Geothermal Energy Use, Country Update for Croatia

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ABSTRACT

After years of struggle, the first geothermal power plant started electricity production at the very end of 2018. It is located at the well-known Velika Ciglena site, near town of Bjelovar, where geothermal water outflow with 172°C was found at depths of 2000 m at the top of massive fractured carbonate reservoir reaching almost 5000 m depths. The installed capacity is >16.5 MW_e and 10 MW_e is for a moment, possible output to the limited capacity of a local power grid. Even that makes it now the largest operating ORC system in the EU. The innovative advanced geothermal power plant is in development in Draškovec, to the NW of the country. There is also an interest in development of electricity generation in several sites where production and exploration licences were already issued (Lunjkovec-Kutnjak and Legrad-1, Kotoriba, Ferdinandovac-1). Three tenders for exploration licences at the electricity generation prospects are in preparation (Babina Greda, Rečica-Karlovac, and Slatina). At the geothermal field Zagreb, recently overtaken by private investor, rising of consumption is gained by the further geothermal district heating development. The direct use of geothermal heat in greenhouses is present at Bošnjaci and Sv. Nedelja. Detailed studies are done for development of geothermal district heating in Karlovac, Križevci, Virovitica, Ludbreg and number of other locations. Finally, the interest for the geothermal energy consumption is raised at numerous Spas such as Varaždinske Toplice, Velika and others, including shallow drilling (several hundred meters) for development of the new one in Bjelovar. Use of shallow geothermal energy, using ground source heat pumps (GSHP) is getting more and more developed for use at: malls, hotels, industrial and warehouses and individual housing, but for reasons that are not intended to fully ensure regulation, energy consumption is deeply in the grey zone and officially unknown.

1. INTRODUCTION

Croatia's geothermal potential is indicated by more than 25 natural thermal springs, most of which are used for recreational and medical purposes. Most of them are located in NW and central part of Croatia (the Pannonian region) but there are also several hypothermal springs along the Adriatic coast (the Dinaric region). Moreover, with the oil and gas exploration and production activities in the Pannonian region of the country, intensely conducted in the second half of the 20th century, many hydrothermal reservoirs were found and some developed, proving the geothermal potential and setting the path to increase of geothermal utilization. Conservative estimation of the proved part of resources is 100 MW_e for electric power production and substitution of ¼ of nowadays gas consumption with geothermal direct heat consumption (Kolbah et al., 2018).

2. GEOTHERMAL FEATURES OF CROATIA

Based on geological features, Croatia can be divided into two different geothermal regions: the Pannonian basin area to the north and Dinarides to the south. The Pannonian region where water bodies have cap-rock covers is characterized by geothermal gradient varying about 50°C/km (Figure 1), reaching, in certain locations, values of even more than 70°C/km. On the other hand, Dinarides region with carbonate platform sediments and deep penetration of karst, strongly affected by atmospheric or see water, is characterised by so far quite low geothermal gradient measured, of less than 20°C/km (Figure 1). In spite of that, geothermal resources should be expected even there, in that tectonically very active area, marked with spas and numerous hypothermal and mineral springs.

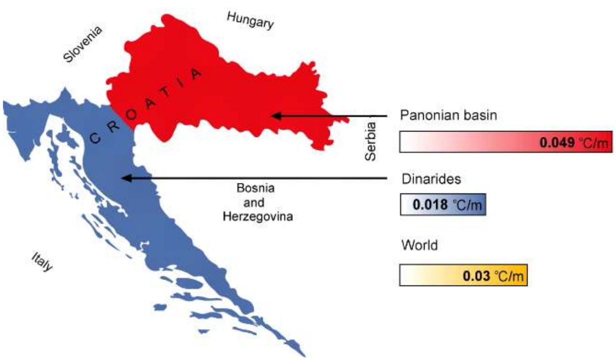

Figure 1: Geothermal gradients in Croatia.

Water temperature of natural springs in the Pannonian region reaches 65°C, whereas the temperatures of natural thermal springs in Dinaric region are reaching at most 28°C in the Istria Spa (Table 1).

