Geothermal Energy Use, Country Update for Slovenia

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ABSTRACT

In geothermal energy use in Slovenia in its northeastern part, belonging to the Pannonian Basin geothermal region, practically no progress was achieved in geothermal development during the last three years, since not a single new geothermal borehole was drilled there. Two boreholes (for a doublet system) for the planned district heating of Murska Sobota town are still inactive since 2015. Most production wells there tap thermal water from the Miocene sand aquifers, that is from Mura Fm. with temperatures of 54 to 62 °C and from Špilje Fm. with up to 76 °C. The installed capacity and annual energy use of all 31 users in the country amounted to 62.43 MWt and 578.6 TJ. More efficient use of thermal water is evident at some sites due to implementation of concession fees in 2015 for thermal water utilization, which led to lower annual energy use in 2018 compared to 2016-2017, owing to a bit lower pumped volumes and more correct data. Greater progress is evident in shallow geothermics, where the number of smaller ground-source heat pump (GSHP) units of typically 12 kW reached around 11,182 with 135.6 MWt capacity and 683.3 TJ/yr energy use (Dec. 2018). The number of bigger GSHP systems with heat pumps of rated power over 20 kW is in constant increase during the last 14 years, resulting in 49.5 MWt and 132.7 TJ/yr, with some 588 HP units sold so far, mostly in public or private buildings. The total numbers in 2018 for both deep and shallow geothermics were 247.47 MWt and 1,516.79 TJ/yr (421.33 GWh/yr). Drilling activity for direct heat use was much lower than in previous period, with only 0.15 km in total of 3 reinjection boreholes at Izlake, with no production boreholes nor temperature gradient ones. It's expected that energetic renovation of older buildings and installation of the GSHP units will continue in the future as one of the obligations to reach the renewable energy targets.

1. INTRODUCTION

Geothermal resources in Slovenia were described already before the 20th century. Development in the 18th and 19th century led to emergence of health resorts at eight different locations and, at the same time, the first investigations into the origin, chemistry and healing effects of thermal waters were performed (Lapanje & Rman, 2009). The real systematic explorations began much later in 1974 after the first oil crisis. The present status of direct heat use and development in the last three years is presented in the paper. However, geothermal energy use in Slovenia (with surface of 20.273 km^2) has been statistically followed by Geological Survey of Slovenia on regular basis since 1994 with update reports presented at World Geothermal Congresses (Rajver et al., 2015 and references therein), while at European Geothermal Congresses since 2013.

Very probably it's not expected that at the present state of knowledge any electricity production from geothermal in Slovenia could be realistic by 2025. Due to lack of natural steam reservoirs, geothermal energy in Slovenia cannot be converted in Dry Steam or Flash Steam power plants into electric power. Only binary technology is promising, but it is also disputable, temporal as well as geologically. The government supports in principle the direct use of geothermal energy through different projects where few leading agencies are involved in geothermal development, principally in shallow geothermics. So, private companies and energy consulting agencies are involved in demonstration projects for greater ground-source (geothermal) heat pump (GSHP) development. The goal of appropriate ministries is also to raise the general public awareness to deal more carefully with energy consumption. Leading companies and institutes involved in geothermal development are: Geological Survey of Slovenia, Petrol-Geo d.o.o. (as subsid. of Petrol d.d.) and several small business enterprises.

Emphasis of direct use of geothermal energy is on exploitation of low temperature resources for space and district heating, for greenhouses and thermal spas. During the last 18 years the direct use showed only slight and changing increase and recently just a stagnant state with exception of the GSHP units. The reasons depend on the locality. Overexploitation of geothermal resources in some localities of the north-eastern part of the country (Kralj and Kralj, 2000; Rman, 2014; Rman et al., 2012 and references therein) is one of the problems, plus 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 and heat pumps for the improvement in using the available heat in a better way, and not to discard it at a too high temperature. GSHP sector is the only category showing a strong steady growth.

2. GEOTHERMAL RESOURCES AND POTENTIAL

A description of geology, geothermal resources and potential is given in the previous country updates (Rajver et al., 2015, 2016 and references therein). Geological and tectonic setting of Slovenia is quite complicated as it is subdivided into several tectonic units with different hydrogeological properties and geothermal conditions (Figure 1). In the northeast, the Mura-Zala basin (the southwestern part of the Pannonian basin) and the Eastern Alps (incl. magmatic rock complex) are parts of the European plate. Predominately carbonate Southern Alps, the External and the Internal Dinarides and the Adriatic foreland represent parts of the Adriatic microplate. More information on geological aspects is described in papers by Ravnik et al. (1995), Placer (2008), Pleničar et al. (2009) and references therein. The 24 thermal (natural and captured) springs have constant temperature close to or above 20°C, with 36°C as a maximum, however, there are several drilled localities where no surface thermal manifestations previously existed, and the thermal water was discovered during the oil and gas drillings (Lapanje and Rman, 2009). Details about the geothermal field of Slovenia and geotectonic background are described by Ravnik (1991), Ravnik et al. (1995), Rajver et al. (2012), Diepolder et al. (2015). Geothermal resources in the Pannonian and Krško basins have been studied in more detail (Rajver et al., 2002; Rajver and Ravnik, 2003; Rman et al., 2015).

2.1 Potential for geothermal power production

Natural steam reservoirs at relatively shallow depths haven't been detected yet. 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 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 this NE part indicate potential geothermal resources, technically exploitable for electricity production, but only with restrictions (Rajver et al., 2012). The perspective geothermal reservoirs are (for localities' details see Rajver et al., 2016):

(a) hydrothermal reservoirs in depths less than 3 km and at temperature high above 80 °C: aquifers of the Lendava, Špilje and Haloze formations, NE of Murska Sobota and near Lendava.

(b) hydrothermal reservoirs in depths of 3 to 6 km and at temperature above 150 °C: carbonate rocks of the Pre-Neogene basement in the Radgona-Vas tectonic half-graben and in the Boč-Ormož antiform.

(c) EGS (HDR systems) at least 4 km deep in low permeable metamorphic or magmatic rocks: the Pohorje granodiorite massif and the Pre-Neogene basement of the Mura-Zala basin.

According to the current geological knowledge these reservoirs are very limited in space. New geological investigations and geothermal wells should be targeted on finding a geothermal aquifer with a wellhead fluid temperature high above 90 °C and a yield above 25 kg/s which allows the binary cycle utilization. This may also be achieved by using EGS technology. However, deeper wells would be needed to reach at least the 150 °C isotherm.

2.2 Resources and potential for direct use

The northeastern part has been intensively investigated in recent years within the European projects TRANSTHERMAL (Lapanje et al., 2007), T-JAM (Lapanje et al., 2010; Nádor et al., 2012), TRANSENERGY (Rman et al. 2015), GeoMol (Diepolder et al., 2015) and project in progress 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. Better insights are gained in characteristics of the geothermal field, hydrogeological conditions of eastern Slovenia and potentials for direct heat utilization (Rman, 2014; Rman et al., 2015; Tóth et al., 2016). The area has an elevated surface heat-flow density (HFD), above 100 mW/m^2, with expected temperatures above 80°C at 2 km depth east of the Maribor - Ptuj towns line (Rman et al., 2012). All production wells there exploit thermal water from Neogene aquifers with exception of those in Maribor (number 12, in Figure 1). About 20 inactive and some 11 new potential wells exhibit the wellhead temperatures of 20 to 72°C and have a total maximum yield of 281 kg/s, resulting in the ideal thermal power of 23.9 MW$_t$. The geothermally most utilized northeastern area that belongs to the Mura-Zala basin is filled by Neogene marine and fresh water sediments. Clays and marls predominate, with intercalations of porous sands and sandstones, where mineral, thermal and thermo-mineral waters are found. The most extensive Upper Pannonian-Pontian geothermal sandy aquifers, which are widely utilized by Hungary and Slovenia, are composed of 50 to 300 m thick sand-prone units that are found in depth interval of about 0.7 to 1.4 km in the interior parts of the Pannonian basin, with temperatures from 50 to 70 °C (Nádor et al., 2012).

