Current and future trends in geothermal energy utilization in the western part of the Pannonian basin

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ABSTRACT

Historical utilization of regional and transboundary geothermal resources was identified between Austria, Hungary, Slovakia and Slovenia. Its status was determined for the period 2010-2011 and based on a unified methodological approach and field inspections. The assembled data were verified and harmonized in a database with three levels applied: organizational (user's contact details), formational (hydrogeological data) and object-linked (production characteristics). The web-database is linked to Google maps and available on http://akvamarin.geo-zs.si/users/, while the results and a web-map service are published on http://transenergy-eu.geologie.ac.at/.

The research identified 148 active and 65 potential geothermal energy users with 403 geothermal objects spread over the area of 47,700 km^2. The 307 active wells produced above 30 million m^3 of thermal water in 2009 (no data from Austria is included due to confidentiality reasons). The amount is rising. Among the 11 lithostratigraphical categories of geothermal aquifers, the highest discharge is estimated from the Mesozoic carbonate basement rocks which have transboundary settings in many cases. The Paleozoic carbonates produce water with 109°C in Austria, which is used for electricity production in Bad Blumau together with constant reinjection. Unfortunately, re-injection is not a common practice as only two more periodical reinjection systems are applied in the Mesozoic carbonates in Podhájska (Slovakia) and the Upper Pannonian sands in Lendava (Slovenia). The latter reservoir is regional, cross-cut by the state borders and captured by the majority of abstraction wells in the area, providing thermal water with temperatures up to 91°C. The individual space heating, sanitary water heating, greenhouse or district heating is applied in Slovakia and Slovenia often but drinking and industrial water as well as agricultural use are more common in Hungary. The predominant utilization is still the traditional category - bathing & swimming. The current abstraction has caused over-exploitation in some areas, plus the lack of reinjection significantly deteriorates the quantity status of geothermal aquifers and the surface water ecology. The waste water management is often inappropriate, while operational monitoring is not harmonized nor executed sufficiently.

The further geothermal development can focus on activation of the inactive boreholes at first, where from the surplus of about 20% of the current thermal water abstraction may be produced. The most promising aquifers are hosted in the Pannonian-Pontian clastic and the Mesozoic carbonate rocks, which may have a transboundary character. Moreover, the concession permits foresee the increase of production for at least twice the current abstraction. The hypothetic thermal water abstraction may rise to over 60 million m^3 per year consequently, but it was not investigated during the research whether this is hydrogeologically feasible or which would be the effects on the current and among various users.

New geothermal development needs to be based upon: unified and transboundary (where needed) management strategy of exploitation, including best available technologies, harmonized operational monitoring, high thermal energy efficiency, public awareness activities and proper waste water management, including reinjection where possible. This has to be applied as soon as possible among current users also in order to control interference between them and regional impacts on the aquifers status.

1. INTRODUCTION

The European integrated climate and energy policy aims to increase the proportion of renewables by 20%

by 2020. This ambitious goal is manifested in the 2009/28/EC Directive on the promotion of the use of energy from renewable sources, on the basis of which each country prepared its national renewable energy action plan (Table 1).

Table 1. National renewable energy action plans (Beurskens et al., 2011).

	Electricity		Heating and cooling		
	2010 (GWh)	2020 (GWh)	2010 (ktoe)	2020 (ktoe)	% growth
Austria	2	2	19	40	111
Hungary	0	410	101	357	253
Slovakia	0	30	3	90	2900
Slovenia	0	0	18	20	11

The first two countries already approached to the transboundary geothermal aquifers identification, resource assessment and development of joint management strategy (Nador et al. 2012). However these activities are needed in the whole western part of the Pannonian basin as its geological settings are of transboundary character and therefore the area of E Austria, SW Slovakia, W Hungary and NE Slovenia was investigated within the framework of the Central European programme project Transenergy.

In order to enhance the use of transboundary aquifers in the area but also simultaneously ensure their sustainable utilization, a need for harmonized management strategy was identified; however, their current status and exploitation characteristics had to be described first to be able to plan necessary actions in the future. Therefore we wanted to (1) provide an integrated assessment of geothermal energy utilization and its future development trends in the described transboundary area, (2) identify geothermal aquifers with indications on overexploitation, and (3) provide hints for geothermal investors, so that they will be aware of thermal water properties and mitigate potential technological issues before they appear.

