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Geothermal Country Update of Ecuador: 2015-2020

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ABSTRACT

The groundbreaking geothermal event in this period 2015 – 2020 was the drilling of the first deep exploration well in the history of Ecuador in Nov. 2017 in the Chachimbiro prospect. The well, located at an elevation of 3460masl reached a depth of 1978m with a BHT of 235 °C, and was drilled with the help of non-reimbursable funding and technical cooperation of JICA to CELEC. A follow up 2nd stage, to be funded by a government to government loan through JICA is envisioned for drilling 5 additional appraisal wells and for the installation of a 5MWe wellhead unit, both to be tendered by CELEC under JICA regulations; positive results would aim for a 50 MW power plant.

Chachimbiro is the first priority prospect, of 11 prospects in the Geothermal Plan launched by the government in 2010, to complete the prefeasibility stage with a successful deep exploration well. Three high temperature prospects, namely Chacana-Jamanco, Chacana-Cachiyacu and Tufiño-Chiles, and one low temperature prospect, Chalpatán, are almost ready for deep exploratory drilling. The other six prospects are Chalupas, Guapán, Chimborazo, Chacana-Oyacachi, Baños de Cuenca and Alcedo, which are awaiting government funding to complete prefeasibility stage studies and site deep exploration wells to tap geothermal energy for electricity generation and direct uses.

On the other hand, CELEC has installed a state of the art laboratory for water and gas analysis for geothermal exploration and purchased equipment for Grav-Mag- MT surveys and rock studies; it also has been very keen on capacity building by sending staff members to overseas training programs in Japan, Iceland, El Salvador and Costa Rica.

Utilization of geothermal energy is still restricted to direct uses in swimming pools (5.16 MWt and 102.4 TJ/yr for annual utilization). Nevertheless, the IIGE, which is in charge of the development of low temperature geothermal resources, has started the construction of the first greenhouse powered by GSHP with horizontal ground loop. The IIGE also launched the study of the use of low to medium temperature geothermal resources in the country energy mix. The expected outcome of this study should be the Geothermal Resource Map, which will be done with the technical support of CEGA in the framework of the government to government agreement with Chile. IIGE future developments include the study for a geothermal desalination plant in Galápagos as well as geothermal heating using PCR (phase change materials) for urban and rural buildings.

Taking into account the tectonic setting of the Ecuadorean territory, including the 200 miles of ocean surrounding the Galapagos Archipelago and covering the front of the mainland coast, six geothermal plays are proposed as to locate and consider geothermal potential (theoretical): 1.Galápagos Rift, 2.Galápagos Hot Spot, 3.Northern Andes, 4.Southern Andes, 5.Coastal Fore-arc basin, and 6. Oriente Foreland basin.

Government policies, according to the Master Plan for Electricity, aim to develop renewable resources, including geothermal, to substantially lessen the use of fossil fuels. The current energy mix is dominated by hydro (62.58%), fossil fuels (35.06%) and other (2.37%) with a total installed generation capacity of 8059.28 MWe. The gross energy production is 29353.28 GWh/yr (as of Jan. 2019), where 21382.42 GWh are from renewables and 7971.49 GWh are from fossil fuels.

Finally, geothermal energy utilization in Ecuador is challenged to be cost-efficient in light of an abundant hydro resource, as well as to be environmentally safe and socially accepted.

1. INTRODUCTION

This paper is a follow up of the country update for the previous interval (Beate & Urquizo, 2015). It summarizes geothermal activities in Ecuador for the period 2015-2020. Nevertheless, the history of exploration before 2015 and the description of explored and under-explored areas or prospects hasn't been included in this summary, since no substantial changes have occurred in this last period, apart from the Chachimbiro deep exploration drilling; in this case, the reader is kindly referred to the previous country updates (Beate and Salgado, 2010 and Beate and Urquizo, 2015) and to the references therein.

Ecuador is a democratic republic, located on the equatorial pacific margin of Western South America; it has 17 million inhabitants (INEC, 2019) living in a territory of 256,370 km2 (IGM, 2019); the official language is Spanish and the GNP was 108 398 MUSD for the year 2018 (BCE, 2019).

Since the approval of the new Constitution in 2008, the government has steered towards a stronger participation of the state in exploration and development of the country's energy and mineral resources. It is the aim of the government to change the energy matrix towards the substitution of the fossil fuels for power generation with indigenous, clean, renewable energy resources, mainly hydro, but also including wind, solar, geothermal and biomass.

The leading agencies for geothermal energy are MERNNR (Ministry for Energy and Non-Renewable Resources), CELEC EP (Public Corporation for Electricity Generation and Transmission) and IIGE (Institute for Geological and Energy Research), SENAGUA (National Secretariat for Water) and MAE (Ministry of the Environment).

Public funding has been allocated for geothermal exploration to both high and low temperature resources. In accordance to the Constitution, which dictates that the State will be responsible to provide and regulate public services such as electricity, energy concessions can be granted by exception through private finance initiatives (i.e. public auctions), private investment or joint ventures with public companies where the State of Ecuador owns at least 51 % interest, but final adjustments for geothermal regulations are still pending.

The following pages include an overview of Ecuador's geological setting, a listing of geothermal resources and potential, together with the state of geothermal utilization and a discussion of the actual and future development.

