Proceedings World Geothermal Congress 2023
Beijing, China, September 15 - 17, 2023

Geothermal Energy Use – Country Update for Slovakia (2019 – 2022)

Branislav Fričovský[1], Radovan Černák[1], Klement Fordinál[2], Katarína Benková[1], Ondrej Pelech[3] and Daniel Marcin[1]

1) Dept. of Hydrogeology and geothermal energy, Dionýz Štúr State institute of Geology, Mlynská dolina 1, Bratislava, Slovakia
2) Dept. of Younger geological units, Dionýz Štúr State institute of Geology, Mlynská dolina 1, Bratislava, Slovakia
3) Dept. of Old geological units, Dionýz Štúr State institute of Geology, Mlynská dolina 1, Bratislava, Slovakia

branislav.fricovsky@geology.sk, radovan.cernak@geology.sk, daniel.marcin@geology.sk

Keywords: geothermal energy, geothermal potential, Slovakia, geothermal water body, direct use, geothermal development

ABSTRACT

Geothermal energy use in Slovakia experiences long tradition regarding especially balneotherapeutical or recreation purposes. In past, most of exploration and drilling was made by the state, and later switching to exclusively private investors since early 90's. Focus for direct uses resulted in a systematic geothermal exploration and prospection, identifying low-enthalpy water-dominated reservoirs at the most. Recent statistics carried out for the WGC2023, record similar features when compared to previous. The data show 283 wells proving almost 441 MWt of geothermal reserves. A total number of 122 wells yields the installed capacity of 233 MWt. Recreation – i.e. direct use of thermal waters in pools or use of geothermal water to heat a secondary pooling loop-- prevails in all characteristics: 49 wells, 41 sites, almost 97 MWt installed capacity delivering 572 TJ of heat – yet considering only wells where recreation is a primary stage of cascades. A relatively low load/capacity factor, i.e. 0.2 / 0.26, is due to many resorts were designed open-air, i.e. clearly depending on yearly seasons. The geothermal district heating is still used in 4 towns – Galanta, Šaľa, Veľký Meder and Sereď. Hybrid systems involving natural gas boilers share 35 to 99 % on a total heat delivery, i.e. produced 221 TJ from 5 wells of total installed capacity of aproximately 21 MWt. There are, however, two projects being prioritized – the GDHS for the city of Košice using wells at the Ďurkov site (3 wells now, more in consideration) and the GDHS for the city of Kežmarok, where a new well was completed in 2022 now at a testing stage. With individual heating that takes part as primary stage at 10 sites (i.e. 33.4 MWt installed capacity, aproximately 290 TJ heat produced), the heating is still beyond recreation, however, yielding higher LF/CF due to relatively stable operation. Agriculture and fish-farming is operated as primary use on 11 sites, out of which two (Turčianske Teplice, Vrbov) serve the later. Plans to introduce first binary units for power production (CHP-type) are still in consideration, especially at the Žiar Basin and the Košice Basin by the PW Energy.

1. INTRODUCTION

The International Energy Agency (IEA) data as of 2020 - 2021 still rank Slovakia as a fossil-fuels dominated economy with their 60 % share on primary energy mix. In power production, the nuclear shares ~53% followed by renewables (25%) of which hydropower gets the highest contribution (16%) – however, there is no any geothermal power plant in operation yet. Regarding the heat production, fossil fuels represent still almost 73%, with the natural gas claiming lead with 50% share, while renewables yield 21% in cumulative – including biomass (17 %) and geothermal energy (1 %).

Despite obviously low shares of geothermal, tradition of its use dates far back beyond Medieval with dozens of warm and thermal-healing springs in the country, so that first written mentions on spas exist since 17th to 18th Centuries, whilst first well installed to tap thermal waters is documented as of 1899 in the Kováčová spas (the Zvolenská kotlina Basin), serving nobility. The systematic research and prospection on deep geothermal resources followed late in 70's to help answering global fuel economy concerns. Recent national datasets record 283 wells proving the presence of geothermal resources, however, only ~25 were installed after 2004. Such a low number of recent wells can be a consequence of the transition in drilling investments, from exclusively governmental investments up to 1989, to exclusively by the private sector in the last years. However, important changes can be expected in the country, due both to the EU environmental policies and to internal economy challenges in Slovakia. The reassumption of activities of the Association of Geothermal Energy of Slovakia in 2022, is also expected to contribute to accelerate the geothermal development.

Geothermal resources are adjusted to 31 geothermal water bodies according to the Water Framework Directive No. 2006/60/EC of the EU Parliament and the Council (WFD). Majority of proven geothermal resources are single-phase geothermal water, with only a few wetsteam mixtures. Something similar is expected for reservoirs not yet drilled, but there are localities where a wetsteam contribution may be higher, still probably at not sufficient rate for effective separation, while double-phase or vapor-dominated resources are just unlikely. Besides the general consensus on prevailing direct-use potential of geothermal resources in the country, limited options on binary power productions still exist. Meanwhile, all 77 online sites are exclusively for direct-use.

2. GEOLOGICAL AND HYDROGEOTHERMAL CHARACTERISTICS

2.1 Regional geology overview

Regional geological settings of Slovakia refer to its geotectonic evolution and recent position as part of the Variscan to Alpine orogeny that formed Western Carpathians – WCs realm (e.g., Schmid et al., 2006; Plašienka, 2018). In recent arrangements, the WCs consist of the External – EWCs, thin-skinned nappes dominating syn-orogenic turbiditic deposits forming the Flysch Belt-- and the Internal (or Inner) – IWCs, i.e., a territory of Paleozoic to Neogene basin and range morphological structures accompanied with Neogene volcanism. The Pieniny Klippen Belt that separates both parts represents remnants of a complex shear zone composed of solid Mesozoic carbonates enveloped with progressively weathering, typically flysch-like siliciclastics.

The IWCs contribute with vast majority of identified geothermal resources. A generalized vertical profile begins with crystalline bedrock of thick-skinned Early – Mid Paleozoic nappes (plutonic and metamorphic complexes) and Late Paleozoic – Mid Cretaceous thin-skinned nappe series. The latter begins with usually Paleozoic metasilicates and siliciclastics and rare volcanics, Early Triassic siliciclastics (sandstones, quartzites, shales), Mid – Triassic carbonates, Late Triassic pelitic carbonates and claystones, and Jurassic to Mid Cretaceous pelitic carbonates, organogenic limestones, marlstones, etc. Atop, Central Carpathian Paleogene Basin (transition from basal conglomerates and detritic carbonates to claystone, flysch-type and sandstone dominated formations) covers transgressively the pre-Cenozoic relief. The Miocene – Quaternary sediments of the Pannonian basin system reach particularly large thickness in the Vienna, Danube and East Slovak basins, as product of different depositional environments (continental to marine) developed through the realm of the IWCs. Neovolcanites of Miocene – Pliocene age are substantial to Miocene extension, producing volcanoclastics and flow products as part of Neogene basin fillings in the Inner Western Carpathians. Quaternary cover is exclusively terrestrial, with only rare fresh-water travertines.

2.2 Regional hydrogeothermics

2.2.1 Geothermal field and activity

In general, the geothermal field of the Western Carpathians is controlled by: (1) different structure and depths of neotectonic blocks with an increase in crustal thickness; (2) non-uniform mantle propagation; (3) spatial distribution of Neogene – Quaternary volcanism; (4) local and regional hydrogeological conditions; and (5) course and depth-seating of major crustal fault systems (Fendek et al., 1999; Franko & Melioris, 1999).

The surface heat flow density varies from 50 to 120 $mW.m^{-2}$ with a mean of 82.1 ± 20 $mW.m^{-2}$ (Bodiš et al., 2018). Projection (Figure 1) outlines local highs within the Eastern Slovakian Neogene Basin (90-130 $mW.m^{-2}$) and the Danube Basin Central Depression (> 90 $mW.m^{-2}$), with obvious northward trend of its decrease to the intramountain depressions (40-70 $mW.m^{-2}$), whilst regional minima (30-50 $mW.m^{-2}$) are recorded from the Flysch Belt (Marcin et al., 2014; Majcin et al., 2017). Apparently, the heat flow is rather controlled by variation in crustal thickness (reduced in Neogene sedimentary basins), while volcanics contribute with enriching a shallow crust with sources of radioactive decay heat, rather than heat from active magmatism / volcanism. The only exception is the buried Beša – Čičarovce – Malcov volcanic system in northern part of the Trebišov Basin.

