COLOMBIA – A GEOTHERMAL OPPORTUNITY

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ABSTRACT

Colombia has increased its interest in using geothermal resources as part of the solution for energy transition. This is motivated by clear evidence of considerable geothermal potential for power generation and the existence of low and medium enthalpy systems as possible source for direct use and other uses. The Colombian geological and tectonic setting facilitates the presence of geothermal systems associated with volcanoes and sedimentary basins. Numbers highlight the geothermal potential in Colombia. There are at least 20 active volcanoes with hydrothermal features and geothermal gradients from oil wells reveals values up to 65°C/km. Preliminary estimations show that about 20% of energy demand could be supplied using geothermal resources. These numbers contrast with the use of low temperature resources limited to bathing and the absence of geothermal power generation in Colombia. Currently, electricity generation capacity comprises approximately 70% hydro and 30% fossil fuels, such as natural gas and coal. These facts certainly make Colombia a great geothermal opportunity.

New Zealand and Colombia has strengthened their cooperative relationship in the recent years. An example of this is the crucial role New Zealand played as a supporter of the peace agreement that ended about sixty years of civil war in Colombia. This is now bringing access to unexplored geothermal areas and an atmosphere convenient to develop geothermal projects. Today, the challenges lie mainly in creating a legal and regulatory framework to incentivate geothermal projects, and taking actions for raising awareness about the benefits of geothermal uses and capacity building around geothermal. Transfer of experiences, knowledge and technology between New Zealand and Colombia in geothermal development could be significant for Colombia to become a world-class geothermal country.

1. INTRODUCTION

Colombia's privileged geographic and geological location highlights the country as a world-class geothermal destination with a great potential to be developed. Colombia has a high volcanic activity due to being located in the Pacific Ring of Fire. The subduction of the Nazca plate under the North Andean Block favored the Colombian terrain as a geothermal hotspot (Figure 1).

Over the last 50 years, research projects have been focused on the characterization of areas with surface geothermal manifestations (CHEC et al., 1968; CHEC et al., 1983; OLADE et al., 1982). Currently, the most well-known geothermal areas are San Diego; Cerro Bravo-Cerro Machin Volcanic Complex (which include Nevado del Ruiz, Santa Rosa and Cerro Machín), Paipa, Azufral, Chiles-Cerro Negro, and Dabeiba. The features of the preliminary conceptual models from the mentioned areas show great possibilities for power generation by using geothermal resources (Alfaro, 2015).

In Colombia, the subsurface temperature gradient is not only associated with volcanic activity. There also exists a geothermal anomaly in areas of sedimentary basins (Alfaro et al., 2015). These areas are found in Los Llanos basin, Caguan-Putumayo basin and the Magdalena Valley (INGEOMINAS-ANH, 2009) (Figure 2A).

The Colombian electricity sector reflects the country's natural resources, abundant freshwater and a strong oil and gas industry. It has facilitated construction of a power capacity based around 70% hydro complemented by the use of fossil fuels (Salazar et al., 2017). However, natural phenomena such as droughts caused by El Niño/Southern Oscillation (ENSO), affects the hydroelectricity production. This fact and international commitments on climate change, motivated Colombia to build a cleaner and firm energy matrix which includes geothermal as part of the solution (Poveda et al., 2011; Colombia, 2019). Thus, legal and governmental initiatives in the recent years are creating a national interest in improving knowledge of areas with geothermal potential that are currently limited to bathing and swimming.

Furthermore, a synergy between professionals, academy, companies from public and private sectors is already active around building up a regulatory framework to deploy geothermal projects for power generation and direct uses. For instance, the Colombian Geothermal Association (AGEOCOL by its Spanish acronym) was created in 2018 and the National Geothermal Meeting (known as RENAG by its Spanish acronym) has occurred yearly in Colombia since 2016. This meeting gathers geothermalists from Colombia and overseas to discuss the needs and solutions to make geothermal an industry in the country. Colombia is also a diverse country with 81 different ethnic groups and has active participation of communities and citizens in the approval of energy projects (Van Der Hammen, 2003). One of the main conclusions of RENAG is the importance of direct uses to familiarize the Colombian society with the advantages of geothermal as a clean and sustainable source (AGEOCOL, 2018).

