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The Current Status of Geothermal Energy Research and Use in Bosnia and Herzegovina

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ABSTRACT

Geothermal research, development and use in Bosnia and Herzegovina (B&H) have been performed from 2010 to 2014 in similar qualitative and quantitive level as 2005 - 2009 with exception of greater application of small GHP systems. Only one hydrothermal new field is discovered (Domaljevac) and existing fields are not enlarged with new drillholes except Slobomir near Dvorovi in this period. Therefore, geothermal indications and significant achieved results of research with the purpose of further successful investigations are presented.

Central and northern parts of B&H north of line Bihać-Prozor-Foča – Internal Dinarides, 40% of the whole territory, have significant hydrogeothermal resources with 87 active deposits, while in the southern part - External Dinarides there is not any indication of geothermal potential. The most productive large confined deep systems are in hyperthermal Pannonian basin and numerous convective systems in semi opened structures in other regions. The main aquifers are karstified Mesozoic carbonates, among them Triassic limestones with great effective thickness, more than 500 m and the highest energetic potential.

All active deposits with springs and wells present low enthalpy resources (<400 kJ/kg) with temperatures less than 100°C, while very abundant aquifers with enthalpy greater than 500 kJ/kg are proved in the collapsed drillhole Bij-1- Semberija at depth of 2,410 m only. Total proved power of 87 deposits is 251 MWt and energy 3,965.47 TJ/year and possible power is ca 795 MWt with reference to 10°C with energy of 12,539.33 TJ/year. To utilize these proved powers, reconstruction works in wells of ca 30 deposits should be done, because of the decrease of their flow rates caused by various factors and new deeper drillings in ca 60 deposits. Presented data undoubtedly show the possibility of sustainable use of geothermal energy in numerous sites, but many obstacles make reality of application quite different.

Power of hydrogeotherms in used 31 deposits is 206.3 MWt with individual power from 0.1 to 15 MWt while geothermal direct heat use is about 22 MWt which indicates a very low level of utilization of geothermal energy compared to quoted available capacities. As the temperature outputs from installations are far higher than 10°C i.e. the differences of temperature input and output of systems are very small, the real power utilization is much lower than it is possible. Very small capacity factor (ca 0.35) is clear evidence also of inadequate and low use of installed geothermal facilities.

Direct use of geothermal energy is implemented at 21 localities. Spas and recreation centers are the main users of hydrogeothermal energy (18) and a minor part individual space heating (6). At 3 spas are installed heat pumps only, but there are dozens of pumps units which extract heat from ground waters for heating of buildings, public institutions and individual houses. There are 20 thermal and thermomineral spas and recreations centers where swimming pools are heated by geothermal water directly or indirectly through heat exchangers and GHPs.

Heating of buildings using heat pumps is a substantial increase compared to the previous period. It is evident a growing number of companies involved in installing heating systems using heat pumps.

The most significant works in 2012 were the reconstruction of 2 wells - Dv-1 and Sv-1 - Semberija (not yet in exploitation) and drilling a new well for hydrocarbons at locality near Ob-1 - Obudovac – Bosnian Posavina.

1. INTRODUCTION

The electricity production in Bosnia and Herzegovina with a population of ca 3.8 million, amounts to 14695 GWh/yr as of December 2014; fossil fuels 61.6%, hydropower38 % and other renewable sources amounts to 0.4%, what is similar to data from 2009 (APPENDIX - Table 1). Nowadays there are no expectations or projects for any production of electricity from geothermal. The first solar power plant began with work in 2013 with a production of 516 MWh/year from solar photovoltaic power plant and wind power plant with power of 300 kW; this is the first usage of these new and renewable energetic resources in B&H for electricity production. There are some projects for utilization of wind, solar within the renewables in the following period. There are not supports from government toward direct use of geothermal energy through different projects in the present period but various private investors and users in the terrain try in the frame of their activities and possibilities investigate and use this kind of energy.

Investigation and exploitation of hydrogeotherms as natural mineral resources is under jurisdiction of two entities of state in Bosnia and Herzegovina: 1) Federal Ministry of Energy, Mining and Industry (Federation of Bosnia and Herzegovina - FB&H) and 2) Ministry of Industry, Energy and Mining (Republic of Srpska - RS). These two ministries give approvals for investigation and exploitations. Concessions for explorations in FB&H give ministries of ten cantons and Ministry of Industry, Energy and Mining in Republic of Srpska.

There are entity incentives and subsidies funds for exploitations of renewable energy resources: Fund for Protection Environment of FB&H from 2003 and Fund for Protection of Human Environment and Energy Efficiency of RS from 2011, but so far there have been no investments.

Two main projects about geothermal have been made in this period: Catalogue of mineral, thermal and thermomineral waters of FB&H 2006 – 2011 with GIS database by Geological Survey of FB&H and Atlas of Geothermal Resources of RS in 2012 by Republic Geological Survey. These two entity surveys are involved in geothermal research, but now have not any project in operation. There is no government funding or participation for geothermal energy exploration – exploratory and productive drillings and use after 1992. Because of this fact the drilling activities are significantly diminished compared with the period before 1992. There are a few domestic companies for drilling of shallow drillholes and wells up to depth of about 500 m but for deeper drilling are required companies from countries in the region.

The attempts of initial projects of the use of hydrogeoterms for district heating were done in Banja Luka and Bijeljina, but now the project has not started.

One can expect governmental stimulations by new regulations to facilitate and enlarge investigations in new geothermal fields, deeper systems of higher enthalpy, doublet production-reinjection well systems and polyvalent use of hydrogeotherms. Particular support and financial stimulation of the use of renewable resources are expected for individual houses and small business objects to decrease consumption of conventional emergent and to protect human environment as it is the case of good practice in EU.