2. SETTINGS OF THE INVESTIGATED AREA

The project area is bordered by the Transdanubian Central Range unit on the east and southeast (Maros et al. 2012). The northwestern boundary is contoured by the Vienna Basin, than it crosses through the northern Danube Basin to the southeast, and is closed along the Transdanubian Central Range towards the southwest. On the west, the basement contains the Palaeo- and Mesozoic crystalline and sedimentary sequences of the Lower to Upper Austroalpine nappe, the Penninic, the Graz Palaeozoic and the Rhenodanubic (Magura) units. In the north, the basement rocks belong to the Central Western Carpathians nappe system. On the southeast, the geological units of the basement are built by the Transdanubian Range unit and subsequently the inner and outer Dinaric related units. Large sedimentary basins were filled during the Tertiary and Quaternary sedimentation, resulting in many regionally important geothermal aquifers positioned in the Vienna, Kisalföld–Danube, Styrian and Mura-Zala basins (Fig. 1).

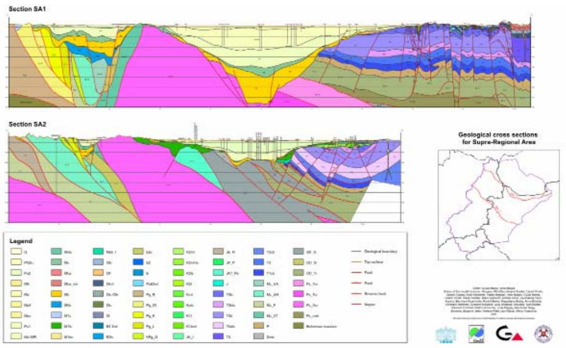

Fig. 1. Cross-sections in NW-SE direction through the investigated area denoting very diverse geology. Scale 1:500 000, vertical exaggeration 10x (Maros et al. 2012).

During the harmonization process, the reported 290 formations were joined by lithostratigraphy, differing among carbonates, volcanic and clastic sediments and rocks, into the 11 units, of which only 4 are tapped very often (Fig. 2). These aquifers are not necessarily hydraulically connected transboundary aquifers but the groups are used solely to compare hydrogeological units with different properties.

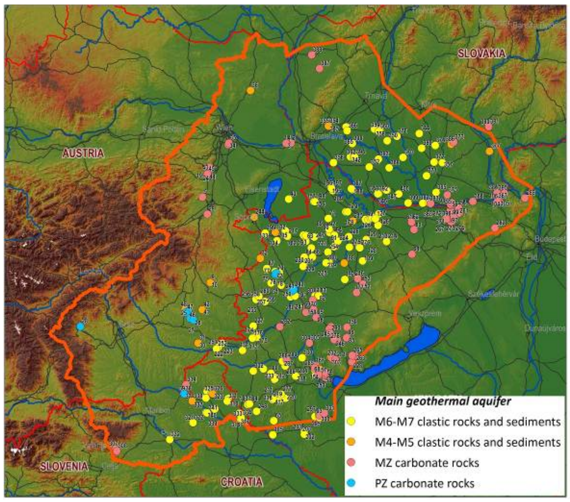

Fig. 2. Map of the most exploited geothermal aquifers, captured by more than 10 wells.

3. METHODS

Numerous wells which tap fresh and thermal groundwater are known to exist in the investigated area. The outflow temperature of 20 °C was agreed upon as being the lower limit which enabled a geothermal well or a spring to be included into this research, since it is officially used for denomination of thermal water in Austria and Slovakia, unofficially in Slovenia, whereas in Hungary this term is used for waters with temperature above 30 °C (Prestor et al. 2012).

From a general overview of the world-wide geothermal energy use, which is prepared every five years for the needs of the World geothermal congress, and it can be noticed that direct use prevails in the four countries (Goldbrunner, 2010; Fendek et al. 2010; Rajver et al. 2010; Tóth, 2010).

A comprehensive overview on geothermal energy use was achieved gradually. A collection of harmonized information on actual utilization in the four countries was performed in 2010 and updated at the end of 2011. A unified methodological approach was taken from the beginning, and field inspections were performed according to instructions given in a manual and a questionnaire. The assembled data were unified, verified and harmonized during its transfer into the database developed with MS SQL Server 2008 R2 software. Three significance levels were applied there. In the 1st level, user-specific data were included containing company name, contact person, address and web page, plus general data on thermal water sources, use, production characteristics and waste water monitoring. In the 2nd level, hydrogeological characteristics of geothermal aquifers, such as outflow temperature or maximum momentary and optimum yield were compiled. Transboundary aquifers from the neighbouring countries were jointly interpreted, being united based on lithostratigraphy. Being quite characteristic, utilization problems and solutions were also assembled. Additionally, 3rd level information was linked directly to an individual thermal water producing object (a well or a spring). The technical data include object location, drilling depth, direction, purpose and perforated sections. Hydrogeological data were combined as interference test results, observed changes in operation and abstraction characteristics. Application of quantity and quality operational monitoring was also verified.