2. GEOLOGIC AND TECTONIC SETTING

The configuration of the Colombian territory is due to the interaction of the Cocos, Nazca, Caribbean South American plates, and the Coiba microplate. On a regional basis, this interaction results in a great variation of the stress tensors that creates separate seismotectonic provinces. An important consequence of this phenomenon is the movement towards the North-northeast of the North Andean block. This movement can be recognized offshore by the Caribbean Deformed Belt, a later and more distal compressional phase of the accretion prism that includes the Sinú and San Jacinto deformed belts. The North Andean Block includes smaller triangular blocks bounded, on all their sides by wrench faults. This complex pattern of plate and blocks interaction results in seismotectonics regimes on which transpressive and transtensive deformations play an important role (INGEOMINAS, 2007; Velandia et al., 2005) (Figure 1).

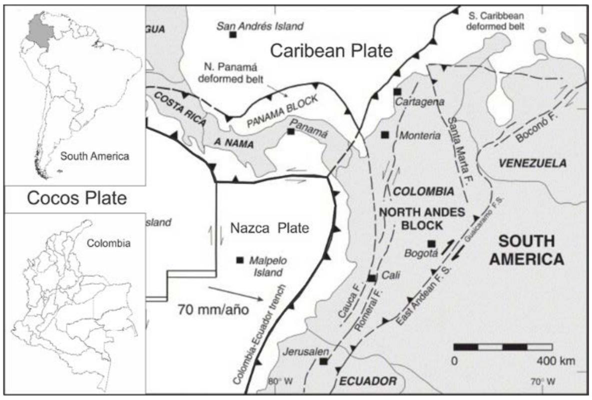

Figure 1: Location and tectonic context of Colombia. Tectonic map by Velandia et al. (2005).

3. GEOTHERMAL AREAS

The hydrothermal systems in Colombian are related to igneous and volcanic bodies located in the North Andean Block mostly along the central and western cordilleras. The systems that have been identified in the Cordillera Central are (Figure 2B, 2C): San Diego Area; Cerro Bravo – Cerro Machín Volcanic Complex, which includes Cerro Bravo, Nevado del Ruiz, Santa Isabel, Paramillo de Santa Rosa, Nevado del Tolima and Cerro Machín volcanoes; Nevado del Huila volcano, Coconucos Volcanic Chain, Yerbabuena, Sotará, Sucubum, Doña Juana, Galeras and Sibundoy volcanoes. Also, significant hydrothermal systems exist along the Western Cordillera, and related to Azufral, Cumbal volcanoes and Chiles – Cerro Negro Volcanic Complex. Additionally, there is a hydrothermal system associated with Paipa Volcano which is located in the Cordillera Oriental. Other presumably low temperature geothermal systems would be feeding hot springs located all along the Cordillera Oriental and its faulted East border with Orinoco and Amazonas regions, as well as isolated springs found in the Caribbean and Pacific regions (Forero, 1958; SGC, 2014).

3.1 Nevado del Ruiz Volcano (NRV)

The NRV geothermal area is the most studied one in Colombia. The active stratovolcano NRV is in the Los Nevados National Natural Park, close to the city Manizales (Caldas department) in the middle of the Cordillera Central. In this area, the only exploratory geothermal well reached a depth of 1468m crossing seven lithological units and a zone with hydrothermal alteration that was associated with circulation of high temperature fluids. The well showed local and low permeability, and a temperature of 200 ºC (Monsalve et al., 1998). The geology of the volcanic complex NRV is highly influenced by a thick layer of rocks and deposits of volcanic origin that are in a discordant contact with the Cajamarca Complex. Furthermore, González et al. (2015) described a 3D conceptual model consisting of a convective hydrothermal system that interacts with the magmatic flow that ascends through a tripartite system of magmatic chambers. The flow pattern of the geothermal fluid is structurally controlled by the faults of Nereidas, Rio Claro, Santa Rosa, Samaná Sur and the discontinuity of the prevolcanic basement, favoring superficial manifestations of sulphide, chloride and bicarbonate waters. Geochemical geothermometer calculations indicate that the reservoir temperature can reach up to 260 ºC (Alfaro et al, 2005; Alfaro et al, 2002). Likewise, there is an advanced argillic alteration that causes the occurrence of a clay cap, which restricts the circulation of hydrothermal fluids (Forero, 2012).

The prefeasibility studies identify six points of interest for potential geothermal exploitation (Ossa, 2018). Additionally, 2D numerical modeling of heat transfer and rock thermal conductivity at reservoir scale suggests a geothermal potential range between 54 MWt to 130 MWt (Velez et al., 2018).

3.2 Santa Rosa

The geothermal area of Santa Rosa is also part of Los Nevados National Natural Park and near NRV. The specific characteristics of numerous hot springs found, suggest that this area is independent from NRV geothermal system. For instance, hydrothermal calcium carbonate deposits that were previously silica (opal and chalcedony) are frequently found in Santa Rosa (Fetzer, 1942). These deposits are not found in NRV. Furthermore, Santa Rosa seems to be richer in CO_2 (Alfaro et al., 2002).

