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D.7.1.1 Summary report on the results of benchmark evaluation for the 3 pilot areas with transboundary comparison and transnational evaluation

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Contents

1. INTRODUCTION

The main aim of the DARLINGe project is to support the **enhanced and efficient use of geothermal energy** in Europe. A **benchmarking methodology** has been developed as a semi-quantifying tool which will, in the long-term, help to achieve and maintain good status of geothermal aquifers by simultaneously fostering an increase in efficiency of energy production and by promoting good examples in management of such exploitation.

Data was collected based on unified code-list to enable a rapid and transparent comparison among the six target countries: Hungary, Slovenia, Croatia, Serbia, Bosnia and Herzegovina and Romania. It enables **fast and graphical comparison of 12 different indicators** among themselves and selected entities. The used methodology is presented in the chapter Benchmarking methodology in the report D.3.1. Manual on the use of the transnational tool-box, compiled by A. Nádor in June 2018.

Based on this approach an Excel spreadsheet has been developed and is published on DRGIP under Benchmarking, Benchmarking tool. One file (Benchmarking tool example) has been filled-in and serves as an example how it should be used to make a proper automatic calculation. The second file Benchmarking tool is the one the user should download and fill-in with its own data to realize his strengths and weaknesses for further improvement and development of the site.

Within the project additional explanations had to be given to properly answer the questions for two indicators and the answers are summarized in following chapters: i) How do you evaluate the critical groundwater levels to which you have to make a statement in the benchmarking evaluation?, and ii) How do you proceed with sites where they emit waste thermal water in channels or surface streams which have either very low flow rate or are dry?

The benchmarking tool has been tested and evaluated based on detailed information gathered for **about 225 geothermal wells and springs in the southern part of the Pannonian basin**. Two types of geothermal aquifers (basin fill sediments and basement rocks) prevail there. In practice, three transboundary pilot areas were compared disregarding tapped aquifers: the Hungarian-Serbian-Romanian area, the Croatian-Hungarian-Slovenian area, and the Bosnian & Herzegovinian-Serbian area (Figure 1). The three were further divided to eight sub-parts as Hungary and Serbia had two pilots. Each part of the pilot area was evaluated with 12 indicators being grouped into four general aspects:

- **Management**: Licencing procedure, Monitoring requirements, Monitoring setup, Passive monitoring setup
- **Technology & energy**: Operational issues, Cascade use, Thermal efficiency, Utilisation efficiency
- **Environment**: Reinjection, Over-exploitation, Status of water balance assessment
- **Social**: Public awareness.

However, this summary gives an **overall evaluation** of all 12 indicators for **each pilot area jointly** and does not provide the results per individual sites. Our aim was to identify most relevant indicators:

- which show very good practice so that their experience may be transferred to other places, and

- where there are still many possibilities for improvement and might be reasonable to be included in action plans for further energy efficient development of geothermal energy use.

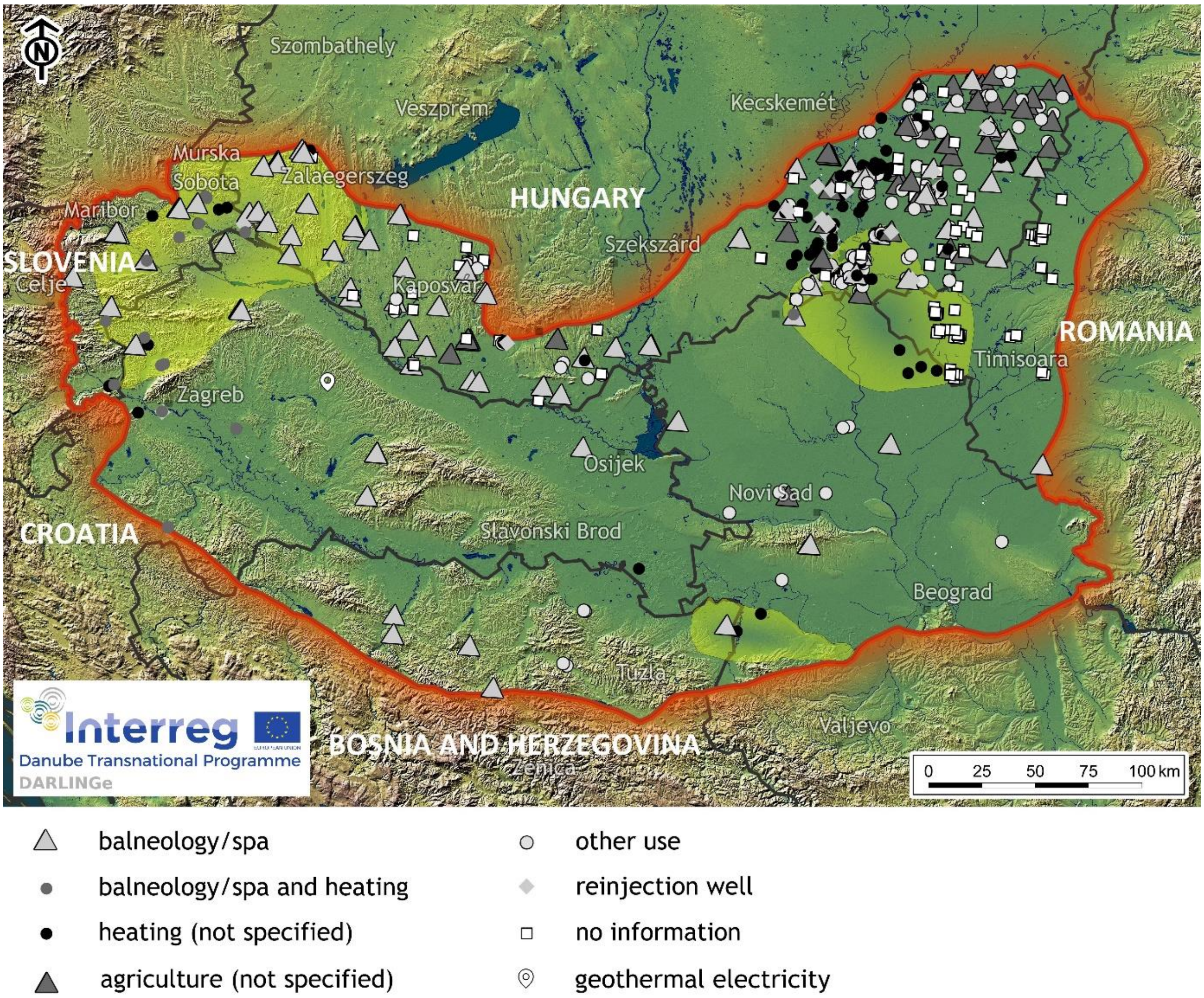


Figure 1: Three transboundary pilot areas (in yellow) with marked types of thermal water utilization

2. BENCHMARKING INDICATORS ON PILOT AREA HR-HU-SI

The westernmost, **HR-HU-SI pilot area**, has had 54 geothermal objects included in the survey (Figure 2) though hundreds of oil and gas exploration and production boreholes were drilled in the area. Nine are positioned in NW HR, from which five are wells and four are springs, all being active and tapping the carbonate basement reservoirs. In NE Slovenia, 28 wells were investigated, 21 of them being active and majority (76% of active ones) tapping the porous basin fill reservoir. In W HU, 17 active wells were included in the survey, and 82% are producing from the basin fill reservoir.