2. OVERVIEW OF ECUADOR´S GEOLOGICAL SETTING

Mainland Ecuador, located at the pacific equatorial margin of western South America, consists of three geographically and geomorphologically distinct regions: the coastal plains or Costa to the W, the Andes high mountain chain or Sierra in the center and the upper Amazon basin or Oriente flatlands to the East. A fourth region comprises the Galapagos Archipelago, roughly located about 1000 km W of mainland Ecuador, in the Pacific Ocean (Fig.1)

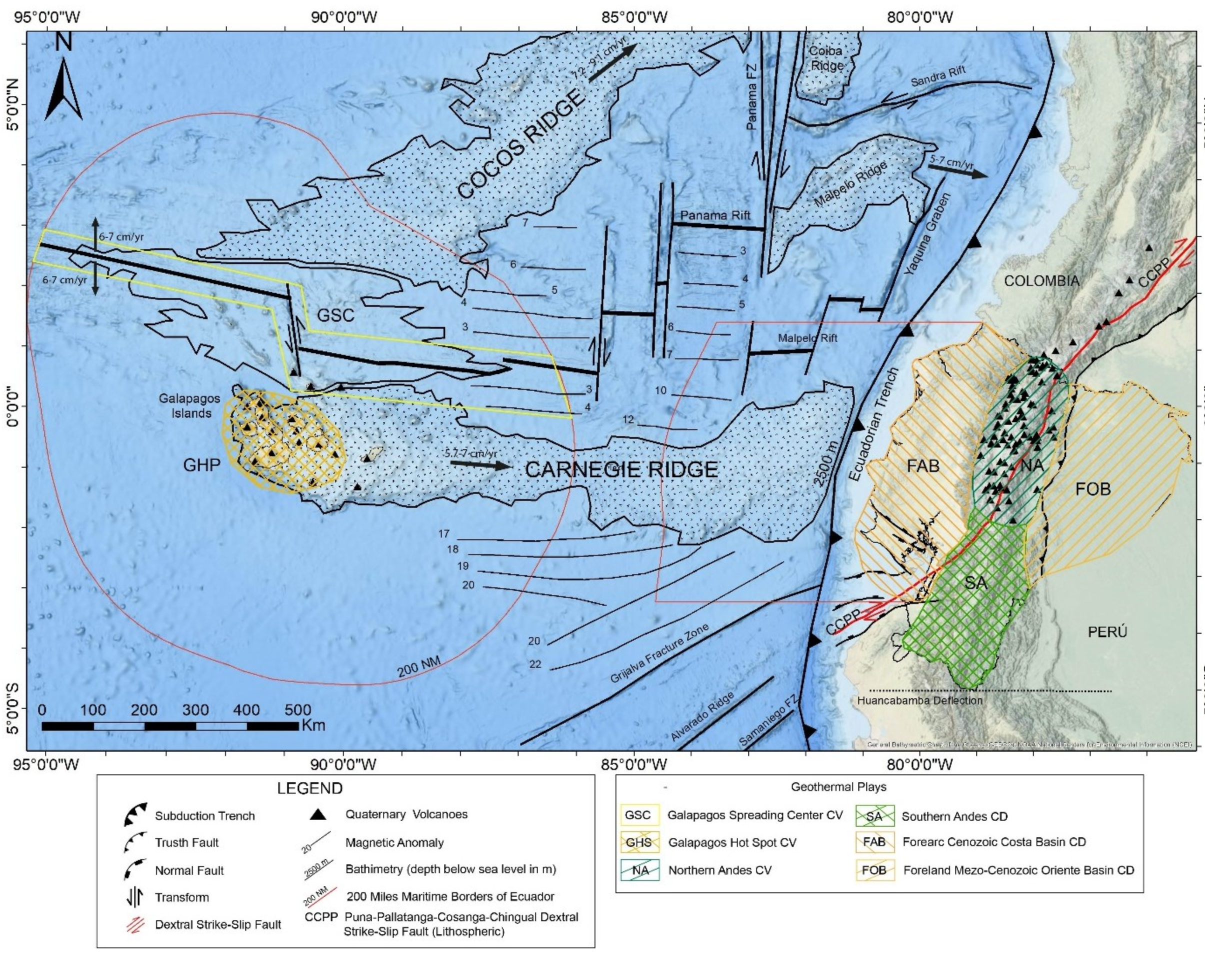

Figure 1. Geodynamic setting of Ecuador and its Geothermal Plays. Redrawn after The Global Multi-Resolution Topography (GMRT) Synthesis (Ryan, W.B.F. et al., 2009) and Maritime limits of Ecuador-IOA (2011) and modified from Bernard and Andrade (2011), Spikings et al., (2001) and Gutscher et al., (1999).

The Andes are the backbone of the country. They consist of two parallel NNE striking mountain chains: a) the Eastern Cordillera or Cordillera Real, which are sub-linear NNE striking belts of juxtaposed metamorphic rocks of mainly Paleozoic age, intruded by both, S and I – type batholiths of early – mid Mesozoic age; and, b) the Western Cordillera or Cordillera Occidental, which core consists of oceanic lithosphere with a Mid-Cretaceous basaltic plateau on top, accreted towards the continent in late Cretaceous; further Paleocene volcanics and volcaniclastic material was added in now folded and faulted sequences; these rocks are intruded by Neogene I-type granitoids (Litherland et al., 1993; Vallejo, 2007). Both cordilleras have been uplifted and are capped by mid- to late Tertiary volcanics. Between the two Cordilleras, the Interandean Valley developed; it is laterally bonded by active faults, mainly thrust faults, and consists of thick late Tertiary to Recent volcaniclastic and epiclastic sedimentary sequences. Covering both Cordilleras and the Interandean Valley in the Northern half of the Sierra, a broad, well developed, cal-alkaline volcanic arc extends northwards into Colombia (Barberi et al., 1988; Hall & Beate, 1991). This continental arc is of Quaternary age and consists of more than 80 volcanoes, of which at least 20 have been active in the Holocene (Hall et al., 2008) and two are currently in eruption. The Southern half of the Sierra shows extensive, Oligo-Miocene explosive volcanism, but now extinct, due to the flattening of the slab since late Miocene (Gutscher et al., 2000).

The Costa is the flat region west of the Andes; it comprises a late Cretaceous to Cenozoic fore –arc basin underlain by cold early Cretaceous, oceanic crust; no active volcanism is present in this region (Litherland et al., 1993).

