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Geothermal Country Update Report for Slovenia, 2015-2019

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ABSTRACT

In north-eastern Slovenia, the most geothermally utilized region and belonging to the geothermally anomalous Pannonian Basin, no significant progress with new deep drillings was achieved in geothermal development for direct heat use of thermal water during the last five years. The geothermal energy use in Slovenia stagnates. It does not develop. Improvements are just better utilization schemes at several localities with introduction of heat exchangers and heat pumps of bigger rated power for more economical geothermal heat use. Of three geothermal boreholes, recently drilled just before 2015 with good characteristics and depths between 1.2 and 1.52 km, only one, 1.48 km deep, is in production for greenhouse and soil heating for the tomato production since 2013 at Renkovci, while two others (for a new doublet system) at Murska Sobota are considered stranded as the Municipality preferred other energy sources for district heating operation. They all tap thermal water from the Late Miocene (Pannonian-Pontian) sand aquifer with temperatures of 44 to 77 °C. No other new direct heat user has appeared in the country, and no deep research has been done to check the probable existence of suitable deep geothermal systems to be enhanced for binary power production in this period. The installed capacity and annual energy use of 31 users amounted to 62.1 MW_t and 600 TJ. Greater progress is achieved in shallow geothermal energy use, where the number of smaller GSHP units of typically 11 to 12 kW is ca 12,074 with 147.4 MW_t capacity and 737 TJ/yr energy use (Dec. 2019). The number of bigger GSHP systems with heat pumps of rated power over 20 kW is also in constant increase during the last 5 years, resulting in 53.5 MW_t and 272.2 TJ/yr, with some 656 systems accounted for, however detailed operational data for the latter are difficult to get, especially for buildings in private sector (factories, touristic facilities, etc) since there is no regulation in place. The total complete numbers are 262.9 MW_t and 1609.5 TJ/yr. It is expected the trend of energetic renovation of older buildings (including blocks of flats in the 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.

1. INTRODUCTION

The paper describes the present status of direct heat use and development in the last five years. However, Geological Survey of Slovenia follows on regular basis the geothermal energy use since 1994 with update reports presented at the World (Rajver et al., 2015 and references therein) and European Geothermal Congresses (Rajver et al., 2019 and references therein). The main task of the future development of energy in Slovenia (with 20.273 km^2 and 2.1 million inhabitants) is to ensure a balance between the three basic pillars of energy policy, which are inextricably intertwined: climate sustainability, security of supply and competitiveness of energy supply (NECP, 2018). The goal of reducing greenhouse gas (GHG) emissions has consequences for determining the share of renewable energy sources (RES) in end-use.

By the Directive on the promotion of the use of energy from RES, Slovenia assumed the obligation to achieve 25% of renewables in the total energy consumption by 2020. To achieve the goal by 2030, two scenarios have been developed: wind (higher wind power consumption) and solar (increased use of solar energy), where both from the economic and environmental aspects the solar scenario being better, and this scenario is defined as the scenario of the updated Action Plan for RES (AP RES 2010-2020, update 2017). The implementation of measures considers the environmental objectives in the fields of water, biodiversity, environment and cultural heritage. AP RES primarily directs projects for the exploitation of RES outside protected areas. Interestingly, the Ministry of Infrastructure in its AP RES does not foresee any generation of electricity from geothermal energy until 2030, however, an accelerated construction of new hydro and solar power plants is in the first plan (Internet 1).

During the transition to a low-carbon society, solar energy will take over some of the burden of abandoning fossil fuels. Slovenia will continue to intensively increase the use of solar energy, especially for the electricity production, as well as the passive use of solar energy with modified and to solar energy adapted designs of buildings. Solar energy is expected to play an important role in the self-handling of buildings, neighbourhoods, wider communities with electricity in connection with energy storage and heat from heat pumps (HPs). Greater use of solar energy will require a greater integration of systems, the introduction of new ways of storing energy and creating an environment for exploiting production and business opportunities. In the transition to a low-carbon society, an important source of heat will be aerothermal, geothermal and hydrothermal energy. Slovenia will encourage the use of all three forms, especially for heating in the environmentally friendly manner and mainly with the help of HPs. Water energy provides an extremely quick and economically favourable response to changes in demand for electricity and will therefore continue to play a leading role in ensuring the quality and reliability of the power system (Resolution on the Energy Concept of Slovenia proposal, 2018).

The goal of appropriate ministries is also raising the general public awareness to deal more carefully with energy consumption. Leading companies and institutes involved in geothermal development are: Petrol Geo Co., Geological Survey of Slovenia, and several small business enterprises (Rajver et al., 2015 and references therein). Petrol d.d. and IRGO Consulting established a consortium for the installation of larger GSHP units, which has been very successful in the public sector (at municipality level) in recent years through the so called public-private partnership. During the last 20 years direct heat use of thermal water experienced mostly stagnant phases. The reasons depend on the locality. The problems are overexploitation of geothermal resources in some localities of north-eastern Slovenia (Rman et al., 2012; Rman, 2014 and references therein), occasional technical problems, and weak incentives for efficient use of the resources. In principle direct use of geothermal energy is basically managed by two ministries with few agencies and institutions in geothermal development: 1) Ministry of the Environment and Spatial Planning (MOP) for the water permits and concessions for thermal water usage for touristic purpose and heat extracting, and 2) Ministry of Infrastructure (MzI) for concessions for geothermal energetic source. There are also 3) Ministry of Agriculture, Food and Forestry, and 4) Ministry of Economy (Directorate for Tourism). They support geothermal development, but partially, and they can, instead of stimulating, achieve even the opposite effect because they are not harmonious and mutually interconnected. Each ministry sees only its partial interests, pursues partial goals, which leads to the fact that Slovenia does not move forward regarding geothermal development. The water permits, important for water source geothermal heat pumps (GHPs), are regulated by the Environmental Agency (ARSO) of the MOP. Energy consulting agencies are involved in demonstration projects for greater GHP development, and with layers and tools (Atlas of Sustainable Energy, Internet 2) for the integration of shallow geothermal energy into energy planning. In cooperation with the MOP, the LIFE Climate Path 2050 project (Internet 3) is being carried out in Slovenia, the general goal of which is to support decision-making, which will enable Slovenia to set its own goal of reducing greenhouse gas (GHG) emissions by 2050 and to contribute to the international goal of maintaining global temperature growth.

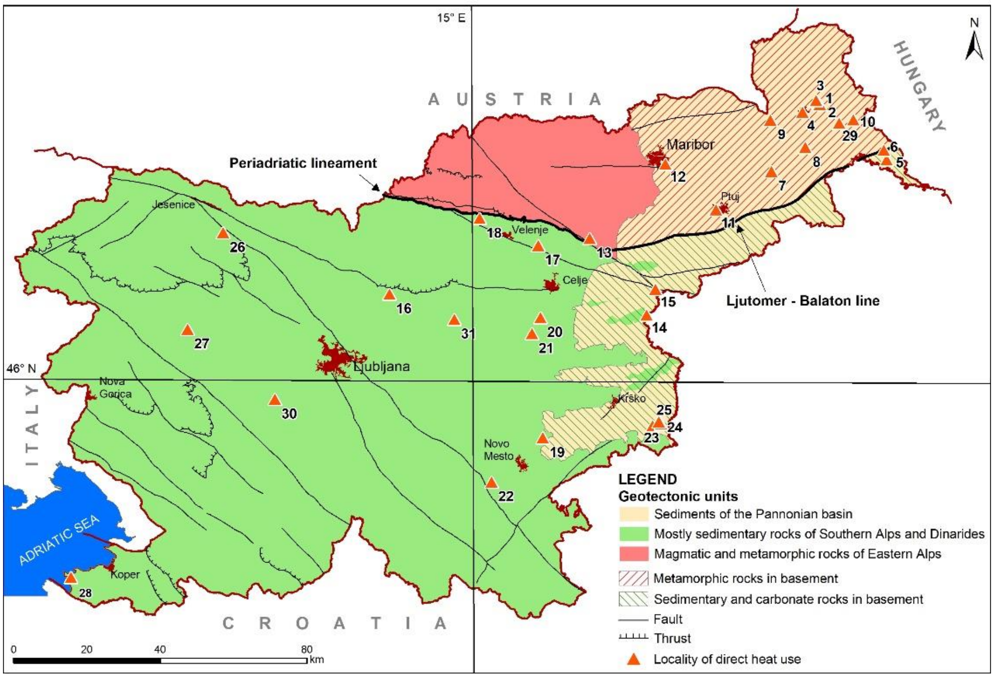

Figure 1: Generalized geological map of Slovenia with localities of direct heat use in 2019 (geology after Poljak, in Rajver et al., 2016); see Table 3.

