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Database of users and

database of current and potential utilization parameters

Title Database of users and database of utilization parameters

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Transboundary Geothermal Energy Resources of Slovenia, Austria, Hungary and Slovakia

Work package WP3 Utilization aspects

3.2.1 Database of users

3.2.2 Database of current and potential utilization parameters

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1. Introduction

The TRANSENERGY project aims at the development of a practical decision supporting tool for potential users and authorities which will help to enhance geothermal energy utilization in a sustainable way. In order to do so a reliable recognition of the existing (un)sustainable use of geothermal resources has to be made and some additional topics such as identification of the possible operational problems for different thermal water users and their solutions needs to be addressed, together with the suggestions for mitigation of the possible negative environmental effects. The previous research (Prestor et al. 2010; Rman et al. 2010) have indicated numerous problems and shown that the utilization management is not unified in the four project countries. Therefore, the data availability and quality among the project partners is various.

A general overview of the geothermal energy use in each country is prepared every five years for the needs of the Country update reports presented on the World geothermal congress. The last series of reports were prepared in 2010, for the period 2005-2009 (Goldbrunner, 2010; Fendek et al. 2010; Rajver et al. 2010; Tóth, 2010). As the TRANSENERGY project focuses only on the near-border areas these reports were not directly applicable for our purpose but served only as a general reminder of the issues that need to be addressed in details with our work. For our needs a unified transboundary methodological approach was applied in the four project countries. This enabled gaining representative data on the current and potential thermal water users in 2011 in the TRANSENERGY project area.

As the first step a manual on field inspection of thermal boreholes and springs was elaborated together with the field questionnaire. Both were distributed among the project partners to serve as a foundation for the data collection, which was later compiled in the Database of users and in the Database of current and potential utilization parameters. The questions included into the field inspection questionnaire were set to identify the available datasets on users' company data and contact persons, thermal water extraction objects and emissions of the thermal waste water into the environment. The questions regarding the utilization parameters were more detailed, focusing on the borehole technical characteristics, hydrogeological data, thermal water properties, exploitation characteristics and annual extraction as well as on the applied operational monitoring. Results of the performed field inspection and other communication strategies with the thermal water users were incorporated into the databases.

The collected data interpretation was made by various numerical and graphical techniques as presented in this report, and will be upgraded by elaborated Utilization maps in the near future. The data processing was done in the SQL program, MS Office Excel and Statistica.

We believe that this report provides reliable guidelines on the state of the current geothermal utilization in the project area. This overview should act as an expert basis for enhancing a sustainable exploitation of the geothermal resources in the areas where this is still possible. The potential new users as well as the existing ones can also benefit directly from this research. In it the most common utilization problems and methodologies for their mitigation are presented, which may give additional ideas for their solutions. The areas of dense exploitation infrastructure are presented at the same time. So both, the users and the authorities, are informed about where the exploitation problems are expected to arise or perhaps are already observed.

2. Structure of the databases

The first idea was to prepare two separate databases, the Database of users and the Database of current and potential utilization parameters. However, during the field data collection it was realized that only one database should be elaborated, but enabling a multi-level approach to the specific data of interest. Therefore, we prepared a conceptual model of the database in the SQL program in which three interpretation levels are defined (fig. 1). The input fields were defined as optional (can be left blank) or mandatory (input is necessary) and having a single choice or multiple options function applied (table 1).

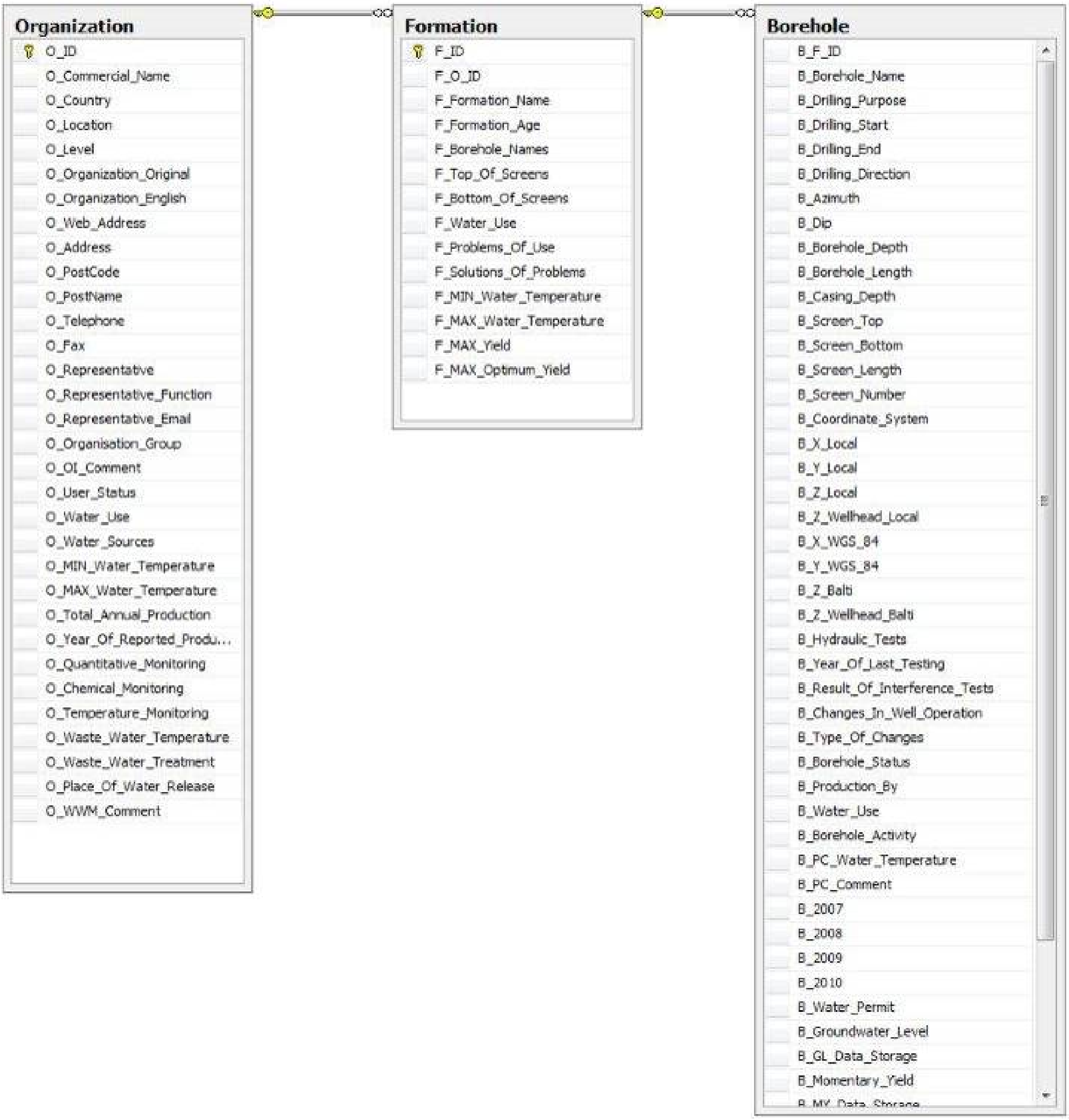

Figure 1: Conceptual model of the joint database, the Database of users and the Database of current and potential utilization parameters

The first 'organization' level is the least scientific as it consists of the actual and potential geothermal energy user's contact details (table 1). The data on company names, contact persons, addresses, web pages and similar are compiled here. In addition, the management organization-specific data are presented addressing the main and the most associated general data on the thermal water use, production characteristics and waste water monitoring. The second 'formation' level already requires a more scientific approach (table 2). The exploited aquifers characteristics for each user and formation separately are reported here. These data are a result of merging some specific boreholes' datasets. The general hydrogeological aquifers' characteristics and thermal water properties can be seen from this datasets. The most precise and site-specific data are compiled at the third 'borehole' level (table 2). The technical, hydrogeological, production and monitoring parameters for each borehole separately are reported here.

Table 1: Database of users fields with their types and necessity description

Group name	Field name	Field type	Data input
Organization information	Commercial name	text	mandatory
	Country	text	mandatory
	Location	text	mandatory
	Level	text	mandatory
	Organization (original)	text	mandatory
	Organization (English)	text	mandatory
	Web address	text	optional
	Address	text	optional
	Postcode	number	optional
	Post name	text	optional
	Telephone	number	optional
	Fax	number	optional
	Representative	text	optional
	Representative function	text	optional
Produced water management	Representative e-mail	text	optional
	Organization group	text	optional
	Comment	text	optional
	User status	text	mandatory
	Water use	text	mandatory
	Water sources	text	mandatory
	Max.water temperature (°C)	number	optional
	Min.water temperature (°C)	number	optional
	Total annual production (m3)	number	optional
	Year of reported production	number	optional
Waste water monitoring	Quantitative monitoring	text	mandatory
	Chemical monitoring	text	mandatory
	Temperature monitoring	text	mandatory
	Waste water temperature (°C)	number	optional
	Waste water treatment	text	optional
	Place of water release	text	optional
	Comment	text	optional

Table 2: Database of utilization parameters fields with their types and necessity description

Group name	Field name	Field type	Data input
Formation characteristics	Formation name	text	Mandatory
	Formation age	text	mandatory
	Borehole names	text	mandatory
	Top of screens (m bWHD)	number	optional
	Bottom of screens (m bWHD)	number	optional
	Water use	text	mandatory
	Problems of use	text	optional
	Solutions of problems	text	optional
	Max.water temperature (°C)	number	optional
	Min.water temperature (°C)	number	optional
	Maximum yield (l/s)	number	optional
	Max. optimum yield (l/s)	number	optional
Borehole characterization	Borehole name	text	mandatory
	Drilling purpose	text	mandatory
	Drilling end	year	optional

	Drilling direction	number	mandatory
	Azimuth	number	optional
	Dip	number	optional
	Borehole depth (m)	number	optional
	Borehole length (m)	number	optional
	Screen top (m bWHD)	number	optional
	Screen bottom (m bWHD)	number	optional
	Screen length (m)	number	optional
	Screen No.	number	optional
	Main producing formation	text	mandatory
	Mixing aquifers	text	optional
Position	Coordinate system	text	mandatory
	X local	number	mandatory
	Y local	number	mandatory
	Z local	number	mandatory
	X WGS 84	number	optional
	Y WGS 84	number	optional
Production Characteristics	Hydraulic tests	text	mandatory
	Year of last testing	number	optional
	Result of interference tests	text	optional
	Changes in well operation	text	mandatory
	Type of changes	text	optional
	Production by	text	mandatory
	Water use	text	mandatory
	Borehole activity	text	mandatory
	Water temperature (°C)	number	optional
	Comment	text	optional
Annual production (m3)	2007	number	optional
	2008	number	optional
	2009	number	optional
	2010	number	optional
	Water permit	number	optional
Operational monitoring	Groundwater level	text	mandatory
	data storage	text	mandatory
	Momentary yield	text	mandatory
	data storage	text	mandatory
	Cumulative quantity	text	mandatory
	data storage	text	mandatory
	Water temperature	text	mandatory
	data storage	text	mandatory
	Chemical monitoring	text	mandatory
	data storage	text	mandatory

One of the main goals of the databases elaboration was to provide a unified utilization data collection. The harmonized transboundary datasets which can be directly applicable for the interpretation and graphical presentation can be achieved only if the original data is clear, precise and unified. As very heterogeneous data, differing in quality and quantity, were gathered by the field inspection, its unification, joining and quality check was needed in order to fulfil the objective. This was achieved by the preparation of many pull-down menu options which are used in the different database fields (table 3).

Table 3: Unification of the data selection criteria by the pull-down menus

Field name	Code	Possible choices
User country		PULL-DOWN 1
	1	Austria
	2	Hungary
	3	Slovakia
	4	Slovenia

User level		PULL-DOWN 2
	1	local
	2	national
	3	regional
User status		PULL-DOWN 3
	1	active production
	2	no data
	3	potential investor
	4	potential user
Water use		PULL-DOWN 4
MULTIPLE CHOICES	1	Agricultural use
	2	Air conditioning (Cooling)
	3	Animal farming
	4	Bathing and swimming (including balneology)
	5	CO2 reinjection
	6	District heating (other than heat pumps)
	7	drinking water
	8	Electricity production
	9	Greenhouse and soil heating
	10	Groundwater heat pumps
	11	Individual space heating (other than heat pumps)
	12	Industrial process heat
	13	Industrial water
	14	Irrigation well
	15	Liquidated borehole
	16	Mineral water
	17	Natural spring
	18	No use
	19	No use - negative research
	20	No use - prepared for future use
	21	Observation well (piezometer)
	22	Other
	23	Sanitary water heating
	24	Snow melting
	25	Unknown
	26	Water reinjection well
Monitoring		PULL-DOWN 5
	1	annual data
	2	continuous data
	3	daily data
	4	half-year data
	5	monthly data
	6	no data
	7	no monitoring
	8	occasional point measurements
	9	quarterly data
	10	weekly data
Waste water treatment		PULL-DOWN 6
MULTIPLE CHOICES	1	dechlorination plant
	2	no data
	3	no treatment
	4	reinjection
	5	seepage purifying plant
	6	taken by other user

Borehole drilling purpose		PULL-DOWN 7
	1	coal research
	2	gas storage
	3	geothermal borehole
	4	geothermal heating
	5	hydrogeological borehole
	6	natural spring
	7	oil and gas prospection
	8	reinjection
	9	structural borehole
Drilling direction		PULL-DOWN 8
	1	inclined
	2	no data
	3	vertical
Coordinate system		PULL-DOWN 9
	1	BMN 34 (Austrian)
	2	D49 (Slovene)
	3	EOV (Hungarian)
	4	JTSK (Slovak)
Data storage		PULL-DOWN 10
	1	no
	2	no data
	3	yes
Water production by		PULL-DOWN 11
	1	natural outflow
	2	no data
	3	pumping
	4	still outflowing well but pumping for higher yields
Borehole activity		PULL-DOWN 12
	1	constant
	2	inactive
	3	no data
	4	occasionally (at peak loads)
	5	only in summer
	6	only in winter
	7	periodically
Problems of water use		PULL-DOWN 13
MULTIPLE CHOICES	1	calcite scaling
	2	CH_4 degassing
	3	CO_2 degassing and blowouts
	4	H_2S degassing
	5	pump failures
	6	sand particles/clogging
	7	silica scaling
Type of borehole changes		PULL-DOWN 14
MULTIPLE CHOICES	1	seasonal variations
	2	temperature decrease
	3	temperature rise
	4	water level decrease
	5	well cycling
	6	yield decrease
	7	yield rise

The database of users is actually a database of the ‘organization’ information level, which describes the user company’s main contact details. The shorter ‘commercial name’ is a linking parameter with the rest and more detailed geothermal data. It is quite common that the thermal water users exploit more boreholes or thermal springs at the same time but the produced thermal water and waste water management as well as the operational monitoring applications are usually site dependent. Therefore, this data is stored in the Database of users and not defined separately for each geothermal object in the Database of utilization parameters. An example of the input data for one user is given in the following figure 2.

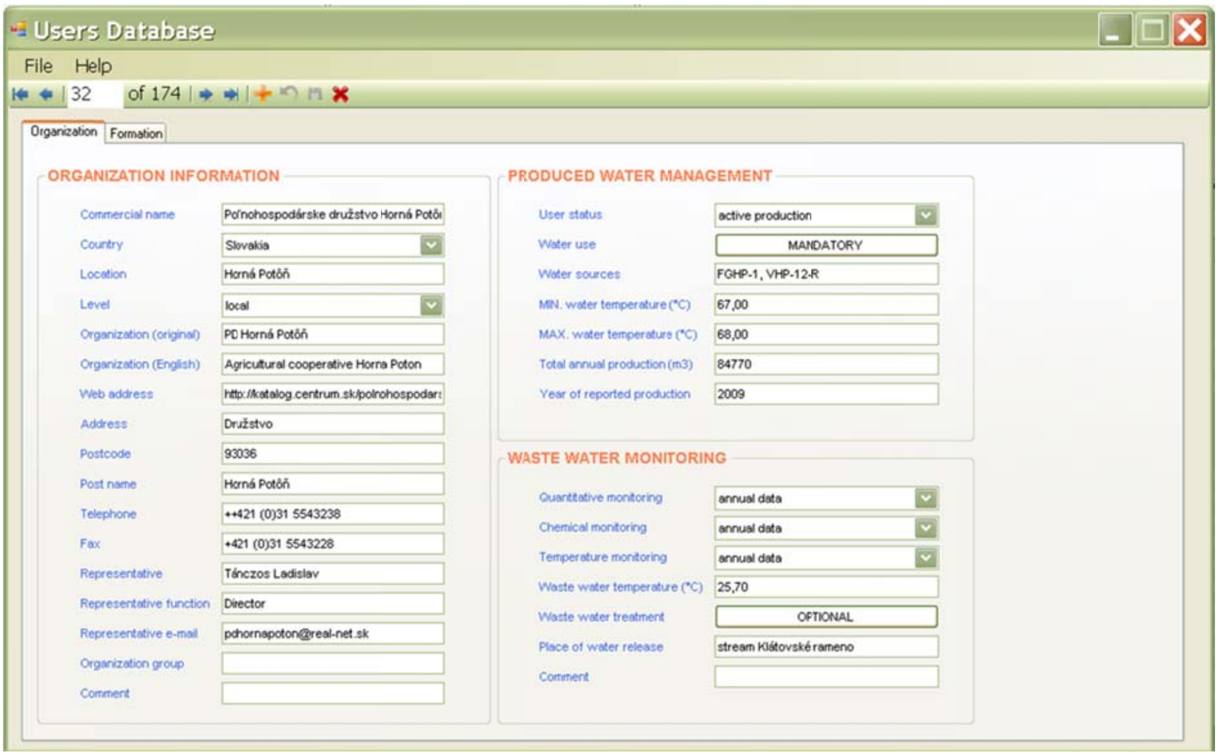

Figure 2: Database of users – 'organization' level

The second interpretation level (‘formation’) is connected to the exploited aquifers characteristics. The data from the individual objects at each user’s site are joined by the main exploited geothermal aquifer name. This enables a direct comparison between the different sites which are using the same geothermal aquifers. As it is quite characteristic for the individual geothermal aquifer, the problems and solutions emerging from the thermal water use are also described here as well as the hydrogeological properties such as the produced water temperature, maximum momentary and maximum optimum borehole yields (fig. 3).

