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Geothermal energy in Mexico: update and perspectives

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ABSTRACT

As of December 2019, the geothermal-electric installed capacity in Mexico is 1005.8 MWe, with five geothermal fields in operation: Cerro Prieto, Los Azufres, Los Humeros, Las Tres Vírgenes, and Domo de San Pedro. The running or operating capacity is 947.8 MWe, as several old back-pressure power units in three of these fields are currently used only as backup for more modern and efficient condensing, flash units. Cerro Prieto is still the largest field in Mexico and the second worldwide, with 570 MWe in operation. The Cerritos Colorados field, with a potential of 75 MWe confirmed by several deep wells drilled in the eighties, is still in standby with good probabilities to be developed in the future. According to the 2015 country update report (Gutiérrez-Negrín et al., 2015), Mexico's installed geothermal capacity decreased 1.1% in the last five years (2015-2019), but the running capacity increased 13% in the same period. The variation is largely explained because the first four units of the Cerro Prieto field, with a combined capacity of 180 MWe, were still included five years ago, but not in this current report. The electric generation produced in those fields was 5,375 GWh during 2018, representing 1.7% of the national electric output. The state utility CFE (Comisión Federal de Electricidad) has been awarded exploration permits on 13 geothermal zones scattered in several states, and seven private companies are exploring 13 additional zones under their own exploration permits, awarded after the Geothermal Energy Law was passed in 2014. Geothermal direct uses in Mexico continued sub-utilized, with 156.1 MW of thermal power installed in hot pools and spas, but some small geothermal heat pumps were installed in 2018 as part of the CeMIE-Geo demonstration projects on direct uses. The geothermal roadmaps recently commissioned by the Energy Ministry envisions 1,670 MWe of geothermal power by 2030 from conventional, hydrothermal resources, and 3,800 MWt of direct uses applications from geothermal energy by the same year, 63% of which could proceed from cascade uses in geothermal fields. Those figures mean a growth of 70% for geothermal power and more than 24 times for direct uses in the next decade. The Mexican Center for Innovation in Geothermal Energy (CeMIE-Geo) and the UE-Mexico's GEMex Project were the main boosters for geothermal R+D+I in the past five years.

1. INTRODUCTION

During the last five years (2015-2019), geothermal energy continued to be utilized in Mexico mainly in its indirect use to produce electric energy, with only a small development of its direct uses. That has been the general situation of geothermal energy in this country practically since 1959, when the first geothermal power plant integrated to the grid started to operate in the Pathé geothermal zone located in central Mexico with 3.5 MWe in capacity.

Comparing with December 2013, the geothermal electric capacity installed in December 2019 has decreased 1.1%, because that year it was reported 1,017.4 MWe and now there are 1005.8 MWe. However, the 2013 figure still included four units of 37.5 MWe each in the Cerro Prieto geothermal field (Gutiérrez-Negrín et al., 2015). These units were the first to start operating in the field, Units 1 and 2 in 1973 and the other two in 1979, and were put out of operation in 2011 (Units 1 and 2) and 2012 (Units 3 and 4), and in 2013 they remained installed in the field even without operation. All these power units were removed in 2016, and since then the installed capacity in the field decreased in 150 MWe to 570 MWe.

It is important to highlight that in the last five years there were relevant investments in research and development of geothermal direct uses, including the installation of the first geothermal heat pumps in Mexico, even though the thermal installed capacity is practically the same for 2014.

2. ELECTRIC ENERGY

In December 2019, which is the last available date by the moment this report was written, the total electric power installed capacity in Mexico was 83,737 MWe (Table 1; most data from ESTA, 2020). Five years ago, the electric installed capacity in the country was reported to be 62,475 MWe (Gutiérrez-Negrín et al., 2015), and therefore there has been an increase of 34% in the last five years.

As presented in Table 1, 68.3% of the installed capacity in the country comes from fossil fuels, mainly natural gas and coal, with hydroelectric plants representing 15.1%, wind power plants 7.5%, solar (photovoltaic) 5.9%, nuclear 1.9%, and geothermal-electric plants 1.1% (Fig. 1, left). In 2013, geothermal represented 1.5% of the total installed capacity in the country, while power plants based on fossil fuels amounted the same current 68.3% (Gutiérrez-Negrín et al., 2015).

It is worth mention that 59.2% of the total power capacity in Mexico is owned and operated by the state utility CFE (Comisión Federal de Electricidad), including almost all (97%) the geothermal-electric installed capacity. The remaining power plants in operation are owned and operated by private companies.

During 2019 the electricity production in Mexico amounted 321,575 GWh (Table 1), representing an increase of 8.2% compared to the total electric generation in 2013, which was 297,095 GWh (ESTA, 2020). More than four fifths of the electric generation in

2019 (81.7%) came from fossil fuels (262.6 TWh), with hydroelectric plants producing 5.9%, nuclear 3.4%, wind 4.8%, geothermal 1.7%, and solar 2.5% (Fig. 1, right), according to Table 1. More than a half of the total was generated by plants owned and operated by the CFE.

In total, renewables sources (hydro, wind, geothermal, solar, and bioenergy) contributed with 14.9% of the electric energy generated in Mexico in 2019 (Table 1). However, nuclear generation and efficient co-generation is considered as clean energy, besides the renewable energy sources, according to the Electric Industry Law. We don't have data about co-generation, but including the nuclear generation, the electricity generated by clean energy sources in Mexico in 2019 was 18.3% (Table 1), which is behind the necessary pace to reach the national goal of producing 35% of the total electric energy with clean energy sources by 2024, set by the Energy Transition Law.

Table 1: Present and planned production of electricity.

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables* (Wind+solar+bioenergy)		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	948	5,375	57,203	262,600	12,683	19,100	1,608	10,800	11,295	23,700	83,737	321,575
Under construction in December 2019	0		2,234		189		0		10,961		13,384	
Funds committed, but not yet under construction in December 2019												
Estimated total projected use by 2025	1,051		63,840		13,169		1,608		22,256		101,924	

*Other renewables include:
- Wind energy: 6,268 MWe and 15,400 GWh
- Solar (only PV): 4,978 MWe and 8,200 GWh
- Bioenergy: 49 MWe and 100 GWh

Geothermal generation is reported for 2018

In 2013 geothermal generation was 6,069.7 GWh (Gutiérrez-Negrín et al., 2015), contributing 2.0% to the total in that year, taking into account the total reported by Sener (2015). In any case according to Table 1, the geothermal generation in Mexico dropped around 11% between 2013 and 2018, which is mainly due to the reduction in the installed capacity, but also because the more recent unit reported in Los Azufres (Unit 18, Table 2) started to operate up to 2019.

