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Geothermal Energy Use – Country Update for Slovakia

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ABSTRACT

Slovakia is a part of the Western Carpathians realm, an orogeny controlling geothermic activity of the territory through geological development, geodynamics and deep geological structure. Because of any recent volcanic activities, the entire territory of the country is of a moderate geothermic activity, with mean surface heat flow density of 82.1 $mW.m^{-2}$. Low to moderate enthalpy (up to 150 °C) single-phase, geothermal waters have been successfully sampled of low, to moderate-low thermodynamic quality.

Recently carried actions in reconstruction of geothermal energy database have documented 236 wells successfully sampling thermal waters at wellhead temperatures of T_{wh} = 18 – 135 °C, deliverability up to Q = 100 $l.s^{-1}$ and proven thermal capacity of 437 MWth since 1970's. Until 2019, 6,233 MWth were assessed as probable.

In 2017 (the last complete data accessible – see text for explanations), 114 wells were in active operation at a nameplate capacity of 229 MWth, generating 0.53 TWh,th of thermal energy and 1,988 TJ of heat. Only direct use projects are online. This does not account for large-scale heat pumps and small GSHP / BHE installations as relevant data are not available. In total, 86 wells support 48 sites where geothermal water is used for recreation and balneology, leading sectoral geothermal energy use in the country by far (1,118 GWh,th and 1,325 TJ). Since 2016, four hybrid (geothermal – natural gas) district heating plants are in operation based on 5 geothermal wells in towns of Galanta, Šaľa, Veľký Meder and Sereď (44 GWh,th and 159 TJ). Geothermal space heating and cooling is realized at 10 sites with optional cascades (75 GWh,th, 273 TJ), while 13 wells produce geothermal waters at 12 sites for greenhousing purposes (63 GWh,th, 230 TJ). A mean total load factor for all geothermal wells under recent production is 0.302.

Since the last Country Update, only three new wells were commissioned in Púšť, Poľný Kesov and Veľký Meder. No power production projects are officially in a process of licensing in the country. Several research projects are recently running with a support of the EU and the Government (Ministry of Environment) on hydrogeothermal evaluation (e.g. the Komárno High Block and the Komárno Marginal Block), sustainable management optimization (the Ďurkov depression) and shallow geothermal energy use, such is the GeoPLASMA-CE and MUSE (Interreg-CE and H2020). By July 2019 together 13 private-sector held claims on geothermal prospection areas were active e.g. in Vlčany, Lovča, Teriakovce, however data on realized actions are not accessible.

1. INTRODUCTION

In a last decade, legislative actions were adopted to promote use of renewable energy resources in Slovakia, responding to the Directive 2009/28/EC of the European Parliament and the Council on the Promotion of the use from energy from renewable energy sources (RES) and its amending directives 2001/77/EC and 2003/30/EC, that obliged an overall 14 % of RES on the primary energy mix by 2020. A proportion of geothermal energy on heat production reaches app. 2 % only.

Tradition in use of geothermal energy for curative and recreational purposes that owes to dozens of thermal springs in the country dates far beyond Medievals (Fendek et al., 1999). Systematic actions in geothermal resources prospection, however, have been launched in 70's to answer global concerns in fuel economics. Previous country updates (e.g. Remšík & Fendek, 1995; Fendek & Franko, 2000; Fendek & Fendeková, 2005, 2010, 2015) reported distribution of geothermal waters according to 27 geothermal prospective areas (GPAs). With transition towards goals given by the Water Framework Directive No. 2006/60/EC of the EU Parliament and the Council (WFD), geothermal reservoirs are adjusted to 31 (some just currently) delineated Geothermal Water Bodies (GWBs). Several of these (e.g. the Vienna Basin, Danube Basin Central Depression, Levoča Basin – SE part, Humenné Ridge) associate transboundary aquifers. This subsequently summoned a call on a database reconstruction, including wells in spas, previously omitted. Multiple regional hydrogeothermal studies carried on former GPAs assessed total probable reserves for 6,233 MWth (for discussion see Fričovský et al., 2020 paper from WGC2020), however no national scale booking has been carried yet.

Any research and prospection of geothermal resources follows the Act No. 569/2007 Coll. (Act on geology) as amended by the Act No. 311/2013 Coll., applying a provision on licensing withdrawals of geothermal waters in category B, and that sets objection on approvals by Ministry of the Environment as based on long-term pumping tests on wells, estimation of hydraulic, physical-chemical properties of water, including qualitative and quantitative monitoring (Fendek et al., 2016). The objection on geothermal water withdrawals and payment for those is 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 (and 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.).

2. GEOLOGY AND REGIONAL HYDROGEOTHERMICS

2.1 Review on regional geological structure

Geological structure of Slovakia owes to the Western Carpathians (WCs); the thrust-belt formed through the Alpine orogeny in the northern branch of the European Alpine mountain chain (Schmid et al., 2008, Plašienka, 2018), comprising north-vergent crystalline thick-skinned and (mostly Mesozoic) sedimentary thin-skinned nappe superunits. The WCs are divided into the Internal – IWCs and External – EWCs (Mišík, 1997).

The EWCs consist of thin-skinned nappes, composed of syn-orogenic turbiditic deposits (sandstones and claystone alternation) thrusted onto WC realm in Neogene, forming the Carpathian Flysch Belt. The Pieniny Klippen Belt to the south represents a complex shear zone remnants composed of "solid" Mesozoic carbonates enveloped with progressively weathering siliciclastics that forms a division line between the EWCs and IWCs. The latter are characterized by the Miocene basin and range morphological structure of the Core mountains Belt . In general, crystalline (metamorphic and plutonic complexes) early Paleozoic basement is enveloped by Mesozoic nappes where siliciclastics prevail in Early and Late Triassic, limestones, dolomites and transient varieties are major in a Mid Triassic, while lithology of Jurassic to Early (Mid) Cretaceous successions relate to shallow (organogene to detritic carbonates, less pelites) or deep (pelitic carbonates, pelites, marlstones) marine origin. Other characteristic feature of the Western Carpathians is the Central Carpathian Paleogene Basin (transition from basal conglomerates and detritic carbonates to claystone- , flysch-type and sandstone- dominated formations) transgressively overlying IWC nappes in the central and eastern Slovakia (e.g. Podtatranská kotlina basin). The sedimentary Neogene reaching particularly high thickness in the Vienna, Danube and East Slovakian basins expresses records of different depositional environments (continental to marine) developing through the realm of the Western Carpathians, where sand(-stones) clay(-stones) are variously altered, with minor contribution of carbonates or evaporites. The Miocene extension of the IWCs was accompanied by substantial volcanism, forming Miocene – Pliocene neovolcanic mountains in the central and eastern Slovakia. The Quaternary cover is exclusively of continental origin. Among prevailing siliciclastics, fresh-water carbonates develop where thermal springs pond.

2.2 Regional hydrogeothermics

2.2.1 Geothermic activity

Outline of geothermic activity in the Western Carpathians follows: add 1: different structure and depths of neotectonic block with a manifest in overall crustal thickness; add 2: non-uniform mantle propagation; add 3: spatial distribution of Neogene – Quaternary volcanism; add 4: local and regional hydrogeological conditions; add 5: course and depth-seating of major crustal fault systems (Fendek et al., 1999; Franko & Melioris, 1999).

For the region of the WCs, a mean geothermal gradient is 30 °C.km^{-1}. The surface heat flow density varies 50-120 mW.m^{-2} (Figure 2), with a mean of 82.1 ± 20 mW.m^{-2} (Bodiš et al., 2017). Highest geothermic activity is repeatedly documented within Eastern Slovakian Neogene Basin (90-130 mW.m^{-2}) and the Danube Basin Central Depression (> 90 mW.m^{-2}), decreasing slightly within tertiary intramountain depressions (40-70 mW.m^{-2}), whilst regional minima (30-50 mW.m^{-2}) are recorded from the Outer Flysch zone (Marcin et al., 2014; Majcin et al., 2017). Apparently, with absent recent geodynamic activity, zones of increased geothermic activity relate well with distribution of regional crustal thinning.