Data interpretation was made by various numerical and graphical techniques, using MS Office Excel, Statistica and ArcGIS software. All public data are available on a web-database available at http://akvamarin.geo-zs.si/users/, in reports and on an interactive map (http://transenergy-eu.geologie.ac.at/).

4. RESULTS

4.1 Geothermal energy users

There are 387 wells and 16 natural springs identified in the research area (Table), managed by 214 users of which 70% produce thermal water. Their activity was assigned on the basis of field inspection performed in 2010 and information known in 2011. The 59 potential users possess a geothermal well or a spring but were without production at that time, plus six unclassified users were treated as potential in further evaluation. If the number of active users is compared to the country's area, Hungary is the most densely exploited (5.5 per 1000 km^2), Slovenia is second (3.8 per 1000 km^2), followed by Slovakia (2.4 per 1000 km^2) and Austria (1.1 per 1000 km^2). None potential users were ascertained in Austria, while many were found in Slovakia which has also the highest percentage of preserved wells. More than 76% of geothermal objects were active in 2011, of which the main share appertains to Hungary.

Table 2. Number of geothermal energy users in the research area

	Users		Wells and springs	
	Active	**Potential**	**Abstraction**	**Preserved**
Austria	20	0	42	6
Hungary	90	39	206	53
Slovakia	23	21	30	29
Slovenia	16	5	29	8
Total	**148**	**65**	**307**	**96**

*non-classified users treated as potential while non-classified wells as preserved

Users are mainly positioned in the flatlands of the Pannonian Basin. Denser exploited areas are perceived near the state borders while at highlands areas with no exploitation are indicated due to outcropping Pre-Neogene basement rocks in the west and central-east part of the investigated area which results in less favourable geothermal conditions.

4.2. Thermal water temperature

Lognormal wellhead temperature distribution was interpreted from the data, supporting the prevailing direct use of geothermal energy. The temperature distribution is not the same in all countries. More than third of the wells produce water at a temperature of 20-30°C and only 5 have higher temperature than 90°C. A very large number of lower temperature wells is reported for Hungary (Fig. 3) with water being used as a drinking water source or for swimming and bathing. If these wells were excluded, the 30 to 50°C interval would be the most abundant. In Austria, water with temperature between 30 and 40°C prevails, in Slovenia the one with 50 to 60°C, while in Slovakia even higher. The temperature depends on geological position of the geothermal aquifer and its type. However, it is interesting that 60% of the reported waste water temperatures are in the same range of most abundant temperatures (25-30°C), which indicates a poor thermal efficiency. Some subthermal springs were also reported.

