European Geothermal Congress 2013
Pisa, Italy, 3-7 June 2013

Geothermal Energy Use, Country Update for Slovenia

Dušan Rajver, Joerg Prestor, Andrej Lapanje, Nina Rman

Geological Survey of Slovenia, Dimičeva 14, 1000 Ljubljana, Slovenia

dusan.rajver@geo-zs.si

Keywords: geothermal potential, recent development, utilization, direct utilizations, heat pumps.

ABSTRACT

Geothermal energy use in Slovenia has been followed on regular basis since 1995. In the last period 2007 - 2012 there is no growth but slow and constant increment of the energy contribution from direct use of thermal water. Three district heating systems are operating; the additional one is under construction. A significant potential of existing thermal wells is still unused and could be exploited most probably after 2015. Capacity factor of existing utilization is still rather low. Stronger initiatives for BAT use are needed. The most needed research and development should be focused on reinjection possibilities in the Pannonian basin sediments in NE part of Slovenia and on cascade use possibilities. Three very important international projects (Transthermal, T-JAM under Interreg IIIA initiative, and Transenergy within the Central Europe programme) were conducted in the last years. They enabled to reveal the potential of further thermal water abstractions development, considering the cross-border sustainable management and environmental goals.

Contribution of geothermal energy from heat pumps shows growth (16.5 %) and will overcome thermal water utilization in the following few years. But, there is still lack of advanced technologies applications. The action plan was elaborated in the frame of Geo.Power (Interreg IVC) that would initiate the quick growth in the next period 2014 – 2020.

Direct heat use categories use annually 164.3 GWh_{th} (591.51 TJ) of geothermal energy, and ground source heat pumps additional 96 GWh_{th} (346 TJ). There is no electricity generation from geothermal sources in Slovenia so far. The identified middle enthalpy resources in NE Slovenia are not suitable for economical electricity production from geothermal energy due to significantly low yield.

1. INTRODUCTION

Total electricity production in the country amounted to 16,056 GWh in the year 2011, and the share of electricity from renewable resources was 24.1 % (SURS). By 2015, electricity production on geothermal base is not foreseen yet.

This paper describes the present status of direct heat use and development in the last five years. There was no intermediate report for the country presented for the European Geothermal Congress 2007. However, geothermal energy use in Slovenia has been statistically followed by Geological Survey of Slovenia on regular basis since 1995 with update reports presented at the World Geothermal Congresses (Rajver et al., 2010 and references therein).

Emphasis of direct use of geothermal energy in Slovenia is on exploitation of low temperature resources for space and district heating, and for thermal spas. During the last 15 years direct use shows only slight increase with exception of the geothermal heat pumps. The reasons depend on the locality. The problems could be overexploitation of geothermal resources in some localities of the north-eastern part of the country (Kralj and Kralj, 2000; Rman et al., 2012 and references therein), occasional technical problems, 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 one showing a growth.

Main geothermal exploration and drilling activity took place recently in the NE part of the country for direct use purpose. 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.

Initial development of the geothermal heat pump sector was in the 1970-80's. Somehow slow increase followed still in the 1990's and since the beginning of this century the sector shows a considerable growth.

2. GEOTHERMAL RESOURCES AND THEIR POTENTIAL

The geological and tectonic setting of Slovenia is complicated because its territory lies in the convergent area of the African and Eurasian tectonic plates. 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, External and Internal Dinarides and Adriatic foreland represent parts of the Adriatic microplate. Details about the geothermal field and tectonic background of the whole country can be found in papers of Ravnik et al. (1995), Placer (1998) and Rajver and Ravnik (2002), while geothermal field with higher temperatures in the deeper parts is presented by Rajver et al. (2012).

Twenty-four thermal (natural and captured) springs have constant temperature close to or above 20 °C with 36 °C as maximum, however, there are several localities, especially in the northeast, where no surface thermal manifestations existed before the thermal water was discovered during the oil and gas drillings (Lapanje & Rman, 2009).

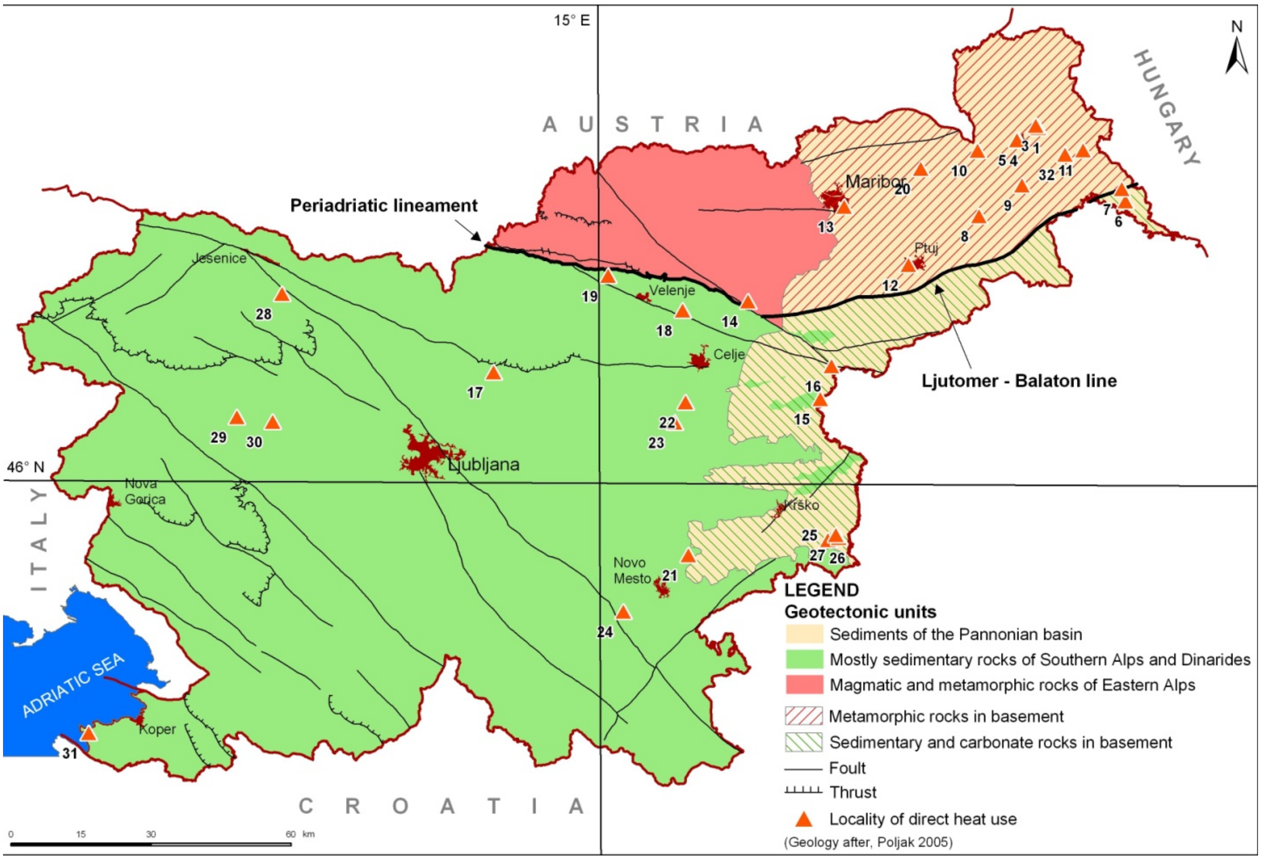

Figure 1: Generalized geological map of Slovenia with localities of direct heat use (geology after Poljak, 2005).

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 the deeper fault zones in the Pre-Neogene basement locally. It's the area south of the Ljutomer-Balaton fault where the Pre-Tertiary basement consists of clastic and carbonate rocks which are 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 only limited exploitable for electricity production (Rajver et al., 2012). The perspective geothermal reservoirs are:

(a) hydrothermal reservoirs in depths to 3 km and at temperature high above 80 °C: aquifers of the Lendava, Špilje and Haloze formations NE of Murska Sobota and in 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 on the Boč-Ormož antiform.

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

According to the current geological knowledge these reservoirs are very limited in space. New geological investigations and geothermal wells should be targeted on finding a geothermal aquifer with a wellhead fluid temperature high above 90 °C and a yield above 25 kg/s which allows the binary cycle utilization. However, deep wells would be needed to reach the 150 °C isotherm, which is a lower limit for electricity production with classical turbines (Figure 2).