Thermal waters producing from porous basin fill sediments have the highest outflow temperatures in Slovenia, around 60 °C, so they are used for balneology and heating. There is one production-reinjection well pair in Lendava. These waters reach about 40 °C in Hungary, where they are used mainly in swimming pools, and even less in Croatia, therefore they are not used for thermal water exploitation there. Basement reservoirs are mainly carbonates, producing above 95 °C in Hungary and about 40 °C in Croatia. There is one production-reinjection well pair at Zalaegerszeg, where one-third of the produced water is reinjected.

In general, all sites show good to very good practice in **licensing procedure**, monitoring requirements and setup at the exploitation sites. All countries identified that geothermal energy use (not thermal water abstraction!) is poorly supported in official strategies and action plans, and often, the officials are undereducated in the topic. Moreover, often procedures for now investors are rather long, while in Hungary, the problem are also rapid changes of legislation and frequent reorganization of managing authorities.

Slovenia probably has the strictest **monitoring regulations**, demanding automatic, continuous and hourly recordings of water temperature, discharge rate and groundwater level, sometimes even with on-line reporting to the Environmental Agency. Croatia and Hungary can also transfer from Slovenia an example on implementation of passive monitoring of geothermal aquifers. However, national observation wells in geothermal aquifers are yet not established in Slovenia, as only a research network has been in operation since 2009 and is also used for the national Water Framework Directive reporting. Moreover, though Hungary has a well-equipped water level monitoring system and delineated thermal water bodies with a national requirement to have a minimum one observation well, none is situated on the Hungarian side of this pilot area. Still, three production wells form part of the national quality and quantity monitoring system in Zalakaros (K-8, K-14) and Lenti (B-33). There are no national/regional monitoring/observation objects in Croatia because geothermal aquifers are not delineated yet.

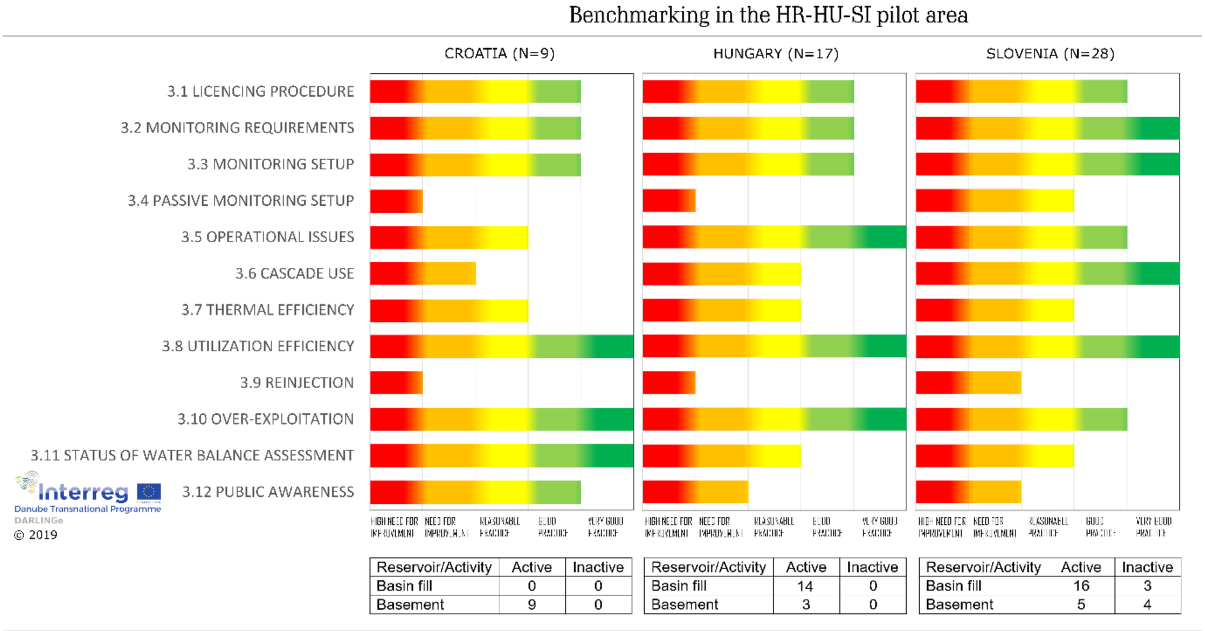
Improvements in **monitoring performance** can be targeted to automatic measurements providing quality results, permanent archiving, authorization and regional interpretation of reported data by authorities. So, all can get quality feedback of the state of aquifers and practice and are able to foresee needed measures for future.

All countries show reasonable experience in mitigating **operational issues** and **over-exploitation**. Many geothermal wells produce gases, CO_2 or CH_4, however, no usage of the gas was reported. Local operational issues stand for reduction of well's capacity either due to collapse of the open hole in carbonate rocks or clogging with silt in porous sediments, while CO_2 outbursts and consequently scaling in the pipelines occur mostly in basement reservoirs. Potential of over-exploitation is indicated only in NE Slovenia, where some trends in decreasing groundwater levels in basin fill reservoir have been recorded.

In general, all sites show very good practice in **utilization efficiency**, meaning that regionally most of granted waters is already exploited and if geothermal energy production would like to be increased, new sites will have to be developed.

Cascade use is very successful in Slovenia, also due to legislative requirements that all thermal water concessionaires will have to reach 70% thermal efficiency in the following years. All three countries have reached only moderate **thermal efficiency**, so we suggest that the first actions in the region support enhancement of energy efficiency abstraction from the already produced rates of thermal water. By installing additional heat pumps as new stages of cascade use, several tens-percent more of geothermal heat will be produced and, at the same time, thermal environmental impact will be reduced. This impact and longevity of thermal water production from the most exploited joint basin fill reservoirs can only be achieved if the whole region improves its **reinjection** indicator, which is the poorest of all indicators.

There are few geothermal visitor centres available (Dobrovnik, Renkovci, Murska Sobota) in Slovenia, and no in Croatia and Hungary. Some **public information at a user site** exist on properties of geothermal wells and springs, thermal water temperatures and chemistry and utilization but there is mostly no public information on monitoring, best available technology and operational issues. Maybe Croatia can support implementation of more reliable water balance assessment and providing greater public awareness in other two countries. Further development is possible only by more efficient dissemination of good practice and exchange of knowledge among users, authorities and investors.



Reservoir/Activity	Active	Inactive
Basin fill	0	0
Basement	9	0

Reservoir/Activity	Active	Inactive
Basin fill	14	0
Basement	3	0

Reservoir/Activity	Active	Inactive
Basin fill	16	3
Basement	5	4

Figure 2: Benchmarking indicators for all three countries in the HR-HU-SI pilot area with input data information.

3. BENCHMARKING INDICATORS ON HU-RS-RO PILOT AREA

In the **HU-RS-RO pilot area**, we evaluated that more than 170 geothermal wells from the region (Figure 3). More than 140 operate only in Hungary, and therefore it was not possible to gain information for each. Consequently, for this part the benchmark evaluation was performed as expert judgement for all wells together. To avoid potential bias, the original one-person expert opinion was cross checked, and where necessary modified based on multi-lateral consultations. In Serbia, five wells were investigated, three active ones and two inactive ones. In Romania, three active and 19 inactive wells were included. Wells in all three countries produce water from the the joint transboundary basin fill reservoir. As number of wells and applied evaluation method differ between the countries, the comparison of results is not straight forward.

All three countries show good practice in existing regulations of thermal water exploitation and licencing procedure, however, in practice, some obstacles are identified and affect the duration of procedure, such as authorities reorganisation and poor knowledge of officials on geothermal topics. Large issue which also affected our work was that most information on the licenses is **confidential**, especially in Romania. But also other countries reported that only some information are treated as public.