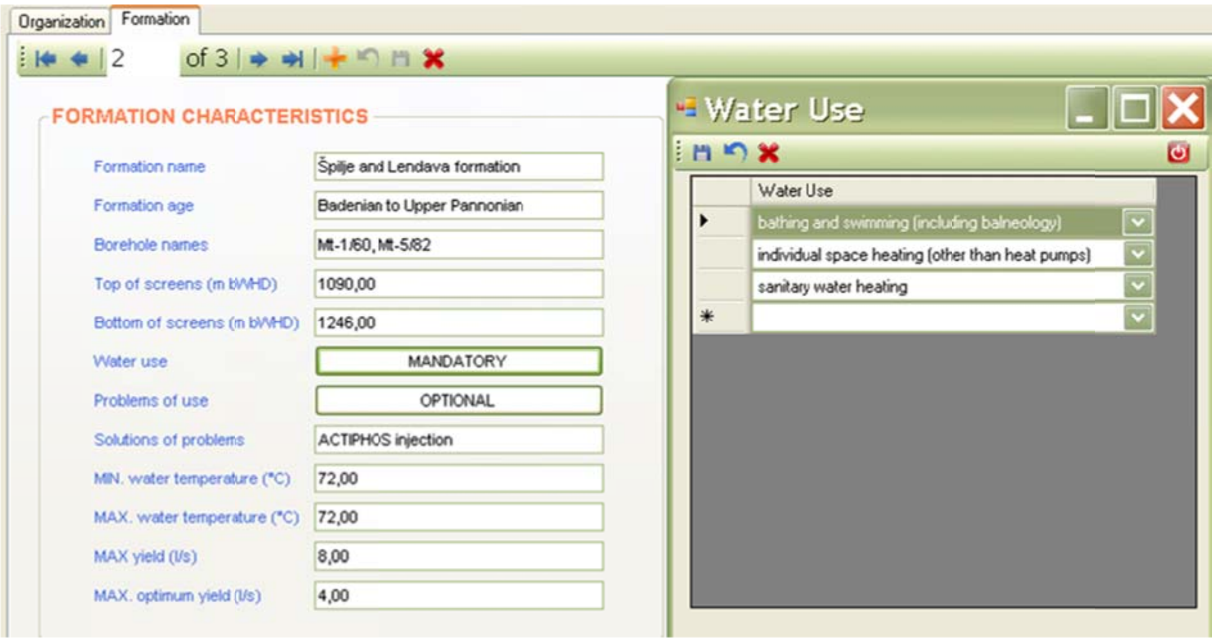

Figure 3: Database of current and potential utilization parameters – 'formation' level

The third interpretation level ('borehole') is the most detailed and it is linked directly to the individual thermal water producing object (a borehole or a spring). Not only the general technical data on boreholes are gathered here but also details on the hydrogeological, production and operational monitoring practice (fig. 4). The collected technical data include the location (coordinates), borehole drilling depth and purpose, drilling direction and perforated section intervals. Valuable hydrogeological data are combined in the interference test results, the changes in operation description, the exploitation characteristics and the reported annual production parameters. The last but not at all unimportant data are collected in the operational monitoring group, where the existing aquifer pressure / groundwater level, temperature, chemistry and quantity monitoring is described.

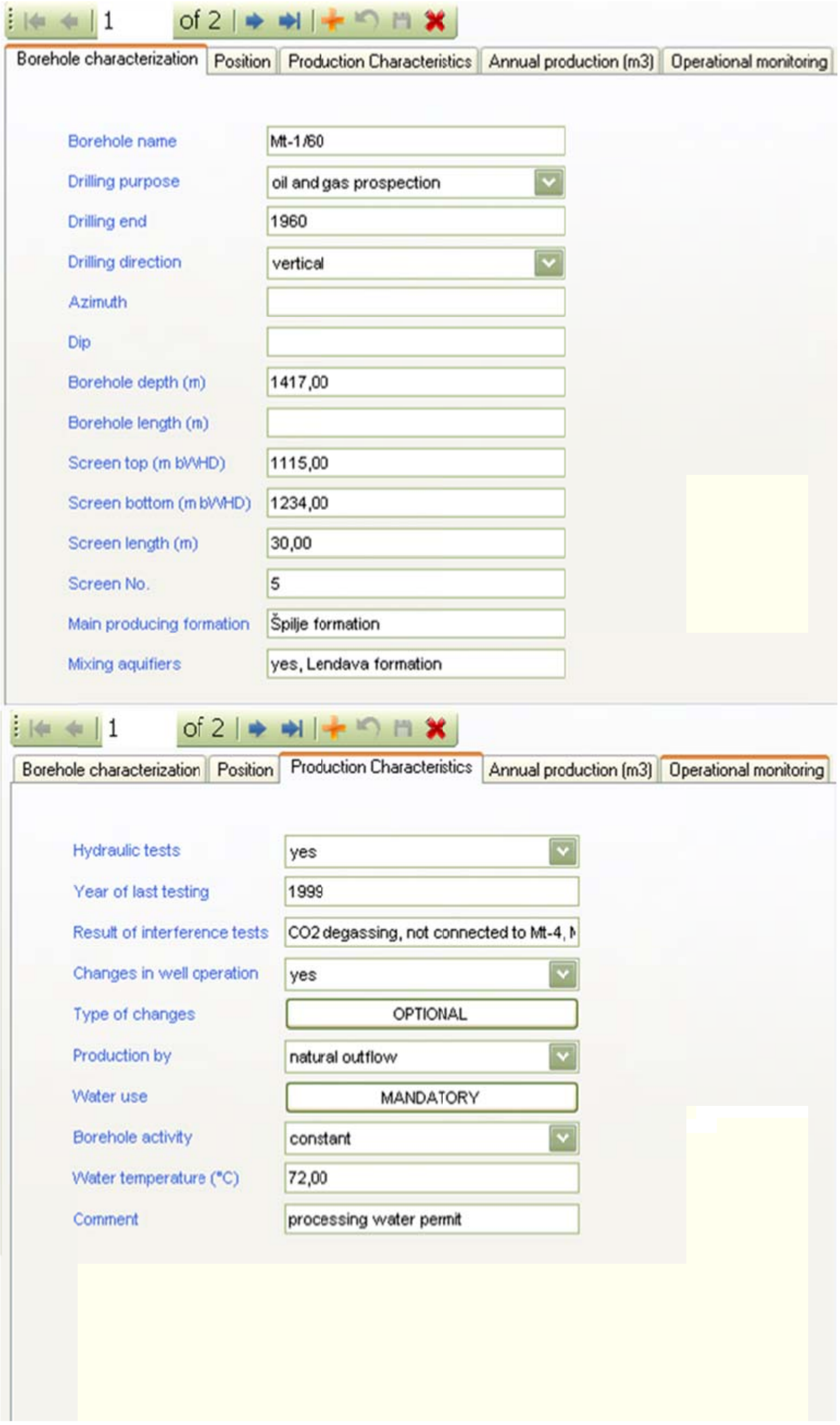

Figure 4: Database of current and potential utilization parameters – 'borehole' level

3. Presentation of the databases on the project website

The representative data on the thermal water users in the four TRANSENERGY project countries Austria, Hungary, Slovakia and Slovenia will be used as a template and a data source for the elaboration of different utilization maps, which will be available on the project website (http://transenergy-eu.geologie.ac.at/). The maps represent one of the core outputs of the TRANSENERGY project, and are discussed in details in a separate report.

However, the main data on the thermal water users in the TRANSENEGY area are already available on the project website or directly on the link http://akvamarin.geo-zs.si/users/. The database can be examined by selecting the country of interest and later the user's organization name in the upper window. When the selection is done the available organization, thermal water production and waste water monitoring data is presented in the lower window (fig. 5).

Figure 5: The database available at the TRANSENERGY webpage

4. Results and interpretation of Database of users

As numerous shallow wells which capture groundwater are known to exist in the investigated project area, we set the **wellhead temperature of 20°C** as the lowest temperature which enabled the borehole to be included into the database. This temperature was suggested by Hintz & Grünhut (1907) as the lower limit for using the term 'thermal water'. This criterion was fulfilled for 401 boreholes in the TRANSENERGY project area (table 4).

Table 4: Quantitative status of the Database of users (number of contained data)

	Organizations	Formations	Boreholes
Slovenia	20	27	35
Slovakia	44	50	59
Austria	20	26	48
Hungary	129	189	259
Total	213	290	401

All together 213 organizations were identified in the project area (fig. 6), which are involved in different thermal water utilization activities. Most of them are active users but potential (with only inactive wells) and non-classified users were also determined.

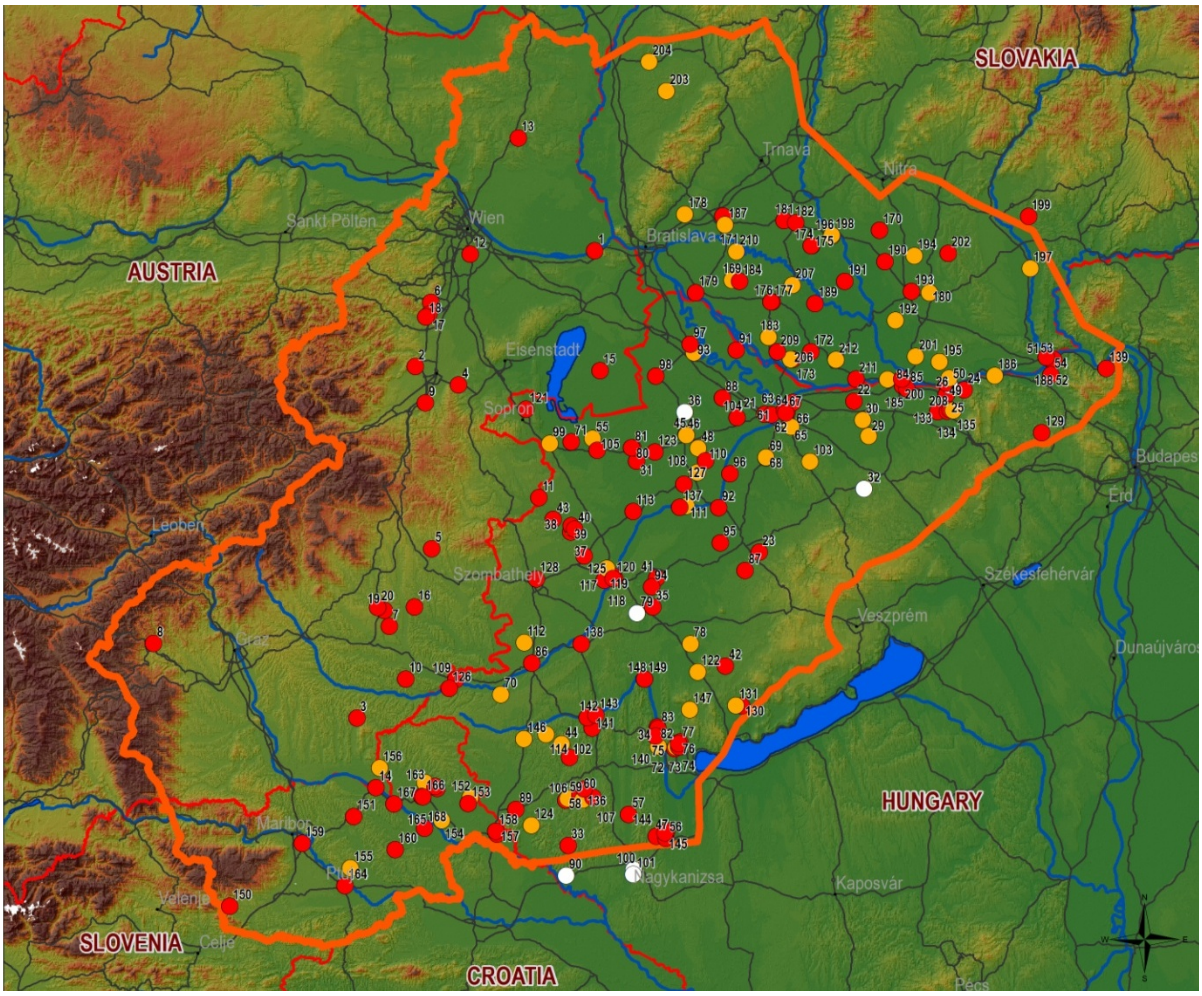

Figure 6: Location of the geothermal users identified in the TRANSENERGY project area (red – active, orange – potential, white – unknown)

4.1 The status of geothermal users

Of the 213 identified user organizations the main share appertains to Hungary (fig. 7). The second is Slovakia (21%), while Slovenia and Austria have similar shares of 9%. If the number of organizations is compared to the country's project area, Hungary is the most densely exploited (7,8 all users and 5,5 active users per 1000 km^2), Slovenia (5,1 all users and 3,8 active users per 1000 km^2) is second, followed by Slovakia (4,6 all users and 2,4 active users per 1000 km^2) and Austria (1,1 users and active users per 1000 km^2). If the number of boreholes and springs is compared in the same way, the order stays the same. **From this it can be noticed that the Hungarian project area is the most densely exploited for the thermal water production, followed by the Slovenian, Slovakian and Austrian.** This can be partly contributed to the outcropping Pre-Tertiary basement rocks in the west of the project area and consequently less favourable geological conditions for the thermal water exploitation, and partly to the vast number of drinking thermal water wells used in Hungary.

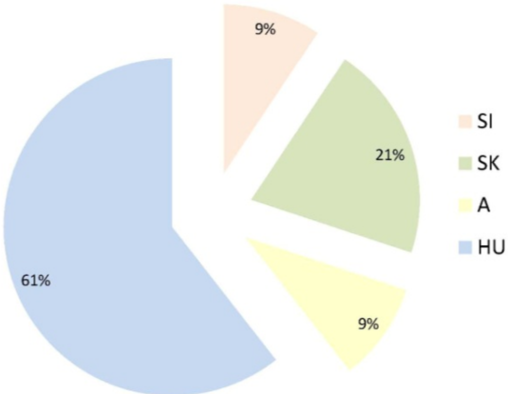

Figure 7: Identified users in the TRANSENERGY project countries (213 organizations)

148 of the identified organizations are **active users** which currently produce thermal water (fig. 8). Their status was assigned on the basis of the performed field inspection in 2010, available extraction quantities in 2009 or 2010 or current status known in 2011. Furthermore, 59 potential users were identified who already possess a thermal borehole or a spring but are without production. As the geothermal energy use is still rising, the 3 potential investors were reported but only for Slovenia. Unfortunately, there were still 6 undefined users.

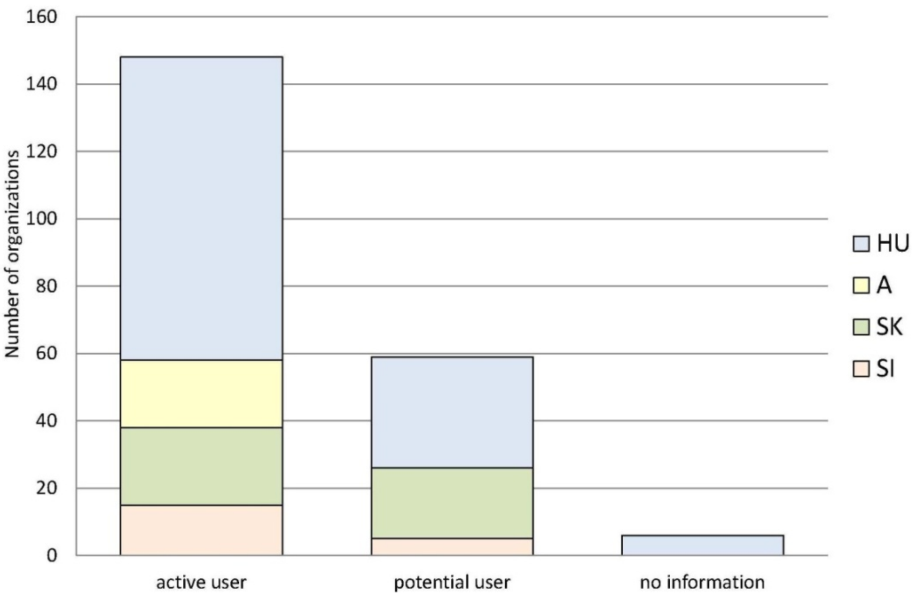

Figure 8: Users status of 213 organizations in the TRANSENERGY project countries

4.2 Thermal water utilization

Various types of thermal water use can be noticed from the figure 9. The most abundant is its use for **bathing and swimming including balneology**, which is the most traditional type of use. It is followed by **drinking and industrial water** use. However, this type of use is reported only for Hungary. This is a consequence of the Hungarian legislation where the lowest temperature for the thermal water term application is 30°C and not 20°C as used in this research. The **individual space heating** follows but it is not reported for Austria at all. Sanitary water heating is reported only for Slovakia and Slovenia. Many wells are inactive: the reasons may be the actual non-use, the lack of data or the different interpretation of the terms (observation wells were separately reported only for Hungary). The agricultural use and greenhouse heating are applied to a little over 10 boreholes, while district heating, reinjection and electricity production are even less abundant.