We expected a larger number of projects that promote the use of geothermal energy in B&H as a project LEGEND (Low Enthalpy Geothermal Energy Demonstration Cases for Energy Efficient Building in the Adriatic area) and deal with the concepts of energy efficiency and the use of low-enthalpy geothermal energy in the Adriatic area. This is a European project co-financed by the IPA Adriatic Cross Border Cooperation Programme and managed by the Province of Ferrara (Italy); nongovernmental organization LIR -Banja Luka implements this project which covers north-western part of B&H.

2. GEOTHERMAL RESOURCES AND POTENTIAL

2.1. Aspects of research

The first researchers of mineral, thermal and thermomineral waters in B&H were Austrian geologists E. Ludwig (1890) and F. Katzer (1919), they performed for the first time physical and chemical analyses with geological data, utilization and explanation of water genesis. Geothermal data and parameters are obtained thanks to oil investigation performed over 50 years ago and fundamental and detailed works with drillings in 35 deposits mainly from 1975 to 1992.

All geothermal fields in the Pannonian basin were discovered during hydrocarbon exploration activities and some of them are currently in use; well S-1 is in production from 1957 without any technical intervention in it, but because of unsuccessful drilling it has a flow of 7 l/s only and it is the reason of drilling new well Dv-1 in 1991 (completed in 2011) with distance of 0.8 km (Miošić, 1989) with outflow of 20 l/s.

The first comprehensive study of geothermal energy in B&H was made from 1980 to 1983 (Miošić, Čičić) from which followed the first published monograph (Čičić, Miošić, 1986). In the period 1986 – 1992 regions of Bosanska Krajina-Banjaluka, Bihać, Spreča fault zone, Semberija were investigated with multidisciplinary approach with a few wells, maximal depth was 1,345 m. Numerous drillholes with investigation works as geology, geophysics, seismology, hydrogeology and isotopes of waters and gases in other well-known deposits in use with springs, were performed in the period 1975 – 1992. Fundamental, regional and most detailed investigations were designed and conducted by N. Miošić from Geological institute – Sarajevo and main investor was Government of B&H.

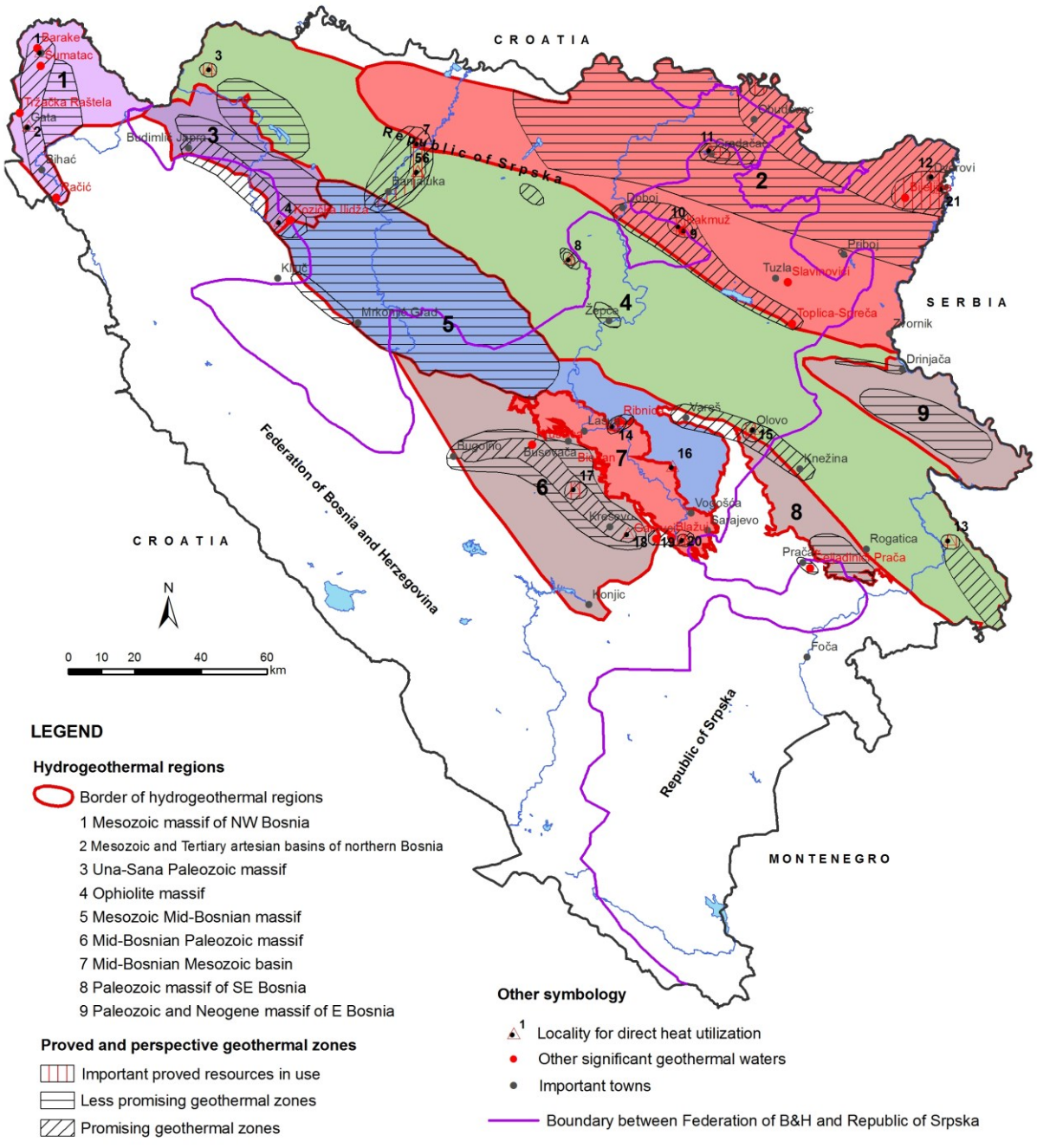
2.2. General overview

Geology background is given in the previous country update (Miošić, Samardžić, Hrvatović, 2010).