Hydraulically connected sandy lenses of the Upper Pannonian-Pontian Mura Fm. represent the best yielding low temperature geothermal aquifer in the sedimentary basin in Slovenia. It is utilized at Banovci (number 8 in Fig. 1), Dobrovnik (10), Lendava (5 and 6), Mala Nedelja (7), Moravske Toplice (1, and 3), Tešanovci (2), Murska Sobota (4), 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 and Murska Sobota 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% mostly. The 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. Since 76 °C is the highest wellhead temperature at 2 wells there, it is a signature that no thermal water comes from horizons deeper than ca 1700 m (Fig. 3).

In the SE part of the country the thermal water is mostly found in the Krško sedimentary basin along its southern edge in the Mesozoic carbonate rocks beneath the Tertiary cover. A small 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 yields ranging from ca 1 to 13 kg/s (numbers 23, 24, 25 in Fig. 1), while at Šmarješke Toplice (19) up to 15 kg/s per well.

2.3 Potential for ground-source heat pumps

2.3.1 Ground - water systems (GCHPh and GCHPv)

Clastic rocks cover over half of the Slovene territory, carbonate rocks about 40%, while pyroclastic, metamorphic and crystalline rocks less than 8%. For horizontal heat exchangers suitable rocks are sand and sandy clay, flysch rocks such as sandy marls or loose sandstone and sandy claystone. For vertical heat exchangers (or BHEs) the most suitable are dolomite, dolomitic limestone and limestone, and most of magmatic and metamorphic rocks. Fig. 2 shows geological and hydrogeological potential for the GSHP applications that include the ground-coupled heat pump (GCHP) types of installation (horizontal and vertical). Shallow karstic underground is neither very favourable for vertical systems presenting the uncertainty in drilling, with prediction in higher drilling costs.

2.3.2 Water – water systems (GSHPw)

The northeastern part of Slovenia (Pannonian basin) appertains to a major groundwater basin with relatively high recharge (100–300 mm/year) in Quaternary and shallow Tertiary layers. The rest of the Slovene territory is of complex hydrogeological structure with very high recharge (>300 mm/year). About 7% of the territory is covered by extensive and highly productive gravel and sand alluvial aquifers which are very favourable for open GSHP systems. The major cities are situated on these alluvial plains. The temperature of groundwater is characteristically between 10 and 15 °C. Groundwater table is 2 m to 25 m deep and the water quality is rarely aggressive. Individual open vertical systems can be successfully used also in the areas of inter-granular aquifers of medium hydraulic conductivity and above the fissured aquifers of medium hydraulic conductivity (dolomitic aquifers). Limestone aquifers cover 35% of the territory where the groundwater accessibility is rather low and conditions not favourable for open vertical systems. Closed vertical systems are more applicable. Similar conditions are for the other 35% of territory with only minor and discontinuous aquifers (flysch layers, marl, sandstone, siltstone, claystone) where closed vertical and horizontal systems are mostly applicable. Temperature distribution at a depth of 250 m below the surface (Fig. 8) shows the best conditions for GSHP systems, especially deeper BHEs (somewhere >20 °C) in the NE part, and elsewhere only average temperatures between 10 and 16 °C.

2.3.3 Thermal energy storage

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. Groundwater flow velocities are characteristically rather high in most alluvial aquifers, reaching the magnitude of 10 m/day which could not be so favourable for conventional ATES. Nevertheless, specific conditions should be explored locally. According to the hydrogeological setting in Slovenia and pretentiousness of ATES technology, borehole thermal energy storage (BTES) could be applied in higher extent than ATES.

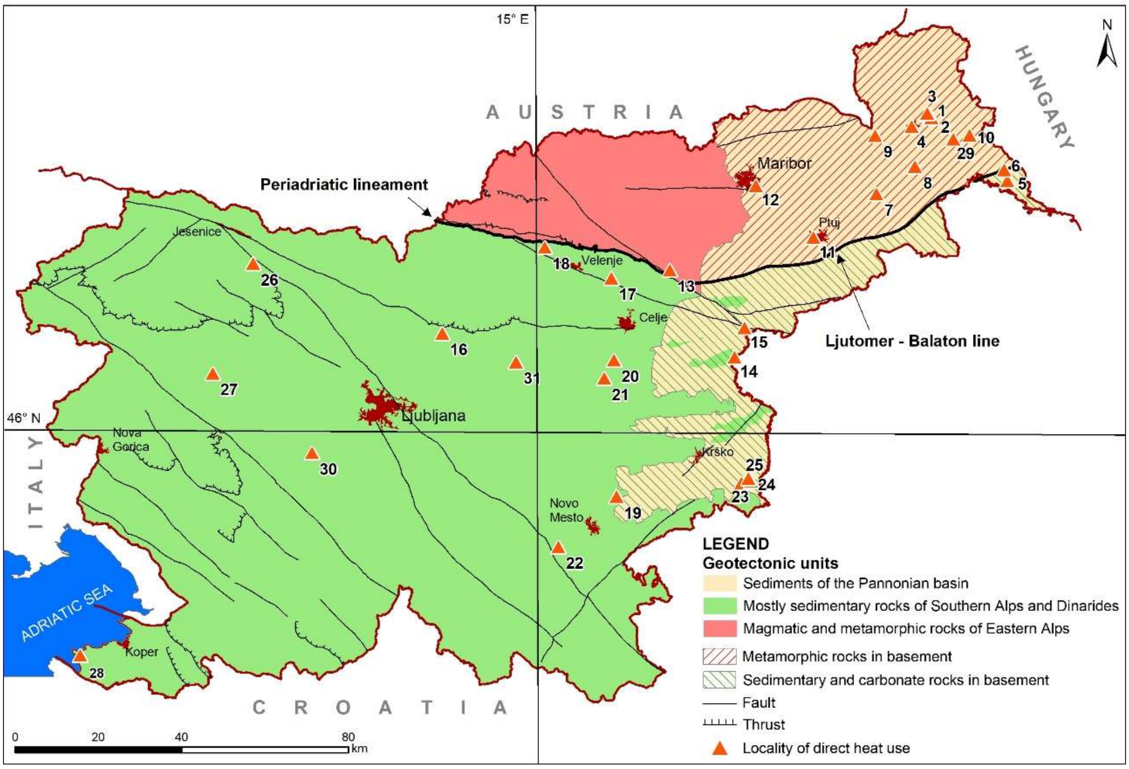

Figure 1: Generalized geological map of Slovenia with localities of direct heat use in 2018 (geology after Poljak, in Rajver et al., 2016).