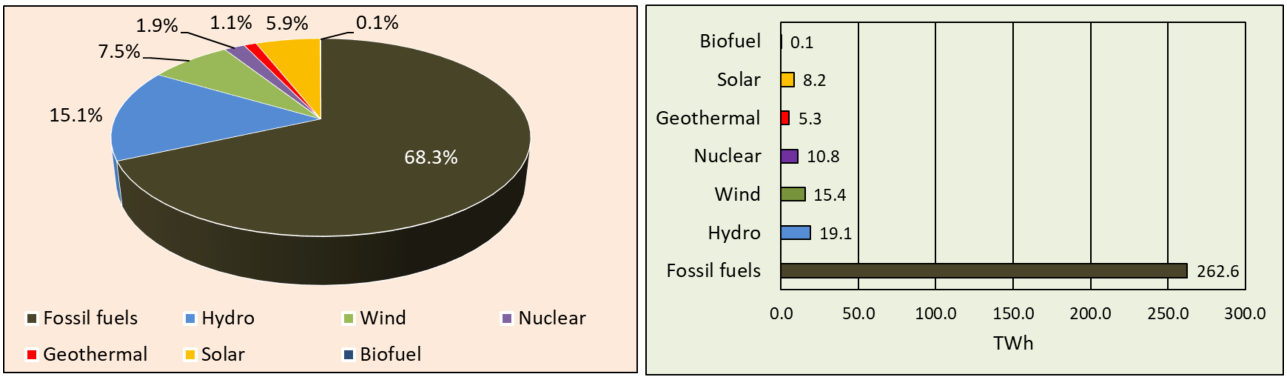

Figure 1: Total electric installed capacity (left) and total power generation (right) by energy source in Mexico in 2019.

It is estimated that in December 2019 there were 13,384 MWe of new power plants under construction (Table 1), 83% of which were based on renewable energy, mostly wind and solar power plants. Practically all of these new wind and solar power plants were being constructed by private companies that won the three past public auctions to buy renewable energy and are expected to be in operation in 2020-2021. The hydro and fossil-fueled plants reported in construction also in Table 1, were being constructed by the CFE. Some more recent programs released by Sener and the CFE seem to include the refurbishment of old hydro power plants and the construction of new ones, but all the plans were stopped due to the Covid 19 pandemics, which produced a drop in the electricity demand during the first semester of 2020.

Table 1 also presents the expected geothermal electric capacity in 2025: 1,051 MWe. This figure considers the retirement of 30 MWe of the oldest power units in Los Azufres and Los Humeros to be replaced by new and more efficient power units. It also includes the probable installation of small plants of 10 MWe in some of the geothermal zones currently under exploration by the CFE and other private companies. The expected geothermal capacity in 2025 is barely 12% higher than the operating capacity in December 2019 (or 5.6% higher than the installed capacity), and it's aligned with the Geothermal Technologic Roadmap for Mexico, which expects 1,025 MWe in 2024 (Sener, 2018). By the way, the country update report presented in the WGC2015 expected 1,395 MWe as the geothermal-electric capacity in Mexico in 2020 (Gutiérrez-Negrín et al., 2015), which of course has been resulted too optimistic.

Regarding the total electric capacity in Mexico, it is estimated that in the next six years (2020-2025), it could reach almost 102 GWe, out of which fossil-fueled power plants will drop to 62.6% from 68.3% they represented in December 2019 (see Table 1 and Figure 1). That total means an increase of almost 22% from the current figure (83.7 GWe), which now looks a little overestimated considering the economic downturn expected as a consequence of the pandemics.

3. GEOTHERMAL FIELDS AND PRODUCTION

Since the last WGC2015, a new geothermal field was integrated to production in Mexico. It is the Domo San Pedro field, located in the state of Nayarit, at the western tip of the physiographic province of the Mexican Volcanic Belt (Fig. 2). Thus, there are currently five fields in production, Cerro Prieto, Los Azufres, Los Humeros, Las Tres Vírgenes and Domo San Pedro (Fig. 2), with an installed capacity of 1005.8 MWe and a running or operating net capacity of 947.8 MWe (see Tables 1 and 2).

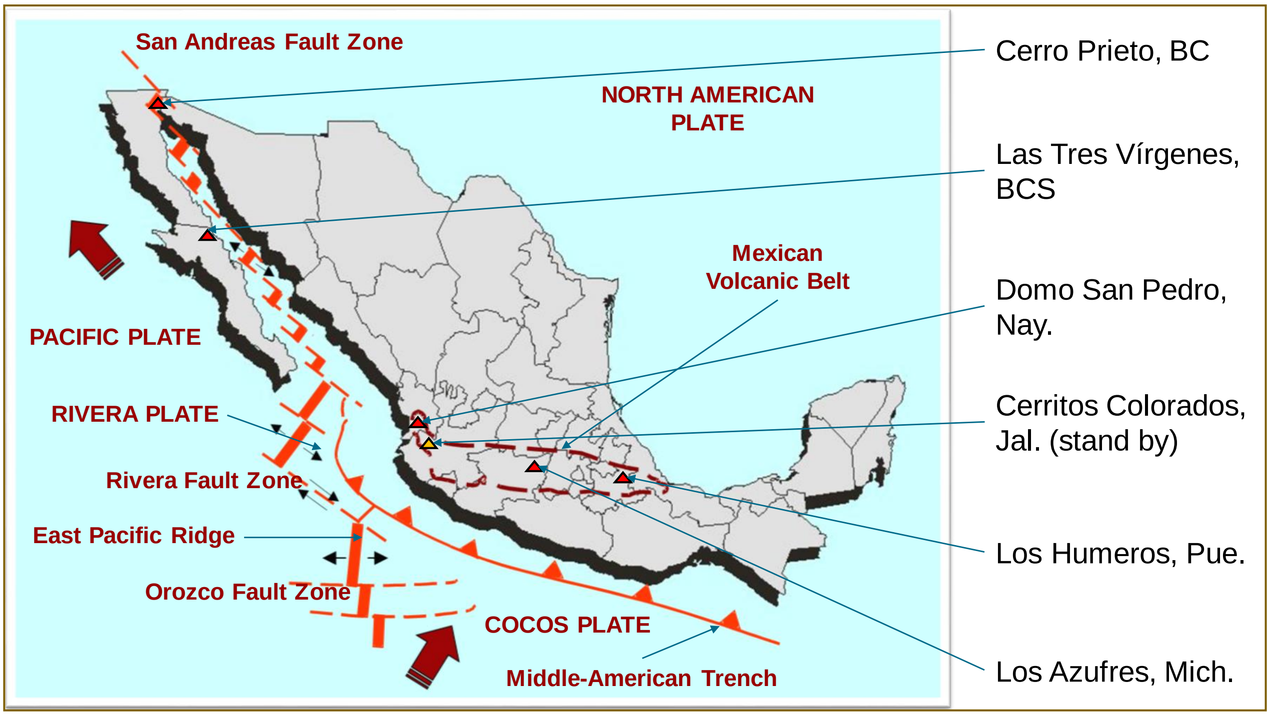

Figure 2: Geothermal fields in Mexico and tectonic scheme.