There are hot springs grouped into two sectors known as San Vicente and Santa Rosa. According to Alfaro et al. (2002), the hot springs of San Vicente are along the line of the Campoalegrito River, with temperatures between 28 °C to 89 °C and chloride composition. The springs of Santa Rosa are located on sections of the San Ramón River and the Santa Helena stream. These hot springs have temperatures between 44 °C to 68 °C and bicarbonate chemical classification. These variations in temperature and chemical composition suggest that the springs with the greatest direct contribution of the reservoir fluid are those of San Vicente. Fluid geochemistry studies have suggested that the Santa Rosa geothermal reservoir has a temperature above 250 °C. In these two sectors there is a geothermal anomaly reflected not only by the presence of hot springs, but also by estimated values of geothermal gradients between 120 °C/km and 130 °C/km.

Currently, the Geothermal Resources Exploration Group of the Colombian Geological Survey (GREG-SGC) is developing studies related to structural geology and characterization of hydrothermal alterations in Santa Rosa. Structures in NNE and NW direction have been identified. The NNE traces are the most regional structures with a marked fault scarp, associated with the Romeral fault system. According to field data, these structures are reverse faults with planes dipping east. The NW structures control the traces of the tributaries in which the hot springs are located. Apparently, these structures behave as strike slip faults. The volcanic building, the hot springs and some hydrothermally altered areas are located on the interception of the NNE with the NW structures. The hydrothermal alteration has been identified locally in the sectors of La Tigrera. To the west, in La Sierra sector, the hydrothermal alteration presents a greater extension, especially at the headwaters of the Campoalegrito and San Ramón rivers and at the fossil fumarole Azufrera Betania. In these places, lavas of porphyritic texture outcrop are composed of phenocrysts of altered plagioclase and some mafic minerals that sometimes appear to be chloritized (Rodríguez et al., 2019).