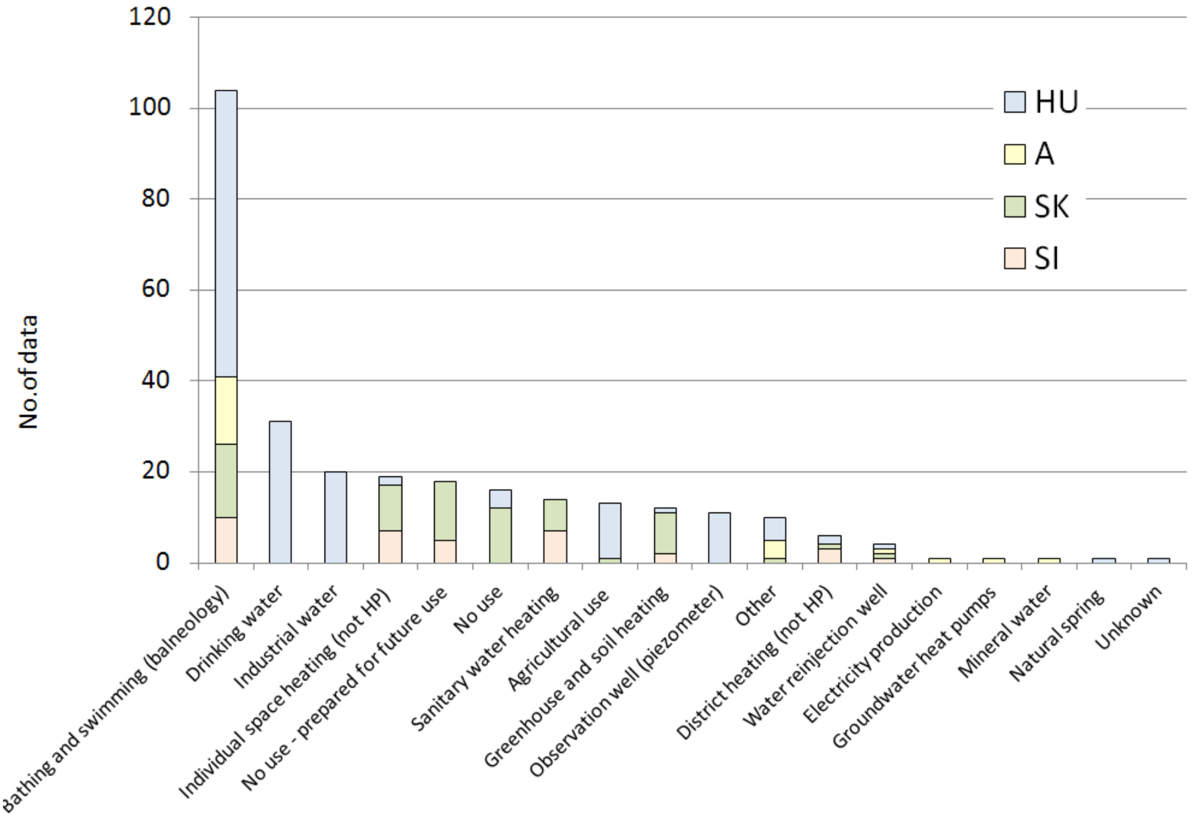

Figure 9: Thermal water use in the TRANSENERGY project countries (283 inputs for 213 organizations)

If comparison between the countries is made (fig. 10), it is noticeable that the thermal water utilization rather differs between them. **Austria** is the only project country which produces electricity from the geothermal energy. It is also the only one who reported the use of thermal water as a mineral water source, plus the water is being used for the (high temperature) groundwater heat pumps there. It can be noticed here that the shallow geothermal heat pumps were not a part of this investigation. On the other hand, **Hungary** is the only country where the thermal water is reported to be used as a drinking and industrial water source and largely for agriculture, as well as having observation wells which were included into ‘no use’ category in other countries. The main share of the bathing and swimming use also belongs to Hungary, while the three remaining countries have similar number of wells used for this purpose. **Slovakia and Slovenia** reported the thermal water use also for greenhouse heating, district heating, sanitary water heating and individual space heating. The reinjection wells are reported in all four countries. The waste water from the electricity production from the well Blumau 2, owned by the Spa Therme Blumau Betriebs GmbH in Bad Blumau (A), is constantly reinjected into the exploited Paleozoic carbonate geothermal aquifer (dolomite). The company Nafta - Geoterm in Lendava (SI) has a reinjection well Le-3g, into which the cooled thermal water used for district heating in colder season is injected into the Pannonian-Pontian clastic geothermal aquifer (Mura formation). The Termálne kúpalisko Podhájska in Podhájska (SK) has a reinjection well GRP-1 active in winter months into which the waste greenhouse heating water is injected into the Mesozoic carbonate geothermal aquifer (Ramsau dolomite and Lužná formation). The Hungarian reinjection well Mosonmagyaróvár K136., owned by the Flexum-Termál Gyógyfürdő in Mosonmagyaróvár, has not been completed and so it is inactive. It was planned to be used for injection of water into the Pannonian-Pontian clastic geothermal aquifer (Zagyva formation).

Figures 9 and 10 can be **misleading** as only some countries have **inactive boreholes**. The figures represent the reported utilization for the organization level data, which was obviously not accurately selected by all participants. To the presented 'no use' numbers the following has to be added: Austria has reported 4 inactive boreholes for an active user which has many other active wells and this type of (no)use is not separately noticed on the organization level. For Hungary 38 inactive and 15 boreholes with no information are reported. Consequently, these kinds of organization level utilization data are high for Hungary but not so many boreholes are actually used. Hungary has a national database with even more inactive wells than included into this database.

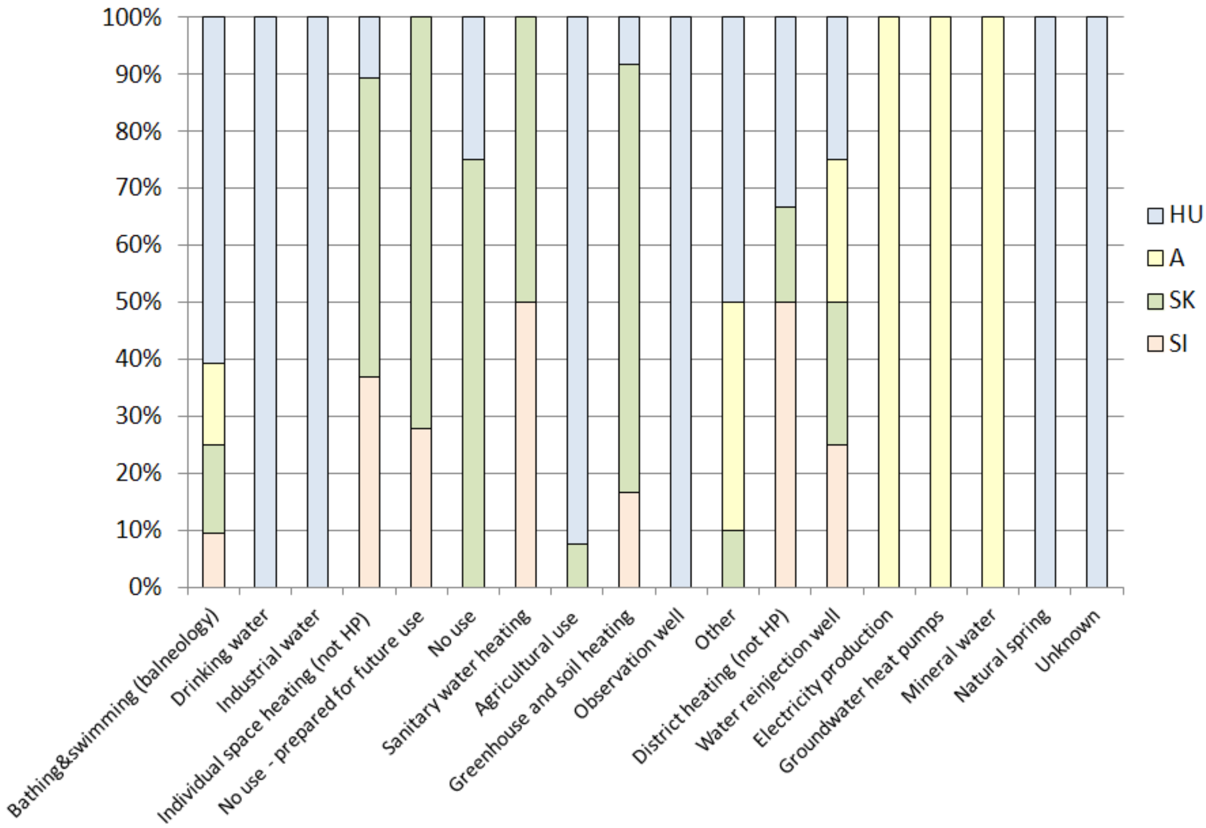

Figure 10: Share of different types of thermal water use in the TRANSENERGY countries (283 inputs)

4.3 Thermal water production

One of the most important information we acquired from this research is the actual annual thermal water production in the project area. Most of the national geological surveys, with the exception of the Austrian GBA, were able to collect the data on the production for individual organizations in the last few years. In Austria the users have to report the annual production to the water authority of their province, but the data are confidential. The reporting consensus for an individual user is planned to be established during the water granting procedure in the future. Most of the user organizations have reported the 2009 values and they are presented on the figure 11. The **total annual production reached 31.6 million m^3 of thermal water in 2009, neglecting Austria**. If the latter is included the value could be a few millions higher. The shares are rather consistent with the number of boreholes in an individual country. The large annual production should make the users and the management authorities aware that the thermal water is not an infinite source. As it was already indicated by some research (Rman et al. 2011), most of the (potential) transboundary geothermal aquifers store very old water which indicates a slow recharge. From this it can be concluded that the **geothermal energy can be a sustainable source** only if the thermal water extraction does not exceed the natural recharge of the geothermal systems.

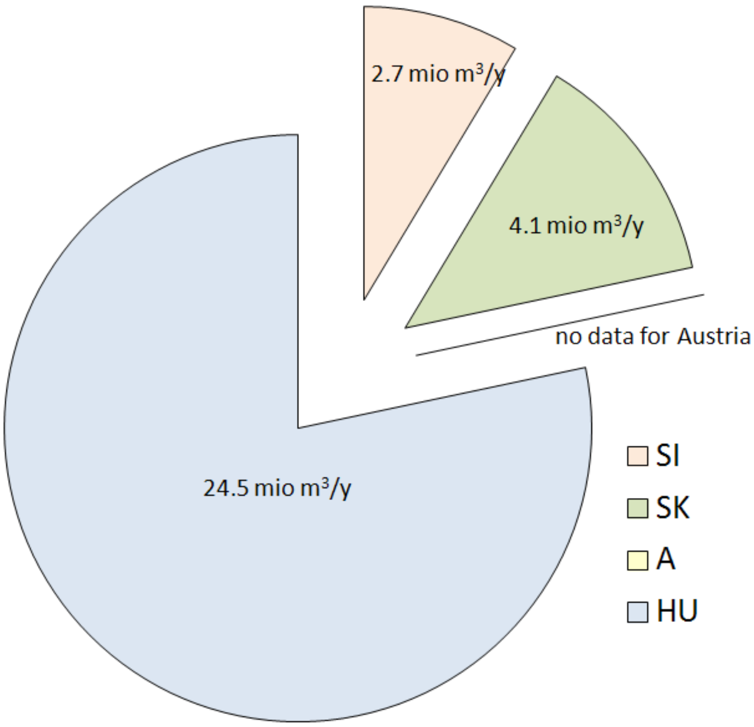

Figure 11: Total thermal water extraction in 2009 in the TRANSENERGY project area (174 organizations with available data)

4.4 Thermal waste water management

In addition to the production data the waste water management was inspected on the organization level. Most of the produced thermal water is still emitted directly to the surface waters therewith causing their thermal and chemical pollution.

Despite this fact only poor data on the waste water treatment exists (fig. 12). The simplest reason may be the lack of time for the project activities like the field inspection. Incomplete waste water monitoring and its regulations and/or reporting activities are also probable. If users without data are excluded, the majority of others **do not treat waste thermal water** at all. Only 7% of the users clean waste water at the sewage purifying or dechlorination plants, while the 1,5% inject it (3 wells). Only one user in Slovenia is reported to use the waste thermal water for the additional thermal energy extraction (for heating a greenhouse).

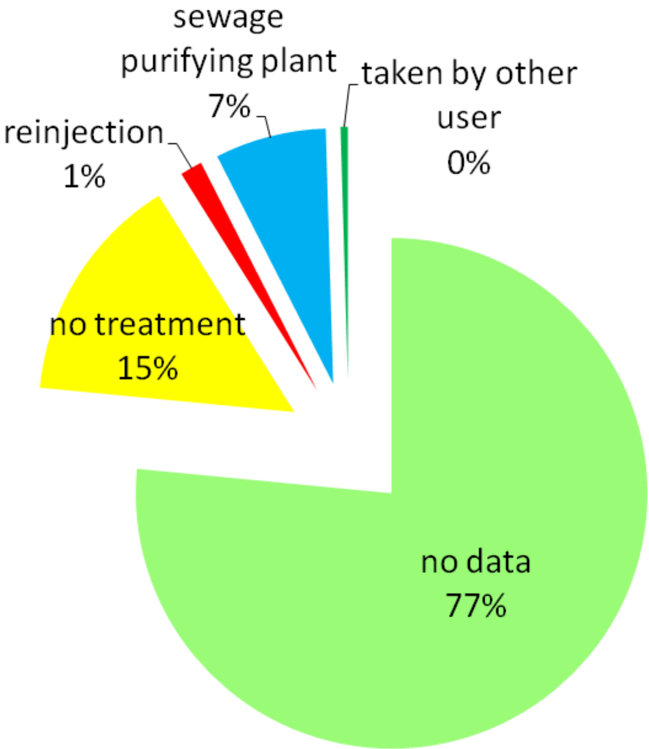

Figure 12: Waste water treatment in the TRANSENERGY project area (148 active users)

A similar comparison has been done for the individual project countries (fig. 13). In **Hungary**, the waste water is released partly into the community sewage system (drinking water) and partly into the surface waters (other uses of thermal water). In the first case, the released water should be registered by the sewerage company, whereas in the second the water should be treated and its amount reported. In **Austria** waste water management is not nationally prescribed yet but individual state governments are responsible for its elaboration and execution. The conditions and restrictions for the waste water treatment will be defined during the water rights granting procedure as a sub article of the law in the future. There are some guidelines recommended by the ÖWAV– Regelwerk (rules and standards are derived indirectly from water legislation) at the moment in which it is stated that the water that has been used for balneology should not be reinjected into the aquifer, while the water which was used for electricity or heat production should be reinjected. However, no law for obligatory reinjection exists. In **Slovenia** the two users who were granted a permit for utilization of a geothermal energy source are obliged to reinject water by the current legislation, while others are not. Despite this, the reinjection is applied only in Lendava in Slovenia. On the **Slovak** territory only one user has a permit for geothermal water utilization with obligation for its reinjection in the winter period. During the summer period this geothermal water is diluted, cooled and used only for swimming pools. Other users are following the Water Law and are permitted to release waste water into surface waters without any special treatment.

Most of the waste water is taken to the sewage purifying plants in **Austria**, while in **Slovakia and Slovenia** no treatment prevails. The reinjection is constantly applied in Austria, while in Slovakia and Slovenia it operates during the winter season.

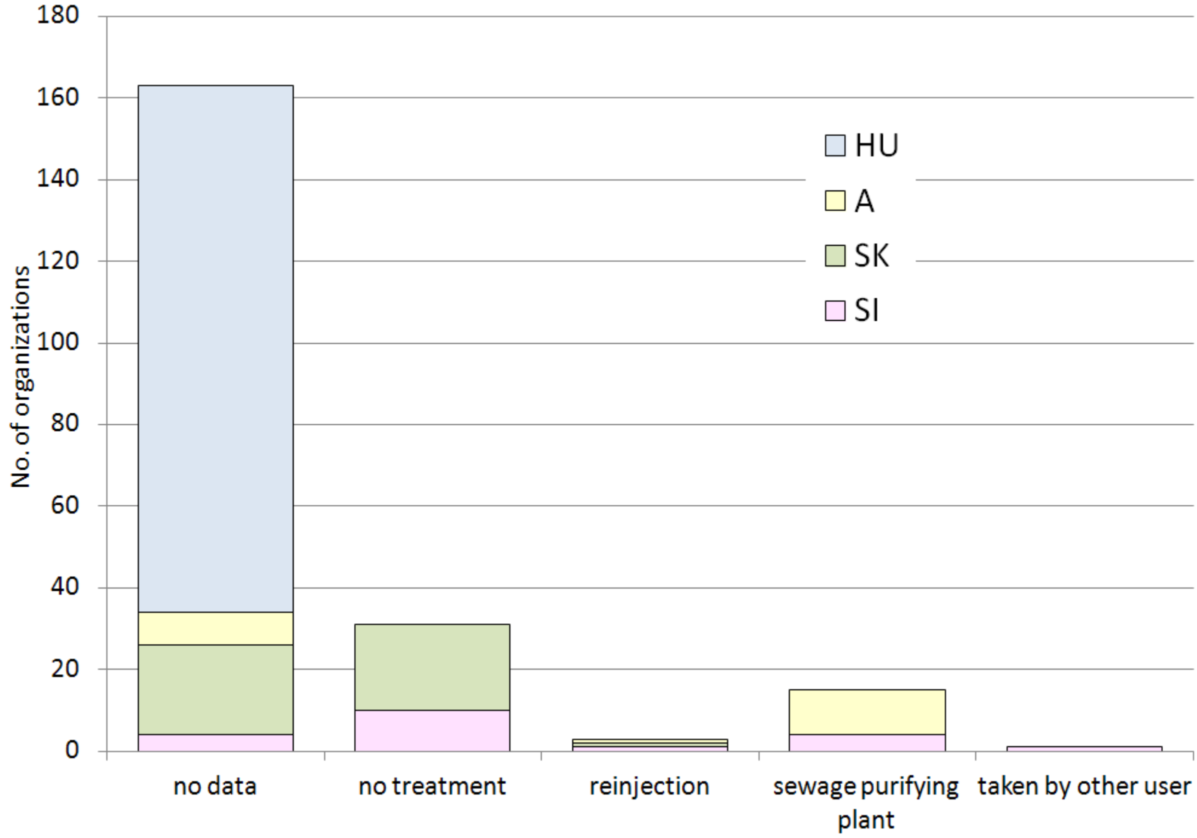

Figure 13: Waste water treatment in the TRANSENERGY project countries (148 active users)

Beside the waste water treatment the applied waste water monitoring of the quantity, chemistry and temperature was inspected. The possible database selection options for all waste water and operational monitoring application types were: annual data (if monthly, quarterly, half-year or annual data are available), continuous data (the maximum reporting period is daily), occasional data (no systematic, just random occasional measurements), no monitoring applied and no data on monitoring application available.