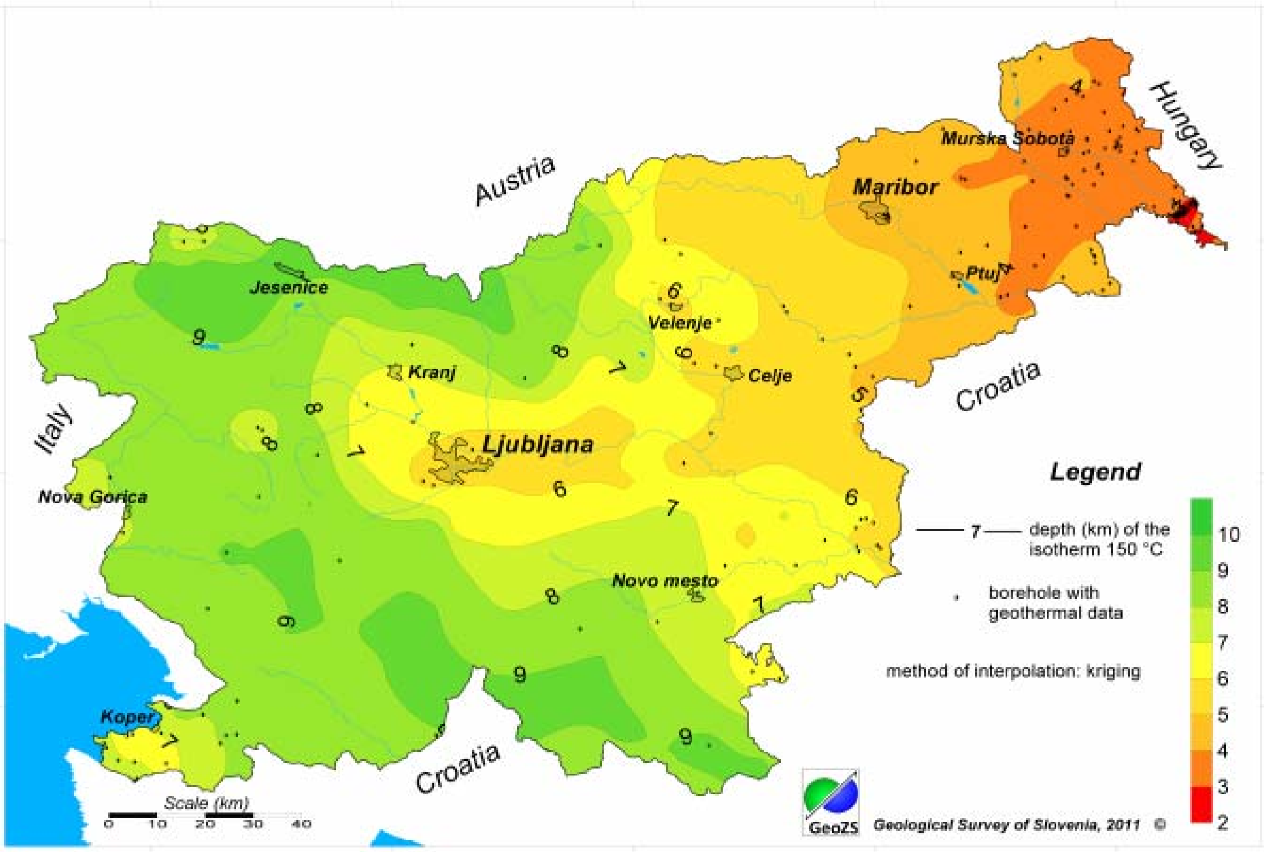

Figure 2: Expected depths (km) of the 150 °C isotherm in Slovenia.

2.2 Resources and potential for direct use

In the following, some general characteristics of the geothermal resources and potential for direct use are explained, based on division of the country into simplified tectonic units (Figure 1).

a) Pannonian basin – Northeastern part of Slovenia

Northeastern area of the country 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) and Transenergy (Goetzl et al., 2012). The results give better insights in characteristics of geothermal field and hydrogeological conditions of the Mura-Zala sedimentary basin. The area has an elevated surface heat flow density (HFD), above 100 mW/m^2, with the expected temperatures above 80 °C at 2 km depth east of the Maribor and Ptuj towns line (Rman et al., 2012). All production wells there exploit thermal water from Neogene aquifers with exception of those in Maribor (No. 13 in Figure 1) and Benedikt (No. 20 in Figure 1) (Rman et al., 2012). Geothermal aquifers in the fractured metamorphic rocks of the Pre-Tertiary basement were captured in Maribor with 6 wells (maximum depth of 1.6 km) in early 1990's and in Benedikt in 2004 with a 1.86 km deep exploitation well (Kralj and Vršič, 2007; Kralj, 2009). The latter has a maximum yield of 10 l/s with the highest water temperature (72 °C) at the wellhead so far among the current production wells. In Maribor three production wells have temperature of only 39 °C due to very limited total yield of 1.5 l/s. About 19 inactive and potential wells in this area exhibit the wellhead temperature range of 28 - 62 °C, and have total yield of 68 l/s, resulting in the ideal thermal power of 9.4 MW$_t$.

The geothermal most utilized northeastern area that belongs to the Mura-Zala basin (SW part of the Pannonian basin) is filled by Tertiary 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 Pannonian-Pontian geothermal sandy aquifers, which are widely utilized by Hungary and Slovenia, are composed of 50 - 300 m thick sand-prone units that are found in a depth interval of about 700 - 1400 m in the interior parts of the Pannonian basin, where temperature reaches from 50 to 70 °C (Nádor et al., 2012 and references therein).

Hydraulically connected sandy lenses of the Pannonian-Pontian Mura Fm. represent the best yielding low temperature geothermal aquifer in the sedimentary basin in Slovenia, which is utilized at Banovci, Dobrovnik, Lendava, Mala Nedelja, Moravske Toplice, Murska Sobota, Petišovci and Ptuj. The best production wells have flow rate at maximum utilization of few tens of l/s, for example in Moravske Toplice with over 30 l/s, however, the average flow rate barely exceeds 10 l/s per well. Isolated turbiditic sandstone aquifers of the Pannonian-Pontian Lendava Fm. are exploited at Banovci, Lendava, Mala Nedelja, Moravske Toplice and Murska Sobota in depths of 0.8 - 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 and organic substances at temperatures up to 72 °C.

b) Pannonian basin – Eastern part of Slovenia

In the eastern part of Slovenia and south of the Ljutomer-Balaton fault the main geothermal aquifers are located beneath the sediments of the Pannonian basin. In Rogaška Slatina (No. 16 in Figure 1) thermal water is captured with a 1.7 km deep well in the Triassic dolomitized clastic rocks. The maximum yield is 8 l/s with temperature of 56 °C at the wellhead. Further to the south in Podčetrtek (No. 15 in Figure 1) thermal water is found in Triassic dolomite with maximum yield of 17 l/s and temperature of almost 42 °C.

In the SE part one of the best investigated areas is the Krško sedimentary basin where thermal water is found along its southern rim in the Mesozoic carbonate rocks beneath the Tertiary cover. In the eastern part of the basin is a small Čatež geothermal field that 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 yields ranging from less than 10 l/s to several tens of l/s.

c) Eastern Alps

This area is one of the least investigated as regard to hydro and geothermal conditions. Magmatic and metamorphic rocks are covered with Tertiary sediments only in the valleys. The cover of sediments reach over 1 km in thickness but owing to only average geothermal gradient and surface HFD (40 to 70 mW/m^2) such a thermal cover thickness has almost no influence on the resulting temperature. Few exploration geothermal wells have been drilled within this area, all of them in its western part. The only potential well is MD-1 at Mislinjska Dobrava (1260 m in depth), which has finished in the bottom interval of 80 meters of Neogene basal dolomite breccia and conglomerate. The expected yield of the well is 3 l/s and temperature around 40 °C, resulting in ideal thermal power of 0.4 MW_t (referring to 15 °C). In Zreče (No. 14 in Figure 1) the water discharges from Triassic dolomite aquifer beneath the Miocene thermal cover. Maximum yield of 15 l/s can be abstracted from the deepest production well with temperature of 34 °C.

d) Southern Alps and Dinarides

Tertiary sediments within this tectonic unit represent a significant role as the thermal cover only in some areas. Exploitation wells especially in the central part of the country capture thermal water mostly from the Mesozoic or Paleozoic carbonate and clastic rocks in the fault zones, running along the Tertiary basins (Lapanje & Rman, 2009). The examples are production wells in Topolšica, Dobrna, Laško and Rimske Terme (No. 19, 18, 22, 23, respectively in Figure 1). In Topolšica, Laško and Rimske Terme thermal water is captured predominately in Triassic dolomite aquifers with ascendant flow. In Dolenjske Toplice (No. 24 in Figure 1) and in Vaseno (No. 17 in Figure 1) the thermal water flow is also ascendant from the dolomite and partly limestone aquifers. The production well in Dobrna, for instance, abstracts thermal water from Triassic dolomite aquifer, which is located beneath the 450 m thick cover of Tertiary sediments. Temperature of thermal water (35 °C) is consequently preserved.

There are at least 9 unused wells within this tectonic unit. Temperature of thermal water at wellheads is in the range of 20 - 48 °C (maximum at Lajše) and total yield of the wells is 165 l/s, with the ideal thermal power of 7.7 MW_t.