2.2.2 Geothermal play-typing

Geothermal resources in the WCs are thus associated with conduction-dominated foreland-basin / orogenic belt-type geothermal plays, i.e., CD2 (Moeck, 2014). However, the Beša – Čičarovce system fits either convection-dominated magmatic intrusion (CV2) or extensional domain (CV3) type (Moeck and Beardsmore, 2014; Fričovský et al., 2016). To limit most of generalizations, a proposal on sub-typing (Fričovský et al., 2019) has already been reported (Table 1)

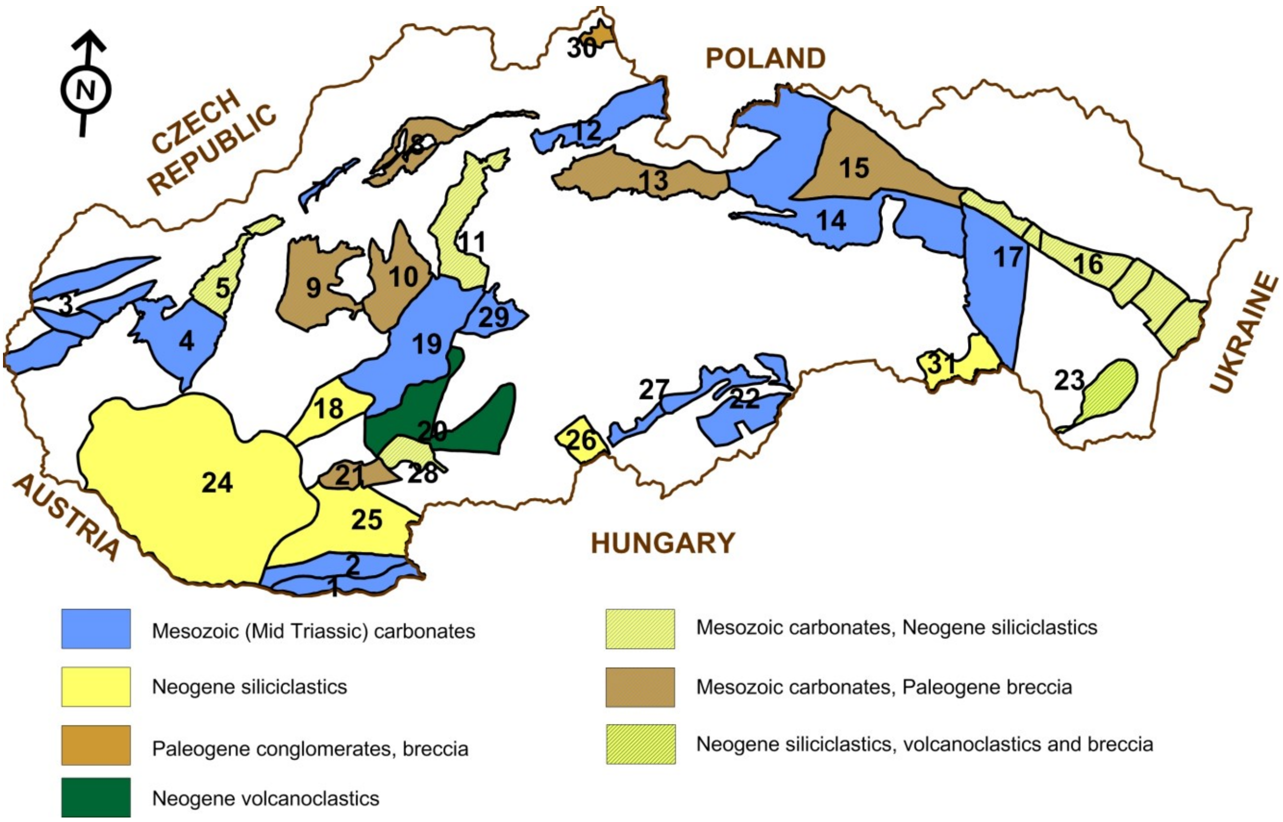

Figure 1: Prevailing reservoir lithology in geothermal water bodies – see Figure 2 for GWBs (Geothermal Water Bodies) codes

Table 2: Regional play-types review in the Western Carpathians

Sub-type / systems	Prevailing hydrogeological regime	Reservoir stratigraphy	Reservoir lithology	Flow regimes	Examples
Intramountain-depressions systems – CD2a	open to closed	Mid Triassic Paleogene	carbonates -Tr2 breccia, conglomerates - Pg	Basin-constriction, fault-plane, lateral-leakage, bedrock-high	Liptov Basin, Skorušiná Basin, Turiec Basin, Levoča S and W part
Neogene sedimentary basin embayment – CD2b	open to semi-open	Mid Triassic Neogene	carbonates – Tr2, sandstones, conglomerates - Ng	Stratified-reservoirs, lateral-leakage, vertical-evasion, bedrock-high	Piešťany embayment, Ilava Basin, Levice Block, Komjatice depression
Neogene volcanics foot slopes and adjacent basins – CD2c	open to closed	Mid Triassic Neogene	carbonates – Tr2, volcanoclastics - Ng	Fault-plane, lateral-leakage, bedrock-high	Zvolen Basin, Žiar Basin, Bátovce-Rykinčice depression, Turovce-Levice horst
Neogene sedimentary basins – CD2d	semi-closed to closed	Neogene Mid Triassic	(volcano)-siliciclastics-Ng, carbonates – Tr2	Stratified-reservoir, vertical-evasion, basin-constriction	Danube Basin Central Depression, Vienna Basin, Moldava Basin, Trebišov Basin
Buried volcanic systems and aprons – CV2/3a	semi-closed to closed	Neogene	volcanoclastics, volcanic breccias and lava flows – Ng	Vertical-evasion, lateral-leakage, apron-leakage, fault-plane	Trebišov Basin, Košice Basin

2.2.3 Geothermal resources

Majority of sampled (proven) geothermal resources are single-phase geothermal waters tap in screened reservoir depths of tens to 3,600 m at temperatures of 20-150 °C (Černák et al., 2014). A wetsteam phase was observed only in wells at the Ďurkov site (Košice Basin) and during the oil and gas prospection as the borehole crossed nearby the Beša – Čičarovce structure in N part of the Trebišov Basin. Local or regional models however expect the temperature to reach 180-240 °C at depths up to 4,000 – 6,000 m (Majcin et al., 2017) with consecutive increase in the vapor phase fraction. Formation of double-phase or steam-dominated reservoirs is rather unlikely under these hydrogeothermal settings and insulated free convection cells extensions. Therefrom, geothermal resources are generally low to moderate-low in terms of exergetic quality (e.g. Fričovský et al., 2016). Geothermal waters originate as marinogenic (seawater or degraded), petrogenic (meteoric with various degree of circulation) and mixed-type (Bodiš et al., 2018), giving an extensive TDS range of 0.4-90 $g.l^{-1}$ (Marcin et al., 2014).

2.3 Geothermal potential assessment

Geothermal resources are, by far, restricted to 31 geothermal water bodies (GWBs, Figure 2) following the WFD (Kullman et al., 2005; Fričovský et al., 2020a), which is a significant increment related to CUs before 2019 (e.g. Fendek and Fendeková, 2015; Fendek et al., 2016) or to the Atlas of Geothermal Energy of Slovakia that recognized only 26 prospective geothermal areas (PGAs) (Franko et al., 1995).

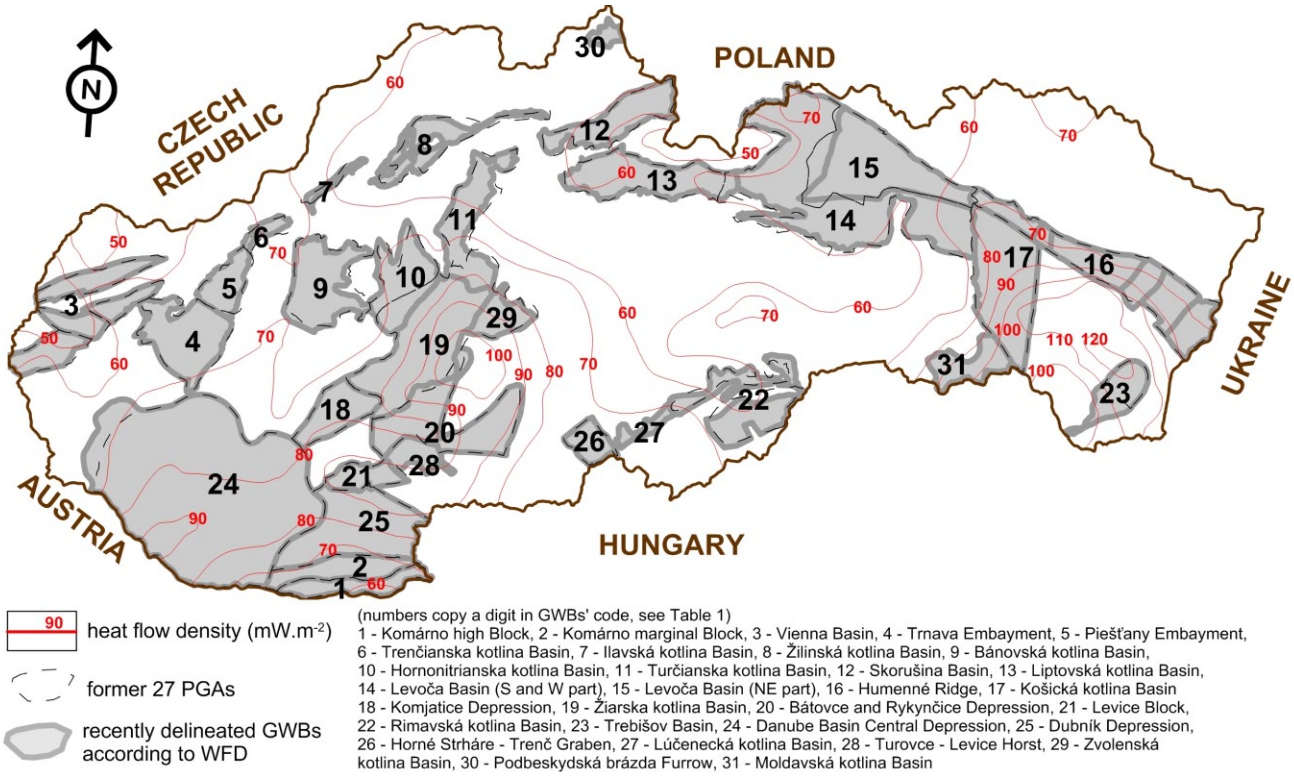

Figure 2: Outline of geothermal water bodies in Slovakia as of 2023.

