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Geothermal Resources and Energy Use in Russia

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ABSTRACT

Russia possesses unique reserves of geothermal energy for production of electricity, provision of district heating systems for industrial and agricultural needs. Exploitation of geothermal resources, implementation of drilling operations for geothermal fluid production has been carried out in Russia and former Soviet Union for more than 60 years. Today, almost all territories in the country has been well investigated. It was found that numerous regions have reserves of hot geothermal fluid with temperatures ranging from 50 up to 200^{o} C at depth from 200 to 3,000 m. These areas are located in the European part of Russia: Central region; Northern Caucasus; Daghestan; in Siberia: Baikal rift area, Krasnoyarsk region, Chukotka, Sakhalin. Kamchatka Peninsula and the Kuril Islands have the richest resources of geothermal power available for the production of up to 2,000 MW of electricity and for more than 3,000 MW of heat for district heating system. Utilization of geothermal resources in Russia is especially important for heat supply to northern territories of our country. In Russia more than 45% of total energy resources are used for heat supply of cities, settlements and industrial complexes. Up to 30% of those energy resources can be provided using geothermal heat. Utilization of geothermal heat is planned in the following regions of Russia: Krasnodar Region (heat supply of Labinsk town as well as complex geothermal use in Rozoviy town), Kaliningrad Region and Kamchatka (heat supply of Yelizovo and construction of Pauzhetsky binary power plant of 2.5 MW capacity and extension of the existing Mutnovsky GeoPP (50 MW) utilize secondary steam for the production up to 12 MW of electricity.

1. INTRODUCTION

The economic and political changes that have taken place in Russia greatly influence the way the power industry is developing. Power and heat generation in Russia mainly is based on fossil fuel utilization and operation of nuclear and hydro power plants. Nowadays contribution of geothermal energy is comparatively modest, although the country possesses significant geothermal resources. Contemporary economic situation in Russia depends on development of its energy potential. Difficulties with fuel transportation make the problem of power supply sounder, particularly in northern and eastern regions of the country. Under these circumstances, it is natural that the regions should strive to use their own energy resources and develop renewable sources of energy. In the Far Eastern regions, Sakhalin, the Kuril Islands, and, particularly, in Kamchatka, utilization of the Earth's thermal energy is coming to be a subject of great importance. Figure 1 illustrates the main territories of Russia possessing geothermal power resources for industrial utilization. There are 8 main regions promising for "direct" utilization (heat supply to residential and industrial buildings, heating of greenhouses and soils, in the cattle breeding industry, fish farming, in industrial manufacture, for chemical elements extraction, for increase of a reservoir recovery, for frozen rocks melting, in balneology etc.), as well as for heat generation with application of heat pumps and power production at binary cycle GeoPP. One of them – region 5 (Kamchatka and the Kuril Islands) is region of active volcanoes being most promising for "direct" utilization of geothermal heat and construction of single and double flash GeoPP. So far 66 thermal water and steam-and-hydrothermal fields have been explored in Russia. Half of them is in operation providing approximately 1.5 million Gkal of heat annually, which is equal to the annual replacement of almost 300 thousand tons of conventional fuel. Vartanjan, Komjagina (1999).

1 - space heating by heat pumps, 2 – direct use, 3 - power generation

1 **– Northern Caucasus (Alpine area),** ***2*** **– NorthernCaucasus (platform area),** ***3*** **– West Siberia,** ***4*** **– Baikal adjacent area,** ***5*** **- Kuril-Kamchatka region,** ***6*** **–Primorje,** ***7-8*** **– Okhotsko-Chukotsky volcanic belt**

