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Geothermal Energy Use, Country Update for Slovenia

Dušan Rajver[1], Andrej Lapanje[1], Nina Rman[1], Joerg Prestor[1]

[1] Geological Survey of Slovenia, Dimičeva 14, 1000 Ljubljana

dusan.rajver@geo-zs.si

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ABSTRACT

Geothermal energy use in Slovenia has been followed on regular basis since 1994. Only a small progress was achieved in geothermal development during the last three years, in its northeastern part, belonging to the Pannonian Basin geothermal region. New geothermal borehole was drilled there with good characteristics and depth of 1.2 km. Greenhouse and soil heating of the tomato production has been active since 2013 at Renkovci from a borehole drilled there in 2011, while two wells (a production and reinjection borehole) for the planned district heating of some parts of the Murska Sobota town are currently inactive. They all tap thermal water from the Late Miocene (Pannonian-Pontian) sand aquifer with temperatures of 55 to 65°C. The installed capacity and annual energy use of the 34 users amounts to 65.62 MW_t and 486 TJ. More efficient use of thermal water is foreseen due to implementation of concession fees in 2015 for thermal water utilization, which will probably lead to lower annual energy use in 2016. Greater progress is visible in shallow geothermics, where the number of smaller geothermal heat pump (GHP) units of typically 12 kW is around 9,038 with 112.6 MW_t capacity and 599.4 TJ/yr energy use (Dec. 2015). The number of greater GHP systems with heat pumps of rated power over 20 kW is in constant increase during the last 10 years, resulting in 24.0 MW_t and 132.7 TJ/yr, with some 312 systems accounted for so far, mostly in public or private buildings (schools, kindergardens, factories, etc). The total numbers for both deep and shallow geothermics are 202.2 MW_t and 1,218.1 TJ/yr. Drilling activity was much lower with ca 1.6 km of new boreholes, both production and exploration, including the temperature gradient boreholes. It's expected that trend of 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 2020. 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 geothermal heat pump 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: Petrol-Geoterm Co., Geological Survey of Slovenia, 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 15 years direct use shows only slight and changing increase with exception of the geothermal (ground-source) heat pumps. 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. Geothermal (ground source) heat pump sector is the only category showing a strong steady growth. Main geothermal exploration and drilling activity took place recently in the NE part for direct use purposes. The activities were oriented in drilling new production and reinjection wells to increase and improve the direct use of geothermal heat, notably for district heating, greenhouses and touristic purposes.

2. GEOTHERMAL RESOURCES AND POTENTIAL

A description of geology, geothermal resources and potential is given in the previous country updates (Rajver et al., 2013, 2015 and references therein). Slovenia lies in the convergent area of the African and Eurasian tectonic plates, consequently its geological and tectonic setting is quite complicated. 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 existed before 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 (areas 4 and 3 in Figure 2). 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 (areas 4, 3 and 2 in Figure 2). 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; 2013). The perspective geothermal reservoirs are:

(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 (area 1.a in Figure 2).

(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 (areas 2 and 4-> in Figure 2).

(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 (white area between the colored zones and beneath 1.a, in Figure 2).

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. Deeper wells would be, however, needed to reach the 150°C isotherm.

2.2 Resources and potential for direct use

The northeastern part of Slovenia 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), and GeoMol (Diepolder et al., 2015). Better insights are gained in characteristics of the geothermal field, hydrogeological conditions of the Mura-Zala sedimentary basin 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 exploit thermal water from Neogene aquifers with exception of those in Maribor and Benedikt (№. 13 and 20, respectively, in Figure 1). About 19 inactive and potential wells in the area exhibit the wellhead temperatures of 28 to 62°C, and have a total yield of 68 kg/s, resulting in the ideal thermal power of 9.4 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 700 to 1400 m 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 (9), Dobrovnik (11), Lendava (7), Mala Nedelja (8), Moravske Toplice (1 and 3), Tešanovci (2), Murska Sobota (4 and 5), Petišovci (6), Ptuj (12) and Renkovci (32) (all are numbers in Figure 1). The best production wells have flow rates at a maximum utilization of a few tens of 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 and also with organic substances at temperatures up to 72°C in Moravske Toplice.

In the SE part of Slovenia 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, while at Šmarješke Toplice 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 more suitable rocks are: sand and sandy clay, flysch rocks such as sandy marls or loose sandstone, sandy claystone. For vertical heat exchangers (geoprobes or BHEs) the most suitable are: dolomite, dolomitic limestone and limestone, and majority of magmatic and metamorphic rocks. Figure 3 shows geological and hydrogeological potential for the ground-source heat pump (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, prediction and 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 wells and thus 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 (more details in Rajver et al. 2013). Individual open vertical systems can be successfully used also in the areas of inter-granular aquifers of medium hydraulic conductivity and also 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 100 m below the surface (Figure 8) shows the best conditions for GSHP systems (somewhere >14°C) in the NE part, and elsewhere only average temperatures between 8 and 14°C.

2.3.3 Thermal energy storage

Aquifer thermal energy storage systems (ATES) are weakly applied so far or not exploited at all. Very few attempts were made to explore this possibility in Slovenia up to date. Groundwater flow velocities are characteristically rather high in most alluvial aquifers, reaching the magnitude of 10 m/day which could not be very 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.