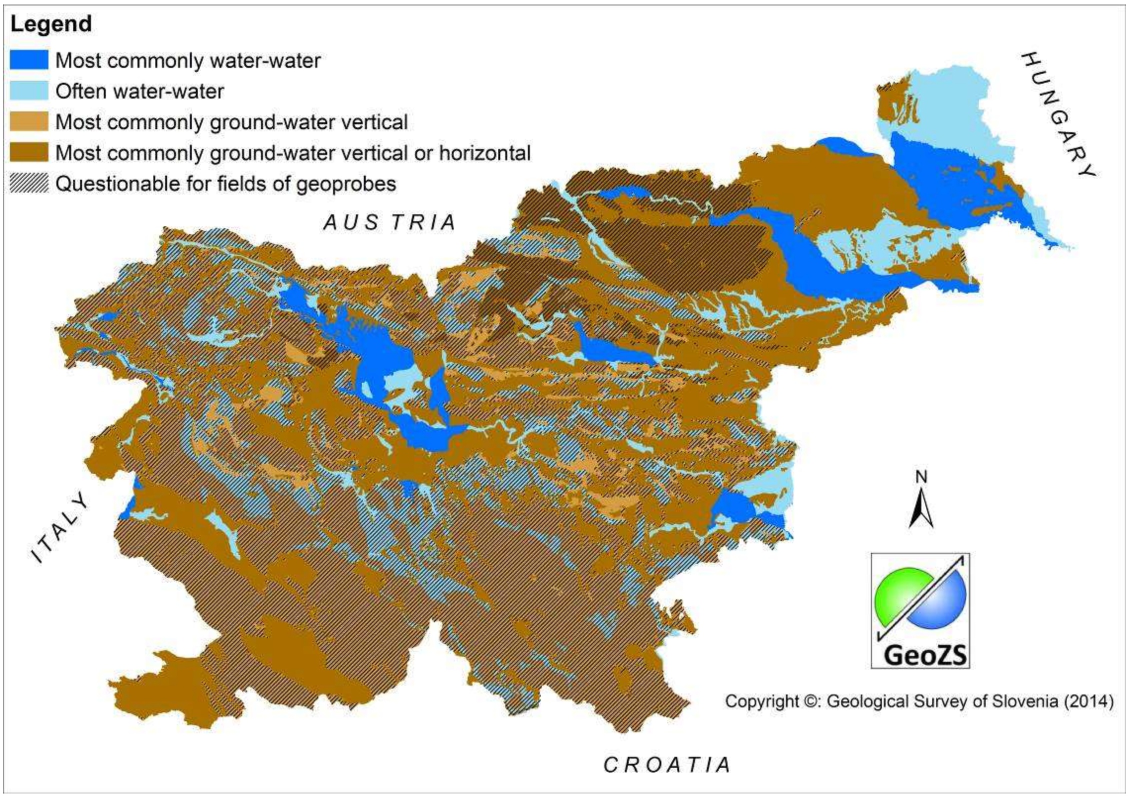

Figure 2: Potential for the GSHP applications in Slovenia (improved after Prestor et al., 2012).

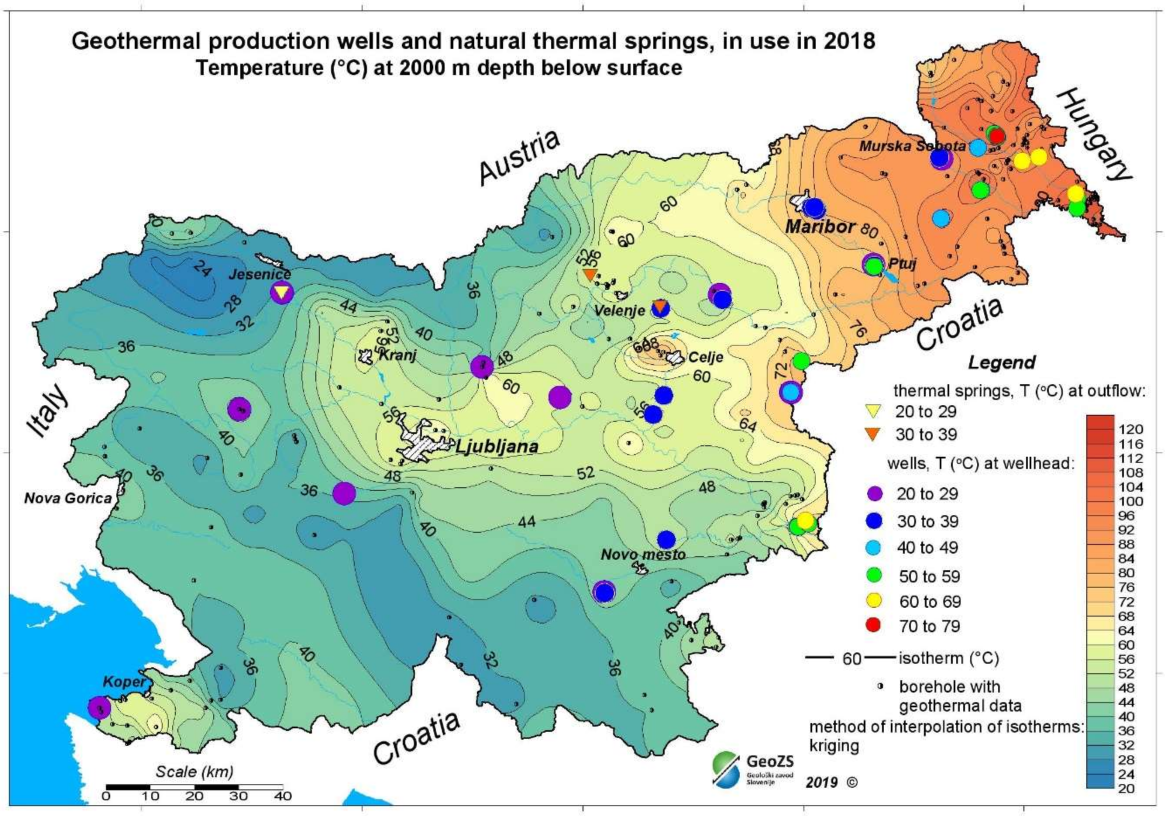

Figure 3: Production geothermal wells and natural thermal springs, in use in 2018 in Slovenia (status: Dec. 2018); Expected temperatures at 2000 m depth beneath the surface.

