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Croatia Country Update 2020 - Finally the start of power production

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ABSTRACT

After some turbulent attempts, the local developers and international companies succeeded to break the ice and the first geothermal power plant has started production and contribution to the national power grid (for now 10 MW_e can be passed into the power grid due to grid limitation, but up to potentially 20MW_e). That is a small but crucial step and should raise attention to the understanding and utilization of the geothermal energy potential, which is significant for the country's needs. This long-expected event, combined with the recent taking over of control of several thousand abandoned hydrocarbon exploration and production wells by the government, together with massive geophysical-geological studies available to investors, will cut costs and risk of the utilization of Croatia's geothermal potential. Finally, these efforts will be supported by a new legislative framework for renewable energy sources. These crucial events should raise the interest for new exploration / production licenses, both for power generation and direct heat utilization.

In the Croatian part of Neogene-age Pannonian basin, the main geothermal advantage is the favorable terrestrial heat flow. Heat conduction is easier there because of regional crust thinning (less than twenty kilometers) and the presence of the geothermal fluids (predominantly water convergence through massive structures of Mesozoic fractured carbonate aquifers, insulated with the younger basin fill). In the lower scale, they are followed by the basin material origin; carbonate fractured massif and high-profile reservoirs, together with layered sandy bodies, with intergranular porosity, insulated with the fine-grained shales, marls and clays.

Here, some extraordinary geothermal water bodies at economically reasonable depths from less than 1,000 m to hardly over 3,000 m can be found. They can produce a significant outflow from several tens to more than a hundred liters per second, with temperatures from one hundred to higher than two hundred degrees Celsius. Since most of the already tested fields outflow is artesian, enhanced and dry rock geothermal approaches are not discussed here. Together with geothermal water production, it is often possible to produce significant quantities of the unconventional hydrocarbon dissolved aquifer gas. Geothermal water production can be used to enhance production in aged hydrocarbon fields.

Other geothermal energy targets are numerous poorly developed natural geothermal springs, and shallow (500 -> 1000 m) "geo-temperate waters" structures which are also attractive for low cost / low energy gain, mostly utilizable for recreation and balneology. Some of them can rise to worthy energy production, not mentioning standard procedures to pump the energy from the neutral Earth layer by heat pump technology and hybrid energy systems.

Beside proven geothermal potential of the north Croatian part of the Pannonian sedimentary basin, the geothermal potential is expected also at the tectonically active belt of the Dinaridic carbonate platform range stretching to the southwest. It is indicated by some natural geothermal springs and shows, but its potential will be revealed by better understanding of hydrocarbon games and fields, together with expected deep geothermal water.

Now after "geothermal electricity" is running through the Croatian power grid, conservative expectation from the already proven part of geothermal potential is about 10% of the expected potential. From discovered fields it is realistic to expect 100 MWe (2% of the existing capacity in the country) several hundred MWt in co-generation there, followed by additional 500 MWt direct geothermal heat consumption from new sites and/or using several hundred abandoned oil and gas deep wells, what amounts to 25% of today's natural gas consumption.

Already, such conservative predictions of geothermal energy production can change the lethargic visions of the energy mix of the country into the self-sustaining domestic clean and stable energy supply and make the country meaningful in the EU and world economy. The geothermal energy resources are a trigger to the complex development of Croatia for all who come and stay in the country.

1. INTRODUCTION

This report is the last in the series since WGC Florence 1995 (Čubrić et al., 1995; Jelić et al., 2000; Jelić et al., 2005; Jelić et al., 2010; Kolbah et al., 2015). Croatia is now an EU member parliamentary democracy State, where the Prime Minister is the head of government. A growing number of industry factors are pressuring the state policies to recognize geothermal energy resources as important.

The Ministry of Environment and Energy is responsible for energy sector activities and policies, whereas exploration and production of geothermal waters are serviced by the Croatian Hydrocarbon Agency (CHA). The high-level effort is undertaken there, to ensure geological and international legal framework to enhance existing initiatives and provide further support. They are especially looking for possibilities to ease and ensure funding. Geothermal energy sources are recently developed by private domestic and international investors, gradually more supported by the local communities.