2.3 Potential for ground-source heat pumps

a) Ground - water systems ($GCHP_h$ and $GCHP_v$)

Clastic rocks cover over half of the Slovene territory, carbonate rocks about 40 %, while pyroclastic, metamorphic and crystalline rocks less than 8 %. Thermal conductivity is measured by the laboratory of the Geological Survey of Slovenia on the rocks that are cored from the boreholes all over Slovenia. These measurements were mostly and more systematically effectuated before the year 2000. After 2000 the measurements are more sporadic, occasional. Characteristic values of thermal conductivities were presented by D. Rajver in the frame of Geo.Power project (Pestotnik et al., 2012). 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. Geological and hydrogeological potential for the GSHP applications is presented in Figure 3.

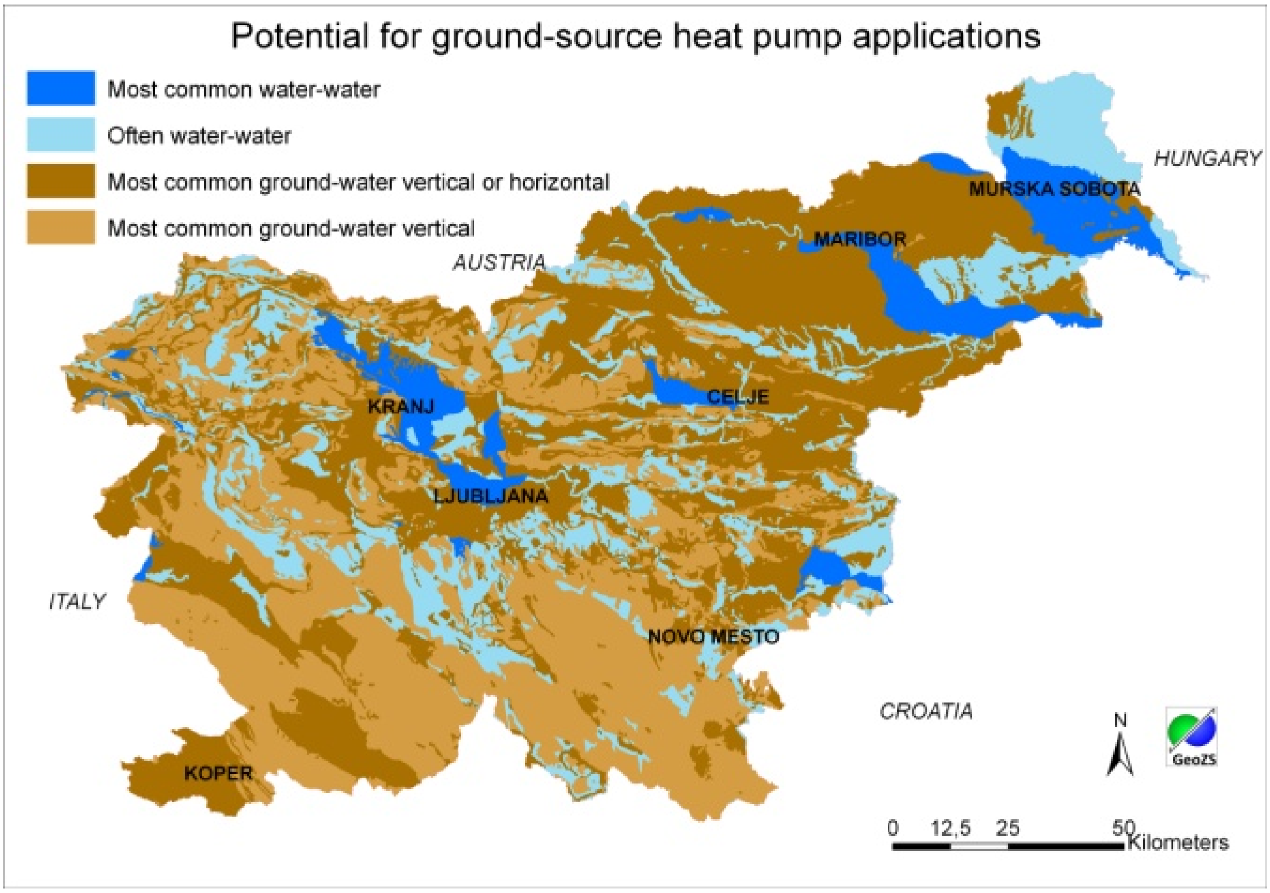

Figure 3. Potential for the GSHP applications in Slovenia (Prestor et al., 2012).

Karstic rocks are very important as a component of shallow underground also in the areas of numerous settlements. Such shallow underground is neither very favourable for vertical systems presenting the uncertainty in drilling, prediction and higher drilling costs.

b) Water – water systems (GSHP$_w$)

Northeastern part of Slovenia (Pannonian basin) appertains to major groundwater basin with relatively high recharge (100 – 300 mm/year). The rest of the Slovene territory is of complex hydrogeological structure with very high recharge (> 300 mm/year) (Pestotnik et al., 2012). About 7 % of the territory is represented by extensive and highly productive gravel and sand alluvial aquifers that are very favourable for wells and thus for open vertical GSHP systems. The major agglomerations (Ljubljana, Maribor, Celje, Kranj, Ptuj, Domžale, Kamnik, Murska Sobota, etc.) are situated on these alluvial plains. Temperature of groundwater is characteristically between 12 and 15 °C. Groundwater table is 2 m to 25 m deep, the water quality is rarely aggressive, usual electric conductivity is about 400 µS/cm.

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).

35 % of the territory is covered by limestone aquifers, where the accessibility of groundwater is rather low and conditions are not favourable for open vertical systems. Closed vertical systems are more applicable. Similar conditions are for the other 35 % of the 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 4) shows the best conditions for GSHP systems (mostly >14 °C) in the NE part, while elsewhere only average temperatures mostly between 8 and 14 °C.

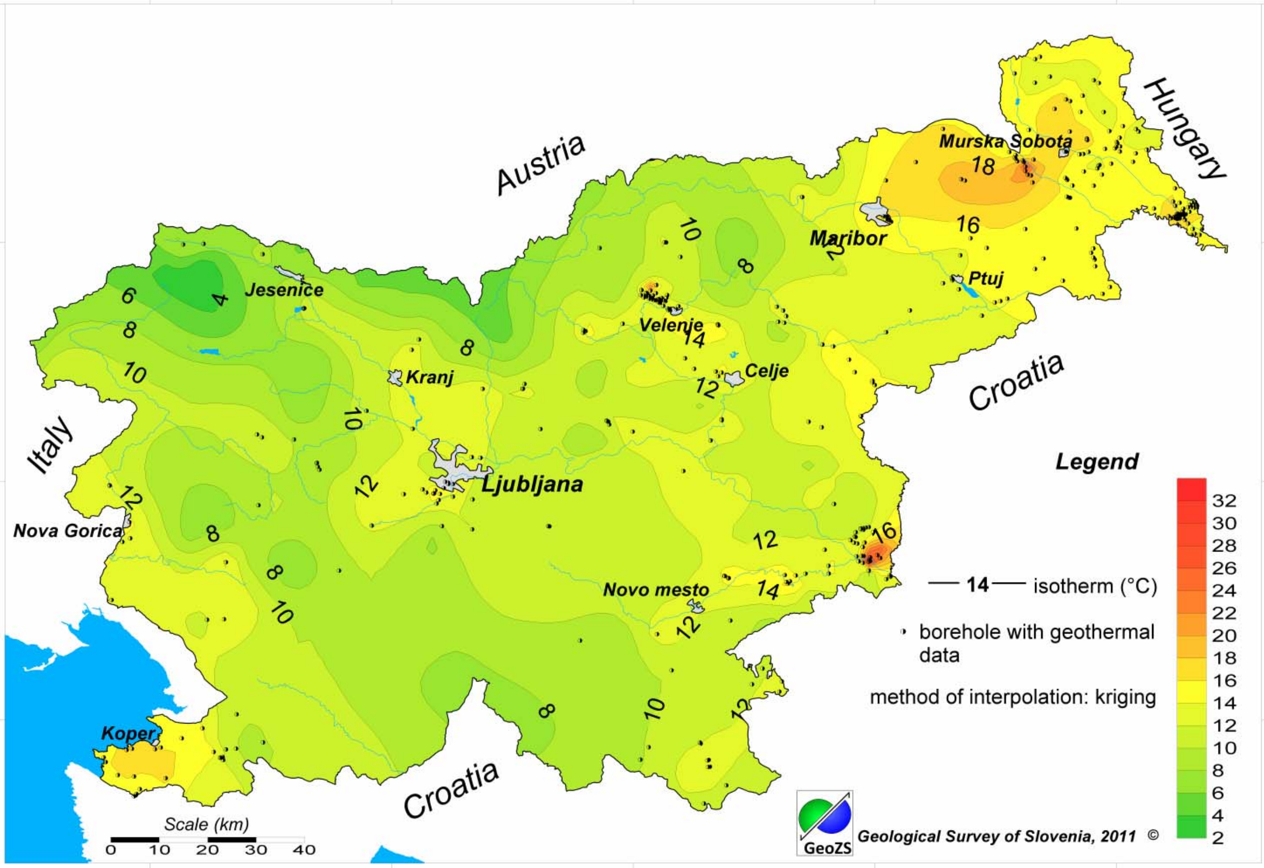

Figure 4. Temperature distribution at a depth of 100 m depth below the surface in Slovenia.

c) Thermal energy storage

Aquifer thermal energy storage systems (ATES) are not exploited yet or very weakly exploited till now. We believe that very few attempts were made to explore this possibility in the country so far. Groundwater flow velocities are characteristically rather high in the most important alluvial aquifers in Slovenia. They reach 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. One very interesting BTES system in Slovenia is mentioned in the subchapter 3.4 below.