Waste water quantity is often annually reported in Hungary, while temperature and chemistry are controlled only occasionally. **Slovakia and Slovenia** have the prevalent annual data in quantity and occasional in waste water quality and temperature, while in **Austria** continuous monitoring application is most commonly reported (fig. 14).

The thermal pollution of surface waters by the emitted thermal water is implied from the figure 15. Only 69 users (47% of active ones) have reported waste water temperature, measured before being emitted to the environment. Less than 5% of active users reach temperature below 20 °C, 8% of active users emit water with 20-24,9 °C, while the 25-29,9 °C interval is represented by 16%. 18% emit the water with temperature above 30 °C.

This shows that in the most cases the **energy extraction efficiency is insufficient and the applied utilization technology unsuitable**. Therefore, the users who want to extract more thermal water in the future should be first obliged to decrease the waste water temperature below 20 °C and afterwards start discussing the enlarged production.

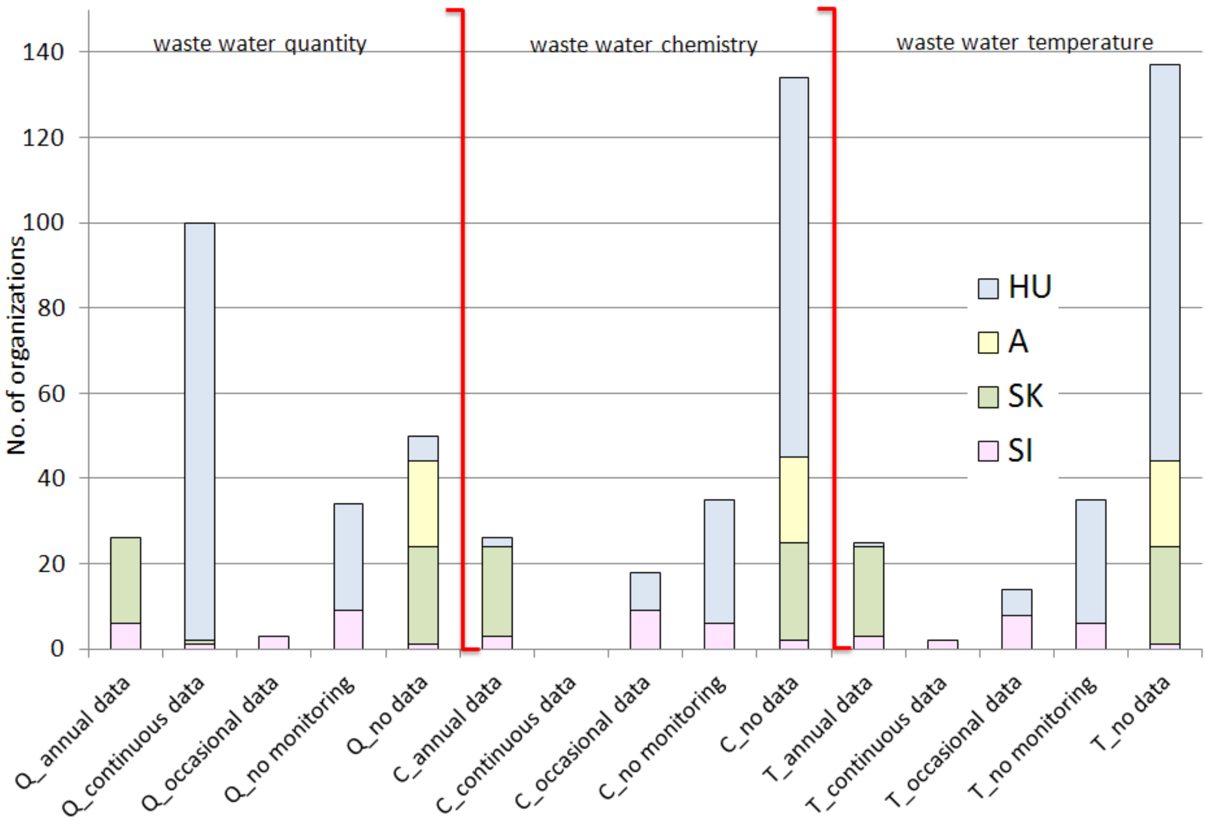

Figure 14: Waste water monitoring types in the TRANSENERGY project countries (213 users)

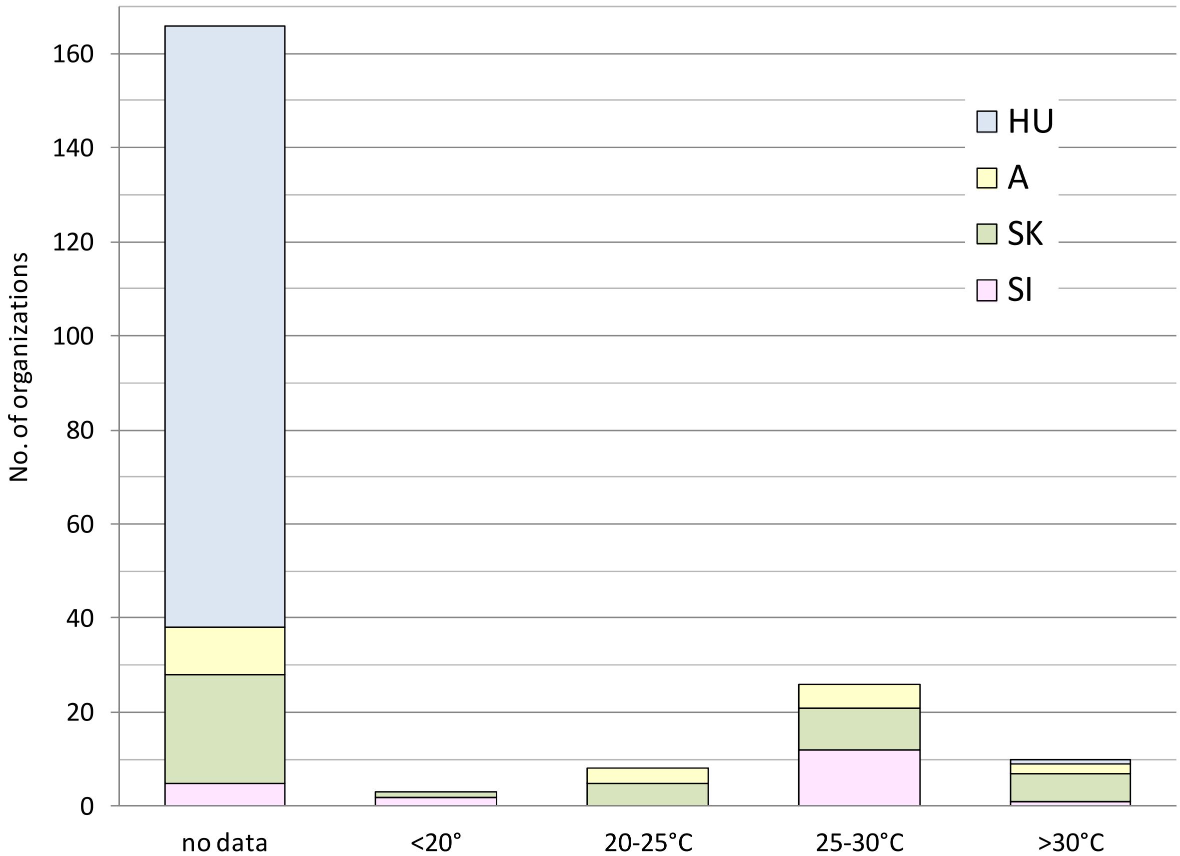

Figure 15: Waste water temperature in the TRANSENERGY project countries (213 users)

5. Results and interpretation of Database of current and potential utilization parameters

5.1 Geothermal aquifers characteristics - 'formation' level

The database of current and potential utilization parameters contains 290 different formations and their combinations which are individually linked to 213 users. The names of the formations are reported as given by the individual countries so they are not synchronized in the database. When neglecting organizations using the same formations, the amount of the various formations and their combinations is too high to be useful for any interpretation. Therefore, we joined various formations from the four project countries by their **stratigraphic age and lithology**, differing between the carbonate, volcanic and clastic sediments and rocks. This resulted in the recognition of the 11 geothermal aquifers whose properties were interpreted in more details. In this work package the **transboundary character** of the geothermal aquifers **was not investigated**.

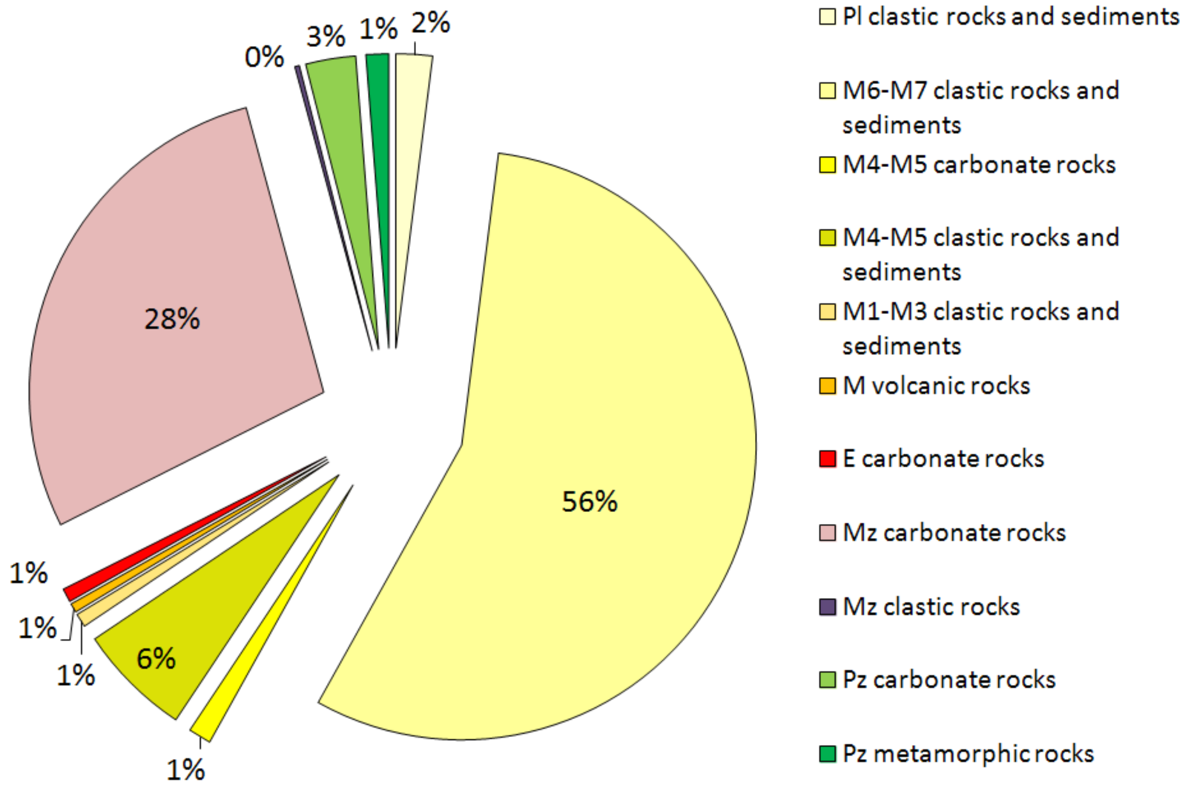

Figure 16: Main captured geothermal aquifers in the TRANSENERGY project area (401 boreholes)

Due to the favourable geological conditions and thermal water properties the Mesozoic and Miocene rocks form the most exploited geothermal aquifers (fig. 16). Over **half of the boreholes** (56%) capture thermal water from **the Pannonian-Pontian clastic aquifers**. The second most exploited aquifer (28%) is formed by the **Mesozoic carbonate rocks** (limestone and dolomite). The Middle Miocene clastic (6%) and the Paleozoic carbonate (3%) aquifers are also important. The others are either of a more local character, containing thermal waters which are more difficult to use, or the water temperature is too low to be classified as thermal.

Comparison between the countries (fig. 17) reveals that the Pannonian-Pontian clastic aquifers are exploited in all four project countries, being the most exploited geothermal aquifers in **Hungary, Slovenia and Slovakia**. All four countries produce thermal water also from the Mesozoic carbonate rocks, which represent the most important geothermal aquifers in **Austria** but are important also in Hungary. This difference can be ascribed to the geology as the Mesozoic rocks get shallower towards the west of the project area. The rest of the identified geothermal aquifers are less frequent.

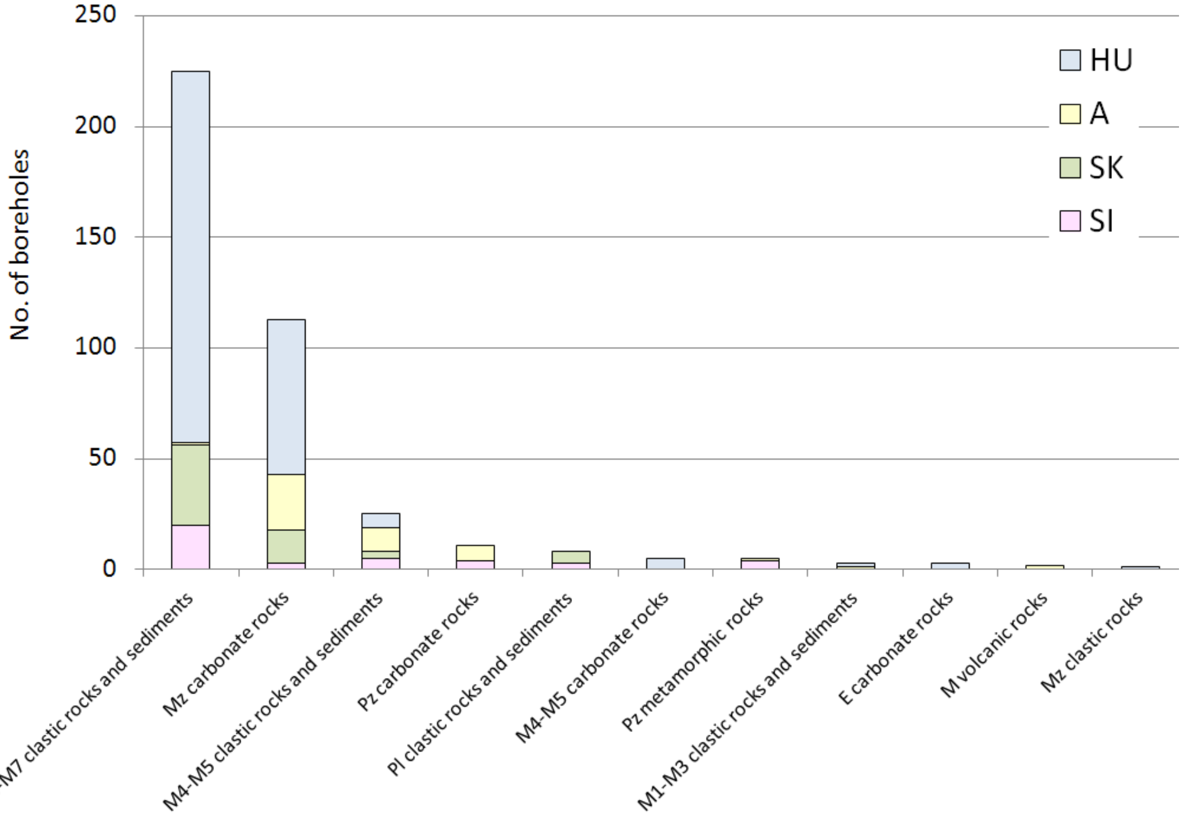

Figure 17: Main captured geothermal aquifers in the TRANSENERGY project countries (401 boreholes)

The **problems of the thermal water use** were not an obligatory parameter in the database, therefore, the amount of this kind of data is various. However, from the reported data it can be noticed that similar problems occur over the whole project area.

The Paleozoic carbonate and metamorphic aquifers often produce thermal water with an abundance of CO_2 gas. When degassing, the carbonate scaling in wells and pipes occurs which some users prevent by the injection of inhibitors into the production wells. The Mesozoic carbonate aquifers can also produce thermal water with large amount of CO_2. When the water degasses in the well or on the surface, the gas is released to the air and the carbonate scaling often occurs at the same time. The scaling problems of the water from the Mesozoic aquifers are either unsolved or no data is available on its mitigation. The Middle Miocene clastic aquifers are reported to produce thermal water with some CO_2 and/or CH_4 gas, which are released into the air. The associated carbonate scaling is sometimes mitigated by the injection of scaling inhibitors into the wells. The Pannonian-Pontian clastic aquifers can produce thermal water with some CO_2, methane and/or H_2S, all three degassing to the air. The carbonate scaling is rarely reported, however, if emerging, it is being mitigated by the inhibitor injection. In these wells the pump failures sometimes occur, mostly due to too high extraction rates and/or sand clogging. The Pliocene clastic geothermal aquifers may produce thermal water with degassing CO_2, but no major utilization problems are reported. For the other geothermal aquifers no utilization problems or their mitigation are reported.

The difference in **captured geothermal aquifers depth** is evident from the figure 18, which shows the depth range of the perforated sections for all boreholes in the four project countries together. The most exploited Pannonian-Pontian clastic and the Mesozoic carbonate aquifers show the largest intervals, which are directly connected to the geology / aquifers depth. Where the thermal springs occur like in Hévíz (HU) the aquifer depth is 0 (it outcrops), while in other places it may be positioned much deeper or a deeper capture is needed to gain the thermal and not the cold water. The deepest captured aquifer is approx. 3 km deep, but the **prevalent geothermal aquifers are positioned between 500 m and 2 km** below the ground.