The Oriente is an extensive sedimentary basin, which overlies cratonic basement (Baldock, 1982). Older rocks include Jurassic batholiths and a Cretaceous carbonate platform, covered by Tertiary epiclastic sediments. Along the cordilleran foothills, large thrust faults cut the sequence with a NS strike. Quaternary alkaline volcanoes are present along the western margin of the basin in a back arc setting (Hall et al., 2008). Mid-to Late Cretaceous intraplate basaltic volcanism affected the central part of the basin (Barragan & Baby, 2014)

The Galapagos Archipelago, together with the aseismic submarine Carnegie ridge, represents the Galapagos Hot Spot (GHS) trace above the Nazca Plate. The islands consist of about fifteen Quaternary basaltic shield volcanoes, increasing in age towards the East. Just N of the Islands, the Galapagos spreading center (GSC) follows a EW strike and it is off set by the 91ºW transform (Fig. 1).

Geodynamic processes are controlled since late Oligocene by the nearly orthogonal convergence between Nazca and South American plates, which has generated regional uplift and crustal faulting and deformation, as well as extensive volcanism (Lonsdale, 1978). The western and northern part of the country constitutes the North Andean Block, which moves in a NE direction along the dextral strike slip CCPP fault (Yepes et al., 2016; Vaca et al., 2019).

3. GEOTHERMAL RESOURCES AND POTENTIAL

Six geothermal plays (GTP), following Ecuador´s tectonic setting, together with its geology and geothermal manifestations, are proposed after IGA-IFC (2014) and summarized (from W to E), in order to update the known prospects (what, where, characteristics of resource and potential of prospects) and to assist on the assessment of exploration potential and targeting on high and low temperature geothermal resources (Fig. 1 and Table 1).

Table1. General Characteristics of the Geothermal Plays of Ecuador.

Geothermal Play	Dominant heat transfer mechanism	Tectonic setting	Volcanic activity		Status of geothermal exploration	Geothermal potential (theoretical)	Remarks
			Style	Age			
Galapagos Spreading Center	Convection	Rift	Basaltic	Quaternary	Unexplored	High	Protected area
Galapagos Hot Spot	Convection	Hot spot	Basaltic	Quaternary	Early reconnaissance	High	Protected area
Northern Andes Highlands	Convection	Continental arc	Andesitic, dacitic-rhyolitic	Quaternary	Reconnaissance to prefeasibility	High	Half dozen projects in prefeasibility stage (First deep exploration drilling @Chachimbiro)
Southern Andes Highlands	Conduction	Continental arc	Rhyolitic, andesitic	Tertiary	Early reconnaissance	Moderate	Early prefeasibility stage in Baños de Cuenca prospect
Costa Forearc Basin	Conduction	Forearc basin	-	-	Early reconnaissance	Low	Initial observation for direct uses
Oriente Foreland Basin	Conduction	Foreland basin	Basaltic	Cretaceous	Early reconnaissance	Moderate to high	Potential use of many out of service deep oil wells

Geothermal Play 1: GSC. This convection-dominated play is located to the N of the Galapagos Archipelago and consists of the submarine crest of the active Galapagos Spreading Center (GSC) and the 91ºW Transform, and the small-to moderate size, basaltic, northern islands of Genovesa, Marchena, Pinta, Wolf and Darwin (Fig.1). The oceanic rift has been active since Late Oligocene and very high heat flow values are reported since the dawn of plate tectonics (Williams et al., 1974). Intense submarine hydrothermal activity, including black smokers, has been described in literature. The rift is cut by the seismically active 91ºW transform and separated for more than 100km, where the southern part of the rift is quite close to Pinta Island (about 30 km). Due to rift-transform interaction (Harpp et al., 2002), several ridges do connect the northern islands with rift activity, enhancing volcanism in this area; many historical and sub-historical lava flows are commonplace. Genovesa is on top of such a ridge and its central caldera shows signs of past hydrothermal activity (Beate, 1978); on the other hand, ridge-paralell NE fractures cross the island and show very recent associated basaltic lava flows (Harpp et al., 2003). This play has not been explored yet for geothermal energy, despite the high heat flow scenario. On the other hand, it is part of the Galapagos protected area, which renders any geothermal development as utopic under present technological and environmental constraints.