2. GEOLOGY BACKGROUND WITH GEOTHERMAL RESOURCES AND POTENTIAL

Croatia is settled within two main regional geological provinces – Pannonian basin to the north, and Dinarides to the south. Both units are results of indentation of Ancient Ocean and their archipelagos backed by the African plate to the Euro-Asian plate bay, controlled by Check and Moesia massifs that started in Cretaceous. Today's geological setting in Croatia, was developed in several phases resulting in the rise of the main part of Dinaridic carbonate platform, with southwest verging foreland, mostly developed in the Adriatic offshore, backed by mountain belt extending in a northwest-southeast direction along with important strike-slip compensation. At the inner Pannonian side, north branch of Dinaridic carbonate platform's archipelagos are twisted around central Bosnian massifs and its fragments, by indentation entered deeply into the future basin area, even to the north and to the east of the Croatian Pannonian territory, forming the basin basement and marking the proto basin troughs initially filed with sin-orogenetic material. That rise of the main part of Dinarides was caused by subduction of the Adriatic plate and deepening of the Moho discontinuity to 35-40 km in the narrow northwest-southeast direction and consequently formation of a back-arc type basin in the Pannonian area. Future basin area was firstly characterized by uprising and thinning of the crust and differential erosion of sedimentary cover and opening of proto basins with local sedimentation, followed by isotactic subsidence in the mid-Miocene, finally setting Moho discontinuity in the Pannonian area at about 25-30 km (Figure 1).

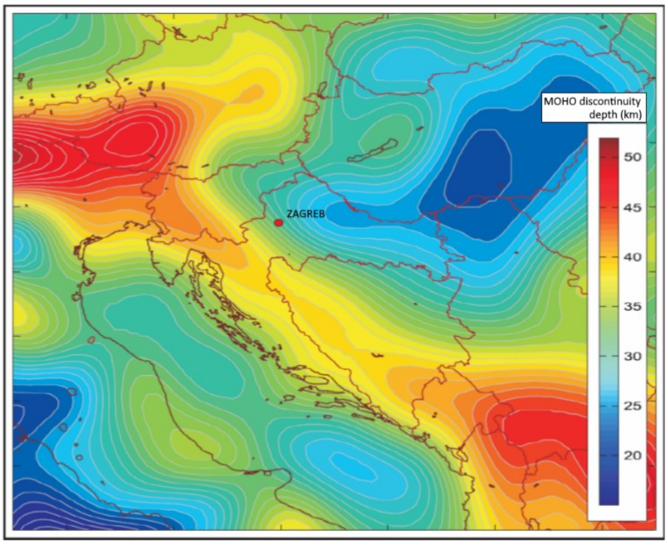

Figure 1. Map of Moho discontinuity depths in SE Europe (Grad et al., 2009)

Described geological features in the Pannonian area, such as crustal thickness, basin sedimentary cover and fragments of a massive carbonate platform sequences, control the geothermal features of the country in crustal and important deep water body settings (Kolbah, 2010), controlling geothermal surface flow by thermal conduction and convection models. The Pannonian basin area has a significant geothermal potential where the geothermal temperature gradient is commonly higher than 40°C/km and in top of important geothermal water bodies reaches values of more than 70°C/km. The terrestrial heat-flow density is also high, ranging from 60 to over 100 mW/m^2 with an opportunity to find high-temperature water accumulations (Figure 2). Accordingly, along with hydro-geothermal resources, here we can also expect possible dry rock or enhanced geothermal energy resources.