Monitoring requirements are quite strict in Hungary, abundant in Romania (no need for annual reporting approval) and rather loose in Serbia, both, regarding the number of parameters and no need for approval from an authority. All countries suggest that data quality check, regional interpretation and proper archiving are **needed to be implemented** in future. Groundwater assessment complies with the EU Water Framework Directive even in non-EU Serbia.

In Hungary, **monitoring setup** is good, one-third of wells automatically measures piezometric levels and abstracted quantity, about half also temperatures, and the same rate systematically performs water chemistry analyses. Additionally, manual measurements are done. In Romania, quantities, piezometric levels and water temperatures are automatically measured in active wells and occasionally, manually in inactive ones. In Serbian pilot area, only sporadic measurements are performed. In general, monitoring systems should be applied more stringently in those zones where signs of over-abstraction can be detected or predicted.

In Hungary, the basics of the national monitoring system (network of observation wells) are well organised, but the development of the system does not follow the overexploited zones. Passive monitoring in SE Hungary is considered as very good. In Serbia and Romania, it is not required nor applied.

Water chemistry is mostly not too complicated and therefore most **operational issues** are successfully mitigated, locally scaling or gas outburst occur. Especially in Hungary, several old wells have poorly maintained wellheads.

Thermal efficiency is quite high in all three cases, but it is attributed more to the quite high water temperature than to high efficiency of heat abstraction as **cascade systems** are still not applied widely enough. Cascade use of thermal water is more and more popular in Hungary, generally operating with maximum two stages. Three stages are very rare, but there are a few examples, among the case of Mórahalom. The doublet configuration of one abstraction well (B-45) and one injection well (B-46) (1270 m and 900 m, respectively) allows sustainable resource management of the 63 °C thermal water from basin fill reservoir. The annual thermal water production is around 190,000 m^3. Via a series of individual heat exchangers at each of the served buildings, thermal water is cooled down to 40 °C and additionally (FP7 Concerto project) by a heat-pump to 20 °C with additional 600 kW. Thermal waters of the Mórahalom region (and in a broader context, the south of Hungary) for every 2 m^3 of thermal water produce an average of 1 m^3 methane (annually about 95,540 m^3) which was previously released to the atmosphere. Within the Geothermal Communities project two small-scale combined heat and power (CHP) engines (4-stroke, in-line 4-cylinder engine) were installed to utilise the separated gas content which equals to roughly 89,950 m^3 CH_4/year.

One of the problems is that **EU fundings do not support combination** of different utilisation types like district heating systems, agricultural utilisation, exploiting the gas-content of thermal water or adding heat-pumps. In Serbia, the several-stage applications are still rare, while in Romania typical systems has two stages, respectively, for heating and then for domestic hot water, the waste water temperature being 35 °C. Due to favourable geological conditions, thermal water temperature is between 60 and 80 °C and used water 35 to 45 °C.

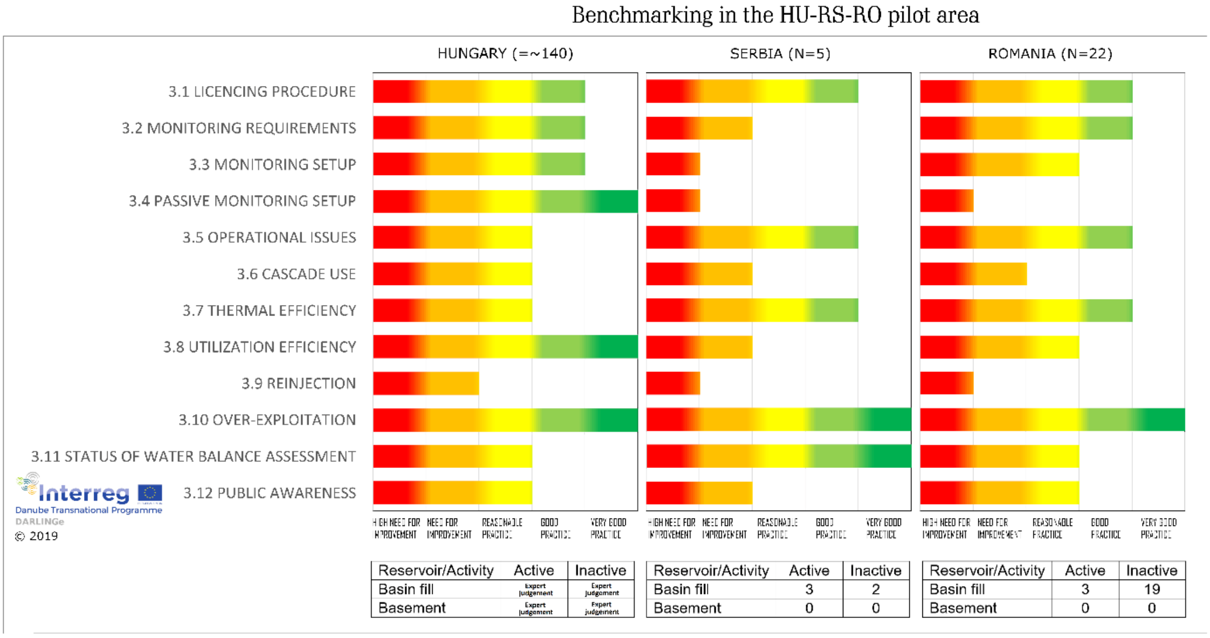
Users typically produce close to what they have in their licence in Hungary. However, we evaluated that the licensed total annual production amount is around 12 million m^3 while the actual production is around 7.6 million m^3. In the Hungarian case a “penalty fee” must be paid if less than 80% of the licenced amount of groundwater is unused. A minimum fee of 80% of the licenced amount of abstracted water has to be paid even if a much lower amount is abstracted. Abstraction above the licenced amount is forbidden and the water fee per cubic meter is double above 110% of the licenced amount. Other two countries have rather high reservations and lower actual production and therefore lower **utilization efficiency**. In Serbia, only two users abstract quantities close to the granted ones while other much less. Development is at a standstill also in Romania where lots of wells have granted permits but are inactive for several years already.

In Hungary, there is no consensus on **over-exploitation** criteria. In general, there is a trend of decreasing piezometric levels on the SE-ern part of the Great Hungarian Plain but not everywhere else. This is the largest production zone of thermal waters in Hungary, however, there is a co-effect of cold water production as well as hydrocarbon production. In some wells in Szeged, the decrease is observable, but no change was observed in water quality, minor change was observed in water temperature in a small number of wells, and in about 10% of the wells pumps had to be lowered. No over-exploitation problems are noticed in north Serbia. There is no legal consensus on the criteria for over-exploitation in Romania and no effect have been reported.

The status of water balance assessment differs among countries. In SE Hungary, the exploitable volume of water is defined by static calculations and, mostly, critical abstraction or levels are not defined. Opposite is in Serbia where renewable and available volume of water are assessed, and critical point of abstraction and critical level point are both defined. Also data is updated on the basis of actual measurements. In Romania, critical points are defined. There are evaluations of aquifer’s state performed and minor improvements can be done for **water balance assessment**, and the interpretation show good state in all three cases.

Reinjection is applied only in Hungary, but it is not obligatory by law, it depends on the decision of regional authority. Technical circumstances (such as volume) of reinjection are not supervised. There are eight to ten (about 5%) reinjection wells in the pilot area in hydraulically connected layers. Efficiency of injection is mostly between 40-60% or in a few cases 20-40%. At Serbian and Romanian part of the pilot areas, no reinjection is in operation.