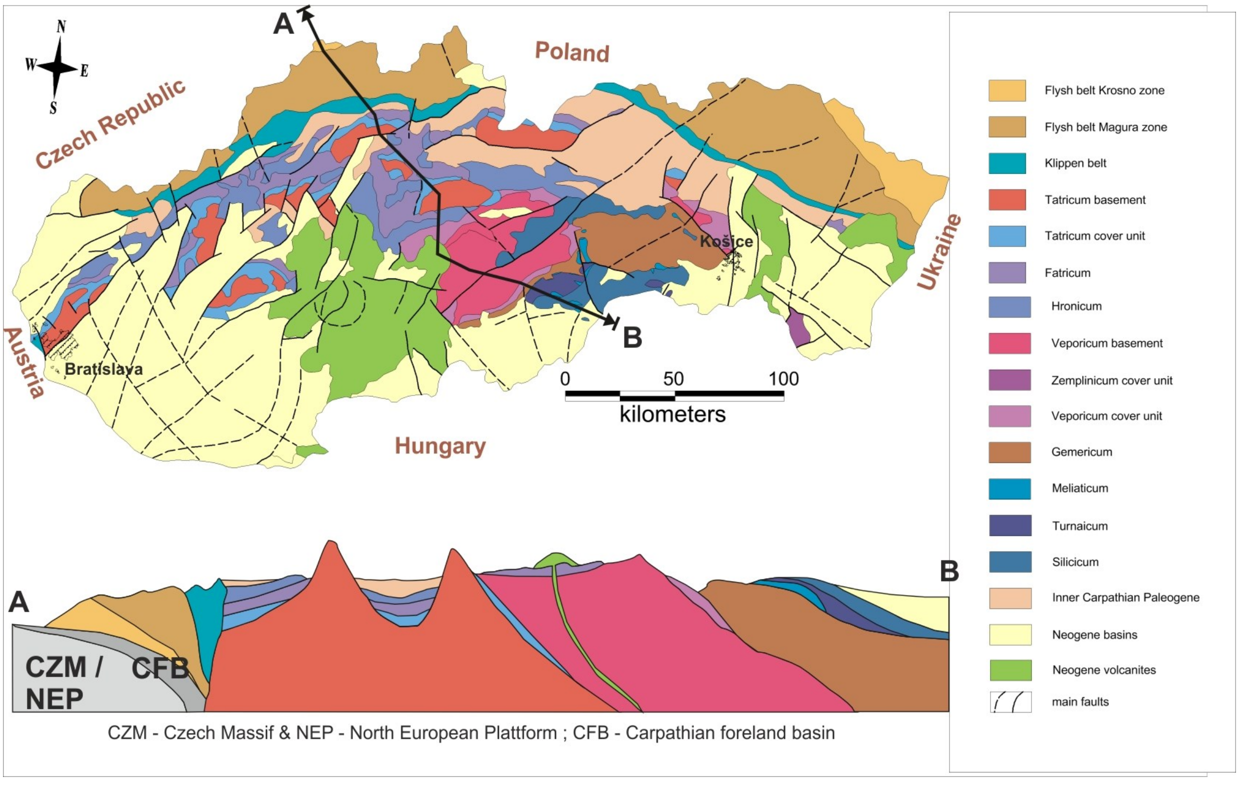

Figure 1: Simplified map of tectonic units of the Slovakia – the Western Carpathians.

2.1.2 Origin and quality of geothermal waters

Owing to geodynamic evolution and deep geological structure, geothermal resources associate with conduction-dominated orogenic belt / foreland basin play types (Moeck, 2014). The Beša-Čičarovce structure (part of the Trebišov Basin GWB) appears an exception, assuming the magmatic intrusion type (Moeck – Beardsmore, 2014). The structure, however, has not been subjected to a regional hydrogeothermal evaluation. Indices on presence of geothermal waters exist based on oil and gas wells and some geophysical measurements. Although generally conductive environment, presence of separate and spatially limited convection cells in reservoirs can not be omitted, whether due to formation of density gradient or driven by overheating (Fričovský et al., 2018). Apparently, several sub-types or concepts may be recognized for hydrogeothermal structures, not yet officially catalogued:

• structures associated with intramountain depressions: usually hydrogeologically open, with petrogenic type of chemistry; natural recharge at hydrogeological massifs at periphery; reservoirs in Mid Triassic carbonates; basin-constriction, fault-plane, lateral-leakage and bedrock-high systems (e.g. systems in the Liptov Basin or Levoča Basin – S and W part GWBs);

• structures associated with embayments of Neogene sedimentary basins: typically open to closed; petrogenic to mixed type of chemistry; natural recharge at hydrogeological massifs at periphery or through lateral inflow; reservoirs in Mid Triassic carbonates, Paleogene detritic carboates and conglomerates, Neogene sands and sandstones; stratified-reservoirs, lateral-leakage, and bedrock-high systems; (e.g. structures in the Piešťany Embayment or Ilava Basin GWBs);

• structures at footslopes of Neogene volcanic mountains and in adjacent basins: open to semi-open; petrogenic type of chemistry; natural recharge at slopes of volcanic systems or vertical evasion; reservoirs in Neogene volcanoclastics and sedimentary formations, deep reservoirs in Mesozoic carbonates; fault-plane and lateral-leakage systems; (e.g. systems in the Zvolen Basin, Žiar Basin and Bátovce Depression);

• structures associated with Neogene sedimentary basins: open to close, petrogenic to mixed chemistry; natural leakage (if any) at regional peripheries; stratified-reservoirs and basin-constriction types; reservoirs in Neogene siliciclastics or Mesozoic carbonates; e.g. (systems in the Danube Basin Central Depression, Moldava Basin, Trebišov Basin).

Single-phase, low to moderate-low exergy (SExI = 0.05-0.145) geothermal waters were sampled in wells (Fričovský et al. 2016), with temperatures through screened reservoir depths (tens to 3,600 m) of 20-150 °C (Černák et al., 2014). Geothermal models assume reservoir temperatures at 4,000-6,000 m up to 180-240 °C (Majcin et al., 2017). Geothermal waters are principially of marinogenic (originally seawater, or degraded), petrogenic (originally meteoric with various degree of vertical circulation) and mixed origin with complex chemistry (Bodiš et al., 2018). Thus, the TDS extends widely, between 0.4-90 $g.l^{-1}$ (Marcin et al., 2014).

2.2 Geothermal Water Bodies: situation by 2019

An initial proposal on 26 GWBs delineation in territory of Slovakia (Kullman ml. et al., 2005) adopted boundaries according to the GPAs (Franko et al., 1995), presented in country updates from 1995, 2000 and 2005. Following goals of the WFD, the geothermal database is now updated. Passporting additional wells from geological or hydrogeological prospection (including curative thermal waters) sampling thermal waters of T_{wh} > 18 °C revealed, however, position of wells out of primary boundaries, highlighting a need to redefine the entire concept of GWBs, both extending primary boundaries towards recharge zone or hydrogeological basins, or defining the new. Recently, 31 GWBs are listed (Figure 2), covering up to 36 % of the entire territory (17 638 km^2).

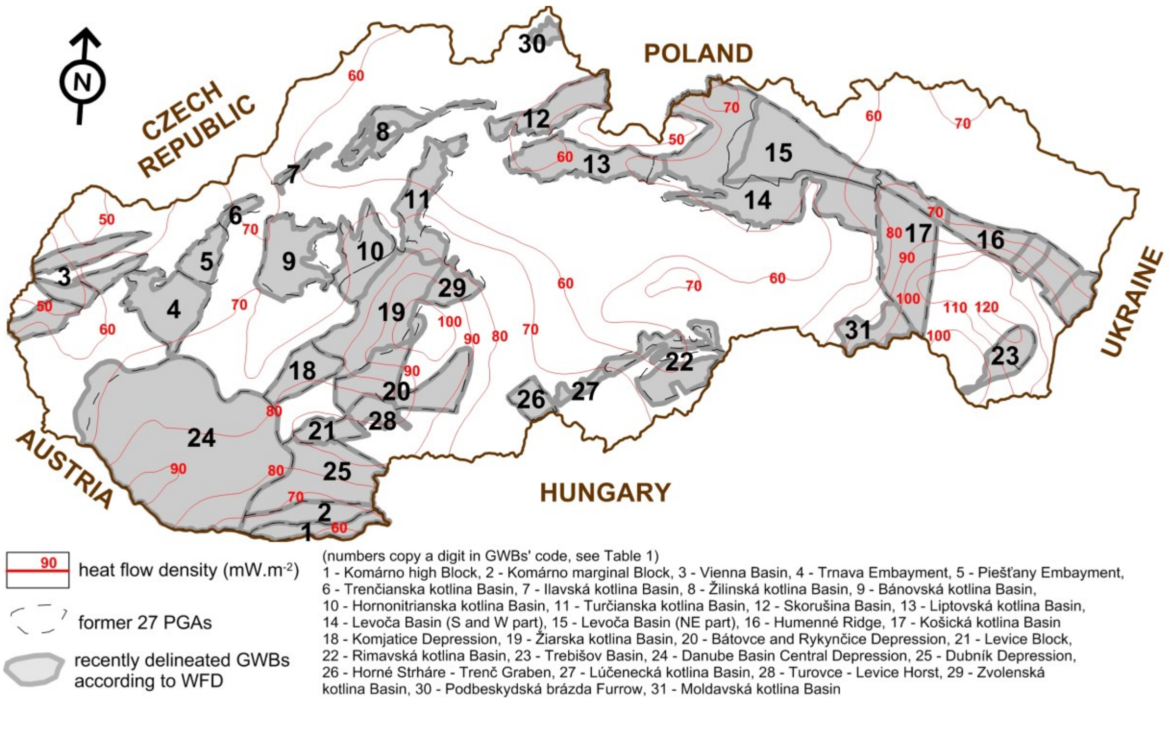

Figure 2: Geothermal Water Bodies in Slovakia: recent delineation with primary reservoir lithology and geothermic activity.