2. GEOLOGY BACKGROUND, GEOTHERMAL RESOURCES AND POTENTIAL

More detailed description of geology, geothermal resources and potential was given in the previous country updates (Rajver et al., 2015, 2016 and references therein). Geological and tectonic setting of Slovenia is subdivided into several tectonic units with different hydrogeological properties and geothermal conditions (Figure 1). In the northeast, the Mura-Zala basin (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 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 et al. (1995), Rajver et al. (2012) and 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 Slovenia. In the E-SE part of the Pomurje (NE Slovenia) high temperature resources are only hypothetically expected in deeper fault zones in the Pre-Neogene basement. Focus should be in 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 the NE part of the country indicate potential geothermal resources, technically exploitable for electricity production, but only with restrictions (Rajver et al., 2012). The perspective geothermal reservoirs may be found as:

(a) hydrothermal reservoirs in depths less than 3 km and at temperature well above 80 °C: aquifers of the Lendava, Špilje and Haloze formations, NE of Murska Sobota and at 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 quite limited in space. New geological investigations and geothermal wells should be targeted on finding a geothermal aquifer with a wellhead fluid temperature well 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. Deeper wells would be, however, needed to reach the 150 and 200 °C isotherms.

2.2 Resources and potential for direct use

North-eastern Slovenia was intensively investigated in the last decade within the European projects, the most recent ones being TRANSENERGY (Rman et al., 2015; Tóth et al., 2016) and DARLINGe (i.e. Szöcs et al., 2018). The results give better insights in characteristics of the geothermal field and hydrogeological conditions of the geothermally most utilized Mura-Zala sedimentary basin (Rman, 2014). The area has an elevated surface heat flow density (HFD), over 0.10 W/m^2, with expected temperatures above 80 °C at 2 km depth east of the Maribor - Ptuj line, where maximum temperature may reach 150 °C at depths of 2.5 to 3 km (Rman et al., 2012; Rajver et al., 2012; Tóth et al., 2016). 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. Today all production wells in Mura-Zala Basin exploit thermal water from Neogene aquifers with exception of those in Maribor (number 12 in Figure 1). 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 sandprone 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). The other 20 inactive and 11 new potential wells in Slovenia 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 ca 24 MW_t.

Important progress has been made in understanding fluids evolution, origin, source and dynamics of thermal and mineral waters and natural CO_2 vents - mofettes (Rman, 2016). For the latter, we have used a georadar to identify the concentrated outflow zones of cold CO_2 gas while noble gases have determined their origin and degassing processes. Geothermal research has improved knowledge on groundwater flow and heat transfer mechanisms in the regional and transboundary geothermal aquifers in east-northeast parts of Slovenia as well as enhanced development of methodologies for water balance assessment and determination of renewable thermal water quantities. Chemical and isotopic composition of 60 active ouflows were analysed (Bräuer et al., 2016; Rman, 2016; Gabor & Rman, 2016). As a special case in the European region noble gases, also at mofettes have been systematically analysed. Noble gases, Sr and B isotopes have been applied as new methods to determine temperatures of paleo-infiltrated waters, more precise retention times and water origins. A great accomplishment is also elaboration of a new 3D lithostratigraphic model of NE Slovenia which is also comprised of processes important for understanding kinematics of a wider area and forms firm grounds for development of methodology to evaluate the geothermal potential of the region (Diepolder et al., 2014, 2015). This analysis has distinguished thermo-mineral waters connected to hydrocarbons from mineral waters connected to the emissions of geogene CO_2. The retention time has mostly been determined based on tritium activity and rarely by C^{14} concentrations, where both have confirmed prevailing old components. Most gases are of atmospheric origin; however, some isolated geothermal aquifers also show crustal gas origin. Some mineral waters and mofettes show significant contributions of mantle helium which is an extremely rare phenomena, thus we plan to focus our future research to this topic.

Modelling within TRANSENERGY project showed that thermal water production from the Upper Pannonian aquifers was causing transboundary drawdown cones of more than 0.5 m (in the model layer 6, see Tóth et al., 2016), and that they extended as far as 60 km in the neighbouring countries. Calculated drawdowns vary from 1 to 6 m due to production in each individual country involved in the project (Austria, Hungary, Slovakia, Slovenia), but are between 2 and 10 m in total when the regional production is simulated (Fig. 2e). Locally, these values exceed 20 m at the production sites. The inspection of impacts of individual countries has shown that the Slovenian production could potentially cause a maximum drawdown of ca 6 m at the HU-SI border, and a negligible effect toward Austria. In practice, all countries exploit aquifers simultaneously, and therefore the effects of total production have to be summed up (Fig. 2e). The most exploited and, consequently, affected transboundary area is the Mura-Zala basin (HU-SI), with the maximum drawdown of ca 10 m, beside the Danube basin (HU-SK) with the approximate drawdown of 6 m. If thermal water production were to increase to five times the present rate, the drawdown effects would become even more pronounced (Fig. 2f). The maximum drawdown could increase to over 40 m at the HU-SI border.

Geothermal research has been also focused on hydraulic connections among regional and transboundary geothermal aquifers in NE Slovenia. Within the GeoMOL project its 3D lithostratigraphic model was improved (Diepolder et al., 2014, 2015; Šram et al., 2015). Using hydrogeochemical and hydrogeological methods we have analysed the renewability of thermal waters and limits of their sustainable exploitation. Properties of various strata, their water balance, water exploitation rates and potentials were analysed (Rman et al., 2015; Rman et al., 2016). Regional monitoring system was established, and evaluation of the quantity and quality state of these aquifers was performed. Numerical models of groundwater flow and heat transfer were elaborated and used to distinguish among natural and anthropogenic impacts on the water balance (Rman et al., 2016; Tóth et al., 2016). Recommendations to manage transboundary geothermal systems were developed (Szöcs et al., 2015; Szöcs et al., 2018).

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 two wells there, it is a signature that no thermal water comes from horizons deeper than ca 1700 m (compare with the isotherms in Fig. 3).

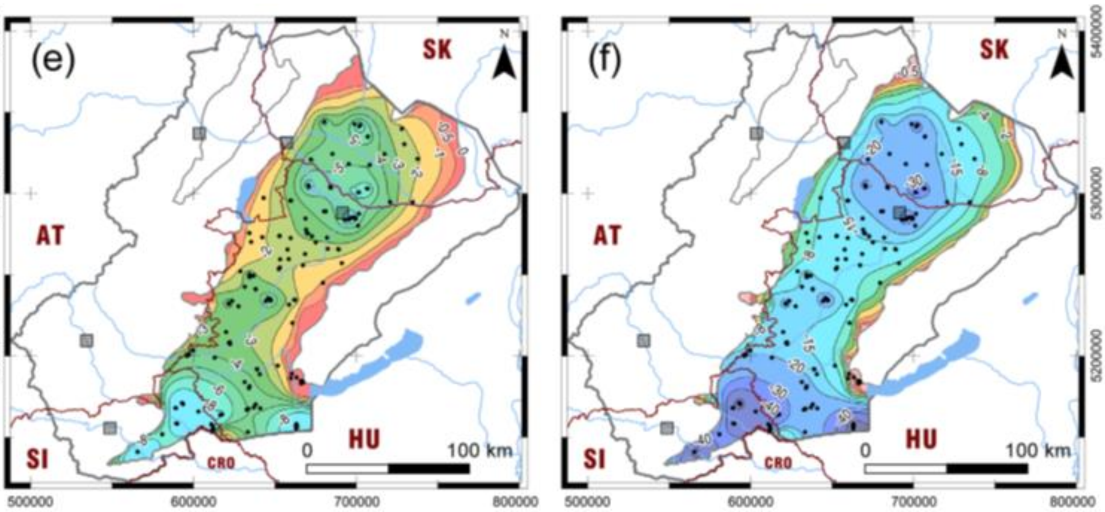

Figure 2. Simulated cross-border steady state groundwater drawdown in the Upper Pannonian geothermal aquifer (model layer 6) caused by thermal water production: (e) in all countries together, and (f) at five-fold increase in production in all countries. Black dots: locations of production wells. AT: Austria, HU: Hungary, SK: Slovakia, SI: Slovenia.

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 (Rajver and Ravnik, 2003). A small Čatež geothermal field in the eastern part of the basin is characterized by elevated geothermal gradient and HFD (>60 mK/m; >0.15 W/m^2) which are conditioned by the prevailing convection. The maximum depth of the wells is 0.7 km, and they produce thermal water from Triassic dolomite with annual yields ranging from 1 to 13 kg/s (numbers 23, 24, 25 in Fig. 1), while at Šmarješke Toplice (number 19) up to 15 kg/s per well.