There are no visitor centres in Serbia and Romana, some in Hungary. Water temperature and chemistry are especially publicly available for spas. There is no **public information** available on monitoring results, best available technology and operational issues and waste waters.
Also in this pilot area, dissemination of good practice on thermal water exploration, properties, exploitation and management should be enhanced to be able to foster faster geothermal development in future.



Reservoir/Activity	Active	Inactive
Basin fill	Expert judgement	Expert judgement
Basement	Expert judgement	Expert judgement

Reservoir/Activity	Active	Inactive
Basin fill	3	2
Basement	0	0

Reservoir/Activity	Active	Inactive
Basin fill	3	19
Basement	0	0

Figure 3: Benchmarking indicators for all three countries in the HU-RS-RO pilot area with input data information.

4. BENCHMARKING INDICATORS ON BA-RS PILOT AREA

The **BA-RS pilot area** has had only four geothermal wells available for evaluation (Figure 4), two are positioned in Bosnia and Hercegovina (Dvorovi and Slobomir) and two in Serbia (Bogatić), one of the latter was inactive at the time of evaluation. All produce from basement carbonate reservoirs. As the number of wells is very low, it is necessary to point out that the results can be treated as rather biased, or better, too dependent on a practice of a single user.

The evaluation shows that **regulations** and monitoring requirements are reasonable in both countries. In general, it is expected that adaptation of legislation related with accession process to the EU and possible reorganization of managing authority can slow down the granting procedures for geothermal. Additionally, officials are usually undereducated.

Monitoring requirements differ between the countries, but both can improve the authorization of reported data and storage in proper databases. While many parameters are reported in Bosnia and Herzegovina, only abstracted quantity and chemistry in Serbia. Practices in **monitoring application** differ much between the sites. There are no official obligations and practices on national **passive monitoring** of geothermal resources in both countries. The knowledge on the **status of water balance** is regarded enough to evaluate the quality and quantity status of these aquifers. While no over-exploitation is evident in Bosnia and Herzegovina, decrease in groundwater availability and impacts on ecosystems are observed in Serbia.

Due to low number of wells and very user-subjective approach, there is a difference in applied technology for exploitation of thermal water between the countries. Is seems to be more effective in Bosnia and Hercegovina as **cascade use** is properly applied and no operational issues are critical. In general, cascade use is not widely applied but individual good cases, also related to high outflow temperatures, make this indicator very good in Bosnia and Herzegovina and open for improvements in Serbia. In the first case, also thermal efficiency is higher and will be further improved by new cascade unit (an aqua park) while in Serbia lots of investments still need to be done to get more energy from water. Both countries report that improvements are needed in the direction of increasing **thermal efficiency**; this means that more cascades need to be applied to extract more thermal energy from thermal water, especially regarding that water temperatures are high, much over 50 °C. Also, the quantities of exploited water are below the allowed ones in permits, so further development is possible. In Bosnia and Herzegovina, wells typically produce less than in their licence. High **utilization efficiency** is related with relatively low outflow and absence of additional pumping from wells and high water need at the user site.

While in Serbia there is no **reinjection** applied, in Bosnia and Herzegovina an interesting example occurs. Used thermal water is injected in a shallow fresh water aquifer even though it is reinjection is not obligatory by law. This case effects of reinjection are not supervised, despite expected negative effects.

There are also no visitor centres available, but users are open to present their systems to interested parties. Water temperature are always available, chemistry mostly in spas, and often also utilization type. However, no information exists on waste water treatment, available technology, operational issues and monitoring results. Activities for public awareness raising are needed.

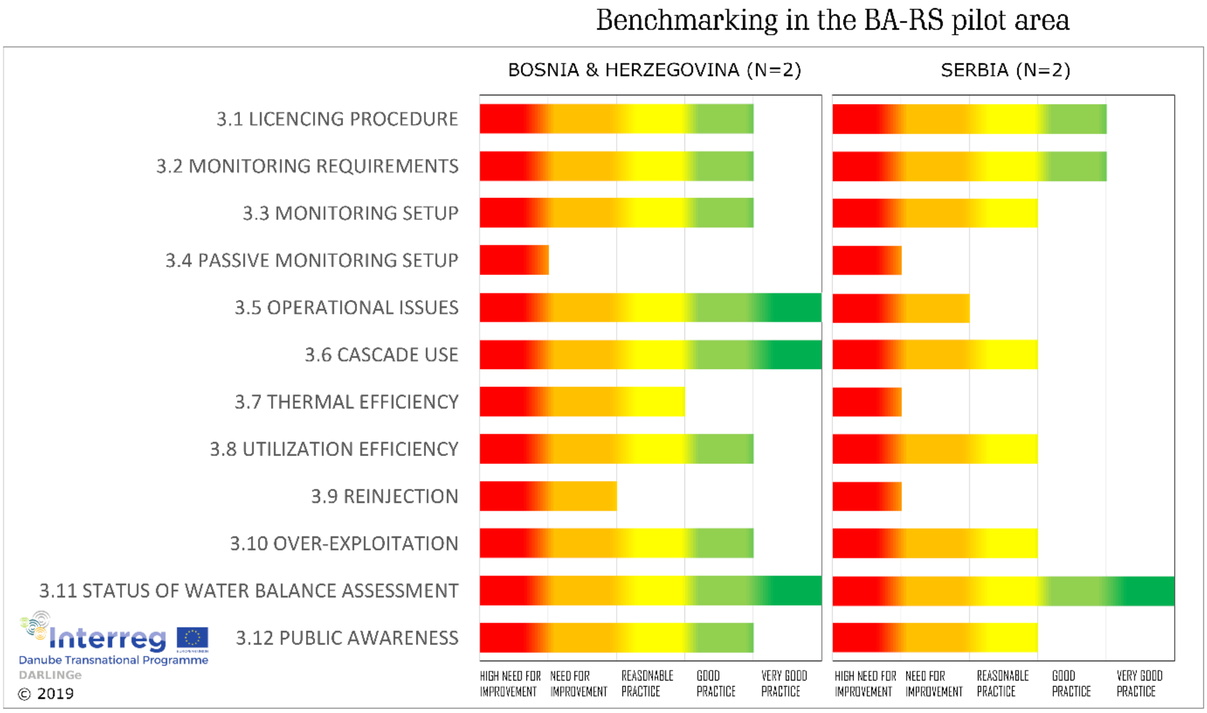


Figure 4: Benchmarking indicators for both countries in the BA-RS pilot area with input data information.

5. SUMMARY INDICATORS

According to the proposed methodology, based on individually calculated 12 indicators we summarised them into four groups:

- Management: Licencing procedure, Monitoring requirements, Monitoring setup, Passive monitoring setup
- Technology & energy: Operational issues, Cascade use, Thermal efficiency, Utilisation efficiency
- Environment: Reinjection, Over-exploitation, Status of water balance assessment
- Social: Public awareness.

And further on, they we joined per each pilot area into one sole number, the geothermal summary indicator. Knowing that results can be attributed to five classes 0 (many possibilities for improvement) to 100 (very good practice), the results of such summary indicators are presented in the text below.

Within the HR-HU-SI pilot area it is evident that management and technology&energy groups are well developed while more work needs to be done on environmental and social sides (Figure 5, Table 1). In general, the joint, geothermal summary shows good practice for Slovenia and reasonable practice in other two countries.