3. STATUS OF GEOTHERMAL UTILIZATION

3.1 Initiatives for Geothermal power production

Few initiatives appeared recently for setting up a geothermal power plant in the Pomurje region, in the Mura-Zala basin. But neither of them takes sufficient account of the geological, geothermal and hydrogeological facts and the projects have not yet received any financial support. The proposed draft national energy program expects 25 MW_e geothermal energy utilization for geothermal power plants (GPP), but not earlier than till 2030 (NEP, 2011).

During the past years there were some investigations in the Pomurje region, like reinterpretation of the reflection seismic sections and deep exploration-exploitation drilling for gas research. Reinterpretation of the old seismic sections presumably doesn't show clear characteristics of deeper parts of fault systems which are prolonged into the Pre-Tertiary basement.

3.2 Direct uses – other than heat pumps

We recorded use of geothermal energy in Slovenia which consists of direct use of geothermal energy, including the use of direct heat of thermal water (> 20 °C).

The Slovenian geothermal wells produce warm or hot water from a variety of hydrogeothermal reservoirs. At present (Dec. 2012) 58 operational geothermal wells all over the country produce thermal water warmer than 20 °C. Their ideal thermal power is 99 MW_t (referring to 15 °C). Of them, 35 wells (60 %) are used for multipurpose utilization, i.e. at least for two categories of use. Beside, at least 15 potential production boreholes exist which are currently out of use, however, some of them are occasionally in production.

After realized data demand and collection from the users we've found that at present 32 users exploit geothermal energy directly from thermal water with various categories of use, mostly in thermal spas and health resorts or recreation centres (Figure 5).

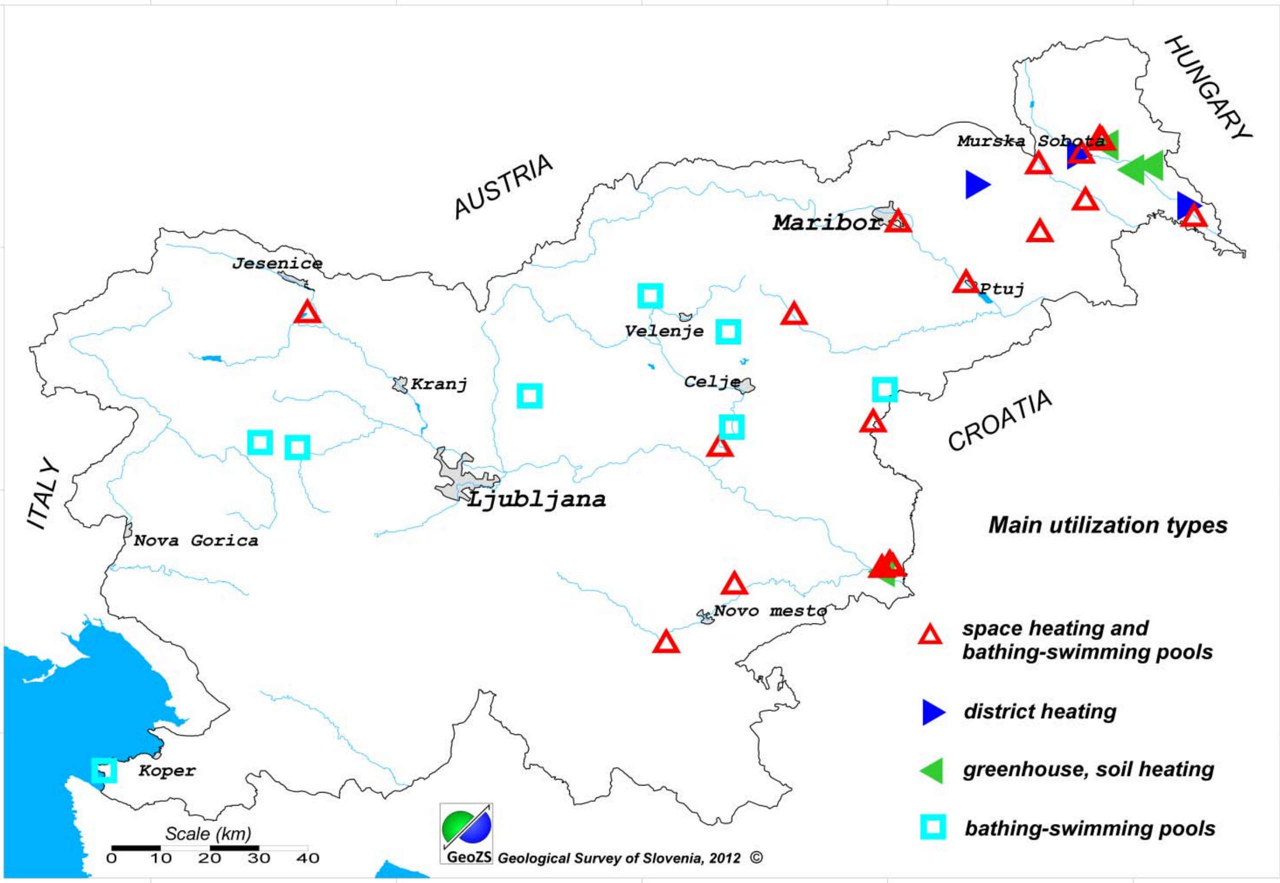

Figure 5. Main utilization types for direct heat use of geothermal energy in Slovenia (status Dec. 2012).

There are 18 thermal spas and/or health resorts and 9 recreation centers, and five of the latter are part of the hotels' accommodation. **Individual space heating** is carried out at 18 locations with 35 production wells, mostly in the balneology centers, thermal spas and resorts (hotels and bungalows), where heat exchangers or heat pumps are used for better performance. Cascade use is much present, where individual space and sanitary water heating is usually followed by heating of spa infrastructure (swimming pools) and balneology. There are few users with the opposite way of cascade use. **Air conditioning** (cooling) is reported only in three locations using 6 production wells. Geothermal energy is utilized for **district heating** at three locations: in Murska Sobota for heating the residential areas (16,000 m^2) and a new theater, while in Lendava a larger number of public buildings and blocks of flats (50,000 m^2) is heated. District heating is a small scale in a village Benedikt with few public buildings (4,222 m^2) also operated. It means 3 operating thermal wells, one at each location. However, wellhead temperature of 49 °C in Murska Sobota and 66 °C in Lendava are not high enough for the systems to operate in full, so oil boilers are used at peak hours. The centralized installation in Murska Sobota is planned for enlargement and improvement when two new wells (doublet) enter the utilization system. **Snow melting** of the sidewalks is applied within the doublet system in Lendava. **Greenhouse heating** is carried out at three locations, in Dobrovnik (3 ha for orchids), Tešanovci (1 ha for tomatoes) and Terme Čatež (ca 4.5 ha for flowers). There are two production wells in Čatež and one in Dobrovnik, while the greenhouse in Tešanovci receives already used thermal water from the nearby thermal resort Terme 3000. In autumn 2012 a new greenhouse for growing tomatoes in Renkovci started using thermal water for heating (No. 32 in Figure 1). However, it is not included in the energy use statistics yet as it is in a testing phase. Swimming pools for **bathing and swimming** (incl. balneology) are heated indirectly through heat exchangers or filled directly by geothermal water from a total of 50 production wells. Actually, there are many users where the pools are filled directly with thermal water (for example Terme Čatež, Cerkno and many thermal resorts in NE Slovenia). Exploitation has been interrupted at two locations since 2009, these are the leather industry in Vrhnika (**industrial process heating)** and the thermal spa in Medijske Toplice. On the other hand two new users have appeared, Paradiso in Dobova with space heating and swimming pools and a small Kopačnica spa.