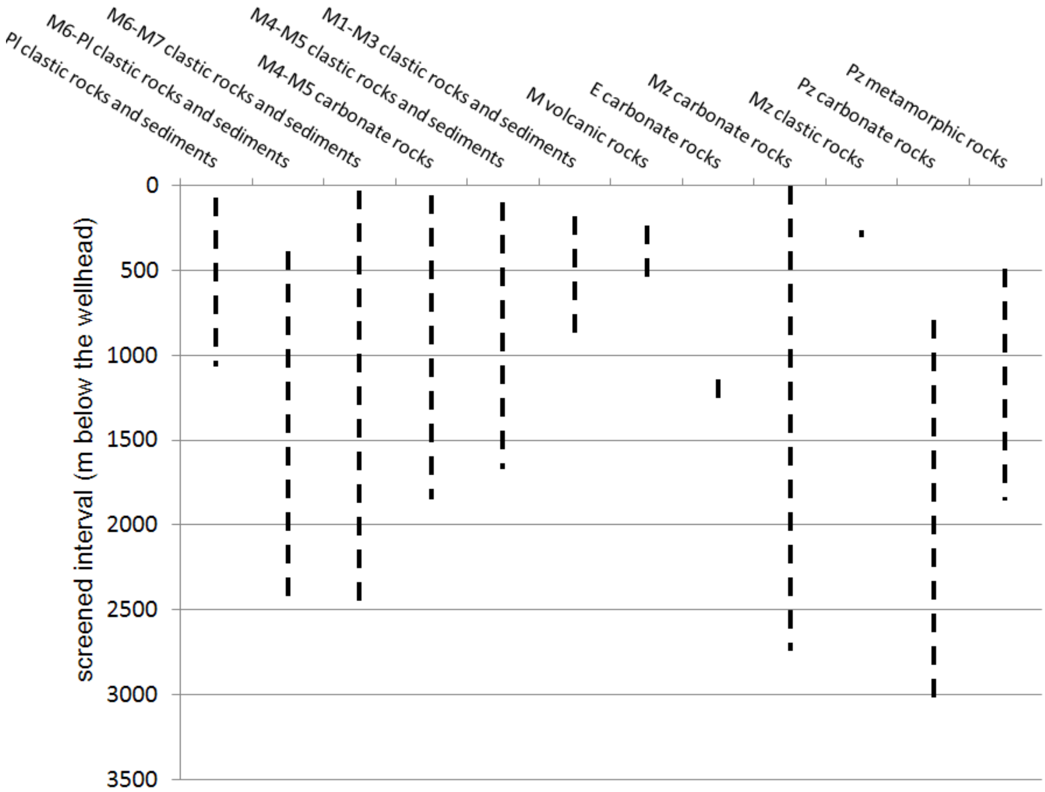

Figure 18: Screened intervals of the identified geothermal aquifers (the shallowest and the deepest depth)

The maximum wellhead thermal water temperature, differing due to the various geothermal aquifers, can be noticed from the figures 19 and 20. It has to be pointed out here again that the lowest reported temperature was selected at 20°C and this value does not represent the lowest natural outflow temperature from the geothermal aquifers. The **highest wellhead temperature of 109°C** is reached by water from the **Paleozoic carbonate rocks**, which is used for electricity production in Austria, followed by the water from the **Mesozoic carbonate rocks** in Hungary, used for bathing and swimming only, and the **Pannonian-Pontian clastic aquifers** in Slovakia, used for greenhouse heating. The stratigraphically older aquifers do not necessarily hold warmer thermal water as their spatial and geological distribution is not totally continuous throughout the four project countries. The **Pliocene aquifers** reach up to 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 geothermal 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 in Austria up to 65°C and in Hungary 56°C. 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 **Mesozoic carbonate aquifers** also show differences between the countries with produced water temperature up to 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, producing water with up to 78°C in Slovenia and 42°C in Austria.

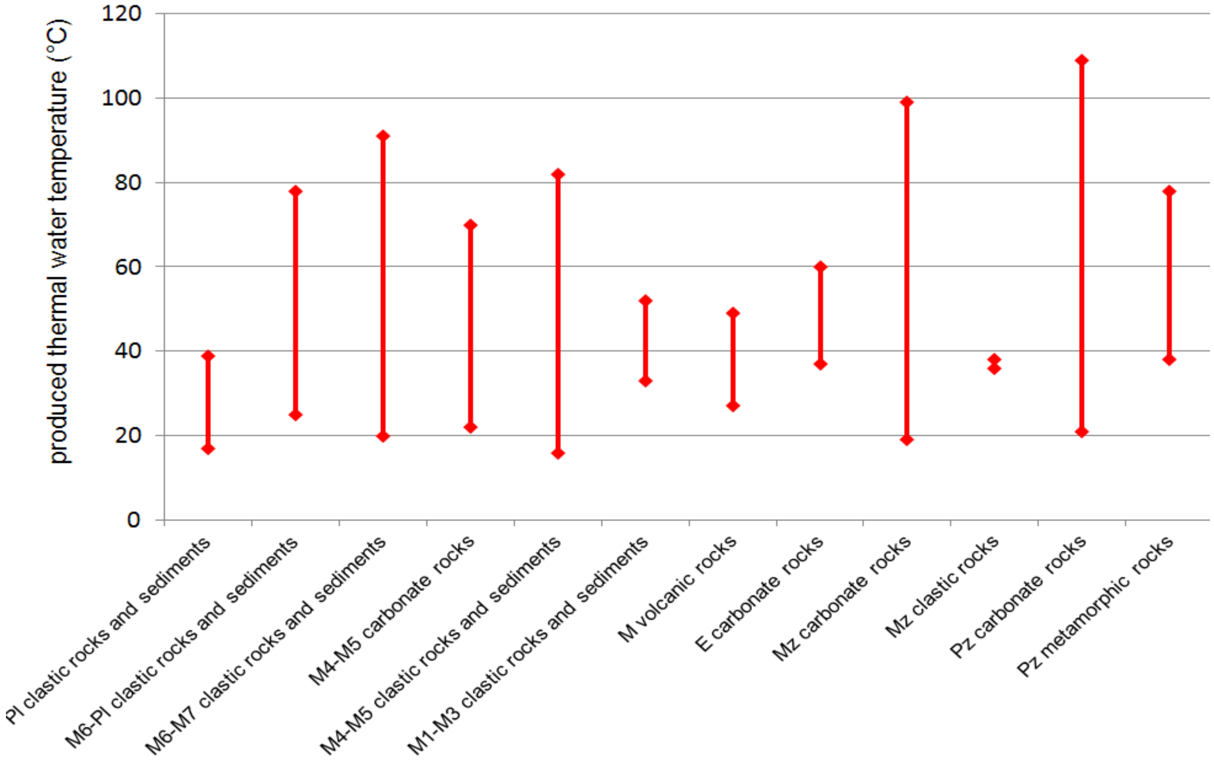

Figure 19: Thermal water temperature intervals for the identified geothermal aquifers (401 boreholes)

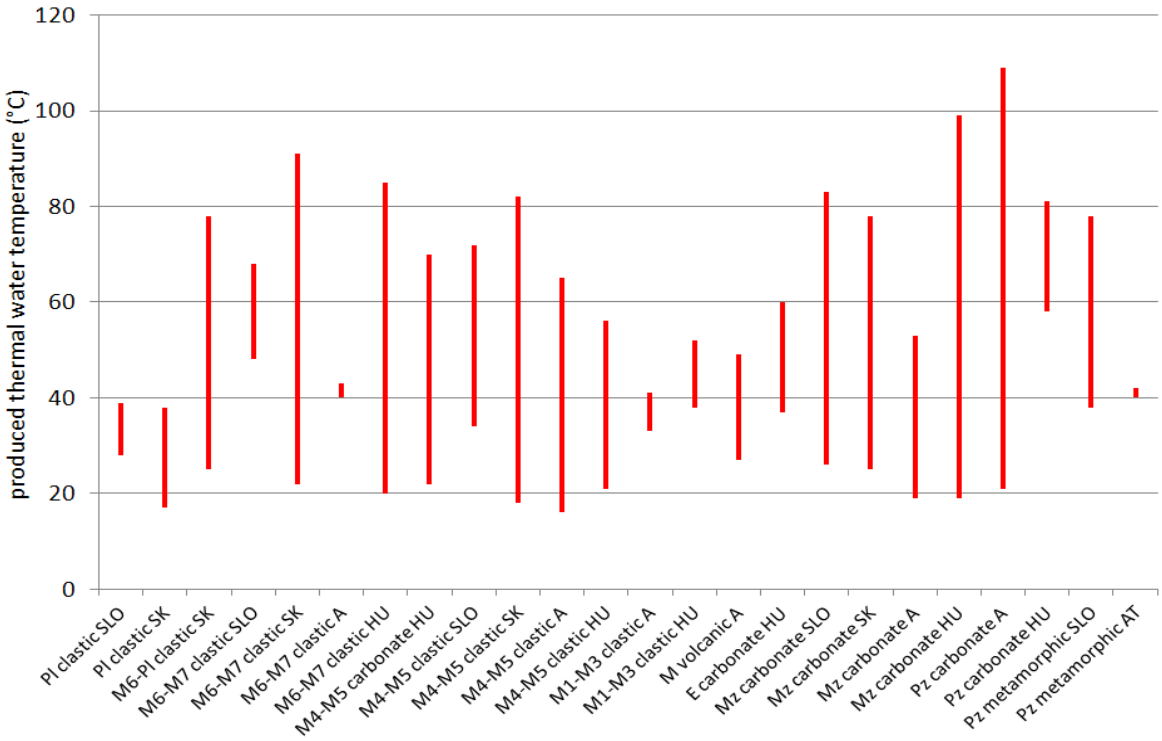

Figure 20: Thermal water temperature intervals (401 boreholes)

What else can we say about the already discussed geothermal aquifers? Some **characteristic production statistics** is gathered in the table 5 from which it can be denoted that four aquifers are captured with more than 10 boreholes. The **Pannonian-Pontian clastic aquifers** with the predominant intergranular porosity are reported to 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 yields 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 much more productive. Some shallower wells produce up to 650 l/s of thermal water, not neglecting the lake / spring in Hévíz (HU) naturally discharging 400 l/s. The optimum production rates are also large, approx. 28 l/s. **Paleozoic carbonates** have very high maximum yield reaching values up to 187 l/s and 76 l/s on average, and also rather high optimum yield, around 21 l/s on average.

Table 5: Yield characteristics of geothermal aquifers in the TRANSENERGY project area

	maximum yield (l/s)				**optimum yield (l/s)**			
	No. samples	**Min.**	**Max.**	**Average**	*No. samples*	**Min.**	**Max.**	**Average**
Pl clastic rocks and sediments	*2*	10	12	**11,0**	*2*	8,0	**8,0**	**8,0**
M7-Pl clastic rocks and sediments	*9*	1	33	**13,9**	*6*	0,4	23,0	**9,8**
M6-M7 clastic rocks and sediments	*152*	0	133,6	**15,4**	*35*	2,5	35,0	**12,1**
M4-M5 carbonate rocks	*2*	8,3	55	**31,7**	*0*	0,0	0,0	
M4-M5 clastic rocks and sediments	*16*	1	53	**8,8**	*11*	0,5	30,0	**6,4**
M1-M3 clastic rocks and sediments	*2*	15	41,66	**28,3**	*1*	10,0	10,0	**10,0**
M volcanic rocks	*1*	5	5	**5,0**	*1*	3,0	3,0	**3,0**
E carbonate rocks	*2*	6,7	41,7	**24,2**	*0*	0,0	0,0	
Mz carbonate rocks	*54*	1,55	650	**35,9**	*17*	3,0	110,0	**28,0**
Mz clastic rocks	*1*	10	10	**10,0**	*0*	0,0	0,0	
Pz carbonate rocks	*4*	6	186,6	**75,6**	*4*	3,0	30,2	**20,8**
Pz metamorphic rocks	*2*	1,2	15	**8,1**	*3*	0,5	8,0	**3,7**
No. of samples	***247***				***80***			

5.2 Thermal water production – 'borehole' level

The interpretation of the formation level data can be complemented with more detailed information collected on the borehole level of the database. The following text will present the available interpretation results.

First, we collected some technical data on the **drilling purpose** (fig. 21). As the purpose of our research is geothermal energy utilization, the prevalent boreholes included in the database are obviously geothermal. For Slovenia it can be noticed that quite some oil and gas prospection boreholes are now being exploited for the thermal water extraction and the same is true for Slovakia. Both have also identified reinjection wells. The Austrians made a distinction between geothermal and oil boreholes, natural springs and the reinjection well. The Hungarians classified most of their boreholes as hydrogeological but also some originally oil and gas prospection or structural boreholes produce thermal water beside thermal springs. From this data we can conclude that the drilling purpose terminology is probably not totally consistent between the project countries but the general transboundary trend is obvious. **The geothermal or hydrogeological boreholes** are used to produce the thermal water in majority, however, some originally **oil and gas prospection boreholes** also serve to the same purpose now.

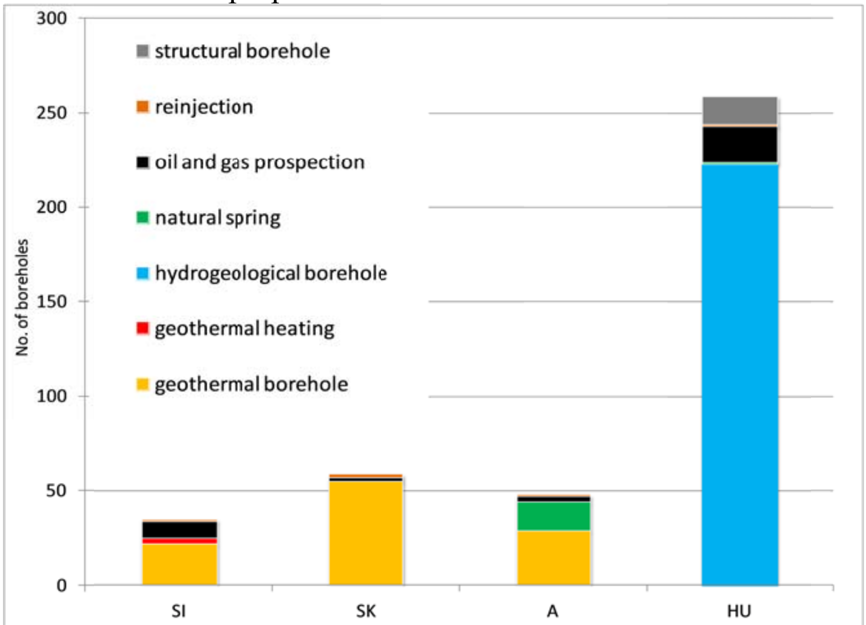

Figure 21: Drilling purpose of the boreholes nowadays used for thermal water extraction (401 boreholes)

The **state of the current and potential exploitation of the inspected geothermal aquifers** can be roughly estimated from the (in)activity of the inspected boreholes. The borehole is defined as active if there was some water production reported for 2009, or if the experts know that it is active, even though no production values are available. 'No data' boreholes are taken as inactive. 20% of all boreholes are inactive. The data (fig. 22) indicate that the most exploited Pannonian-Pontian clastic aquifers have **64%** and Mesozoic carbonate aquifers **63%** of **constantly active** boreholes and moreover both **25%** of **inactive** boreholes which represent **geothermal potential**. Our data show that the other aquifers do not have such a development potential but there are some individual inactive boreholes which can provide the additional amount of thermal water if needed/wanted.

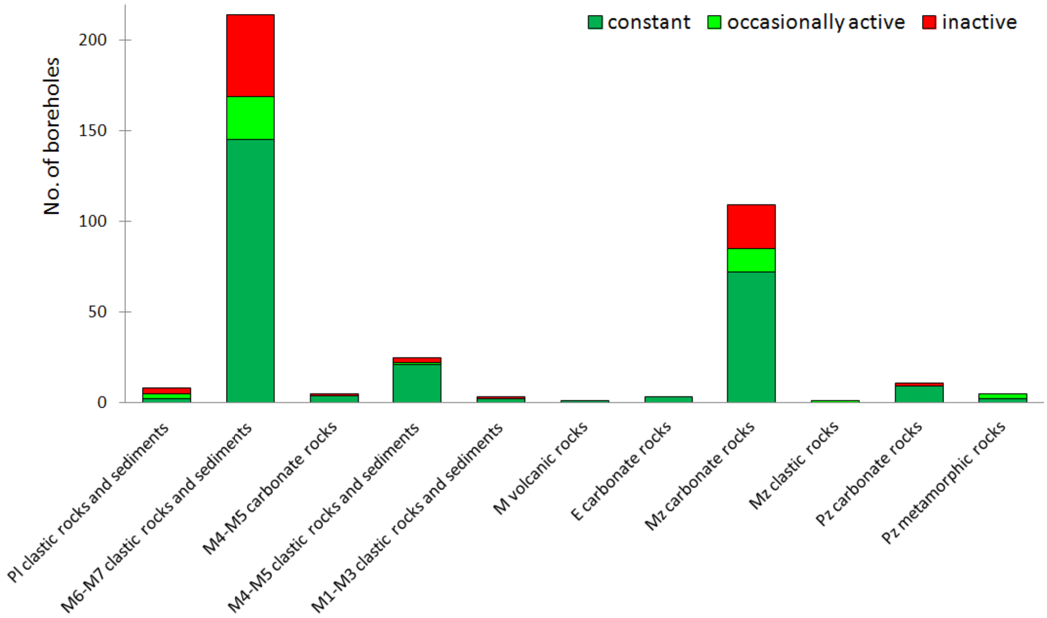

Figure 22: Activity of the thermal water wells in various geothermal aquifers (401 boreholes)

The borehole activity was compared by the project countries and the main geothermal aquifers (fig. 23). With the exception of **Austria**, where only the Mesozoic carbonates and Miocene volcanic rocks represent the potential geothermal aquifers, the **other countries** show the trend mentioned in the previous paragraph (88% of the inactive boreholes capture the Pannonian-Pontian clastic or Mesozoic carbonate aquifers). In Slovenia and Slovakia some potential also exists for the Pliocene geothermal aquifers, in Slovenia also for the Middle Miocene clastic rocks, while in Hungary also for the Middle Miocene and Paleozoic carbonate rocks and Lower Miocene clastic rocks.