Under the new Geothermal Energy Law, the CFE was awarded with the exploitation concessions for the first four fields, which it has managed before the law was passed, and it currently owns and operates the well-fields and the power units installed in them, with its own personnel. The Domo San Pedro's concession was awarded to the private company Geotérmica para el Desarrollo (Geodesa), which is part of Grupo Dragón.

The 45 power plants installed in Mexico in December 2019 produced 5,375 GWh in 2018 (Tables 1 and 2) at an average annual capacity factor of 62.7% considering the installed capacity in 2018, or 66.6% taking into account the running or effective capacity in the same year. The geothermal-electric output in those fields was 11.4% lower than in 2013, when 6,069.7 GWh were produced, and 23.7% lower than in 2008, when a generation of 7,047 GWh was achieved only in the four fields managed by CFE (Gutiérrez Negrín et al., 2015).

The annual capacity factor varies from one to another field. For instance, in 2018 the nine power plants operating in Cerro Prieto produced 3,251.2 GWh, which means 65.1% as annual average capacity factor. However, with 1,441.1 GWh generated in the same year, the eight plants in operation in Los Azufres in that year achieved a capacity factor of 74.8%, which was the highest in the country. The lowest one was in the Las Tres Vírgenes field, with an annual average of 54.3%.

As listed in Table 2, there are nine power plants in operation in Cerro Prieto, all of condensing type of single and two-flash, and capacities ranging from 25 to 110 MWe, the latter composed of two 55-MWe with each turbine arranged in tandem. The Unit 1 of Cerro Prieto IV (CP-IV), with 25 MWe of net capacity, generated 223.62 GWh in 2018, presenting the best capacity factor of the field and the country (102.1%), which means that it was operated a little bit beyond its nameplate capacity during certain times during the year. The units of CP-IV are the most recent in the field, with 19 years in operation (Table 2). In addition, the Unit 5 of CP-I, which works with low-pressure steam, produced 250.2 GWh and reached a very good capacity factor of 91.3%, despite its 36 years of operation. Units 1 and 2 of CP-II, with 32-33 years in operation, generated 1,157.38 GWh, at an average capacity factor of 80.1% (see Table 2).

Table 2: Utilization of geothermal energy for electric power generation as of 31 December 2018.

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 2018 GWh/yr	Total under Constr. or Planned MWe
Cerro Prieto[a)]	CP-I[a)] U-5	1982	1		1F	30.0	30.0	250.20	
	CP-II U-1	1986	1		2F	110.0	110.0	774.25	
	U-2	1987	1		2F	110.0	110.0	782.56	
	CP-III U-1	1986	1		2F	110.0	110.0	466.88	
	U-2	1987	1		2F	110.0	110.0	159.60	
	CP-IV U-1	2000	1		1F	25.0	25.0	223.62	
	U-2	2000	1		1F	25.0	25.0	207.62	
	U-3	2000	1		1F	25.0	25.0	174.40	
	U-4	2000	1		1F	25.0	25.0	212.08	
	CP-I U-6								40.0
Los Azufres	U-2	1982	1		O	5.0	5.0	28.59	
	U-3	1982	1	N	O	5.0	0.0	0.00	
	U-4	1982	1	N	O	5.0	0.0	0.00	
	U-5	1982	1	N	O	5.0	0.0	0.00	
	U-6	1986	1		O	5.0	5.0	17.77	
	U-7	1988	1		1F	50.0	50.0	318.69	
	U-9	1990	1	N	O	5.0	0.0	0.00	
	U-10	1992	1		O	5.0	5.0	41.32	
	U-11	1993	1	R	B	1.5	0.0	0.00	
	U-12	1993	1	R	B	1.5	0.0	0.00	
	U-13	2003	1		1F	26.5	26.5	170.82	
	U-14	2003	1		1F	26.5	26.5	198.50	
	U-15	2003	1		1F	26.5	26.5	190.60	
	U-16	2003	1		1F	26.5	26.5	207.48	
	U-17	2015	1		1F	50.0	50.0	274.35	
	U-18[b)]	2019	1	N	1F	26.5	26.5	0	
	AZ-4								10.0
Los Humeros	U-1	1990	1	N	O	5.0	0.0	0.00	
	U-2	1990	1	N	O	5.0	0.0	0.00	
	U-3	1991	1		O	5.0	5.0	12.96	
	U-4	2003	1	N	O	5.0	0.0	0.00	
	U-5	1991	1	N	O	5.0	0.0	0.00	
	U-6	1992	1		O	5.0	5.0	41.32	
	U-7	1994	1	N	O	5.0	0.0	0.00	
	U-8	2008	1		O	5.0	5.0	33.58	
	HUM II-A	2012	1		1F	26.6	26.6	205.1	
	HUM II-B	2013	1		1F	26.6	26.6	0.5	
	HUM III-A	2016	1		1F	26.6	26.6	208.0	
	HUM III-B		1		1F				26.5
Las Tres Vírgenes	U-1	2002	1		1F	5.0	5.0	23.60	
	U-2	2002	1		1F	5.0	5.0	23.95	
	U-3								1.7
Cerritos Colorados[c)]	U-1		1		1F				25.0
	U-2		1		1F				50.0
Domo de San Pedro[d)]	U-1	2015	1	N	O	5.0	0.0		
	U-2	2015	1	N	O	5.0	0.0		
	U-3	2016	1		1F	25.5	25.5	126.6	
Other zones[e)]									40.0
Total			**44**			**1,005.8**	**947.8**	**5,375.0**	**193.2**

[a)]Units 1-4 of CP-1, with a combined capacity of 180 MW, were retired and dismantled from the field and are not included here.

[b)]Unit 18 of Los Azufres was commissioned in 2019. Units 2, 6 and 10, of 5 MW each, are planned to be put out of operation in 2020.

[c)]Formerly La Primavera, with a total assessed geothermal potential of 75 MWe.

[d)]Electric generation in Domo de San Pedro is estimated.

[e)]It includes planned plants in four geothermal zones, according to Sener, 2019.

Notes: 1) N: Not operating (temporary), R: Retired, Blank: in operation; 2) 1F: Single flash, 2F: Double flash, B: Binary, O: Other (back-pressure); 3) Electric installed capacity in June 2018; 4) Electrical capacity actually up and running in June 2019.

As commented before, the oldest power units in Cerro Prieto (U-1 to U-4 in CP-I), with 37.5 MWe each, were put out of operation in 2011-2012. In 2016 they were removed from the field. Before their removal, the installed capacity in Cerro Prieto used to be 720 MWe. However, even with its current capacity of 570 MWe, Cerro Prieto is still the largest geothermal field in Mexico, and the second in the world just behind the Geysers.

The Cerro Prieto field is located in northwestern Mexico (Fig. 2), within a pull-apart basin between the Cucapah-Cerro Prieto and Imperial faults that are of strike-slip type and belong to the San Andreas system, and therefore all the region is subject to transtensional stresses. The heat source seems to be a basic intrusion producing a thermal anomaly, which in turn has been produced by the thinning of the continental crust in the basin. A sequence of sedimentary rocks (sandstones interbedded into shales) with a mean thickness of 2,400 meters are hosting the geothermal fluids (Gutiérrez-Negrín, 2015).