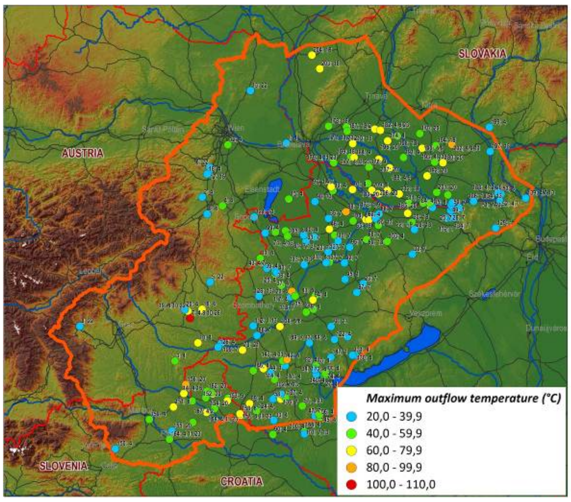

Fig. 3. Maximum outflow temperature and types of thermal water utilization

Water with the highest temperature of 109°C is produced from the Paleozoic carbonates in Austria and used for geothermal electricity production. About 90°C water from the Mesozoic carbonates in Hungary is used only for bathing and swimming while the one from the Pannonian-Pontian clastic aquifers in Slovakia is used for greenhouse heating. The stratigraphically older aquifers do not necessarily hold warmer thermal water as their spatial and geological distribution is not continuous throughout the four countries. The Pliocene aquifers produce water below 40°C, although when mixed with the Upper Miocene formations as in Slovakia, the temperatures rise to 78°C. The most exploited Pannonian-Pontian clastic aquifers produce thermal water with up to 91°C in Slovakia, 85°C in Hungary, 68°C in Slovenia and only 42°C in Austria. The Middle Miocene clastic aquifers reach maximum of 82°C in Slovakia, 72°C in Slovenia, while up to 65°C in Austria and 56°C in Hungary. The Lower Miocene and Eocene aquifers in Hungary and Austria reach maximum of 60°C, which is probably a result of rather low screened depths. The second most exploited, the Mesozoic carbonates, produced water at temperatures 99°C in Hungary, 83°C in Slovenia, 78°C in Slovakia and only 53°C in Austria. The Paleozoic metamorphic rocks are exploited only in Slovenia and Austria, yielding water with up to 78°C in Slovenia and 42°C in Austria.

4.3 Thermal water utilization

Due to wide temperature range 17 utilization types are reported, with the most abundant use for bathing and swimming (including balneology) at more than 100 user sites. It is a traditional type of use, being followed by more than 30 Hungarian users which capture (thermal) drinking water as the second most abundant utilization type. In this country, more than 20 users employ it for industrial or agricultural water as well as observation wells were reported and assigned ‘no use’ category. District, space and sanitary water heating are the second most often applied in other countries (Fig. 4). It is interesting that heating is often reported in Slovenian and Slovakian spa resorts and greenhouses, while it is very rarely found in Austria and Hungary. More exotic uses are represented by a football court heating in Moravske Toplice and a pavemenet heating in Lendava (SI).

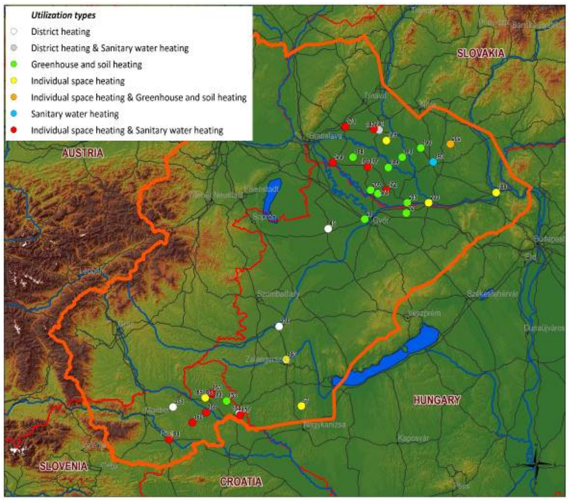

Fig. 4. Thermal water utilization map with locations of users who use water for space / water heating

Geothermal electricity is produced only in Austria where two geothermal heat pumps are also reported (Waltersdorf, Bad Blumau) as well as thermal mineral water. Only four reinjection wells exist in the area, one in each country. The waste water from the ORC binary plant in Bad Blumau (A) is constantly injected into the exploited Palaeozoic dolomite aquifer through the Blumau 1/1a well. The Slovene company Nafta Geoterm manages a reinjection well Le-3g in Lendava into which cooled water from a district heating system is injected into the Pannonian-Pontian sandy aquifer in the colder season. The Slovakian company Termálne kúpalisko Podhájska in Podhájska injects used water from a greenhouse heating system into the well GRP-1 in winter, screened in the Mesozoic carbonate aquifer.

The Hungarian reinjection well Mosonmagyaróvár K136., owned by Flexum-Termál Gyógyfürdő in Mosonmagyaróvár, has not been completed into the Pannonian-Pontian sandy aquifer and is inactive. 95 inactive wells are either not used either their status was assigned due to lack of abstraction information or different interpretation of the terms occurred. For example, observation wells were reported only in Hungary, while in Slovenia they are categorized as inactive and being prepared for future use. Hungary has a national database with even more inactive wells than included into this research. Moreover, Austria has reported 6 inactive wells but this type is not separately apprized for a user, which has other active wells, so this overview is only informative (Fig. 5).

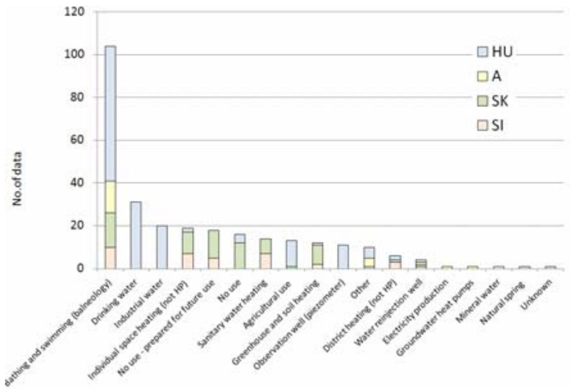

Fig. 5. Abundance of different utilization types of thermal water.