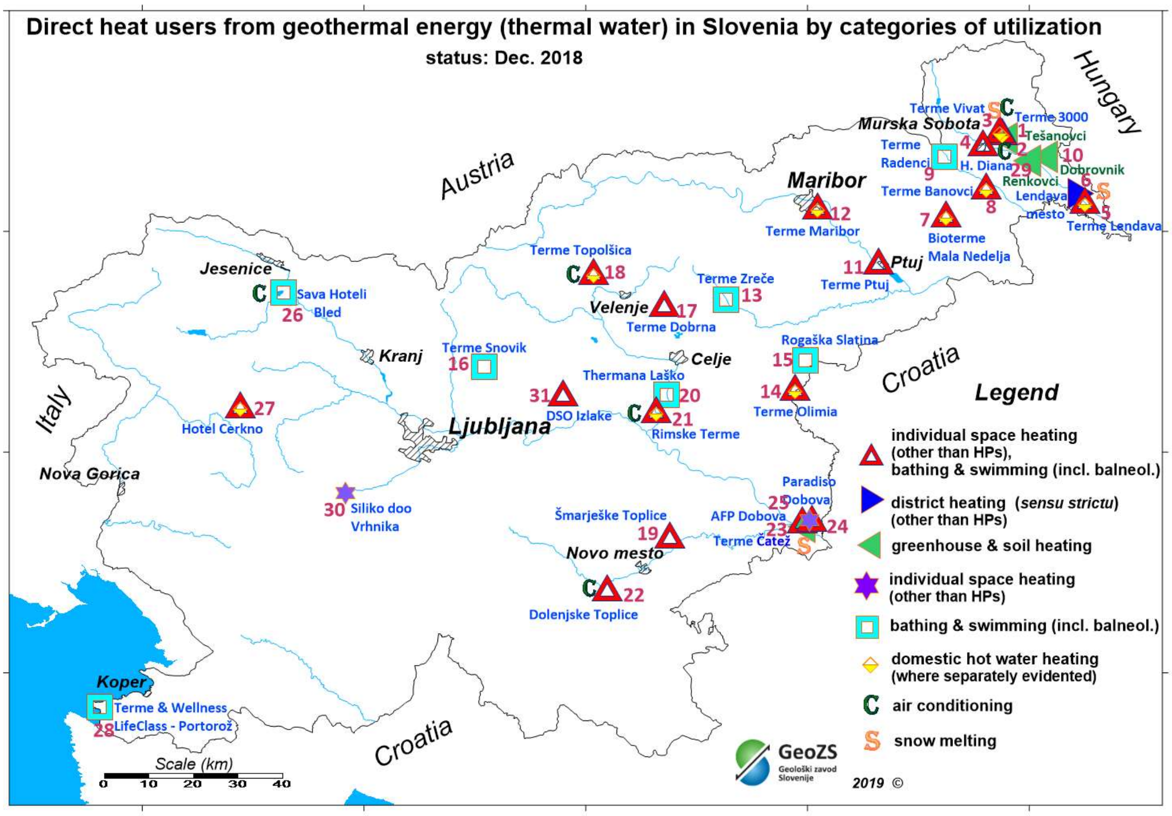

Figure 4: Main utilization types for direct heat use of geothermal energy (thermal water) in Slovenia (status: Dec. 2018); numbers are the same as in Fig. 1.

3. GEOTHERMAL UTILIZATION

There is no electricity generation from geothermal resources in Slovenia up to date. Geothermal utilization of thermal water heat is based on direct use from 55 production wells plus 3 thermal springs, implemented at 31 localities. At 3 localities, which were reported for EGC 2016, geothermal energy is not used anymore. Due to economic reasons the Benedikt municipality and Komunala Murska Sobota switched to another energy source for their district heating systems, while the small Toplice Kopačnica pool was closed by the nearby municipality Gorenja Vas. Therefore, since the EGC 2016 report no new direct heat users have emerged in Slovenia. Figure 4 shows main utilization types for direct heat use.

In Slovenia, geothermal energy is estimated to currently supply for direct heat uses and geothermal (ground-source) heat pump (GSHP) units at least 1,516.79 TJ/yr (421.33 GWh/yr) of heat energy with corresponding installed capacity of 247.47 MW_t. Of these values direct use is 62.43 MW_t and 578.57 TJ/yr (160.71 GWh/yr, by 23% more than in 2015), and the remainder, 185.04 MW_t and 938.23 TJ/yr (260.62 GWh/yr, by 35% more than in 2015) are GSHPs (Table E). Since 2013 the GSHPs are the main application of use with more than 50%, followed by geothermal "DH plants" (according to explanation to tables C, D1 and D2), 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 5 and 6). Since few years ago we follow the thermal water extraction by the monitoring system, established at 23 localities, and we receive pretty much correct values from the other 8 users, only few corrections had to be made for values as back as to 2015. The values for capacity and energy supplied by the GSHP units are quite correct as we try to determine as much exact number of units sold (installed) as possible.

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 4), where several public buildings (school, kindergarten, etc.) and blocks of flats (total 50,000 m^2) are heated under the Petrol Geo d.o.o. (subs. of Petrol d.d.) authority. Namely, in Murska Sobota the residential areas and a theater under Komunala authority are not heated geothermally anymore (due to unfavorable concessions fees introduced), nor at Benedikt in a small scale for few public buildings, both since 1st Jan. 2016. The future of geothermal DH there remains uncertain. However, following the explanations for Tables C and D1, there are 16 users with geothermal DH plant network. These are 15 spas and/or thermal resorts with bathing/swimming pools and balneology facilities, where besides space heating (and at five users also cooling), also greenhouses (at two users), and snow melting (at three users) are accounted for. The total geothermal energy used for these DH plants is 447.772 TJ/yr (124.381 GWh/yr). Of these (Table C), in 2018, the space heating itself took 144.408 TJ (40.113 GWh) of geothermal heat, DH *sensu stricto* 18.098 TJ (5.027 GWh), air conditioning 28.249 TJ (7.847 GWh), greenhouses 21.503 TJ (5.973 GWh), snow melting 14.641 TJ (4.067 GWh), bathing and swimming (incl. balneology) 178.951 TJ (49.707 GWh) and domestic hot water (DHW) heating 41.921 TJ (11.645 GWh).

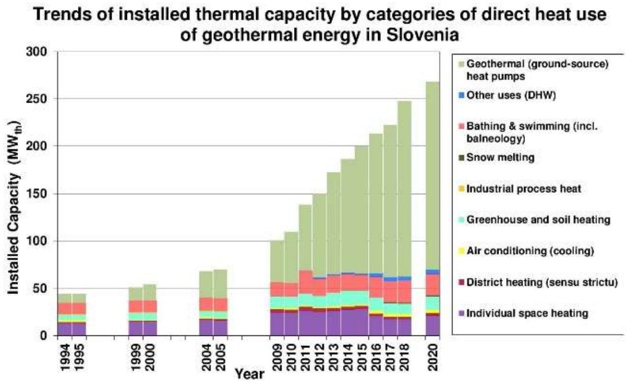

Figure 5: Geothermal direct use applications in a period 1994-2018 (total capacity in 2018: 247.47 MW_t).

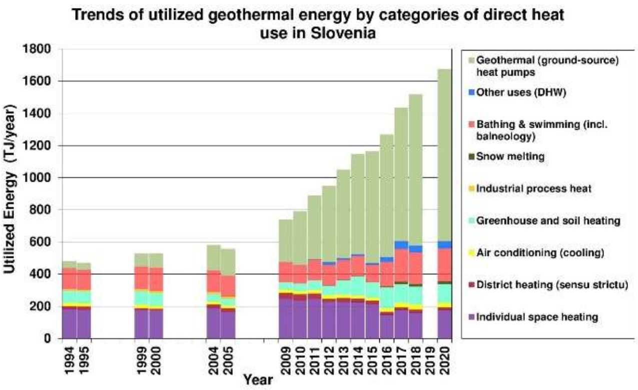

Figure 6: Geothermal direct use applications in a period 1994-2018 (total energy used in 2018: 1516.79 TJ).