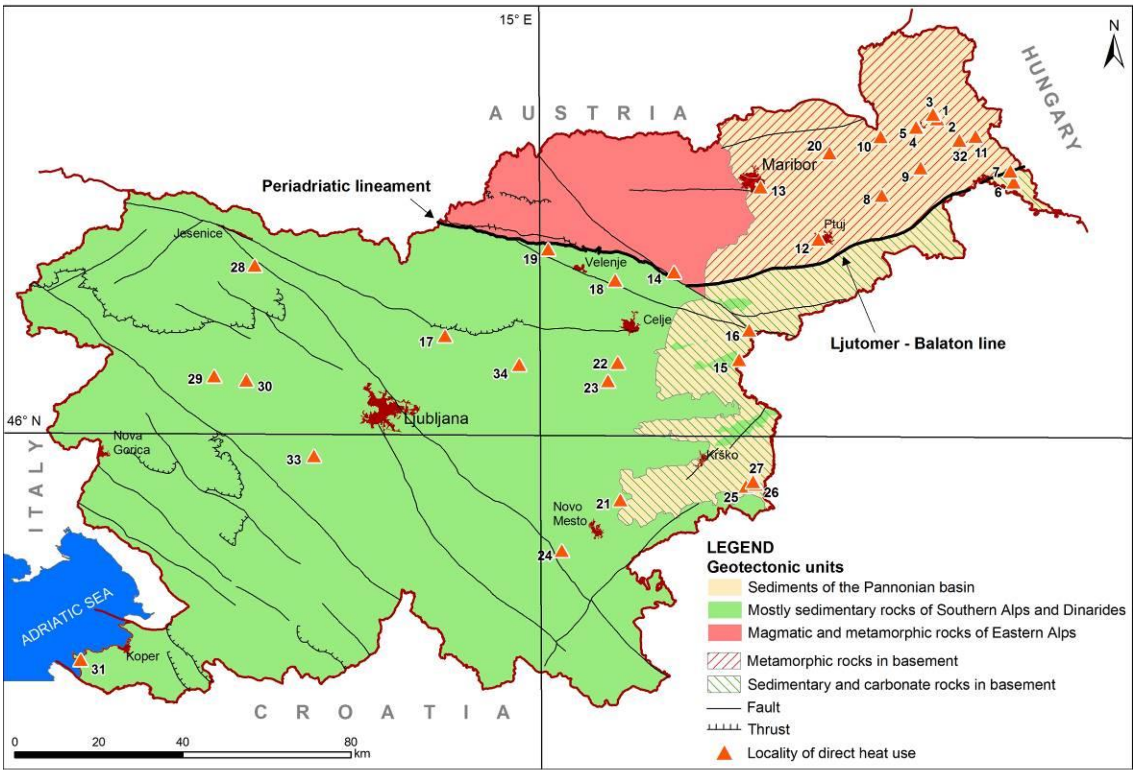
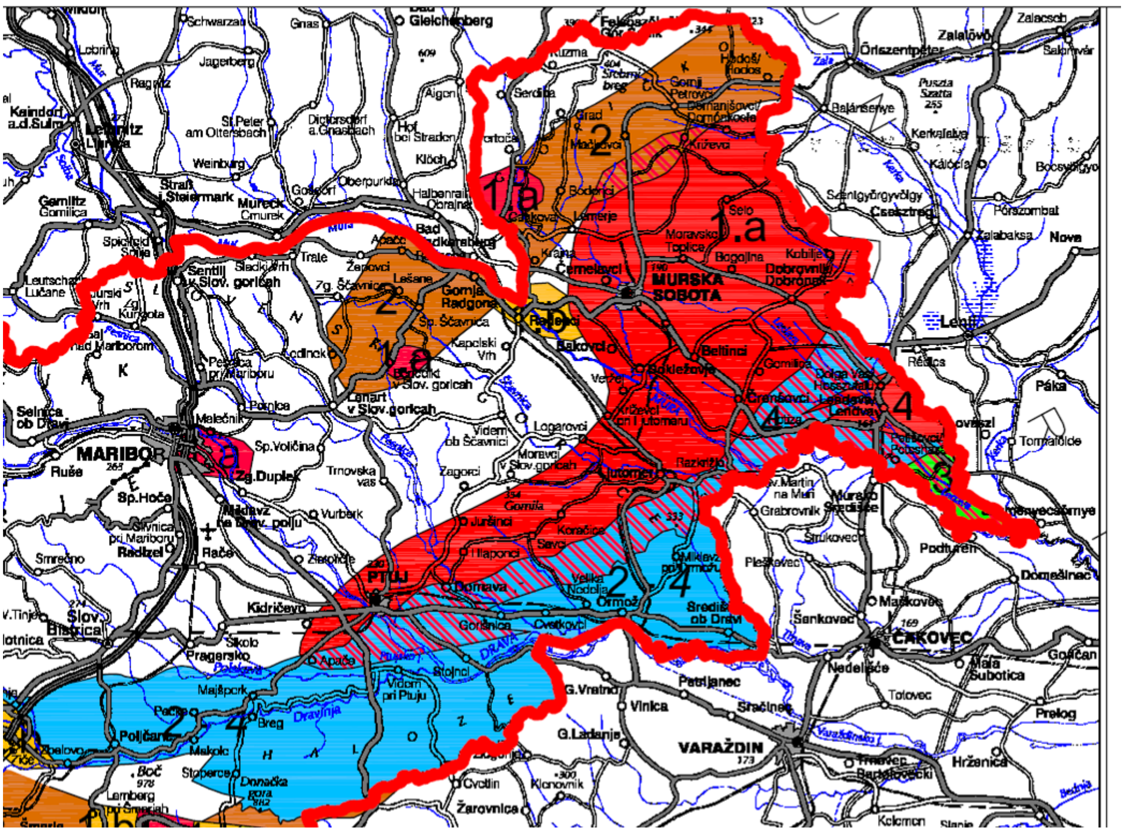


Figure 1: Generalized geological map of Slovenia with localities of direct heat use (geology by Poljak, in Rajver et al., 2013).



