture in Slovenia” was carried out. In 2022, the use of geothermal energy in agriculture took place in only three locations, which together contributed to 6.6% of the total use. Shallow geothermal energy systems are not used for greenhouses or other extraction purposes in agriculture, nor is there any information about use for drying or cold storage. Given the lack of information about the existence of geothermal potential and possible technological solutions, as well as weak past investments, we see a great need for systematic incentives (financial and information-development) if we want to increase the use of geothermal energy in agriculture in the short- and medium-term. As a first step could be the result of the aforementioned task, where priority areas for investment incentives for the development of deep and shallow geothermal energy for use in greenhouses should be defined in 2023.

5. CONCLUSION AND FUTURE DEVELOPMENT

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 88.5 TJ every year in the last 6-year period. Actual (Dec. 2022) contribution in direct heat use from deep geothermal energy reached 551.86 TJ and thermal energy used by all GSHP units so far reached 1294.73 TJ, all together 1846.58 TJ (512.94 GWh). Consequently, target values (Website 4) on use of renewable energy sources are still quite distant, and a lot of effort will be needed beyond 2022.

A geothermal doublet scheme is operational only in Lendava. In northeastern Slovenia the localities are the most vulnerable to overexploitation of thermal water as most users capture water from the same aquifer. In this sense the Murska Sobota community achieved a good success with drilling the two new boreholes 8 years ago for enlarging the district heating purpose in the northern parts of town. The results of testing in 2012/13 showed thermal capacity of the new doublet could reach 4 MW_{th} and geothermal energy use 8.8 GWh/year. This could be the second doublet system operating in the country when it becomes functional, but it is still not. The planned extension to about 7 geothermal DH systems (*sensu stricto*) in the country by 2016 (Rajver et al., 2020) proved to be unrealistic so far, as the extensions at Murska Sobota and Benedikt and new plants at Turnišče and Ormož did not happen. Situation about the major planned investments in deep geothermal is unclear in near future in these communities.

Currently, most progress is foreseen through implementing new projects from the EEA Grants in years 2022-2024. The SI-Geo-Electricity project will hopefully result in a pilot power plant on an abandoned gas well, and the INFO-GEOTHERMAL, Supporting Efficient Cascade Use of Geothermal Energy by Unlocking Official and Public Information, will not only train future professionals but also prepare new professional bases and legislation amendments for the use of geothermal energy in the cascade use systems and for geothermal electricity, and establish an active support environment to accelerate the development of this sector. Many private investments are foreseen in shallow geothermal but from a research point of view the ARRS CRP project GeoCOOL FOOD - Cold food storage using shallow geothermal energy will help Slovenia to store its cabbage and lettuce products for a longer time.

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