3.2 Agriculture (greenhouses) and industry

In eastern Slovenia the heating of greenhouses using geothermal water began in 1962 at Čatež (number 23 in Fig. 1). It was performed there by the Flowers Čatež Co. on 4.5 ha for cultivation of flowers. At Tešanovci near Moravske Toplice (number 2) the Grede Agricultural Co. uses the already thermally spent water flowing from Moravske Toplice (Terme 3000) with 40°C to heat 1 ha of greenhouse for tomato production. At Dobrovnik (number 10), the greenhouses of 4 ha by Ocean Orchids Co. cultivate orchids, both for domestic and foreign markets. At Renkovci (number 29), greenhouses of 4 ha were built 6 years ago for tomato and exotic fruit cultivation. The total geothermal energy used in 2018 in greenhouses (15.5 ha) was 111.529 TJ (30.98 GWh). Without two greenhouses (5.5 ha) as part of DH plants (Tešanovci and Čatež, numbers 2 and 23), geothermal energy used at Dobrovnik and Renkovci greenhouses (total 10 ha) was 90.026 TJ (25.008 GWh) (Table C). Total value is slightly higher compared with 26.194 GWh in 2015, due to improved temperature difference used at Tešanovci and Dobrovnik (numbers 2 and 10, resp.), and owing to corrections for Čatež already made. At Čatež, the Terme Čatež d.d. has all production boreholes closely spaced which exploit the same fractured Triassic dolomitic aquifer. The geothermal use for industrial process heat does not exist anymore since January 2009.

3.3 Individual space heating of buildings with domestic hot water heating

Space heating is implemented at 20 localities (Fig. 4), predominantly thermal spas and resorts, mostly through heat exchangers (e.g. Moravske Toplice, Banovci, Terme Lendava, Ptuj, Maribor, etc.) or geothermal heat pumps (e.g. Cerkno, Hotel Diana in Murska Sobota, Izlake, Vrhnika, Dobova Paradiso, 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 2018 was 161.336 TJ (44.816 GWh). Without 15 users, already accounted for as “DH plants” (and excluding Tešanovci greenhouse), geothermal energy used at other five localities (Hotel Diana in M. Sobota, Izlake, Dobova AFP, Hotel Cerkno and Vrhnika, numbers 4, 31, 25, 27 & 30, resp. in Fig. 1) for space heating and DHW amounted to 17.775 TJ (4.938 GWh) (Table C). Total value is lower compared with 59.1 GWh in 2015. Since 2015 space heating with geothermal heat was introduced only at Topolšica (18 in Fig. 1). The DHW heating is included in these values at one locality (Cerkno, number 27), while for the other 15 users the DHW heating is already included as part of DH plants’ network. However, for 10 users it was possible to calculate separately geothermal energy used for DHW heating, some 42.768 TJ in 2018 (11.88 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 front of all other types in 2018. There are 15 thermal spas and health resorts, and additional 10 recreation centres (8 of them as part of the hotels’ accommodation) where swimming pools with a surface area of about 51,600 m^2 and volume of 67,160 m^3 are heated by geothermal water directly or more commonly indirectly through heat exchangers 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 197.328 TJ in 2018 (54.813 GWh). At some users improvements were achieved by better temperature range utilization, first of all at Moravske Toplice (Terme 3000), and at Banovci using heat exchangers, while at Dobrna using GHPs. Utilization at Rimske Terme (number 21 in Fig. 1) has been established again following a general reconstruction of swimming pools and a resort/health center. Apart from geothermal heat for bathing and swimming, already reported for the 15 users within the DH plant networks, this category is also operational at 10 other users: Hotel Diana in M. Sobota (number 4 in Figures 1 and 4), Radenci (9), Zreče (13), Rogaška Slatina (15), Snovik (16), Laško (20), Bled (26), Portorož (28), Hotel Cerkno (27) and Izlake (31). Of total values, the used geothermal heat there amounted to 18.377 TJ (5.105 GWh) in 2018.

Snow melting of the sidewalks using geothermal heat from the already utilized thermal water was applied within the doublet system in Lendava (number 6 in Fig. 1), with about 0.074 TJ in 2018. Snow melting was more applied under two football grounds at Hotel Vivat at Moravske Toplice (number 3) with 0.412 TJ, and under three football grounds at Čatež (number 23) with 14.155 TJ. Altogether the used geothermal heat is 14.641 TJ (4.067 GWh), included within DH plants, compared to 0.667TJ in 2015.

Air conditioning (AC or cooling) of the hotels’ spaces using geothermal heat is not well documented and is so far operational only at six localities: Moravske Toplice Terme 3000 (number 1 in Fig. 1) and Hotel Vivat (3), in hotels at Bled (26), Dolenjske Toplice (22), Topolšica (18) and Rimske Terme (21), contributing about 32.866 TJ in 2018 (9.129 GWh), compared to 5.53 GWh in 2015. Only Bled is the site not included already within the DH plant networks, and geothermal heat for AC was there 4.617 TJ (1.283 GWh) in 2018.

3.5 Geothermal heat pumps

At 12 health or spa resorts, already belonging to the DH plant networks, plus at Hotel Diana (Murska Sobota), at hotels at Radenci, Snovik, Laško, Bled and Izlake (numbers 4, 9, 16, 20, 26, 31) and at Siliko Vrhnika (number 30), the GHPs, typically of bigger capacity (13.2 MW$_t$ 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 small decentralized units in Slovenia is becoming more popular and widespread. The market boom in larger scale began during the last 10 to 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. The ubiquitous heat content within the uppermost part of the Earth’s crust is available practically everywhere in Slovenia except perhaps in the higher mountainous levels (Fig. 2). Depending on local conditions the GSHP units consist of closed loop GCHP (horizontal and vertical heat collectors) ones, or open loop groundwater heat pumps (GWHP). Technical, environmental and economic incentives can be considered advantageous for more rapid introduction of the GSHP systems. This is also backed by support programs from utilities and from the government through subsidies or credits.

The estimation of exact number of GSHP units presently installed in Slovenia was not easy task, nevertheless quite correct numbers are established despite no available national statistics exist. The HP units' sales give practically all the quantity for their estimation, and we successfully acquire them from domestic producers and numerous merchant agents of imported units. As of 31st Dec. 2018, there are about 11,182 operational small GSHP units (typical 12 kW) that extracted 683.25 TJ (189.792 GWh) of geothermal heat in 2018. Of these, 46.3% are open-loop systems that extracted about 352.89 TJ from shallow groundwater, 42.4% are horizontal closed-loop (with 251.53 TJ), and 11.3% are vertical closed-loop systems (with 78.83 TJ). Closed-loop units together removed 330.36 TJ/yr from the ground. There are also bigger capacity GSHP units (>20 kW) installed within about 588 systems in public and other buildings, which extracted 254.98 TJ in 2018. It is discovered year by year that not all of them are operational. Of them, 465 units are open-loop water-water type (79.1%), 91 units are vertical closed-loop (15.5%) and 32 (5.4%) are horizontal closed-loop systems. With total 11,770 GSHP units some 938.227 TJ (GWh) of heat was extracted in 2018, while 67.68 TJ/yr of heat was rejected to the ground in the cooling mode, mostly by GWHP and vertical GCHP systems. Capacity factor for the small GSHP units is 16.0%, and for the bigger units (>20 kW) is 16.3%, the lowest among all the application types, reflecting that small and big units usually utilize a rather narrow temperature difference (< 4 deg.) and for individual heating also the shortest time of full load operating hours, which means not more than 6 months with 12 h/day in Slovenian climate conditions, therefore, usually less than 2000 h/year.