Useful (Economic) resources:			
Identified		**Undiscovered**	
1.a	proven	2	
1.b	probable		
1.c	possible		
Subeconomic resources:			
3	Identified		
4	Undiscovered		
4	Proven useful identified resources (1.a) lying over undiscovered and/or subeconomic resources		

Figure 2: Distribution of NE Slovenia with regard to resources of geothermal energy according to accessibility and geological assurance (Rajver et al., 2011)

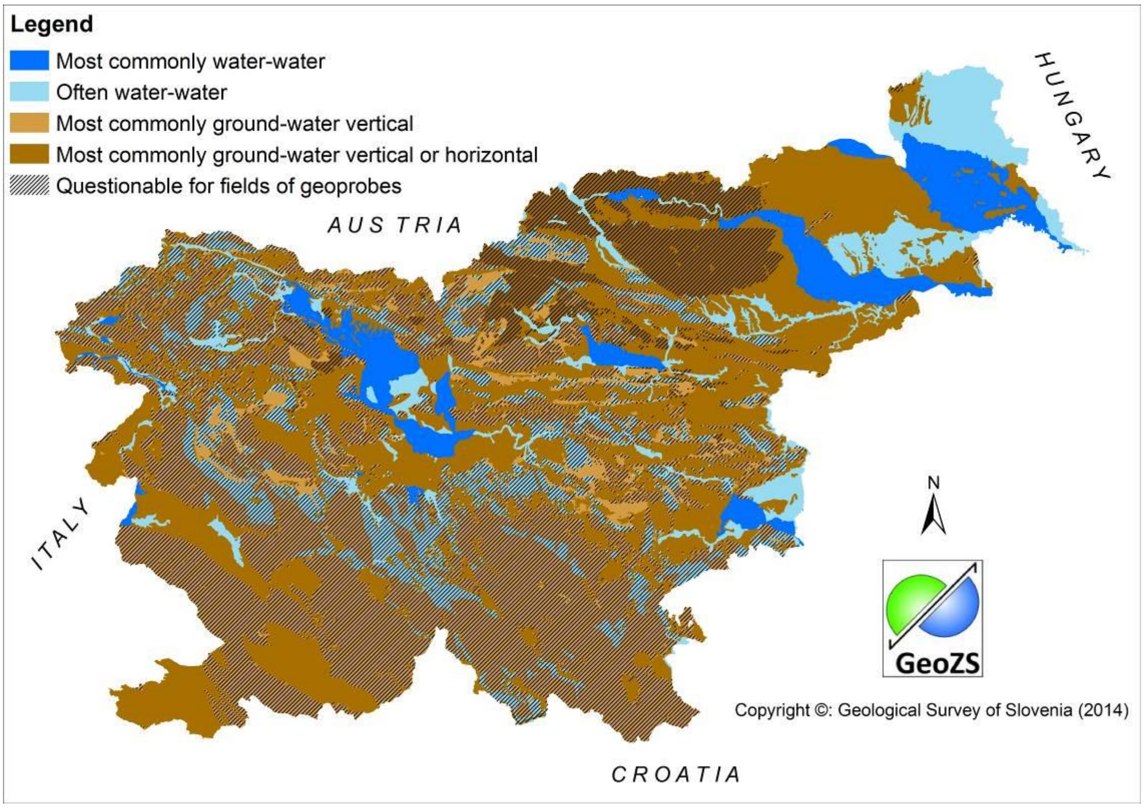


Figure 3: Potential for the GSHP applications in Slovenia (improved after Prestor et al., 2012).

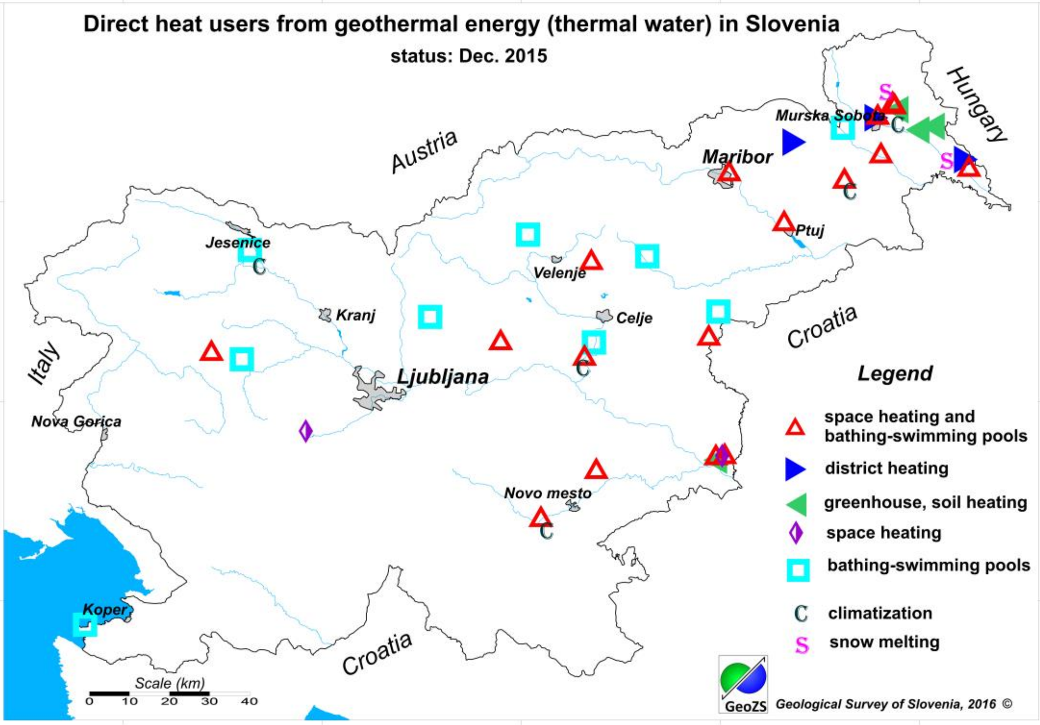


Figure 4: Main utilization types for direct heat use of geothermal energy (thermal water) in Slovenia (status Dec. 2015).

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 57 production wells plus 3 thermal springs, implemented at 34 localities, including 3 localities, Renkovci, Izlake and Vrhnika (№ 32, 33 and 34 in Figure 1, respectively), which were not reported for EGC 2013. The reasons are that at Vrhnika after a 4-year hiatus the geothermal use of the same thermal source started again in 2013 by a new user, Siliko Co., while at Izlake the geothermal utilization is actually going on constantly since 1987 by the Retirement home (DSO), but was omitted in the past reports because of poor information on the use in that area. Instead, geothermal direct use at Medijske Toplice has been recorded all the time until it went bankrupt in Nov. 2009. Therefore, since the EGC 2013 report the new users are at Izlake, Vrhnika and Renkovci. The user at Renkovci is a greenhouse complex named Paradajz Co., located in the north-eastern Slovenia. It uses the regional Upper Pannonian-Pontian sand and loose sandstone geothermal aquifer. Figure 4 shows main utilization types for direct use heat.