The Cerro Prieto geothermal system is a dominant liquid reservoir, and the wells produce a mixture of fluids at surface conditions with approximately 60% water and 40% steam. The liquid fraction has a sodium-chloride chemical type with neutral to alkaline pH. It is a diluted brine with an average of 27,400 mg/kg of total dissolved solids (TDS), varying from 20,000 mg/kg in the sector CP-I to 33,000 mg/kg in the area of CP-II. The steam fraction contains an average of 1.4% in weight of un-condensable gases, ranging from 1% in CP-I to 1.8% in CP-III, being CO_2 the main component (89% of total gases) (Portugal et al., 2005).

Los Azufres is located in the central part of the country, inside the Mexican Volcanic Belt province (Fig. 2) at an average elevation of 2,850 masl. The installed capacity in December 2019 is 270.5 MWe composed of the 15 units listed in Table 2, and includes two 50 MWe each condensing, single flash power units, five 26.5 MWe each flash units (including the most recent, Unit 18, commissioned in 2019), seven 5 MWe back-pressure and two 1.5-MWe binary cycle power units. Four out of the seven backpressure and the two binary cycle units are out of operation, and thus the running capacity is 247.5 MWe (Table 2). However, the remaining three units of 5 MWe each that were operating in 2019 are planned to be out of operation in 2020. As commented before, the electric energy generation in 2018 was 1,441 GWh at an average capacity factor of 74.8%. Both figures are lower than those reported five years ago: 1,542 GWh and annual capacity factor of 92.2%, despite the lower installed capacity of 194 MWe in 2013 (Gutiérrez-Negrín et al., 2015). The 5-MWe backpressure Unit 10 produced 41.32 GWh along the year, presenting so the best capacity factor of the field (94.3%), and the 25-MWe Unit 16 reached an 89.4% capacity factor with 207.48 GWh of electric output (Table 2).

The Los Azufres field lies in a complex Plio-Pleistocene succession of basalts, andesites, dacites and rhyolites representing three probable volcanic cycles. The heat source seems to be the magma chamber feeding the San Andrés volcano, the highest peak in the area. The geothermal fluids are hosted into the middle and lower portion of a package of interstratified lava flows and pyroclastic rocks of andesitic to basaltic composition, with ages between 18 and 1 Ma, and more than 2,700 m of thickness. This package is overlain by flow-structured rhyolites of 1.2 ± 0.4 Ma in age, which include obsidian flows and perlite structures in some sites (Gutérrez-Negrín, 2015).

Deep geothermal fluids in Los Azufres are sodium chloride-rich waters with high CO_2 contents, and pH around 7.5. Although fluid temperatures can be as high as 320ºC, 240 to 280ºC are commonly measured in the field. Geochemical studies have shown that chemical reactions between the volcanic rocks and geothermal fluids are close to equilibrium (Verma et al., 1989). Main un-condensable gases in the separated steam are CO_2 (94% in volume), with H_2S (2.5% in volume) and minor concentrations of H_2, CH_4, N_2 and NH_3 (combined 3.5% in volume). In general, production wells have shown a decrease in the temperature of the fluids and an increase in the steam fraction of the reservoir (Barragán-Reyes et al., 2012).

Los Humeros geothermal field is also located in the central part of the country, in the eastern portion of the Mexican Volcanic Belt province (Fig. 2) at an average altitude of 2,800 masl. The installed capacity in the field is 119.8 MWe, composed of the 11 power units that appear in Table 2. As it is indicated in the table, five of the eight backpressure units of 5 MWe each are out of service, so the operating capacity is 94.8 MWe. One of the 25 MWe single flash units (Unit HUM II-B) was out of operation most part of the year, and therefore the electricity generation of the field was only 501.5 GWh, at an average capacity factor of 60.3%, plunging from 94.7% reported in 2013 (Gutiérrez-Negrín et al., 2015). However, Unit 6 reached a capacity factor of 94.3%, and the other two condensing units were operating at 88-89%.

The Los Humeros field has been developed inside the Los Potreros volcanic caldera, with 5 to 8 km in diameter, which in turn is nested within the older and larger Los Humeros caldera. The latter is a roughly circular caldera structure of 18 to 20 km diameter, formed ~165 ka ago, when a volcanic eruption extruded around 155 km^3 of magma giving place to the Xaltipan Ignimbrite. The Los Potreros caldera was formed ~70 ka ago, according to recent geochronological dates (Carrasco-Núñez et al., 2018), as result of a new explosive extrusion of approximately 20 km^3 of magma that formed the Zaragoza Ignimbrite. The last volcanic eruption phase occurred between 10 ka and less than 3 ka ago, and it is represented by two extreme volcanic sequences: one is of basic composition (SiO_2<55%) between 7-4 ka, and the other is acidic (SiO_2>65%) with ages of 10-3 ka. According to some thermal-barometric modelling, the current and heat source could be a differentiated magma chamber, stratified into several smaller chambers located at different depths that probably share the same feeding source located at the lower crust, perhaps up to 30 km depth for the olivine basalts (Carrasco-Núñez et al., 2020).

The wells in Los Humeros produce a mixing with more than 85% of high-enthalpy steam and 15% water, and only one well produces mainly water. It is of sodium-chloride to bicarbonate-sulfated type with high content of boron, ammonia and arsenic. The chemical composition of water varies through time and depends on the depth of the well and the diameter of the production orifice. In general, it is low-salinity with partial equilibrium at temperatures of 280-310°C. According to their isotopic behavior, geothermal fluids are a mixing between 'andesitic' water and meteoric fluids of light isotopic composition (δ18O: -14.5, and δD: -105) or paleo-fluids (Barragán et al., 2008).

The Las Tres Vírgenes geothermal field is the smallest one (Fig. 3). It is located at the middle of the Baja peninsula in the state of Baja California Sur (Fig. 2). There are only two condensing, single flash 5 MWe each power units that started operations in 2002 (Table 2). In 2018 these plants generated 47.55 GWh at annual average capacity factor of 54.3%. This is the lowest capacity factor of all the fields operating in Mexico, yet Las Tres Vírgenes provided 30.7% of the electrical demand in the Mulegé system (Sener, 2019), which is a tiny electric circuit isolated of the national grid.

Figure 3: View of Las Tres Vírgenes, B.C.

The field is inside a Quaternary volcanic complex composed of three volcanoes aligned N-S, developed at the western limit of a deformation zone related to the opening of the California Gulf. The geothermal system is structurally controlled and it is located into a system of right strike-slip faults of low and high angle related to a tension zone, and some left strike-slip lateral faults. The oldest lithological unit is a Late Cretaceous (99.1 ± 0.8 Ma) granodioritic intrusion, part of the California Batholith (Macías and Jiménez, 2012). This is the host rock of the geothermal fluids, and its top is found at depths of 900 to 1,000 m in the geothermal wells. The heat source of the system is related to the magma chamber of the La Virgen volcano, the youngest and most southern of the volcanic complex. The geothermal reservoir is liquid dominant (more than 3 parts of brine and 1 part of steam) with temperatures ranging from 250 to 275°C.