Figure 1: Promising geothermal area of Russia

2. SOUTHERN PART OF RUSSIA

Daghestan Republic at the Northern Caucasus is one of the biggest area for the development of geothermal energy. Total amount of resources at the depth of 0.5-5.5 km allows to obtain approximately 4 million m^3/day of geothermal fluid. At present, more than 7.5 million m^3/year of hot water 50-110^0 C is used in Daghestan. Among them, 17% as hot water; 43% for district heating; 20% for greenhouses and 3% for balneology and mineral water production. Totally in Daghestan about 180 wells have been drilled at a depth from 200 to 5,500 m. The regions of such towns as Kizlyar, Tarumovka and Jushnosukhokumsk, possess unique reserves of hot water. For instance, Tarumovskoye deposit has the reserves of geothermal water of high salinity (200 g/l) with temperature up to 195^{o}C. Six wells have been drilled to depths of about 5,500 m, the deepest geothermal wells in Russia. Tests indicate high reservoir permeability with wells producing between 7,500 and 11,000 m^3/day at wellhead pressures of 140-150 bara (Magamedov et. al., 1999).

Figure 2: Geothermal resources of the Sothern part of Russia in Krasnodar and Stavropol regions, Daghestan and Chechen Republics

In Caucasia and Ciscaucasia thermal waters make multilayer artesian basins in sediments of Mesozoic and Cenozoic era. Mineralization and temperature of these waters vary significantly: in fore deeps at depths of 1-2 km - from 0,5 to 65 g/kg and from 70 to 100ºC respectively, while on the Scythian platform at depths of 4-5 km – from 1 to 200 g/kg and from 50ºC to 170ºC also respectively (Kononov, Polyak and Kozlov, 2000). In Dagestan total amount of explored thermal water reserves makes 278 thousand m^3/day with flowing operation, and with used water reinjection – 400 thousand m^3/day, herein heat potential being equivalent to the annual replacement of 600 thousand tons of conventional fuel. Main explored thermal water resources with temperature between 40-107^{0}C and mineralization between 1.5-27 g/l are located in the Northern Dagestan. For the last 40 years 12 major thermal water fields have been discovered and 130 wells have been drilled and prepared for exploitation in this region (Fig. 2). However presently only 15% of the potential of known thermal water reserves is used (Aliev, Palamarchuk and Badavov, 2002). Krasnodar region also possesses significant reserves of geothermal heat. It has wide experience of geothermal energy source utilization. Thus, 50 geothermal wells are in service, which produce water in the amount of up to 10 million m^3 having temperature between 75-110ºC. Region wide-scale utilization of geothermal energy use in Krasnodar region will allow providing by 2020 up to 10% of all heat demand and up to 3% of all energy demand of the region. Geothermal energy has big perspectives in Krasnodar region. The aggregate heat capacity of geothermal fields being in service makes 238 MW.

3. CENTRAL PART AND SIBERIA

Besides the economic viability of widely located low potential geothermal resources utilization for heat and power generation is becoming more and more evident; such resources are mostly available in mineralized water fields with temperatures between 30-80^{0}C (sometimes even up to 100^{0}C) at depths between 1-2 km. Such resources are located in the central part of Middle-Russian basin (Moscow syneclise) that comprises 8 regions: Vologodsky, Ivanovsky, Kostromskoy, Moskovsky, Nizhegorodsky, Novgorodsky, Tverskoy and Yaroslavsky. There are also promising opportunities to efficiently utilize thermal waters in Leningrad and especially Kaliningrad regions. Efficiency of their utilization can be provided through application of heat pumps and binary circulating systems. Broad use of geothermal heat is possible in the center of the European part of Russia. Siberia also possesses geothermal heat reserves, which can be used for heat supply and agriculture. (Fig.1) Thermal waters of West Siberia platform form a big artesian basin in the platform cover being almost 3 million. km ^{2} in area extent. At depths down to 3 km resources of thermal water with temperatures between 35 and 75 ^{0}C and mineralization between 1 and 25 g/kg are evaluated at 180 m3/s. Injection of high mineralized thermal waters and brines requires their reinjection after using their heat potential to prevent pollution of the environment. Utilization of even 5% of their reserves will allow generating 834 million Gkal/year, which will save 119 million. tones of conventional fuel. In Baikal adjacent area there are numerous thermal resources, flow rate of which may often reach many thousands of cubic meters a day with temperature varying between 30 and 80oC and higher. Usually mineralization of such waters does not exceed 0,6 g/l. If consider the chemical content of thermal waters, mostly they are alkaline, sulfate or sodium bicarbonate. The majority of these resources is located in Tunkinsky and Barguzinsky cavities and along the coastline of Baikal lake. Kononov and Povarov (2005), Svalova and Povarov(2013). There are also thermal water resources in Primorje and Okhotsko-Chukotsky volcanic belt.