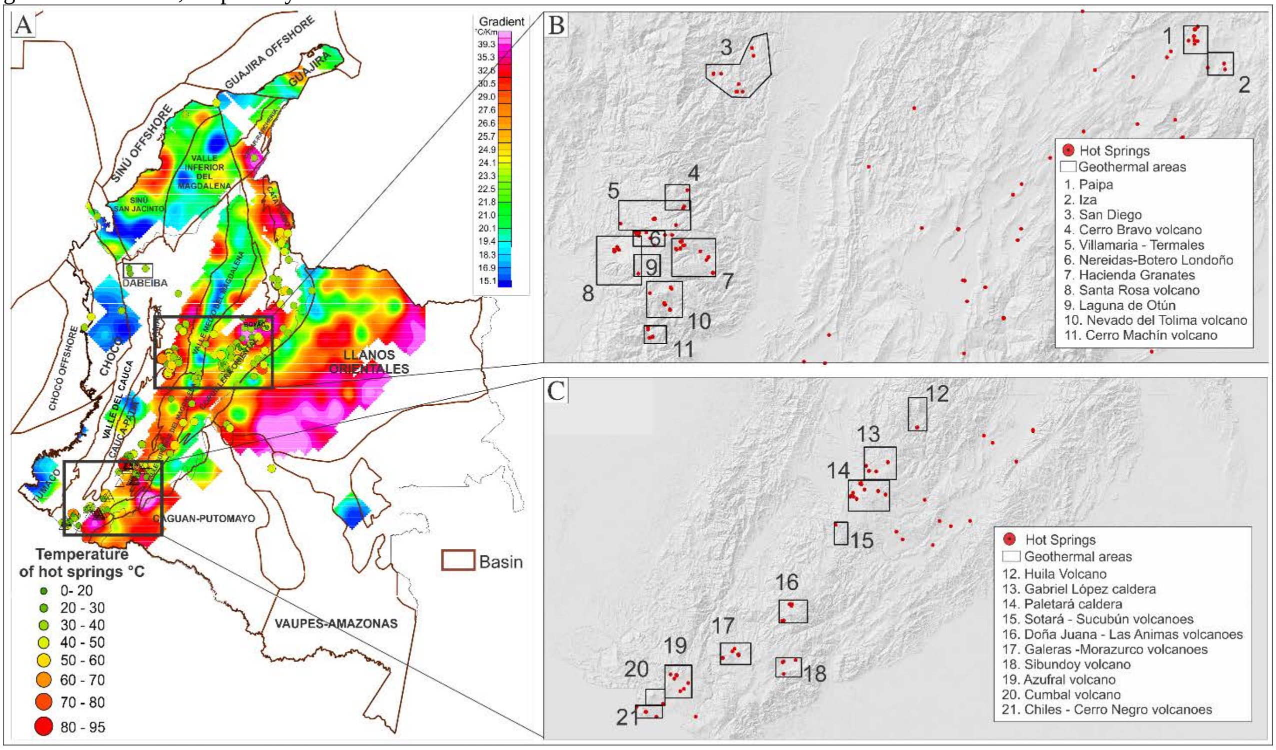

Figure 2: A. Geothermal gradient map. B and C show the main geothermal areas. NRV comprises the contour areas of Hacienda Granates, Villamaria-Termales and Nereidas-Botero Londono.

3.3 Cerro Machín

Based on the geology of the volcano Cerro Machín and its eruptive products, the Colombian Geological Survey (SGC by its Spanish acronym) and university research groups have started geophysical (magnetotelluric – MT - and potential methods) and geological detailed studies (Thouret et al., 1995; Cepeda et al., 1995; Méndez, 2001). Geoconsul (1992) evaluated the geothermal potential of Cerro Machín volcano and proposed a small dominant liquid reservoir of about 250 °C located in volcanic deposits. The geothermal activity in this area is represented by discharges of water and gas near the volcano, rivers and streams. New outflows of gases were also found near to the vicinity of the Tapias town, along with abundant travertine deposits. According to Alfaro et al. (2002), the hot springs are bicarbonate with discharge temperatures ranging from 40 °C to 94 °C. A reservoir temperature between 220 °C to 240 °C is estimated from Na/K geothermometers. Based on the model Enthalpy-Silica, the temperature of the reservoir is estimated of 245 °C. However, for some thermal springs, and by the model Enthalpy-Chlorides, the temperature of the reservoir could reach up to 300 ° C. The preliminary field work results carried out recently by SGC confirms the structural control of the Cajamarca fault in NE direction with dextral component (Mosquera et al., 1982; Cepeda et al., 1995; Cuellar et al., 2014; Rueda-Gutiérrez et al, 2019). Hydrothermal alteration is almost restricted to intra-crater domes that have a strong interaction with steam. The argillic alteration predominates; although, petrographic and geochemical analyzes have not been performed yet. Given these results and taking into account the description of two earthquake swarm areas by Londono (2016), just below the main crater and near to Tapias town, the exploration area has been expanded to the east. GREG-SGC is currently conducting studies of MT, time-domain electromagnetic (TDEM), gravity and magnetic, and also new water and gases sampling. These studies will be carried out during the years 2019 and 2020 with the aim of understanding the structure of the subsurface and to generate a geothermal conceptual model.

3.4 San Diego

Prefeasibility studies of San Diego geothermal area, located on the Central Cordillera in the municipality of San Diego, Caldas department, was initiated three years ago by SGC. The area, about 95 km north of NRV, comprises two volcanic structures: San Diego Maar and a new discovered volcano called “El Escondido de Florencia.” It also comprises three hot springs sites: San Diego, Florencia and El Espíritu Santo, with the highest discharge temperatures of 43 °C. The Florencia’s hot springs probably reflect the higher contribution from the geothermal reservoir, with chemical composition characterized by neutral pH, sodium chloride water type, a relatively high lithium content and the higher oxygen-18 enrichment. However, a high magnesium concentration indicates a significant dilution with shallower water. Based on a relatively high SiO_2 content, the minimum temperature of the deep geothermal fluid is estimated as about 160 °C. Na/K geothermometers indicate the possibility of a higher temperature reservoir.

A more detailed geological map emphasizes the structural geology and hydrothermal alteration characterization (Rueda-

Gutierrez et al., 2016). Geophysical studies, including MT and other methods, as well as complementary gas and fluid geochemistry are currently being carried out.

An outcrop from this area of a metamorphic basement of the Central Cordillera, suggests a deep reservoir characterized by secondary permeability. Also, the reservoir could be in part hosted by igneous rocks, which covered about half of the geothermal area.

3.5 Paipa

After forming a preliminary conceptual model based on surface studies by Alfaro et al. (2005), new contributions have come up recently about Paipa's geothermal area. An inventory of hot springs, stable isotopes study of low temperature and low conductivity water cold springs (representative of meteoric water), surface hydrothermal alteration characterization, geoelectrical, gravimetry, magnetic and MT studies, were carried out to define the new conceptual model.