The more recent geothermal field in operation in the country is Domo San Pedro, located in Central Mexico at the western portion of the Mexican Volcanic Belt (Fig. 2). By the moment, it is also the only field privately operated in Mexico. Two 5 MWe backpressure, wellhead plants were installed and put in operation in this field in the first quarter of 2015, being both second-hand power plants that were thoroughly serviced and upgraded by the operator (Grupo Dragón) to test the reservoir behavior and quickly start commercial power generation (IGA, 2015). In the last quarter of 2016 a new condensing, single flash power plant of 25 MWe (net) was commissioned, and the backpressure units stayed as backup. Total electric output in 2018 in this field was estimated at 126.6 GWh (Table 2), at an average capacity factor of 56.7%.

The Domo San Pedro geothermal field is related to a couple of massive dacitic domes Quaternary in age (~0.1 million years) whose magma chambers seem to be the heat source of the geothermal system. Together with the other volcanic structures, the San Pedro domes are emplaced in the northwestern edge of the Tepic Graben, considered as a pre-rifting regional structure. The geothermal fluids are found in Tertiary andesitic rocks and Cretaceous granitic rocks at temperatures around 280°C (Gutiérrez-Negrín, 2015b).

Main data on geothermal-electric generation in Mexico in 2018, compared with similar data in the last 24 years are presented in Table 3 (data for previous years taken from Gutiérrez-Negrín et al., 2015).

Table 3: Data on geothermal-electric production in Mexico in the last 24 years.

Data	1995	1999	2003	2008	2013	2018
Installed capacity (MW)	753	755	953	958	1,107	979
Running capacity (MW)	753	755	953	958	839	921
Electricity output (GWh)	5,682	5,619	6,282	7,047	6,070	5,375
Annual average capacity factor (%)	86.1	85.9	74.5	84.0	82.5	66.6
Steam produced (million metric tons)*	55.0	56.3	67.5	65.9	55.7	50.9
Annual average steam specific consumption (tons/MWh)	9.7	10.0	10.7	9.35	9.27	8.47
Production wells (number)*	173	164	197	229	223	225
Average steam produced per well (t/h)	36.3	39.2	39.1	32.8	28.5	25.8

**The corresponding data for 2018 from Domo de San Pedro are estimated.*

4. DRILLING OF GEOTHERMAL WELLS

Between January 2014 and December 2018, 49 geothermal wells were drilled in Mexico for geothermal-electric purposes, as shown in Table 4, almost 86% of which were production wells drilled in the five geothermal fields under exploitation. Five injection wells (~10% of the total) were constructed in all the fields but Las Tres Vírgenes, and only two were exploration wells drilled in a new geothermal zone. There are not reported gradient wells of less than 100 m depth. It is assumed there were no wells deeper than 100 m for direct uses in the period, since most of bathing and spa facilities use water from hot springs and only exceptionally from hot-water wells constructed with other purposes. It is common that some of those facilities in the central part of Mexico construct wells to use the hot water, although these wells are usually less than 100 m deep.

Table 4: Geothermal wells drilled in Mexico from January 1, 2014 to December 31, 2018.

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration	(all)	2				4.0
Production	>150° C	42				119.1
	150-100° C					
	<100° C					
Injection	(all)	5				10.3
Total		**49**				**133.4**

As deducted from Table 4, the average depth of the 42 wells drilled with production purposes in the country was around 2,835 meters, while the injection wells present an average depth of 2,055 m, similar to the depth of the only two exploration wells included in that table. Of course, those average figures are variable depending on the field, since the production wells drilled in Cerro Prieto and Domo San Pedro had an average depth between 3,100 and 3,300 m, while in Los Azufres it was around 2,000 meters.

Most of the wells reported in Table 4 were located in the Cerro Prieto geothermal field, with 22 production and one injection wells representing almost 55% of the total. It means that in average, almost five wells (4.6) were drilled in that field every year, which represent an important reduction in the number of wells drilled annually. In the previous five years (2009-2013) 60 wells were drilled in Cerro Prieto, with an average of 12 wells per year (more than double of the current 4.6) and an average depth of 2,954 meters (Gutiérrez-Negrín et al., 2015).

Considering the drilling data reported before (Gutiérrez-Negrín et al., 2015), it is possible update the accumulative total number and depth of geothermal wells drilled in Mexico up to 2018. It is important to be aware that these include only deep geothermal wells (more than 100 m depth) than have been drilled for geothermal-electric purposes. The figures presented in Table 5 include all the historic data presented in previous reports, since the first exploration wells in the four geothermal fields operated by CFE up to the most recent wells drilled in other zones currently under exploration. The historic geothermal zones include the following: San Marcos, Jal., Volcán Ceboruco, Nay., Laguna Salada, BC, Acoculco and Las Derrumbadas, Pue., Los Negritos, Mich., San Antonio El Bravo and Maguarichic, Chih., Aguacaliente, El Centavito and Santispac, BCS, Santiago Papasquiaro, Dgo., Pathé, Hgo., Tulecheck, BC., and another zone under exploration in 2018 and 2019.

Table 5: Geothermal wells drilled in Mexico from 1963 to December 31, 2018.

Field	Number of wells	Depth (km)	
		Total	Average
Cerro Prieto	452	1,120.2	2.478
Los Azufres	100	161.7	1.617
Los Humeros	58	126.4	2.180
Las Tres Vírgenes	12	24.8	2.070
Domo San Pedro	9	24.5	2.720
Cerritos Colorados	13	23.1	1.777
Other zones	40	56.8	1.420
Total	**684**	**1,537.6**	**2.248**

According to Table 5, in the approximately 55 years spent between 1963 and 2018, 684 geothermal wells have been drilled for exploration, production and injection, with a combined total depth of 1,537.6 kilometers and an average depth of 2,248 meters. A little more than two-thirds of those wells are located in the Cerro Prieto field, representing almost 73% of the combined depth of drilling. In average, more than 12 geothermal wells for geothermal-electric purposes have been drilled every year in Mexico since 1963.

5. GEOTHERMAL DIRECT USES

Contrary to indirect uses, direct uses of geothermal resources have been scarcely developed in Mexico, being restricted practically to bathing and swimming facilities with recreational and/or therapeutic purposes, despite the great number of thermal manifestations identified in surface. Iglesias et al. (2015) compiled the information related to hot springs and other thermal manifestations in Mexico, which has been collected mainly by CFE, and estimated that there are more than 1,600 points with low to middle temperature that can be grouped into more than 900 geothermal systems in 26 states of the country. One half of those systems present temperatures between 62 and 100°C, and 40% between 100 and 149°C, with the remaining 10% with temperatures below 62°C (5%) or higher than 149°C (5%). They estimated that if only 0.1% of the energy of such geothermal resources could be recovered, that would represent more than 40,000 MWt of installed capacity (Iglesias et al., 2015).