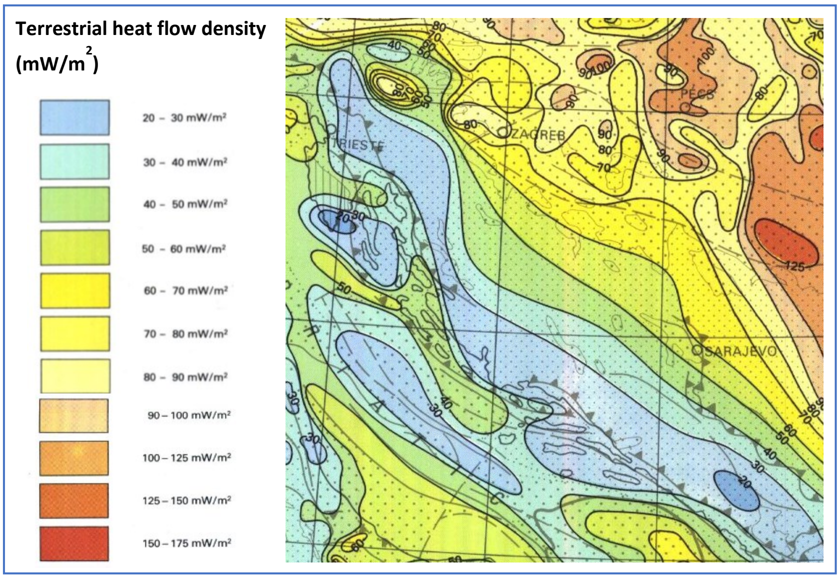

Figure 2. Terrestrial heat flow density in Croatia (Hurtig et al., 1992)

On the other hand, there is missing consolidated sedimentary cover in the Adriatic and exposed thick carbonate sequences at the surface in Dinaridic area, with bit ticker crust in the relatively narrow zone, but it is still a tectonically very active area, given a completely different surface geothermal heat flow picture under the deep penetration of huge masses of surface and seawater. The Dinarides area, with poor geothermal features at the moment, geothermal temperature gradient ranges between 10 and 30°C/km and the terrestrial heat-flow density between 20 and 60 mW/m^2 (Figure 2). Deep geothermal water bodies, as well as hydrocarbon accumulations, are indicated in the area by the surface geothermal and hydrocarbons exploration, but we leave it to the expected future discoveries.

The geothermal potential of the Pannonian basin area is marked with 30 major natural springs of thermal water, many of which have been known since Roman times. They exhibit temperatures up to 65°C and have often been developed with wells in order to reach waters with higher temperatures or increase flow rates.

Moreover, waters with higher water temperatures were found in the course of oil and gas research taken in the Pannonian basin area in the second part of the 20th century. In that time, massive geological and geophysical exploration finalized with more than 4,000 deep wells drilled. Nearly fifty oil and gas fields and five geothermal fields (Elezović et al., 2018) were put in production.

There are two main types of geothermal aquifers: the one with intergranular porosity in clastic sediments of Mesozoic and Tertiary age and the other with secondary porosity - fractures and caverns of Mesozoic and Miocene carbonates. Mesozoic massive carbonate deposits with highly developed secondary porosity provide reservoirs with richer flows and higher formation temperatures such as Velika Ciglena (175°C) now in production, Kutnjak-Lunjkovec (140°C), and Slatina (190°C) with high production level favorable for electricity generation by modern technology and economy.

Quantification of geothermal resources for power production and other sources expect to cover 20% of domestic demand (Kolbah et al; 2018). Except for that exceptional places, most of the basin area of north Croatia show potential for acceptable production rates and temperatures for direct heat geothermal consumption. For that preferentially we can use clastic deposits reservoirs up to 1,000 m depth, but other reservoirs can be useful and even more prolific if the production rate was higher (Brkić et al; 2009). Examples of such locations are in Bošnjaci in Vukovar-Srijem county or Sveta Nedelja in Zagreb county where greenhouses are heated by geothermal energy.

3. GEOTHERMAL UTILIZATION

Geothermal energy is traditionally used for balneology and space heating, nowadays in 15 active Spas. Beside Spas, there are three locations of greenhouses where geothermal energy is used for heating, two locations of individual space heating, and a small district heating system. Due to low utilization capacity of direct heat, only 360 TJ of thermal energy was produced in 2019.