Oil and gas exploration and production were intensely conducted in the NW part of Croatia in the second half

Table 1: Croatian natural springs with flow rates and water temperatures

Geothermal region	Natural spring - location	Flow rate (l/s)	Temp. (°C)
Pannonian region	Daruvarske toplice - Daruvar	21.0	46.6
	Harina Zlaka	3.7	32.8
	Jezerčica – Donja Stubica	34.2	38.0
	Krapinske Toplice	41.0	40.8
	Lešće	15.0	34,0
	Lipik	6.8	58.3
	Podevčevo	n/a	18.7
	Podsused - Zagreb	2.0	20.0
	Stubičke Toplice	17.0	65.0
	Sutinske Toplice	10.0	37.4
	Sv. Helena - Samobor	19.7	25.8
	Sv. Ivan Zelina	35.0	24,1
	Sv. Jana	40.0	24.6
	Šemničke toplice - D. Šemnica	6.0	31.0
	Topličica - Gotalovec	10.0	25.7
	Topličica - Madžarevo	n/a	22.5
	Topličina - Marija Bistrica	3.5	17.8
	Topusko	100.0	65.0
	Tuheljske Toplice	85.0	41.0
	Varaždinske Toplice	95.0	57.6
	Velika	3.6	28.6
Dinarides region	Istarske toplice - Livade	2.0	28.0
	Mokošica	n/a	16.0
	Splitske toplice - Split	24.0	21.3

of the 20th century. Thanks to that, massive acquisition of deep geology, geophysics, hydrodynamic and other information's is done, and more than 4000 deep wells drilled, all of which is under government control. Large number of geothermal reservoirs was revealed and characterized with two main type of Mesozoic to Neogene age aquifers: in clastic sediments and in massive–significant carbonates. The latter provide thick, massive reservoirs with richer flow rates, in the range of 100 l/s, and higher measured water temperatures such as Velika Ciglena (175°C), Kutnjak-Lunjkovec (140°C), and Slatina (190°C).

Similar geological features are discovered in several other locations, for example Rečica-Karlovac in the central part of Croatia, Draškovec, Legrad-1, Merhatovec and Ferdinandovac-1 to the NW and Babina Greda to the east (Figure 2). Besides these, middle temperature reservoirs were found in the Zagreb area (50-80°C), Ivanić (76°C), Križevci (66°C) and others (Figure 2). Anyway, only few of these high temperature locations had been developed to a state of geothermal field with licenses for exploration or production.

Geothermal field Zagreb with its 14 wells is currently under exploration licence of new developer with agreement for new consumer at nearby student campus and plans of using geothermal energy in district heating of shopping centre and buildings and also a possibility of building a modern aquapark.

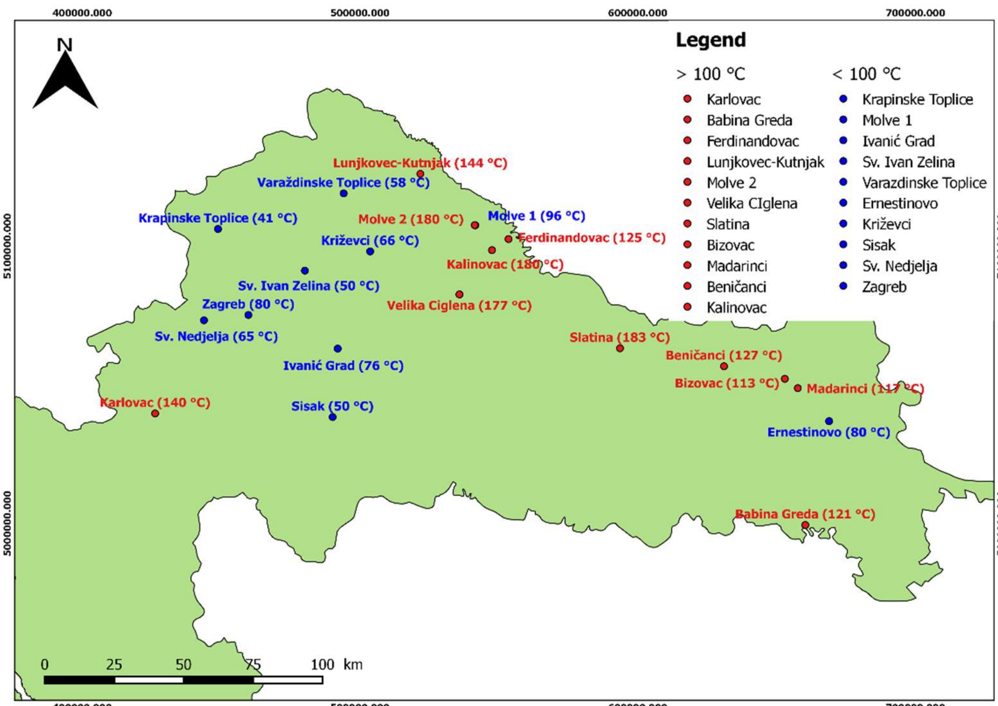

Figure 2: Geothermal water sources in Croatia.