Hydrogeothermal convective systems exist in all regions except 9, closed and semi closed systems exist in regions 2, 3, 4, 6, 7 and closed supposed systems are in regions 5, 7 and 9 (Čičić, Miošić, 1986) (Fig. 1). Most of the convective phenomena with active springs and wells are in regions 2, 4, 6 and 8, while west of Domaljevac in region 2 there are no data of hydrogeotherms. All reservoirs are with expressed anisotropy and discontinuity horizontally and vertically, they have independent aquifer horizons through the depth.

Hydrogeotherms are mostly renewable resources based on isotopic content, there are a few waters of no meteoric origin in closed deep artesian horizons (Do - 1, Sl-1, brines in wells around Tuzla, Biohan). All waters are dominantly pre-nuclear ("dead" waters - $^{3}H=0$) with very slow circulation and long residence times in the aquifer and naturally protected by insulator rocks as roof barriers of aquifers from any surface contamination. Hydrogeotherms have various origins, content of constituents, concentration and location of forming in different rock ages and complicated geological structures. There are specific waters of rare and effective physical and chemical composition. Thermal water having TDS from 0.15 to 0.8 g/l , about 90% have a TDS of 300 to 500 mg/l and the thermomineral from 1 to even 300 g/l, a great variety of very acid type of pH=3 to hyperalcalic with pH=12, diverse composition of free and dissolved gases and GWR. Low TDS, optimal for drinking of thermal waters, make them suitable for water supply with a high purity of all waters without any negative influences of anthropological pollution. Physical and chemical properties make possible the wide range of application for public water supply, bottling as common and mineral waters, healing as effective balneological and recreational mean and nonconventional power resource.

Hydrogeotherms have different yields and temperatures in numerous springs and wells. The highest temperatures were measured in the oil wells of the Pannonian Basin, where for the depths of 1,000-5,000 m below the surface is expressed by uniform spacious isothermal stratification of aquifers; in other regions deeper than 1,000 m have no temperature measurements (Table 1).



Lithostratigraphic distribution	Hydrogeothermal regions	Number of aquifers through depth
Paleozoic limestones, dolomites, marbles and quartzites	8, 6	2 aquifers
Paleozoic and Triassic limestones and dolomites	4	2 separated aquifers
Paleozoic, Triassic and Jurassic limestones	5	3 separated aquifers
Paleozoic, Triassic, Jurassic and Cretaceous limestones and dolomites	1	4 aquifers
Paleozoic,Triassic, Jurassic, Cretaceous and Tertiary limestones, dolomites and clastites	2, 7	>5 separated aquifers
Triassic, Jurassic and Cretaceous limestones and dolomites	3	3 separated aquifers

Fig. 1. Litostratigraphic distribution of aquifers along deepth, hydrogeothermal regions and perspective geothermal zones of Bosnia and Herzegovina

Hyperthermal Pannonian Basin is multilayered built of five separate aquifer horizons through the depth at area of 6500 km^2 (Table 2).

The most productive reservoirs with the highest enthalpy - Triassic carbonates have a large range of depths in the Pannonian basin due to disjunctive and plicative tectonics, while their positions in the regions 4, 5 and 7 are of far greater complexity with inversion of sedimentation, faulting and thrusting (Table 3).

Table 1. Maximal temperatures of hydrogeothermal regions 1, 2, 4 and 7 for depths 500 to 5,000 m below surface

Depths, m	**500**			**1,000**				**2,000**	**3,000**	**4,000**	**5,000**
Region	**1**	**2**	**7**	**1**	**2**	**4**	**7**	**2**	**2**	**2**	**2**
T max (°C)	21	39	30	32	62	62	42	101	147	182	209

Table 2. The ranges of depth and temperature of the top of the aquifers of the Pannonian Basin B&H

Formation	**Depth (m)**	**Temperature (°C)**
T_3	1,290 – 3,900	64 – 177
K_2	780 – 1,530	42 – 93
M_2^2	625 – 1,227	37 – 63
M_3^1	262 – 1,185	20 – 63
Pl_1^2	250 – 565	21 – 38

Table 3. Depths and temperatures at the top of Triassic aquifer of hydrogeothermal regions 1, 4, 5 and 7

Regions ⇒ Systems ⇓	**1**	**4**	**5**	**7**
Triassic – T_3	1,000 m 30°C*	2,000 m 80°C**	3,000 m 85°C**	2,500 m 95°C**

* Measured temperature, ** Prognostic temperature

The values of conductive and convective geothermal parameters, temperatures at depths of 1,000-5,000 m and depth with temperatures of 120°C are given in Table 4 for subregions of the Pannonian Basin - Semberija, Bosnian Posavina and Tuzla basin. The greatest parameters i.e. potentiality has Semberija and the least Tuzla basin.

Table 4. Geothermal gradients, heat flow and temperatures of Northern Bosnia basins

Basin ⇒ Parameter ⇓	**Semberija**		**Bosnian Posavina**	**Tuzla basin**
Geotherm. gradient (mK/m)	41.4 – 53.9*		28.2 – 66.6*	29.1 – 56.3*
Heat flow (mW/m^2)	82.8 – 116.6*		61.0 – 100.8*	60 – 134.9*
Temp. at 1,000 m (°C)	53 - 62		40 - 62	39 - 53
Temp. at 2,000 m (°C)	93 - 101		78 - 92	
Temp. at 3,000 m (°C)	141 - 147		122 - 128	
Temp. at 4,000 m (°C)			168 - 182	
Temp. at 5,000 m (°C)			203 - 209	
Depth with temp. of 120°C (m)		2,420	2,625 – 2,900	

* Convective parameters

2.3. Indicative direct hydrogeothermal factors

Indicative proved direct quantified factors of hydrogeothermal potentiality in Bosnia and Herzegovina are the followings:

- thermal spring with maximum yield is Toplica-Spreča with flow of 250 l/s and temperature of 24°C,