2.3 Geothermal potential

At current state-of-art, the geothermal database (still in processing) includes 236 wells already proving 437 MWth of geothermal reserves (unified reference temperature T_{ref} = 15 °C). A cumulative productivity of all wells counts Q = 2,716 $l.s^{-1}$. The number includes wells administered by the Inspectorate of Spas and Springs dedicated for curative purposes, however, proving a geothermal potential with temperature at a wellhead over 18 °C (39 wells in 13 localities). According to previous geothermal division of Slovakia, total probable reserves were estimated as for 6,233 MWth for 26 GPAs, however, frequently using different evaluation techniques (budget or volumetric method), time scaling (30 to 40 years) or reference temperature, either for GPAs not considering reinjection. Table 1 presents proven thermal potential and deliverability of actually listed GWBs, including primary aquifer lithology and stratigraphy.

Most of a proven potential (ca. 25 %) has been identified within the Danube Basin Central Depression – DBCD (48 wells, R_{pv} = 107 MWth, Q = 487 $l.s^{-1}$), followed by the Levoča B. – S and W part (12 wells, R_{pv} = 35 MWth, Q = 252 $l.s^{-1}$) and the Liptov B. (11 wells, R_{pv} = 26 MWth, Q = 201 $l.s^{-1}$). Reservoirs with karst-fissured permeability (Mid Triassic carbonates) prevail (126 wells, R_{pv} = 253 MWth, Q = 1,137 $l.s^{-1}$) among those of fissured (Mid Triassic dolomites, Paleogene breccia and volcanoclastics), pore (Neogene compacted sandstones) or intragranular in Neogene sands and gravels (48 wells, R_{pv} = 96 MWth, Q = 511 $l.s^{-1}$). Only 6 wells targeted Neogene volcanoclastics, products of mostly andesite and rhyolite volcanism, proving 4,65 MWt (1 %) and 44 $l.s^{-1}$.

Table 1: Geothermal Water Bodies in Slovakia: geothermal potential characteristics.

GWB code	GWB name	Wells (total / online)	R_{pv}	Q	Primary aquifer lithology (Ms – Mesozoic, Pg – Paleogene, Ng – Neogene)
		(-)	MWth	$l.s^{-1}$	(-)
SK300010FK	Komárno high Block	11/7	19.21	258	carbonates (Ms)
SK300020FK	Komárno marginal Block	5/0	3.13	19.3	carbonates (Ms)
SK300030FK	Vienna Basin	2/0	9.5	35	carbonates (Ms)
SK300040FK	Trnava Embayment	1/1	0.55	13.9	carbonates (Ms)
SK300050FK	Piešťany Embayment	16/6	19.4	115.9	carbonates (Ms), sandstones (Ng)
SK300060FK	Trenčianska kotlina Basin	0/0	0	0	carbonates (Ms)
SK300070FK	Ilavská kotlina Basin	12/6	2.92	44.6	carbonates (Ms)
SK300080FK	Žilinská kotlina Basin	13/9	6.28	94.5	carbonates (Ms), siliciclastics (Pg)
SK300090FK	Bánovská kotlina Basin	7/3	5.26	59.8	carbonates (Ms), siliciclastics (Pg)
SK300100FK	Hornonitrianska kotlina Basin	17/11	14.27	114.8	carbonates (Ms), siliciclastics (Pg)
SK300110FK	Turčianska kotlina Basin	16/7	10.77	91.8	carbonates (Ms), breccia (Ng)
SK300120FK	Skorušina Basin	2/1	18.29	127.9	carbonates (Ms)
SK300130FK	Liptovská kotlina Basin	11/6	26.26	201.5	carbonates (Ms)
SK300140FK	Levoča Basin (W and S part)	12/5	35.16	252.3	carbonates (Ms)
SK300150FK	Levoča Basin (NE part)	4/0	16.18	22.25	carbonates (Ms), breccia (Pg)
SK300160FK	Humenné Ridge	2/1	0.66	7.6	carbonates (Ms), sand/-stones (Ng)
SK300170FK	Košická kotlina Basin	4/0	78.22	172.7	carbonates (Ms)
SK300180FK	Komjatice Depression	1/0	2.5	11.4	sands, sandstones (Ng)
SK300190FK	Žiarska kotlina Basin	13/10	10.49	83.42	carbonates (Ms)
SK300200FK	Bátovce and Rykynčice Depression	1/0	1.62	11.83	volcanoclastics (Ng)
SK300210FK	Levice Block	2/1	20.74	76.66	carbonates (Ms), sand/-stones (Ng)
SK300220FK	Rimavská kotlina Basin	3/1	1.76	56.44	carbonates (Ms)
SK300230FK	Trebišov Basin	3/1	2.1	20.41	sands, volcanoclastics (Ng)
SK300240FK	Danube Basin Central Depression	48/27	106.8	487	sands, sandstones (Ng)
SK300250FK	Dubník Depression	4/1	3.7	24.27	sands, sandstones (Ng)
SK300260FK	Horné Strháre – Trenč Graben	5/2	1.82	28.43	sands (Ng)
SK300270FK	Lúčenecká kotlina Basin	1/1	1.04	10.63	carbonates (Ms)
SK300280FK	Turovce – Levice Horst	9/4	3.95	84.3	carbonates (Ms), sand/-stones (Ng)
SK300290FK	Zvolenská kotlina Basin	7/3	13.88	139.4	carbonates (Ms)
SK300300FK	Podbeskydská brázda Furrow	1/0	0.06	0.95	sandstones, breccia (Pg)
SK300310FK	Moldavská kotlina Basin	3/0	0.66	30.27	sands, sandstones (Ng)

3. GEOTHERMAL UTILIZATION AS BY 2017 (2019)

3.1 Remarks on actual reporting

As regulated by the Act no. 364/2004 Coll (Act on water) and its amendments, this CU presents and analyzes actual geothermal production based on geothermal water withdrawals reports to the Slovak Hydrometeorological Institute as of 2017. More actual data are not available by now. Yet localities exist where geothermal energy is utilized, however, no official reports are provided, such as several wells in Borša (Trebišov Basin), Sklené Teplice (Žiar Basin), Poľný Kesov and Komárno (both DBCD) and others. When compared to 2019, no new sites were added to the list as well as no sites online in 2017 were shut-down. With completion of datasets on actual use and distribution of sites, there changes at a different time-scale are made when compared to the CU submitted for the European Geothermal Congress 2018 (Fričovský et al., 2018b) or CU for WGC2015 (Fendek & Fendeková, 2016). A brief comparison for Slovak Republic between CUs from 2015 – 2020 is listed in Table 2.

Table 2: Geothermal potential and utilization comparison for recent and previous CUs.

parameter	WGC2015	WGC2020	remarks and notes
Number of wells	82	114	added wells providing geothermal water for healing in spas
Installed capacity (MWth)	136	229	corresponds to increase in number of online wells
Total yield ($l.s^{-1}$)	591	570	effect of obligation of operators to pay for reported withdrawals
Yearly heat production (TJ)	2185	1987	derived from cumulative productivity; 3 sites shut down

3.2 Geothermal energy production in general

Even though repeatedly presented optimistic prospects, geothermal energy is used for direct purposes only in the country, as by 2019. When taking results from 2017 as the most actual (assuming no major changes in total yearly geothermal water production), 114 wells work online, i.e. 48 % out of total. There are 74 sites that benefit from presence and production of a geothermal resource. At such configuration, the total installed thermal capacity when balanced for T_{ref} = 15 °C is 229 MWth (52 % of proven reserves). This represents a mean online output per well of 0.59 MWth. A sum of actual thermal output provided by operators is 67 MWth (15 % of proven reserves and 29 % of installed capacity). According to reported data, cumulative production of geothermal energy reached 528 GWh,th and 1,988 TJ as a result of cumulative production of geothermal waters of 16.7 $.10^6$ m^3. An average load factor of all wells producing has been calculated for 0.302.

Geothermal waters are recently used in 22 GWBs out of 31 (see Table 3). Actual thermal output above 5 MWth is reported only from 4 GWBs. The Danube Basin Central Depression is developed for the most, as a result of vicinity of the region to the capital (Bratislava) and multiply examined Neogene sands and sandstones, reducing a risk for production. 25 localities operate geothermal fluids, mainly for greenhouse heating, such as in Zemné or Zlatná na Ostrove. Within DBCD, the only geothermal (hybrid) district heating sites exist in Veľký Meder, Galanta, Šaľa and Sereď. Relatively high geothermal energy production in the Piešťany Embayment reflects existence of popular Piešťany Spas (6 wells). In the Levoča Basin S and W part, utilization of geothermal energy concentrates rather to the north (9.35 MWth, 2.37 .106 $m^3.yr^{-1}$), combining individual space heating (Veľká Lomnica), balneotherapy (Vyšné Ružbachy spa) and recreation (Poprad, Vrbov). Similarly to that, the geothermal energy is variably used in the Liptovská kotlina Basin (6 sites, 7.63 MWth, 1.98 $.10^6$ $m^3.yr^{-1}$), providing heat for buildings (Bešeňová), balneotherapy (Lúčky) and recreation (Bešeňová, Liptovský Ján).

Table 3: Distribution of geothermal energy production in GWBs (only producing actively).