Table 1: Summary indicators for the HR-HU-SI pilot area in classes

	NW Croatia		**NE Slovenia**		**SW Hungary**	
Indicator	**Points**	**Class**	**Points**	**Class**	**Points**	**Class**
IMAN	16,9	**75**	21,9	**100**	18,1	**75**
IT&E	13,1	**50**	20,0	**75**	16,3	**75**
IENV	20,0	**50**	17,5	**50**	16,7	**0**
ISOC	6,2	**75**	2,4	**25**	3,8	**25**

IGEO	***15,0***	***50***	***17,5***	***75***	***11,9***	***50***

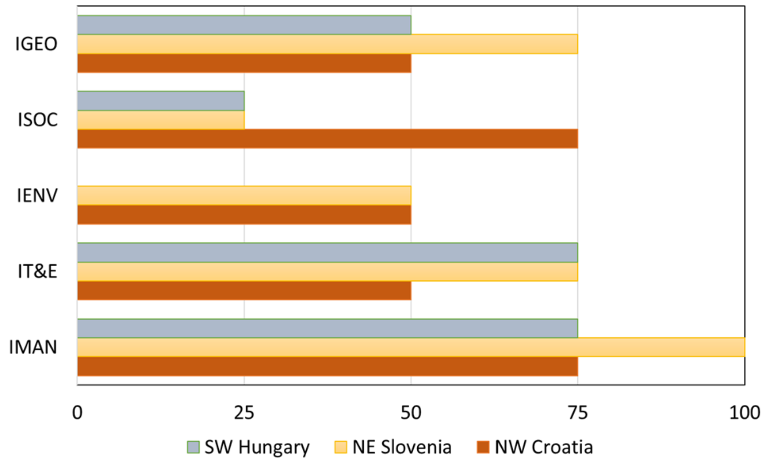


Figure 5: Summary indicators for the HR-HU-SI pilot area

Within the HU-RS-RO pilot area it is evident that management group is most developed, while technology&energy and environment are equal (Figure 6, Table 2). In general, the joint, geothermal summary shows good practice for Romania, reasonable for Hungary and with some need for improvement in Serbia.

Table 2: Summary indicators for the HU-RS-RO pilot area in classes

	SE Hungary		**W Romania**		**N Serbia**	
Indicator	**Points**	**Class**	**Points**	**Class**	**Points**	**Class**
IMAN	18,1	**75**	20,6	**100**	6,9	**25**
IT&E	13,8	**50**	17,5	**75**	12,5	**50**
IENV	15,8	**50**	18,3	**50**	20	**50**
ISOC	0,8	**0**	6,0	**50**	3	**25**
IGEO	**13,1**	**50**	**18,3**	**75**	**10**	**25**

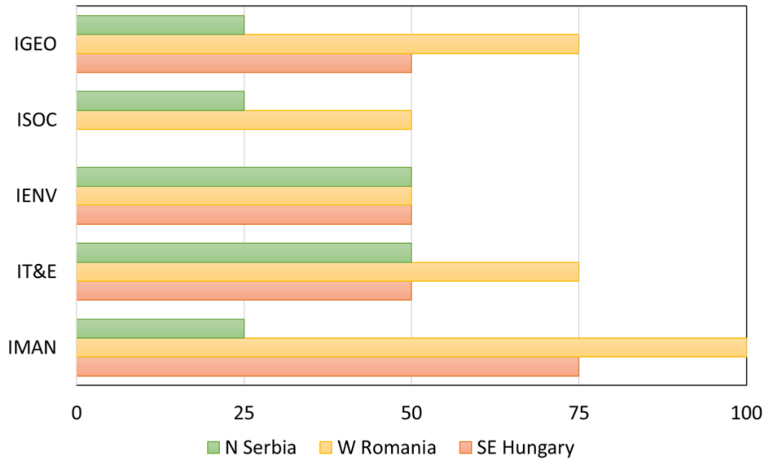


Figure 6: Summary indicators for the HU-RS-RO pilot area

Within the BA-RS pilot area it is evident that Bosnia and Hercegovina has good practice in all aspects while Serbia indicates need for further improvements (Figure 7, Table 3). This is valid also for the general, geothermal summary indicator.

Table 3: Summary indicators for the BA-RS pilot area in classes

	N BiH		S Serbia	
Indicator	**Points**	**Class**	**Points**	**Class**
IMAN	16,9	**75**	14,4	**50**
IT&E	20,0	**75**	7,5	**25**
IENV	23,3	**75**	11,7	**25**
ISOC	6,5	**75**	5,5	**50**
IGEO	**18,8**	**75**	**8,8**	**25**

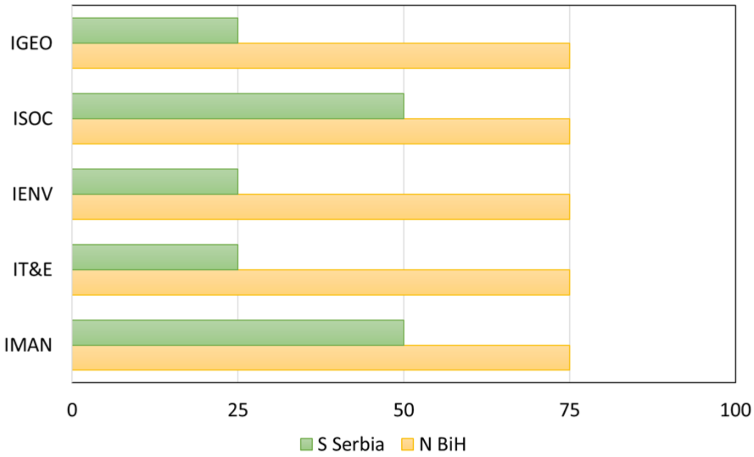


Figure 7: Summary indicators for the BA-RS pilot area

Comparing the three pilot areas and their four summary indicators together, we receive very general evaluation. All have good management (rules and regulation), most reasonable technology& energy and environmental indicators, while social one is really poorer (Figure 8, Table 4). The geothermal summary points out the best management practice in HR-HU-SI pilot area, which is also economically best developed, and the same, medium value for the other two pilots.

Table 4: Summary indicators for the three pilot areas in classes

	HR-HU-SI		HU-RS-RO		BA-RS	
Indicator	**Points**	**Class**	**Points**	**Class**	**Points**	**Class**
IMAN	20,0	**75**	18,1	**75**	15,6	**75**
IT&E	17,8	**75**	14,4	**50**	13,8	**50**
IENV	17,5	**50**	16,4	**50**	17,5	**50**
ISOC	3,4	**25**	1,8	**0**	6,0	**50**
IGEO	**15,6**	**75**	**13,1**	**50**	**14,4**	**50**

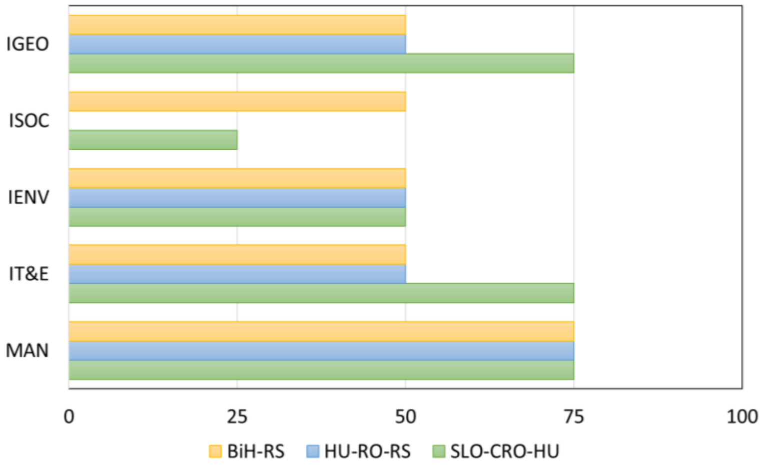


Figure 8: Summary indicators for all three pilot areas together

During work on this project, we often discussed that there are many obstacles which have to be overcome to finally start developing geothermal energy use is a proper manner, compatible to the huge potential of the Pannonian basin. But regarding these summary indicators, one gets an impression that management/legislative aspects are very well developed (mostly they are, just the actual implementation is poor), technology is successfully applied, there are no environmental issues. Only authorities and general public should get more acquainted with geothermal topics, and then the development will take off.