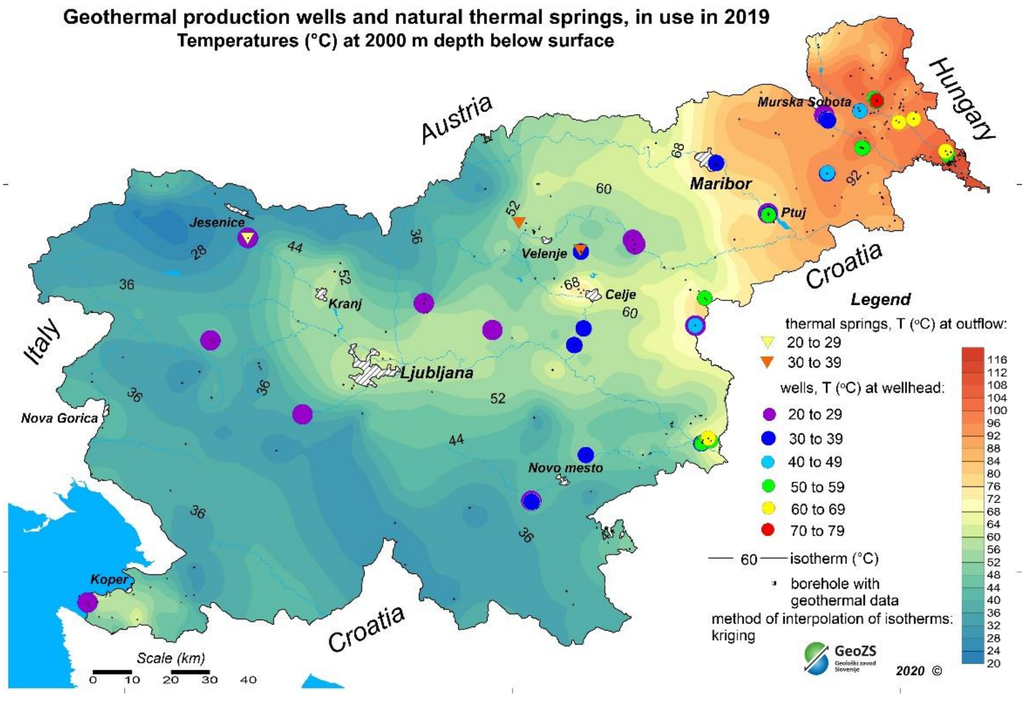

Figure 3: Production geothermal wells and natural thermal springs, in use in 2019 in Slovenia, and expected temperatures at 2000 m depth beneath the surface.

2.3 Potential for ground-source heat pumps

<u>2.3.1 Ground - water systems (GCHPh and GCHPv)</u>

Clastic rocks and sediments cover over half of the Slovene territory, carbonate rocks about 40%, while pyroclastic, metamorphic and crystalline rocks less than 8%. More suitable rocks for horizontal heat exchangers are: sand and sandy clay, flysch rocks such as sandy marls or loose sandstone, sandy claystone. For vertical heat exchangers the most suitable are: dolomite, dolomitic limestone and limestone, and majority of magmatic and metamorphic rocks. Figure 4 shows geological and hydrogeological potential for the geothermal (ground-source) heat pump (GSHP) applications, and among them for ground-coupled heat pump (GCHP) units as well.

Shallow karstic underground is neither very favourable for vertical systems presenting the uncertainty in drilling, prediction and higher drilling costs.

2.3.2 Water – water systems (GSHPw)

North-eastern Slovenia (within 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 wells and thus for open GSHP systems. The major cities' agglomerations are situated on these plains. The temperature of groundwater is characteristically between 10 and 15 °C. Groundwater table is 2 to 25 m deep and the water is rarely chemically aggressive. Individual open vertical systems can be successfully used also in the areas of inter-granular aquifers of medium hydraulic conductivity and in the fissured aquifers of medium hydraulic conductivity (dolomitic aquifers). 35% of the territory is covered by limestone aquifers, where the groundwater accessibility is rather low and conditions not favourable for open vertical systems. Closed vertical systems are more applicable.

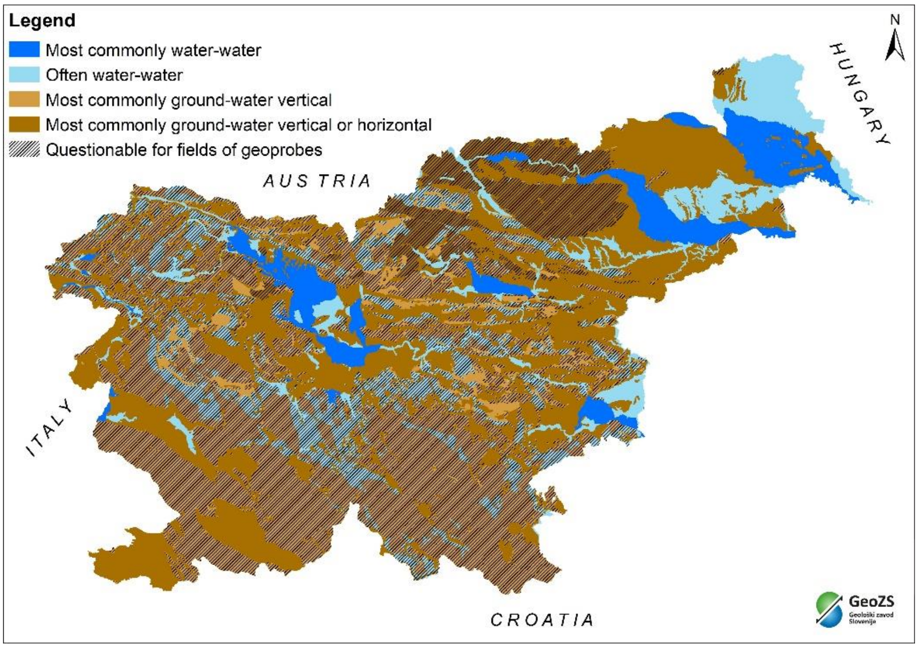

Figure 4: Potential for the GSHP applications in Slovenia (improved after Prestor et al., 2012, in: Rajver et al., 2019).

Similar conditions are for the rest 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, also for deeper BHEs, somewhere even over 20 °C in north-eastern part, and elsewhere only average temperatures between 9 and 15 °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 might 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.

3. GEOTHERMAL UTILIZATION

It is not expected that at the present state of knowledge any electricity production from geothermal could be realistic by 2025, despite the data presented in the EGEC report (Dumas et al., 2013) about geothermal electricity PP investigation near Murska Sobota for an EGS project by Timo Ltd. In 2020, geologically most promising regions for geothermal electricity production in NE Slovenia were re-interpreted, together with establishment of workflow for well testing and project development. As for the direct heat use from thermal water the government introduced the concessions for thermal water utilization which were delivered in 2015 to almost all the users. Consequently, the data reporting on thermal water use is since then more correct owing to monitoring established on production wells at many user localities. An increase of experience is evident at many direct heat users, notably with introduction of heat exchangers and heat pumps of greater capacity for the improvement of using the available heat in a more efficient way, and not to discard it at a too high temperature. No new geothermal surveys have taken place in the country, while drilling activity for direct use purposes was very modest in the last 5 years. The geothermal (ground source) heat pump (GSHP) sector is the only one showing a significant increase.

Geothermal utilization of thermal water heat is based on direct use from 55 production wells (46.53 km is their total depth) and 3 thermal springs, implemented at 31 localities. At 3 localities, which were reported for WGC 2015, 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 in January 2016, while the small Toplice Kopačnica pool was closed in the spring of 2018 by the nearby municipality Gorenja Vas. At Medijske Toplice hotel thermal water use stopped in Nov. 2009 for unknown time due to economic reasons. Not far away, thermal water is used at Izlake (number 31 in Fig. 1 and 5 and Table 3) for the Senior Citizens Home building from a nearby deeper well. Instead of the leather industry IUV at Vrhnika thermal water there is continued to be used from the same well for the space heating of the Siliko Co. factory building (Table 3). Therefore, since the WGC 2015 report a new direct heat user is at Izlake, where the thermal water use started already in 1987 and whose small contribution was omitted in previous reports. Figure 5 shows main utilization types for direct heat use.