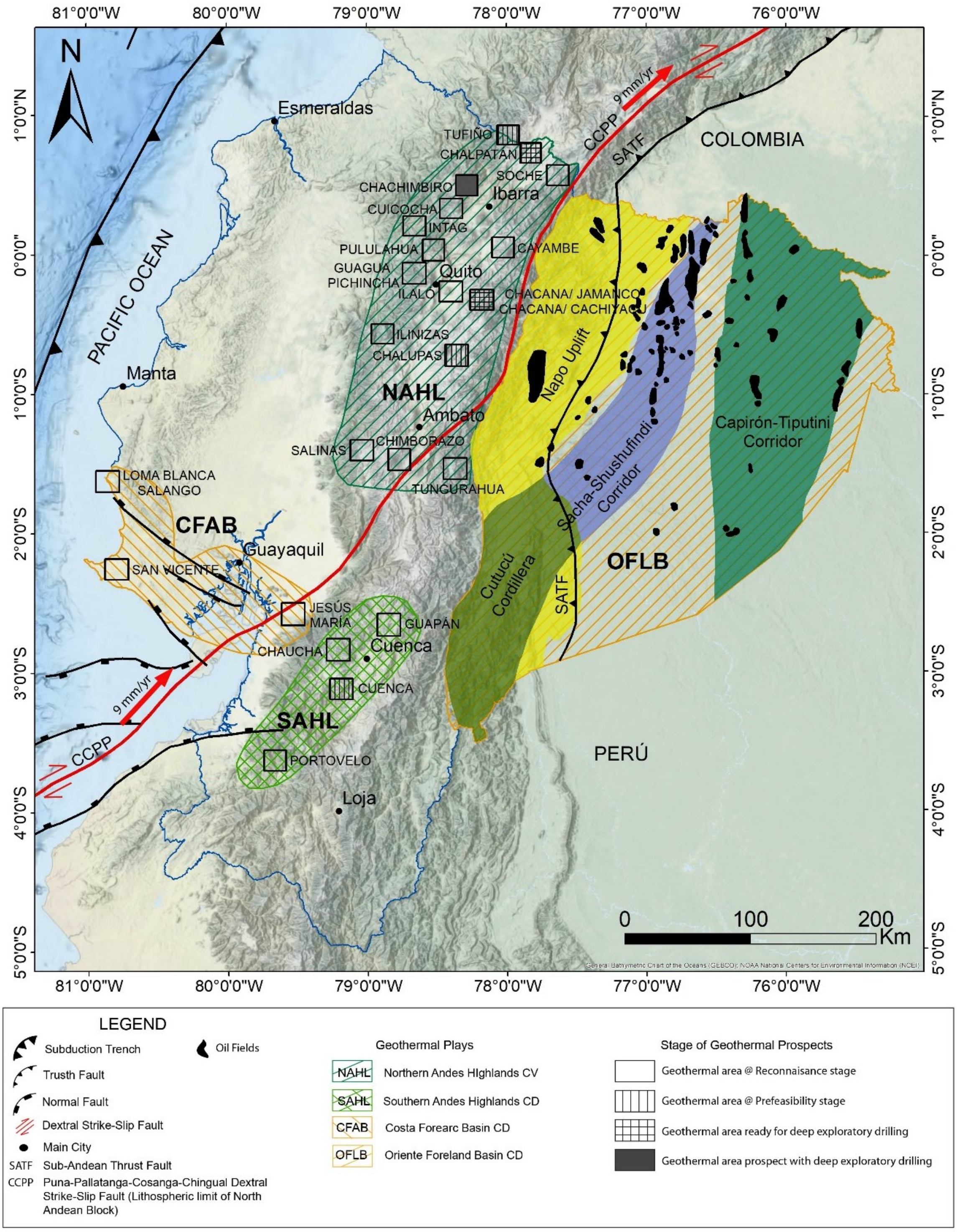

Figure 2. Geothermal Plays showing location and exploration stage of Geothermal Prospects in mainland Ecuador. Modified from Vaca et al., (2019); Beate and Urquizo (2015) and Baby et al., (2013).

<u>Geothermal Play 2: GHS.</u> This convection-dominated play comprises the central part of the Galapagos Platform, which has been constructed by the Galapagos Hot Spot (GHS) on top of the East- drifting lithospheric Nazca Plate. The majority of the 15 islands are constructed by basaltic shield volcanoes with central calderas of Quaternary age (Harpp and Geist, 2018). Most of the recent and current volcanic activity is located in the bigger western islands, which are closest to the hot spot up-flow. The central and eastern islands show a general eastwards increase in age due to the drift of the Nazca plate, nevertheless, many of these islands also show signs of recent volcanic activity. This is due to plume-rift-asthenosphere interactions along time. This play has not yet been explored for geothermal resources, despite the high theoretical potential due to massive volcanism and high regional heat flow, mainly for strict environmental and conservation policies, since Galapagos is a National Park.

Only one geothermal prospect is known until now from volcanological studies. It is located on Isabela Island inside the collapse caldera of Alcedo shield volcano. It shows extensive hydrothermal alteration, numerous explosion craters (at least seven), strong geothermal fumaroles discharging vapor at 97°C (locally superheated at 130ºC) and a heat source related to a primary basaltic origin but also to shallow rhyolitic intrusions associated with explosive silicic volcanism of recent age (c.a. 120 ka, Geist, 1994) like obsidian flows and rhyolitic plinian tephra. The area is situated on the SSW structural rim of the caldera, which might indicate good permeability at depth, were a shallow high-temperature water-dominated geothermal system is present. Empirical gas geothermometry indicates temperatures of 260 to 320oC for this intra-caldera reservoir, which is probably capable of producing up to 150 MWe (Goff et al., 2000).

This spectacular geothermal prospect is located inside the Galápagos National Park, and any intend to explore and exploit it must obey strict environmental regulations, if a geothermal permit is granted at all. Other limitations are the lack of any infrastructure, few distant power users without transmission line and scarce or no water for drilling. If power is tapped, it would imply the construction of submarine transmission lines to the load centers located in Isabela, Santa Cruz and San Cristóbal islands.

Geothermal Play 3: CFAB. This conductive-dominated play comprises the geographic Costa region and represents the fore-arc basin, which mainly consist of Tertiary shallow marine sediments overlying cold basaltic oceanic crust of mid-K age (Baldock, 1982; Litherland et al., 1993). Given that the northern part of this play has no geothermal manifestations and sediment cover is rather shallow, we recommend the southern part of the play for GT exploration purposes. Several warm springs are located along the coastal front (i.e. Salango-Agua Blanca) and the southern part is dominated by the Ancón oil field (Salinas warm springs at a methane-rich mud volcano) and the Gulf of Guayaquil gas field, where production drilling has reached deep levels of the basinal sequence (86ºC BHT at 4899 m, Barba, 2017). Geothermal gradients are about low average for this kind of geological setting, showing a range from 17 to 24 ºC/km (Barba, 2017), due to the presence of a cold mid-cretaceous oceanic basement. Nevertheless, the availability of out-of-service deep reaching production wells, indicates the presence of an already-drilled low-temperature GT resource which awaits to be assessed and, eventually, tapped for direct uses. On the other hand, this area is cut by the dextral strike-slip CCPP fault, which enters the Gulf from the ocean in a NE direction and represents the border of the North Andean block, which trace can be followed all though Ecuador and Colombia up to Venezuela (Yepes et al., 2014). This main structure is active and apparently controls the location of the hot springs of Jesus Maria (55ºC), at the Andean foothills, at the E border of this play. Low temperature geothermal resources for direct use are the main target in this conduction dominated play.