In reality, this is not the case as shown by SWOT analysis and the individual 12 indicators in this report. Therefore, we have concluded that the summary indicators over-generalise the situation and cannot be used as a supporting tool to develop targeted and pilot area specific action plan. We will rather use the content-more-informative individual 12 indicators instead.

6. ADDITIONAL EXPLANATIONS REGARDING EVALUATION OF THE CRITICAL GROUNDWATER LEVELS

Most countries provided answers to the question: How do you evaluate the critical groundwater levels to which you have to make a statement in the benchmarking evaluation?

In **Federation of Bosnia and Herzegovina and Republic of Srpska**, the critical pumping point is defined based on long term pumping tests. There are two criteria: quantity (ratio of pumping rate and drawdown) and chemical and physical water properties related with appropriate pumping rate. E.g. allowed drawdown could be acceptable but if the chemistry and physical properties are not acceptable, the pumping rate is considered as one beneath the critical level. In GD-2 Slobomir case, pumping rate of 44 l/s increase content of sand and water turbidity (endanger pumps and heat exchangers functionality) even though here is acceptable well drawdown. Maximal pumping rate adjusted to provide both, quality and quantity correctness, and proven by long term pumping test, is 40 l/s.

In **Croatia,** the critical pumping point is defined based on long term pumping tests. The quantity criteria - ratio of pumping rate and drawdown are only one that is defining the critical point. When steady state is disturbed, the critical pumping point is reached out.

In **Hungary**, critical groundwater levels are not defined in general. They were modelled and defined within the T-JAM project for the W part of the country. A good example are the critical yield and temperature which were defined for the Lake Hévíz area by hydrodynamic modelling. If the yield of the lake is less than 390 l/s for a longer lasting period in two consecutive years, then the abstractions from thermal wells which are in the recharge area of Lake Hévíz have to be reduced by 10%. Such criteria, which might be critical levels or critical yields/production were introduced in the 2019/2004 Governmental Decree and are supposed to be defined in the future within the framework of the quantity limit definitions for groundwater bodies connected to the River Basin Management planning.

In **Romania**, there are no situations where wells need pumping in the pilot area. The wells are exploited only artesian, avoiding the hydraulic shock by the sudden opening of the wells at maximum flow rates. The increase of flow rates is progressively achieved, in order to avoid carrying away of sand from the reservoir, because this leads to silting of the wells. However, when it is necessary to exploit higher flows, the critical pumping point shall be determined based of long-term pumping tests, without exceeding the allowable speed entry of the water in the screens, otherwise this could lead to the carrying away of sand from the productive layers. On the other hand, the maximum allowable flow should not determine the increase with more than 1% the sand content in water. By some information, the critical point is defined as a decrease in the artesian flow with approximately 15% after cold periods and intensive exploitation. This is not the case now, when the regional exploitation is at a low level.

In **Slovenia**, the critical groundwater levels have to be determined in the operational monitoring programs and annual reporting documents, published by the Slovenian Environmental Agency. It is a hydrogeological parameter which is, in practice, usually determined per an individual geothermal object as a groundwater level in m a.s.l. and/or a flow rate which is used to reach this level. Both are usually determined by long-term pumping tests (30 days or until a new quasy-equilibrium at a given pumping rate is reached when the quantity and quality of groundwater are stable and acceptable). New statistical methods are also being tested lately and might propose better approach in future. Reaching this level, the user should first inspect the well, usually by step tests, to determine whether its technical conditions have changed, and it might need revitalization. If not, he should undertake mitigation measures to prevent further deterioration of the aquifer's state.

7. ADDITIONAL EXPLANATIONS REGARDING USED THERMAL WATER EMISSIONS TO CHANNELS WITH VERY LOW FLOW RATE

Most countries answered the question: How do you proceed with sites where they emit used/waste thermal water in channels or surface streams which have either very low flow rate or are even dry.

In **Federation of Bosnia and Herzegovina**, the conditions of wastewater discharge into the environment and the public sewage system are defined by the Decree on the conditions of wastewater discharge into the environment and public sewerage systems (Official Gazette of the Federation of Bosnia and Herzegovina, No.101/15, 1/16 and 101/18): If technologic waste water is not discharged into a public sewage system, i.e., if they are discharged or planned to be discharged into the environment, then users have to purify their waste water (for your money) and thus purified water can be released into the environment in compliance with the limit values prescribed by the Decree. This Decree sets limit values for wastewater discharge in 1) surface water bodies and 2) public sewage system. In the Banja Dvorovi (well S-1), waters that are used for heating of buildings and balneology are discharged in the sewage system. The water used for recreation in open-air swimming pools is discharged into the sinking pit. The waters in Slobomir (well GD-2) after use are discharged into a shallow well at alluvial aquifers. Water discharges into the dry streams are not mentioned in the regulations, therefore the limitations are only the parameters of the discharged water which must not exceed the prescribed values:

e.g. the water temperature must not exceed 30 ° C if the water is discharged into the surface water bodies. For discharge into the sewerage system, the limit value is 40 ° C. The reinjection obligation does not exist in BiH, nor have any regulation referring to reinjection.

In the **Republic of Srpska**, waste water is discharged into surface waters in accordance with the Rulebook on Waste Water Discharge in Surface Water (Official Gazette of Republika Srpska, No 44/01) - hereinafter Rulebook. The Rulebook or any other regulation does not regulate the discharge of waste water into sinking pit (upojna jama), dry surface stream, channel or reinjection well. So, the discharge of waste water into the sinking pit in Dvorovi and the shallow well in Slobomir are not in accordance with the regulations of the Republic of Srpska. According to the Rulebook (Art. 9), discharge of waste water into the water stream must be such to ensure complete mixing of waste water and stream water (recipient) in the shortest length, which should not be longer than 500 m. Therefore, the waste water and the water of recipient must be completely mixed in length of 500 m. The conditions that should be fulfilled in case of waste water discharge in surface water are following (Art. 10): i) Waste water quality must be within the permitted limits of concentrations according to the Rulebook, ii) The water quality of the recipient, after complete mixing with waste water, i.e. 500 m from the waste water discharge site, must be below the limits prescribed by the Decree on Water Classification and Classification of water stream. If one of these two requirements are not fulfilled, it is considered that the conditions for discharging waste water into the surface water are not provided. The conditions for the discharge of waste into the sewage system are under Rulebook on the conditions of waste water discharge into public sewerage (Official Gazette of Republic of Srpska, no. 44/01). The criteria for waste water temperatures in the Republic of Srpska are the same as in the Federation of Bosnia and Herzegovina: $t \leq 30$ °C if the water is discharged into the surface water and $t \leq 40$ °C for discharging into the sewerage system.