The greatest share of the geothermal energy direct use accounts for GSHP units mostly for space heating in small decentralized units (36.9 %), and after that, individual space heating at thermal spas and recreation centres (33.2 %), followed with lower share by bathing and swimming including balneology (12.9 %) and closely by greenhouse heating (12.1 %). Other categories are much less present. The growing GSHP category has already surpassed all other applications as regard the installed capacity and energy use (Figure

6, **Fehler! Verweisquelle konnte nicht gefunden werden.**). The energy use trend for most categories shows slight growth or not much change and noticeable increase for the GSHPs. The contribution of GSHPs is difficult to be determined because the complete evidence has not yet been established. In assessing the share of GSHPs, we used the analysis and forecasts of the market growth in the Action Plan for the greater expansion of GSHPs in Slovenia (project Geo.Power).

Different categories of geothermal energy use as of December 2012 are represented in table 1. Total capacity of 125.2 MW_{th} includes also industrial process heating (0.4 MW_{th}), which is not in use now.

Use of geothermal heat for swimming pools (bathing and swimming) has been evaluated with consideration of the actual inflow water temperature into the pool or in some cases the inflow temperature of thermal water entering the heat exchangers before the swimming pools' system and outflow temperature from such a system. Quantities of the annual energy used are calculated based on the actual input and output temperatures of thermal water in the heating system and year-round average flow-rate of individual wells.

Table 1: Installed capacity and energy used of geothermal direct use applications in Slovenia in Dec. 2012.

Category	Installed capacity [MW_{th}]	Energy used [TJ/yr]	Energy used [ktoe/yr]
Individual space heating	27.3	311.0	7.43
District heating	3.7	22.6	0.54
Air conditioning (cooling)	1.6	23.1	0.55
Greenhouse and soil heating	13.6	113.8	2.72
Snow melting	0.03	0.2	0.005
Bathing and swimming (incl. Balneology)	16.6	120.8	2.89
Geothermal (ground source) heat pumps	62.0	346.0	8.26
Total	125.2	937.5	22.4

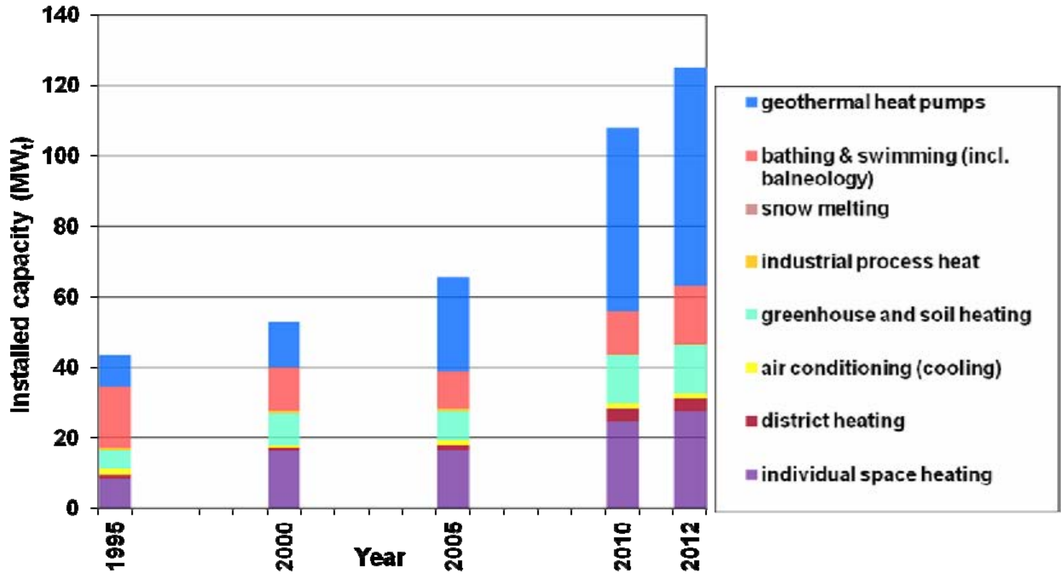

Figure 6. Geothermal direct use applications in Slovenia in a period 1995-2012 (total capacity in 2012: 125.2 MW_t).

3.3 Ground-source heat pumps (small decentralized units for direct use)

Another category of direct use of geothermal energy are numerous decentralized (ground-source heat pump) units. The most unreliable is the estimation of the contribution of the GSHPs in the utilized geothermal energy which is calculated with a very approximate expected trend growth in the number of units of heat pumps in all three modes of operation, open loop water-water (W), closed loop with horizontal (H) and vertical collectors (V).

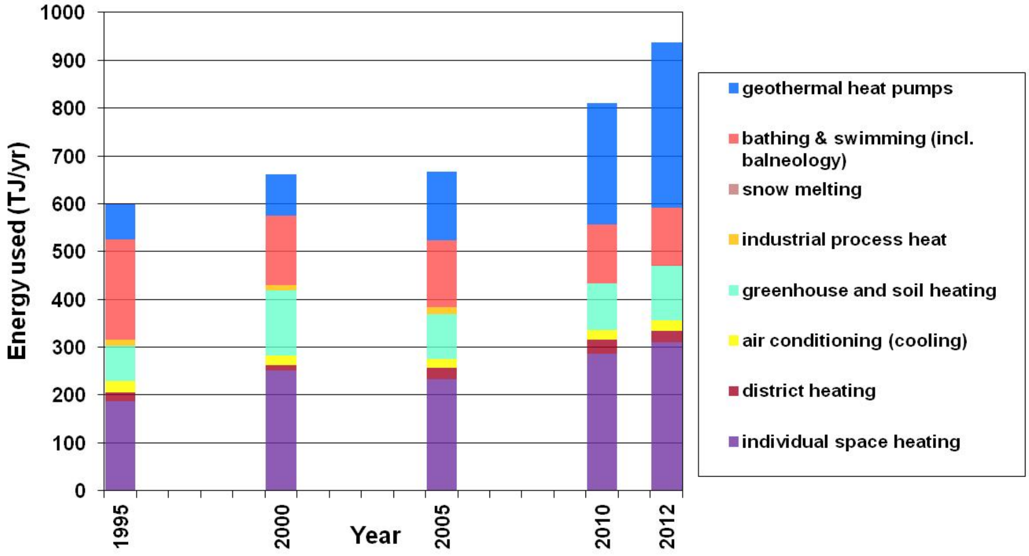

Figure 7. Geothermal direct use applications in Slovenia in a period 1995-2012 (total energy used in 2012: 938 TJ).

Statistical Office of the Republic of Slovenia effectuated inquiry for statistical analysis of energy and fuel use in households - Household Energy Consumption Survey (APEGG) in 2010. Inquiry comprised a representative sample (n ≈ 6,000), from which they received 3,945 answers of total 670,127 occupied dwellings in Slovenia. Statistical analysis showed that 0.41 % of occupied dwellings were using GSHP for space heating (about 2,792 to 3,053 GSHP units; about 57 % water-water $GSHP_w$ and 43 % ground-water systems $GCHP_v$ and $GCHP_h$).

The last assessment by acquiring more exact numbers of sold units from sellers was obtained in 2010 (Rajver et al., 2010). The assessment for June 2010 was about 4,400 units (type of installation: horizontal ground coupled $GCHP_h$ about 2,000 – 45 % and vertical ground coupled $GCHP_v$ about 200 – 5 %, $GSHP_w$ water source 2,200 – 50 %).

From the above mentioned Rajver's market observations it is evident that the market was in the initial phase practically till 2008. The market growth starts in 2008. The most probable actual growth rate is about 16.5 %, nevertheless surely higher than 13 % and not higher than 18 %.

Actual (2012) and projected (2015) energy contribution from GSHP installations (Table E) is assessed assuming that market growth rate is 16.48 % (6,173 units in 2012 and 9,755 units in 2015). It is assumed that average heat capacity of GSHP units installed till 2012 was 10 kW (P_{RATED}), average SPF ($GSHP_w$) was 3.5, average SPF ($GCHP_v$) was 3.2 and average SPF ($GSHP_H$) was 3. At the same time it is presumed that equivalent of full capacity operation is 2,246 hours/year.

We only roughly estimate that the share of new constructions using GSHP is actually not higher that around 10 % and that in 2015 will not be more than 15 %.

3.4 Recent developments

a) Thermal water direct use

New developments were primarily oriented in new exploitation drillings, with deeper wells in NE Slovenia. A geothermal well Re-1g of almost 1.5 km depth was drilled in Renkovci at the end of 2011, and after a testing phase it will be used for greenhouse heating. In autumn 2012, a new exploitation well Sob-3g was drilled north of Murska Sobota to a depth of 1.5 km for a district heating purpose (Rman et al., 2012). It is in a testing phase, while a (planned) reinjection well Sob-4g was completed in winter 2013 in the vicinity. The existence of geothermal potential has been also proved at few other localities, such as in Korovci with almost 2.2 km long directionally drilled exploration-exploitation well Kor-1α into the fractured Haloze Fm. breccia and the Pre-Neogene dolomite in 2008. There were also new drillings in the SE part of the country. A new production well of 450 m depth was drilled for thermal spa in Dolenjske Toplice for heating and balneology. Closer to Croatian border there is a new hotel in Dobova which uses thermal water for space heating and swimming pools. The production well VC-1 of 700 m depth is located in the Čatež geothermal field, and has a wellhead temperature of 56 °C and good average flow rate.