Geothermal Play 4: NAHL. This convection-dominated play comprises the northern half of the Andes Cordillera; it is characterized by the presence of extensive active Quaternary volcanism and hosts the most explored geothermal sites in the country.

Chachimbiro is the first priority prospect, of 11 prospects in the Geothermal Plan launched earlier by the government (Beate, 2010), to complete the prefeasibility stage with a successful deep exploration well. A detailed description and status assessment for all these prospects is given in the previous country-update (Beate & Urquizo, 2015), and apart from Chachimbiro, no changes have occurred in this period 2015 – 2020 for the other prospects. Three high temperature prospects in this play, namely Chacana-Jamanco, Chacana-Cachiyacu and Tufiño-Chiles, and one low temperature prospect, Chalpatán, are almost ready for deep exploratory drilling. The other six prospects are Chalupas, Chimborazo, Chacana-Oyacachi, Baños de Cuenca, Guapán and Alcedo, where the latter three correspond to plays 5 and 2 (Alcedo), respectively. These prospects are awaiting government funding to complete prefeasibility stage studies and site deep exploration wells to tap geothermal energy for electricity generation and direct use.

Since the second quarter of 2016 to the first quarter of 2018 some complementary studies were done in Chachimbiro project including the very first exploratory well named PEC1. Everything was possible thanks to an agreement to improve the level of current studies at Chachimbiro. JICA contracted the company Mitsubishi Materials Techno Co -MMTEC- from Japan to develop additional studies, to do the drilling and do the planning of the next stage. As a counterpart, CELEC EP team worked actively in the whole process using geophysical equipment, doing civil works along the access routes, installing laboratory facilities for geology and geochemistry, assessing environmental issues and improving community relations.

PEC 1 is located at 3537.71 masl and was completed on November 2017 to 1978m depth; MMTEC contracted Halliburton for drilling, directional and cementing services and CETAGUA for mud services.

PEC 1 is a slim hole well with a final 6-1/8" diameter. Drill cuttings were analysed in the field under the stereoscopic microscope, as well as for IR spectrometry and magnetic susceptibility. Thin sections, polarization microscopy and X-ray diffraction test were done in parallel in the local Celec EP laboratory as well as in Japan, meanwhile fluid inclusion analysis were done in Japan only. The well confirmed the geology of the earlier conceptual model (CELEC EP/SYR, 2012a) starting with dacitic pyroclastic rocks and lavas, andesitic rocks and lavas, basaltic andesite to andesitic pyroclastic rocks. Some tests were made in the well and the highest temperature at the bottom reached 235ºC, about 3 months later after the end of the drilling operation.

In accordance with the agreement, JICA sent an expert from the last quarter of 2015 to the first quarter of 2018, to support and advice the Chachimbiro works as well as other activities related to geothermal development in this geothermal play. So, more gravity surveys and thermal spring samplings were done in Chacana Jamanco, Chacana Cachiyacu, Chachimbiro and Chalupas geothermal prospects and, by the way, improving local capabilities.

Geothermal Play 5: SAHL. This conductive-geothermal play is located in the southern half of the Andes Cordillera and is characterized by extinct mid-late Tertiary volcanism; the last eruption happened 3.6 Ma ago (Beate, 2001). Many hot to warm springs are scattered in the area (De Grys, 1970), although Baños de Cuenca (75ºC) and Guapán (50ºC), together with Portovelo (55ºC) represent the hottest ones. IIGE´s early pre-feasibility study points to deep temperatures of 100 to 140 ºC for Baños de Cuenca, being the most likely heat source the normal geothermal gradient; a gravity and MT survey is planned for the near future. These prospects have been described in the fore going 2010-2015 country up date. With the support of the JICA expert, some gravity surveys were done by CELEC EP and more thermal spring were sampled to complement previous studies and to plan the next stage of MT surveys in Baños de Cuenca.

Geothermal Play 6: OFLB. This conductive dominated play comprises the eastern Oriente Foreland basin, which is a thick sequence of Mesozoic to Tertiary age sediments, including a carbonate platform and continental siliciclastic units (Baldock, 1982). These rocks host many oil fields, from which Ecuador has drawn an important part of its cash for the last half century through oil exports. The oil industry has drilled in this time about 2000 production wells covering a great deal of the basin and an average GTG of 22ºC/km on 100 wells has been obtained by Burgos (2014). A recent study by Angulo (2019) shows BHT distribution and preliminary values for geothermal gradients for most of the oil production areas. Results indicate low GT gradients for the Central Corridor (av. 16.75ºC/km), but rather anomalous high gradients for the areas located on each side of the Corridor: av. 57.11ºC/km in the W area and av. 56.9 ºc/km for the area to the E, reaching a maximum value of 88ºC/km. The western part is called the Napo- Cutucú uplift and shows the older rocks of the sequence, including the large outcropping Pungarayacu tar field as well as active alkalic back-arc volcanoes (i.e. Sumaco). It is possible, that deeper fluids are reaching shallower levels following paths along fractures and faults. The eastern part is called the Capirón-Tiputini oil play and shows a closer vertical distance to the hotter (?) basement. The existence of high GT gradient anomalies and a thorough knowledge of geology and structure of the Oriente basin, together with the straight forward availability of many out-of-service deep production wells in this geothermal play at sites with anomalous GTG, opens up the opportunity to readily consider the assessment and development of low – medium temperature resources for direct uses or even for electricity generation.

4. GEOTHERMAL UTILIZATION

In 2018, the National Institute of Energy Efficiency and Renewable Energy (INER) and the Geological Survey of Ecuador (INIGEMM) merged into the National Institute for Geological and Energy Research (IIGE), in order to optimize resources and increase its operational effectiveness. As a result, previous studies related to geothermal energy started by INER were transferred to the IIGE and new research projects with an approach to geothermal energy utilization are currently being executed.