In **Croatia**, according to the Water act OG 153/09, 130/11, 53/13 and 14/14 and regulation on the limited values of wastewater emissions OG 80/13, 43/14, 27/15, 3/16, the emitted waste thermal water not directly defined, so you have big empty space for manoeuvre. It is only obligatory that the emitted waste thermal water must be below 30 °C and in the case of releasing wastewater during the production of heat and electricity and if the thermal water is used for balneology purposes, (swimming pools) it is obligatory to purify and then emit it. In addition, in the case when you have dry stream or melioration channel, you can emit purified clean water.

In **Hungary**, the regulation of waste/used thermal water is based on the 220/2004 (VII:21.) Government Decree and on the 28/2004. (XII. 25.) ministerial decree which sets the technology limits. Emission data are collected by the water authorities during their official inspection of waste water dischargers (based on their water/environmental permits). These data come partly from the authority laboratories' own control measurements, and partly (basically) from the self-monitoring data of users. Self-monitoring is legally binding for dischargers, while emission data are collected by the "VAL/VÉL" data collection system. However, as authorities should improve the capacity to enforce the requirements of the legislation its implementation is not uniform. Theoretically waste thermal water has to be below 30 °C and water chemistry also has to fulfil the criteria established by this decree. According to the 31/2004 ministerial decree the state implements a WFD surface monitoring network/programme where the impacts of the emissions are controlled. The WFD monitoring is representative for both the temporary and the other (natural and artificial) river water bodies, but the density/frequency of the monitoring should be improved. In the Great Hungarian Plain for example, usually the discharge into the River Tisza is checked, which has a large enough yield not to register thermal effects in it. Sometimes smaller channels and streams are also checked. It is a common practice that waste thermal water is first released into an "artificial thermal lake" and stored it there until it cools down (eg.

if it is from district heating, then it is stored until the end of the heating season in spring), and the cooled thermal water is released into the rivers through channels.

In **Romania**, there are no situations of discharging geothermal waste waters in dry channels. Such channels belong to the owners of the respective land or local administrations (Norm of 28 February 2002, published in the Official Monitor of 20 March 2002). Discharge in these channels is not subject to the regulations of the National Water Administration (Apele Române). However, from the point of view of environmental regulations, waters with highly polluting physico-chemical characteristics, containing hazardous substances, with high salinity or high temperatures, cannot be discharged. All of them are well regulated and controlled. The conditions in which geothermal waste water can be discharged shall be determined and imposed since the beginning by the environmental permit, without which the objective cannot function. The fines are also quite high if the inspectors find that the conditions imposed by the laws and permits in force are not met.

In **Slovenia,** waste thermal water is managed by the Decree on the emission of substances and heat in the discharge of wastewater into waters and public sewage system (Off. Gaz. RS No 47/05, 45/07, 79/09 and 64/12). It defines that environmental permit should be granted for emissions, defining also monitoring procedures, threshold values for chemical parameters and temperature. There are several restrictions for emissions: waste water temperature should be below 30 °C when emitted to surface or groundwaters and below 40 °C when released to public sewage system, and moreover, pH, metals, chloride, sulphate, organic compounds etc. have defined mass balance limits which should not be exceeded annually. When surface and thermal waste waters mix, the mixture should be less than 3 degrees warmer that the stream above the emission, so the stream flow rate is an important parameter also. Thermal water used in swimming pools is usually transported to purifying plants before emitted into the environment which water used only for heat abstraction is usually emitted to channels without any chemical processing. In practice, most users in NE Slovenia emit waste thermal water into intermittent streams as large rivers are far away. Currently, solutions are being searched for how to deal with this in future. The debate is focused on several possibilities: i) to build a pipeline to the closest permanent stream or a river with sufficient flow rate to emit waste thermal water; ii) to seek a permit for infiltration of this water into the intermittent channel or an infiltration pond, iii) to make a reinjection well. All solutions are rather expensive.

9. CASE STUDY OF A WASTE THERMAL WATER IMPACT IN CROATIA

In all six partner countries it is common that waste thermal water is not reinjected back into the aquifer but is rather emitted to surface waters or ponds. In practice, actions at the sites very rarely completely comply with regulations, and therefore the Croatian partner investigated if and to what extent the mineralization and temperature of used/waste thermal water can affect the environment.

In Croatia, regulation that considers chemical monitoring of the waste thermal water does not exist. However, according the general Regulation on the limit values of wastewater emissions (OG 80/13, 43/14, 27/15, 3/16), in a case of releasing waste water from production of heat and electricity and if thermal water is used for balneology purposes (swimming pools), it is obligatory to do monitoring. Chemical monitoring consists of organic parameters, inorganic parameters (metals+nutrients etc), pH, temperature, colour, odour, suspended matter etc. and microbiological parameters, if the pool waters are considered. Moreover, it is obligatory that the waste thermal water temperature before it is released into recipient is below 30 °C. If thermal water is used in swimming pools, waste thermal water should be chemically treated before it is released.

The experiment was carried out in December 2018 at Tuheljske Toplice site. The basement aquifer is formed by carbonate rocks and the chemical composition of thermal water is a typical Ca-Mg-HCO_3 water which is quite like shallower groundwaters. So, this represents a more optimistic scenario with lower impact on chemical conditions of the streams.

The colder month was pick up because during the warmer periods of the year additional warming up of surface waters appears due to insolation and the influence of thermal water is not visible. Thermal springs at the site are forming the Toplica stream that is confluent of the Horvatska stream. Physical and physico – chemical properties of waters were measured in springs, Toplica stream near springs, Toplica stream after the waste thermal water plant, Horvatska stream upstream and downstream of confluence Toplica stream (Figure 9).

Figure 9: Sampling points: 1- thermal springs; 2 - Toplica stream near springs; 3 – Toplica stream after waste thermal water plant; 4 – Horvatska stream upstream; 5 – Horvatska stream – downstream

It was observed that electrical conductivity (EC) values of springs and stream Toplica were very similar in the range from 604 to 629 µS/cm (Figure 10) and there was no huge difference between stream water near the springs and after waste thermal water plant. EC values in Horvatska stream (both sampling points) were higher in compare with previous one. At the downstream sampling point, the water from Horvatska stream is slightly diluted. The highest temperatures was measured at springs 31 °C, then in stream Toplica near the springs 24.5 °C, and at the point after waste thermal water plant as 23.3 °C. The water temperature at the upstream point in Horvatska stream was 3 °C and at the downstream point 10 °C. However, this effect of heating up was lost in couple hundred meters downstream due to higher amount of water in Horvatska stream.

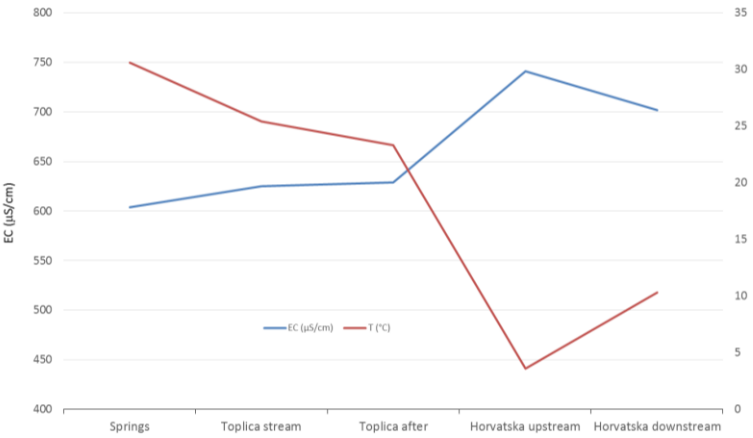


Figure 10: Electrical conductivity (EC) and temperature of sampled waters

The lowest pH was measured in spring water (Figure 11) and it was observed a slight influence of lowering the pH in the stream water of Horvatska in the downstream sampling point. In addition, the dissolved oxygen content is the lowest in spring water and high dissolved oxygen content is observed in all sampling points in streams.