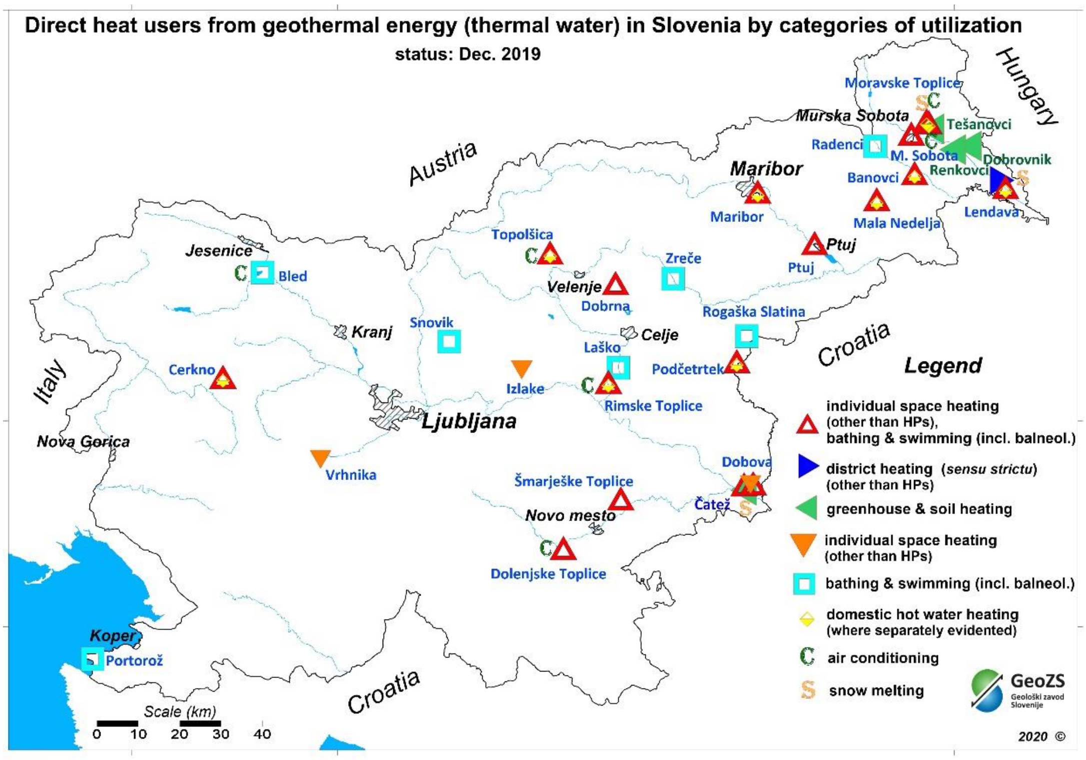

Figure 5: Main utilization types for direct heat use of geothermal energy in Slovenia (status Dec. 2019; see table 3).

In Slovenia, geothermal energy is estimated to currently supply for direct heat uses and GSHP units ca 1,609.48 TJ/yr (447.08 GWh/yr) of heat energy with corresponding installed capacity of 262.94 MW_t. Of these values direct use from thermal water is 600.03 TJ/yr (166.68 GWh/yr, by 13.9% more than in Dec. 2014) from 62.06 MW_t and the remainder, 200.88 MW_t and 1009.45 TJ/yr (280.40 GWh/yr, by 63% more than in Dec. 2014) are GSHPs (Table 5). Since 2014 the GSHPs are the main application of use, with almost 63% in 2019, followed by bathing and swimming (incl. balneology), individual space heating (with domestic hot water, DHW) and greenhouse heating (Figures 6 and 7). Since 2015 the thermal water extraction is followed by the monitoring system established at users who monitor this usage together with experts from GeoZS. From the other eight users fairly correct values are received, 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 fairly accurate as we try to determine as much exact number of units sold (installed) as possible.

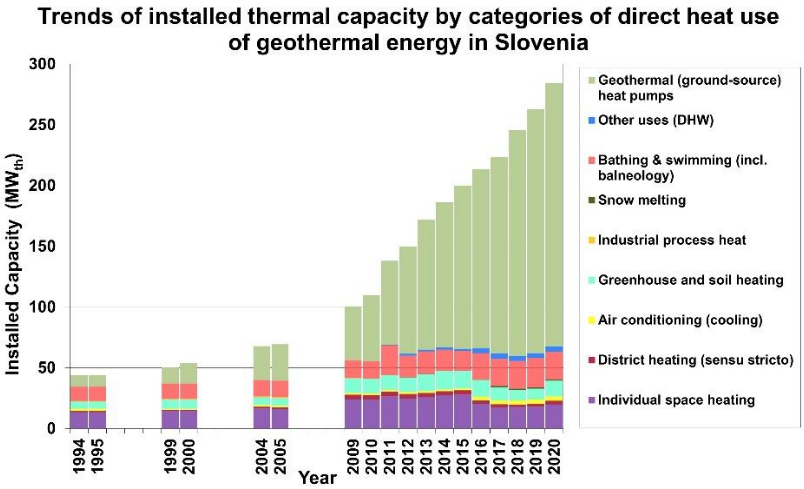

Figure 6: Trends of installed thermal capacity by categories of direct heat use of geothermal energy in Slovenia in a period 1994-2019 (total capacity in 2019: 262.94 MW_t). For 2020 is a forecast from NREAP 2010-2020 before Covid pandem.

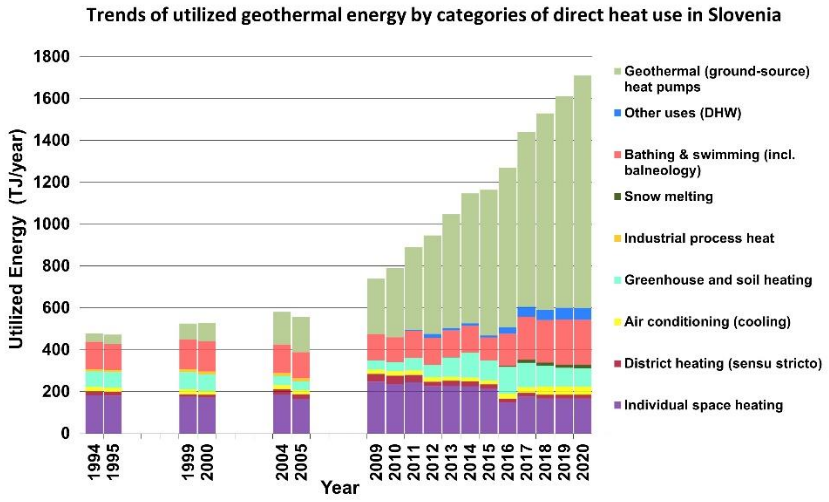

Figure 7: Trends of utilized geothermal energy by categories of direct heat use in Slovenia in a period 1994-2019 (total energy used in 2019: 1609.48 TJ). For 2020 is a forecast from NREAP 2010-2020 before Covid pandemic.

3.1 Individual space heating with domestic hot water heating

Space heating is implemented at localities of 20 users, predominantly thermal spas and resorts, mostly through heat exchangers (e.g. Terme 3000 and Terme Vivat at Moravske Toplice, Terme Banovci, Terme Lendava, etc.) or geothermal heat pumps (e.g. Bioterme Mala Nedelja, Cerkno, Terme Čatež, Hotel Diana in Murska Sobota). The GHP units usually of bigger capacity are installed now at localities of 20 users to increase the thermal water temperature. The total geothermal energy used for individual space heating is 167.4 TJ/yr (46.51 GWh/yr, Table 5) as compared with 225.3 TJ/yr in 2014. The main reasons for lower energy used are more efficient thermal energy use and less energy needed, DHW issue and more correct reporting from the users. Five years ago, it was possible to calculate DHW heating separately for only few users, while for 2019 we did it separately for ten users. At other six users DHW heating is included in the space heating category. During the last five years individual space heating with geothermal heat was introduced at one user at Topolšica (number 18 in Fig. 1 and 5). The heating of DHW, reported separately at 10 localities, contributes 3.9 MW_t and 55.7 TJ/yr (15.46 GWh/yr, Table 5).

3.2 Bathing and swimming (incl. balneology)

This is the leading category of direct heat use of thermal water in the country, implemented at 25 localities. There are 15 thermal spas and health resorts, and additional 10 recreation centres (7 of them as part of the hotel accommodations) where swimming pools with a surface area of 51,600 m^2 and volume of 67,160 m^3 are heated by geothermal water directly or indirectly through heat exchangers or geothermal heat pumps (GHPs). Wellhead water temperatures in thermal spas range from 21.5 to 76 °C. The total geothermal energy used for bathing and swimming amounted to 215.4 TJ/yr (59.83 GWh/yr, Table 5) in comparison with 127 TJ/yr in 2014. Some users improved the temperature range utilization, such as at Dobrna, Topolšica, Šmarješke Toplice, Laško and Rogaška Slatina (numbers 15 and 17 to 20 in Fig. 1 and 5) with the heat exchangers introduced, while at Šmarješke Toplice, Laško and Terme Lendava using the GHPs. At Rimske Terme a general reconstruction of swimming pools and resort center was finished.