- the spring with the highest temperature (58°C) is in Ilidža - Sarajevo with total power of all the wells of this deposit of 50 MWt,
- spring at the highest elevation of 750 m a. s. l. is Ilidža-Knežina,
- the highest temperature of artesian well, flow 25 l/s, is Do-1 – Domaljevac, Temperature 96°C, depth of 1,275 m and the power of 9 MWt,
- Temperatures of 120°C are at depths of 2,420 m in Triassic aquifers (Bij-1) is obtained by extrapolation from measured corrected temperature with maximal thermometer in depth 2,252 m which amounted to 112°C. Yield of this horizon is unknown because of total loss of circulation of drilling mud and collapse of drill hole.
- the highest measured nonsteady and uncorrected temperature at maximum depth of 3,913 m is in the borehole Br-1-Brvnik, 177°C with G=42.4 mK/m and q=93.3 mW/m^2,
- maximal extrapolated permissible nonsteady temperature at 5,000 m is registered in drillhole Ob-1 – Posavina with a temperature of 209-220°C.
- the maximum convective geothermal gradient of 66 C/km is in the drillhole Do-1 – Domaljevac for depth of 1,275 m,
- the maximum convective heat flow is 134.9 mW/m^2 (Sl-1),
- artesian well GB-1-Gracanica from 1979 with the depth of only 68 m has outlet temperature of 39°C, initial eruptive yield before casing was flow of 414 l/s, GWR= 2.5 of free 99% pure CO_2 - this cavernous Triassic limestones with large values of effective porosity and transmissivity have the same temperature of 39°C at 23 m and 600 m depth and the entire aquifer behaves as one isotherm,
- in Tičići by Kakanj, where the temperature of the source before drilling was 28°C, with a yield of 2 l/s, artesian outflow in drillhole IT-1 was flowing at 35 l/s and 56°C at depth of 82 m only (Slišković, 1986, 1993),
- in nearest deposit – Radići spring had a temperature of 32.8°C, flow of 0.5 l/s and outflow in drillhole IT-2 is 22 l/s and temperature of 39°C,
- in Lješljani, well SB-1, depth 670 m, with several inflows of water through depth has artesian outflow of 7 l/s, temperature 32°C, temperature at bottom of the well was 34°C, and the spring before drilling at a distance of 30 m of SB-1, had a temperature of 18°C and flow of 0.2 l/s (Miošić, 1991),
- in Fojnica well FB-2, depth 150 m, has artesian outflow of 650 l/s at initial eruption and after casing flow of 250 l/s, the same water temperature of 22.6 °C and shut in well pressure of 5.8 bar at the mouth of the well; near FB-2 is Memića spring of the same chemistry and genesis, having temperature of 21°C and flow of 0.7 l/s (Slišković, 1993).

These data clearly show that there are proven hydrogeothermal exploitative potentials in B&H at relatively shallow depths. Due to the low level of geothermal research and complexity of geological structure, there are the possibilities of similar positive hydrogeothermal surprises at other sites.

Beside these proven data various geological, geophysical indications point to the existence of yet unexplored semi-closed and closed-deep accumulations of hydrogeoterms with high productivity and enthalpy in various geological structures.

2.4. Basic data of springs and wells of hydrogeotherms

There are 57 thermal and 30 thermomineral water deposits in B&H with 175 springs and 127 drillholes with overall yield of 2,921.1 l/s (Table 5). Proven power of hydogeotherms can be used by reconstruction of numerous wells in about 30 of the most productive deposits with the highest temperatures, while presented possible power can be obtained by rehabilitation and mostly new deeper wells only.

Table 5. Yield and power of springs and wells of deposits of hydrogeotherms

Type of water	$Q_{springs}$ (l/s)	Proven power (springs) (MWt)	Number of deposits with springs only	$Q_{springs + wells}$ (l/s)	Proven power (springs + wells) (MWt)	Number of deposits with springs and wells	Possible power (springs + wells) (MWt)	Total number of deposits
Thermal waters	330	12	31	1827.9	106.815	26	315.44	57
Thermomineral waters	42.1	1.65	9	1093.2	144.6	21	479.80	30
Total	372.1	13.65	40	2921.1	251.415	47	795.24	87

The largest number of deposits is in the ofiolitic zone - 44; herein larger reservoirs have temperatures around 40°C. Here 30 deposits of thermal waters have flow of 829 l/s and power of 34 MWt, thermomineral waters have a flow of 391 l/s and power of

48.3 MWt in only 11 deposits. This zone has the largest power of both waters and maximum power of hydrogeotherms are in the Central Bosnian basin (flow 480 l/s, power 68 MWt).

There are 40 deposits with springs, 34 with springs and drillholes and 13 deposits (mainly in the Pannonian Basin) with wells only. Temperatures of spring waters of 36 deposits are <20°C and 44 deposits have single yield <10 l/s. 51% of thermal waters have temperature <20°C.

Drilling was carried out at 26 deposits of thermal waters, from this number in 13 deposits one well and in 21 deposit of thermomineral waters was drilled, in 9 deposits was drilled one borehole; the average depth of wells is less than 400 m, only the IB-10 in Ilidža has depth of 1,100 m, deeper drillings than 1,000 m are in the Pannonian Basin only, no wells are drilled in 39 deposits and 13 deposits without any spring were discovered by drillings.

18 deposits of thermal and 16 deposits of thermomineral waters have springs and wells, while 8 deposits of thermal and 5 of thermomineral waters have only wells. In 31 deposits of thermal and 8 deposits of thermomineral waters have no wells drilled.

Depths of all 127 active wells range from <100 m to 1,345.5 m (S-1-Dvorovi), they give low enthalpy hydrogeothermal resources t<20°C to 96 °C at the surface of terrain.

Power of 31 deposits of thermal water springs amount to 12 MWt, thermomineral waters in 9 deposits 1.65 MWt only; it can see there is no effective use of waters without drillings (Table 5). The power of 53 deposits is less than 1 MWt and 7 deposits only have individual power greater than 10 MWt (Table 6). 34 reservoirs with individual power higher than 1 MWt have total power of 218 MWt, and the other 53 deposits have total power of only 13 MWt.