First attempts to catalogize geothermal resources in Slovakia may be attributed to the Atlas of Geothermal Energy of Slovakia (Franko et al., 1995), assessing a total thermal potential of 5,538 MWt including 176 MWt as proven reserves associated with 26 prospective geothermal areas. A discussion on representativeness and limits of discrete regional assessments (Table 2) has already widely developed (e.g. Fričovský et al., 2019, 2020a,b, 2022), picking disputable use of various methods based on averaged values, or the questionable use of constants in setting the recovery factor and balancing evaluation indifferent periods as most robust. To solve a variety of inconsistencies, a pilot project of probabilistic catalog of geothermal potential was presented at the WGC2020 (Fričovský et al., 2020b) based on unifying the evaluation through the USGS volume method simulation using Monte Carlo techniques and local recovery factors, and upscaling according to the effective reservoir / production efficiency method. The assessment also was based on conceptual models of all GWBs, including a probabilistic geothermal reserves interpretation (Sanyal – Sarmiento, 2005) and a modification of the reserve capacity ratio concept (Fričovský et al., 2020b) to address sustainable reservoir capacity, both for short (40 years) and long / sustainable (Axelsson et al., 2001) periods of production (Table 3). The assessment results are:

- Total thermal potential balanced for 40 years: 6,716 MWt, i.e., sustainable thermal potential = 3,350 MWt
- Total thermal potential balanced for 100 years: 2,686 MWt, i.e., sustainable thermal potential = 1,340 MWt.

Table 2: Regional play-types review in the Western Carpathians (supporting Figure 1)

Reference	Number of considered GWBs	Assessed thermal potential (MWt)	Proven thermal potential (MWt)	Total thermal potential (MWt)
Franko et al., 1995	26	5,362	176	5,538
Fendek and Franko, 2000	26	5,362	176	5,538
Fendek and Fendeková, 2010	27	6,288	365	6,652
Marcin et al., 2014	27	6,234	348	6,582

Table 3: Total and sustainable probabilistic thermal potential in Slovakia – 2020 probabilistic pilot model

Category	Short-term production period (40 years)	Sustainable production period (100 years)
Geothermal water bodies	31	
Proven potential (MWt)	437	
Actual thermal output (MWt)	67.6	
Installed capacity (MWt)	229.4	
Thermal potential (MWt)	6,716	2,686
Sustainable capacity (MWt)	3,350	1,340
Sustainable potential to develop (MWt)	2,750	1,187

The pilot model was recently updated, where "best guess" setting of probabilistic distribution functions was replaced by background geological and geothermal models, and the simulations was guided through advanced conceptual models, recognizing whether systems are not only open or closed in terms of natural recharge, but whether reservoirs are sedimentary-stratified, or bound to two or more units within Mid Triassic carbonates experiencing hydraulic communication (i.e., lateral-leaking, vertical-leaking) or not. The new catalog, including revised classification of sustainability of use and prospectivity for future sustainable development of geothermal energy use is due in 2024.

3. GEOTHERMAL ENERGY USE AS OF 2020 - 2021

3.1 Reporting

According to the Act No. 354/2004 Coll. (Act on water) and its amendments, the CU presents and analyzes actual geothermal production data based on water withdrawals submitted to the Slovak Hydrometeorological Institute as of 2020 - 2021. Since this is a chained process, there are localities where geothermal energy is utilized but no official reports by operators are provided. A comparison between latest CUs is in Table 4 below.

For geothermal waters in spas with therapeutic uses, the regulation is introduced within Act No. 358/2005 Coll (the Spa Act) that entitles the Inspectorate of Spas and springs (ISS) by the Ministry of Health of the Slovak Republic to issue provisions on groundwater withdrawals and upscale objections on qualitative automatized monitoring of the produced resource (Božiková & Bodiš, 2016).

There are no available data and reports on shallow geothermal energy installations at small scales for private households. A pilot project on assessment of shallow geothermal energy potential, the GeoPLASMA-CE, has already been published for the WGC2020 (e.g., Goetzl et al., 2020; Švasta et al., 2020), however, only with a regional focus to the Bratislava region.

Table 4: Geothermal potential and utilization comparison for recent and previous CUs.

Parameter	WGC2015	WGC2020	WGC2023	Remarks to WGC2020 – WGC2023 changes
Number of wells online	82	114	121	new wells added, included those in spas
Installed capacity (MWt)	136	229	230	wells in spas (actualized) have low installed output
Total yield ($l.s^{-1}$)	591	570	473	seasonal weather + COVID-19 restrictions
Yearly heat production (TJ)	2,185	1,987	1,684	seasonal weather + COVID-19 restrictions

3.2 Geothermal energy production – general review

Actual national database records 283 wells proving geothermal resource, i.e., geothermal, or thermal-healing water, drilled in 30 out of 31 geothermal water bodies. Geothermal energy is produced from 122 online wells, operated in 22 GWBs for 77 sites (Table 5). It is, however, critical to note that neither technical state, nor existence of many installations drilled prior 2004 is reported, so around 42 % of the wells (122 in total) may be wrong in terms of borehole restoration. Obviously, the Danube Basin Central Depression is the most explored, installed and produced geothermal water body, where all but balneotherapeutical purposes are utilized.

Table 5: Geothermal energy use by GWBs

Geothermal water body	Wells	Online wells	Sites	Rpv (MWt)	Pth_in (MWt)	Pth_act (MWt)	Qpv (kg/s)	Qcum (m3/rok)	ETH(GWh,th)	EQ (TJ)	SITES
Komárno high Block	11	7	3	19	16	2	258	1.26	13	47	R
Komárno marginal Block	5	0	0	3	0	0	19	0	0	0	-
Vienna Basin	2	0	0	9	0	0	35	0	0	0	-
Trnava Embayment	1	1	1	1	1	0	14	0.06	1	1	R
Piešťany Embayment	16	6	1	20	16	3	120	0.64	30	107	B
Trenčianska kotlina Basin	0	0	0	0	0	0	0	0	0	0	-
Ilavská kotlina Basin	12	6	1	3	2	1	45	0.55	12	42	B
Žilinská kotlina Basin	13	9	4	7	4	1	95	0.5	6	23	R,B
Bánovská kotlina Basin	8	3	3	5	3	1	62	0.25	5	20	R
Hornonitrianska kotlina Basin	18	10	4	15	10	3	115	0.83	21	76	R,B
Turčianska kotlina Basin	16	6	3	11	2	1	92	0.24	4	15	R,B
Skorušina Basin	2	1	2	18	16	0	128	0.09	3	10	R
Liptovská kotlina Basin	22	8	5	30	23	9	282	2.34	70	253	I,R,B
Levoča Basin (W and S part)	20	6	6	36	25	7	268	1.7	59	215	I,A,R,B
Levoča Basin (NE part)	5	0	0	5	0	0	22	0	0	0	-
Humenné Ridge	4	1	1	1	0	0	12	0.07	1	5	R
Košická kotlina Basin	4	0	0	73	0	0	173	0	0	0	-
Komjatice Depression	1	0	0	3	0	0	11	0	0	0	-
Žiarska kotlina Basin	18	15	4	10	8	4	85	1.14	36	130	I,R,B
Bátovce and Rykynčice Depression	1	0	0	2	0	0	12	0	0	0	-
Levice Block	5	1	1	28	14	2	114	0.37	19	67	R
Rimavská kotlina Basin	4	1	1	2	1	0	59	0.08	1	5	R
Trebišov Basin	10	1	1	3	1	0	27	0.16	2	8	I
Danube Basin Central Depression	49	27	25	104	78	20	507	3.25	165	580	D,I,A,R
Dubník Depression	4	1	1	5	4	2	34	0.24	14	49	A
Horné Strháre – Trenč Graben	8	2	2	7	1	0	89	0.12	1	6	R
Lučenecká kotlina Basin	1	1	1	1	1	0	11	0.06	1	4	R
Turovce - Levice Horst	9	4	3	4	3	1	84	0.2	2	6	R,B
Zvolenská kotlina Basin	7	3	3	14	4	1	139	0.16	4	15	R,B
Podbeskydská brázda Furrow	1	0	0	1	0	0	0	0	0	0	-
Moldavská kotlina Basin	5	0	0	1	0	0	45	0	0	0	-

Symbols: D – geothermal district heating, I – individual space heating, A – agriculture, R – recreation, B – balneology, Pth_in – installed capacity, Pth_act – yearly mean thermal output, Rpv – proven reserves, Qpv – proven deliverability, Qcum – cumulative geothermal water withdrawal, ETH – geothermal energy production, EQ – geothermal heat production

According to Table 5, geothermal production numbers as of 2020 – 2021 are as follows:

- actual proven reserves R_{pv} = 441 MWt
- installed thermal output P_{th_in} = 233 MWt
- mean yearly thermal output P_{th_act} = 58 MWt
- cumulative thermal waters production Q_{cum} = 14.3 x10^6 m^3
- ideal geothermal energy production E_{TH_IN} = 2,014 GWh,t (production of GTE at nameplate capacity 365 days a year)
- geothermal energy production E_{TH} = 470 GWh,t
- geothermal heat production EQ = 1,684 TJ

Comparing actual to ideal geothermal energy production, the wells operate at ~23 % of their capacity. That may due not only to seasonal weather variation that controls heating duty in stand-alone individual or district heating sectors, but also because many of open-air geothermal resorts are closed during the winter season. Our data provide a picture on primary-use for wells operated in cascade, yet there are few data in some cases due to the energetical design, and so the actual geothermal energy production can be higher by a factor of few percentage points.