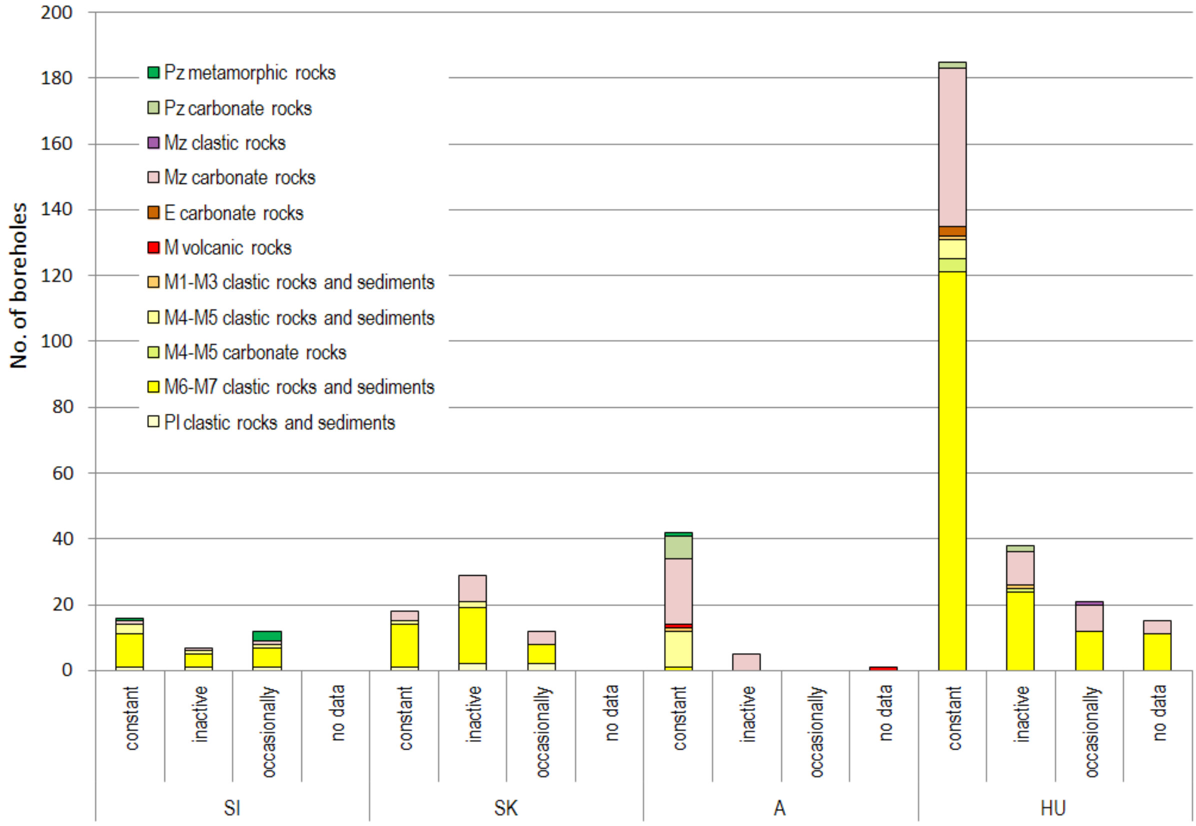

Figure 23: Activity of the thermal water wells in the TRANSENERGY project countries (401 boreholes)

The **geothermal potential** as it was discussed up to now can be directly transferred to the annual production values in order to provide a more illustrative approach. However, a problem occurred for this interpretation as the **Austrian partners could not provide the values on the annual extracted amount of thermal water**. As they do not indicate an important exploitation of the Pannonian-Pontian clastic aquifers, the missing data should not affect our calculations for these geothermal aquifers much. But since they do exploit the Mesozoic carbonates and have some inactive boreholes that capture it, the actual and potential thermal water extraction from it is surely greater than the reported in the following text and figures. The annual thermal water production in 2009 was already discussed at the figure 11, while here the following can be added (fig. 24). The comparison of the previous three years (2007, 2008, 2009) shows a **slowly increasing trend of the thermal water extraction**. The reported total production rose from 29,0 million m^3 in 2007 and 28,4 million m^3 in 2008 (the amount of available production data was lower for 1% = 3 boreholes) to the **30,3 million m^3 of thermal water in 2009**. The increase is mostly due to the increased production in Slovakia where at the same time less data was missing for the year 2009 as for the previous years (fig. 25).

In addition to this obviously increasing production trend, there is another worrying fact that should be considered in the geothermal aquifers management activities in the future. The project partners could provide the data on **already granted or applied for annual production of the thermal water** in Austria, Slovakia and Slovenia. It is known for Hungary that the granted production is also higher than the reported one. The users pay water fee after the reported production but at the same time the minimum 80% of the total granted amount has to be paid. The data show that the granted or requested amounts are at least **double the current actual production**. If the potential annual production is calculated assuming double the 2009 extraction for the three countries with the available production data, the **hypothetic thermal water production** could rise to **over 60 million m^3 per year** in the future (neglecting Austria).

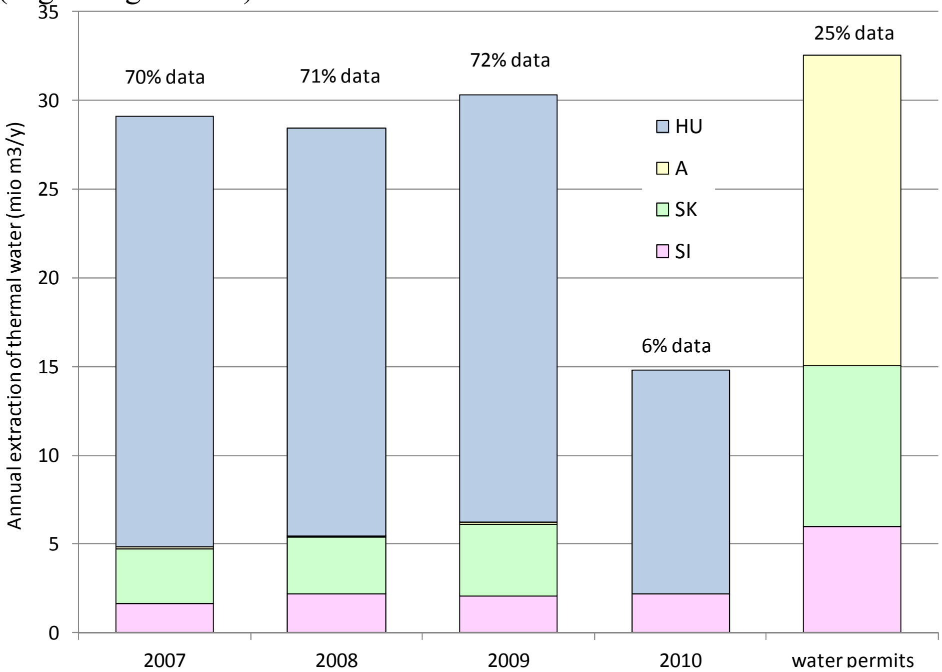

Figure 24: Total annual extraction of the thermal water by different years in the TRANSENERGY countries with the percentage of boreholes with the available data (401 boreholes)

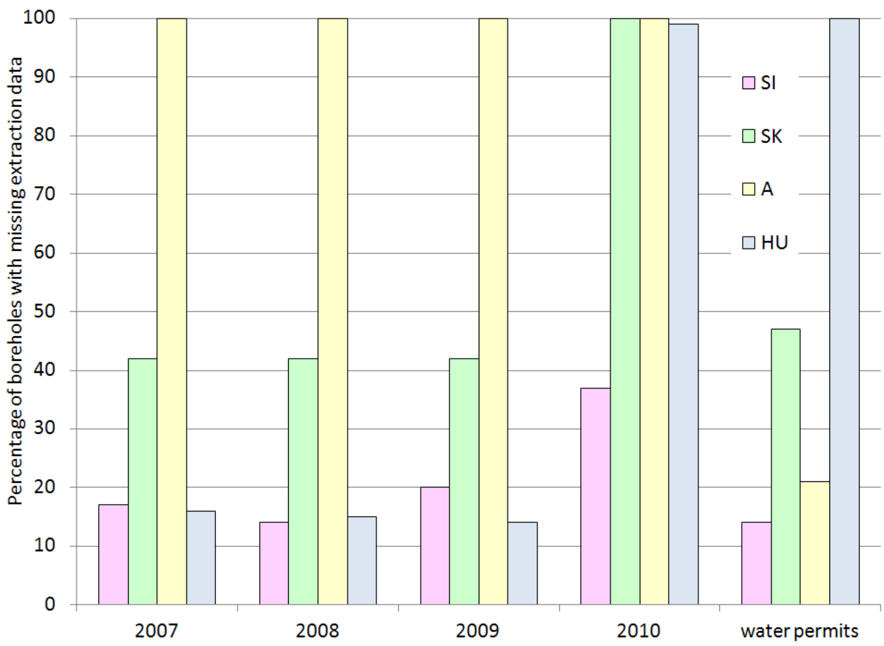

Figure 25: Percentage of boreholes with the missing production data in the TRANSENERGY project countries (401 boreholes)

Similar comparison and calculations can be done for the individual geothermal aquifers. The various amount of the available production data is given in the table 6, while the graphic comparison on the figure 26.

Table 6: Percentage of boreholes with the available production data per year by geothermal aquifers (401 boreholes)

% of boreholes with annual abstracted quanitity known in a year	2007	2008	2009	2010	water permits
Pl clastic rocks and sediments	57	43	71	43	86
M6-M7 clastic rocks and sediments	83	84	83	6	17
M4-M5 carbonate rocks	20	40	40	0	0
M4-M5 clastic rocks and sediments	44	44	44	16	68
M1-M3 clastic rocks and sediments	67	67	67	0	0
M volcanic rocks	0	0	0	0	100
E carbonate rocks	100	100	100	0	0
Mz carbonate rocks	57	57	59	3	23
Mz clastic rocks	100	100	100	0	0
Pz carbonate rocks	36	36	36	0	55
Pz metamorphic rocks	80	80	80	20	100

The **Pannonian-Pontian clastic geothermal aquifers** have the majority of the active boreholes (fig. 23) but due to their less favourable hydrogeological characteristics such as lower yields (as discussed at the table 5) their **annual thermal water production is lower than from the Mesozoic carbonate aquifers**. From the former approximately 11.4 million m^3 per year was produced in 2009, while from the latter around 19.4 million, of which 12.6 appertains to the Hévíz spring (neglecting Austria without production data).

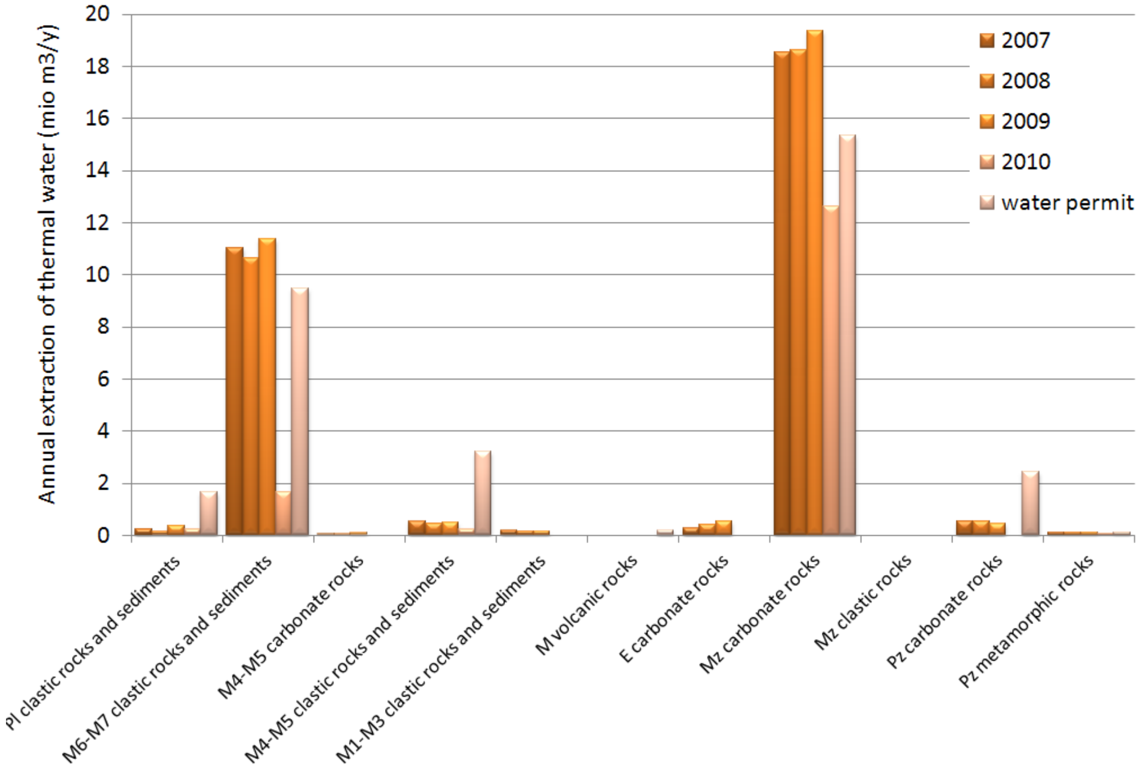

Figure 26: Total annual thermal water production by geothermal aquifers (2007- 2010) (401 boreholes)

The increasing trend of the thermal water production is noticed for all the most important geothermal aquifers (fig. 26). If these numbers are **increased for 20%,** which is the percent of all inactive boreholes, the production could rise to **36 million m^3**. The current potential of Pannonian-Pontian clastic aquifers is 2.8 million m^3, while of the Mesozoic carbonates 1.7 million m^3, neglecting the Hévíz spring as this outflow is natural and cannot be modified. This represents the actual **technical geothermal potential** but nothing is known if this is hydrogeologically possible, which would be the negative effects for the users, etc.

Some observations on the thermal water production conditions and its changes can be interpreted from the data gathered in the database of current and potential utilization parameters. Most of the boreholes (69%) **produce thermal water by pumping** (fig. 27) and only 14% by natural outflow. The reinjection boreholes are treated separately as the water is pushed into the well and (usually) not produced from it.

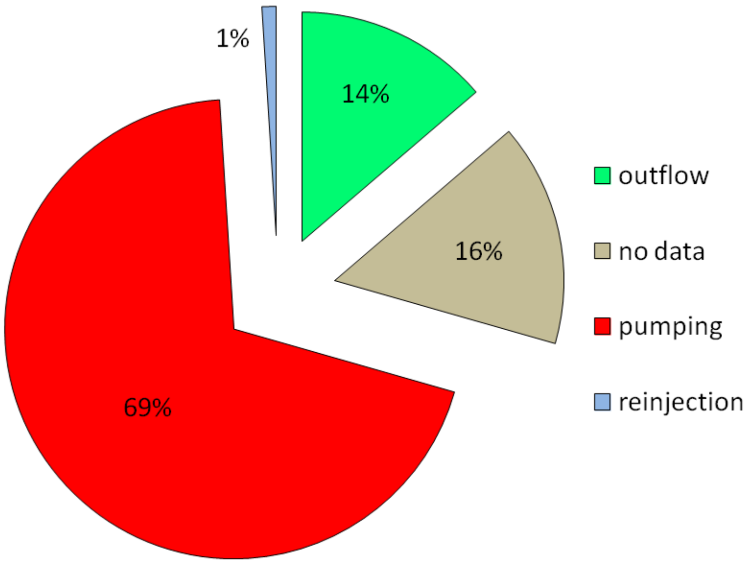

Figure 27: Types of the thermal water production (401 boreholes)

The **natural outflow of thermal water** is (was) characteristic for many geothermal aquifers but due to the long-term exploitation and higher needed production yields it is becoming of minor importance nowadays (fig. 28). In the most exploited Pannonian-Pontian clastic and Mesozoic carbonate aquifers there are only about **10%** of boreholes where pumps are yet not needed. The Slovenian Paleozoic metamorphic and also Slovakian Middle Miocene clastic aquifers plus Hungarian Middle Miocene carbonate still have pressures to provide more than **20%** of the boreholes with outflow, while in the Slovak Pliocene clastic aquifers the number reaches **25%**. For the others the production is predominantly by pumping.

The **changes in operation** were reported for many of the inspected boreholes (fig. 29). While the **Mesozoic carbonate aquifers** obviously receive much recharge as they produce the most thermal water of all but only 9% of boreholes indicate temperature and water level decrease, this is not the fact for others. In the **Pannonian-Pontian clastic and Middle Miocene clastic aquifers** yield, temperature and water level decrease, and sometimes well cycling, are noticed by more than 20% of the boreholes. The 29% of boreholes in the **Pliocene clastic aquifers** show the water level decrease and the problem is even greater (60%) in the boreholes capturing the **Paleozoic metamorphic rocks**. From this it can be concluded that **the Mesozoic carbonates receive enough recharge to balance the current thermal water production but this is definitely not the case with the rest of the inspected aquifers**. In the Middle Miocene and Pannonian-Pontian clastic aquifers where the temperature decrease is reported it is possible that the overexploitation causes inflow of the shallower and colder (probably also less mineralized) water into the geothermal aquifers.