In addition, the Mexican Center for Innovation in Geothermal Energy (CeMIE-Geo), a national R+D+I (research, development and innovation) project funded by the federal government during more than four years (2014-2019), carried out seven individual technical projects, aimed to promote geothermal direct uses, including ground-source (geothermal) heat pumps (GHP). They were: Project 10 (feasibility analysis of a prototype of greenhouses air-conditioned by GHP), Project 11 (technological development for using low-enthalpy geothermal resources), Project 13 (demonstrative installation of GHP in Los Humeros village and Mexicali), Project 16 (development of a pilot poly-generation plant with a cascade-use of geothermal energy), Project 22 (design of module system for air-conditioning spaces with GHP), Project 27 (design and development of a food dehydrator based on geothermal heat), Project 30 (demonstrative installation of GHP in university facilities in Morelia) (data from García-Gutiérrez et al., 2019). The projects are currently finished, as well as the CeMIE-Geo, but the permanent facilities left by, or derived from, these projects are reported in Table 6: Agricultural Drying and GHP.

However, despite the high potential for geothermal direct uses in Mexico and the CeMIE-Geo projects, our best estimate is that direct uses in Mexico are more or less the same reported five years ago, currently amounting to 156 MWt, excepting GHP, as presented in Table 6.

Table 6: Utilization of geothermal energy for direct heat uses (other than GHP) as of 30 June 2019.

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)]
Los Azufres, Mich.	B	38.000	72.0	55.0			2.703	34.960	78.391	0.920
Los Azufres, Mich.	H	1.250	110.0	88.0			0.115	1.250	3.627	1.000
Domo San Pedro, Nay.	A	1.667	180.0	105.7			0.518	1.350	13.230	0.810
La Primavera, Jal.	B	63.000	48.0	31.0			4.481	58.650	131.511	0.931
Aguascalientes*	B	265.000	43.0	30.0			14.414	194.139	332.890	0.732
Chiapas*	B	1,000.000	36.0	29.0			29.288	847.656	782.640	0.847
Chihuahua*	B	38.000	39.3	25.0			2.274	29.680	55.982	0.781
Coahuila*	B	56.000	32.0	25.0			1.640	33.390	30.829	0.596
Durango*	B	34.000	52.5	38.0			2.063	15.975	30.553	0.470
Guanajuato*	B	293.000	40.8	29.0			14.466	254.232	395.692	0.867
Hidalgo*	B	271.000	41.5	32.0			10.772	250.800	314.265	0.925
Jalisco*	B	368.000	37.8	30.0			12.010	316.350	325.467	0.859
México*	B	103.000	35.1	25.0			4.353	95.424	127.123	0.926
Michoacán*	B	161.000	44.5	33.0			7.747	152.785	231.752	0.949
Morelos*	B	95.000	45.0	30.0			5.962	74.580	147.557	0.785
Nuevo León*	B	295.000	38.0	30.0			9.874	250.700	264.539	0.850
Querétaro*	B	770.000	31.8	26.5			17.075	697.174	487.373	0.905
San Luis Potosí*	B	292.000	36.8	31.0			7.086	233.888	178.929	0.801
Sinaloa*	B	7.000	72.5	61.0			0.337	4.601	6.979	0.657
Tlaxcala*	B	10.000	35.0	28.0			0.293	8.308	7.671	0.831
Veracruz*	B	42.000	65.0	48.0			2.987	39.328	88.185	0.936
Zacatecas*	B	163.000	36.6	28.5			5.524	138.700	148.186	0.851
TOTAL		**4,366.917**					**155.981**	**3,733.919**	**4,183.370**	**0.850**

Note: Data from Domo San Pedro by Project iiDEA-DGA200.
* It is reported the estimated total flow rate of all the bathing sites in the state, and the average inlet & outlet temperature. Figures are the same reported in previous years, since there are not available updated data.

Notes:
Types are as follows: A: Agricultural drying (grain, fruit, vegetables), B: Bathing and swimming (including balneology), H: Individual space heating (other than heat pumps). 2) Enthalpy information is given only if there is steam or two-phase flow. 3) Capacity (MWt) = Maximum flow rate (kg/s) x [inlet temperature (°C) – outlet temperature (°C)] x 0.004184. 4) Energy use (TJ/year) = Average flow rate (kg/s) x [inlet temperature (°C) – outlet temperature (°C)] x 0.1319. Capacity factor = Annual energy use (TJ/year) / Capacity (MWt) x 0.03171.

The data for individual space heating included in that table corresponds to the heating system of the CFE's facilities in the Los Azufres geothermal field, and is the only geothermal space heating system in the country as of June 2019. It was originally deployed in 1997 and expanded and updated between 2008 and 2014, and currently provides heat to the offices, laboratories and other facilities of the CFE in the field, as well as all the hot water required. The system uses 1.25 kg/s of separated brine before reinjection, to heat the ground water used in the heating system (Ávila Apolinar, et al., 2017).

Data for agricultural drying reported in Table 6 are from a dehydrator installed in the Domo San Pedro geothermal field, capable to produce up to 200 kg of dry fruit per day (Pérez-González et al., 2020), that uses separated geothermal brine from the wells before reinjection. It is the only dehydration installation using geothermal fluids operating in the country as of June 2019, and it was derived from the former CeMIE-Geo's Project 11. Data of bathing and swimming (including balneology) in Table 6 are the same reported five years ago (Gutiérrez-Negrín et al., 2015), and correspond to geothermal spas and swimming facilities grouped into 18 states of Mexico, which have been developed and are operated by private investors. A minor part of those bathing and spa facilities are operated by state or municipal governments, through tourism offices or associated to local owners. It is worth to recall that this information is probably outdated.

Regarding GHPs, the first units in Mexico were installed as part of the mentioned projects 10, 13 and 30 of the former CeMIE-Geo. Thus, there are currently 11 GHP units with a combined capacity of 133 kWt (Table 7) operating as demonstrative projects in the states of Puebla, Baja California and Michoacán.

The first project is composed of two GHPs with a combined capacity of 21 kWt, installed in a small school and a health clinic located both in the Los Humeros village, within the geothermal field of Los Humeros. The second project is a greenhouse conditioned by four GHP units with 35 kWt in capacity, operated by the Polytechnic University in Mexicali, BC; this is the only project where we have all the data required in Table 7. A second project in the same city and university is composed of three GHP units with 42 KWt in capacity, and is used to condition laboratory facilities. The final project in operation was developed by the Michoacán University in Morelia, Mich., to condition one edifice with two GHPs and 35 kWt in capacity. All of the units are ground-coupled, combining in most cases horizontal and vertical arrangements. No data about annual energy use and capacity factors of those units were available, excepting for the greenhouse project in Mexicali.

Table 7: Geothermal (ground-source) heat pumps as of 30 June 2019.