4. KAMCHATKA AND KURIL ISLANDS

However, the richest geothermal heat reserves are in the Far East part of Russia. In particular, Kamchatka and the Kuril Islands (Fig. 3) have the richest resources, with a generating power capacity of up to 2,000 MW and of heat capacity no less than 3,000 MW utilizing a steam water mixture and hot water. Since the middle of 50’s systematic geophysical surveys and drilling have been carried out in Kamchatka geothermal field. To date 385 wells have been drilled to depths of 170 to 1800 m including 44 wells producing a two-phase fluid at an emergence temperature of more than 160 ^{0}C. In 1966, Pauzhetskaya geothermal power plant was commissioned south of Kamchatka; at present it is under successful operation generating the cheapest electricity in that region. The estimated potential of this geothermal field is about 50 MW (up to 30 years) (Povarov, 2000).

Practically all territory of Kamchatka has geothermal heat available in the form of hot water, two-phase fluid and steam. In the south of Kamchatka near the Pauzhetskaya GeoPP, exploration of the Koshelevskaya geothermal system has discovered resources sufficient for GeoPP, with a capacity of about 350 MW. North of Mutnovskaya GeoPP there are resources available for the generation of 180-200 MW. The eastern part of Kamchatka is estimated rich of high temperature geothermal water resources, for a power capacity of about 250 MW. In the center and northern part of Kamchatka the estimated power capacity of the geothermal resources with temperatures above 150 ^{0}C is 550 MW, and the estimated heat capacity of the geothermal resources with temperatures below 150 ^{0}C is up to 600 MW. Nowadays there are 5 geothermal power plants in Kamchatka and the Kuril Islands under successful operation and 2 more under construction (Fig. 4). Main high potential (steam and hydrothermal) systems of Kamchatka are: Mutnovsky, Pauzhetsky, Koshelevsky, Bolshebanny and Kireunsky fields. At present power and heat supply of Kuril Islands is mostly fulfilled from diesel electricity generators and heating boiler-houses operating on imported coal. At the same time, Kuril Islands are rich with geothermal resources. Their expected capacity reaches 300 MW. Geothermal power and heat plants of required capacity can be constructed in the vicinity of each large settlement, operating or planned facilities of Kuril Islands - on Kunashir, Iturup, Paramushir islands, etc. Several geothermal reservoirs were explored and several geothermal manifestations were detected at the mentioned islands. For example, at Kunashir Island, according to exploration works data, the expected reserves of the geothermal reservoir "Goryachy Plyazh - Mendeleyevskoye" are estimated at 52 MW. The expected reserves of the most northern island of Kuril ridge - Paramushir, calculated by various methods, can support operation of a geothermal power plant with capacity of 15- 100 MW. A similar geothermal power complex is under construction at Iturup Island. It will permit supplying electricity for Kurilsk city. Construction of a geothermal power plant is implemented on site at the foot of Baransky volcano, 21 km away from Kurilsk city. Two power modules were installed on two sites, with total capacity of 3.6 MW. In 2006 start-up complex with capacity of 1.8 MW was commissioned. Reserves of fluid for Okeansky reservoir, "Kipyashchy" area, show a geothermal power plant’s capacity of 5.0 MW. Geothermal heat supply of Kurilsk city is not planned due to the terrain relief complexity.