3. DIRECT GEOTHERMAL ENERGY USE IN CROATIA

Today, geothermal water is used for bathing and space heating. Out of 18 active Spas, in 6 of them geothermal energy is used for both bathing and space heating while in the rest is used only for bathing. Geothermal heat is used in most Spas throughout the year as a part of medical rehabilitation system in Croatia, but several larger Spas are popular as recreation centres. Few smaller Spas with only outdoor pools are popular for recreation in summer time.

Beside in Spas, geothermal energy is used for district heating in three locations: Topusko, Zagreb and Bizovac, and in two several hectares large hydrophone technology greenhouses (Sv. Nedjelja and Bošnjaci).

Total capacity of this production amounts to 81 MW_t. Of the total amount, 42.3 MW_t is the capacity of district heating, 24 MW_t is the capacity of bathing and swimming, 6.5 MW_t is the capacity in greenhouses, and 12.6 MW_t is the capacity of individual space heating. Geothermal water temperatures vary between 25°C and 96°C. Utilization has, except mentioned greenhouses where yield was enhanced by pumping, additional surface systems as buffers and following technology, low capacity factor, around 0.27. Therefore, aiming to increase efficiency, with investments in modernisation of existing systems and opening a number of new-ones, with contemporary attracting additional consumers, the production of geothermal heat could be significantly higher than today's 300 TJ/y. Very conservative quantification based on 500 deep wells (of existing >4000) with 750-1300 MW_t can cover ¼ of nowadays natural gas consumption (Kolbah et al., 2018).

4. POSSIBILITIES OF GEOTHERMAL POWER GENERATION IN CROATIA AND NEW DEVELOPMENTS

Interest for geothermal exploration and development of geothermal projects is growing in the last few years. The interest is mostly focused on power generation projects in well-known geothermal locations such as Velika Ciglena and Kutnjak-Lunjkovec, but there are several other interesting locations already under exploration licences: Draškovec, Kotoriba, Legrad-1, and Ferdinandovac-1. Recently, the interest has been expressed for Slatina, Rečica-Karlovac and Babina Greda.

After discovery and development with 4 deep wells and well testing conducted 20 years ago, at Velika Ciglena site, geothermal power plant was commissioned at the end of 2018. The installed capacity is >16,5 MW_e, but deliverance, for a moment, is limited to the capacity of the local power grid of 10 MW_e. The plant is operated by Geoen-MB Holding.

At Draškovec site innovative advanced geothermal power plant with internalization of carbon compounds AAT Geothermae is under development. This is a unique project where the hybrid system will be designed to use both direct heat of the geothermal water as well as un-conventional hydrocarbon gases dissolved in the water for electricity production. That gases will be separated from the water and burned in gas CHP power stations. Furthermore, the CO_2 from combustion, as well as any brought up with the hot water, will be captured at a rate of 98% and safely re-injected into the aquifer (AAT Geothermae, 2018). Drilling of first two wells is done and the other preparatory works for drilling 6 more wells is ongoing. District heating of the Spa centre and nearby town Prelog is planned as the next phase of the project. Expected acceleration of that project is bond to already announced government defining relations to ease development and production.

5. POSSIBILITIES OF NEW GEOTHERMAL DISTRICT HEATING PROJECTS

The local communities and the investors have shown interest in developing district heating projects in the cities of Zagreb, Karlovac and Križevci and in other industrial and agricultural areas in the northern part of the country.

After decades, with the recent overtake of private operator, geothermal field Zagreb is activating already developed capacity to rise consumption.

Karlovac is well known geothermal area where high temperature geothermal water was found at 3.5 to 4.1 km depths, in two wells about 10 km away from the city. The highest water temperature at the well was registered during well logging at 138°C. The wells were sealed and abandoned because no oil and gas were found but it was a geothermal discovery. Recently, a tender has been announced for geothermal exploration licences in that area. Although the location is suitable for geothermal power plant, City of Karlovac is interested in an area closer to the city where geothermal waters with somewhat lower temperatures are expected, but still high enough for district heating (Kolbah et al., 2017). Karlovac has gas operated district heating network but is looking for geothermal source in order to lower prices for consumers and lower CO_2 emissions in the city.