4. DISCUSSION

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 in Slovenia amounts to roughly 62.43 MWt, including GHPs at thermal spas. The annual energy use at 31 localities amounted to 578.57 TJ (160.71 GWh), which is by 23.5% higher than in 2015 (468.56 TJ as corrected value). It is a consequence of some ups and downs at several users. Annual energy use (Fig. 6, 7) is now lower for individual space heating, DH *sensu stricto* and greenhouses, and higher for air conditioning, bathing with balneology, snow melting and DHW heating in comparison with situation in 2015. However, the GSHP sector exhibits the largest share (61.9%) in direct use, compared to 59.7% in 2015.

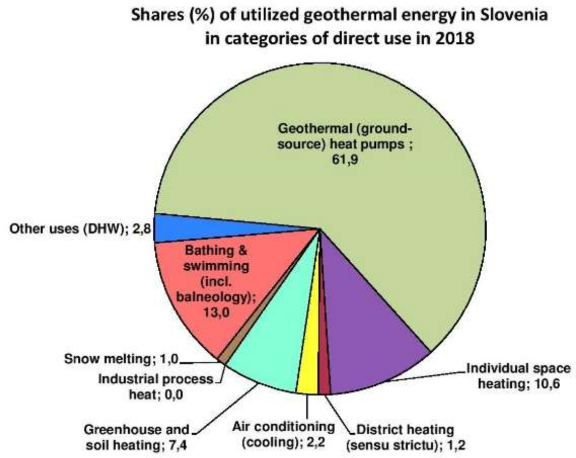

Figure 7: Shares of geothermal energy used in Slovenia in categories of direct use in 2018 (status 31st Dec. 2018).

Considerations on high enthalpy geothermal resources in Slovenia were initiated in previous years whether there are possibilities for electricity production in the north-eastern part (Pannonian basin) where the highest temperatures at depths of 3.5 to 4.5 km are encountered. The capacity of deep wells, also existing ones, is yet to be determined and tested, or new deep exploration (wild cat) boreholes should be drilled at appropriate sites, which must be previously confirmed by better geophysical (seismic, microseismic, microgravimetric, MT) investigations with a goal to create an EGS.

The investments in geothermal (Table F) are just approximate and incomplete, since many direct users and those of shallow geothermal don't report such data. Nevertheless, the trend was slowed down with almost no research and surface exploration and practically without exploration or production drilling. Also, there was much less construction of new buildings and swimming pools at thermal resorts or spas. Since 2015 also no geothermal gradient boreholes have been drilled in Slovenia.

5. RECENT DEVELOPMENTS AND FUTURE PROSPECTS

Three users in northeastern Slovenia do have plans for reinjection of thermally used water due to clear evidence regional trend of decreasing of the thermal water level. At Čatež geothermal field two wells will be abandoned, and a new make-up well is being drilled this year. At Snovik one well will be remediated. No other projects are underway for further geothermal direct use development. In the NE part of the country the Petrol Geo d.o.o. (in Lendava) has improved some old oil wells into geothermal ones which can be used for aquaculture or greenhouses. The exploration wells at Janežovci near Ptuj, near Korovci and at Mislinjska Dobrava still wait for appropriate financial support to develop the site and to start producing.

5.1 Thermal water direct use

A doublet scheme is operational in Lendava downtown. In north-eastern Slovenia the localities are the most vulnerable to overexploitation of thermal water as most users capture water from the same aquifer. The problem has yet to be tackled with needed care. In this sense it is unfortunate that the Murska Sobota municipality has not completed the extension project for the DH system there with inclusion of previously drilled two boreholes in the northern parts of town (Rman et al., 2012). Thermal capacity of the new doublet could reach 4 MW_t and geothermal energy use 8.8 GWh/year. It could have been the second doublet system operating in the country provided it becomes active at all in future.

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. Main results will be available in summer of 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; Tóth et al., 2016). 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, effective problem solutions, regarding thermal water scaling and degassing, as well as performing new research for potential geothermal sites and implementation of doublets. As the number of users increases, interference between them has already been noticed. Besides, increased demand for thermal water from the same aquifers causes negative quantitative trends, and potential disputes between nearby users. Almost all thermal water users now have an operating production monitoring established and from now on resource assessment and state evaluation will be much more reliable to plan the measures which are really needed to reach both, environmental and energy goals. 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 from its establishment.

The planned extension to about 7 geothermal DH systems (*sensu stricto*) in Slovenia by 2016 (Dumas et al., 2013) 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 in these communities.

5.2 Ground source heat pumps

There were several projects in the past in Slovenia, however, two were running in the last 3-year period. GRETA is officially finished in March 2019 and GeoPLASMA-CE in autumn 2019. They are focused on promotion and fostering of utilization of shallow geothermal sources, more precisely:

(a) GRETA (Near-surface **G**eothermal **Re**sources in the **T**erritory of the **A**lpine Space) involved 12 partners from six Alpine countries and had these objectives: (i) identify near-surface geothermal energy potential in the Alpine Space, (ii) foster exchange of knowledge and best-practices on a transnational basis, (iii) integrate near-surface geothermal energy into environmental policy instruments. This is also for Slovenia an important contribution in stronger implementation of the GSHP technology within the RES energy plans (Prestor et al., 2018).

(b) GeoPLASMA-CE (Interreg CE project) involves 11 partners from six Central European countries and deals with different aspects of shallow geothermal use for heating and cooling in both, urban as well as non-urban regions in Central Europe. New management strategies for a reasonable and sustainable use of shallow geothermal application will be explored in 6 different pilot areas located in Germany, Czech Republic, Poland, Slovakia, Austria and Slovenia. The project aims at generating web-based information systems for visualization of shallow geothermal potentials and risks of use. It also intends to initialize an expert platform for connecting experts and stakeholders in the field of shallow geothermal use in CE.

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 bigger rated power. 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. Of these bigger systems some 465 water-water type systems are found, plus 91 vertical closed-loop and 32 horizontal closed-loop systems. Few bigger open-loop systems have 4 production and 4 reinjection wells or more. Similarly, the biggest closed-loop system near Maribor has 24 BHEs (150 m depth each), another system in Koper has 58 BHEs (with depths of 18 to 32 m).

Our effort to distinguish the numbers of the GSHP units with rated power of >20 kW from the total number is quite tedious, since it is difficult to find appropriate objects with such installations, but as a first attempt Figure 8 shows the first ca 180 systems with GSHP units of bigger power, with addition of so far known hydrothermal HP units. Data for this figure are collected on a voluntary basis.

As regard to GSHPs contribution the Heat Pumps Barometer (EurObserver, 2018, Table 3 therein) shows, to our opinion, just slightly lower numbers of GSHP units in operation in 2016 and 2017 for Slovenia than ours, but also too low numbers of sold GSHP units than are ours, especially in 2017 (Table 2 therein). Figures 9 to 11 show the trend of all GSHP units (in number, capacity and energy use) since our first data acquisition in 1994. 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 12:1 in favor of air-water HPs.

6. CONCLUSIONS

Owing to lower annual flowrates from several wells at different users, which is an 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 its growth rises for about 78.65 TJ (21.85 GWh) every year in the last 5-year period. Actual (Dec. 2018) contribution in direct heat use from deep geothermal energy reached 578.57 TJ (160.71 GWh) and thermal energy used by all GSHP units so far reached 938.23 TJ (260.62 GWh) yearly, all together 1,516.79 TJ (421.33 GWh or 36.228 ktoe). Consequently, target values from draft of renovated NREAP-SI (NREAP, 2010) are still quite distant and a lot of effort will be needed in this programming period and beyond 2020.