Table 6. Power range of hydrogeothermal deposits

Power ⇒ Type of waters ⇓	**< 0.1 MWt**	**- 1 MWt**	**1 - 10 MWt**	**>10 MWt**	**TOTAL**
Number of thermal deposits	18	18	18	3	57
Number of thermomineral deposits	12	5	9	4	30
Total	30	23	27	7	87

Yields of thermal waters are greater than thermomineral, while their power is lower, which means the temperatures of thermal waters are lower. Drillings were made in zones of natural springs mainly, to small depths with technical problems and environmental difficulties, which lead to impossibility of deeper drilling and even to collapses of wells. Drillings were often performed at a venture without studies about site and characteristics of primary aquifers and especially new programs on the basis of chemical and isotopic indicators. Complexity of geology and existence of evident of irregularities in shallow depths point out to the justifiability of deeper drillings in the aim to get additional capacities and the higher temperatures of waters.

2.5. Important achieved results of researches

Larger yields in wells in relation to total capacities of all springs of individual deposit were obtained in all drilled deposits (47). At 14 locations of thermal waters are obtained by drilling the same temperature as the maximum of springs, and the two even smaller, with only the two slightly higher temperatures than the maximum spring temperature.

In most deposits of thermomineral waters are obtained by drilling higher temperatures, and nowhere is it lower than at the spring. So, in each deposit was justified to perform drillings and the wells are well located. It is obvious further deeper drillings will give greater yields surely and higher temperatures generally. Waters of higher temperatures in convective systems can be obtain in deposits of thermomineral waters only.

Pumping of wells give greater yields but do not obtain higher temperatures, which means aquifers have large water abundance and they do not interfere with younger and cooler waters, but also there is no inflow to the aquifer of warmer, deeper waters and the horizons are hydraulically separated along geological column. The greater difference between yields of wells and springs give the greater difference of their temperatures. Most of wells decrease their yields over time, i.e. artificial discharge is greater than natural recharge and the latter one can not be accelerated. Springs of thermomineral waters have a higher temperature than the thermal water; the maximum is 57°C and 35°C of thermal. All wells have artesian hydraulic type and only four reservoirs with wells are without outflows. Thermomineral waters of HCO_3^- - Ca^{++} type are shallower and cooler than the other ones; almost all thermal waters are of HCO_3^- - Ca^{++} type.

Springs of thermomineral waters have lower temperatures and yields than thermal waters as it the case also in wells. Ascendent discharge communications at thermomineral springs have lower transmissivities than at thermal springs i.e. the more complicated and the longer paths of circulation to the first ones and due to the cooling exist also the low temperature and the yield of thermomineral springs; this means by drillholes at thermomineral deposits encountered new inflows cutting more ascendent flows of higher temperatures and higher wellhead pressures through the depth and drillholes have fast water circulation compared to their neighbor springs which have very less water velocities.

All warmer thermomineral waters have first or second anion SO_4^{--} or Cl^- type, which means that their primary aquifers are from Permo-Triassic (P-T_1) or deeper horizons, although the main reservoirs Triassic limestones are from shallow depths; it means here is developed normal lithostratigraphic sequence of sedimentation, which is an essential indication for further investigation

especially for guiding of drillings. From this arises, ex contrario, hydrogeothermic points to solve geological and tectonic complex of terrain.

Where the low yields of springs and roof barriers aquifers are continuous i.e. where no outcrops of aquifers, one can expect higher temperature of thermomineral waters. Faults in individual deposits are very deep and damaging pretectonic stratification and separation aquifer horizons vertically and allow ascension water from deep in the shallower horizons.

Meanwhile, still is not yet recognized and identified mixing of waters anywhere where drilled, all water horizons are mutually separated. Examples that show clearly the separation of accumulations and ascendant drains are: different types of waters at close distance - Ilidža (thermomineral with and without H_2S, with CO_2 and thermal), Fojnica (thermal waters of different temperature and mineralization of wells), Klokoti (high and low mineralization of drillholes), Mala Kladuša (different temperature, yield and depth of wells), Sanska Ilidža (thermal springs in Kozica at distance of 4 km from Sanska Ilidža decrease yields due to intensive and long-lasting pumping of thermomineral waters, but no water changed its physical and chemical parameters), Gata (thermomineral and cold water Bistrica), Slatina (thermomineral warmer and lower temperature), Tičići – Radići, Banja Vrućica (different temperature of waters), Srebrenik (thermal and mineral water), Bokavić Ševar (mineral and thermal water), Dvorovi (shallow thermomineral in Tertiary and deeper thermal water in Triassic).

The existence of different closed water reservoirs was proved by shallow drillings even in the zones of convective hydrogeothermal systems, as in many sites without such springs, were discovered and captured waters of completely different composition related to natural springs. Proven shallow water circulation irregularities parameters have significant importance and practical use for directing new investigation works.

3. GEOTHERMAL UTILIZATION

Archaeological remnants show the use of hydrogeotherms from Roman or even in earlier period as it is the case in Ilidža 2,400 years B. C.

The current direct use of geothermal energy in relation to the period 2005 to 2009 differs only in the cease of work of spa Kulaši and Gornji Šeher, which used water for bating and swimming and individual space heating and beginning of the use of thermal water (borehole GD-2) in Slobomir-Semberija for heating University buildings.

Direct use of geothermal energy is implemented at 21 localities (APPENDIX -Tables 3 and 5, Fig. 2). Spas and recreation centers are the main users of hydrogeothermal energy (18), then individual space heating (6). Geothermal heat pumps are used in 3 spas; there are no heating of waters in swimming pools with GHPs.

Utilization of geothermal energy for direct heat expressed in TJ/yr is the following:

1) individual space heating and sanitary waters (66.65 %),

2) bathing and swimming including balneology (33.35 %)

3.1. Bathing and Swimming

There are 18 spas of thermal and thermomineral waters and recreation centers with swimming pools, which are heated by geothermal waters directly or indirectly through heat exchangers.