3.3 District heating

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, as they both switched to fossil fuel. Only in Lendava town a greater number of public buildings (school, kindergarten, Petrol Geo HQs, etc.) and blocks of flats (total 65,000 m^2) are heated since 2010 under the Petrol Geo l.l.c. authority (belonging to Petrol p.l.c.). The total geothermal energy used for district heating is 18.0 TJ/yr (4.99 GWh/yr) and is for 22 % lower compared with 23.23 TJ/yr in 2014.

3.4 Greenhouses

In eastern Slovenia the heating of greenhouses using geothermal water began in 1962 at Čatež (number 23 in Fig. 1 and 5). It is performed there by the Flowers Čatež Co. on 4.5 ha for cultivation of flowers mostly for the domestic market. At Tešanovci (number 2 in Fig. 1 and 5) near Moravske Toplice, the Grede Agricultural Co. uses the already thermally spent water flowing from Terme 3000 with 40°C to heat 1 ha of greenhouse for tomato production. At Dobrovnik, the greenhouses of 4 ha were constructed by Ocean Orchids Co. for orchids cultivation, both for domestic and foreign markets. At Renkovci, new greenhouses of 9 ha were built for tomato and also exotic fruit cultivation. Geothermal heat use runs there since autumn 2013. The total geothermal energy used in the greenhouses (total 18.5 ha) is 88.3 TJ/yr (24.54 GWh/yr, Table 5), which is lower compared with 118.4 TJ/yr in 2014. However, the installed capacity is today more correctly calculated at 8.8 MW_t compared to 15.3 MW_t in 2014.

3.5 Air conditioning

Air conditioning (cooling) of the hotels and other touristic buildings using geothermal energy is not so well documented as it is in operation to our knowledge only at six localities (Terme 3000 and Terme Vivat at Moravske Toplice, Topolšica, Rimske Terme, Dolenjske Toplice and Bled hotels), contributing about 39.29 TJ/yr (10.91 GWh/yr, Table 5) of extracted energy, compared to 19.14 TJ/yr in 2014, which is by 108% higher.

3.6 Snow melting

This relatively new direct use application in the country is implemented in three localities, in small amount at Lendava (number 6 in Fig. 1 and 5) for the sidewalks using geothermal heat from the already utilized thermal water within the doublet system there with about 0.074 TJ, but much more 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 15.469 TJ. Altogether the used geothermal heat is 15.95 TJ/yr (4.43 GWh/yr), compared to 1.38 TJ/yr in 2014 (increase by 1056%).

3.7 Geothermal heat pumps

At seven recreation centres and at twelve health or spa resorts, plus at Vrhnika and at Izlake (numbers 30 and 31 in Fig. 1 and 5), the GHP units, 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 included within other direct use categories.

3.7.1 Ground source heat pumps

Geothermal energy use for space heating in small decentralized units is becoming more popular and widespread in Slovenia. The market penetration in larger scale began obviously some 11 years ago following a »lazy« period 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 ubiquitous heat content in the topmost part of the crust is available practically everywhere except in the very high mountains. Technical, environmental and economic incentives can be considered advantageous for more rapid introduction of GSHPs. It is also backed by support programs from utilities and government through subsidies or credits. Depending on local conditions (Fig. 4) the GSHPs consist of closed-loop GCHP units (horizontal and vertical heat collectors), or open loop groundwater heat pumps (GWHP). Technical, environmental and economic incentives are considered advantageous for more rapid introduction of the GSHP systems.

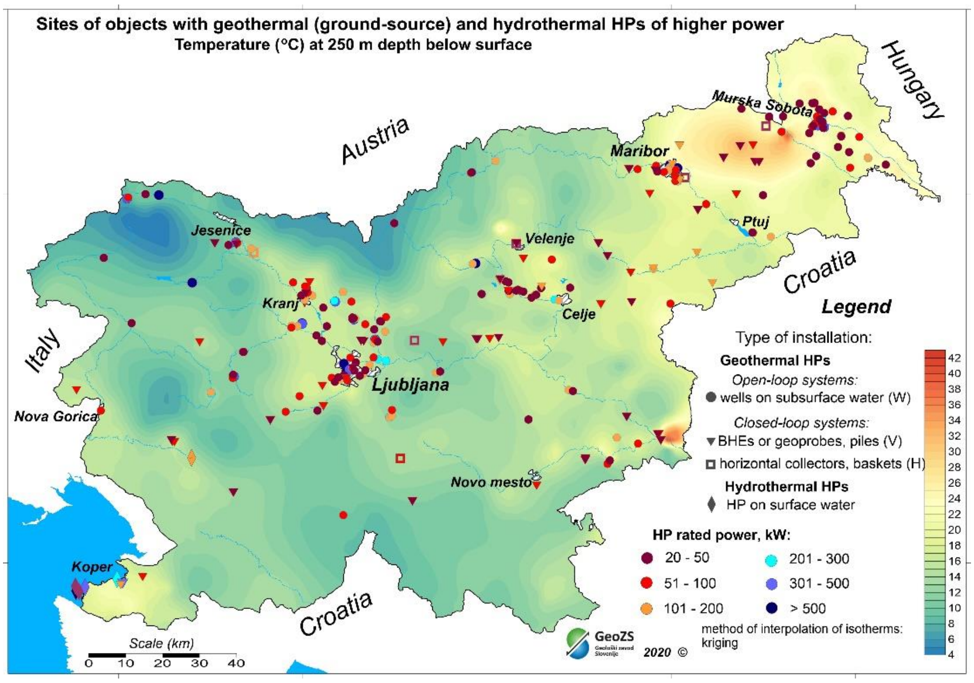

Figure 8: Distribution of the 260 installations for which detailed data on GSHP systems have been collected so far, with rated power of at least 20 kW, by type of installation, and 6 known hydrothermal HP unit systems (all data collected on a voluntary basis). The isotherms show temperature at 250 m depth.

The estimation of exact number of operational GSHP units in Slovenia is not an easy task, nevertheless quite correct numbers are acquired despite no available national statistics. 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. In 2019 we found 16 domestic HP producers in the country, nine of them produce and sell also GSHP units. Of total 60 foreign HP brands in Slovenian market, 13 of them sell GSHP units via domestic merchants. As of 31st Dec. 2019, there are about 12,074 operational small GSHP units (typical 12 kW) that extracted 737.3 TJ (204.79 GWh) of geothermal heat in 2019. Of these, 47% are open-loop systems that extracted about 386.1 TJ from shallow groundwater, 40% are horizontal closed-loop (with 255.9 TJ), and 13% are vertical closed-loop systems (with 95.3 TJ). Small closed-loop units together removed 351.1 TJ/yr from the ground. There are also bigger capacity GSHP units (>20 kW) installed within about 656 systems in public and other buildings, which extracted 272.2 TJ in 2019. However, it is discovered year by year that perhaps 4 - 5% of them are not yet operational. Of them, 515 units are open-loop water-water type (79%), 108 units are vertical closed-loop (16%) and 33 (5%) are horizontal closed-loop systems. 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 8 shows ca 190 big units for which detailed data have been collected so far, reflecting their concentration in more inhabited and plain regions. With total 12,730 GSHP units some 1009.45 TJ (280.4 GWh) of heat was extracted in 2019, while presumably at least 200 TJ/yr of heat was rejected to the ground in the cooling mode, mostly by GWHP and vertical GCHP systems. Capacity factor for all GSHP units is

0.161, and it is 0.16 for small units and 0.163 for the bigger units (>20 kW). So, this factor is 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 5 are based on data from the users and best estimates of few missing data. The total thermal capacity currently installed for direct use of thermal water energy amounts to roughly 62.06 MW_t, including big GHP units at thermal spas, but without numerous mostly small GSHP units. The annual energy use at 31 users amounted to 600.03 TJ, which is by 13.9% more than in 2014 (526.6 TJ as corrected value), which is a consequence of better and more economic utilization. In comparison with energy use numbers in the WGC 2015 report the annual energy use (Figures 7 and 9) is considerably lower for individual space heating (by 26%), district heating (by 22%) and also for greenhouse heating (by 25%), much higher for air conditioning (by 108%) and for bathing and swimming (70%), and considerably higher for DHW heating (by 295%) and snow melting (by 1055%). The use for industrial process heat is suspended. However, the GSHP sector exhibits the largest share (62.7%) in direct use, followed by bathing and swimming, individual space heating and greenhouses (Fig. 9).