In Slovenia, geothermal energy is estimated to currently supply for direct heat uses and geothermal (ground-source) heat pump (GSHP) units at least 1,218.1 TJ/yr (338.4 GWh/yr) of heat energy with corresponding installed capacity of 202.25 MW_t. Of these values direct use is 65.62 MW_t and 486 TJ/yr (135 GWh/yr), and the remainder, 136.64 MW_t and 732.1 TJ/yr (203.4 GWh/yr) are GSHPs (Table E). The main application of use turns out to be now the GSHPs, followed by resort and spa use for individual buildings space heating, for greenhouses and for swimming pools with balneology (Table C; Figures 5 and 6). The main reason that the total energy use does not show nowadays about 1,330 TJ/yr despite great increase of shallow geothermal energy use is inadequate reporting from one big user of direct heat from thermal water (Čatež Terme). They reported wrong (too high) values for the annual flow rate from their boreholes for the previous years, some 61 kg/s instead of ca 19.5 kg/s, as reported just recently for 2015. Consequently the total annual energy use at Čatež is smaller for ca 31.3 GWh (112.8 TJ). However, few approximate corrections had to be made for its values also as back as to 1994. The values for capacity and energy supplied by the GSHPs are to our knowledge quite correct as we try to determine as much exact number of units installed as possible.

3.1 Geothermal district heating

Only three geothermal district heating (DH) plants are considered in Slovenia at present (Table D1). In Murska Sobota the residential areas (ca 300 flats with 16,000 m^2) and a new theater under Komunala authority are heated geothermally through heat exchangers, especially from October to April, while in Lendava a greater number of public buildings (school, kindergarten, etc.) and blocks of flats (total 50,000 m^2) are heated under the Petrol Geoterm Co. authority. District heating is a small scale in a village Benedikt with few public buildings (4,222 m^2) in operation since 2010. The total geothermal energy used for district heating is 21.85 TJ/yr (6.07 GWh/yr), and is lower compared with 23.5 TJ (6.27 GWh) in 2012. The reason is lower use in Murska Sobota and improved monitoring of measured used energy in Lendava. Due to unfavorable concessions fees introduced by the Government in 2015 the Murska Sobota Komunala stopped with running the DH plant on geothermal energy on January 1, 2016. The future of geothermal DH there remains uncertain.

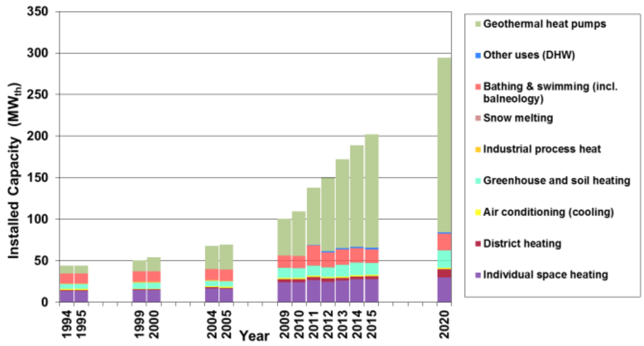


Figure 5: Geothermal direct use applications in a period 1995-2015 (total capacity in 2015: 202.25 MW$_t$).

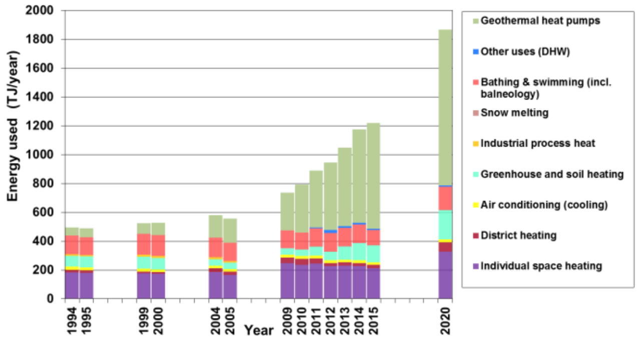


Figure 6: Geothermal direct use applications in a period 1995-2015 (total energy used in 2015: 1218.09 TJ).

3.2 Agriculture (greenhouses) and industry

In eastern Slovenia the heating of greenhouses using geothermal water began in 1962 at Čatež (№ 25 in Figure 1). It was performed there by the Flowers Čatež Co. on 4.5 ha for cultivation of flowers mostly for domestic market. At Tešanovci near Moravske Toplice (№ 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 (№ 11), the greenhouses of 4 ha were constructed by Ocean Orchids Co. for orchids cultivation, both for domestic and foreign markets. At Renkovci (№ 32), new greenhouses of 4 ha were built 3 years ago for tomato and also exotic fruit cultivation. Geothermal heat use runs there since autumn 2013. The total geothermal energy used in the greenhouses (13.5 ha) is 117.18 TJ/yr (32.55 GWh/yr), which is much higher compared with 58.92 TJ/yr (16.37 GWh/yr) in 2012, as a result of new user at Renkovci, with corrections for Čatež already taken into account. At Čatež, the Terme Čatež Co. acquired the Flowers Čatež Co. and it has all production boreholes closely spaced which exploit the same fractured Triassic dolomitic aquifer. At neither of the localities mentioned there is no geothermal DH, according to belief of maintenance managers there. The geothermal use for industrial process heat does not exist anymore since January 2009 when the IUV leather industry in Vrhnika went bankrupt.

3.3 Individual space heating of buildings with domestic hot water heating

Space heating is implemented at 19 localities, 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 only in case of too low thermal water temperature for this type of use. The total geothermal energy used for space heating is about 212.7 TJ/yr (59.1 GWh/yr) as compared with 226.68 TJ (62.97 GWh) in 2012. During the last three years space heating with geothermal heat was cancelled at two localities: Radenci and Bled (№ 10 and 28 in Figure 1) due to more convenient gas boilers, and was introduced at Dobrna (№ 18 in Figure 1), with the one at Izlake running for years. The heating of domestic (sanitary) hot water is included in these values at nine localities, while for 6 other users it was possible to get separate values, some 10.18 TJ/yr (2.83 GWh/yr) of used geothermal heat.