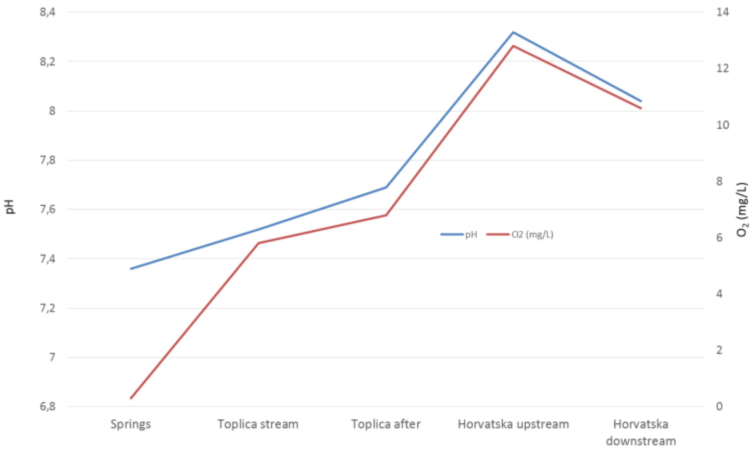


Figure 11: pH-values and dissolved oxygen content of sampled waters

Total inorganic carbon (TIC) content in spring and Toplica stream was very similar (Figure 12), only total organic carbon (TOC) content was slightly higher in Toplica stream. Nevertheless, the highest TOC and TIC values are measured in the water sampled at the Horvatska upstream. Due to dilution, TIC and TOC values were slightly lowered at the Horvatska downstream.

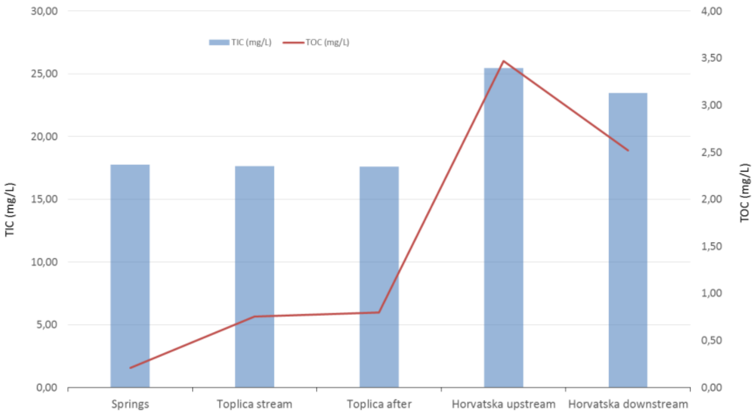


Figure 12: Total inorganic and organic carbon content in sampled waters

Temperature impact was observed on the secondary stream at the place where Toplica stream flows into Horvatska stream. But, even a positive effect on stream quality was observed. The water in Horvatska steam is under great anthropogenic pressure with high concentrations of nutrients, such as phosphate, nitrite, ammonium, total nitrogen etc. Only phosphate and chloride are presented here (Figure 13) because nutritive elements in spring and Toplica stream were below detection limit of the instrument. It is observed that the water from Toplica stream has positive effect on quality of stream waters (nutrients, TOC and mineralization) of otherwise rather polluted Horvatska stream. In addition, frogs and fish were observed in the Toplica stream but not in Horvatska stream.

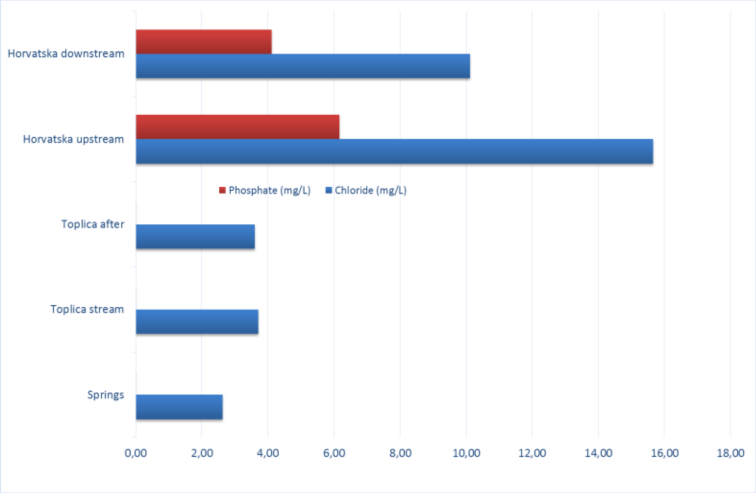


Figure 13: Chloride and phosphate contestations in sampled waters

10. SUMMARY OF RESULTS

Eight sub-regions within three transboundary pilot areas were investigated in the southern part of the Pannonian basin. The westernmost, **HR-HU-SI pilot area**, has had 54 geothermal objects included in the survey, mostly tapping joint porous basin fill reservoir. In the **HU-RS-RO pilot area**, more than 170 geothermal wells were evaluated. More than 140 operate only in Hungary and were accounted for based on expert judgement. All produce water from the joint transboundary basin fill reservoir. The **BA-RS pilot area** has had only four geothermal wells available for evaluation, all producing from basement carbonate reservoirs.

In order to get most up-to-date information, field visits were performed where possible in 2018. To harmonize the evaluation, we had several joint discussions on the methodology. The latest version is incorporated into the Benchmarking tool, Excel spreadsheet with automatic calculation of indicators based on given answers, which is available at Benchmarking chapter on the DRGIP portal.

Individual 12 indicators were calculated from well- and site- specific information at all eight sub-regions. This was supplemented by four summary indicators on management, technology&energy, environment and social approach, and summed up to a joint summary geothermal indicator at the end. However, this approach was found out to be too general to use benchmarking as a supporting tool to develop targeted and pilot area-specific action plans. Therefore, we rather used the original 12 indicators instead.

The overview indicates that future activities should regionally support:

- **Implementation** of quite good regulative and legislation procedures **into practice**.
- **Open information** on granted concessions to the public as much as possible (location, water quantity, water properties, ...)
- **Harmonization** of monitoring setup which controls all hydraulically relevant parameters (groundwater levels, quantities, water temperature and chemistry) and technical conditions of the wells.
- All users should be obliged to **report** monitoring results to an authority which should authorize it, prepare regional interpretations of the state (also for WFD) and store/archive the data properly.
- Implementation of passive monitoring in regionally or **transboundary important** geothermal reservoirs.
- Quantity of abstracted water is close to the permitted amounts in several regions so further geothermal development will have to be founded on **new exploitation sites** there.
- Operational issues are only local and many good examples for their mitigation can be found in the Pannonian basin region.
- Over-exploitation effects are only of a local character at the moment, but to keep it so,
- **Reinjection systems** will have to be much widely applied when talking only about heat production, especially in transboundary basin fill reservoirs.

- **Increase of thermal efficiency** is a simple technological solution to produce more energy with the same rate of thermal water production. This can be achieved by
- Fostering application of **cascade use** by at least three stages, by installing additional heat pumps and similar technologies.
- A serious approach to developing **education materials and social skills** to promote geothermal. Insufficient public data are available at general-public websites and user-site promotion materials, and even authorities and investors have rather poor knowledge and information on characteristics of geothermal energy technology use, possible environmental impacts and the need for intersectoral cooperation to be able to foster faster geothermal development in future.