Between these 18 spas there are also 6 public recreational centers where geothermal water is used only in open-air swimming pools during the summer season. There are 4 spas with open-air swimming pools active in the summer and in the same time in these spas indoor pools with accompanying facilities work all time of the year. Water temperatures in thermal spas range from 17.4 to 75°C. The total geothermal energy used for bathing and swimming is estimated at 83.25 TJ/yr.

Thermal waters are used in 5 spas from which one radioactive (Fojnica) and 2 recreation centers (Toplica - Lepenica and Mala Kladuša). Thermomineral waters are used in 12 locations: 5 spas, 7 recreation centers. Between 7 recreation centers of these waters one has hyperalkaline water – pH=11.75 (Lješljani). Extreme high yields are in five thermal spas with single flow >80 l/s and in 9 thermomineral spas with single flow >100 l/s but this capacities are partially in use only.

3.2. Individual Space Heating and Sanitary Waters

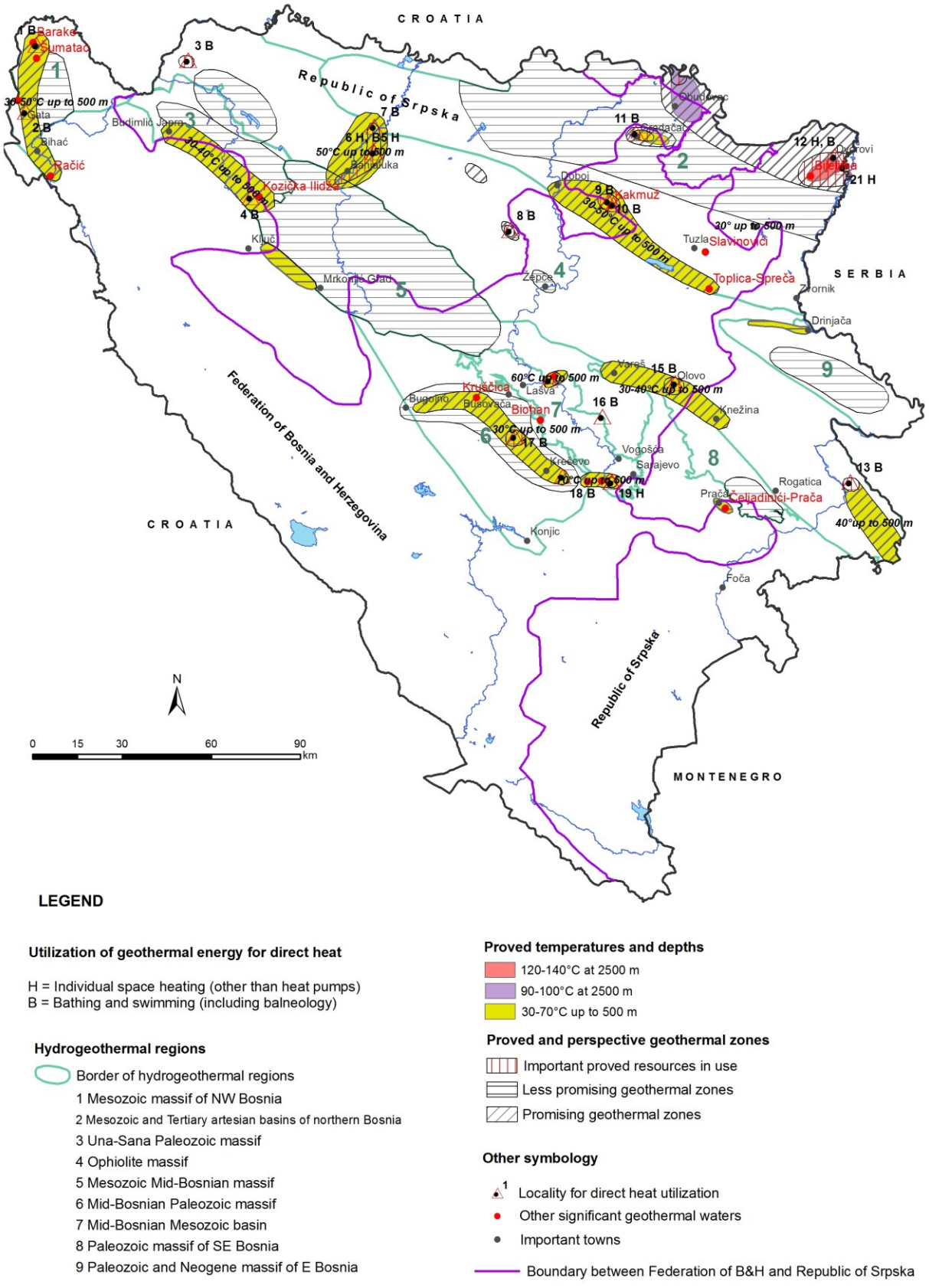
The second most important type of direct use of heat is mainly at spas for space heating (3 spas). Individual space heating with heat exchangers is performed in 6 localities (Ilidža Terme, Ilidža Termalna rivijera, Slatina-Banjaluka, Slateks-Slatina, Dvorovi and Slobomir). Average use of this type of heating is about 6 month a year, but sanitary waters are heating during whole year. Total geothermal energy used for individual space heating is 166.38 TJ/yr.

3.3. Geothermal heat pumps

There are dozens of installations for use of low-enthalpy geothermal energy installed in public and private facilities (health centers, hotels, schools, business buildings etc.), as well as family houses in B&H use this type of space heating. It is estimated that there are about 100 buildings in B&H, which is heated by heat pumps.

There are more than ten company which install heat pump systems (MIS TRADE -Nova Topola, NECO ecological systems – Bijeljina, Rimp – Tuzla, Hidrogeoinženjering – Tešanj, Termolux – Banjaluka, etc.).