Until 2019, utilization of geothermal resources in Ecuador was restricted to direct uses only, that is, for bathing resorts, balneology and swimming pools. A summary of many, but not all, hot and warm springs used for swimming pools is shown in Standard Table 3, giving a total installed capacity of 5.157 MWt and an annual energy output of 102.401 TJ/yr, which remains unchanged since the last update.

Nevertheless, the IIGE, which is in charge of development of low temperature geothermal resources, has started the construction of the first greenhouse powered by GSHP with horizontal ground loop.

A ground Thermal Response Test was undertaken on site to determine accurate values of Thermal Conductivity, Soil Diffusivity and Volumetric Heat Capacity. Heat will be extracted from six slinky horizontal ground loops and one horizontal ground loop at a depth of 2m at an average temperature of 17.5ºC. A GSHP will deliver warm air inside the greenhouse with the aid of fan coils when ambient temperatures fall under 12ºC. A state of the art control system, which opens and closes lateral windows, will be installed also inside the greenhouse to keep optimal conditions throughout the day.

As a result of a Cooperative Joint Commission between the governments of Ecuador and Chile, the Chilean Cooperation Agency has sponsored the development of an energy prospective study for the introduction of low and medium grade geothermal resources into the Ecuadorian productivity matrix. The project is being carried out by the IIGE with the support of the Andean Geothermal Centre of Excellence (CEGA). A geothermal resource map based on low and medium enthalpy resources and high temperature wells was also developed. This new updated information is expected to draw public and private attention to future investments in replacing the use of diesel with geothermal steam for industrial purposes.

5. DISCUSSION

Standard Tables 1 to 8 show clearly that conventional energy generation by hydro (62.58%) and fossil fuels (35.06%) dominates by far the Ecuadorean energy market, with a total installed capacity of 8059.28 MWe and a gross production of 29353.91 GWh/yr (BNE, Jan. 2019).

They also show that, at present, other forms of energy production, i.e. nuclear and geothermal are non-existent and renewables like biomass, biogas, wind and solar energy are still marginal (190.8 MWe and 487.15 GWh/yr). In the future, the general trend is to favor hydro, with an increase in renewables and a substantial decrease in fossil fuel, which in turn favors geothermal energy development.

Because there is no electricity production from geothermal in Ecuador, Standard Table 2 is not included.

Standard Table 3 shows the utilization of geothermal energy for direct use, without changes since the 2015 update. This information has to be taken as a minimum estimate for hot spring waters used for swimming pools. Inlet-temperature is a safe parameter, but outlet-temperature has been arbitrarily assumed to be 35°C if temperature is above 40°C, 20°C if it is between 30 and 40°C and 15°C if it less than 20°C. The average flow rate has been assumed to be 63% of the maximum flow rate, which is also arbitrary. The maximum flow rate has been measured at the spring in most cases, but in others it has been estimated. This activity has been improving towards efficiency in the last years, but is difficult to assess due to lack of data and specific studies.

Standard Table 4 shows the very first GSHP installed in Ecuador, which is expected to be fully operational by the end of 2019.

Standard Table 6 includes the only and first deep geothermal exploration well in Ecuador, completed in November 2017 at the Chachimbiro Geothermal Project to a total depth of 1987m; BHT reached 235 ºC.

An earlier shallow (540m) gradient hole was drilled by the government in 2009 at the Ecuadorean side of the Bi-National Tufiño Geothermal Project.

Some very shallow wells have been drilled in the last decades to obtain water for swimming pools, but data are scarce and wells are not included here as geothermal wells; most wells have been drilled to obtain water only for agricultural or industrial uses, without using any heat.

Allocated professional personnel to geothermal activities (Standard Table 7) has increased substantially in the first half of this period, mainly from the side of the government with CELEC EP and INER/IIGE and less so with MERNNR and universities in Quito (EPN and Yachay Tec), although it diminished strongly in the second half due to government funding restrictions; there is no professional geothermal personnel employed by the private industry.

Foreign Aid Programs are turning into reality with participation of JICA to CELEC EP and CEGA/CHILE with IIGE. The Geological Survey of Ecuador is now part of IIGE and is re-starting ground-level geothermal exploration in the country.

Standard Table 8 shows that public investment has been allocated to geothermal activities in this last five year term (2015 to 2020) in the amount of 15 MUSD for research of the Chachimbiro geothermal project, including the drilling of one deep exploration hole. This has been possible due to the positive political decision of the present administration to explore and develop the geothermal resources in Ecuador and with the straight forward participation of JICA/government of Japan.

General policies and planning regarding electrical energy are issued by the government through the MERNNR (Ministry of Energy and Non-Renewable Resources). The MERNNR coordinates the electric energy issues with ARCONEL, which is in charge of the regulation of the sector, its electrification master plan, of supervising power generation projects, concessions/contracts for power generation, prices and environmental issues. One of the problems in the electricity market is the availability of energy, rather than the installed capacity, since the reservoirs for hydro generation are in some cases small and fossil fuels are expensive and not always at hand. This situation favors the demand of geothermal power as base load. The problem was temporarily solved by importing energy from Colombia and Peru, but this tendency has reversed in the last 2 years, with the commissioning of the new hydro projects.

Any project to generate electricity, including geothermal, needs a permit issued by ARCONEL, which in turn demands a water-use permit from SENAGUA (National Agency for Water Issues) and an environmental permit from the Ministry of the Environment (MAE). According to the current constitutional law, energy in any form belongs to the state and its exploration and development is strictly regulated by the government, since energy is a strategic issue.

6. FUTURE DEVELOPMENT AND INSTALLATIONS

The next immediate step towards geothermal electricity generation in Ecuador is the field development of the Chachimbiro project through an ODA loan from JICA to CELEC EP. This phase is planned to start soon and involves the drilling of 5 appraisal wells and the installation of a 5MW well-head power plant with a budget of around 65 MUSD. This project will push forward other geothermal proposals as well as give experience to local staff and local companies, and create new opportunities for surrounding communities and academia.