The Paleozoic carbonate and metamorphic and the Mesozoic carbonate aquifers often produce thermal water abundant with CO_2. When degassing, carbonate scaling in wells and pipes occurs, which some users prevent by injection of inhibitors into the wells. The Middle Miocene clastic aquifers are reported to produce thermal water with CO_2 and/or CH_4 gas, which are released into the air. The Pannonian-Pontian clastic aquifers can produce thermal water with some CO_2, methane and/or H_2S but its scaling tendency is rarely reported. Pump failures occur sometimes in these wells, mostly due to high extraction rates and/or sand clogging.

4.4 Annual thermal water abstraction

Annual thermal water abstraction between 2007 and 2010 was gathered for all countries except Austria. The parameter is reported to the provincial water authority there but the data are confidential. A comparison between the years shows a slowly increasing trend of thermal water abstraction (Fig. 6), as the amount rose from 29.0 million m^3 in 2007 and 28.4 million m^3 in 2008 (available datasets were lower for 1%) to 30.3 million m^3 in 2009 (with 2% more datasets than in 2007). The increase is attributed to higher production in Slovakia mostly while the countries shares are quite consistent with the number of their wells.

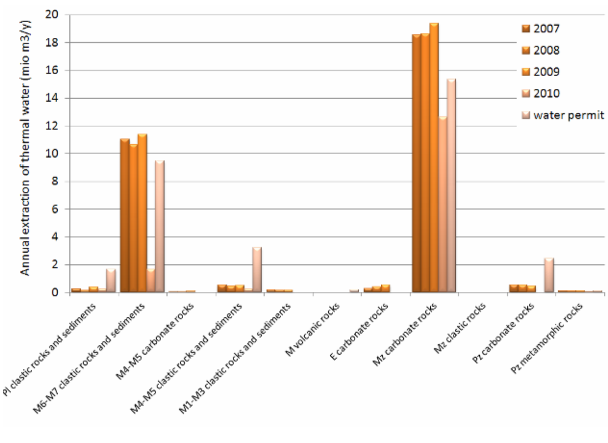

Fig. 6. Annual thermal water abstraction by geothermal aquifers (2007- 2010)

The Upper Miocene Pannonian-Pontian clastic geothermal aquifers are tapped by the majority of active boreholes. Their abstraction summed to 11.4 million m^3 in 2009, and only rarely the production data were missing. Hydrogeologically more favourable Mesozoic carbonate geothermal aquifers have much less production information (none for Austria) but their abstraction summed to 19.4 million m^3 in 2009, of which 65% appertains to the Lake Hévíz spring in Hungary. Increased abstraction was noticed for the recent years.

The most exploited Pannonian-Pontian clastic aquifers have 64% and the Mesozoic carbonate aquifers 63% of constantly active boreholes. Most wells (69%) produce thermal water by pumping. Natural discharge is (was) characteristic for many geothermal aquifers but due to historical exploitation and higher abstraction rates it has significantly decreased recently. In the most exploited Pannonian-Pontian clastic and Mesozoic carbonate aquifers there are only about 10% of wells where pumps are yet not needed. The Slovenian Paleozoic metamorphic and also Slovakian Middle Miocene clastic aquifers plus the Hungarian Middle Miocene carbonates still have high pressures to naturally discharge from more than 20% of the wells, while in the Slovak Pliocene clastic aquifers this number reaches 25%.

The Pannonian-Pontian clastic aquifers with intergranular porosity have the maximum momentary yield up to 133 l/s but the maximum optimum yield is much lower, only about 35 l/s. The average optimum yield is around 12 l/s. The more lithified and cemented Middle Miocene clastic aquifers can produce rates up to 53 l/s but the exploitation of 6 l/s is much more recommended. On the opposite site, the karstified and fissured Mesozoic carbonate aquifers are very productive. Some shallower wells produce up to 650 l/s of thermal water, not neglecting the Lake Hévíz (HU) which naturally discharges 400 l/s. The optimum production rates are also large, app. 28 l/s. The Paleozoic carbonates have very high maximum yield, reaching up to 187 l/s, and 76 l/s on average, but also high optimum yield, around 21 l/s on average.