GWB name	Online wells	Online thermal output	Q_{cumul}	number of sites (D)	number of sites (I)	number of sites (G)	number of sites (B)
	(-)	MWth	10^6 $m^3.yr^{-1}$	(-)	(-)	(-.)	(-)
Komárno high Block	7	2.16	1.55	0	0	0	3
Trnava Embayment	1	0.06	0.13	0	0	0	1
Piešťany Embayment	6	11.4	2.54	0	0	0	1
Ilavská kotlina Basin	6	1.35	0.57	0	0	0	1
Žilinská kotlina Basin	9	0.68	0.47	0	0	0	4
Bánovská kotlina Basin	3	0.59	0.23	0	0	0	3
Hornonitrianska kotlina Basin	11	2.96	0.82	0	0	1	3
Turčianska kotlina Basin	7	0.73	0.32	0	0	0	3
Skorušina Basin	1	0.71	0.192	0	0	0	1
Liptovská kotlina Basin	6	7.63	1.98	0	2	0	4
Levoča Basin (W and S part)	5	9.32	2.37	0	1	0	3
Humenné Ridge	1	0.2	0.09	0	0	0	1
Žiarska kotlina Basin	10	2.36	0.72	0	1	0	3
Levice Block	1	1.61	0.28	0	0	0	1
Rimavská kotlina Basin	1	0.37	0.081	0	0	0	1
Trebišov Basin	1	0.41	0.16	0	1	0	0
Danube Basin Central Depression	27	21.17	3.11	4	5	10	6
Dubník Depression	1	2.09	0.33	0	0	1	0
Horné Strháre – Trenč Graben	2	0.28	0.19	0	0	0	2
Lúčenecká kotlina Basin	1	0.26	0.079	0	0	0	1
Turovce – Levice Horst	4	0.45	0.211	0	0	0	3
Zvolenská kotlina Basin	3	0.84	0.265	0	0	0	3

* D – district heating, I – individual space heating, G - greenhousing, B – recreation and balneotherapy (together)

3.3 Direct geothermal energy utilization: state-of-art by sector

Up to obtained dataset analysis, 114 wells support 74 sites where geothermal energy is used for heat production. The large imbalance is due to adding wells producing curative thermal waters according to WFD. Following a long-term tradition in use of geothermal waters dated beyond to Medievals, sector of recreation (with or without balneotherapy) is predominant in utilizing geothermal waters in Slovakia.

In an attempt to collect recent and previous data, we realized to list sites according to their position in associated geothermal water bodies in text below.

3.3.1 District heating

Four geothermal district heating plants (actually hybrid, combined with natural gas boilers) are now in Slovakia (3 were reported for WGC2015) in towns of Galanta (1996), Šaľa (2011), Sereď (2012) and Veľký Meder (2016), all located within the DBCD. Only 5 wells contribute with 11 % on installed capacity (21.9 MWth), yielding the highest thermal output / well ratio (1.53 MWth). In 2017, the mean thermal output reached 7.65 MWt for all four, producing 159 TJ. A mean capacity factor for GDHS is rougly 0.23. This is because of both, overdesign of plants exceeding demand (Takács & Grell, 2005; Fendek et al., 2015) and a seasonal demand itself. Indeed, the entire CDDP is in a region of lowest mean number of heating (< 210) and frosty (94 - 100) days in a year country (Bochnníček et al., 2002).

The newest plant in Veľký Meder was commissioned in 2017, utilizing geothermal water at 10 $l.s^{-1}$ free flow and with a wellhead temperature of 92 °C, supporting a two plate heat-exchangers stations at a nameplate capacity of 2x1.55 MWth. The waste heat is then cascaded towards small health centre and thermal spa prior discharge into surface recipient.

Although Halás (2015) reported expectations to install a fifth GDHS or cogeneration binary plant nearby town of Košice exploiting geothermal waters associated with Mid Triassic carbonates of the Ďurkov Depression structure (Košice Basin GWB) where wellhead temperature is up to 135 °C and 55 $l.s^{-1}$ is measured as free flow, actions appear stand-by at now. Individually of the private investor, a state-supported study on sustainable reservoir management optimization is carried at the Dionýz Štúr State institute of Geology, planned for submission to the Ministry of Environment by December 2019.

3.3.2 Individual space heating

The individual space heating as a primary utilization purpose takes part at 9 sites: Bešeňová, Liptovský Trnovec, Veľká Lomnica, Borša, Dunajská Streda, Poľný Kesov, Veľký Meder, Senec and Diakovce. However, in Oravice, Vyšné Ružbachy and Topoľníky, heating of buildings supports other purposes, as greenhouses or spas. Fairly unique is use of geothermal waters to heat mine air in Nováky – Laskár along with supplying greenhouses. The installed capacity counts 34.6 MWth, representing 14 % contribution on total, whilst in 2017, the mean output of wells was 9.56 MWt, producing 273 TJ of heat (14 %) according to a cumulative production of geothermal waters at 2.2 .106 $m^3.yr^{-1}$. A mean calculated load factor is 0.34. Both, position of sites in different climatic regions (i.e. seasonal demand) and lower yield rates play a role on the reduction.

3.3.3 Greenhousing

Geothermal waters in agriculture are used mostly for greenhousing, counting 13 wells at 12 sites, out of which 10 operate in the DBCD: Tvrdošovce, Dunajská Streda, Ňarád, Zlatná n. Ostrove, Topoľníky, Horná Potôň, Vlčany, Šurany, Čiližská Radvaň and Zemné, one is located in the Dubník Depression – Bruty, and one in the Hornonitrianska kotlina Basin – Nováky (Laskár), already mentioned above. Although agriculture contributes with 20 % on total installed capacity (45.2 MWth), the actual thermal output drops to 9.43 MWth (14 %), substantially causing low mean load factor of 0.19. Besides seasonal demand, design of greenhouses if cascaded is typically not as high as the maximum available deliverability proven at given wells. In Tvrdošovce and Topoľníky, the geothermal water is seasonally distributed for space heating and outdoor pools.

3.3.4 Recreation

In listing sites and general description, we keep distinguishing between recreation and balneology, compared to tables in appendices. Under recreation, we understand all utilization of geothermal waters serving to heat pools and attractions out of any curative effects, rehabilitation procedures etc.

47 wells supply, thus, 35 sites where geothermal energy is used to heat pools, whether outdoor or indoor. These are: Bánovce n. Bebravou, Malé Bielice, Partizánske (Bánovská kotlina Basin); Diakovce (2 sites), Sládkovičovo (Galanta), Komárno, Nové Zámky, Poľný Kesov, Veľký Meder (Danube Basin Central Depression); Bojice and Chalmová both with two wells (Hononitrianská kotlina Basin); Dolná Streda and Vinica (Horné Strháre – Trenč Grabben); Kaluža (Humenné Ridge); Štúrovo and Virt with 3 wells per each and Patince (Komárno high Block); Podhájska (Levice Block); Poprad and Vrbov with 2 wells (Levoča Basin – W and S part); Liptovský Trnovec and Bešeňová (Liptov Basin); Rapovce (Lúčenecká kotlina Basin); Kurinec – Zelená voda (Rimavská kotlina Basin); Oravice (Skorušiná Basin); Koplotovce (Trnava Embayment); Mošovce – Drienok and Turčianske Teplice (Turčianska kotlina Basin); Kaličiakovo and Santovka (Turovce – Levice Horst); Sielnica (Zvolenská kotlina Basin); Rajec, Rajecké Teplice and Stráňavy (Žilinská kotlina Basin). Reading the list, recreation is provided from a geothermal waters in 18 out of 22 GWBs where thermal waters are produced recently, covering entire territory of the country.

According to available data, the total installed thermal output of wells in service for recreation is 93.7 MWth (40 %), reduced to 23 MWth (34 %) online in 2017. A cumulative production of 7.4 .106 $m^3.yr^{-1}$ generated 821 GWh,th and 190 TJ of heat from geothermal energy, that is 37 % and 35 % share on a total. The mean load factor of 0.22 reflects differences between utilizing geothermal waters in local (typically outdoor) spas of low demand on flow rates compared to proven deliverability (e.g. Diakovce, Kaličiakovo, Kurinec – Zelená voda); and resorts, typically combining indoor and outdoor recreation attractions serving 365 days a year (e.g. Podhájska, Vyhne, Vrbov).

3.3.5 Balneology

Herein balneology is considered individually. Current database lists 13 sites where 39 wells supply thermal water for curative purposes, that is 34 % out of total. Some have not been adjusted to previous CUs, or have not been coupled together with hydrogeological and hydrogeothermal wells in assessment proven reserves in the country. Thermal spas in Slovakia deal with a wide range of health problems supporting whether healing or regeneration processes. Besides bathing and pool activities (direct use in pools or heating a water for pools), geothermal waters at low mineralization and temperature is used for drinking, massages etc. A total installed capacity counts 34 MWth (15 %), reduced to an online thermal output of 17.9 MWth (27 %) operated in 2017. Cumulatively, wells in spa resorts delivered 5 .10^6 m^3 of geothermal waters according to our dataset, producing 155 GWh,th or 640 TJ of heat.

The mean load factor of 0.44 is highest amongst the direct use in the country. There are several factors in control. Exploitation of wells that declared curative effects is strictly regulated, and operators are obliged for precise and regular monitoring of groundwater quality and quantity, resulting in usually smaller withdrawals compared to proven flow rates. Compared to other purposes, wells in curative spa resorts produce 365 days a year.