3.4 Bathing and swimming pools with balneology, air conditioning and snow melting

After individual space heating at thermal resorts and spas and heating of greenhouses this is the third most important type of direct use of geothermal energy. There are 18 thermal spas and health resorts, and additional 9 recreation centres (6 of them as part of the hotels' accomodation) where swimming pools with a surface area of about 50,174 m^2 and volume of 66,322 m^3 are heated by geothermal water directly or indirectly through heat exchangers or geothermal heat pumps. Wellhead water temperatures in thermal spas range from 23 to 62°C. The total geothermal energy used for bathing and swimming amounted to 103.5 TJ/yr (28.75 GWh/yr) in comparison with 129.8 TJ in 2012. At some localities 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. New direct heat users of geothermal for swimming pools are a rather small recreation center Kopačnica in western Slovenia, and Hotel Paradiso in Dobova in eastern Slovenia, while utilization in Portorož and especially at Rimske Terme has been established again following a general reconstruction of swimming pools and resort/health centers.

As new direct use application in the country also snow melting of the sidewalks using geothermal heat from the already utilized thermal water is applied within the doublet system in Lendava, with about 0.014 TJ/yr only. Snow melting under two football grounds is applied also at Hotel Vivat at Moravske Toplice, with 0.653 TJ/yr. Altogether the used geothermal heat is 0.667 TJ/yr (0.185 GWh/yr) compared to 0.192 TJ in 2012.

Air conditioning (cooling) of the hotels' spaces using geothermal energy is not well documented as it is operational only at few localities: Moravske Toplice Terme 3000, Mala Nedelja BioTerme, hotels at Bled, Dolenjske Toplice and Rimske Terme, contributing about 19.93 TJ/yr (5.53 GWh/yr) of extracted energy, compared to 21.86 TJ in 2012.

3.5 Geothermal heat pumps

At 13 health or spa resorts, at Hotels Diana (Murska Sobota) and Cerkno, plus at DSO Izlake and Siliko Vrhnika, the GHPs, typically of greater capacity (11.95 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 taken into account 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 decade after some slow period in the early 1990's with low interest in GHPs 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 crust is available practically everywhere in Slovenia except in the mountainous region. Technical, environmental and economic incentives can be considered advantageous for more rapid introduction of GSHP systems in the country. This is also backed by support programs from utilities and from the government through subsidies or credits. These units consist of ground-coupled closed loop heat pumps (horizontal and vertical heat collectors), or groundwater open loop heat pumps, depending on local conditions.

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 numbers of heat pump sales give practically all the quantity for their estimation, and we were successful in acquiring them from domestic producers and numerous merchant agents of imported units. Currently there are about 9,038 small operational GSHP units (typical 12 kW) that extract 599.4 TJ/yr of geothermal heat. Of these, we estimate that 47.3% are open-loop systems that extract annually about 322.8 TJ from shallow groundwater, 46.2% are horizontal closed-loop (230.4 TJ), and 6.5% are vertical closed-loop systems (47.3 TJ). Closed-loop units together remove 277.8 TJ/yr from the ground, while 38.7 TJ/yr of heat is rejected to the ground in the cooling mode, mostly by vertical systems. There are also greater capacity GSHP units (>20 kW) installed within about 312 systems in public and other buildings. Of them 221 are open-loop water-water type, 62 vertical closed-loop, and 29 horizontal closed-loop systems. Capacity factor for the small GSHP units is 16.9%, and for the larger units (>20 kW) is 17.5%, the lowest among all the application types, reflecting that small and large 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 2200 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 65.62 MWt, including GHPs at thermal spas, but without numerous mostly small GSHP units. The annual energy use at 34 localities amounts to 486 TJ (135 GWh), which is by 2.1% higher than in 2012 (476 TJ as corrected value). It is a consequence of new direct heat users, and some ups and downs at other users. Annual energy use (Figure 7) is lower for individual space heating (6.2%) and bathing and swimming (20.3%), and on the other hand slightly higher for district heating (8.7%) and considerably higher for greenhouses and soil heating (99%) in comparison with situation 3 years ago. The use for industrial process heat is suspended. However, the GSHP sector exhibits the largest share (60.1%) in direct use, compared to 49.7% in 2012.

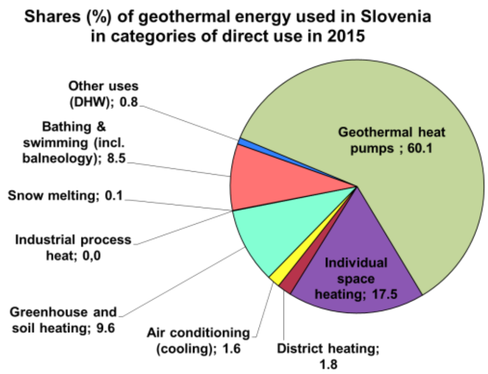


Figure 7: Shares of geothermal energy used in Slovenia in categories of direct use in 2015 (status Dec. 2015).

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 wells have to be drilled at appropriate localities, which have to be previously confirmed by better geophysical (seismic, microseismic, MT) investigations with a goal to create an EGS.

The investments in geothermal (Table F) are, except for direct uses, mostly approximate and incomplete, since many users of shallow geothermal don't report such data. Nevertheless, the trend was slowed down with little research and surface exploration including exploration and production drilling. Also, there was much less construction of new buildings and swimming pools at thermal resorts or spas (e.g. Kopačnica). For the past three years drilling activity was weaker compared with earlier periods. At the north outskirts of Murska Sobota the 1.2 km deep borehole Sob-4g/13 was drilled as the only geothermal production (or reinjection) borehole in the last three years, and it should be in pair for the planned doublet system with a year earlier drilled Sob-3g/12 borehole of 1.52 km depth. Since 2013 only three geothermal gradient boreholes were drilled in eastern Slovenia with total depth of 0.4 km.