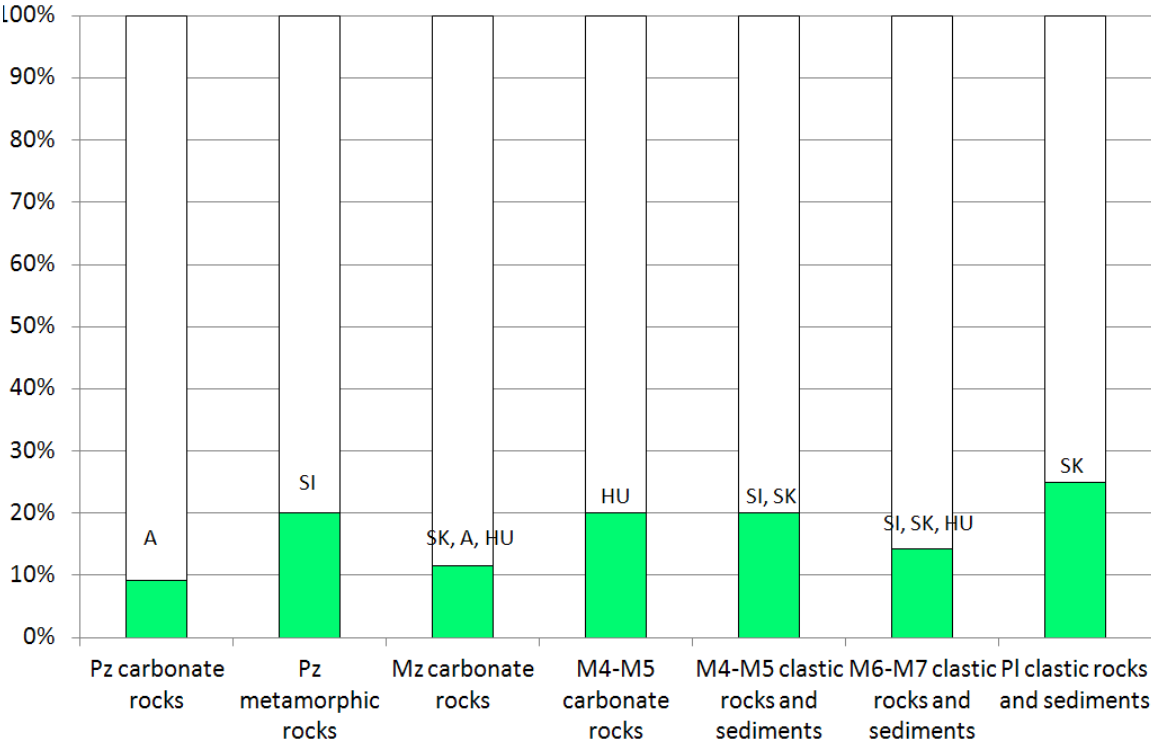

Figure 28: Percentage of the thermal water extraction by natural outflow and by countries

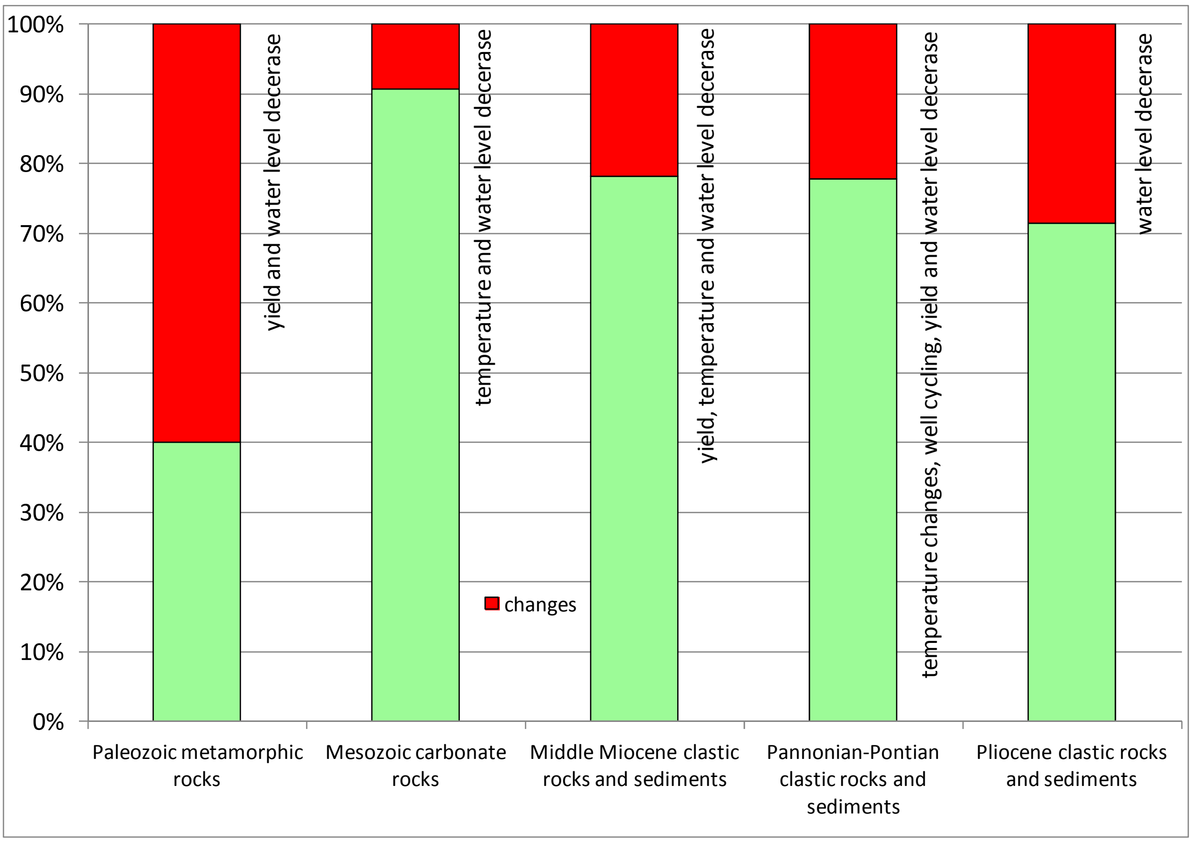

Figure 29: Percentage of the thermal water wells with noticed changes in operation (401 boreholes)

Beside the hydraulic changes and the production capacities described previously, the water temperature is also quite characteristic for the geothermal aquifers.

If the **average wellhead temperature** data from the database is interpreted, its lognormal distribution is evident (fig. 30). From the temperature histogram it is obvious why the direct use of geothermal energy prevails in the project area, with bathing, swimming and balneology on the first place. More than third of the boreholes produce water with temperature between 20 and 30°C and only 5 with the temperature above 90°C. However, it is interesting to remember that the 60% of the available temperature data on the emitted waste water (fig. 15) are in the same range (25-30°C), which again indicates poor geothermal energy efficiency. Some subthermal water was also reported, as well as missing information.

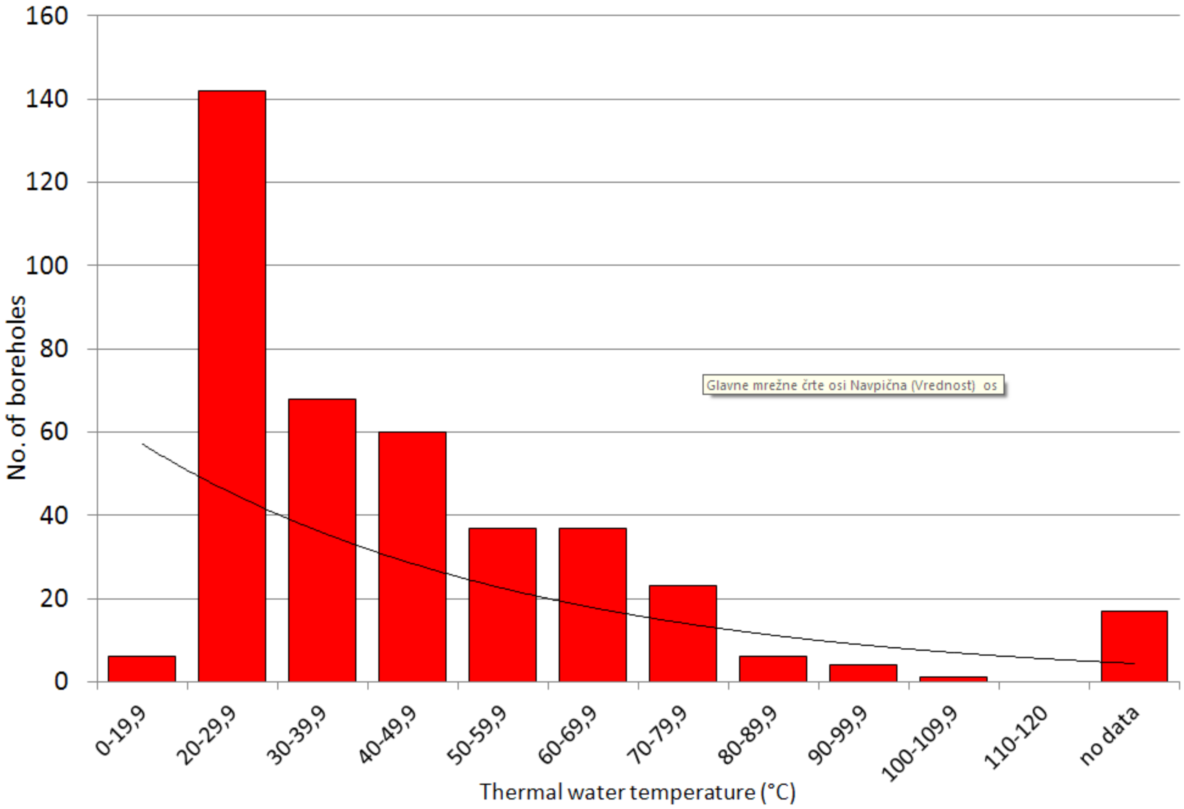

Figure 30: Produced thermal water wellhead temperature distribution (401 boreholes)

The thermal water temperature distribution is not the same in all TRANSENERGY project countries. The general lognormal distribution is caused by the very large number of the lower temperature wells as reported by **Hungary** (fig. 31). Due to its rather low temperature the thermal water is mainly used as a drinking water source or for swimming and bathing. If these wells were excluded, the interval 30 to 50°C would be the most abundant. On the other hand, the rest of the project countries exhibit an almost normal statistical distribution of the wellhead temperature. In **Austria** the boreholes with water temperature between 30 and 40°C prevail, in **Slovenia** the ones with 50 to 60°C, while in **Slovakia** even higher. The temperature depends on the geological position of the geothermal aquifer and its type, therefore, these values are a direct consequence of the structural position of the most exploited aquifers in each country.

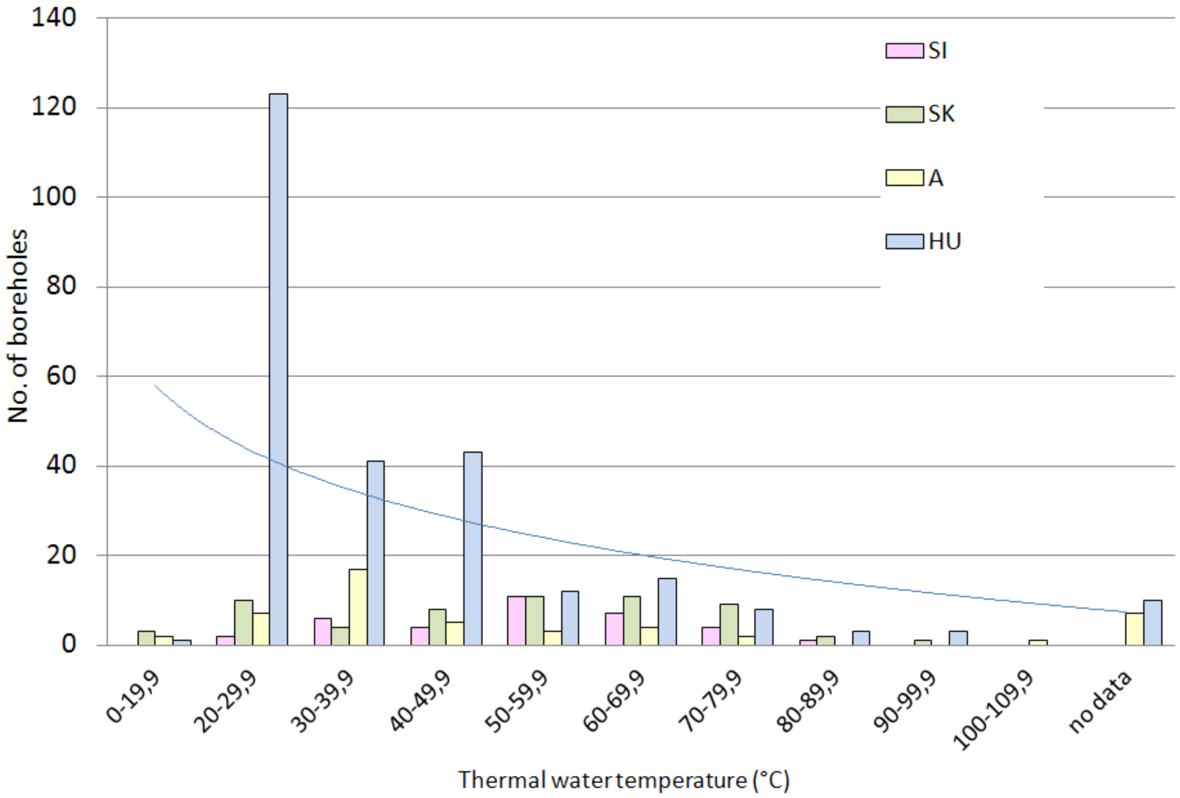

Figure 31: Thermal water temperature distribution in the TRANSENERGY project countries (401 boreholes)

5.3 Operational monitoring – 'borehole' level

The operational monitoring is an important management tool which can provide information on the production characteristics as well as on the geothermal aquifers hydraulic conditions. It should be performed on each borehole separately and should be a responsibility of an individual user. The equipment used should be standardized so the comparison between the measurements / results is possible between different users, monitoring years and countries. In the database of the utilization parameters we gathered the existent data on the **application of different types of the operational monitoring and their data storage**. The actual recorded data were not to our interest in this moment as only the general utilization overview is planned for the project. Based on the performed research, the monitoring data availability is shown for all four TRANSENERGY project countries and the more detailed process of collecting, harmonizing and interpreting the operational monitoring data can be addressed in new projects in the future. In this research the groundwater level or aquifer pressure (m or bar), maximum momentary yield (l/s), cumulative quantity (m^3), thermal water temperature and chemical monitoring were examined. Annual monitoring includes also weekly, quarterly, half-yearly and monthly observations, while continuous consists of hourly and daily readings.

It was already indicated in the previous paragraphs (fig. 29 and accompanying text) that the decrease in the **groundwater level** is often noticed by the thermal water users. The figure 32 reveals that the Hungarian groundwater-level monitoring network is well established and annual observations prevail. Austria is even better as continuous or daily water levels are most often observed. Not much is known on this monitoring type in Slovakia, while in Slovenia some continuous or annual measurements exist. In general, Austria shows the best groundwater level monitoring application, although information is available for very few boreholes. The installed monitoring equipment is the first phase for the acquisition of the reliable and continuous production data. However, this is of no use if the measured data is not recorded and saved in a paper or a digital format. The installed monitoring equipment does not directly result in an actual **storage of the measured monitoring data** as it can be noticed from the following figures.

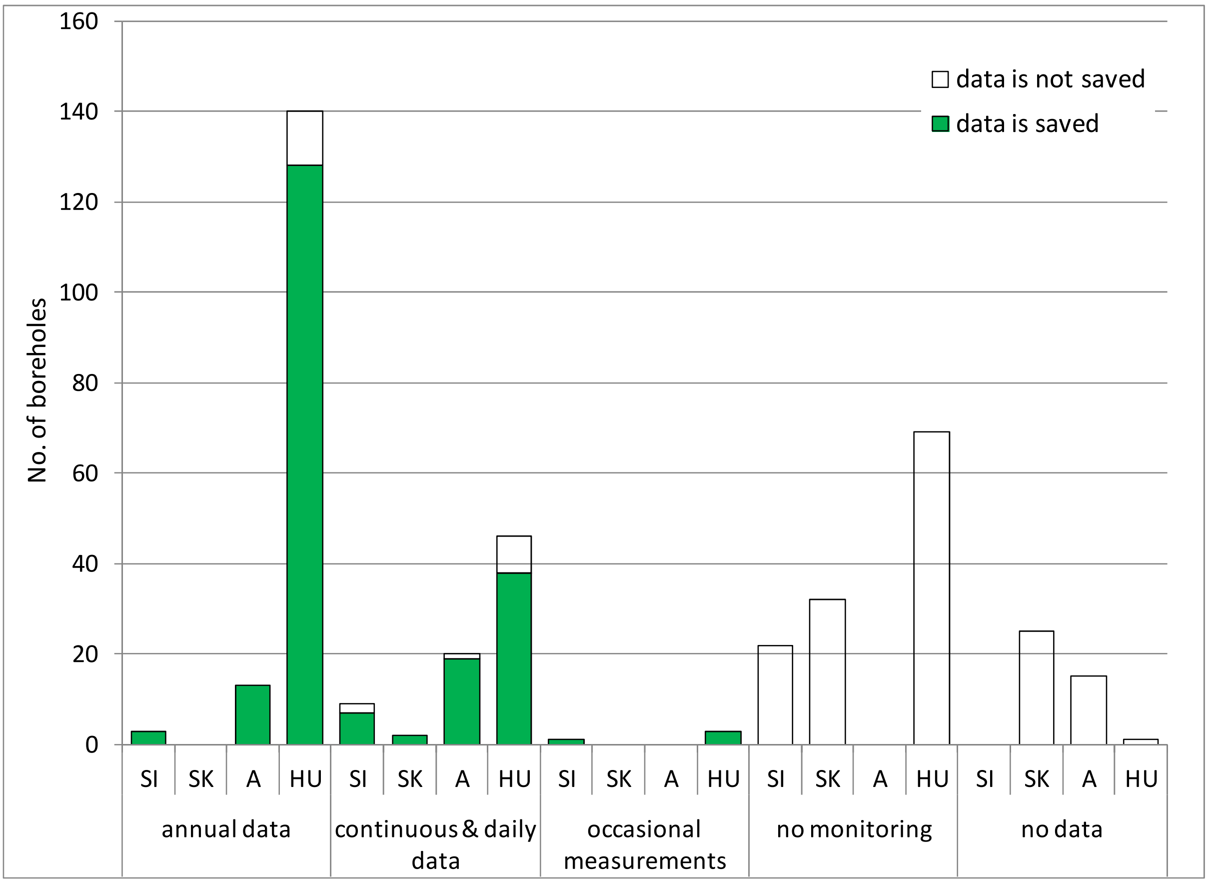

Figure 32: Applied groundwater level operational monitoring (401 boreholes)

The borehole production characteristics can be interpreted from the maximum momentary yield (l/s) and the cumulative produced quantity (m^3/time unit) monitoring. In Slovenia some users continuously observe the **momentary yield** (fig. 33) and even store the reading but many wells are also without monitoring. Similar but without the storage applies for Hungary, while no monitoring is mostly applied in Slovakia. In Austria continuous and annual measurements do exists but without data storage.