The GHPs are used in an open loop water - water system at 3 localities of thermal spas only (Fojnica FB-2, Višegrad, Gata), where water temperature is low for raising the thermal water temperature for space heating. The geothermal energy used for GHPs in spa amounts to about 13.31 TJ/yr.



LEGEND

Utilization of geothermal energy for direct heat

H = Individual space heating (other than heat pumps)
B = Bathing and swimming (including balneology)

Hydrogeothermal regions

- Border of hydrogeothermal regions
- 1 Mesozoic massif of NW Bosnia
- 2 Mesozoic and Tertiary artesian basins of northern Bosnia
- 3 Una-Sana Paleozoic massif
- 4 Ophiolite massif
- 5 Mesozoic Mid-Bosnian massif
- 6 Mid-Bosnian Paleozoic massif
- 7 Mid-Bosnian Mesozoic basin
- 8 Paleozoic massif of SE Bosnia
- 9 Paleozoic and Neogene massif of E Bosnia

Proved temperatures and depths

- 120-140°C at 2500 m
- 90-100°C at 2500 m
- 30-70°C up to 500 m

Proved and perspective geothermal zones

- Important proved resources in use
- Less promising geothermal zones
- Promising geothermal zones

Other symbology

- Locality for direct heat utilization
- Other significant geothermal waters
- Important towns
- Boundary between Federation of B&H and Republic of Srpska

Fig. 2. Priority of drillings according to temperatures of aquifers to depth <500 m and 2500 m below surface

4. DISCUSSION

A number of locations of direct use of geothermal energy is diminished related to the period 2005-2009 but it is increased the number of sites with heat pumps. The work of spa Kulaši stopped in 2013, because of financial problems and Gornji Šeher is now

in reconstruction phase. Meanwhile, it is expected reconstruction and reactivation of those two spas in 2014. There is no heating of greenhouses because of the cease of artesian outflow of well (Domaljevac) and fish farming in swimming-pool Sedra is interrupted too.

The current distribution pipes from eruption trees through the heat exchanger (Ilidža) give great resistance to water flow and make possible the use of 1/3 of available yield only which exist in the mouth of wells. This problem can be solved by combination of greater drawdown of outflow and new heat exchanger facility.

Difference between inlet and outlet temperatures in most localities is very small from which result in a low capacity factor (0.35) what it shows is the inadequate utilization of the installed geothermal capacities. This factor also indicates nonsteady energy demand of consumers though the year. In all facilities the amount of energy used in certain period varies significantly. In most cases available capacities of waters are much higher than those needed to satisfy the actual demand; a large part of installed capacities remains unused over a long period of year, what points out the possibilities of use in other purposes.

Enlargement of capturing of additional greater capacities of waters is possible by new deeper drillings in almost all active hydrogeothermal deposits, the same case is with increase of present utilization and different other views of exploitation of these resources.

The total number of professional personnel in geothermal activities in the period 2010-2014, allocated as follows (in person-years): 15 – Government, 10 – Universities and 10 – Private Industry (APPENDIX - Table 7).

The investment in APPENDIX-table 8 (presents incomplete data, because the numerous users of waters had not the will to present us their costs in utilization of waters. The majority of financial means in period 2010-2014 are of the private sector. The biggest investments in direct use of geothermal energy were in Slobomir, Banja Teslić, Slatina, Terme Ilidža, Fojnica and Sanska Ilidža.

During last five years there was one well drilled in Slobomir (1,800 m) in a known exploitable field near Dvorovi spa and two shallow drillholes in Domaljevac-Šamac. The last drillings discovered a new deposit of hypothermal waters (21°C). Total depth derived three wells is approximately 2,200 m (APPENDIX-Table 6).

There are 11 localities of thermal waters for water-supply from which Toplica Spreča is one of the greatest thermal springs in Europe, two for bottling (3 localities are planned for bottling) and 2 thermomineral waters for bottling also. Extraction of free CO_2 is performed in 2 localities: 1) for industrial use (2 wells in Kakmuž) and 1 for balneological purposes as baths with CO_2 (Teslić).

There is a need to make reinjection wells to prevent decreasing of yields of productive wells and pollution of surficial waters by high mineralized and waters of higher temperatures (Domaljevac, Gradačac, Gračanica, Laktaši, Ilidža, Kakanj, and Teslić).

In numerous sites of B&H, mainly round Banja Luka and Bijeljina, are heating systems with heat pumps but there is not any evidence about number of units.

5. FUTURE DEVELOPMENT AND INSTALLATIONS

Almost nothing is accomplished from that proposed in 2009 and all that remains the task and current activity in the future in order to increase research and intensify the use of geothermal potential particularly.

A large number of wells in 30-prospecting deposits are defective or damaged and requires rehabilitation without which it cannot the adequate use of proven yields and powers.

Solving of interference in wells in many productive deposits of thermomineral waters as they are Gata, Gračanica, Gradačac, Domaljevac, Ilidža, Sanska Ilidža, Slatina is urgent task at once.

The use of new wells in Gradačac area have a consequence to greater drawdown and pollution of wells in Ilidža spa, because of that it needs urgent measures to prevent this situation and make protection projects and their implementation i.e. to determine the maximal allowed quantities of utilization of waters in these wells. However, the optimal solution is to project and drill new reinjection wells.