5. RECENT DEVELOPMENTS AND FUTURE PROSPECTS

A few projects for further geothermal direct use development are planned or under way. In the NE part of the country the Petrol Geoterm Co. (in Lendava) has improved a few old oil wells into geothermal ones which can be used for aquaculture or greenhouses. 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.

5.1 Thermal water direct use

A doublet scheme is operational in Lendava downtown. In the 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 previously mentioned boreholes Sob-3g/12 and Sob-4g/13 for enlarging the district heating purpose in the northern parts of town (Rman et al., 2012). Pumping tests were done in 2012/13. They showed slightly better performance in Sob-4g with the maximum flow rate of 43 l/s and wellhead temperature of 57°C, with ideal thermal power of 5.4 MW_t at a temperature drop of 30°C. Sob-4g was unsuccessfully tested as a reinjection borehole in 2016. Thermal capacity of the new doublet could reach 4 MW_t and geothermal energy use 8.8 GWh/year. It will be the second doublet system operating in the country when and if it becomes active. Few wells, drilled in earlier years, were put in use, namely at Dolenjske Toplice two such wells, V-10/05 of 450 m and V-13/10 of 40 m depth, are in use since 2013, and at Šmarješke Toplice a 242 m deep well V-12/04, was put in use in 2015. There, an old shallow well was also shortly tested for its reinjection capacity but the results are yet not satisfactory.

The European projects T-JAM and TRANSENERGY, running between 2009 and 2013, significantly contributed to a better resource assessment of northeastern Slovenia. It was the first time that geothermal aquifers in the Mura-Zala basin were treated as transboundary, and their potential for higher geothermal development was precisely evaluated using a unified and systematic approach of the Slovene and Hungarian as well as Austrian Geological Surveys. Within this activity, the 3D geological model of the subsurface was elaborated and new geothermal, chemical and isotopic measurements were executed. These were used to update geothermal maps of the region and to set a sound hydrogeological conceptual model of the groundwater flow. The T-JAM project investigated the Upper Miocene porous geothermal aquifer in the Mura formation (Nádor et al., 2012), while TRANSENERGY was more focused into the Pre-Neogene carbonate and metamorphic aquifers in the sedimentary basin basement (http://transenergy-eu.geologie.ac.at/).

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). Transboundary effects of abstraction from the carbonate aquifer in Korovci were tested by a pilot flow and heat model of the Bad Radkersburg-Hodoš area, plus the convection cell in Benedikt was confirmed by a local numerical model (Fuks and Janža, 2013). For the first time a comprehensive overview of the actual thermal water utilization was made (Rman et al., 2013), as well as comparison of the EU, national and local legislation and its effects on the observed geothermal development (Prestor et al., 2013). The research showed that currently exploited aquifers were highly stressed and had to be carefully monitored and effectively managed to enable their further development. 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. Some direct heat users in northeastern Slovenia have been monitored for groundwater level, temperature, yield, and chemical composition of thermal water since 2009 by a research monitoring network (Rman, 2014), but national monitoring is not yet operational. Reinjection should become obligatory and also nationally supported in order to preserve the existent capacities of thermal water, as the doublet system proves to be effective in Lendava.

The EGEC market report shows the planned extension to about 7 geothermal DH systems in Slovenia by 2016 (Dumas et al., 2013). The table "planned GeoDH plants" on page 68 therein presents some new possible developments in the country, e.g. extensions at Murska Sobota and Benedikt with 3.3 and 3 MW_t, respectively, and new plants at Turnišče and Ormož. According to our knowledge, no major investments are planned in these communities. The least expected to be actually developed is the site at Ormož, as the latest exploration well there was not positive.

5.2 Ground source heat pumps

There were several projects, which were still running in the last three years, focused on promotion and fostering of utilization of shallow geothermal sources:

(a) Ground-Med (Advanced ground source heat pump systems for heating and cooling in Mediterranean climate, Programme: Seventh Research Framework Programme),

(b) Legend (Low Enthalpy Geothermal ENergy Demonstration cases for Energy Efficient building in Adriatic area, Programme: IPA Adriatic) and

(c) GeoSEE (Innovative uses of low-temperature geothermal resources in South East Europe, Programme: target 3 – SouthEast Europe).

The project Ground-Med concerns the development of the advanced generation of GSHP systems, aiming to deliver heating and cooling to buildings with a measured year round SPF above 5 (Mendrinos et al., 2010). The Ground-Med technology is demonstrated and monitored at the demo buildings of South Europe, and of them is a Municipal Hall in Benedikt (No. 20 in Figure1) where a GSHP unit is coupled to three borehole heat exchangers (BHEs) of total length 390 m. The system provides heating and cooling to the whole building.

Application of larger and more advanced systems is evident by good practices of GSHPs in the last years.. During the last three years we made a systematic overview and inquiry for objects with installed GSHP units of greater power. These plants are not included in any records, because the owners (investors) do not obtain funds from financial incentives such as smaller individual devices. 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 greater power systems so far some 221 open-loop water-water type systems are found, plus 62 vertical closed-loop, and 29 horizontal closed-loop systems. Few greater open-loop systems have 4 production and 4 reinjection wells or more. Similarly, the greatest closed-loop system has 24 BHEs, while a special case belongs to the settlement "15th Maj" in Koper with 192 active energy piles within the basement of 4 buildings.

We put some effort to distinguish the numbers of the GSHP units with rated power of 20 kW and more from the total number of the GSHP units. However, this job is quite tedious, since it is difficult to find appropriate objects with such installations, but as a first attempt Figure 8 shows the first 103 systems with GSHP units of such greater power, with addition of so far known hydrothermal HP units. Data fot this figure are collected on a voluntary basis. An attempt has been made to present some objects where GSHP units with installed capacity of over 500 kW are installed in Slovenia (Table 1).