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)
Los Humeros village, Pue.	29.3	21	2	H				
Greenhouse, Mexicali, BC	25	35	4	H & V	3.8	1463	0.136	0.170
Laboratories, Mexicali, BC		42	3	H & V				
Laboratories, Morelia, Mich.		35	2	H & V				
TOTAL		**133**	**11**					

Note: By the moment there are not available more data on temperatures, COP, full load, thermal and cooling energy used.

Notes:
1) Average ground temperature for ground-coupled units, or average well water temperature for water-source heat pumps. 2) Type of installation, where H is horizontal ground coupled, and V is vertical ground-coupled. 3) COP is the Coefficient of Performance = output thermal energy/input energy of compressor) for your climate, and is typically 3 to 4. 4) Equivalent full load operating hours per year, or = capacity factor x 8760. 5) Thermal energy (TJ/year) = flow rate in loop (kg/s) x [(inlet temperature (°C) - outlet temperature (°C)] x 0.1319. 6) Cooling energy = Rated output energy (kJ/hour) x [(EER - 1)/EER] x equivalent full load hours/year.

In summary and excluding heat pumps, it can be said that Mexico has around 4,367 kg/s (15,721 t/h) of geothermal fluids flowing in the surface from hot springs and separated brines with average superficial temperature of 53.3°C, out of which 3,734 kg/s (13,442 t/h) are utilized for direct uses, with an installed capacity of 156 MWt, with a mean capacity factor of 0.85 and an annual utilization of 4,183 TJ/year (Table 8).

Table 8: Summary table of geothermal direct heat uses as of 30 June 2019.

Use	Installed Capacity[1)] (MWt)	Annual Energy Use[2)] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3)]
Individual Space Heating[4)]	0.115	3.627	1.000
District Heating[4)]	0	0	0
Air Conditioning (Cooling)	0	0	0
Greenhouse Heating	0	0	0
Fish Farming	0	0	0
Animal Farming	0	0	0
Agricultural Drying[5)]	0.518	13.230	0.810
Industrial Process Heat[6)]	0	0	0
Snow Melting	0	0	0
Bathing and Swimming[7)]	155.347	4,166.512	0.850
Other Uses (specify)	0	0	0
Subtotal	155.981	4,183.370	0.850
Geothermal Heat Pumps	0.133		
TOTAL	**156.114**	**4,183.370**	**0.850**

Notes:
Installed Capacity (thermal power) (MWt) = Maximum flow rate (kg/s) x [inlet temperature (°C) - outlet temperature (°C)] x 0.004184, or = Maximum flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001. 2) Annual Energy Use (TJ/yr) = Average flow rate (kg/s) x [inlet temperature (°C) - outlet temperature (°C)] x 0.1319, or = Average flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154. 3) Capacity Factor = [Annual Energy Use (TJ/year) / Capacity (MWt)] x 0.03171. 4) Other than heat pumps. 5) Includes drying or dehydration of grains, fruits and vegetables. 6) Excludes agricultural drying and dehydration. 7) Includes balneology. No more data from the only 11 GHP in operation were available.

6. PROFESSIONAL PERSONNEL AND INVESTMENTS

Regarding the professional personnel with a university degree devoted to geothermal activities in Mexico, Table 9 presents the data and its variations during the last five years. Professionals working for the government (column 1) are mainly in the federal Ministry of Energy (Sener), working in the Geothermal Direction involved in regulatory activities. The second column reports the CFE personnel working in its geothermal division (GPG: Gerencia de Proyectos Geotermoeléctricos) and include the estimate professional personnel operating the power units and the wells of the geothermal fields.

Column 3 in Table 9 reports the number of professionals working in several universities like the UNAM, the Michoacán, Guadalajara and the Baja California Polytechnic universities, and also in research centers being the most important the geothermal division of the INEEL (National Institute for Electricity and Clean Energies, formerly IIE), and the center of scientific research and high studies of Ensenada (CICESE). Practically all of the personnel have been involved in the mentioned CeMIE-Geo project and its 30 individual projects between 2014 and the beginning of 2019, and in the GEMex project started in 2017 and currently under development. The latter is a Mexico-EU project focused on non-conventional geothermal resources in Mexico (superhot fluids in the Los Humeros field and Enhanced Geothermal Systems in the Acoculco geothermal zone), whose Mexican part is fully funded by federal funds of the Mexican government.

Table 9: Allocation of professional personnel to geothermal activities (restricted to personnel with university degrees).

Year	Professional Person-Years of Effort						
	(1)	(2)	(3)	(4)	(5)	(6)	**Total**
2015	4	305	323	0	0	77	**709**
2016	3	299	304	0	0	30	**636**
2017	2	406	338	0	0	30	**776**
2018	2	396	319	0	0	46	**763**
2019	1	351	300	0	0	43	**695**
Annual average	**2**	**351**	**317**	**0**	**0**	**45**	**716**

Notes:
(1) Government, (2) Public utilities (CFE), (3) Universities, (4) Paid foreign consultants, (5) Contributed through foreign aid programs, (6) Private industry. Data for 2019 as of June 30.

There are not permanent paid foreign consultants or personnel paid by foreign aid programs, and the personnel working in the private industry is reported in the column 6 of Table 9. Almost all the professional personnel reported in this column work for the private companies Grupo Dragón (Geodesa) and Grupo ENAL, which up to now have been the most involved and constant private companies in the development of geothermal-electric energy in Mexico, and a minor proportion working for another companies.

The last column of Table 9 presents the yearly total of professional personnel. The peak amount occurred in 2017, and the average of the last five years is 716 persons per year. It can be noted in Table 9 that the personnel in the CFE (column 2) and universities and research centers (column 3) has presented low variations in the last years, compared to the personnel in private companies.

Table 10, finally, presents the estimated investments in Mexico for geothermal development over the last 25 years. For the most recent period (2015-2019), we have estimated US$55.9 million for research and development, including exploration drilling, and US$313.3 million for field development. These figures add up to US$369.2 million, for an average annual investment of US$73.8 million, and results 11.8% higher than the amount estimated for the previous lustrum, which is more or less what is to be expected. However, two things are novelty in 2015-2019. One is the estimated investment in research and developing of direct uses (around seven million dollars), which in the past years was negligible, and the other is the increasing in the private investment that represent more than a fifth of the total (22%, or around US$82.44 million) and is more than four times higher than private investment estimated in 2010-2104, when it was of around US$16.5 million (Table 10).

Table 10: Total investments in geothermal in (2019) US dollars.

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	7.41	246.64	0	254.05	0	100
2000-2004	11.61	315.17	0	326.77	0	100
2005-2009	15.65	237.69	0	253.34	0	100
2010-2014	64.61	265.67	0	330.28	5	95
2015-2019	55.90	313.29	7.10	362.09	22	78

Research and development data include the projects CEMIE-Geo, GEMex, Prodetes (public) and ENAL (private).
Field development data include estimated investments by CFE (public), and ENAL and Grupo Dragón (private).