3.3 Geothermal energy production by sector

3.3.1 Geothermal district heating

Four geothermal district heating systems (Galanta, Šaľa, Veľký Meder and Sereď) are recently operated in the country, all within the Danube Basin Central Depression (DBCD), with a total number of 5 wells (Table 6). Installations are hybrid, using natural gas for support in different shares, varying from 35 % (Šaľa) to 99 % (Veľký Meder). By 2020 – 2021, the GDHS scored the highest mean thermal output per well, i.e., 1.25 MWt, and so the mean cumulative geothermal water production, i.e., 0.2 x 10^6 m^3 per well. The district heating segment has, however, a higher mean load factor (0.38) and mean capacity factor (0.38) among other direct-use sectors, as result of a relatively stable (baseload) production during the entire year. According to AGES initiative in preparation, there would be a push on governmental financial support towards redesigning recently open-system infrastructure towards geothermal doublets, believed to enhance the hydraulic stability of reservoirs contained into Neogene sands and sandstones.

Table 6: Main characteristics of geothermal district heating systems in Slovakia according to 2020-2021 data

Municipality	Operator	Number of wells	Installed capacity (MWt)	Geothermal water temperature(°C)	E_{TH} (GWh,t)	Share of geothermal energy
Galanta	Galantaterm spol. s r.o.	2	13.3	77	27.8	99
Šaľa	MeT Šaľa, s.r.o.	1	3.4	70	16.2	35
Veľký Meder	Mestský podnik bytového hospodárstva, s.r.o.	1	3.3	92	16.7	98
Sereď	Energetika Sereď, s.r.o.	1	1.9	66	3.5	45

3.3.2 Individual space heating

The individual space heating is provided through 10 wells operating in 10 sites, whether as stand-alone projects or in cascaded systems for recreation (e.g. Bešeňová, Liptovský Trnovec, Diakovce, Komárno, Poprad) or agriculture (Podhájska). In total, geothermal space heating is occurring in 5 out of 22 GWBs. The current design of one well per site is recently used in most geothermal projects in Slovakia, with only few exceptions in recreation or balneotherapy. According to 2020 – 2021 data, Komárno has not been launched or reported until data submission, so it is not enlisted in datasets for this CU. With the overall installed capacity of 33.4 MWt (i.e., 3.3 MWt per well) and mean cumulative thermal output of 9.8 MWt (i.e., 0.99 MWt per well), the yearly heat production of roughly 289 TJ (17 % of geothermal heat delivery) is a fair increase compared to data reported in the WGC2020+1. The mean load factor is 0.34 and the mean capacity factor is 0.36.

3.3.3 Agriculture (greenhouses, fish-farming)

Use of geothermal energy in agriculture / aquaculture occurs as primary stage in 11 sites, provided by 12 wells. Stand-alone systems are mainly used. but there are some cascaded towards recreation, such as heating pools (Tvrdošove, Topoľníky). Most of agricultural use is concentrated in the DBCD (e.g., Dunajská Streda, Ňarád, Zlatná n. Ostrove, Horná Potôň, Vlčany, Šurany, Zemné), with only a few in northern GWBs, such as Koš – Laskár (Hornonitrianska kotlina Basin). Some sites use agriculture as lower cascade stages (e.g., Chalmová, Podhájska, Virt, Bešeňová). Only two localities are dedicated to fish-farming: Vrbov (Levoča Basin – S and W part) and the Turčianske Teplice (Turčianska kotlina Basin).

In terms of primary use (i.e., first stages), the installed capacity is roughly 41 MWt (i.e., 3.4 MWt per well), yet the mean thermal output reached 10 MWt (i.e., 0.8 MWt). Total heat produced by 2020 – 2021 was 293 TJ, out of which the geothermal energy produced was 81 GWh,t. Then, the calculated mean load factor is 0.25 and the mean capacity factor is 0.31. Meanwhile, agriculture is a primary use in 3 out of 22 GWBs where geothermal water is produced

3.3.4 Recreation (here)

Recreation, i.e., using geothermal waters in direct, indirect (heating secondary loops for pools) or mixed (mixing geothermal water with freshwater / groundwater prior pool inlet or right in the pool) systems, is by far the most popular and developed (Table 7) segment of direct-use in the country. In total, 49 wells (40 % out of total) serve recreation as primary stage at 41 others – i.e., 53 % out of all localities (Table 7), use geothermal waters cascaded from GDHS, ISH or agriculture.

Analyzing primary use, most of sites (7) are within the DBCD geothermal water body (e.g., Nové Zámky, Veľký Meder, Dunajská Streda, Diakovce), followed by the Komárno high Block (Štúrovo, Obid, Patince) or the Liptov Basin (Bešeňová, Liptovský Trnovec, Liptovský Ján), or the Bánovská kotlina Basin (Partizánske, Malé Bielice, Bánovce n. Bebravou). The installed capacity is 96.5 MWt as of 2020 – 2021 (i.e., 1.97 MWt per well), whereas the mean thermal output reached 19.7 MWt (0.41 MWt per well). National statistics report 159 GWh,t of geothermal energy produced or 572 TJ of geothermal heat delivered. The factors are 0.2 for load and 0.26 for capacity. The recreation, in terms of primary use, consumed 44 % of total geothermal waters produced, i.e., 6.3 x 10^6 m^3.

Load and capacity factors (mean) calculated for recreation segment are considerably lower compared to other types of geothermal energy use. At least for stand-alone projects utilizing geothermal waters, the capacity drops down as function of seasonal weather variation depending on the locality, and whether the resort is indoor (e.g., Poprad), outdoor (e.g., Vrbov) or combined (e.g., Rajecké Teplice). Apparent misbalance between number of wells and production / installation data can easily be explained by considerably lower mean temperature (39°C) of the resources used for recreation when compared to geothermal district heating (76 °C) or agriculture (68 °C). In addition, stand-alone pool heating has lower demands compared to others.

3.3.5 Balneotherapy

Balneotherapy is the most traditional use of geothermal (or thermal-mineral) waters (Fendek et al., 1999b) with proven curative effects in the country, when considering institutionalized or systematized use. There are 11 spas (Bojnice, Trenčianska Teplice, Vyšné Ružbachy, Lúčky, Piešťany, Turčianske Teplice, Kováčová, Sliač, Sklené Teplice, Dudince, Rajec) producing geothermal waters with 46 wells running online. Besides the temperature, the location and extension of balneotherapeutical uses are limited by geology and the chemical composition of geothermal waters that reportedly have proven curative effects. Moreover, mineral-thermal waters production is subjected to specific restrictions issued by the Ministry of Health and the national Inspectorate of Spas and Springs, including technical limits for production and the extension of protective zones for some resources.

This is the main reason explaining the low installed capacity of 37 MWt (0.8 MWt per well) and the low average thermal output of 10 MWt (i.e. 0.2 MWt per well) for balneotherapeutical purposes, projected into 86 GWh,t of geothermal energy produced and 310 TJ of heat delivered. However, the load (0.34) and capacity (0.36) factors are higher, compared to recreation or agriculture, because spas are generally expected to operate during the whole year.

Production and installation statistics present least uncertainties in quantification, since they are not subjected to cascaded systems that distort previous segments at some extension.

3.3.6 Conclusions on actual geothermal energy use

In terms of geothermal energy use by various sectors, and with considering primary use of geothermal waters (or first stages of cascaded, if installed), the main characteristics / statistics for Slovakia according to 2020 – 2021 data can be resumed as follows (actualized list of sites is in the Appendix at the end of this report):

- Recreation is the dominant purpose of all statistics (Table 7), served with 40 % of online wells in 53 % of all online sites, contributing with 42 % on overall installed capacity and 34 % on the average thermal output of all wells, projected into roughly 34 % share on geothermal energy and geothermal heat production, while sharing 44 % of total geothermal waters production.
- Recreation is also the most extended use considering geothermal water bodies, since it is installed in 18 out of 22 recently producing bodies.
- Geothermal district heating is by far the sector with highest installed (4.1 MWt) and actual (1.5 MWt) thermal output, recently limited to the DBCD only, due to the highest wellhead temperatures.
- Individual space heating has the typical direct-use arrangement of one well – one site in the country, with increases in the number of cascaded use to address either demand or benefits on return, depending on seasonal weather variation if stand-alone.
- Balneotherapy as the only segment generally not connected to cascades, is limited in growth because of strict regulation and restrictions on the nature of the resource.