European projects T-JAM and Transenergy, running between 2009 and 2013, significantly contributed to a better resource assessment of the NE 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 that activity, the 3D geological model of the subsurface was elaborated and new geothermal, chemical and isotopic measurements were executed. These were used to update the geothermal maps of the region (Figure 9) as well as to set a sound hydrogeological conceptual model of the groundwater flow (Figure 8). 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 onto 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, while 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). It was also 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.

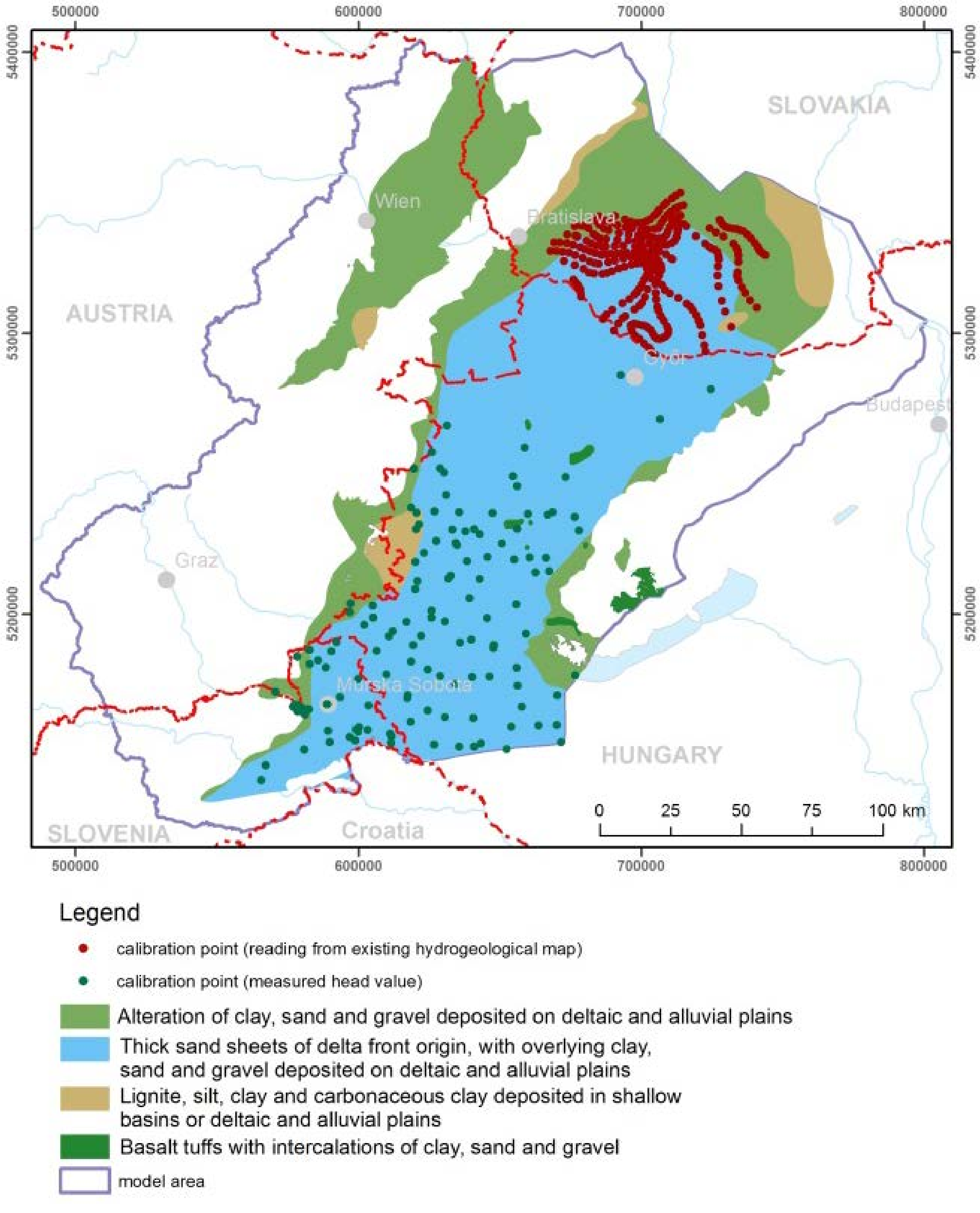

Figure 8. The extent and lithology of the Upper Miocene delta front sand as used for a supra-regional model of groundwater flow (Tóth et al., 2012).

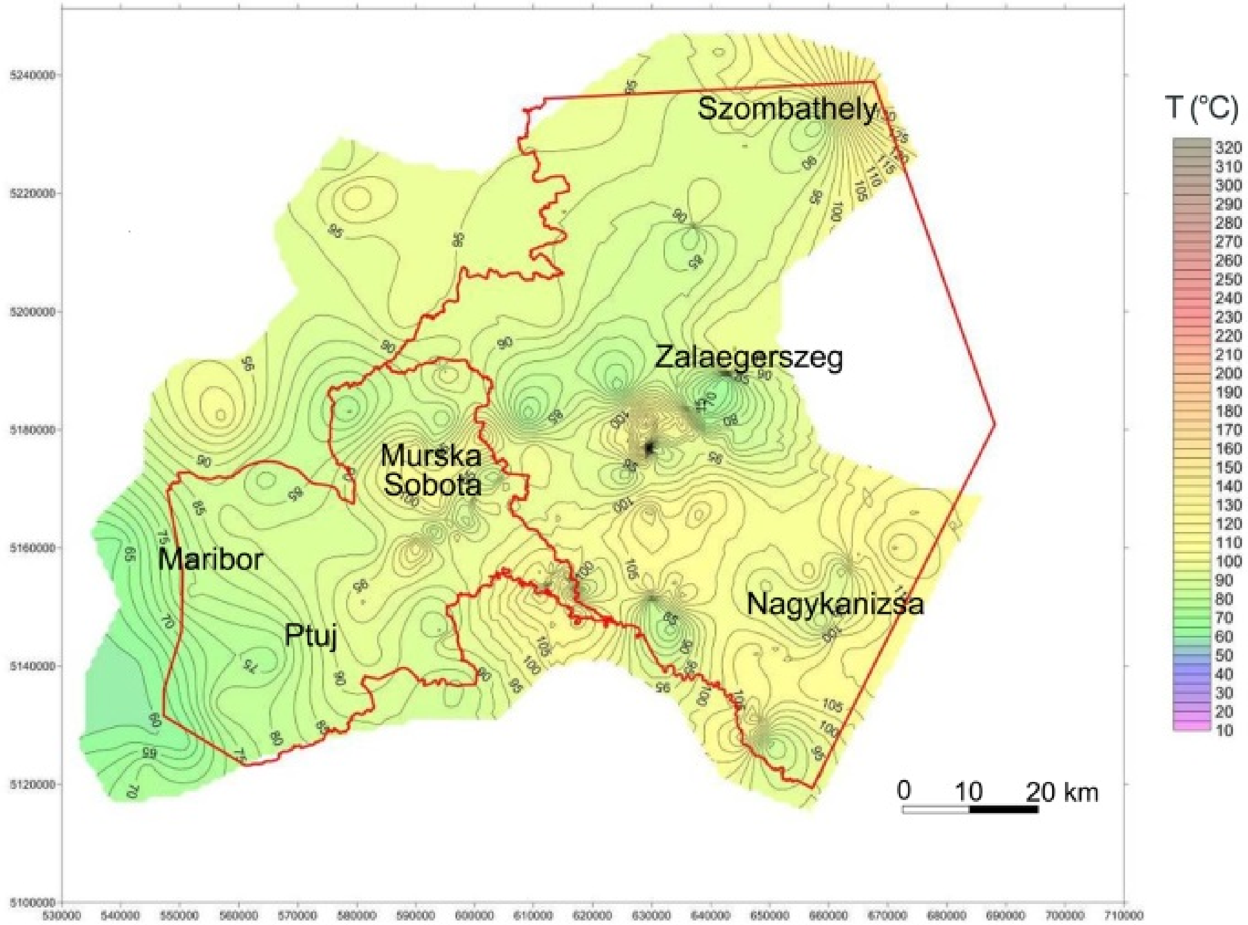

Figure 9. Temperature distribution at a depth of 2,000 m below the surface (Nádor et al., 2012).

b) Ground source heat pumps

There are several projects focused on promotion and fostering of utilization of shallow geothermal sources:

(a) Geo.Power (Geothermal energy to address energy performance strategies in residential and industrial buildings, Programme: INTERREG IVC),

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

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

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

One of the research and consulting enterprises, Gejzir Consulting d.o.o., is active in demonstration projects for greater and advanced development of the GSHP utilization, within the project Ground-Med (Mendrinos et al., 2010). The project Ground-Med, of the 7th Research Framework Programme, concerns the development of the advanced generation of GSHP systems, which aim to deliver heating and cooling to buildings with a measured year round seasonal performance factor SPF higher than 5.