The private investment in R+D+I in geothermal direct uses was expended basically in the mentioned seven projects carried out by the CeMIE-Geo that included the installation of the first GHP in Mexico, but also includes part of the Prodetes award (acronym for development project of sustainable renewable energy) for the project to scale up a geothermal dehydrator in the Domo San Pedro field. All the investments in field development were for geothermal power, and the reported US$313.3 million include expenses of CFE, Grupo Dragón (Geodesa) and Grupo ENAL.

7. PROSPECT AND CONCLUSIONS

From a technical point of view, the prospect for geothermal development in Mexico look great. The potential for conventional geothermal resources, of hydrothermal type, was estimated in around 2,300 MWe some time ago (Gutiérrez-Negrín, 2012), based on the definition for geothermal reserves and resources proposed by the Australian Geothermal Reporting Code (AGEA-AGEG, 2010).

In that code, geothermal reserves are defined as “that portion of an Indicated or Measured Geothermal Resource which is deemed to be economically recoverable after the consideration of both the Geothermal Resource parameters and Modifying Factors. These assessments demonstrate (…) that energy extraction could reasonably be economically and technically justified”. In Mexico, that definition of reserve applies basically to brownfield projects of expansion in the geothermal fields already in operation, plus the assessed potential of the Cerritos Colorados geothermal field (see Table 2). Geothermal resources are defined as “a Geothermal Play which exists in such a form, quality and quantity that there are reasonable prospects for eventual economic extraction… The location, quantity, temperature, geological characteristics and extent of a Geothermal Resource are known, estimated or interpreted from specific geological evidence and knowledge. Geothermal Resources are sub-divided, in order of increasing geological confidence, into Inferred, Indicated and Measured categories.” (AGEA-AGEG, 2010).

A recent update of that estimation indicates that the additional geothermal-electric potential in Mexico is around 2,500 MWe, based only on hydrothermal resources at temperatures ≥150°C, or approximately 2.5 times the current capacity. The geothermal roadmap, published by Sener (2017) and based on the opinions and expectations of geothermal experts, representatives of the academy, the industry and the government, expects to install 750 more megawatts net of geothermal power plants by 2030, to reach around 1,670 MWe in that year. This is a more defined objective representing the vision of the roadmap for that year, which is shared by most of the geothermal experts in Mexico and is barely a third of the mentioned potential of 2,300 MWe.

Regarding direct uses, a specific geothermal roadmap for geothermal direct uses in Mexico, published by Sener in 2018, expects 3,800 MWt in operation by 2030, out of which 2,400 MWt would be installations that use the separated brine in the geothermal fields in operation expected by that year (applications in cascade), 1,000 MWt in applications installed outside the geothermal fields, and 400 MWt in geothermal heat pumps (GHP). Even though it looks as a very optimistic goal, considering that the current capacity in Mexico is around 156 MWt (Table 8), 3,800 MWt is less than 10% of the total potential for geothermal direct uses estimated by Iglesias et al. (2015), as it was mentioned before.

But of course, the additional geothermal potential in Mexico also includes non-conventional resources, and particularly Enhanced Geothermal Systems (EGS). One of the 30 individual projects of the former CeMIE-Geo, consisted of the assessment of the EGS potential in Mexico by following the protocol published by Beardsmore et al. (2010) and endorsed by the International Geothermal Association (IGA). This was Project 7, whose results conclude that the country’s technical potential for EGS is about 2,300 GWe, and that with a recovery factor of 2%, at depths between 3 and 7 km, it would be possible to install around 47,000 MWe, which is more than 47 times the Mexico’s current installed capacity (Hernández-Ochoa et al., 2020).

From the viewpoint of the legal framework of geothermal energy in Mexico, the panorama is also encouraging. Under the geothermal law, the former Geothermal Direction of the Energy Ministry (Sener) has awarded six exploitation concessions and 26 exploration permits as of December 2019. The awarded concessions were for the four geothermal fields that CFE is currently operating and for the Cerritos Colorados field that CFE explored in the eighties and is not yet under exploitation; the sixth concession was for Grupo Dragón (Geodesa) and its Domo San Pedro field. Half of the 26 exploration permits were awarded to CFE, and eight different private companies have got one or more of the remaining 13. Most of the 26 permits issued up to now were for already known geothermal zones with high expectations to contain commercial resources for power development, excepting one for direct uses. Even though some of the permits have expired and no more permits are expected in the near future, the zones already awarded, if properly explored and developed, suggest a promising development in the next decade.

The only current and foreseeable hurdle is, as usual, of economic nature, and is related to the high upfront investments, the high risk in the early stages and the long time required to develop geothermal-electric projects, particularly of greenfield type. Geothermal-electric projects from both CFE and private developers have to compete with solar and wind projects whose initial investments and risks are much lower, and their development time much shorter. And even if the levelized cost of generation are competitive at mid- and long term, basically due to the baseload character of geothermal power plants, investors (and bankers) tend go the easy (and less risky) way.

Thus, financial mechanisms for lowering and sharing risks, especially during drilling the first exploration wells are necessary. In Mexico, the Inter-American Development Bank (IDB) has prepared a program for financing and risk transfer for geothermal energy, currently called Geothermal Financing Mexican Program (PGM), structured under the global loan modality. It consists of two main components: risk mitigation for geothermal projects and financing adapted to the different phases of project exploration and execution. In addition, it will have a third component of technical assistance to support execution and other implementation costs. The program’s total amount is US$108.6 million: US$54.3 million financed with resources from the IDB’s Ordinary Capital, US$51.5 million from a contingent recovery grant financed with resources from the Clean Technology Fund (CTF); and US$2.8 million in technical cooperation. The program’s goal is to finance up to 300 MW of geothermal capacity over a 10-year period. It also hopes to leverage other public and private funds to contribute to Mexico’s geothermal sector with estimated investment levels to the tune of US$4.2 billion for proven geothermal reserves (IGA News, 2018).

In 2018 two parallel processes were developed: First, an International Public Tender to pick the companies that will be in charge of performing the drilling work during the exploration phase; and second, a Call for the Selection of the Eligible Developers who were interested in participating in the program. As of September 2020, the drilling companies have been chosen and four geothermal zones have been awarded to drill at least one deep exploration well in each one. Three of these zones were awarded to CFE (Los Negritos, San Marcos and the extension of Las Tres Vírgenes) and one to the private developer of the extension of Domo de San Pedro.

On the other hand, the Geothermal Development Facility (GDF) was open for projects in Mexico in 2020. GDF is an initiative launched in 2014 in the framework of the COP20 in Lima, Peru, looking for provide financial support to assist in mitigating geothermal exploration risk. Main donors are the German Federal Ministry for Economic Cooperation Development (BMZ), and the EU through the Latin America Investment Facility (EU-LAIF). CFE and some private developers have submitted projects.

Thus, there are reasonably good expectations for resume exploration activities in Mexico, as soon as the Covid-19 pandemic allows it.

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