4.5 Operational and observation monitoring

The operational monitoring practices differ between the countries as well as their application. In Austria, continuous monitoring prevails. In Slovakia, groundwater level monitoring is not established, and cumulative quantity and temperature are annually monitored, while water chemistry is controlled only occasionally. This frequency of chemical analyses is also observed in Slovenia. The monitoring is not uniformed there as at some wells groundwater level, temperature and cumulative quantity are constantly observed, while at others no monitoring is applied. A very good monitoring network is established in Hungary, where the parameters are controlled annually in the representative wells, while in others occasional measurements are performed. Many inactive wells do not have any monitoring applied. Most measured data are stored permanently at each user itself, while the reporting process differs between the countries. The reports are given to the following authorities: to regional authorities in Austria, to the National Environmental Agency in Slovenia, to the Slovak Inspectorate of Spas and Springs for thermal curative waters and to the Slovak Hydrometeorological Institute for waters for energetic use or wellness. In Hungary, the Geological Institute of Hungary has an independent national water level monitoring system, while users report their data to different Regional Environmental and Water Directorates. Beside the water level is monitored in observation wells owned by the regional directorates and the Environmental and Water Management Research Centre (VITUKI). All data from the Regional Water Directorates is sent to the Water and Environmental Protection Directorate (VKKI).

4.6 Waste water management

The observed waste water management practice indicates that thermal and chemical pollution of surface waters is not mitigated in the investigated area. Most waste water is released to surface water flows in Hungary, Slovakia and Slovenia, sometimes through a cooling lake. A small part of waste water is released to public sewage systems or purifying plants, especially if the water is used for drinking as in Hungary. The emitted waste water temperature exceeds 20°C in 95% of known cases and can reach even 40°C, both indicating very poor thermal efficiency of the system. The lowest annual waste water temperature of 15°C is reported in Dobrovnik (SI), where the thermally exploited water warms the rainwater used for irrigation, after being released from the greenhouse heating system.

Periodical reinjection is applied only in the Mesozoic carbonates in Podhájska (SK) and the Upper Miocene sands in Lendava (SI). In Austria, seepage purifying or dechlorination plants are applied often, but emitted temperatures are high. Constant reinjection at 49 to 90°C into the Paleozoic carbonate aquifer is applied in Blumau (AT), but the rest of waste water is emitted to the environment.

4.5 Future potential and issues

If the thermal water abstraction is increased for 20%, which is the percentage of inactive boreholes, the total production could rise to 36 million m^3. However, the current potential of the Pannonian-Pontian clastic aquifers is estimated to 2.8 million m^3 of thermal water, while of the Mesozoic carbonates 1.7 million m^3, neglecting the Hévíz spring. It is estimated that these aquifers do not have such a development potential generally but there are some individual boreholes which can provide additional amount of thermal water if needed. These numbers represents the technical geothermal potential but it was not investigated whether this is hydrogeologically possible or which would be their effects on current users. Beside, data on granted or requested amounts of thermal water in concession permits are at least double the current production in most cases. If the potential annual production is calculated assuming double the 2009 extraction for the three countries with the available production data (neglecting Austria), the hypothetic thermal water abstraction could rise to over 60 million m^3 per year in the future.

With the exception of Austria, where only the Mesozoic carbonates and Miocene volcanic rocks represent the potential geothermal aquifers, the other countries show trend mentioned in the previous paragraph. In Slovenia and Slovakia, additional potential exists in the Pliocene aquifers, in Slovenia also in the Middle Miocene clastics, while in Hungary the Middle Miocene and Paleozoic carbonate and Lower Miocene clastic rocks are perspective.

5. CONCLUSIONS

The presented screening of current and planned thermal water utilization has been made systematically for a transboundary area, and resulted in a wide collection of harmonized geoscientific data. These were organized in a publically accessible database and interactive map available at http://transenergy-eu.geologie.ac.at. The datasets can and have been used to enhance the public and professional's awareness on the actual practice of thermal water exploitation and its (un)sustainable management, pointing out best and worst cases.

We believe that this overview provides reliable guidelines on the state of current geothermal utilization, which is quite poor in many inspected categories. It should be used to enhance sustainable exploitation of geothermal resources in the areas where this is still possible. Densely exploited regions with indications on over-exploitation are not perspective, of course. Now, the users and the authorities are informed about where the exploitation problems are expected to arise or are already evident.

Most common utilization problems and their mitigation are shortly presented. This and the estimated geothermal potential may help new investors to properly adjust their development plans by designing effective exploitation systems which will enable enhanced but still sustainable thermal water abstraction and use in the future.

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