Distribution of (thermal) spas is controlled by geology, chemistry and origin of geothermal waters. Spas Bojnice (Hornonitrianska kotlina Basin); Trenčianske Teplice (Ilavská kotlina Basin); Vyšné Ružbachy and Lúčky (Levoča Basin S and W part); Piešťany (Piešťany Embayment); Turčianske Teplice (Turčianska kotlina Basin); Kováčová and Sliač (Zvolenská kotlina Basin), Sklené Teplice (Žiarska kotlina Basin); Rajec and Rajecké Teplice (Žilinská kotlina Basin) produce geothermal waters associated with Mid Triassic carbonates, at some localities in connection with Paleogene or Neogene siliciclastics and breccia. The Dudince spa (Turovce – Levice Horst) is the only resort where sampled waters originate partly in Neogene.

3.3.6 Fishfarming

Two sites operate for fishfarming in the country. In the Turčianske Teplice, the TTK-1 well (see appendiced TABLE 3) provides geothermal water for fish culture, owned by the Slovak Fishermen's Association. Seasonal use of geothermal waters to supply culturing pools occurs in Vrbov as well, however, geothermal waters at the site are primarily operated for recreation and individual space heating.

3.4 Shallow geothermal energy and large heat pumps installations

Use of shallow geothermal energy in domestic or large-scale installations meets somewhat limited market because of a dense existing natural gas based supply grid. Although some stagnation in 2011, some recovery was observed in 2012 – 2014 (Fendek et al., 2016), assumed to continue in between 2015 – 2019. Only gross assumptions can be made based on sold units reported to the European heating product markets. However, analysis of heat pumps (or borehole heat exchangers) on such a small scale meets several limits:

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

The main estimate of the shallow geothermal energy use can be made by heat pump share on the market (see Table 4). Based on technical segmentation of different heat pump installations ground water source and vertical borehole heat exchangers were taken into account. In large installations, we rather refer to to statistics presented to the EGC2016 (Fendek et al., 2015), not including assumptions on domestic installations in a summary (in appendix tables). Geothermal heat pumps in large installations are used as a support for direct geothermal energy use in individual space heating (cascade systems) in Podhájska, Bojnice, Vyšné Ružbachy, Gbelany, Rajecké Teplice, Piešťany, Senec, Čilistov, Rabča and Borša.

3.5 Developments between 2015 - 2019

In between 2015-2019, several developments contributed to an overall geothermal picture in Slovakia:

- new well installation in Prievidza – Púšť (Hornonitrianska kotlina Basin) owned by Hornonitrianske Bane a.s., the largest brown coal producer in the country; reported first in 2016 – recently not in operation
- new well in Poľný Kesov (Danube Basin Central Depression); reported in 2015 – with data on actual production and drilling results concealed by a private investor, dedicated for individual space heating of a hotel

Table 4: Review on groud source heat pumps: technical segmentation for shallow geothermal energy source including horizontal earth collectors. Source: The European Heating Product Markets, 2018 Edition

Category	2015		2016		2017	
	Attributed volume	%	Attributed volume	%	Attributed volume	%
Ground water source heat pumps	60	36.05	80	35.68	90	35.25
Horizontal Earth Collectors	90	52.9	120	53.3	140	53.64
Vertical borehole heat exchangers	20	11.05	30	11.01	30	11.11
Total	*170*	*100*	*230*	*99.99*	*260*	*100*

- new well in Veľký Meder (Danube Basin Central Depression); reported in 2016 – described above, supplying geothermal (hybrid) district heating system, later cascaded towards health centre and a pool resort

- upgrade of thermal park in Štúrovo (Komárno high Block); commissioned after a final building approval for year-long resort transition, adding indoor pools

4. FUTURE PROSPECTS AND COMMENTS

4.1 Close-future expectations

The list of a close-future expectations is based on known actions already taking place in the country at sites, where geothermal energy is used in direct purposes:

- well GTP-1 in Piešťany (Piešťany Embayment) has been subjected to actualized pumping tests, obtaining provisions on geothermal water withdrawals by Ministry of Environment of the Slovak Republic, now ready to supply rising aqua center in town, with plans for individual space and pool water heating

- the M-2 well in Komárno (Komárno high Block) is ready to supply extending municipal pool resort in town and transition towards cascaded production, where heat will also be used for individual space heating of resort building

- the Lipany-1 well in Lipany (Levoča Basin, NE part) will provide geothermal waters for aquapark as a first site in the GWB.

4.2 Future prospects

A discussion on possibility of geothermal power production has been accenting since completion of wells in the Ďurkov Depression (Vranovská et al., 1999), apparently a most prospective hydrogeothermal system within the Košická kotlina Basin GWB. Halás (2015) reported plans towards construction of geothermal district heating system to supply a town Košice, second largest in the country. In the same paper, a discussion on a binary cycle power plant has been provided. Whatever a purpose, no project operates in the region now.

Prospection claims on geothermal energy held by private companies exist widely spread through the country. In the Košická kotlina Basin (Čižatice) and Žiarská kotlina Basin (Lovča), as well as nearby town of Prešov (Teriakovce) location of claims indicates prospection on availability of power production. Other claims in Vlčany, Dunajská Streda, Prašice, Liptovský Ján, Vyšná Kamenica, Piešťany, Tatranská Lomnica and Motešice may have prospects on direct use of geothermal energy, however, this is not officially known.

4.3 Geothermal energy and the country

A rapid transition in geothermal energy utilization development took part at the end of 20th Century. While in previous years a key role in prospection on geothermal resources has been covered by the state and its institutions, such is the Dionýz Štúr State institute of Geology (by the Ministry of Environment of the Slovak Republic), major contribution in drilling and exploration is nowadays carried by private investors. Unfortunately, no platform coupling academia / research institutions (e.g. is the Water Research Institute, Water Research Institute) with praxis (private sector) exist, with Slovak Geothermal Association stand-by. Such a situation is, however, alarming, and there is a call to restore such cooperation.

Recently, lessons on geothermal energy and its natural aspects are provided at the Dept. of Hydrogeology (Faculty of Natural Sciences, Commenius University in Bratislava). Courses on utilization technologies are held at Technical University of Žilina and Slovak Technical University in Bratislava. No specified study programme on geothermal energy is available.

5. SUMMARY

Compared to previous CUs, development of geothermal energy slowed down slightly in the country. While for WGC2015 Fendek and Fendeková (2015) reported six new wells drilled in between 2010 – 2015, three wells have been completed between 2015 – 2019 (according to official reports). However, reconstruction of a database reveals the real amount of thermal energy proven increased from 387 MWth towards 437 MWth, with some contribution of added wells in thermal spas dedicated for curative purposes (114 online now, 82 in the last CU), not included previously. Ongoing interpretation of WFD recalled an increase in number of geothermal water bodies, now 31, compared to previously delineated 27. Also the nameplate capacity of online wells increased from 136 MWth to 229 MWth. A crucial development, considering the scale is, however, building approval of district heating system for town of Veľký Meder.

Increase in number of wells does not however correspond with summary of a yearly geothermal energy production, showing a decrease that corresponds with a turndown of a mean cumulative yearly discharge (591 $l.s^{-1}$ to 570 $l.s^{-1}$). Indeed, the total amount of geothermal energy production dropped by 10 % or from 2,185 TJ towards 1,987 TJ. There are two aspects that must simply be accounted:

- some sites were reduced in activity, and thus in a demand, such is the thermal park in Galanta (DBCD), now using thermal waters for heating (district and individual) only

- some sites may shut-down, such is a case of Kremnica, where geothermal waters supplied pools, now geothermal water is drained within conduit system without any use prior outlet

- given by the Act No. 364/2004 Coll., operators are obliged to report withdrawals and pay, however, sites where geothermal energy is used do exist, although not reported to the Ministry of Environment (e.g. Borša in the Trebišov Basin or Poľný

Kesov in DBCD), some may modify an overall discharge, ostensibly reducing yield rates, and, thus, production characteristics. No integrated and automatic systems on withdrawal monitoring exist.

No shut-downs in between 2017 – 2019 are known. For 2017 (last complete data available), the total installed capacity of online wells amounts 229 MWth. At cumulative yearly geothermal water production of 16.68 .10^6 m^3 the total energy production counts 1,987 TJ from 114 wells supplying 74 sites.

A first summarizing report on geothermal energy utilization in Slovakia (as part of former Czechoslovakia) presented to a global community is of 1975 at UN Symposium on the Development and use of geothermal resources (Franko & Račický, 1975). In continuation to that, sector of recreation or use of geothermal waters for heating pools (including pools in curative spas) prevail in the country. Indeed, if balneotherapy is included into recreation (symbol B) 86 wells (76 %) produce at 48 sites (65 %) 66 percents (1,325 TJ) of geothermal energy generated in the country. According to expectations, number of sites for recreation with use of geothermal waters will increase in a close future.