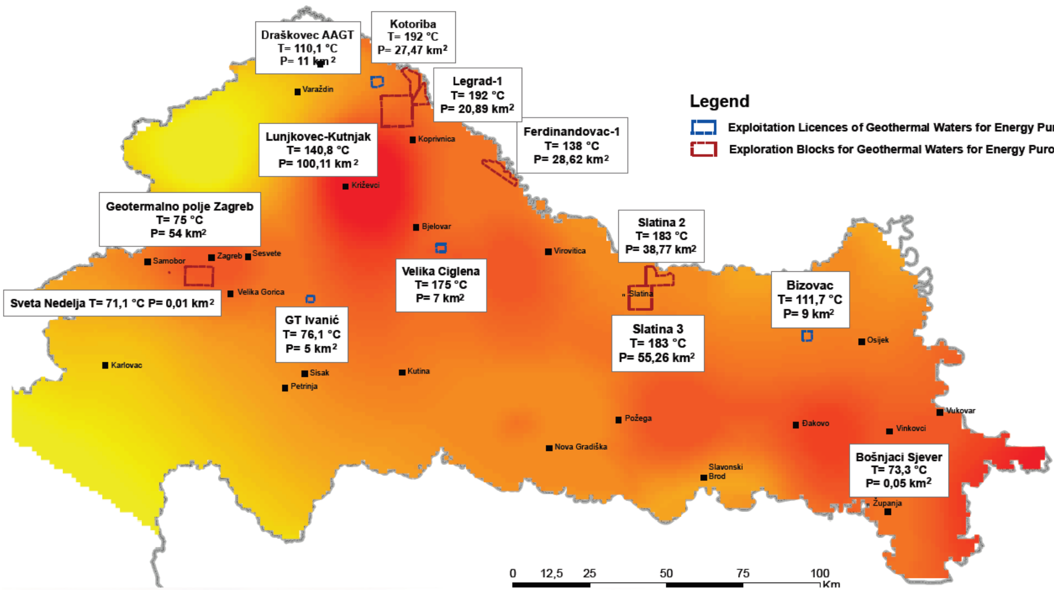

Figure 3. Exploitation and exploration licences of geothermal waters for energy use in Croatia (Croatian Hydrocarbon Agency, 2019)

At the end of 2018 first geothermal power plant Velika 1 was put in operation at Velika Ciglena Site. This was a huge achievement for Croatian geothermal sector, as the site has been known since the 1980s. At the location are two production-injection doublets, a 16.5 MW turbine has been installed, and 10 MW are delivered to the power grid. Altogether, the capacity of all active geothermal installations amounts to 75.5 MWt, and 16.5 MWe.

Along with the Velika Ciglena site, production licenses are also issued for a greenhouse (Bošnjaci), two Spas (Bizovac and Ivanić), and a hybrid geothermal power plant development in the NW part of Croatia (AAT Geothermae) (Figure 3).

Shallow geothermal energy shows significant potential for utilization in Croatia. The continental region and region of the Adriatic coastline have a great perspective for utilization of ground source heat pumps. In the continental region, this is due to favorable geothermal gradients and the geological setting. Even though along the Adriatic coastline the geothermal gradient shows low to moderate values, a favorable shallow geothermal potential is present because of the geological setting, which shows that rocks are mostly carbonates, with favorable thermal conductivity. Ground source heat pump installations are growing in popularity throughout Croatia, becoming more attractive for space heating and cooling in both private houses and the service sector. Collected data on heat production shows 32,6 TJ/y, of which 30 TJ/y is used for heating and 2,6 TJ/y was produced as cooling energy (Macenić et al., 2018).

4. DISCUSSION

In the last three years, a detailed survey of utilization of existing geothermal capacities was conducted in Croatia, with review of data of average flow rates, inlet and outlet temperatures. Additionally, four Spas were closed, in Ivanić Grad Spa thermal water is no longer used, and two new ones opened. Therefore, although similar capacity is still in place, only 56% of thermal energy is produced compared to 2015.