3.4 Shallow geothermal energy and large heat pumps installations

It has been predicted that use of shallow geothermal energy or large-scale installations doesn't have much market because of a dense existing natural gas heating grid supply. This situation will probably change at some scale due to local and international changes in economy and the fossil-fuels market, including more options for financial support from national authorities and EU funds. The rise in installations observed in 2012 – 2014 (Fendek et al., 2016) is, thus, expected to continue in a close future. However, there are no reports available in regards to the installed capacity, excepting gross assumptions when taking sold units reported to the European heating product markets. Thus, new solid data are limited due to:

- The lack of legal instruments for proper reporting (for private companies) to state authorities when drilling new boreholes for closed-loop systems, causing lack of accurate data
- The absence of national-scaled database on installed units and the installed capacity.

As it was mentioned in previous reports (e.g. Fendek et al., 2016; Fričovský et al., 2020), only some relative assumptions can be made. So, we expect that the proportion of horizontal earth collectors may vary 45 – 55 %, groundwater source heat pumps 30 – 40 %, and vertical heat exchangers 5 – 15 %.

Large geothermal heat pumps installations are used as support for direct-use, typically for individual space heating or to supply cascades, such in the cases of Podhájska, Bojnice, Vyšné Ružbachy, Gbelany, Rajecké Teplice, Piešťany, Senec, Čilistov, Rabča and Borša. Assuming relatively stable during production, the overall installed capacity of 1.6 MWt for reported period would probably supply ~14 TJ of heat into the system.

Table 7: Key data on geothermal production / installations of direct-use.

Sector	Number of wells	Number of sites	Pth_inst (MWt)	Pth_act (MWt)	ETH (GWh,t)	EQ (TJ)	LF (-)	CF (-)	Qcum 10^6 m^3
District heating	5	4	20.6	1.5	64	221	0.38	0.39	1.02
Individual space heating	10	10	33.4	1	80	289	0.34	0.37	2.35
Agriculture / fish-farming	12	11	41.2	0.8	81	293	0.26	0.31	1.73
Recreation	49	41	96.5	0.4	159	572	0.20	0.26	6.29
Balneotherapy	46	11	37.7	0.2	86	310	0.34	0.36	2.93

Symbols: Pth_inst – installed capacity, Pth_act – yearly mean thermal output, Qcum – cumulative geothermal water flow, ETH – geothermal energy production, EQ – geothermal heat production, LF: Load factor. CF: Capacitity factor.

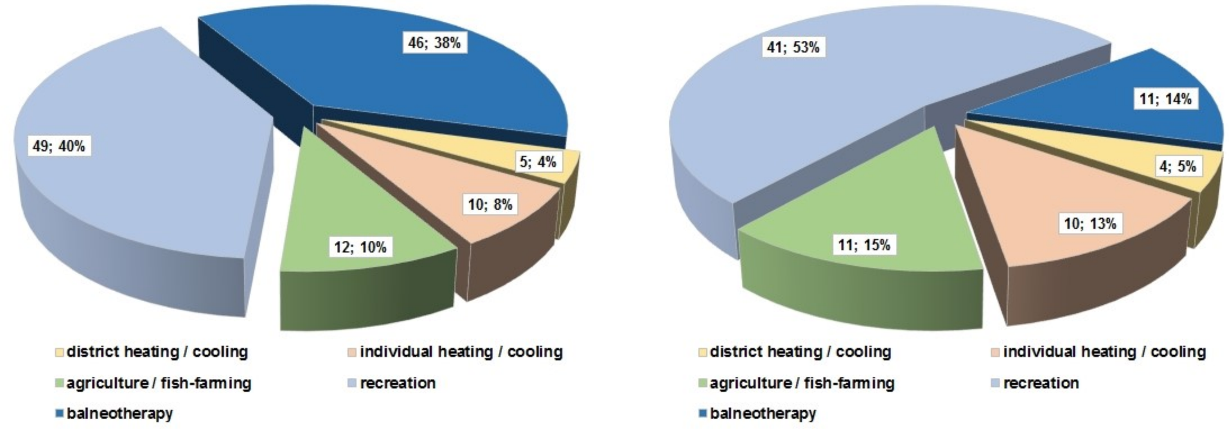

Figure 3: Geothermal wells (left) and sites (right).

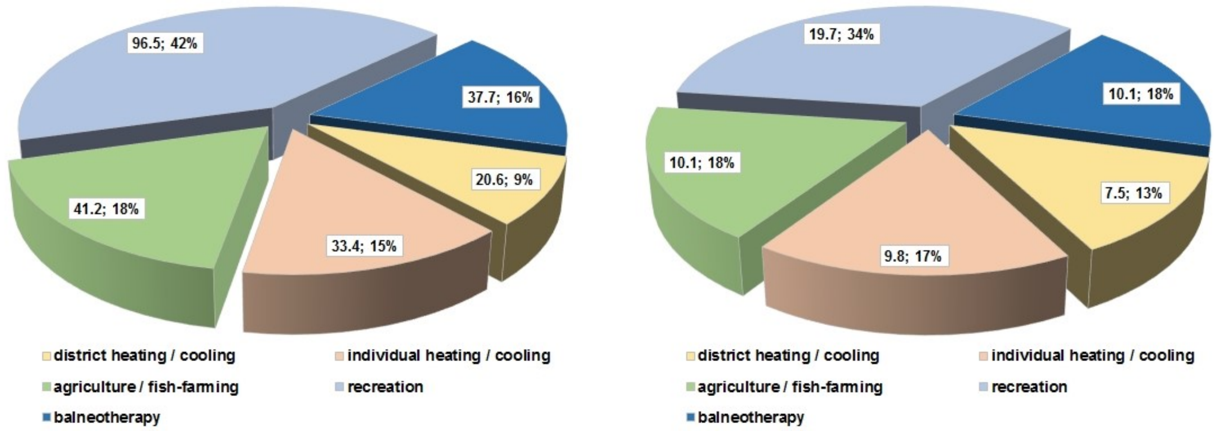

Figure 4: Installed (left) and actual (right) thermal output (MWt) by sector.

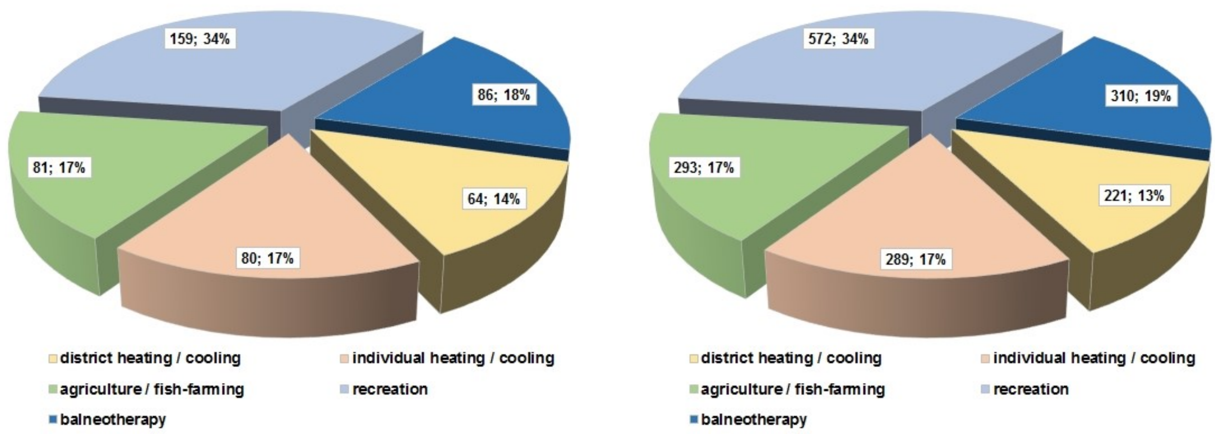

Figure 5: Geothermal energy (left, in GWh,t) and heat production (right, in EJ) by sector

4. GEOTHERMAL ENERGY USE: PROJECTIONS AND OTHER COMMENTS

4.1 Pipeline projects and future considerations

We use here our knowledge on running geothermal projects and changes in their status compared to the latest reports (Fričovský et al., 2020a, 2022):

- The Lipany Thermalpark (Levoča Basin – SE part) using Lipany-2 well is recently in seasonal use as an open-air resort, but no reports on geothermal waters production were submitted to the Water Research Institute, so this facility is not considered here, expecting to be reported in the next report. The well has been completely restored and reported to be under pumping tests.

- There is another thermal park launched in 2020 in the town of Komárno (Komárno high Block), with no available data and then not considered in this report. The Komárno park uses well M-2in cascaded system to provide individual space heating and to heat pools after a complex restoration.