Promising of research areas are:

a) the main spot hydrogeothermal open, semi-open and semi-closed structures (Lješljani, Gata, Račić, Balkana, Sanska Ilidža, Slatina, Laktaši, Gornji Šeher, Vrućica, Kulaši, Gradačac, Tičići, Ilidža, Toplica-Spreča, Vruća voda, Vajićeva voda, Rasol-Priboj, Sedra-Breza, Čeljadinići, Slanica-Tuzla);

b) the main linear hydrogeothermal open, semi-open and semi-closed structures (Budimlić Japra, Kozica, Mrkonjić Grad, Busovača fault zone, Šumatac-Velika Kladuša, Vogošća-Lašva, Spreča fault zone, Vareš-Olovo-Knežina, Trebovac, Drinjača, Višegrad-Priboj, Lepenica-Kreševo-Fojnica-Kruščica, Žepče;

c) the main spatial hydrogeothermal closed proved and supposed systems: Artesian basins of Posavina and Semberija, Middle Bosnian basin, Banja Luka basin, Bihać – Cazin basin, Jurassic-Cretaceous flysch trough Sarajevo-Banja Luka, Prijedor depression, Paleozoic Una massif, Sana, Mid Bosnian schist massif, Palaeozoic massifs of east and southeastern Bosnia, Tuzla basin, Ofiolitic zone and Mesozoic basin of Middle Bosnia.

With the investigation aspect is a open burning question whether there are hydrogeoterms of higher enthalpy in deeper horizons in to now investigated deposits with higher temperatures by shallow drillings and in which lithostratigraphic units, whether there are closed systems - ophiolites, Lješljani, Gata, Ilidža and Tičići.

There are various complicated circulation patterns of waters and to determine areas of strong convection, which are often masked by a low yields and temperatures of springs and to define the degradation of the natural distribution of thermal fields, is an important task, because these zones have the highest enthalpy; these zones are often relatively shallow and do not require deeper drillings. Determination of primary, secondary and transit aquifer models of recharge, formation and discharge of aquifers, the ascendent convection and the existence of a mixing zones are crucial tasks for more future successful research. Determining the plausible geological and geothermal models of terrain for various types of geothermal potential is the basic theoretical and practical task, which allows locating shallower boreholes for capturing of hydrogeotherms as the most favorable geothermal resources.

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TABLES APPENDIX – STANDARD

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 2014				9051		5579			13*	65		14695
Under construction in December 2014					20	96			48*	103	68	199
Funds committed, but not yet under construction in December 2014												
Estimated total projected use by 2020				17851		5743			139	386		23980

* Production elekctricity from wind and solar sources.

Data sources: Power Utility of B&H-Sarajevo, Power Utility of Republic of Srpska-Trebinje and Power utility of Croatian union Herzeg Bosnia-Mostar

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2014 (other than heat pumps)

[1] I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting
H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

[2] Enthalpy information is given only if there is steam or two-phase flow

[3] Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[4] Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

[5] Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
1 Mala Kladuša Ilidža	B	100	28	22			2,51	1	0,66	0,008
2 Gata	B	2	38	35			0,025	1	0,4	0,51
3 Lješljani	B	9	30	26			0,15	9	3,56	0,75
4 Sanska Ilidža	B	20	32,4	31			0,12	6,7	1,24	0,33
5 Slateks-Slatina	H	21	42	36			0,53	10,5	5,54	0,33
6 Slatina-Banjaluka	H, B	50	43	32			2,3	30	43,53	0,6
7 Laktaši	B	15	31	27			0,25	10	3,96	0,5
8 Vrućica	B	7	38	35			0,09	7	1,85	0,65
9 Terme Ozren	B	20	38	30			0,67	6,7	7,07	0,33
10 Gračanica PEB-4	B	80	37,7	30			2,58	27	27,42	0,34
11 Gradačac	B	0,35	28,5	25			0,005	0,35	0,09	0,57
12 Dvorovi	H, B	7	75	30			1,32	7	27,7	0,67
13 Višegradska Banja	B	7,5	31	28			0,09	7	1,85	0,65
14 Tičići-Kakanj	B	40	50	28			3,68	1	2,9	0,025
15 Olovo	B	5	34	28			0,13	4,6	3,03	0,74
16 Sedra Breza	B	7	17,4	11			0,19	7	2,21	0,37
17 Fojnica FB-1	B	8	30	26			0,13	2,5	1,32	0,32
18 Toplica Lepenica	B	16	20,6	17			0,24	5,3	2,52	0,33
19 Ilidža Termalna rivijera	H	55	58	44			3,22	45	53,42	0,53
20 Ilidža Terme	H, B	25	58	50			0,83	25	26,38	1
21 Slobomir	H	35	75	50			3,66	10	32,98	0,29
TOTAL							22,72	223,65	249,63	0,35

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2014

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground in the cooling mode as this reduces the effect of global warming.

[1] Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps

[2] Report type of installation as follows: V = vertical ground coupled (TJ = 10^{12} J)
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)

[3] Report the COP = (output thermal energy/input energy of compressor) for your climate

[4] Report the equivalent full load operating hours per year, or = capacity factor x 8760

[5] Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (°C) - outlet temp. (°C)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

Note: please report all numbers to three significant figures

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 (TJ/yr)	Cooling Energy (TJ/yr)
No detailed information available; a total number of 100 installed units can be assumed by 2014.								
TOTAL								

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2014

[1] Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[2] Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

[3] Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^{6} W)
since projects do not operate at 100% capacity all year

Note: please report all numbers to three significant figures.

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]	9,94	166,38	0,53
Bathing and Swimming[7]	12,78	83,25	0,21
Subtotal	22,72	249,63	0,35
Geothermal Heat Pumps			
TOTAL			

[4] Other than heat pumps

[7] Includes balneology

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2010 TO DECEMBER 31, 2014 (excluding heat pump wells)

[1] Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1]	(all)					
Production	>150° C		1			1,8
	150-100° C					
	<100° C				2	0,4
Injection	(all)					
Total			1		2	2,2

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

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Prograr
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2010	3		2			2
2011	3		2			2
2012	3		2			2
2013	3		2			2
2014	3		2			2
Total	15		10			10

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2014) US$

Period	Research & Development Incl. Surface Explor. & Exploration	Field Development Including Production Drilling & Surface	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999						
2000-2004						
2005-2009						
2010-2014*	0.0442	0.378	25.442		79	21

*Data relating to a total of 6 users geothermal energy (direct use): Sanska Ilidža, Gradačac, Lješljani, Ilidža Terme, Fojnica and Terme Gračanica.