For heating, 4 sites operate as (hybrid) district heating systems, at 10 space is heated individually 365 days a year, 3 sites use thermal waters for heating residential spaces individually and 10 sites work with large heat pump installations, producing 323 TJ of heat in 2017. For agricultural purposes (greenhousing prevails) geothermal waters are used at 12 sites with a total heat production of 229 TJ. Similarly to previous CUs, no geothermal power plant is even in a phase of construction or drilling in the country. Although of willing optimism, this is, nowadays, a question of mandatory investments.

REFERENCES

Bochníček, O., Lapin, M. and Soták, J.: Mean annual number of heating, summer and frosty days 1:2000000. In: Miklós, L. (Ed.): Lanscape Atlas of Slovak Republic, *Ministry of Environment of the Slovak Republic, Bratislava*, (2002).

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).

BRG BUILDING SOLUTIONS: The European Heating Product Markets, 2018 Edition – Slovakia. June 2018, Manuscript, web access: http://staging.brgbuildingsolutions.com

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)**, (1999), 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**, (1999), 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, (2016b).

Fričovský, B., Vizi, L., Surový M. and Mižák, J.: Numerical indices implications on reservoir convection for the Ďurkov depression hydrogeothermal structure, Košice Basin, Geologické práce, Správy, 132, (2018), 3-30 [in Slovak, English abstract and summary].

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).

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 [in Slovak, English abstract and summary].

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.

Mišík, M.: Slovakia. in: Encyclopedia of European and Asian Regional Geology, Moores, E. M. and Fairbridge, R. W., (Ed.), 656-664, *Springer Publishers, Dodrecht* (1996).

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, Proceedins 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.

Remšík, A. and Fendek, M.: Geothermal Country Update for Slovakia, Proceedings World Geothermal Congress 1995, Florence, Italy, (1995).

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.

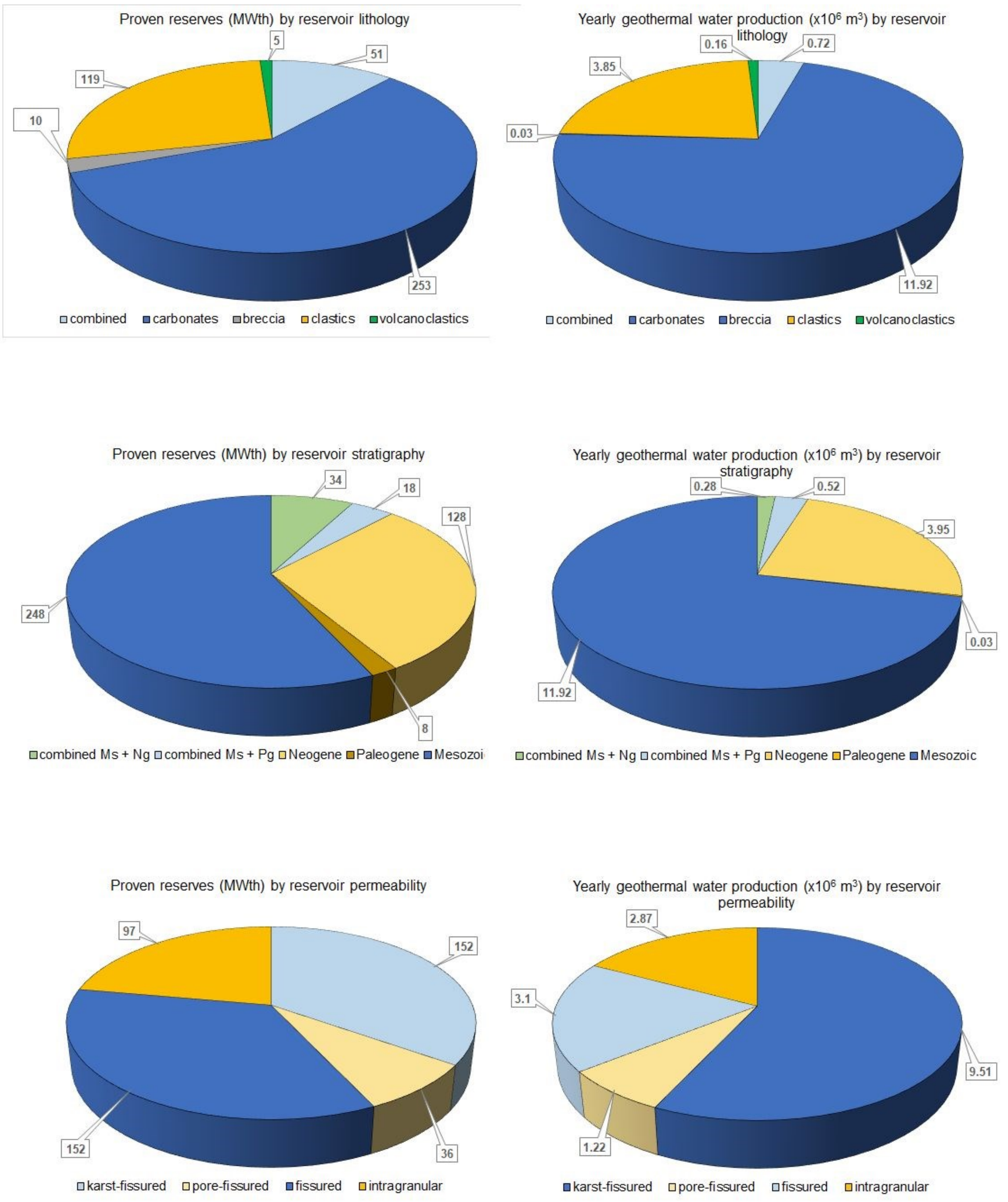

Figure 3: Distribution of proven reserves and cumulative geothermal water production in different geological and hydrogeological conditions.

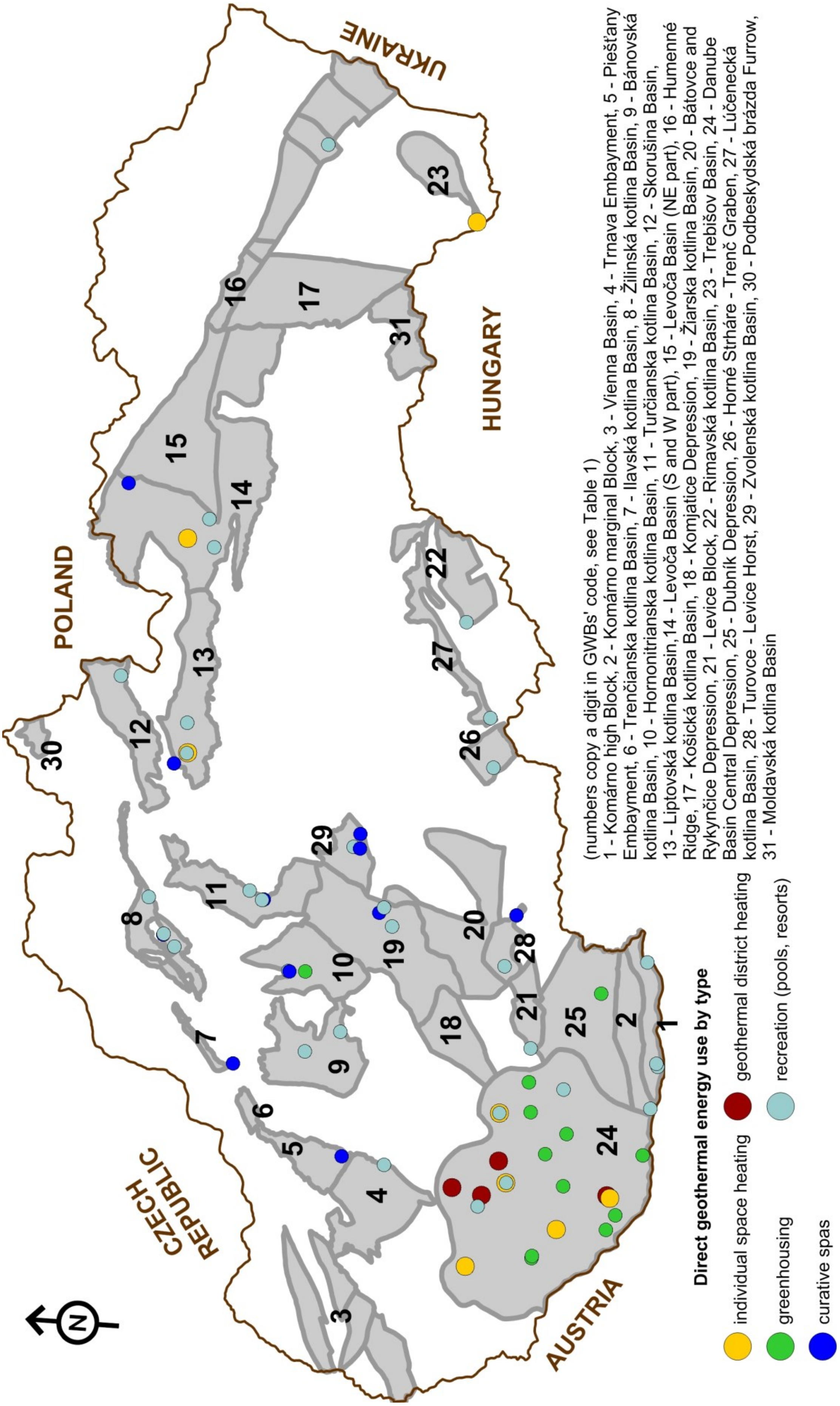

Figure 4: Geothermal sites in Slovakia by type of use up to 2019. Note many may overlap due to scale.