Most of the Spas in Croatia are outdated, seeking funds for renovation and increased energy efficiency. There is a lot of interest for geothermal projects, both for direct utilization and for power production, so it remains to be seen how fast the geothermal utilization will advance in the coming years.

Geothermal energy, as well as the other renewable energy sources, falls under an incentive scheme for eligible producers of energy. The incentive price for electricity produced from geothermal power plants amounts to 1.5669 HRK/kWh (0.21 EUR/kWh) and is paid by the Croatian Energy Market Operator (HROTE) for the electricity delivered to the power system.

Cost of heat produced form geothermal energy depends on its use and overall project, but the average savings compared to other fuels, particularly gas, amount to about 30%.

Mid-2018 adoption of a law on exploration and exploitation of hydrocarbons introduced a chapter solely devoted to geothermal energy. The procedure of obtaining a license for exploration and production is united into a joint procedure enabling faster and simpler processing.

5. FUTURE DEVELOPMENT AND INSTALLATIONS

There are a number of perspective locations suitable for geothermal utilization of which 8 exploration licenses have been issued in the last couple of years: 6 for electricity production, 2 for space heating (Figure 3).

Hybrid geothermal power plant AAT Geothermae is an ongoing project that, along with geothermal water energy in an ORC power plant, plans to use methane dissolved in geothermal water in four cogeneration units with the internalization of exhaust gases, separation of CO_2 and its injection along with geothermal water outflow back to the reservoir. This project was declared as a project of national interest for Croatia.

Geothermal field Zagreb, with its 14 wells, and current production in 3 of them is under additional exploration aiming to connect to a part of the city district heating system, now using natural gas.

Intensive preparation for exploratory works is ongoing in Slatina, one of the perspective locations that was recently issued an exploration license.

The overview of research conducted in shallow geothermal energy potential shows a good scientific basis for implementation in future heating and/or cooling of commercial and residential buildings/objects.

6. CONCLUSION

Besides the icebreaking development in the power production at the Velika Ciglena, direct heat testing is expected at the geothermal field, Zagreb. Challenged by the private, international initiatives, a lot of work was done in understanding the nature and potential of this important national energy resource, from additional hydrocarbon production, CO_2 management, water recovery, balneology, and development of continental tourism. With abundant natural resources it is obvious that geothermal resources can provide meaningful energy production, both electricity and heat. Projects requiring high scientific and technological levels such as the ongoing hybrid geothermal power plant with internalization of CO_2, and more are expected in the coming years. The production potential of these projects could cover up to 20% of Croatia's domestic energy needs (electricity and heat).

ACKNOWLEDGEMENTS

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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	16	76	2048	4667	2212	5608			60 (biomass) 42 (biogas) 576 (wind) 85 (solar)	450 310 1300 79	5039	12490
Under construction in December 2019	4	25							52 (biomass) 12 (biogas) 162 (wind)	380 85 300	176	790
Funds committed, but not yet under construction in December 2019												
Estimated total projected use by 2020	20	120	1941	3100	2356	6482			153 (biomass) 50 (biogas) 734 (wind) 96 (solar)	734 350 1720 134	5354	12640

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2019

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

2) 1F = Single Flash B = Binary (Rankine Cycle)
2F = Double Flash H = Hybrid (explain)
3F = Triple Flash O = Other (please specify)
D = Dry Steam

3) Electrical installed capacity in 2019

4) Electrical capacity actually up and running in 2019

Locality	Power Plant Name	Year Commissioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe[3)]	Total Running Capacity MWe[4)]	Annual Energy Produced 2019 GWh/yr	Total under Constr. or Planned MWe
Velika Ciglena	Velika 1	2018	1		B	16.5	16.5	76	20
Total			1			16.5	16.5	76	20