As regard to GSHPs contribution the EGEC market report (Dumas and Sanner, 2013) showed some strange numbers for Slovenia to our opinion, more exactly too high values for renewable heat produced in 2011-2012 by GSHPs (graph 6 therein). Also data after EurObserv'ER 2013 are not realistic in table on page 43 therein, namely the production of about 25 ktoe/yr from 4,669 GSHP units in 2012 is too high. Thermal energy used by 9,350 GSHP units (small and big units together) so far is just 17.49 ktoe (Table E). Figure 9 shows the trend of all GSHP units since the first data acquisition in 1994. Also in Slovenia 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 15:1 in favor of air-water HPs.

6. CONCLUSIONS

Direct use from thermal water from geothermal aquifers does not show any clear increase on yearly basis, due to lower annual flowrates from several wells at different users, which is an evidence of delivered maximum allowed pumping quantities, and some technical difficulties. The GSHP market is more predictable, as its growth is rising for about 79.8 TJ (1.9 ktoe) every year in the last 5-year period. Actual (Dec. 2015) contribution from geothermal energy is assessed to be 486 TJ from thermal water direct use and 732.1 TJ from GSHPs, all together 1,218 TJ (29.09 ktoe). Consequently, target values from NREAP-SI 2010 (in: Rajver et al., 2013) are still far distant and a lot of effort will be needed in this programming period 2014 - 2020.

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. For the first time, neighbouring countries (Slovenia, Austria, Hungary and Slovakia) discussed about the management of the geothermal resources that appertain to the common cross border sedimentary basin.

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 is essential for sustainable transboundary resources management. In the frame of the above mentioned projects, very important progress was made where common characterization of actually 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, 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 also 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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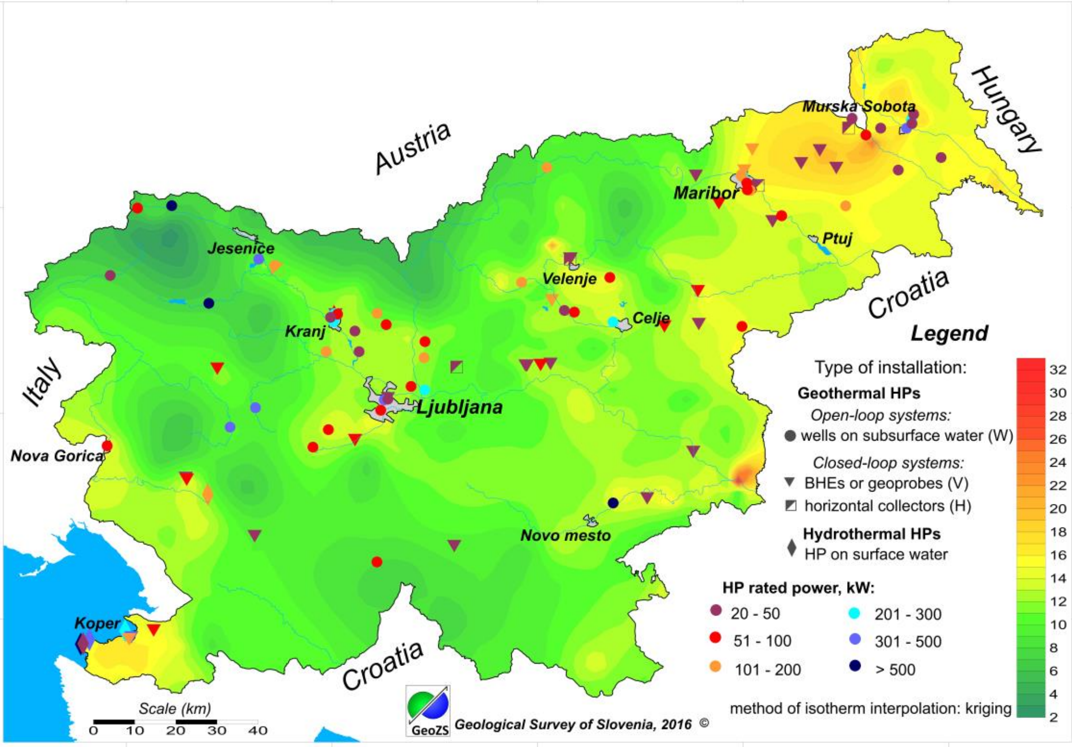

Figure 8: Distribution of the first 103 collected data on GSHP systems with rated power of 20 kW or more, by type of installation, and known hydrothermal HP unit systems (data collected on a voluntary basis). The isotherms show temperature at 100 m depth.

Table 1: Existing objects with GSHP units with installed capacity (rated power) over 500 kW.

Locality	Plant Name	Year commis-sioned	Cooling	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2015 produc-tion (GWh_{th}/y)	Geoth. share in total prod. (%)
Bohinjska Bistrica	Bohinj Park EKO hotel – Aqua Park	2009	Y	0.816	1.4	0.7581	39.1
Gozd Martuljek	Hotel Špik	2009	N	0.505	1.075	0.9072	92
Otočec	Hotel Sport – Terme Krka	2015	Y	0.673			

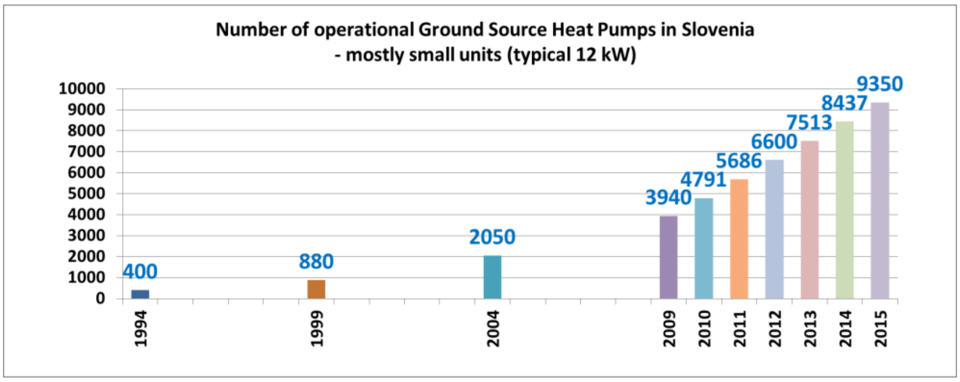

Figure 9: Trend of operational GSHP units (both small and great rated power or capacity) since 1994.