In 1980's in Križevci, geothermal water of 68°C was found with exploration well around 1.5 km deep. Two schools, agricultural college with greenhouses, gym and open swimming pool are located in the close vicinity of the well. All these building could be connected to a district heating system driven by geothermal heat (Karan et al., 2012).

Recently, the studies are done for several cities in the Pannonian region of Croatia, such as Virovitica, Ludbreg, Prelog etc., to recognise their geothermal potential and begin the projects of using geothermal heat for district heating and other purposes.

In the two-greenhouse set that uses geothermal energy additional drilling and enhancing production is projected and financial support for that project is demanded.

6. CONCLUSIONS

The interest for its geothermal resources in Croatia is still far below its proven potential what is in disagreement with facts that country is becoming an EU leader with the largest operational ORC power plant at the end of 2018. Significant role of proven potential is not officially recognised at the several more production and exploration geothermal fields such as Lunjkovec-

Kutnjak, Kotoriba, Legrad-1, Ferdinandovac-1, Draškovec and lot more already discovered sites, where conservatively quantified potential could be set at 100 MW_e. Discovered sites need to be properly tested and developed and surely there are still more similar leads. Better times are expected with announced definition of government relation to their developers and production.

Interest for direct geothermal heat use is growing slowly, but rising, by both investors and consumers in agriculture and industry as well as district heating at locations like Zagreb Karlovac, Križevci, Virovitica and Ludbreg.

Total capacity of geothermal production nowadays amounts to 81 MW_t. Of this 42.3 MW_t is the capacity of district heating, 24 MW_t is the capacity of bathing and swimming, 6.5 MW_t is the capacity in greenhouses, and 12.6 MW_t is the capacity of individual space heating. That are scary low numbers compared to the relatedly easy reached resources (well depth about 1000 m). Direct use geothermal potential of the 750-1300 MW_t can cover ¼ of nowadays natural gas consumption in a country.

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Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2018 *	16.5	3.5	5000*	11983*	0.33	0.03
Under construction end of 2018	4.3	n/a	n/a	n/a	n/a	n/a
Total projected by 2020	16.5	75.7	5350	12774	0.31	0.59
Total expected by 2025	20.8	224 est	6000 est	15134 est	0.33	0.67
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2018 (indicate exploration/exploitation if applicable):					Under development: 5 (exploration licence)	
					Under investigation: 3 (exploration licence)	
					There are 3 active exploitation licences.	

* If 2017 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units *	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2018 pro-duction (GWh_e/y)
Velika Ciglena	Velika 1	2018	1 RI	O	B-ORC	16.5	16.5	3.5
total						16.5	16.5	3.5

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
R	Retired	2F	Double Flash	O	Other

* In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2018	42.3	44.7	6.5	10.9	12.6	12.1	24.0	15.3
Under constru-ction end 2018	-	-	-	-	-	-	-	-
Total projected by 2020	42.3	44.7	6.5	10.9	12.6	12.1	24.0	15.3
Total expected by 2025	61.3	77.7	10.0 est	20.0 est	20.0 est	30.0 est	30.0 est	30.0 est

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP	Cooling	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2018 produc-tion (GW_{th}/y)	Geoth. share in total prod. (%)
Topusko	Topusko	1998	-	-	26.3	26.3	29.8	100
Zagreb	GP Zagreb (Mladost and KBNZ)	1987	-	-	14.6	14.6	9.0	100
Bizovac	Bizovac	1974	-	-	1.4	1.4	5.9	100
total					42.3	42.3	44.7	100

Table E: Shallow geothermal energy, ground source heat pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2018		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2018 *	n/a	n/a	n/a	n/a	n/a	n/a
Projected total by 2020	n/a	n/a	n/a			

Table F: Investment and Employment in geothermal energy

	in 2018		Expected in 2020	
	Expenditures (million €)	Personnel (number)	Expenditures (million €)	Personnel (number)
Geothermal electric power	n/a	10 est	n/a	20 est
Geothermal direct uses	n/a	30 est	n/a	35 est
Shallow geothermal	n/a	n/a	n/a	n/a
total	n/a	**40** est	n/a	**55** est

Table G: Incentives, Information, Education

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	-	-	-
Financial Incentives – Investment	-	-	-
Financial Incentives – Operation/Production	-	-	-
Information activities – promotion for the public	yes	yes	yes
Information activities – geological information	yes	yes	yes
Education/Training – Academic	yes	yes	yes
Education/Training – Vocational	no	no	no

Key for financial incentives:					
DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium	O	Other (please explain)
RC	Risk coverage	REQ	Renewable Energy Quota		