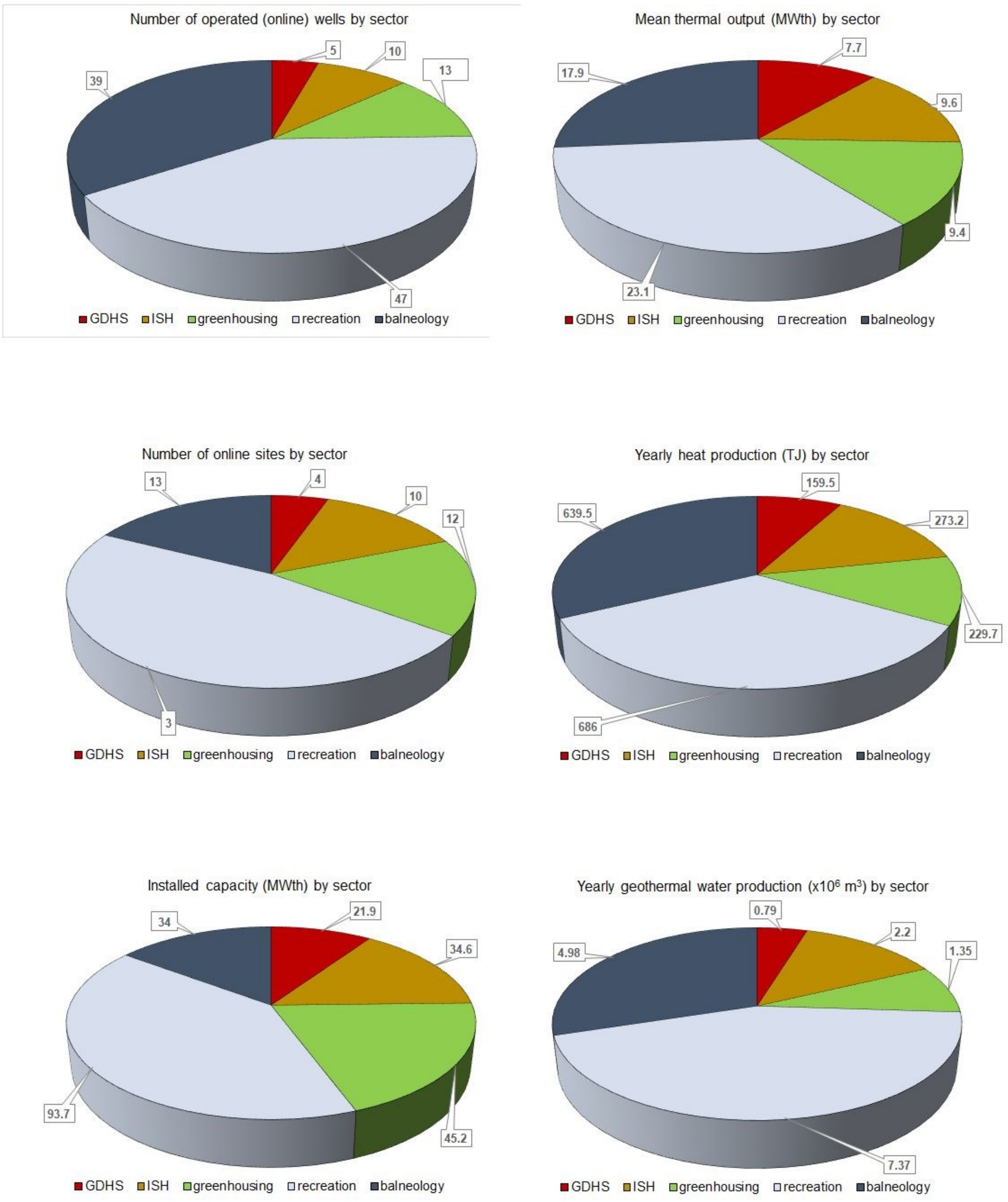

Figure 5: Direct geothermal energy use in Slovakia – distribution by energy sector. Note that fishfarming (scale) and heat pumps (uncertainty) are not included; recreation and balneology is depicted individually.

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2019	0	0	1,369	5,36	2,584	5,207	1,950	15,720	510	1,630	6,442	27,917
Under construction in December 2019	0	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Funds committed, but not yet under construction in December 2019	0	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Estimated total projected use by 2020	0	0	0	0	n/a	n/a	2,850	22,900	n/a	n/a	2,850	22,900

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019 (OTHER THAN HEAT PUMPS)

Locality		Type	Maximum Utilization			Capacity	Annual Utilization		
			Flow Rate	Temperature (ºC)			Ave. Flow	Energy	Capacity factor
			(kg/s)	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	
OPKS	Štúrovo	B	2.81	35.8	22	0.5	2.81	1.24	0.08
VŠ-1			49	39	22	4.86	1.01	0.18	0.01
FGŠ-1			13.1	40	22	7.33	13.1	29.75	0.13
SB-2	Patince	B	45	27	18	2.26	6.45	7.37	0.1
JRD	Virt	B	6.6	26	18	0.3	4.4	4.68	0.47
HVB-1			10.00	26	18	0.46	7.2	7.65	0.5
vrt VŠE			18.3	24	18	0.69	16	12.75	0.57
KB-1	Koplotovce	B	14.5	24	20	0.55	4	2.13	0.11

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019 (OTHER THAN HEAT PUMPS) - continued

			Maximum Utilization			Capacity	Annual Utilization		
Locality		Type	Flow Rate	Temperature (°C)			Ave. Flow	Energy	Capacity factor
			(kg/s)	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	
VLÚ-2	Piešťany	B	4	17	15	0.03	0.62	0.16	0.35
VLÚ-3			3.4	40	20	0.34	2.75	6.94	0.65
V-5			24.5	63.5	20	4.7	13.3	132.97	0.49
V-1			23.5	65.5	20	4.69	23.5	141.12	0.9
V-4A			24	65	20	4.74	24	142.58	0.9
V-8			2.2	65.3	20	0.44	2.2	13.15	0.89
SB-3	Trenčianske Teplice	B	0.3	38.1	20	0.03	0.18	0.4	0.35
SB-5			1	38.2	20	0.09	0.87	2	0.67
V-2			2	39.6	20	0.2	1.39	3.43	0.55
TT-2			2	38.5	20	0.19	1.68	3.93	0.63
P-1			4.75	38.1	20	0.44	4.62	10.57	0.75
V-3			10.75	39.6	20	1.06	9.17	22.67	0.68
BJ-22	Rajecké Teplice	B	2.3	36.2	20	0.2	0.19	0.39	0.05
BJ-19			1.27	34.2	20	0.1	0.37	0.67	0.21
B-1			2.4	37.8	20	0.22	0.51	1.15	0.18
B-2			2.5	38	20	0.23	0.51	1.16	0.17
B-3			2.5	37.8	20	0.23	0.51	1.15	0.17
BJ-21 A			5.5	33.9	20	0.42	4.68	8.24	0.62
RT-1	Rajecké Teplice	B	3.8	38.6	20	0.36	1.9	4.7	0.39
Rk-22	Rajec	B	22	26	20	0.6	2.15	0.64	0.03
HŽK-2	Stráňavy	B	22	24	20	0.84	5	2.66	0.1
HGTP-1	Partizánske	B	12.8	20	18	0.37	0.27	0.03	0
MB-3	Malé Bielice	B	8.5	40	20	0.89	1.08	2.73	0.1
BnB-1	Bánovce n. Bebravou	B	17	40	20	1.78	6.25	15.77	0.28
PA-7	Bojnice	B	4	39.7	20	0.4	2.35	1.47	0.12
BR-6	Bojnice	B	4	40.2	20	0.4	2.89	1.86	0.15
BR-2	Bojnice	B	2.2	50.5	20	0.31	2.38	7.63	0.78
Z-2			6.5	49.9	20	0.9	4.16	15.6	0.56
Termálne			6.6	46	20	0.82	4.48	14.65	0.56
BR-1			10.6	46.2	20	1.32	5.61	18.47	0.45
Š1-NB II	Nováky - Laskár	A	22	46.2	20	1.32	5.61	18.47	0.45
V-3	Mošovce-Drienok	B	4	18.5	17	0.06	1.9	0.36	0.17
B-2	Turčianske Teplice	B	0.003	45.2	20	0.0004	0.003	0	0.75
TJ-3	Turčianske Teplice		0.003	46.9	20	0.0004	0.003	0	0.75
Modrý b.	Turčianske Teplice		0.74	46.9	20	0.09	0.74	2.5	0.89
Ľudový b.	Turčianske Teplice		4	41.2	20	0.42	2.46	6.58	0.5
TJ-20A	Turčianske Teplice		7	42.8	20	0.78	4.41	12.65	0.51
TTK-1	Turčianske Teplice	F	3.5	27	21	0.18	1.26	0.4	0.07
OZ-2	Oravice	B	100	56	26	17.2	6	22.87	0.04
BJ-101	Lúčky	B	8.91	31.4	25	0.59	2.17	1.69	0.1
HGL-3			12.5	35.2	25	1.01	4.89	6.31	0.2
FGTB-1	Bešeňová	I	32	66	26	6.83	14.84	49.23	0.23
ZGL-1	Bešeňová	B	27	62	25	5.3	23.46	108.36	0.65
ZGL-2/A	Liptovský Trnovec	B	31	60	28	5.18	10.01	40.03	0.25