The lower annual energy use in 2018 compared to 2016-2017 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 and development of the potential for new users. It is a consequence of a huge effort made by the authorities and Geological Survey of Slovenia. It was based on several activities that were conducted in the last several years: 1) setting up numerical model of the most important reservoir in northeastern Slovenia, 2) benchmarking of management efficiency of all users, 3) setting up the most important indicators of efficient management for the concession contract, 4) joining data from different authorities and joined evaluation, 5) granting the decrees for the users for establishing their monitoring programs and reporting templates.

With continuation of these activities we can expect significant improvement also in following years. It was also an effort made to improve the requirements for water reinjection, especially regarding fissured and karstified aquifers.

We were faced with ample lack of data and information that are needed to reveal the environmental status of geothermal groundwater resources, to set the environmental goals, to set the critical points when the additional or supplementary measures would have to be implemented and to set up the sustainable management of these resources. Activities in the last years revealed deteriorating status of thermal water resources at different locations and at a regional level in northeastern and eastern Slovenia. It was recognized that the common understanding of natural systems extending across the state borders was essential for sustainable transboundary resources management. Very important progress was made where common characterization of the most important cross border geothermal reservoirs was effectuated on the high expert level. This is the basis for self-confidence and encouragement to develop these resources till 2020 and beyond, following both energy and environmental goals. We can conclude that without these activities any further development of cross border thermal reservoirs would be highly unpredictable or unsecure. In this programming period 2014 – 2020 we can expect successful development towards common transboundary management. Further development in the next programming period should provide best practices of doublet technologies in the Pannonian basin sediments, monitoring and reporting and benchmarking of sustainability of the resources' managements. Supporting the research and development activities focused on reinjection technology/well completion in Neogene intergranular aquifers of the Pannonian basin is highly expected.

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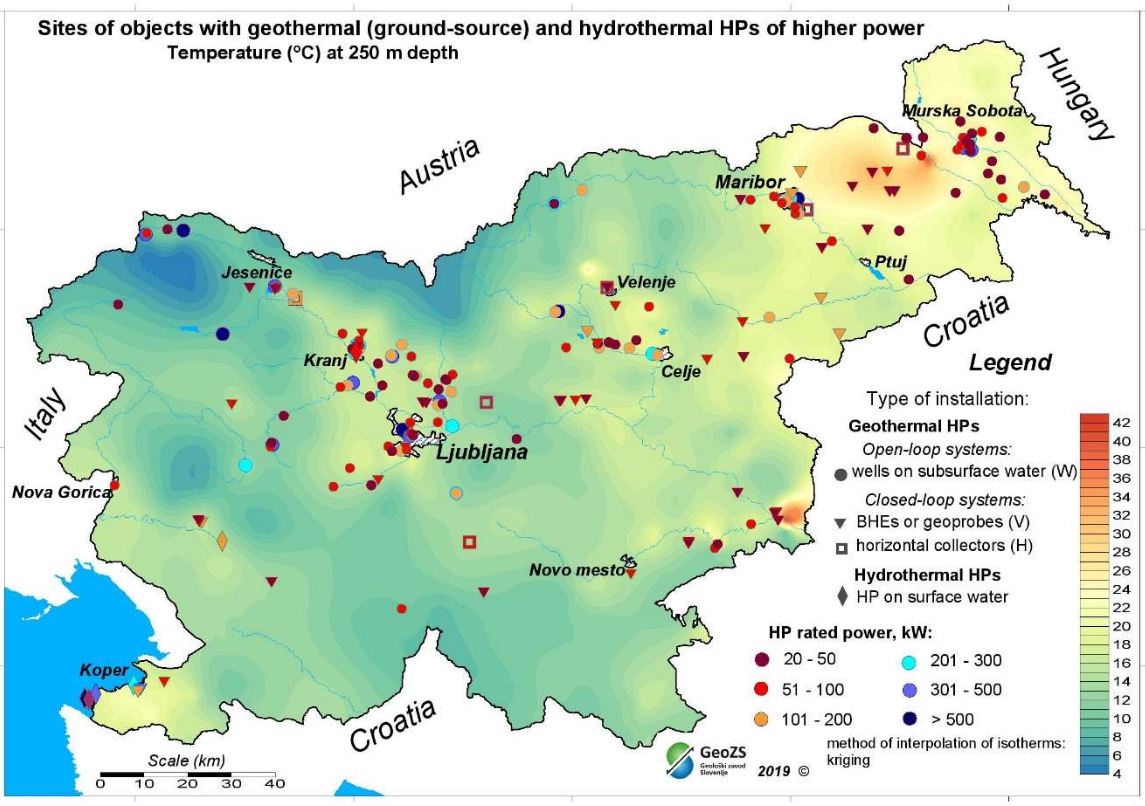

Figure 8: Distribution of the first 190 installations with collected detailed data on GSHP systems with rated power of at least 20 kW, by type of installation, and 6 known hydrothermal HP unit systems (data collected on a voluntary basis). The isotherms show temperature at 250 m depth.

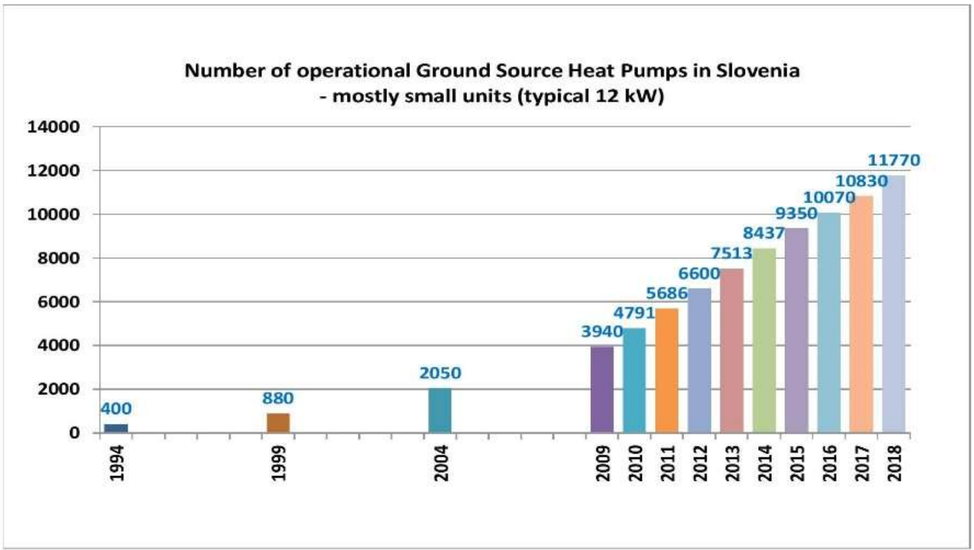

Figure 9: Trend of numbers of operational GSHP units (both small and big rated power) since 1994.