The Ground-Med technology is demonstrated and monitored at the demo buildings of South Europe. One of them is a Municipal Hall in Benedikt where a GSHP unit is coupled to three borehole heat exchangers of different depth (total length = 390 m). The system provides heating and cooling to the whole building. Monitoring of the system performance was foreseen in the heating season 2012/13 (http://www.groundmed.eu).

Application of larger and more advanced systems is evident by good practices of ground source heat pumps in the last years, as for examples:

The Pipistrel Research & Development building (footprint 2,400 m^2) uses GCHP and BTES in a highly advanced and sophisticated technology. The building incorporates geothermal heat exchangers in symbiosis with a large geothermal accumulation field. The solar power plants combined with a cogeneration module covers all energy needs of the building, electricity and thermal energy conditioning included. Geothermal heat exchangers placed around the building are the primary source of thermal energy. A total of 1,200 meters of vertical geothermal heat exchangers provide approximately 36 kW of thermal energy. The

Geothermal accumulation field is a ground collector which functions as a storage for exchange and deriving of thermal energy at rate of 25 W/m^2. The capacity of the accumulation field measures 5,000 m^3 and is placed underneath the whole building in form of 4 collectors each 250 m^2 in footprint. Geothermal heat exchangers are connected to the Geothermal accumulation field so that it is also possible to run the system without using the heat pump on days when pumping the heat transfer medium around the building suffices. Spare heat is accumulated inside the Geothermal accumulation field. As requirements for the higher or lower temperature of the medium arise, the heat pump is activated by the system automatically. A rough estimate for yearly savings of energy is 95,000 kWh.

The settlement "15. maj" in Koper comprises three apartments buildings with privately owned apartments (67 apartment units) and an office building. The vertical structural piles /deep foundation/ down to 40 meters depth are equipped with heat exchangers and consist of a total 50,000 meters of vertical geothermal pipes that provide capacity of approximately 340 kW.

4. FUTURE OUTLOOK OF THE USE OF GEOTHERMAL ENERGY

The present trend exhibits evident increase of geothermal energy use in Slovenia.

There is a moderate but constant increase of direct thermal water use for space heating, district heating, balneology and agriculture. It is expected that this increasing will continue towards 2020 when the total contribution would rise for 2 - 4 ktoe and would be around 18 ktoe in total. Regarding existing installations, there is a lot of space to improve their technologies. A lot of geothermal energy is still lost, i.e. discharged to the environment. Cascade use and reuse of heat could be developed in greater extent for the majority of existing installations in the next period 2014 - 2020.

Investigation potential for geothermal electric power production is limited to northeastern Slovenia, to the area between Ljutomer and Lendava. Further initiatives for setting up a geothermal power plant in the Pomurje region have to be (till 2020) focused to the investigation of deeper parts of that area, i.e. of fault systems prolonging to the Pre-Tertiary basement.

The most favourable areas for new district heating projects or for enlargement of the existing ones are found in the same part of the country, owing to the most favourable expected wellhead temperatures. Till 2015 it is expected to have in operation the enlarged Murska Sobota system which is currently in construction. Thermal capacity of the new doublet could reach 4 MW$_t$ and geothermal energy use 8.8 GWh/year. Abstraction and reinjection wells (SOB-3 and SOB-4) will be the second doublet system operating in the country. This will be very important experience for the further development. Further geothermal district heating development is planned at localities Turnišče and Ormož, both under consortium PannErgy, but are still in negotiation. In Benedikt, the extension to 3.3 MW$_t$ and annual energy use of 14.4 TJ is planned (Bertani et al., 2012). Other areas have less potential for expansion with exception of the eastern part of the Čatež geothermal field.

Observation of ground source heat pumps market shows increasing growth from 13 to 18 %, actually the most probably about 16.5 % (Figure 10). We expect that in the next period 2014 – 2020 the energy contribution from GSHP will become greater than from direct thermal water use. NREAP-SI 2020 target, which is 43 ktoe seems to be too optimistic. To reach this target, the market growth would have to become quick (22 %). Nevertheless, the important market barriers should be overcome by the activities provided in the Action plan that was developed in the frame of Geo.Power project. One of the main activities is facilitation of administrative procedures. One of the most pretentious activities is support for the bigger innovative systems that would replace decrease of new constructions owing to the recession and that would more intensively introduce new advanced and highly efficient technologies.

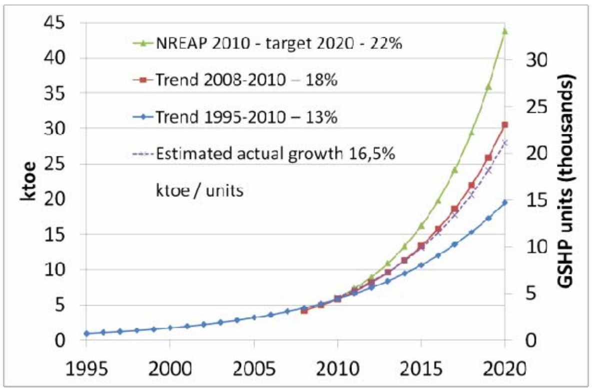

Figure 10. Trend and projected GSHP market growth towards NREAP-SI target 2020.

5. CONCLUSIONS

Certainly, an important progress was made regarding the geothermal energy use in Slovenia in the last 5 years.

Increasing contribution of geothermal energy from thermal water is evident, about 0.3 – 0.5 ktoe every year and estimated GSHP market growth rising from 13 % towards 16.5 %. Actual (2012) contribution from geothermal energy is assessed to be 14.13 ktoe from thermal water direct use and 8.3 ktoe from geothermal heat pumps, all together 22.39 ktoe (260.4 GWh).

It could be possible that the contributions from geothermal energy could be quite overestimated in the National renewable energy action plan for Slovenia 2007 – 2013, namely 16 ktoe from geothermal and hydrothermal HPs for 2012 (NREAP, 2010). The main reason would be that there was no inventory for the time being. We expect that collecting data on the use of geothermal and hydrothermal HPs will be fully established in the following two years.

Nevertheless, target values from (NREAP-SI 2010) are still far distant and a lot of effort will be needed in the next programming period 2014 - 2020.

Years 2009 and 2012 were special milestones for the country's natural resources management, when the pressures and impacts had to be evaluated, significant water management issues have to be identified, program of measures had to be designed and then implemented, all in the frame of Water framework Directive (common EU water policy). We were faced with ample lack of data and information that are needed to reveal the environmental status of these 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 and Hungary) discussed about the management of the geothermal resources that appertain to the common cross border natural basin.

Activities in the last years revealed non stable status of thermal water resources at different locations and also negative trends at a regional level in northeastern and eastern parts of Slovenia. This fact additionally slowed down further development of new abstractions and granting new water and mining rights in the region.

Negative trends were observed also on individual localities in other neighbouring countries. It was recognized that the common understanding of natural systems extending across the state borders was essential for sustainable resources management. In the frame of 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 unsecure or highly unpredictable. In the next 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 Tertiary sediments of the Pannonian basin is highly expected.

We expect that further development will also bring a better use of existing non-used thermal wells and springs. They represent approximately 19.2 GWh/year (1.65 ktoe) of potential that could be used in near future and that represents 41 - 83 % of the foreseen increment of geothermal energy contribution till 2020.

REFERENCES

Bertani, R., Mahieux, C., Ungemach, P. and Sanner, B.: EGEC Geothermal market report, Second edition, Dec. 2012, Brussels (2012).

EurObserv'ER: The state of renewable energies in Europe – 2012 edition, 12th EurObserv'ER report.

Fuks, T., and Janža, M., 2013, Utilization potentials of the low-enthalpy geothermal aquifer of the Bad Radkersburg – Hodoš pilot area – based on 3D modelling results of the Transenergy project, Proceedings (electronic), European Geothermal Congress: Pisa, Italy (this publication) EGEC.

Goetzl, G., Zekiri, F., Lenkey, L., Rajver, D. and Svasta, J.: Summary report: Geothermal models at Supra-Regional Scale for Transenergy project, *MAFI, GBA, GeoZS, SGUDS*, (2012), available on http://transenergy-eu.geologie.ac.at/.

Kralj, P.: Three years of Benedikt geothermal heating system - stage 1 operation, in: International geothermal days Slovakia 2009, Conference and summer school, Session 2: Geothermal district heating projects, (2009), 1-5.