Also, in parallel, JICA, probably in coordination with other multilaterals, is going to support the making of the specific terms of regulation and applicable model for the feasibility to bring in more investment to develop additional geothermal projects. At the same time, dissemination campaigns are going to take place to inform society, authorities and politicians about the benefits of each stage of geothermal development and pointing out the necessity to complement the current electrical matrix, which consists mainly of hydroelectricity, to cope with yearly worsening dry seasons.

An inter-institutional cooperation at government levels is planned in order to efficiently share resources like lab facilities and geo-scientific staff, in order to build core capabilities for a continuous development of geothermal resources

Many efforts have been made by the government of Ecuador to eliminate the use of fossil fuels in the Galapagos Islands in the short term. Although a promising geothermal field exists on Isabela Island´s Alcedo volcano as already mentioned in GT play 2, it is located far away from the nearest town and within a protected natural area. Therefore, electricity generation from geothermal resources seems unlikely for now. Direct uses on the other hand are a much more plausible option. A proposal for a geothermal energy-driven desalination plant has been handed out to local authorities for further consideration (Lloret A, 2015). Presently, the project has been submitted for national and international grant funding to finance reconnaissance studies aimed to increase the prospect´s geo-scientific data.

In November 2018, Ecuador became a member of the Ibero-American Shallow Geothermal Network. Among other research activities related to the development of low and medium grade geothermal sources, the government, through the IIGE, will promote the deployment of ground source heat pumps using phase change materials (PCM) for thermal conditioning of buildings of different types, both in urban, rural and industrial environments, with the use of proven and available Ibero-American technologies.

IIGE has resumed exploration of geothermal prospects in the country with special attention in low and medium enthalpy resources. Gas and water samples are being collected, and geophysical studies, which include resistivity and magnetotelluric surveys, are also expected to be carried out. The main purpose is to update and reassess the information obtained in previous studies and monitor changes in geothermal systems that are already known. Similarly, weather stations have been placed in close range from known geothermal prospects to study hydrological changes that may influence the development of geothermal projects in the future. Finally, geological and geochemical mapping is also being carried out in underexplored locations were locals have reported geothermal activity.

Several regions in the country remain unexplored for geothermal resources, namely the sedimentary basins in the Costa, the back-arc volcanic chain with recently active alkalic volcanoes and the sedimentary foreland basin in the Oriente, as well as the Galapagos Archipelago at both, the hot spot and the nearby spreading center. This increases the exploration potential for geothermal resources in the country, in addition to the follow up exploration of the prospects cited above. Application of actual and future technology will allow to tap hidden resources, those where geothermal evidence at surface is nil (Duffield and Sass, 2003) and consider EGS targets as well.

A good start will be to produce both, the heat flow map and the geothermal map of Ecuador with updated data. In this regard, IIGE is keen to work on the Geothermal Atlas of Ecuador in the following years. It is imperative to get the necessary funding (public and private) to drill the most promising prospects and tap geothermal power in Ecuador.

And Chachimbiro Geothermal Project, with its first 2000m deep exploratory well, is a promising enterprise in the right direction, with CELEC EP as a clear and strong leader.

7. CONCLUSIONS

Ecuador is keen to continue to explore and, consequently, aims to develop its geothermal resources in all its territory, for both electricity generation and direct uses, to increase renewable energy production and to lessen the use of fossil fuels. The leading government agencies for geothermal energy are CELEC EP for generation and IIGE for exploration, research and development of direct uses; both agencies are part of the Ministry of Energy and Non-Renewable Resources and follow the Master Plan for Energy Development.

The Ecuadorean sovereign territory comprises six geothermal plays, namely: Galápagos Hotspot, Galápagos Spreading Center, Northern Sierra with Quaternary active volcanism, Southern Sierra with extinct Tertiary volcanism, Fore-arc Cenozoic sedimentary basin and Fore-land Meso-Cenozoic sedimentary basin. The first three geothermal plays are convection-dominated and the latter are conduction-dominated.

The most advanced exploration yet has taken place in the Northern Sierra Geothermal Play, where 1 prospect, Chachimbiro, has been drilled to 1978m depth with the first-ever deep exploration well in Ecuador´s history, under the technical and financial assistance of JICA to CELEC EP.

Results are encouraging for Chachimbiro (BHT 235ºC) and follow-up funding for appraisal drilling of 5 deep wells and for the installation of one well-head generation unit has been already approved by the government under an ODA agreement with JICA for about 72 MUSD, where 12 MUSD are committed by the Ecuadorean Government.

Other 4 prospects (Chacana-Cachiyacu, Chacana-Jamanco, Chalpatán and Tufiño), also in the Northern Sierra Geothermal Play, are drill-ready for deep wells and cueing for funding; 3 others (Chalupas, Chacana-Oyacachi and Chimborazo) are at early exploration stages. Two prospects in the Southern Sierra Geothermal Play (Baños de Cuenca and Guapán) are also in early exploration stages as well as Alcedo, located in the Galapagos Hot Spot Geothermal Play. The other 3 Geothermal Plays, the Galápagos Spreading Center and the two conduction-dominated sedimentary basins, remain unexplored for geothermal resources at present.

Until today, the only practical use of geothermal energy in Ecuador is in swimming pools. Nevertheless, the first GSHP has been installed and is being tested for greenhouse applications under the guidance of IIGE. It is expected that results from this testing will accelerate the use of GSHPs in residential and commercial sectors. And, in the near future (next 2 -3 years), we are going to see the generation of electricity in Chachimbiro under the leadership of CELEC EP.

Ongoing conversations between the Government of Ecuador and multilateral finance and technical assistance agencies, such as JICA, IDB and CAF, are taking place to re-take nation-wide surface geothermal exploration programs to define drilling targets, increase capacity building and to prepare the regulations for a geothermal law, which should allow both, government and private investment in geothermal energy.