The **cumulative quantity** of produced thermal water (fig. 34) is very important parameter for estimating the annual production. The actual annual values as reported by the users were already discussed (fig. 11, 24, 26 and the text) but here the actual monitoring application is inspected. In Austria quantity is continuously measured, while in other countries at least annual production is available. Wells without monitoring or information are mostly inactive wells.

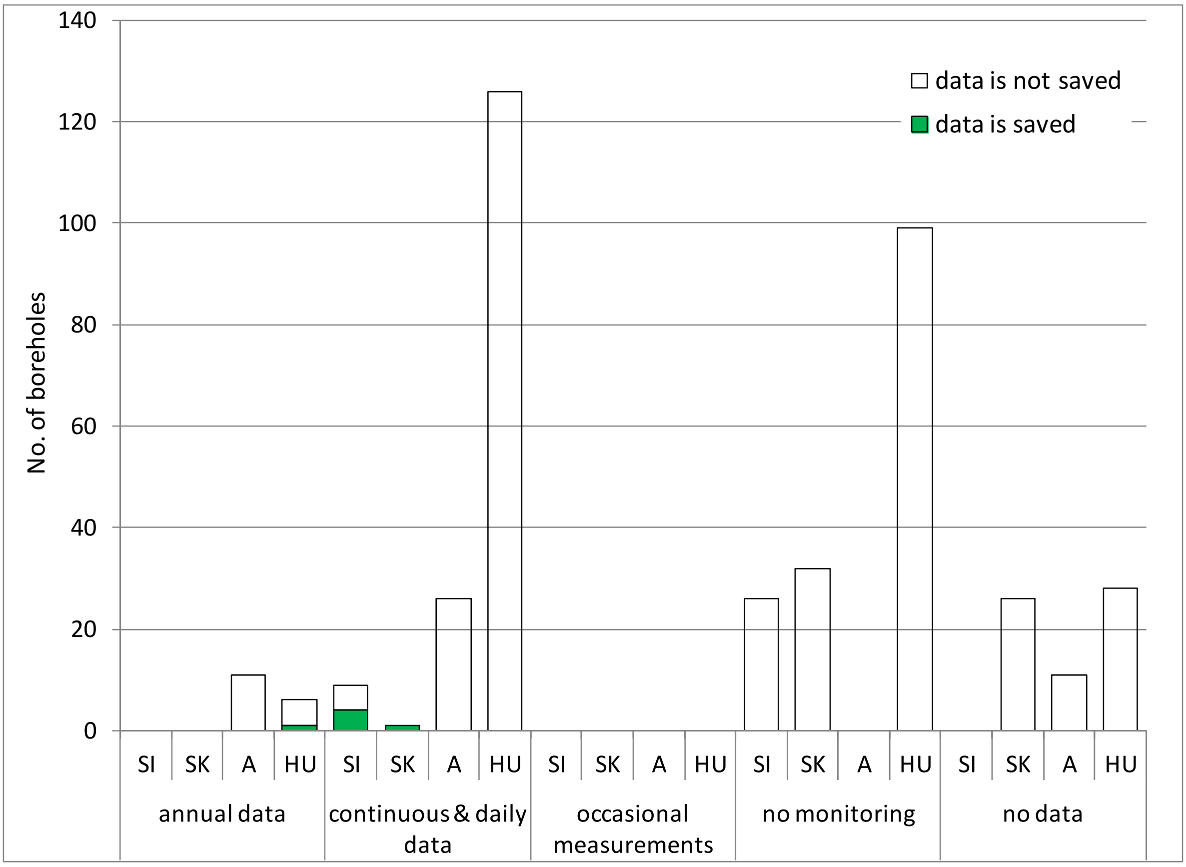

Figure 33: Applied momentary yield operational monitoring (401 boreholes)

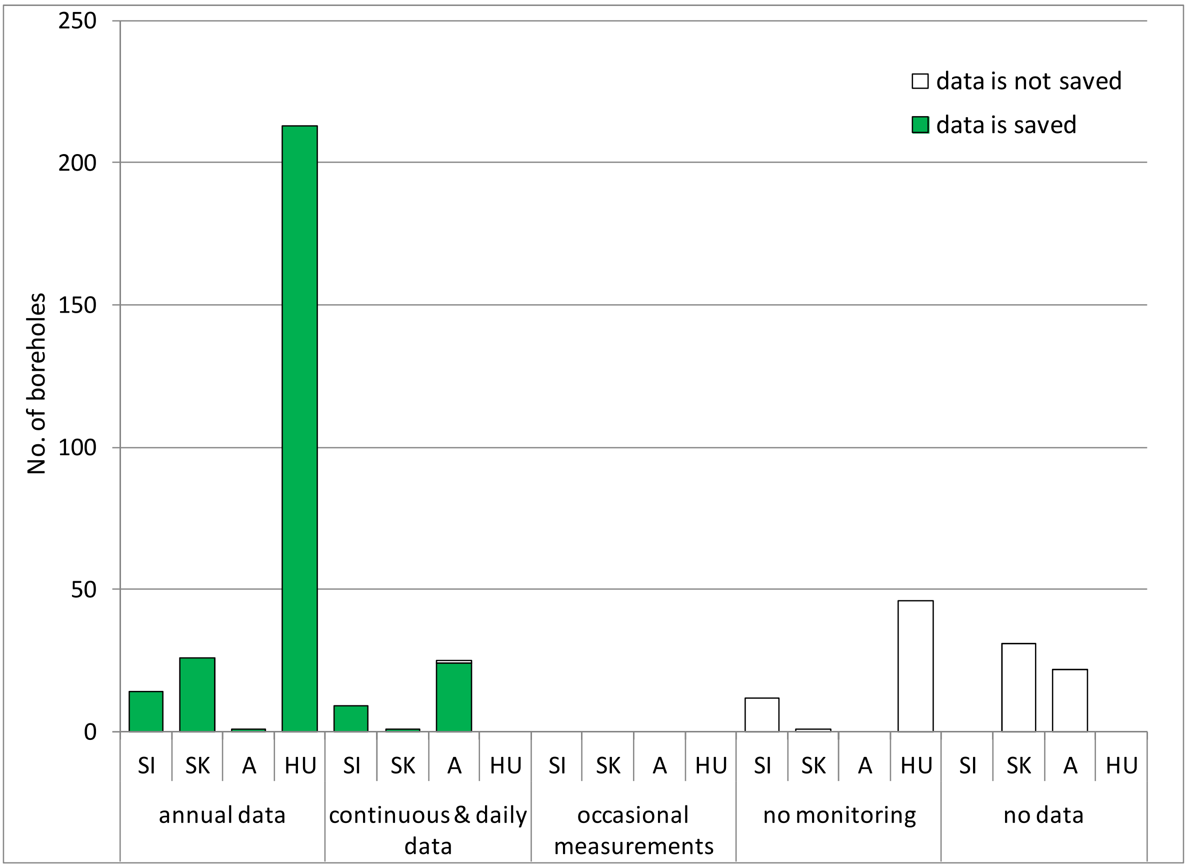

Figure 34: Applied cumulative quantity operational monitoring (401 boreholes)

The **thermal water temperature** (fig. 35) is an important parameter which determines its utilization characteristics to a large extent. If no major production changes are observed, the temperature should stay approximately constant during the productive period, therefore, most of the users control it on an annual basis. The annual temperature monitoring is prevalent type in Hungary and Slovakia, while in Austria and Slovenia continuous measurements are more frequent. No monitoring and no information stand mostly for inactive wells with no monitoring equipment.

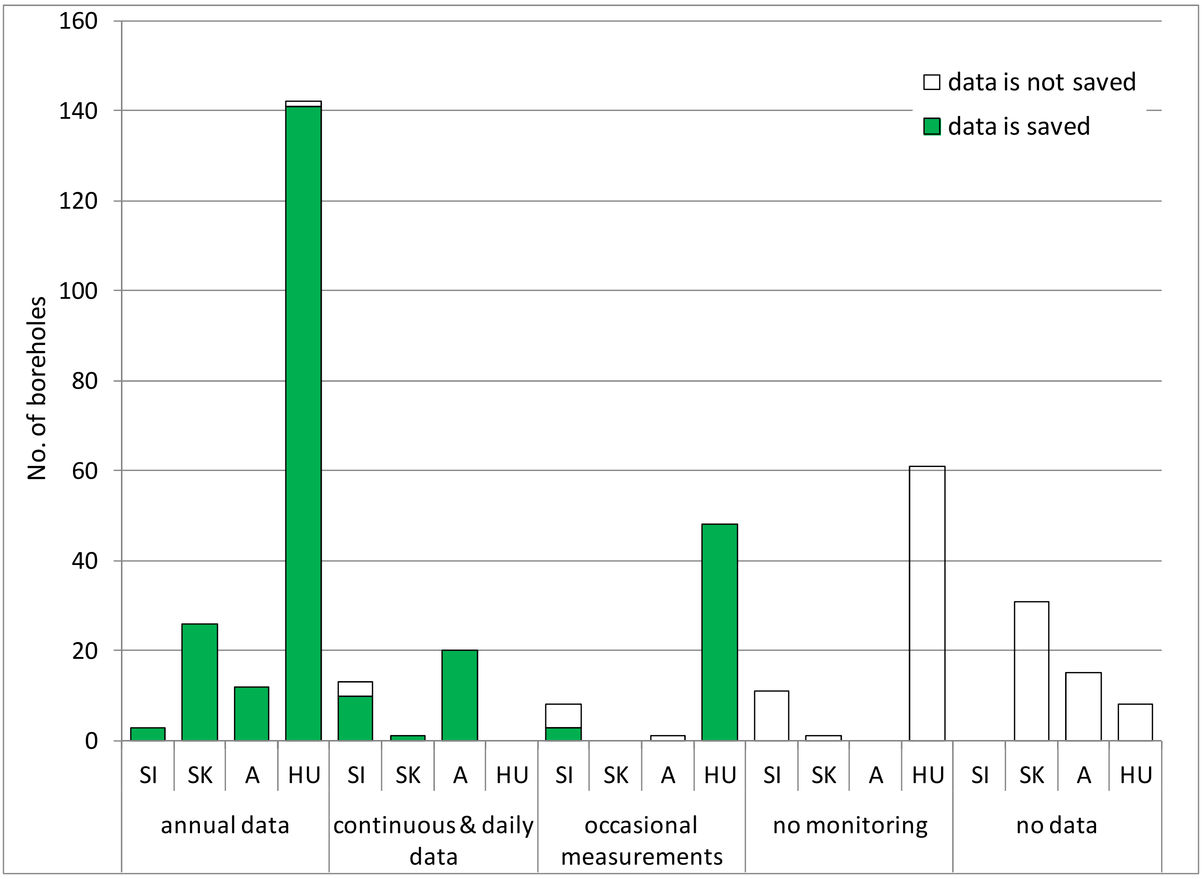

Figure 35: Applied produced water temperature operational monitoring (401 boreholes)

The **chemical composition of thermal water** (fig. 36) should behave similarly as mentioned for the temperature in the previous paragraph. If no major utilization problems occur, it is expected to stay quite constant. The regular and systematic annual chemical sampling is reported only for Hungary, while in Slovenia and Slovakia more or less random occasional measurements are predominant. In Slovenia analyses should be done in an annual basis, but this is yet not established. In Austria electrical conductivity of water is continuously monitored in many wells, while 'small' chemical analyses are usually done annually and 'large' with many parameters are done every 5 years.

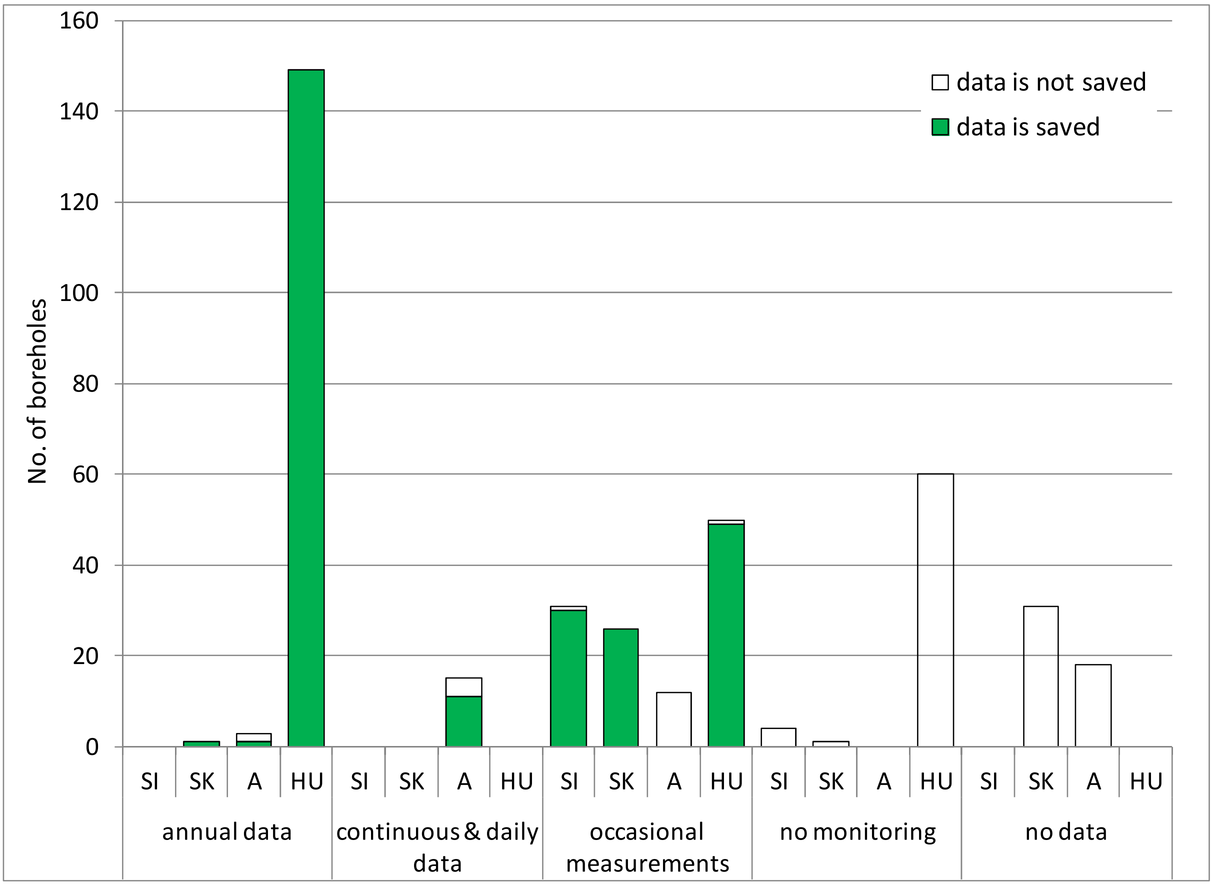

Figure 36: Applied thermal water chemical composition operational monitoring (401 boreholes)

The operational monitoring and its data storage overview indicate that there are major differences in the applied time frequencies and data storage between the countries. Still, **it is already obvious that the operational monitoring realization should be much improved in all four project countries in order to be able to get the representative and systematic thermal water utilization data.**

6. Conclusions

The geothermal energy utilization promotion is not dependent only on the political will of the energy and the water sector managing authorities but it is strongly linked to the hydrogeological conditions in the geothermal aquifers. One of the very important aims of this work package was to establish the general overview of the geothermal energy users and exploited geothermal aquifers describing their current and potential future state.

The conducted research was carried out by a unified methodology which enabled collection of the harmonized transboundary thermal water utilization data. The detailed work performed by all four project partners resulted in the establishment of a database in which all important users and their thermal water production data were gathered. These data are available on the TRANSENERGY project website or directly at http://akvamarin.geo-zs.si/users. There is a difference in the data quality and availability noticed between the project countries but the main general results of the **current utilization overview in 2011** are the following:

- 213 geothermal energy active and potential users owing 401 thermal boreholes are identified in the TRANSENERGY project area.
- 148 users with 306 active thermal water wells which operate on this area produce over 31,6 million m^3 thermal water annually (data for Austria is not available at all).
- Most of the thermal water is produced from the hydraulically very favourable Mesozoic carbonate aquifers (19 mio m^3/y). The majority of the boreholes captures the Pannonian-Pontian clastic aquifers but they are less productive (11 mio m^3/y) (data for Austria is not available).
- The density of active users by countries is: 5,5/1000 km^2 in Hungary, 3,8/1000 km^2 in Slovenia, 2,4/1000 km^2 in Slovakia and 1,1/1000 km^2 in Austria.
- The thermal water is predominantly used for bathing and swimming, followed by drinking and industrial water supply (Hungary), space and water heating, agricultural use etc. The electricity is produced only in Austria. Only 3 reinjection wells operate.
- The most common utilization problems are CO_2 and CH_4 degassing (into the air) and carbonates scaling which is mitigated mostly by the inhibitor injection.
- The changes in wells operation are evident in the Paleozoic metamorphic, Middle Miocene clastic, Pannonian-Pontian clastic and Pliocene clastic aquifers. The yield, temperature and water-level decrease are commonly reported.
- The operational monitoring is heterogeneous between the countries. The continuous monitoring of water level, quantity and temperature is applied mainly in Austria, and annually in others. The water chemistry is annually checked in Hungary, continuously in Austria and occasionally elsewhere. Most measurement data are stored and most of inactive wells do not have applied monitoring.
- The waste water monitoring is often poorly applied. The waste thermal water is emitted to the surface waters without being treated in most cases and at 95% of users its temperature exceeds 20°C.

About the **future thermal water exploitation** the following is noticed:

- 20% of the boreholes are currently inactive and can start producing almost immediately. Consequently, the annual production could increase for additional 6 million m^3.
- The reported granted or applied annual extraction quantities from water permits are at least double the current production.

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