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019 (OTHER THAN HEAT PUMPS) - continued

Locality		Type	Maximum Utilization			Capacity	Annual Utilization		
			Flow Rate	Temperature (°C)			Ave. Flow	Energy	Capacity factor
			(kg/s)	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	
vrt Rudolf	Liptovský Ján	B	24	27.5	21	1.21	12	10.37	0.26
GVL-1	Veľká Lomnica	I	35	62	25	6.88	1.09	5.01	0.02
Izabela	Vyšné Ružbachy	B	20	20.2	18	0.42	2.26	0.63	0.05
Vr-1	Vrbov	B	28.3	56	22	4.86	22.79	96.99	0.63
Vr-2	Vrbov		33	59	22	6.08	22.98	106.27	0.55
PP-1	Poprad	B	61.2	48	22	6.6	25.94	84.76	0.41
GTH-1	Kaluža	B	4	39.4	22	0.41	2.86	6.28	0.49
ST-2	Sklenné Teplice	B	1.09	51.4	20	0.16	0.15	0.6	0.13
Banský			0.76	39.1	20	0.07	0.66	1.6	0.07
ST-4			16	57	20	3	2.84	13.17	0.14
ST-5			4.4	46	20	0.57	2.2	7.6	0.4
ST-1			3.03	52.1	20	0.45	1.8	7.24	0.51
STH-2	Sklenné Teplice	B	3	44.8	21	0.36	0.77	2.44	0.19
HGV-3	Vyhne	B	5.5	29	20	0.32	0.3	0.35	0.03
H-2			2.5	35.8	21	0.21	1.4	1.45	0.38
H-1			5	36	21	0.44	1.18	2.24	0.16
Po-1	Podhájska	B	53	80	34	14.42	8.91	50.72	0.11
GRS-1	Kurinec	B	10.5	33	18	1.01	6.1	4.87	0.15
HJ-6	Borša	I	8.5	32	20	0.58	8.5	7.8	0.41
FGTv-1	Tvrdošovce	A	20	70	18	4.6	0.38	2.46	0.02
Di-1	Diakovce	B	4	38	21	0.39	0.71	1.52	0.13
Di-2	Horné Saliby	I	12	68	26	2.66	7.28	38.08	0.46
Di-3	Horné Saliby	B	15	19	18	0.25	2.54	0.32	0.04
VM-1	Veľký Meder	D	10.4	92.9	20	3.28	6.71	10.07	0.1
Č-1	Veľký Meder	B	10	79	20	2.59	5.23	38.2	0.47
Č-2	Veľký Meder	I	18.2	57	20	3.2	10.95	50.71	0.5
GNZ-1	Nové Zámky	B	4.5	59	20	0.83	2.69	5.49	0.21
SEG-1	Sereď	D	9	66	20	1.94	1.22	7	0.11
DS-1	Dunajská Streda	A	15.2	91	22	5.82	2.33	13.1	0.07
VTP-11	Ňarád	A	14.6	74	25	3.6	3.38	15.39	0.14
FGG-2	Galanta	D	25	80	25	6.8	11.02	43.59	0.2
FGG-3			25	77	28	6.49	7.83	47.55	0.23
FGG-1	Sládkovičovo	B	10.8	62	28	2.13	5.8	24.63	0.37
VZO-13	Zlatná na Ostrove	A	7.5	51	21	1.25	3.59	10.12	0.26
DS-2	Dunajská Streda	I	23	55	22	3.85	2.71	11.19	0.09
FGT-1	Topoľníky	A	23	74	18	5.68	3.38	19.49	0.11
FGHP-1	Horná Potôň	A	20	68	25	4.43	5.29	18.85	0.14
VHP-12-R	Horná Potôň	A	22.3	68	22	4.94	2.57	14.71	0.1
BPK-2	Poľný Kesov	I	4	49	20	0.6	3.99	14.54	0.77
BPK-1	Poľný Kesov	B	1	26	20	0.15	0.3	0.24	0.07
FGV-1	Vlčany	A	10	68	22	2.22	8.3	23.56	0.34
BS-1	Senec	I	12	49	28	1.71	6.53	17.23	0.32
GTŠ-1	Šaľa	D	15	69	20	3.39	8.41	51.28	0.48
GŠM-1	Šurany	A	3.5	49	18	0.5	0.5	0.52	0.03
M-2	Komárno	B	4.5	42	22	0.51	1.2	3.19133	0.197
ČR-1	Čiližská Radvaň	A	6	82	32	3.3	3.84	5.98257	0.057

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019 (OTHER THAN HEAT PUMPS) - continued

Locality		Type	Maximum Utilization Flow Rate (kg/s)	Temperature (°C) Inlet	Temperature (°C) Outlet	Capacity (MWt)	Annual Utilization Ave. Flow (kg/s)	Energy (TJ/yr)	Capacity factor
HGZ-1	Zemné	A	15	55	20	2.38	3.75	17.4	0.22
VTB-1	Bruty	A	15	75	22	2.4	10	69.54	0.87
HGDŠ-1	Dolná Strehová	B	4	35.2	20	0.34	3.63	6.98	0.65
GTL-2	Rapovce	B	11.2	38	22	1.04	4	5.08	0.25
HBV-2A	Kalinčiakovo	B	11.1	25	18	0.46	1.84	0.69	0.03
HBV-1			25	25	18	1.05	3.9	1.45	0.04
S-3	Dudince	B	10.4	27.3	21	0.52	3.2	2.56	0.15
KMV-1	Sielnica	B	3	33	20	0.23	0.2	0.34	0.05
1-A	Sliač - Rybáre	B	11	33	18	0.83	2.52	4.78	0.18
K-2	Kováčová	B	25	48	18	3.14	5.69	21.46	0.22
TOTAL		-	2,845	-	-	437.25	570.3	1,987	-

TABLE 4. GEOTHERMAL (GROUND SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2019 (herein small domestic installations are not included)

Locality	Ground or Water Temp. (°C)[1)]	Typical Heat Pump Rating or Capacity (kW)		Number of Units -	Type[2)] -	COP[3)]	Heating Equivalent Full Load Hr/Year[4)]	Thermal Energy Used[5)] (TJ/yr)	Cooling Energy[6)] (TJ/yr)
Podhájska	40	20		1	W	3.8	9,360	0.153	n/a
Bojnice	38	40		1	W	4.2	4,350	0.273	n/a
Vyšné Ružbachy	19	778		2	W	3.7	8,250	6.845	n/a
Gbelany	9	23		1	W	4	4,550	0.115	n/a
Rajecké Teplice	34	489		3	W	4.5	7,600	4.725	n/a
Piešťany	45	43		2	W	5.4	5,600	0.208	n/a
Senec	40	106.8		2	W	5.5	7,900	0.729	n/a
Čilistov	38	43		2	W	5.6	4,750	0.176	n/a
Rabča	19	81.2		2	W	5.9	3,800	0.266	n/a
Borša	n/a	n/a	n/a	1	W	n/a	n/a	n/a	n/a
TOTAL		1,624		16			50,160	13.49	

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2019

Use	Installed Capacity (MWt)	Annual Energy Use (TJ/yr = 10^{12} J/yr)	Capacity Factor
Individual Space Heating	34.6	273.2	0.38
District Heating	21.9	159.5	0.35
Air Conditioning (Cooling)	0	0	0
Greenhouse Heating	45.02	229.3	0.26
Fish Farming	0.18	0.4	0.07
Animal Farming	0	0	0
Agricultural Drying	0	0	0
Industrial Process Heat	0	0	0
Snow Melting	0	0	0
Bathing and Swimming	127	1325	0.4
Subtotal	229.4	1987	0.34
Geothermal Heat Pumps	1.6	13.5	-
TOTAL	231	2000.5	-

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2015 TO DECEMBER 31, 2019 (excluding heat pump wells)

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1)]	(all)	0	3	0	0	4.707
Production	>150° C	0	0	0	0	0
	150-100° C	0	0	0	0	0
	<100° C	0	3	0	0	4.707 (2 of 3 wells data are available)
Injection	(all)	0	0	0	0	0
Total		0	3	0	0	4.707

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015	2	7	9	-	-	42
2016	2	7	9	-	-	42
2017	2	7	9	-	-	42
2018	3	7	9	-	-	42
2019	3	7	9	-	-	42
Total	3	7	9	-	-	42

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2019) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	6.25	2.5	3.0	-	95	5
2000-2004	3.72	1.32	3.6	-	82	18
2005-2009	4.27	14.4	48.59	-	95	5
2010-2014	3.96	11.61	5.73	-	93	7
2015-2019	n/a	n/a	n/a	n/a	n/a	n/a