Figure 3: Kamchatka and Kuril Islands – active volcanoes zones

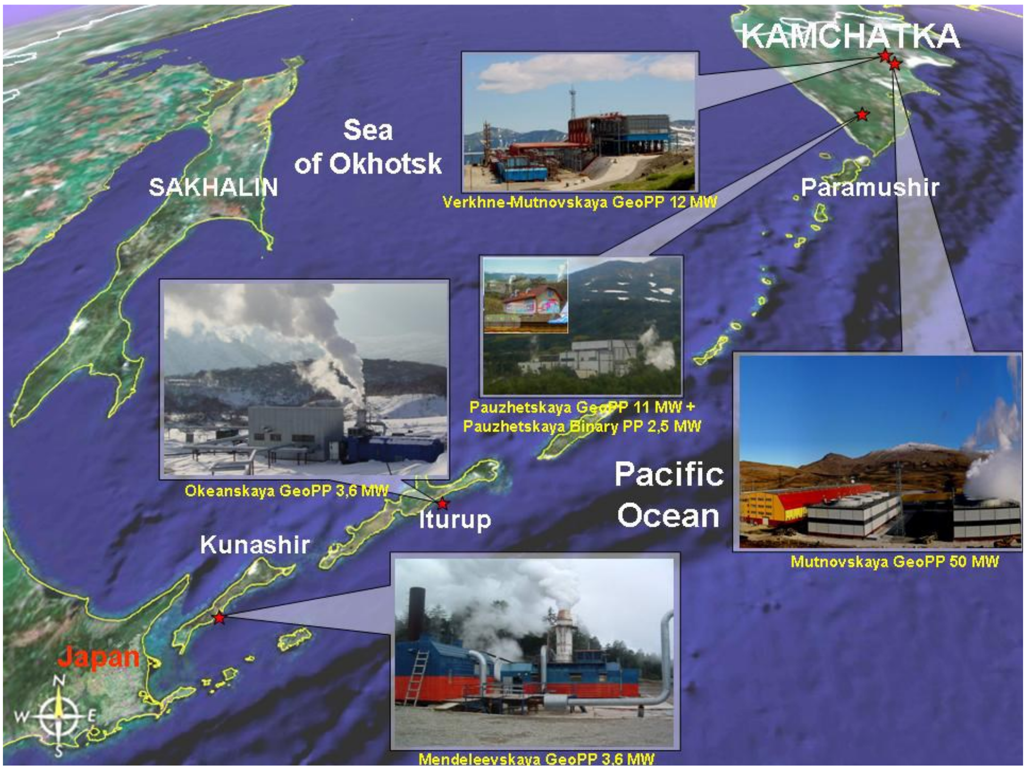

Figure 4: Location of existing geothermal power plants in Kamchatka and Kuril Islands

5. LOCAL GEOTHERMAL DISTRICT HEATING AND POWER SUPPLY SYSTEMS

Direct use of geothermal resources is mostly developed in Kuril-Kamchatka region, Dagestan and Krasnodar Krai, for heat supply and greenhouses heating. Development of geothermal resources is also very promising in such regions as West Siberia, Baikal adjacent area, Chukotka, Primorje, Sakhalin. Besides the economic viability of utilizing widely available, low potential geothermal resources (located in mineralized water with temperature between 30 and 80 ºC and up to 100ºC) fields at depths of 1-2 km for heat and power supply is quite evident. Such resources can be found in the central part of Middle Russian basin. There are also promising opportunities to utilize thermal water in Leningrad and especially in Kaliningrad regions. In line with construction of series of traditional single flash or double flash geothermal power plants and geothermal binary cycle power plants in Kamchatka and Kuril Islands, there are other promising projects in Russia at different stages of development as follow:

- District heating and electricity supply systems for Labinsk City, Krasnodar Krai;
- Complex utilization of geothermal resources in Stavropol Krai;
- District heating and electricity supply of Svetly town, Kaliningrad region.

Construction of new high efficient binary cycle power plants, application of heat pumps and new technologies for dwelling and industrial facilities heating would radically improve the energy supply balance of Russia.