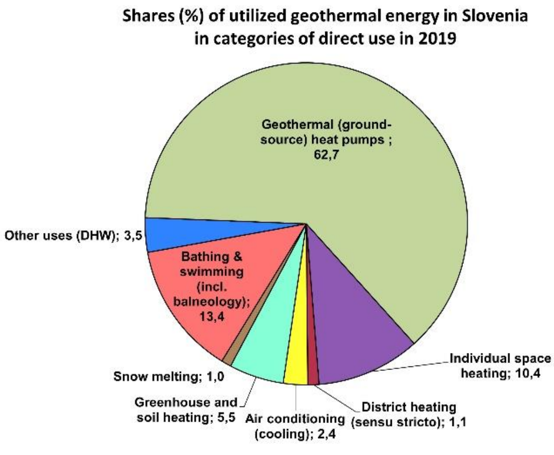

Figure 9: Shares of geothermal energy used in Slovenia in categories of direct use in 2019 (status: 31st Dec, 2019).

Drilling activity was much lower compared with a 2010-2014 period. Only 4 wells have been drilled with a total depth of 0.532 km (Table 6). Of them are 3 reinjection wells at Izlake of total depth 0.15 km, and one well is a replacement well at Terme Čatež. The total number of professional personnel in geothermal activities in 2015-2019 (Table 7) is similar to previous 5-year term, with few technician-engineers at thermal spas also included. Data on investments in geothermal (Table 8) were received from all the users. Nevertheless, trend was slowed down in research and development incl. surface exploration and drilling, as well as in field development with production drilling. Activity was more pronounced in surface equipment constructions and investments in direct utilization (swimming and other pools at thermal resorts or spas with auxiliaries).

Many challenges and related measures are still waiting for Slovenia to switch to clean energy and increase the share of renewables in gross final energy consumption. The European Union (EU) has a leading role in the decarbonization of society worldwide and wants to preserve this role in the future (NECP, 2018). The EU objectives are appropriate and ambitious for this role, and are, of course, binding on Slovenia. RES for achieving commitments remain a key factor. The electricity production in Slovenia amounted to 12,502 GWh/yr, and is based, as of December 2019 (Table 1), on domestic and only partly imported fossil fuels (36%), domestic hydropower (38%), nuclear power (22%), and renewables (4%). Of these, the PV solar units predominate, followed by biogas, biomass, CHP and wind facilities. Coverage of electricity consumption in 2019 by domestic production was 83.5%. Important help for RES is the support scheme, in which more than 2500 producers have been involved since 2009 with a total of 3859 generating installations on RES and for combined heat and power (CHP) with total net power of 412 MW_e (CHP included), which are dominated by solar power plants (Energy Agency, 2019).

Intensive technological development, increased use of electricity and the inclusion of diffuse electricity generation from RES are changing the functioning of electro-energetic systems as well the energy market. At the EU level, the last legislative acts of the Clean Energy Package for all Europeans were adopted in January 2019, which, in addition to increasing the share of RES in end-use energy, also highlights the client's greater role. This role begins being active in the processes of production and storage of electricity and in direct participation in the market with flexibility. There will undoubtedly be necessary investments in networks, especially distribution. But if we really want to achieve wider social benefits through the transition to clean energy, this should be done cost-effectively and, at least in the short and medium-term frameworks, it is necessary to take into account the flexibility potential. This certainly requires a change of mindset, especially in the management and design of networks. Technological development and digitization are the key to this. Therefore, the Energy Agency (2019) established a new regulatory framework in 2018 that further supports market development, adaptation of purchase, and encourages innovation and investment in new technological solutions with the aim of increasing the efficiency of the use of electricity grids.

The share of produced electricity in hydroelectric power plants (HPPs) and in power plants (PPs) on other RES varies from year to year depending on the hydrological and other conditions, as well as the volume of investments in the construction of production units for the use of RES. The share of produced electricity in HPPs and PPs on other RES in Slovenia amounted in 2019 to 41.8% or almost 5 percentage points more than in the year before. The rest of the total electricity production in Slovenia was contributed by the fossil fuel PPs (36.1%) and the Krško Nuclear PP (22.1%). Coverage of electricity consumption with domestic production was 0.6% higher than in the previous year and amounted to 83.5%, where the level of domestic production does not directly reflect the total domestic potential of production facilities but is largely due to the structure of production sources or technologies, their competitiveness and the establishment of the target model of the electricity market. Final price of electricity for an average household consumer (0.167 €/kWh) increased by 1.1% in 2019 with regard to year before and even by 7.6% for the average non-household consumer (0.08 €/kWh). Slovenia does not have so much gas resources and not any gas storage facilities, the supply of this energy product is thus almost entirely dependent on imports. The total consumption of domestic consumers of natural gas was 1.9% higher than in 2018. The retail price of natural gas for the average household consumer (0.06 €/kWh) increased by 2.7% and for the average non-household customer (0.03 €/kWh) by 7.9% which are still much lower than electricity. Cost of direct utilization of geothermal water is ca 0.8 €/kWh (but will be checked later).

4.1 Long-term strategic orientations

In documents (action plans and strategies), geothermal energy is an important area, but it is neglected. Companies and interest groups also stress the need for long-term policies, commitments and objectives. Policymakers need to create stable conditions for 5-10 years, as companies cannot turn from today to tomorrow (Internet 4). If we want to achieve goals by 2050, we will have to take advantage of all the measures, so we need to know the potentials. Geological Survey of Slovenia has prepared an overview of Local Energy Concepts (LEKs) regarding the integration of geothermal energy. It is evident that the bases are necessary at the local level. The common starting points should be somewhat better. In most cases creators of LEKs do not investigate local aspects and use flat-rate (geothermal) data for Slovenia.

4.2 Thermal maps, acceptance maps

The development of spatial maps is important because it clearly indicates the competition between technologies and enables guidance. Data are available to municipalities and investors, provide information on where to exploit geothermal energy and where not. Examples of good practice from abroad show that officially accessible acceptance maps are very important with information on where the potentials are and where they can be exploited and where not and where the conditions for exploitation need to be verified. The map of geothermal potential for the municipality of Ljubljana (GeoPLASMA project) is just one of good examples.

4.3 Decrees on priority use of energy products

The decrees also protect the public utilities of energy distribution in order to ensure environmental objectives. In the case of DH systems, the two objectives (environmental and energetic) are, in principle, not in conflict. The incentives and conditions for the exploitation of geothermal energy within DH systems should be prepared. There are more and more technological solutions, but they are economically challenging. Investors imagine such solutions for larger buildings, but for larger systems they do not.

4.4 Incentives and obstacles

The field of exploitation of geothermal energy needs to be given more emphasis with incentives. Data or information on geothermal energy can be useful in programming the funds of the Climate Fund. We need to conceive funds to help establish technological solutions and achieve the greatest impact for the least money. It is also necessary to direct the exploitation of geothermal energy in technologies that also bring additional benefits and smaller loads. For example, efficiencies of the GWHP and GCHP systems are much better than of air-source HP systems at low outside temperatures and, therefore, from the point of view of ensuring the adequacy of the supply with electricity much more favourable. It is time that the state sends such a signal to make a difference in subsidies. The Norwegian Fund program highlighted geothermal energy. Calls are under way. We need a more systemic environment so that potentials and solutions become more visible in order to see potentials and an appropriate incentive framework. Drilling is namely a great expense. For the sector of DH, it is important that the incentives received are to be reflected in a favourable price of heat. If this sector manages to provide favourable prices, it will be able to deliver the set goals.

Today, water concessions are a major obstacle to the exploitation of geothermal energy in Slovenia. They represent a great deal of cost. Slovenia is one of the few countries that charges the concession for exploiting geothermal energy, although it is a RES. As example in the exploitation of deep geothermal energy, in Murska Sobota the two new wells stand still despite the implementation of the investment, and the exploitation of wood biomass is considered instead. It is necessary to approach the obstacles similarly to the implementation of other technologies (for the exploitation of wood biomass and solar energy) in Slovenia. Informing is important so that a manual for the field of geothermal energy is made for investors.

4.5 How to take advantage of the potential in different sectors?

The analysis showed that it is worthwhile to orient the exploitation of geothermal energy in larger buildings, where exploitation is the most cost effective. The potential in public buildings is great, but all things require their time. When implementing projects in the public sector in a public-private partnership (energy contracting), the return on investment is very important. The private investor will not make a "yes" decision, he will not go into business if the profitability is lower than 10%. If there was a public ESCO (Internet 5, Energy management of buildings by energy service companies which provide comprehensive energy renovation of public buildings), there is no problem. We are in a contradictory situation, because funds are available to Eco Fund, but we are waiting for a private investor to invest in public buildings.