- The GTP-1 Piešťany well (Pieštany Embayment) has successfully passed pumping tests and its production was approved to be used in a resort in the town of Piešťany dedicated to recreation purposes. During the compilation period the project was not yet in operation.

- The well ČZT-1 Čižatice (Košice Basin) has successfully been installed, and recently put stand-by. Water to be produced by this well is planned for in several direct-use purposes (district heating, agricultural use, recreation). The project is searching for options to fund the drilling of a reinjection well, due to the geothermal water chemistry. The proven resource is geothermal water and wetsteam separable under atmospheric pressure, the wellhead temperature is 96 – 98 °C, and the measured production was 14 $l.s^{-1}$ (not subjected to long-term nor required pumping tests).

- The new geothermal well in town of Kežmarok (Levoča Basin – S and W part) has successfully been drilled to its final depth, proving a geothermal resource to be used for district heating. Well is under tests and applying for water production approval.

- A geothermal well in the town of Liptovský Mikuláš (Liptov Basin) is under drilling, as pilot project on industrial use to supplying heat process water in the leather industry.

- The GVL-1 Veľká Lomnica (Levoča Basin – S and W part) is under revision of production approval, looking for increase its heat delivery not only to individual housings, but a nearby hotel resort as well.

- Geothermal wells Vr-1 and Vr-2 in Vrbov (Levoča Basin – S and W part) were under pumping tests to revise production approval, opting to increase heat delivery to local fish-farming, resort space heating and geothermal pools.

There are also some recent few claims on geothermal energy production with unidentified target (tracks are available and updated on a regular base at: https://apl.geology.sk/geofond/pu/):

- The Vlčany area (Danube Basin Central Depression), possibly for agriculture.

- The Krupina area (Bátovce – Rykynčice depression).

- The Dargov area (not adjusted to recently outlined geothermal water bodies – E from the Košice Basin).

- The Partizánska Ľupča area (Liptov Basin).

- The Dolný Kubín / Geceľ area (Žilina Basin), possibly for individual space heating and recreation for local auto-camping.

The project of geothermal district heating for the city of Košice, as the second largest in the country, has been in the pipeline for decades (e.g., Vranovská et al., 2000; Halás, 2015; Fričovský et al., 2020a, 2022). After years of stand-by, new pumping tests were carried out and in 2022 it was signed an agreement between private investors and state authorities to launch construction of the entire system, with option to increase the number of wells. It is expected to start with 30 MWt and 65 GWh,t in 2026, with a targeted increase to 175 GWh,t.

Two projects on binary geothermal power plant installation by PW Energy Ltd. in the Lovča (Žiar Basin) and Prešov – Teriakovce (Košice Basin), area are still under environmental and social evaluation. Plans are to install capacity at 20 – 40 MWe.

Besides the mentioned projects, there is a continuous debate on further geothermal energy development in the country. Most of models (i.e., Fričovský et al., 2016; Majcin et al., 2017; Bezák – Majcin, 2018) discuss possibilities of large-scale power production, which are questionable due to great depths and the probable lack of available vapor phase. Only binary cycleo plants, both small or large scale, seems to be suitable for these power projects. Most prospective depths to reach temperatures higher than 160 °C, are 3,500 – 4,000 m, and still are not completely targeted. So, typical hydrogeothermal systems are most probably to be found. Moreover, such reservoirs are both in carbonates (e.g., the Košice Basin, Žiar Basin) or volcanoclastics to volcanic breccia (e.g., Trebišov Basin), and related to volcanism / plutonism or overheat due to crustal thinning. Therefrom, it seems to be the risk of secondary permeability reductions by healing (e.g., calcite deposition), contact metamorphism, compaction, or all combined. And this conducts to EGS considerations to improve permeability, which are also debatable. On the contrary, there is a general consensus on a more extended development of direct-use applications, based on already proven low enthalpy geothermal resources.

4.3 Geothermal energy and society remarks

4.3.1 Education

There is no specialized geothermal education program in Slovakia. Lectures / classes on technical aspects are delivered on several technical universities (Slovak Technical University in Bratislava, Technical University of Žilina, Technical University of Košice) in a limited outline, addressing basic description of direct-use or power generation systems. To some extension, hydrogeology, hydraulics, geochemistry and methods of research and prospection on geothermal energy are taught within a hydrogeology program at the Commenius University in Bratislava. Still, there is an option for domestic students to attend programs abroad.

4.3.2 Institutional engagement

Years of the Slovak Geothermal Association stand-by basically muted joint actions of experts from a private and public sphere. By the end of 2022, the Association of Geothermal Energy of Slovakia (AGES) was established, grouping private investors and the geological survey of Slovakia as associated partner to strengthen mutual visions and accent conceptions in both, research, prospection, and development of geothermal energy towards governmental authorities.

4.3.3 Legislation

Research and prospection of geothermal resources are recently controlled by the act No. 569/2007 Coll. (Act on geology) as amended by the Act No. 311/2013 Coll., applying a provision on licensing production of geothermal waters and setting restrictions on approvals by Ministry of the Environment, which must be based on long-term pumping tests on wells, estimation of hydraulic, physical-chemical properties of water, qualitative and quantitative monitoring (Fendek et al., 2016). Conditions on geothermal water production and its payment are regulated by Act No. 364/2004 Coll. (Act on water) with later amendments, i.e., 306/2012 Coll. (Fendek et al., 2015). Promotion of RES (including geothermal resources) into national PEM is legislatively regulated through amendments of Act No. 309/2009 Coll. (Act on support of renewable energy sources and highly efficient combined production, latest 377/2018 Coll.). Mineral-thermal waters are regulated through Act No. 358/2005 Coll (the Spa Act).

Private sector and stakeholders report a complicated legislation and EIA attainment as some of the crucial aspects that limit geothermal development. Thus, discussions began on establishing a specialized legislation to promote sustainable use and development of geothermal energy at the platform of Ministry of Environment.

5. SUMMARY

Geothermal energy / resources in Slovakia align with 31 geothermal water bodies of different (sub) play-types whether in intramountain depressions (Mid Triassic carbonates and Paleogene breccias, conglomerates), large Neogene sedimentary basins and their embayments (Neogene siliciclastics, volcanoclastics and Mid Triassic carbonates at pre-Cenozoic basement), or at foot-slopes of Neogene (buried) volcanic systems and within adjacent basins (Neogene volcanoclastics and volcanic breccia and lava flows), generally considered of low to moderately-low exergy. The main potential of geothermal development in Slovakia is by all means in direct-use, although projects on installation of binary geothermal power plants are already waiting to launch the drilling phase. Compared to previous reports, there is no new wells installed in the last couple of years, which may be attributed to the COVID-19 situation and to more emphasis in completing projects rather than start new ones, excepting two new thermal parks.

Currently, there are 283 geothermal wells (441 MWt), but only 122 are in operation with overall installed capacity of 233 MWt as of 2020-2021, with a mean cumulative yearly thermal output of only 58 MWt. Total geothermal energy produced is 470 GWh,t, while total delivered heat was ~1,685 TJ. According to reports delivered to national authorities, 14.3x 106 m^3 of geothermal waters were produced in each period.

Recreation is by all means the most developed segment of geothermal direct-use in Slovakia, with 49 wells serving 41 sites on primary stage, representing almost 97 MWt on installed capacity, with load and capacity factors of only 0.2 and 0.26, respectively, because many resorts are open-air and thus are operated seasonally. Four geothermal district heating systems operate 5 geothermal wells in various combinations with natural gas boilers, and the number has not changed. There is a sound plan to launch district heating using geothermal wells in Ďurkov to supply the city of Košice, scheduled to launch by 2026. Moreover, a geothermal well in the town of Kežmarok was completed, undergoing stimulation and pumping tests to apply for geothermal water approval to be the fifth-sixth GDHS in the country. Balneotherapy, with 11 spas, holds a stable and popular position, meeting its own limits due to strict regulation for preservation of mineral-thermal waters resources. Individual space heating is typically cascaded to recreation, delivering heat to residential and commercial buildings in large resorts. There are nine sites of agricultural geothermal uses as primary stage of cascades, located at the southern part of the country, whereas fish-farming uses are only on two localities (Turčianske Teplice, Vrbov). A pilot project on geothermal energy use in leather processing was recently launched in the town of Liptovský Mikuláš, being at drilling stage.

6. REFERENCES

Axelsson, G., Gudmundsson, A., Steingrímsson, B., Palmasson, G., Armansson, H., Tilinius, H., Flovenz, O.G., Bjornsson, S. and Stefansson, V.: Sustainable production of geothermal energy: suggested definition, *International Geothermal Association News Quaterly*, **43**, (2001), 1-2.

Bezák, V. and Majcin, D.: Lithological composition in deep geothermal source reservoirs of temperature 160 ◦ C in the territory of Slovakia, *Contributions to Geophysics and Geodesy*, **48 (4)**, (2018), 349-363.

Božíková, J. and Bodiš, D.: Mineral waters in Slovakia, legislation and their use, *Slovak Geological Magazine*, **2/2016**, (2016), 57-69.