6. CONCLUSIONS

Russia possesses unique natural resources. Fossil fuel reserves are huge in this country and the following are the energy breakdown: 35% for gas, 33% for wood, 12% for oil. At the same time, however, it possesses enormous reserves of geothermal heat, which energy potential 8-12 times exceeds all hydrocarbon fuel energy potential. This could radically change the energy balance. Summarizing the situation with geothermal energy utilization in Russia, we should mention once again that in Kamchatka three geothermal power plants are in successful operation: 12 MW and 50 MW on Verkhne- Mutnovsky and Mutnovsky fields respectively and 11 MW on Pauzhetsky field (Povarov, 2000). On Kuril Islands (Kunashir and Iturup) there are two small GeoPP with capacities of 3.6 MW, which are also in successful operation. Utilization of geothermal heat is planned in the following regions of Russia: Krasnodar Krai (heat supply of Ust-Labinsk and Labinsk towns as well as complex geothermal use in Mostovskoy Region), Kaliningrad Region (energy and heat supply of Svetly town), Kamchatka Region (heat supply of Yelizovo district and construction of Pauzhetsky binary power plant 2.5 MW capacity and extension of existing Mutnovsky GeoPP).

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APPENDIX: STANDARD TABLES

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify-wind+solar)		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	81.9	440.7	169,764		48,450		27,914		134+534.22		246,868	
Under construction in December 2019												
Funds committed, but not yet under construction in December 2019												
Estimated total projected use by 2020												

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

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

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

Electrical installed capacity in 2019

Electrical capacity actually up and running in 2019

Locality	Power Plant Name	Year Com-missioned	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
Kamchatka	Pauzhetskaya	1966	3		1F	14.5.	8	59.5	2.5.
Kamchatka	Verkhne-Mutnovskaya	1999	3		1F	12	12	58.3	
Kamchatka	Mutnovskaya	2002	2		1F	50	50	322.9	
Kunashir	Mendeleevskaya	2007	1		1F	1.8.	1.8.	n/a	3.2.
Iturup	Okeanskaya	2007	2		1F	3.6.	3.6.	n/a	
Total			11			81.9		440.7	5.7.

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019 (other than heat pumps)

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

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

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (^{o}C) - outlet temp. (^{o}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. (^{o}C) - outlet temp. (^{o}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 (^{o}C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Kamchatka	HDBG	532	85	30			122	372	2701	0.7
Kunashir	HD						20			
Krasnodar	HDBGIAFK	370	80	30			77	222	1465	0.6
Stavropol	AGBH	60	100	30			18	36	335	0.6
Adygeya	HA	49	80	30			10	25	162	0.6
Kabardino-Balkarija	G	70	70	30			2	6	33	0.5
Dagestan	HDBG	339	80	30			71	203	1340	0.5
Karachaevo-Cherkessja	D	25	65	30			4	13	58	0.5
North Osetja	D	21	60	30			3	10	41	0.5
Chechnja	DHBGI	50	80	30			10	25	162	0.6
TOTAL		1500					340	900	6500	

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 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	Type[2]	COP[3]	Heating Equivalent Full Load Hr/Year[4]	Thermal Energy Used[5] (TJ/yr)	Cooling Energy[6] (TJ/yr)
Moscow region	12		500	HW	3			
Sankt-Petersburg	9		200	HW	3			
Nizhniy Novgorod	9		100	HW	3			
Krasnodar	20		50	HW	3			
Kamchatka	20		20	HW	3			
Baikal region	15		20	HW	3			
TOTAL			1000					

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 0.131! (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

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]	110	2185	0.63
District Heating [4]	110	2185	0.63
Air Conditioning (Cooling)			
Greenhouse Heating	160	3279	0.65
Fish Farming	4	63	0.5
Animal Farming	4	63	0.5
Agricultural Drying[5]	4	69	0.55
Industrial Process Heat[6]	25	473	0.6
Snow Melting			
Bathing and Swimming[7]	4	63	0.5
Other Uses (specify)			
Subtotal	422	8380	
Geothermal Heat Pumps			
TOTAL			

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: Electric Power	Direct Use	Combined	Other (specify)	Total Depth (km)
Exploration[1]	(all)		2			3
Production	>150° C					
	150-100° C					
	<100° C					
Injection	(all)					
Total			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 Prograr
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015						
2016						
2017						
2018	1,000	100	300			200
2019						
Total	1,000	100	300			200

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

Period	Research & Development Incl.	Field Development Including Production	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999						
2000-2004						
2005-2009						
2010-2014						
2015-2019	0.5	1	0.5		50	50