5. FUTURE DEVELOPMENT AND INSTALLATIONS

Few projects for further geothermal direct use development were planned or were under way some years ago in north-eastern part of the country. There, the Petrol Geo l.l.c. (from Lendava) improved few old oil wells to be converted into geothermal wells for aquaculture or greenhouses, but the present situation in this matter is unknown. The exploration wells at Janežovci near Ptuj and at

Mislinjska Dobrava still wait for appropriate financial support to develop the site and to start producing. In north-eastern Slovenia at sites of three users (Terme 3000, Ocean Orchids l.l.c. and Paradajz l.l.c., numbers 1, 10 and 29 respectively in Table 3 and Fig. 5) three reinjection wells are planned in the next five years, one at each user, due to clear evidence in regional trend of decreasing of the thermal water level, but the problem is economic one due too low fossil fuel prices, especially gas. At Čatež geothermal field two wells will be abandoned, and a replacement well is being drilled this year. At Snovik one well will be remediated. No other projects are underway for further geothermal direct use development. Considerations on high enthalpy geothermal resources have been initiated whether there are possibilities for electricity production in the north-eastern part 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, better, new deep wells should be drilled at appropriate localities, which have to be previously confirmed by up-to-date geophysical (seismic, microseismic, MT) investigations with a goal to create EGS.

5.1 Thermal water direct use

A doublet scheme is operational only 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 the Murska Sobota community achieved a good success with drilling the two new boreholes 6 years ago for enlarging the district heating purpose in the northern parts of town. The results of testing in 2012/13 were shortly explained in Rajver et al. (2015). Thermal capacity of the new doublet could reach 4 MW_t and geothermal energy use 8.8 GWh/year. This could be the second doublet system operating in the country when it becomes active. The planned extension to about 7 geothermal DH systems (*sensu stricto*) in Slovenia by 2016 (Dumas et al., 2013) proved to be unrealistic so far, 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 near future in these communities.

The Interreg project DARLINGe, running between 2016 and 2019, significantly contributed to a better resource assessment of eastern and north-eastern 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 in Slovenia have had an operating production monitoring systems established and from 2015 on resource assessment and state evaluation is 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.

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 will be in autumn 2019. They are focused on promotion and fostering of utilization of shallow geothermal sources, more precisely:

(a) GRETA (Near-surface Geothermal Resources in the Territory of the Alpine 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) involved 11 partners from six Central European countries and dealt 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 were explored in 6 different pilot areas located in Germany, Czech Republic, Poland, Slovakia, Austria and Slovenia. The project aimed at generating web-based information systems for visualization of shallow geothermal potentials and risks of use. It also intended to initialize an expert platform for connecting experts and stakeholders in the field of shallow geothermal use in Central Europe.

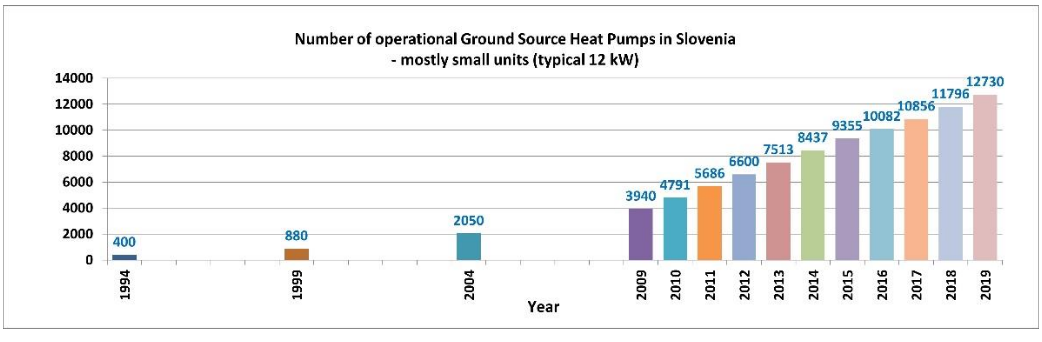

Figure 10: Trend of numbers of operational GSHP units (both small & big-rated power) since 1994.

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. Such units 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 recorded, but they represent a significant share in energy use and installed rated power. Some bigger open-loop systems have 4 production and 4 reinjection wells or more. Similarly, the biggest closed-loop system so far near Maribor has 24 BHEs (150 m each), another system in Koper has 58 BHEs (with depths of 18 to 32 m).

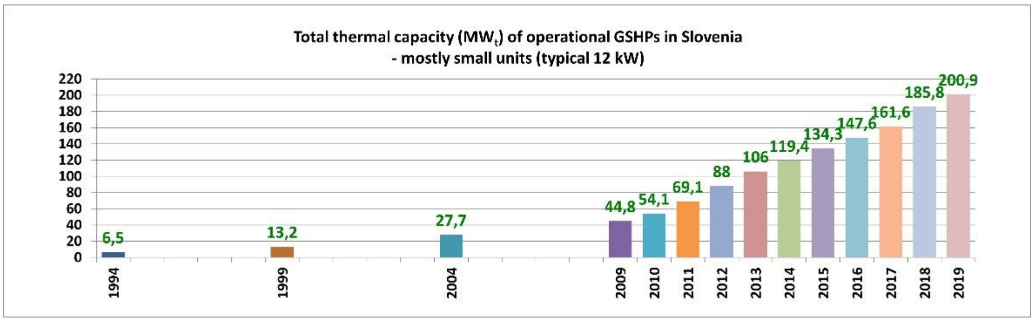

Figure 11: Trend of total thermal capacity of operational GSHP units (both small & big-rated power) since 1994.

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 10 to 12 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. Most 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 favour of air-water HPs.

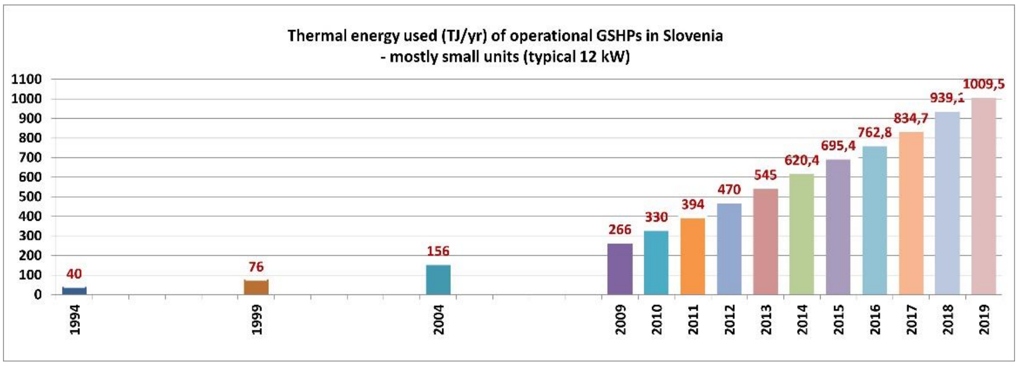

Figure 12: Trend of shallow geothermal energy used of operational GSHP units (both small & big-rated power) since 1994.

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STANDARD TABLES

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (solar,		Total	
	Capacity MW_e	Net Production GWh/yr	Capacity MW_e	Net Production GWh/yr	Capacity MW_e	Net Production GWh/yr	Capacity MW_e	Net Production GWh/yr	Capacity MW_e	Net Production GWh/yr	Capacity MW_e	Net Production GWh/yr
In operation in December 2019	0	0	1.537,70	4.513,30	1.340,80	4.723,70	348	2.766,00	347,60	498,5	**3.574**	**12.502**
Under construction in December 2019												
Funds committed, but not yet under construction in December 2019												
Estimated total projected use by 2020												

Data source: Report on the state of energy in Slovenia in 2019 (Energy Agency of the RS, Table 3 therein):
https://www.agen-rs.si/documents/10926/38704/Poro%C4%8Dilo-o-stanju-na-podro%C4%8Dju-energetike-v-Sloveniji-v-letu-2019/5571e312-7b68-4e97-b5e2-6705c534d783

Net Production: Net production given as Ener. Agency does not collect the gross product. data. Net production = gross electricity gen. - consumption of PPs' auxiliary services.

Other RES (all): Solar, biomass, biogas, wind, CHP (with biomass):

Other RES: Solar only: Capacity: 275.9 MW_e; Net Production: 269.8 GWh/yr.