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 2015 *	0	0	3453 *	12560 *		
Under construction end of 2015	0	0	187 [1]	403 [2]		
Total projected by 2018	0	0	4363 [3]	13903 [4]		
Total expected by 2020			4379 [3]	14530 [4]		
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2015 (indicate exploration/exploitation, if applicable):					Exploitation: 26	

* If 2014 numbers need to be used, please identify such numbers using an asterisk

[1,2] Source: Statistični urad republike Slovenije, http://www.energetika-portal.si/pxweb/Dialog/Saveshow.asp

[3,4] Source: Strategija razvoja elektroenergetskega sistema RS - Načrt razvoja prenosnega omrežja RS od leta 2013 do leta 2022. Izdajatelj: ELES, d.o.o., Hajdrihova 2, 1000 Ljubljana. 2012. Pages 27 and 40, respectively.

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Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2015 pro-duction * (GWh_e/y)
	nothing							
total								

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

* If 2014 numbers need to be used, please identify such numbers using an asterisk

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

Explanation to tables C, D1 and D2: 'Geothermal district heating or district cooling' (Geothermal DH plants) is defined as the use of one or more production fields as sources of heat to supply thermal energy through a network to multiple buildings or sites, for the use of space or process heating or cooling, including associated domestic hot water supply. If greenhouses, spas or any other category is among the consumers supplied from such network, it should be counted as district heating and not within the category of the individual consumer. In case heat pumps are applied in any part of such a network, they also should be reported as district heating and not as geothermal heat pumps. An exception is for distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings; systems of this kind should be reported in table E. For table D2, please give information on large systems only (>500 kW_{th}); installations with geothermal source temperatures <25 °C and depth <400 m should be reported in table E.

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

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for individual 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 2015 *	3.554	6.0724	14.376	32.5486	29.815	61.91	17.872	34.4703
Under construction end 2015								
Total projected by 2018								
Total expected by 2020								

* If 2014 numbers need to be used, please identify such numbers using an asterisk

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

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

Locality	Plant Name	Year commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2015 production * (GWh_{th}/y)	Geoth. share in total prod. (%)
Lendava	Petrol Geoterm, Le-2g	2007	N	N,RI	2.676	5.0	4.742	97
M.Sobota	Komunala, Sob-1	1988	N	N	0.167	1.5	0.484	30
Benedikt	Community, Be-2	2004	N	N	0.711	3.3	0.85	20
total					3.554	9.8	6.0724	56.6

* If 2014 numbers need to be used, please identify such numbers using an asterisk

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

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

Table D2: Existing geothermal direct use other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2015 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Banovci-Veržej	Terme Banovci	1990	N	3.779	4.8	2.2617	99
Čatež	Terme Čatež	1979	N	15.113	15.51	17.3211	89
Cerkno	Hotel Cerkno	2014	N	1.456	2.98	1.6967	93.8
Dobova	Dobova AFP	1996	N	0.962	1	2.4588	100
Dobova	Dobova Paradiso	2010	N	1.216	1.326	0.6336	91
Dobrovnik	Ocean Orchids	2006	N?	5.9	?	13.8500	90?
Dolenjske Toplice	Terme Dolenjske Toplice	2003 /2008	Y	1.351	4.26	4.4614	40
Lendava	Terme Lendava	1997	N	1.531	2.5	6.1775	80
Mala Nedelja	BioTerme	2008	Y	1.381	2.181	0.7380	60?
Moravske Toplice	Terme Vivat	2006	N	2.774	4.409	5.0575	100
Moravske Toplice	Terme 3000	1986/ 1989	N	11	15	23.5780	99
Podčetrtek	Terme Olimia	1988	N	1.068	1.368	6.7386	80
Ptuj	Terme Ptuj	1980	N	1.289	3.1	6.6530	40
Renkovci	Paradajz	2013	N	3.431	?	14.4797	90?
Rimske Toplice	Rimske Terme	2010	Y	1.054	2.384	3.3880	90
Snovik	Terme Snovik	2003	N	0.644	1.704	0.4592	9
Šmarješke Toplice	Terme Šmarješke Toplice	1987	Y	1.88	1.88	4.4306	100
Tešanovci	Grede	2002	N	1.153	1.153	3.0292	100
Topolšica	Terme Topolšica	1982	N	0.638	0.9832	0.4522	80
Vrhnika	Siliko	2013	N	0.566	0.6466	0.4191	66.5
total				58.186	67.1848	118.284	

* If 2014 numbers need to be used, please identify such numbers using an asterisk

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

<u>Explanation to table E:</u> 'Shallow geothermal' installations are considered as not exceeding a depth of 400 m and (natural) geothermal source temperatures of 25 °C. Installations with geothermal source temperatures >25 °C and depth >400 m should be reported in table D1 or D2, respectively. Distribution networks from shallow geothermal

sources supplying low-temperature water to heat pumps in individual buildings are not considered geothermal DH *sensu strictu*, and should be reported in table E also.

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

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2015 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2015 *	9350	136.636	203.358	913	14.555	10 – 20
Projected total by 2018	12000	174	260			

* If 2014 numbers need to be used, please identify such numbers using an asterisk

Table F: Investment and Employment in geothermal energy

	in 2015 *		Expected in 2018	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power			0	0
Geothermal direct uses	0.90	22.1	1	23
Shallow geothermal	8.0	120	10.0	130
total	**8.90**	**142.1**	**11**	**153**

* If 2014 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

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

Table G: Incentives, Information, Education

	Geothermal el. power	Geothermal direct uses	Shallow geothermal
Financial Incentives – R&D	0	0	Scheme of Energy Advice (EnSVet)
Financial Incentives – Investment	0	DIS: Project investment for agriculture – Ocean Orchids, Paradajz LIL: yes; RC: no	DIS, LIL
Financial Incentives – Operation/Production	FIT system available: in practice it is not used yet; NREAP (2010)	FIT system available: in practice it is not used yet	FIT system available: in practice it is not used yet
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)