Kralj, P. and Kralj, P.: Overexploitation of geothermal wells in Murska Sobota, northeastern Slovenia, *Proceedings of the World Geothermal Congress 2000*, Kyushu-Tohoku, Japan, (2000), paper #0434, 837-842.

Kralj, P. and Vršič, S.: Benedikt geothermal heating system, stage I, *Proceedings*. Gaeste: Geothermische Vereinigung - Bundesverband Geothermie, (2007), 1-6.

Lapanje, A., Baek, R., Budkovič, T., Domberger, G., Goetzl, G., Hribernik, K., Kumelj, Š., Letouze, G., Lipiarski, P., Poltnig, W. and Rajver, D.: Geothermal resources of northern and north-eastern Slovenia, *RRA Koroška, GeoZS*, Dravograd, Ljubljana, (2007), 126 p.

Lapanje, A. and Rman, N.: Termalna in termomineralna voda = Thermal and thermomineral water, in: Geologija Slovenije = The geology of Slovenia, Pleničar, M., Ogorelec, B. and Novak, M. (Eds.), *Geological Survey of Slovenia*, Ljubljana, (2009), 553-560.

Lapanje, A., Rajver, D., Székely, E., Kumelj, Š., Mozetič, S., Juhász, I., Bányai, P., Tóth, L. and Hamza, I.: Review of geothermal energy utilization in north-eastern Slovenia and south-western Hungary, *GeoZS*, *MAFI*, (2010), available on http://www.t-jam.eu/.

Mendrinos, D., Karytsas, C. and Rosca, M.: The European project Ground-Med "Advanced ground source heat pump systems for heating and cooling in Mediterranean climate". *Proceedings of the World Geothermal Congress 2010*, Nusa Dua, Bali, Indonesia (2010), paper #2912, 1-7.

Nádor, A., Lapanje, A., Tóth, G., Rman, N., Szöcs, T., Prestor, J., Uhrin, A., Rajver, D., Fodor, L., Muráti, J. and Székely, E.: Transboundary geothermal resources of the Mura-Zala basin: a need for joint thermal aquifer management of Slovenia and Hungary, *Geologija*, **55/2**, Ljubljana, (2012), 209-224. doi:10.5474/geologija.2012.013

NREAP, 2010. National renewable energy action plan 2010-2020 (NREAP) Slovenia. Ministry of Infrastructure and Spatial Planning of the Republic of Slovenia in collaboration with Jožef Stefan Institute. Ljubljana, 2010.

NEP, draft, 2011. The draft for the proposal of the National Energy Plan 2010-2030 (NEP). Ministry of Infrastructure and Spatial Planning of the Republic of Slovenia in collaboration with Jožef Stefan Institute, Energy Efficiency Centre. Ljubljana, 2011.

Pestotnik, S., Rajver, D., Lapanje, A., Prestor., J.: Geo.Power (Interreg IVC) – Benchmarking Report. GeoZS (2011), 21 p., available on http://www.geopower-i4c.eu/.

Placer, L.: Contribution to the macrotectonic subdivision of the border region between Southern Alps and External Dinarides, *Geologija*, **41**, Ljubljana, (1998), 223-255. doi:10.5474/geologija.1998.013

Poljak, M.: Structural-Tectonic map of Slovenia 1:250.000, *Geological Survey of Slovenia*, Ljubljana, (2005).

Prestor, J., Rajver, D., Pestotnik, S. and Lapanje, A.: Low-temperature geothermal energy. Inexhaustible energy source just below our house (in Slovene), *Geological Survey of Slovenia*, Ljubljana, (2012), booklet.

Prestor, J., Nádor, A., Lapanje, A., Rman, N., Szőcs, T., Černák, R., Marcin, D., Benkova, K., Götzl, G., Weibold, J., and Bruestle, A.-K., 2013, A comprehensive overview on the existing regulatory and financial barriers on geothermal energy utilization in Austria, Hungary, Slovakia and Slovenia, Proceedings (electronic), European Geothermal Congress: Pisa, Italy (this publication), EGEC.

Rajver, D. and Ravnik, D.: Geothermal pattern of Slovenia - enlarged data base and improved geothermal maps, *Geologija*, **45/2**, Ljubljana, (2002), 519-524. doi:10.5474/geologija.2002.058

Rajver, D., Lapanje, A. and Rman, N.: Geothermal development in Slovenia: Country update report 2005-2009. *Proceedings of the World Geothermal Congress 2010*, Nusa Dua, Bali, Indonesia (2010), paper #0130, 1-10.

Rajver, D., Lapanje, A. and Rman, A.: Possibilities for electricity production from geothermal energy in Slovenia in the next decade, *Geologija*, **55/1**, Ljubljana, (2012), 117-140. doi:10.5474/geologija.2012.009

Ravnik, D., Rajver, D., Poljak, M., and Zivcic, M.: Overview of the geothermal field of Slovenia in the area between the Alps, the Dinarides and the Pannonian basin, *Tectonophysics*, **250**, (1995), 135-149.

Rman, N., Lapanje, A., Rajver, D.: Analysis of thermal water utilization in the northeastern Slovenia, *Geologija*, **55/2**, Ljubljana, (2012), 225-242. doi:10.5474/geologija.2012.014

Rman, N., Gál, N., Marcin, D., Benkova, K., Weilbold, J., Schubert, G., Fuks, T., Rajver, D., Lapanje, A., and Nádor, A., 2013, Current and future trends in geothermal energy utilization in the western part of the Pannonian basin, Proceedings (electronic), European Geothermal Congress: Pisa, Italy (this publication), EGEC.

SURS: Statistical Office of the Republic of Slovenia. (http://www.stat.si/eng/)

Tóth, G., Rotár-Szalkai, Á., Kerékgyártó, T., Teodóra Szőcs, Gáspár, E., Lapanje, A., Rman, N., Svasta, J., Cernak, R., Remsik, A., Schubert, G., Berka, R., and Goetzl, G., 2012, Supra-regional hydrogeological report (http://transenergy-eu.geologie.ac.at/): Budapest, Ljubljana, Vienna, Bratislava, MFGI, GeoZS, GBA, SGUDŠ, p. 1-67.

Acknowledgements

The Transenergy project is running in the frame of the Central European Program 2007-2013 and is co-financed by ERFD. The Slovene researchers are members of the ARRS Program P1-0020-0215 Groundwaters and geochemistry and were partly financed also from Ministry of Infrastructure and Spatial Planning of the Republic of Slovenia. We are also thankful to Teja Rutar (Statistical Office of the Republic of Slovenia) and to Matjaž Česen (Jožef Stefan Institute, Energy Efficiency Centre) for helpful advices especially with regard to GSHPs statistics. Considerations given by Peter Kralj, Ph.D. (Gejzir Consulting), doc. Željko Vukelić, Ph.D. (Dept. Geotechnology and Mining, Faculty of Natural Sciences, Ljubljana University) and Evgen Torhač, Ph.D. (Nafta-Geoterm, Lendava) are also greatly appreciated. The authors are grateful to Simona Pestotnik and Petra Meglič for their help in preparing some data and figures.

Tables A-E

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2011	0	0	3268	16,056 (1)	0	0
Under construction end of 2012	0	0			0	0
Total projected by 2015	0	0		18,665 (2)	0	0

Source:

(1) http://www.stat.si/eng/novica_prikazi.aspx?ID=5029

(2) NEP, 2011, tab. 58, p. 148

Table B: Existing geothermal power plants, individual sites*

*Geothermal power plants are not available in the country.

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 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)
In operation end of 2012	3.72	6.27	13.96	31.61	45.48	126.42
Under construction end of 2012	4	8.8	1.3	5.2	/	/
Total projected by 2015	<8	<15.1	15.3	36.8	45.48	126.42

Remarks: The column "Geothermal heat in balneology and other" includes also individual space heating with capacity of 27.27 MW_{th}, and production of 86.40 GWh_{th}/yr.

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

Locality	Plant Name	Year commiss.	Is the heat from geo-thermal CHP?	Is cooling provided from geo-thermal?	Installed geotherm. capacity (MW_{th})	Total installed capacity (MW_{th})	2012 geo-thermal heat prod. (GWh_{th}/y)	Geother. share in total prod. (%)
Lendava	Le-2g	2007	no	no	2.72	5.0	4.10	80
M.Sobota	Sob-1	1988	no	no	0.29	1.5	1.32	86
Benedikt	Be-2	2006	no	no	0.71	3.3	0.85	20
total					**3.72**	**9.8**	**6.27**	**58**

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

	Geothermal Heat Pumps (GSHP), total			New GSHP in 2012		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2012	6300	62	96.10	885	9	10
Projected by 2015	9900	98	152			

Capacity: P_{RATED}; Production: E_{RES} (definition: Annex 7 directive)