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019 (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]
Bizovac	HB	6,4	80,0	40,0			1,07	5,00	26,38	0,78
Bošnjaci (Bos-1)	G	20,0	65,0	55,0			0,84	12,00	15,83	0,60
Daruvar Spa(Daruvar)	B	21,0	48,0	21,0			2,37	4,70	16,74	0,22

Aquae Belissae (Daruvar)	B	21,0	46,0	28,0			1,58	3,20	7,60	0,15
Jezerčica Spa (Stubicke T)	B	34,2	37,0	25,0			1,72	0,60	0,95	0,02
Krapinske Toplice (KrT-1) (Krapina Spa)	HB	110,0	40,7	26,0			6,77	6,80	13,18	0,06
Krapinske Toplice (Greenhouse)	G	10,0	45,0	35,0			0,42	7,00	9,23	0,70
Lešće Spa (Lesce)	B	6,2	32,0	15,7			0,42	2,00	4,30	0,32
Lipik Spa (Lipik)	HB	6,8	60,0	28,0			0,91	1,40	5,91	0,21
Livade Spa (N Istria)	B	2,0	28,0	13,0			0,13	0,50	0,99	0,25
Stubičke Toplice - Spa (Stubicke T)	HB	17,0	58,0	28,0			2,13	2,00	7,91	0,12
Sveta Nedjelja (N-1)	G	25,0	63,0	53,0			1,05	20,00	26,38	0,80
Topusko Spa (TEB-3)	HB	136,0	64,0	22,0			23,90	19,30	106,92	0,14
Tuhelj Spa (Tuh.T)	B	85,0	32,9	17,0			5,65	3,30	6,92	0,04
Varaždinske Toplice - Spa (VTB-1)	HB	95,0	57,6	29,0			11,37	16,30	61,49	0,17
Zagreb (Mla-3)	HB	50,0	82,0	32,0			10,46	0,64	4,22	0,01
Zagreb-Univ.Hosp.(Zagreb)	H	14,0	78,0	25,0			3,10	6,10	42,64	0,44
Zagreb Lucko (Luc-1)	H	13,9	55,0	30,0			1,45	0,64	2,11	0,05
Terme Sv. Martin	B	10,0	37,0	32,0			0,21	0,50	0,33	0,05
TOTAL		683,5					75,55	111,98	360,04	0,15

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2019

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the cooling mode. Cooling energy numbers will be used to calculate carbon offsets.

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 - typically 3 to 4

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

6) Cooling energy = rated output energy (kJ/hr) x [(EER - 1)/EER] x equivalent full load hours/yr

Note: please report all numbers to three significant figures
Due to room limitation, locality can be by regions within the country.

Locality	Ground or Water Temp. (°C)1)	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type2)	COP3)	Heating Equivalent Full Load Hr/Year4)	Thermal Energy Used5) (TJ/yr)	Cooling Energy6) (TJ/yr)
TOTAL						1200	30	2,6

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

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)

Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% capacity all year

4) Other than heat pumps

5) Includes drying or dehydration of grains, fruits and vegetables

6) Excludes agricultural drying and dehydration

7) Includes balneology

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]	18,6	51,2	0,09
District Heating [4]	10,5	126,4	0,38
Air Conditioning (Cooling)			
Greenhouse Heating	2,3	87,4	1,20
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	44,1	95,1	0,07
Other Uses (specify)			
Subtotal	75,5	360,1	0,15
Geothermal Heat Pumps			
TOTAL	75,6	360,1	0,15

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)

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)					2.3
Production	>150° C					
	150-100° C					
	<100° C	1				
Injection	(all)					
Total		1				2.3

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 Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015	3	4	3	3	2	6
2016	3	5	3	3	2	6
2017	3	6	3	3	2	7
2018	3	6	3	3	2	7
2019	3	9	3	3	2	10
Total	15	30	15	15	10	36

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	0	0	0	0	0	0
2000-2004	0	1	1	0	0	100
2005-2009	0	0,5	0,5	0	0	100
2010-2014	0,5	3	3	0,5	100	0
2015-2019	4	3	1	40	100	0