Bodiš, D., Remšík, A., Černák, R., Marcin, D., Ženišová, Z. and Fľaková, R.: Geothermal and hydrogeological conditions, geochemical properties and uses of geothermal waters in Slovakia. In: Bundschuh J. – Tomaszewska B. (EDs.), Geothermal Water Management, , 41-69, *Taylor & Francis*, (2018).

Černák, R., Remšík A. and Nador A.: Geothermal energy research in Slovakia and cooperation on geothermal transboundarz project Transenergy, *Slovak Geological Magazine*, **14 (2)**, (2014), 5-16.

Fendek, M. and Franko, J.: Country Update for the Slovak Republic, *Proceedings* World Geothermal Congress 2000, Kyushu-Tohoku, Japan, (2000).

Fendek, M. and Fendeková, M.: Country Update of the Slovak Republic, *Proceedings* World Geothermal Congress 2005, Antalya, Turkey, (2005).

Fendek, M. and Fendeková, M.: Country Update of the Slovak Republic, *Proceedings* World Geothermal Congress 2010, Bali, Indonesia, (2010).

Fendek, M. and Fendeková, M.: Country Update of the Slovak Republic, *Proceedings* World Geothermal Congress 2015, Melbourne, Australia, (2015).

Fendek, M., Remšík, A. and Král, M.: The nature of geothermal resources in Slovak Republic, *Slovak Geological Magazine*, **5 (1-2)**, (1999a), 121-130.

Fendek, M., Rebro, A. and Fendeková, M., 1999: A spell cast: historical aspects of thermal springs use in the Western Carpathian region. In: Cataldi, R. (Ed.): Stories from a heated Earth: Our Geothermal Heritage. *Geothermal Resource Council Transactions*, **19**, (1999b), 251-265.

Fendek, M., Fendeková, M., Fričovský, B. and Blanárová, V.: Geothermal Energy Use, Country Update for Slovak Republic, *Proceedings* European Geothermal Congress 2016, Strasbourg, France, (2016).

Franko, O. and Melioris, L.: Condition for formation and extension of mineral and thermal waters in the Western Carpathians, *Slovak Geological Magazine*, **5 (1-2)**, (1999), 93-107.

Franko O., Remšík, A., and Fendek, M.: Atlas of Geothermal Energy of Slovakia. *Slovak Geological Survey, Bratislava*, (1995).

Fričovský, B., Černák, R., Marcin, D., Benková, K., Remšík, A. and Fendek, M.: Engineering approach in classification of geothermal resources of the Slovak Republic, Proceedings 41st Workshop on Geothermal Reservoir Engineering, Stanford University, CA, USA, (2016).

Fričovský, B., Černák, R., Marcin, D., Blanárová, V., Benková, K., Pelech, O. and Fendek, M.: Geothermal Energy Use, Country Update for Slovakia, Proceedings European Geothermal Congress 2019, Den Haag, Netherlands, (2019).

Fričovský, B., Černák, R., Marcin, D., Blanárová, V., Benková, K., Pelech, O., Fordinál, K., Bodiš, D. and Fendek, M.: Geothermal energy use – Country update for Slovakia, *Proceedings* World Geothermal Congress 2020+1, Reykjavik, Iceland, (2020a).

Fričovský, B., Vizi, L., Marcin, D., Černák, R., Blanárová, V., Ujjobbágyová, Z., Bodiš, D., Benková, K., Pelech, O. and Fordinál, K.: Geothermal energy utilization in Slovakia: First insights from sustainability perspective, *Proceedings* World Geothermal Congress 2020+1, Reykjavik, Iceland, (2020b).

Fričovský, B., Marcin, D., Benková K., Černák, R., Fordinál, K. and Pelech, O.: Geothermal energy use, Country update for Slovakia, *Proceedings* European Geothermal Congress 2022, Berlin, Germany, (2022).

Goetzl, G., Dilger, G., Grimm, R., Hofmann, K., Holeček, J., Černák R., Janza, M., Kozdroj, W., Klonowski, M.R., Hajto, M. and Gregorin, S.: Strategies for Fostering the Use of Shallow Geothermal Energy for Heating and Cooling in Central Europe - Results from the Interreg Central Europe Project GeoPLASMA-CE, *Proceedings* World Geothermal Congress 2020+1, Reykjavik, Iceland, (2020).

Halás, O.: Geothermal District Heating Systems in Slovakia – Current Status and Plans, *Proceedings* World Geothermal Congress 2015, Melbourne, Australia, (2015).

Kullman Jr., E, Malík, P., Patschová, A. and Bodiš, D.: Delineation of groundwater bodies on Slovak territory according to EU Water Framework Directive 2000/60/EC, *Podzemná voda*, **XI (1)**, (2005), 5-18.

Majcin, D., Král, M., Bilčík, D., Šujan, M. and Vranovská, A.: Deep geothermal sources for electricity production in Slovakia: thermal conditions, *Contributions to Geophysics and Geodesy*, **47 (1)**, (2017), 1-22.

Marcin, D., Remšík, A. and Benková, K.: Geothermal water utilization in Slovakia, *Slovak Geological Magazine*, **14 (2)**, (2014), 69-79.

Moeck, I.S.: Catalog of geothermal play types based on geologic controls, *Geothermics*, **37**, (2014), 867-882.

Moeck, I.S. and Beardsmore, G.: A new "Geothermal Play Type" catalog: streamlining exploration decision making, *Proceedings* 39th Workshop on Geothermal Reservoir Engineering, Stanford University, CA, USA, (2014).

Plašienka, D.: Continuity and episodicity in the early Alpine tectonic evolution of the Western Carpathians: How large-scale processes are expressed by the orogenic architecture and rock record data, *Tectonics*, **37 (1)**, (2018), 1-51.

Sanyal, S.K. and Sarmiento, Z.F.: Booking geothermal energy reserves, *Geothermal Resource Council Transactions*, **29**, (2005), 467-474.

Schmid, S. M., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M. and Ustaszewski, K.: The Alpine-Carpathian-Dinaridic orogenic system: correlation and evolution of tectonic units. *Swiss Journal of Geosciences*, **101 (1)**, (2008), 139-183.

Švasta, J., Goetzl, G., Černák, R., Steiner, C. Fuchsluger, M., Porpaczy, C., Rupprecht, D. and Fričovský, B.: Shallow geothermal energy potential in transboundary region between Austria and Slovakia (Results from the GeoPLASMA-CE project), *Proceedings* World Geothermal Congress 2020+1, Reykjavik, Iceland, (2020).

Vranovská, A., Beňovský, V., Drozd, V., Halas, O. and Váňa, O.: Investigation for geothermal energy utilization in the town Košice, Slovak Republic, *Proceeding*s World Geothermal Congress 2000, Kyushu-Tohoku, Japan, (2000).

APPENDIX: GEOTHERMAL SITES OPERATED IN 2020-2021

Wells / Locality		Use	Borehole properties			Installed capacity	Use by 2020-2021		
			Q	Wellhead temperature (°C)			Q	E_{TH}	CF (-)
			(kg/s)	in	out	(MWt)	(kg/s)	(TJ/yr)	
OPKS	Štúrovo	R	6	36	22	0.5	2.77	1.16	0.3
VŠ-1			49	39	22	4.71	1	0.18	0.02
FGŠ-1			70	40	22	7	7.9	17.9	0.08
SB-2	Patince	R	45	27	18	2.17	2.56	2.9	0.04
JRD	Virt	R	6.6	26	18	0.3	4.4	4.68	0.48
HVB-1			10	26	18	0.44	7.2	7.65	0.53
vrt VŠE			18	24	18	0.66	16	12.78	0.59
KB-1	Koplotovce	R	14.5	24	20	0.53	4	0.99	0.11
VLÚ-2	Piešťany	B	4	17	15	0.03	0.02	0.01	0.01
VLÚ-3			3.4	40	20	0.34	1.95	4.94	0.47
V-5			24.5	64	20	4.7	4.5	25.8	0.17
V-1			23.5	66	20	4.7	4.5	25.8	0.17
V-4A			24	65	20	4.7	4.5	24.7	0.17
V-8			6.2	65	20	1.2	4.5	25.6	0.66
SB-3	Trenčianske Teplice	B	0.3	38	20	0.03	0.15	0.34	0.33
SB-5			1	38	20	0.09	0.7	1.6	0.56
V-2			2	40	20	0.2	1.13	2.81	0.45
TT-2			2	39	20	0.19	1.47	3.44	0.58
P-1			4.75	38	20	0.44	4.62	10.57	0.75
V-3			10.8	40	20	1.06	9.5	23.65	0.71
BJ-22	Rajecké Teplice	B	2.3	36	20	0.2	0.78	1.47	0.25
BJ-19			1.27	34	20	0.1	0.21	0.34	0.1
B-1			2.4	38	20	0.22	0.44	0.99	0.14
B-2			2.5	38	20	0.23	0.44	0.99	0.13
B-3			2.5	38	20	0.23	0.44	0.99	0.1
BJ-21 A			5.5	34	20	0.42	4.61	8.13	0.62
RT-1	Rajecké Teplice	R	3.8	39	20	0.36	3.05	7.18	0.64
Rk-22	Rajec	R	22	26	20	0.98	2.29	0.58	0.06
HŽK-2	Stráňavy	R	22	24	20	0.84	5	2.66	0.1
HGTP-1	Partizánske	R	12.8	20	18	0.26	0.27	0.03	0.01
MB-3	Malé Bielice	R	8.5	40	20	0.85	1.95	4.92	0.19
BnB-1	Bánovce n. Bebravou	R	17	40	20	1.78	5.79	14.63	0.27
PA-7	Bojnice	R	4	40	20	0.4	1.18	0.49	0.23
BR-6	Bojnice		4	40	20	0.4	1.1	0.46	0.23
BR-2	Bojnice	B	2.3	51	20	0.31	2.2	2.18	0.9
Z-2			6.5	50	20	0.82	4.23	11.78	0.54
Termál			6.6	46	20	0.82	4.23	13.87	0.54
BR-3			3.2	35	20	0.26	0.55	0.97	0.12
BR-1			10.6	46	20	1.32	2.56	8.46	0.21