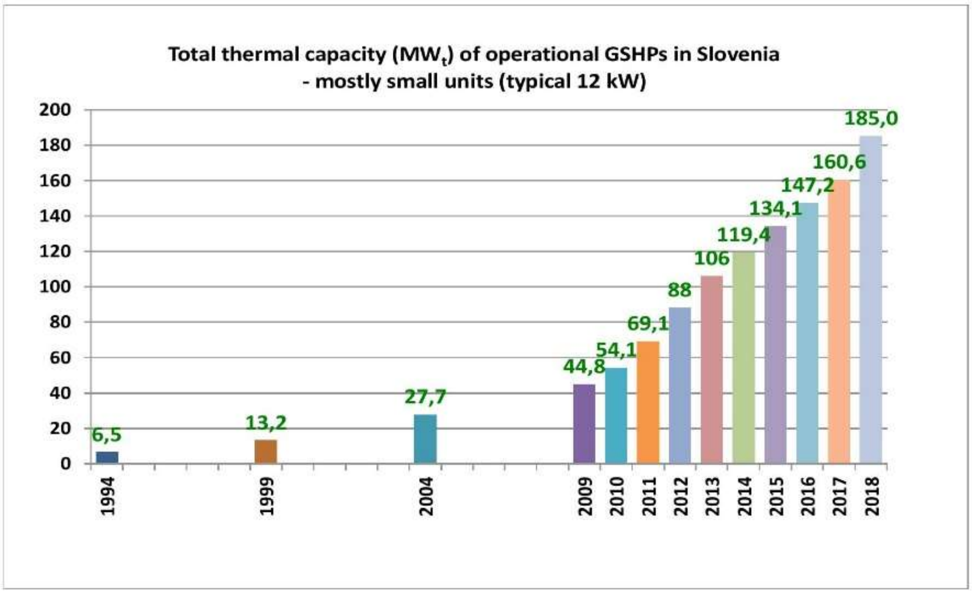

Figure 10: Trend of total thermal capacity of operational GSHP units (both small and big rated power) since 1994.

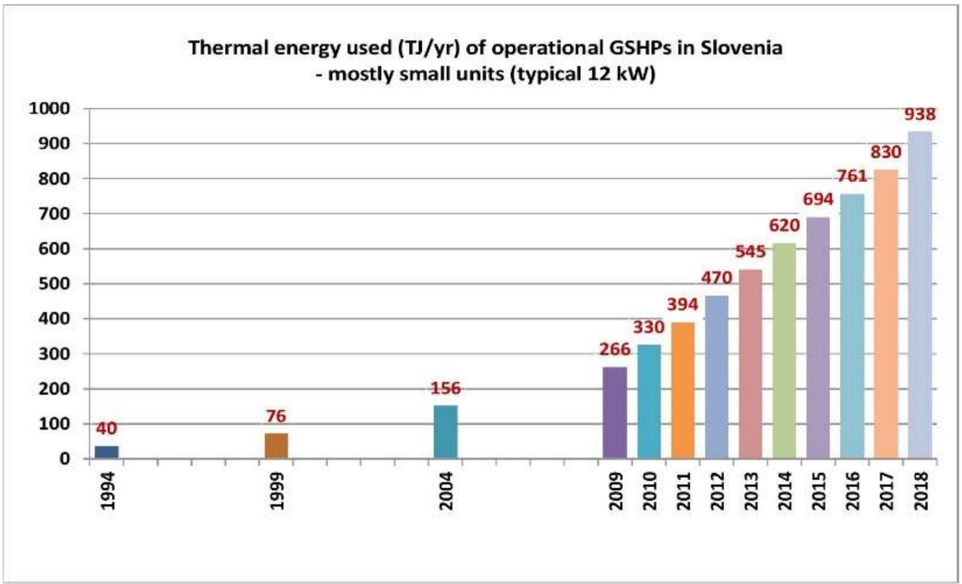

Figure 11: Trend of shallow geothermal energy used by operational GSHP units (both small and big rated power) since 1994.

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 2018			3941	15003		
Under construction end of 2018			/	/		
Total projected by 2020			4226 [3]	13935 [4]		
Total expected by 2025			4627 [3]	15412 [4]		
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2018 (indicate exploration/exploitation if applicable):					Under development	
					Under investigation	

All values: a 100 % share from the Nuclear PP is taken into account (both 50 % Slovenian plus 50% Croatian ownership)

Production values: Net generation (transferred to the network)

[3,4]Source: Capacity in 2018: Indikativna elektroenergetska bilanca 2018, and Poročilo o stanju na področju energetike v Slovenije 2017. Total net generation published on pages ENTSO-E. - An internal study by the EIMV manufacturer; values in the table represent values for scenario 3 from the Development Plan. This plan was approved by the Ministry but has not yet been published on the website, as it is in the process of designing (for data 2020 and 2025)

Table B: Existing geothermal power plants, individual sites

No plants

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 2018	46.89	124.38	8.72	25.01	2.52	4.94	4.30	6.39
Under constru-ction end 2018								
Total projected by 2020								
Total expected by 2025								

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})	2018 production (GWh_{th}/y)	Geoth. share in total prod. (%)
Banovci-Veržej	Terme Banovci	1990	N	N	3.198	4.8	13.7361	99
Čatež	Terme Čatež	1979	N	N	9.227	15.51	22.7964	89
Dobova	Dobova Paradiso	2010	N	N	1.216	1.326	0.5667	91
Dobrna	Terme Dobrna	1855/ 1979	N	N	0.483	0.57	1.9682	85?
Dolenjske Toplice	Terme Dolenjske Toplice	2003 /2008	N	Y	2.524	4.26	5.0633	55?
Lendava	Terme Lendava	1997	N	N	1.745	2.5	7.3798	86
Lendava	Petrol dd/Petrol Geo d.o.o.	2007	N	N, RI	2.209	5.0	5.0273	97
Mala Nedelja	BioTerme	2007	N	N	1.506	2.726	0.7564	60
Maribor	Terme & MTC Fontana	1996	N	N	0.380	0.707	0.3481	60?
Moravske Toplice	Terme 3000	1986/ 1989	N	Y	11.055	15.0	28.1572	99
Moravske Toplice	Terme Vivat	2006	N	Y	3.295	4.409	6.7803	100
Podčetrtek	Terme Olimia	1988	N	N	1.570	1.72	7.3741	86
Ptuj	Terme Ptuj	1980	N	N	1.500	3.1	6.5792	50?
Rimske Toplice	Rimske Terme	2010	N	Y	1.423	2.384	4.2211	93
Šmarješke Toplice	Terme Šmarješke Toplice	1987	N	N	2.583	3.183	3.8271	98
Tešanovci	Grede	2002	N	N	0.753	0.753	4.5789	100
Topolšica	Terme Topolšica	1982	N	Y	2.209	3.304	5.2012	90?
total					**46.888**	**71.253**	**124.381**	**90**

Table E: Shallow geothermal energy, ground source heat pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2018		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2018	11770	185.04	260.62	940	24.46	4 to 5
Projected total by 2020	13650	230	324			

Table F: Investment and Employment in geothermal energy

	in 2018		Expected in 2020	
	Expenditures (million €)	Personnel (number)	Expenditures (million €)	Personnel (number)
Geothermal electric power	0	0	0	0
Geothermal direct uses	*est.* 1	23	*est.* 0.80	23
Shallow geothermal	*est.* 10	130	*est.* 11	130
total	**11**	**153**	**11.8**	**153**

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D			Scheme of Energy Advice (EnSVet), Eco Fund
Financial Incentives – Investment		DIS: Project investment for agriculture LIL: yes; RC: no	DIS, LIL
Financial Incentives – Operation/Production	no	no	no
Information activities – promotion for the public	yes	yes, through media	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	yes, through different studies
Education/Training – Vocational	no	Yes, workshops (explanation)	yes, Chamber of engineers (education)

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)