Nuclear PP: Nuclear: a 50 % share from the Nuclear PP Krsko is taken into account (Slovenia owns 50 % of capacity, the other 50 % is ownership of Croatia).

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019 (other than heat pumps)

1) I = Industrial process heat; H = Individual space heating (other than heat pumps)
C = Air conditioning (cooling); D = District heating (other than heat pumps)
A = Agricultural drying (grain, fruit, vegetables); B = Bathing and swimming (including balneology)
F = Fish farming; G = Greenhouse and soil heating
K = Animal farming; O = Other (please specify by footnote)
S = Snow melting

2) Enthalpy information is given only if there is steam or two-phase flow

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

	Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
			Flow Rate	Temperature (°C)		Enthalpy[2)] (kJ/kg)			Ave. Flow	Energy[4)]	Capacity
			(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5)]
1	Moravske Toplice Terme3000	H,C,B,O	74,0	62,0	27,1			10,79	26,87	116,85	0,34
2	Tešanovci	G	12,0	40,8	25,8			0,75	6,28	11,26	0,47
3	Moravske Toplice Vivat	H,B,O,S,C	21,0	60,6	20,0			3,57	4,90	23,35	0,21
4	Murska Sobota, H Diana	H,B,O	4,8	44,0	21,0			0,46	2,53	7,67	0,53
5	Lendava Terme	H,B,O	10,0	61,6	28,3			1,39	6,23	23,99	0,55
6	Lendava mesto, Petrol dd	D,S	25,0	66,0	42,5			2,46	5,80	18,03	0,23
7	Mala Nedelja BioTerme	H,B,O	22,0	48,5	24,6			2,20	1,60	5,24	0,08
8	Banovci	H,B,O	23,8	56,8	23,5			3,32	13,77	56,99	0,55
9	Radenci	B	10,0	35,5	20,2			0,64	1,01	1,28	0,06
10	Dobrovnik	G	15,0	61,2	16,0			2,84	5,81	31,76	0,35
11	Ptuj	H,B	23,0	39,8	26,7			1,44	13,22	25,17	0,56
12	Maribor	H,B,O	0,5	39,0	13,0			0,10	0,27	0,84	0,28
13	Zreče	B	25,0	30,9	22,4			0,89	3,08	1,66	0,06
14	Podčetrtek Olimia	H,B,O	40,0	36,2	24,2			2,01	23,71	35,38	0,56
15	Rogaska Slatina	B	2,1	54,9	21,9			0,29	0,04	0,06	0,01
16	Snovik	B	10,0	29,1	16,8			0,51	0,80	1,08	0,07
17	Dobrna	H,B,O	6,0	36,0	15,8			0,50	2,73	6,96	0,44
18	Topolšica	H,C,B,O	30,0	32,2	12,3			2,50	11,10	26,62	0,34
19	Šmarješke Toplice	H,B,O	59,0	34,6	22,5			2,98	12,44	16,65	0,18
20	Laško	B	23,6	34,6	20,2			1,43	6,11	6,89	0,15
21	Rimske Terme in Aqua Roma	H,B,O,C	20,0	39,7	22,7			1,42	6,93	15,04	0,34
22	Dolenjske Toplice	H,B,C,O	40,0	34,6	22,5			2,02	10,94	16,40	0,26
23	Terme Čatež + rastlinjaki	G,B,H,O,S	79,0	49,6	20,0			9,77	24,08	89,50	0,29
24	Dobova Paradiso	H,B,O	10,0	56,0	26,0			1,26	0,47	1,71	0,04
25	Dobova AFP	H	10,0	61,0	38,0			0,96	1,86	5,38	0,18
26	Bled, G & P, GH Toplice	C,B	18,4	21,5	15,2			0,49	9,02	7,11	0,46
27	Cerkno	B,H,O	15,0	27,8	17,5			0,66	3,96	5,32	0,26
28	Portorož	B	0,4	24,6	18,0			0,01	0,11	0,06	0,17
29	Renkovci	G	20,5	65,0	21,0			3,76	7,36	40,21	0,34
30	Vrhnika	H	11,0	24,2	12,0			0,56	0,44	0,69	0,04
31	Izlake	H	6,5	25,8	22,0			0,10	1,74	0,87	0,27
TOTAL			**667,5**					**62,06**	**215,20**	**600,03**	**0,31**

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2019

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the cooling mode.
Cooling energy numbers will be used to calculate carbon offsets. Heat rejected to the ground in the cooling mode reduces the effect of global warming.

1) Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps

2) Report type of installation as follows: V = vertical ground coupled; H = horizontal ground coupled; W = water source (well or lake water); O = others (please describe) (TJ = 10^{12} J)

3) Report the COP = (output thermal energy / input energy of compressor) for your climate - typically 3 to 4

4) Report the equivalent full load operating hours per year, or = capacity factor x 8760

5) Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (°C) - outlet temp. (°C)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

6) Cooling energy = rated output energy (kJ/hr) x [(EER - 1)/EER] x equivalent full load hours/yr

Note: please report all numbers to three significant figures
Due to room limitation, locality can be by regions within the country.- It's impossible to present the distribution of HP units by regions in Slovenia.

Locality	Ground or Water Temp. (°C)1)	Typical Heat Pump Rating or Capacity (kW)	Total Heat Pump Capacity (MW)	Number of Units	Type2)	COP3)	Heating Equivalent Full Load Hr/Year4)	Thermal Energy Used5) (TJ/yr)	Cooling Energy6) (TJ/yr)
		small units:	*small units:*						
open loop:	water temp:	small units: 6 to 20 kW							
water-water	3 to 15	typical 12 kW	75,441	5632	W	2.5 to 6.7	800 - 2800	386,10	
closed loop:	ground temp:	small units: 3 to 20 kW							
ground coupled	2 to 14	typical 11-12 kW	53,775	4825	H	2.9 to 5.4	1000 - 2500	255,86	
ground coupled	3 to 16		18,146	1617	V	3.0 to 5.6	600 - 2500	95,27	
small units **Total**			**147,361**	**12074**				**737,227**	
		big units:	*big units:*						
			46,371	515	W			236,65	
			1,336	33	H			6,24	
		each V unit:several BHEs	5,816	108	V			29,33	
		typical > 20 to 200 kW		systems with		SPF only:	500 - 6600		
		maximum: 816 kW		1 or more unit		2.8 to 5.0			
big units **Total**			**53,523**	**656**				**272,221**	
TOTAL			**200,884**	small: 12074	W,H,V	2.5 to 6.7	500 - 6600	**1009,448**	**200,00**
12730 units				**big: 656**	W,H,V				

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2019

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171

Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% capacity all year

4) Other than heat pumps

5) Includes drying or dehydration of grains, fruits and vegetables (TJ = 10^{12} J)

6) Excludes agricultural drying and dehydration

7) Includes balneology (MW = 10^6 W)

Use	Installed Capacity1) (MWt)	Annual Energy Use2) (TJ/yr = 10^{12} J/yr)	Capacity Factor3)
Individual Space Heating4)	18,049	167,432	0,29
District Heating 4)	2,456	17,963	0,23
Air Conditioning (Cooling)	3,589	39,289	0,35
Greenhouse Heating	8,795	88,345	0,32
Fish Farming			
Animal Farming			
Agricultural Drying5)			
Industrial Process Heat6)			
Snow Melting	1,093	15,948	0,46
Bathing and Swimming7)	24,209	215,404	0,28
Other Uses (DHW heating)	3,866	55,654	0,46
Subtotal	**62,06**	**600,03**	**0,31**
Geothermal Heat Pumps	*200,884*	*1009,448*	0,16
TOTAL	**262,94**	**1609,48**	**0,19**

TABLE 6.	WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2015 TO DECEMBER 31, 2019 (excluding heat pump wells)					
1)	Include thermal gradient wells, but not ones less than 100 m deep					
Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1)]	(all)		0		0	
Production	>150° C					
	150-100° C					
	<100° C		1			0,382
Injection	(all)		3			0,15
Total			4		0	0,532

TABLE 7.	ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)
	(1) Government; (4) Paid Foreign Consultants
	(2) Public Utilities; (5) Contributed Through Foreign Aid Programs
	(3) Universities; (6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015		3	1			9
2016		3	1			9
2017		3	1			9
2018		3	1			10
2019		4	1			10
Total	0	16	5	0	0	47

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2019) US$

Period	Research & Development Incl. Surface Exploration & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	1,94	4,08	13,33		99	1
2000-2004	2,56	4,43	45,72		96	4
2005-2009	8,5	7,89	53,1		90	10
2010-2014	0,87	5,92	5,19		56	44
2015-2019	0,57	3,88	31,95		96	4