Wells / Locality		Use	Borehole properties			Capacity	Use by 2020-2021		
			Q	Wellhead temperature (°C)			Q	E_{TH}	CF (-)
			(kg/s)	in	out	(MWt)	(kg/s)	(TJ/yr)	
Š1-NB II	Nováky - Laskár	A	22	59	38	3.84	11	29.2	0.24
V-3	Mošovce-Drienok	R	4	19	17	0.06	1.9	0.36	0.17

B-2	Turčianske Teplice		0.003	45	20	0.0004	0.003	0.01	0.75
TJ-3	Turčianske Teplice		0.003	47	20	0.0004	0.003	0.01	0.8
Modrý b.	Turčianske Teplice	B	0.74	46.9	20	0.09	0.74	2.5	0.89
Ľudový b.	Turčianske Teplice		4	41	20	0.42	1.29	3.45	0.26
TJ-20A	Turčianske Teplice		7	43	20	0.78	3.88	11.17	0.45
TTK-1	Turčianske Teplice	R	3.5	27	21	0.18	2.1	0.4	0.29
OZ-2	Oravice	R	70	56	26	11.4	2.01	7.58	0.02
OZ-2	Oravice	R	30	56	26	4.9	1.1	2.7	0.03
BJ-101			8.91	31	25	0.59	1.58	1.19	0.07
BLK-2	Lúčky / Kalameny	B	22	31	18	1.39	1.36	2.19	0.05
HGL-2			23.5	33	18	1.7	1.14	2.21	0.04
HGL-3			12.5	35	25	1.01	3.84	4.96	0.16
FGTB-1	Bešeňová	I	32	66	26	6.45	14.62	54.7	0.36
ZGL-1	Bešeňová	R	27	62	25	5.3	25.9	119.9	0.76
ZGL-2/A	Liptovský Trnovec	R	31	60	28	5.53	13.7	54.9	0.32
vrt Rudolf	Liptovský Ján	R	24	28	21	1.21	15.8	13.1	0.34
GVL-1	Veľká Lomnica	I	35	62	25	6.51	1.09	5.01	0.03
Izabela	Vyšné Ružbachy	B	20	20	18	0.42	0.97	0.27	0.02
Vr-1	Vrbov	R	28.3	56	22	4.61	10.1	43.1	0.29
Vr-2	Vrbov	A	33	59	22	5.76	23.2	107.7	0.59
PP-1	Poprad	R	61.2	48	22	8.05	17.8	58.23	0.23
GA-1	Gánovce	R	2.8	12	18	0.1	0.74	0.47	0.11
GTH-1	Kaluža	R	4	40	22	0.41	2.29	5.21	0.4
ST-2			1.09	51	20	0.16	0.15	0.58	0.13
Banský			0.76	39	20	0.07	0.53	1.27	0.57
Ľudový			0.4	48	18	0.05	0.26	0.98	0.6
Jozef			0.3	46	18	0.04	0.2	0.69	0.5
Vojtech	Sklenné Teplice	B	0.2	38	18	0.02	0.13	0.33	0.5
Ľudovít			0.2	35	18	0.02	0.13	0.28	0.5
Vilma			0.09	49	18	0.01	0.07	0.26	0.91
ST-4			16	57	20	2.67	10.56	48.89	0.58
ST-5			4.4	46	20	0.54	2.9	9.5	0.56
ST-1			3.03	52.1	20	0.45	1.68	6.76	0.47
STH-2	Sklenné Teplice	R	3	45	21	0.36	1.98	5.93	0.53
HGV-3			5.5	29	20	0.32	0.21	0.24	0.03
H-2	Vyhne	R	2.5	36	21	0.21	0.42	0.78	0.1
H-1			5	36	21	0.42	1.66	3.15	0.24
KŠ-1	Kremnica	I	23.2	47	21	2.96	15.3	50.1	0.54
Po-1	Podhájska	R	53	80	34	13.53	11.81	57.5	0.16
GRS-1	Kurinec (Zelená v.)	R	10.5	33	18	1.01	6.1	4.87	0.49
HJ-6	Borša	I	8.5	32	20	0.58	5.1	7.75	0.43
FGTv-1	Tvrdošovce	A	20	70	18	4.6	0.42	2.69	0.02
Di-1	Diakovce	R	4	38	21	0.39	0.59	1.27	0.11
Di-2	Diakovce (H. Saliby)	I	12	68	26	2.66	7.15	37.5	0.47
VM-1	Veľký Meder	D	10.4	93	20	3.28	6.72	60.5	0.6
Č-1	Veľký Meder (Čalovo)	R	10	79	20	2.59	3.55	26	0.33
Wells / Locality		Use	Borehole properties			Capacity	Use by 2020-2021		
			Q	Wellhead temperature (°C)			Q	E_{TH}	CF (-)
			(kg/s)	in	out	(MWt)	(kg/s)	(TJ/yr)	
Č-2	Veľký Meder (Čalovo)	I	18.2	57	20	3.03	8.66	40.2	0.42
GNZ-1	Nové Zámky	R	4.5	59	20	0.78	4.16	6.78	0.82

SEG-1	Sereď	D	9	66	20	1.81	2.2	12.6	0.22
DS-1	Dunajská Streda	A	15.2	91	22	4.51	3.82	32.5	0.23
VTP-11	Ňarád	A	14.6	74	25	3.5	2.73	12.5	0.16
FGG-2	Galanta	D	25	80	25	6.8	9.77	55.4	0.33
FGG-3			25	77	28	6.1	6.59	33.5	0.21
FGG-1	Galanta/Sládkovičovo	R	10.8	62	28	2.1	5.86	24.9	0.39
VZO-13	Zlatná na Ostrove	A	7.5	51	21	1.1	4.51	17	0.51
DS-2	Dunajská Streda	I	23	55	22	3.85	2.55	10.6	0.09
FGT-1	Topoľníky	A	23	74	18	5.4	1.01	5.26	0.04
FGHP-1	Horná Potôň	A	20	68	25	4.2	4.26	22.9	0.17
VHP-12-R	Horná Potôň		22.3	68	22	4.94	2.57	14.71	0.1
BPK-2	Poľný Kesov	I	4	49	20	0.6	2.95	7.17	0.63
FGPK-1	Poľný Kesov	R	11	70	20	2.44	2.14	8.89	0.17
BS-1	Senec	I	12	49	28	1.71	7.86	20.8	0.41
GTŠ-1	Šaľa	D	15	69	20	3.39	9.57	58.5	0.56
FGK-1	Nová Stráž	R	4	45	20	0.48	0.36	1.13	0.08
ČR-1	Čiližská Radvaň	A	6	82	32	1.8	3.84	5.98	0.47
HGZ-1	Zemné	A	15	55	20	2.38	1.8	7.87	0.11
HGK-1	Kolárovo	R	20.8	78	20	5.15	5.4	38.9	0.24
GN-1	Nesvady	A	2.7	60	20	0.48	2.65	14.1	0.92
VTB-1	Bruty	A	15	75	22	3.54	7.5	49.3	0.44
HGDŠ-1	Dolná Strehová	R	4	35	20	0.34	2.73	5.26	0.53
HG-18	Vinica	R	10	21	18	0.24	4.6	0.41	0.25
GTL-2	Rapovce	B	11.2	38	22	1.04	1.91	3.86	0.12
HBV-2A	Kalinčiakovo	R	11.1	25	18	0.46	2.51	0.56	0.16
HBV-1			25	25	18	1.05	8.73	1.95	0.25
S-3	Dudince	B	10.4	27	21	0.52	2.3	1.71	0.12
KMV-1	Sielnica	R	3	33	20	0.23	0.14	0.22	0.05
1-A	Sliač - Rybáre	B	11	33	18	0.79	1.94	3.08	0.15
K-2	Kováčová	B	25	48	18	3.14	3.16	11.9	0.12
B-3A	Santovka	R	15.5	26	18	0.69	4.35	1.48	0.2
HCH-1	Chalmová	R	13.4	33	18	0.97	2.08	3.3	0.13
BCH-3	Chalmová		5	39	18	0.48	2.37	5.15	0.42

Symbols: D – geothermal district heating, I – individual space heating, A – agriculture, R – recreation, B – balneology, Q: Water flow, ETH – geothermal energy production, CF – capacity factor.