8. ACKNOWLEDGMENTS

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STANDART TABLES - NOTE: TABLE 2/8 IS NOT INCLUDED.

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (wind)		Other Renewables (biogas)		Other Renewables (biomass)		Other Renewables (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	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2019	0	0	2825.3	7971.49	5043.19	20834.70	0	0	21.15	82.69	6.504	45.29	136.4	381.67	26.738	38.07	8059.28	29353.91
Under construction in December 2019	0	0	0	0	303	0	0	0	50	0	0	0	0	0	0	0	353.00	-
Funds committed but not yer under construction in December 2019	0	5	0	0	0	0	0	0	100	0	0	0	0	0	200	0	300.00	5.00
Estimated total projected use by 2020	-	-	2955.26	8338.18	5043.19	21793.10	-	-	22.12	86.50	6.80	47.37	142.67	399.23	27.97	39.82	8198.02	30704.19

Balance Nacional de Energía Enero 2019, https://www.regulacionelectrica.gob.ec/balance-nacional/

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. (^oC) - outlet temp. (^oC)] 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. (^oC) - outlet temp. (^oC)] 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 (^oC)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Baños Cuenca	B	8.000	73.000	35.000	-----	-----	1.272	5.040	25.261	0.629
Baños Tungurahua- Virgen	B	5.120	53.000	35.000	-----	-----	0.386	3.226	7.659	0.629
El Salado	B	5.000	44.300	35.000	-----	-----	0.195	3.150	3.864	0.628
Palictahua	B	2.800	40.700	35.000	-----	-----	0.0067	1.764	1.326	0.627
Chachimbiro- Toma	B	1.500	58.000	35.000	-----	-----	0.144	0.945	2.867	0.631
Pitzantzi	B	0.950	40.800	35.000	-----	-----	0.023	0.599	0.458	0.631
Naugulvi	B	2.000	52.000	35.000	-----	-----	0.142	1.260	2.825	0.631
Cununyacu- Chimborazo	B	1.400	47.500	35.000	-----	-----	0.073	0.882	1.454	0.632
Guayllabamba- Chimborazo	B	5.000	40.000	35.000	-----	-----	0.105	3.150	2.077	0.627
Ilaló- Cununyacu	B	8.000	27.000	15.000	-----	-----	0.402	5.040	7.977	0.629
Tingo	B	1.200	32.000	20.000	-----	-----	0.060	0.756	1.197	0.633
San Antonio	B	12.000	35.500	20.000	-----	-----	0.778	7.560	15.456	0.630
Ushimana	B	1.000	19.000	15.000	-----	-----	0.017	0.630	0.332	0.619
Chunchi	B	2.000	29.500	15.000	-----	-----	0.121	1.260	2.410	0.632
Ilaló	B	5.000	35.000	20.000	-----	-----	0.314	3.150	6.232	0.629
Papallacta- Termas	B	1.100	53.000	35.000	-----	-----	0.083	0.693	1.645	0.628
El Tambo	B	1.000	50.000	35.000	-----	-----	0.063	0.630	1.246	0.627
Jamanco	B	2.000	66.000	35.000	-----	-----	0.259	1.260	5.152	0.631
Cachiyacu	B	1.200	68.000	35.000	-----	-----	0.166	2.756	3.291	0.629
Portovelo- Río Amarillo	B	1.200	57.000	35.000	-----	-----	0.110	0.756	2.194	0.632
Tufiño- Aguas Hed.	B	3.000	53.000	35.000	-----	-----	0.226	1.890	4.487	0.630
San Vicente	B	2.000	38.000	20.000	-----	-----	0.151	1.260	2.991	0.628
TOTAL		72.470					5.157	47.625	102.401	

TABLE 4. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES 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. 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; H = horizontal ground coupled; W = water source (well or lake water); O = others (please describe) — ($TJ = 10^{12}$ J)

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)
Riobamba	17.5	22	2	H	4.11	8760	1.4	1.3
TOTAL	**17.5**	**22**	**2**			**8760**	**1.4**	**1.3**

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)
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]			
District Heating [4]			
Air Conditioning (Cooling)			
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	5,157	102,401	0.31
Other Uses (specify)			
Subtotal	5,157	102,401	
Geothermal Heat Pumps	0.044	1.06	0.76
TOTAL	**5,201**	**103,461**	

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 no ones less than 100m deep.

Purpose	Wellhead Temperature	Number of wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration	(all)	1				1,987
Production	>150 C					
	150-100 C					
	<100 C					
Injection	(all)					
Total		1				1,987

The well reached 1978m deep, the first meter was drilled in august 2017 and the last one on november 2017 and the last temperature registered in march 2018 was 235°C.

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) Contribute Through Foreign Aid Program
(6) Private Industry

Year	Professional Person - Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015	3	9	1	---	1	---
2016	1	17	1	---	11	---
2017	1	18	1	---	15	---
2018	1	10	1	---	8	---
2019	4	6	1	---	1	---
Total	**3**	**6**	**1**	**---**	**---**	**---**

In 2016 complimentary geohysics, geochemistry and geology studies were done, some people from CELEC EP participate working with the experts. In 2017, the first well was drilled and more people from the company was involved, helping in the logistics, health, safety and environmental, learning in the rig, labs, and different services.

In 2018, planning activities were done and because of budget cuts some peopleo was fired from CELEC EP.

In 2019, people are working mainly to complete the Loan Agreement process, civil works and civil designs, monitoring and social management.

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

Period	Research & Deveopment Incl.	Field Development Including Production	Utilization		Funding Type		
			Direct	Electrical	Private	Public	Cooperation
	Millon US$	Million US$	Million US$	Million US$	%	%	%
1995 - 1999	----	----	----	----	----	----	----
2000 - 2004	----	----	----	----	----	----	----
2005 - 2009	0.37	----	----	----	----	100%	----
2010 - 2014	7.2	----	----	----	----	100%	----
2015 - 2019	15	----	0.23	----	----	30%	70%