Based on this information, a neutral sodium sulfate water type is identified as the low temperature saline source that masks hot springs' chemical and isotopes composition. This low temperature saline source is confined to the main discharge zone of the geothermal system. The isotope composition of the springs shows 18O enrichment. A cold water infiltration is estimated to come from about 2,900 meters above sea level (m.a.s.l.) according to geoelectrical survey (Moyano, 2010; Franco, 2012). Likewise, the observed high contrast of gravimetry and magnetometry allowed the identification of some intrusive bodies related to the lava domes with some shallow expressions (Vasquez, 2012; Beltran. 2015). Additionally, based on the mineral characterization from X-Ray Diffraction (DRX), a surface acidic alteration zone was identified in El Durazno, differentiated in advanced argillic (alunite, jarosite) and argillic (kaolinite) (Mojica et al., 2010; Rodríguez et al., 2018). On the other hand, the Uranium Exploration Project, of the SGC, connected El Durazno quarry with an igneous origin. This is consistent with the relatively high surface uranium and thorium concentrations measured in the area with more than 300 and 17 mg/kg, respectively (Gonzalez et al., 2008).

The system presents extensive outcrops comprised by highly permeable sedimentary rocks, which most likely act as a regional recharge zone. Deep infiltration occurs along normal faults. The groundwater is heated by interaction with the crystallized magmatic intrusion underlying the igneous dome complexes. The heat source is more likely the residual heat of the magmatic bodies. It could also be complemented by the radiogenic heat derived from the high concentration of radiogenic elements in those igneous intrusions. The upflow of the geothermal fluid most likely occurs along the contact planes between igneous intrusions and basement rocks at depth, and with the sedimentary sequence at shallower levels. The sedimentary reservoir most likely extend to the Quebrada Honda formation, in the valley located between the two dome complexes, south from Cerro Plateado fault.

The outflow in the north is controlled by Cerro Plateado fault, from the NW towards the western limit of Une formation, which roughly corresponds to El Bizcocho superficial trace. From there, the flow direction turns to the northeast until it finds enough permeability to give rise to the main discharge zone (ITP-Lanceros Sector). Then, the outflow goes to the right of the cross between El Bizcocho and El Hornito faults; an area characterized by high permeability formations Labor and Tierna. At about 1 km to the north of Cerro Plateado, below the cross between El Batán and Rancho Grande faults, exists a small discharge zone called La Playa, which is one steam vent and few hot springs. El Batán hot spring is the hottest of the system (76°C), whose salinity reflects the smaller contribution of the saline sodium sulfate source. The hydrothermal fluid mixes with the lower temperature saline water and gets the contribution of organic gases. On the other hand, a shallower circulation circuit of lower temperature, is posed in the strip defined between the NE faults El Hornito y Canocas. Its heat source could be related to radiogenic heat from El Durazno. This circulation flow would be isolated from the sodium sulfate saline water which most likely follow the same NE strip but to a greater depth.

3.6 Azufral

From the review, update and integration of studies carried out by SGC including the geological map (Calvache et al., 2003), structural geology (Velandia et al, 2006), gravimetry and magnetic (Gómez et al., 2009; Ponce, 2013), geoelectrical surveys (Franco, 2012), surface hydrothermal alteration characterization (Carvajal et al., 2007; Martinez, 2009), fluid geochemistry (Alfaro, 2001; Alfaro et al., 2008) and seismological monitoring, a conceptual model of the hydrothermal system of Azufral Volcano was postulated by Alfaro et al. (2013). The preliminary conceptual model proposes that Azufral volcano hosts a high temperature geothermal system of about 225°C, which dominates over the magmatic system, at present. The geothermal surface manifestations such as hot springs, fumaroles and hydrothermal alteration zones are mainly controlled by faults and their intersections. The geothermal gradient, estimated from the magnetic anomaly, is higher than 120°C/km. A geothermal reservoir would be located about 2 km deep. The boiling zone, identified from the advanced argillic alteration on surface, associated to active acidic sulfate fluid discharges in steam vents and hot springs, points out the upflow zone at the volcano summit. The outflow, with a direction toward the east is controlled by NW-SE structures and the topography, 6 to 8 kilometers away from the crater Azufral, where there is an accumulation of geothermal fluid. From the accumulation area, a flow happens towards the Southeast through a faulted zone. Recently an MT acquisition was concluded to update the preliminary conceptual model.

3.7 Chiles-Cerro Negro

The area is in the Cordillera Occidental, in Nariño department, Colombia and the province of Carchi, Ecuador (at the border of both countries). Gas geothermometers suggest reservoir temperatures up to 230°C. Reservoir rocks is more likely to be fractured Tertiary volcanic, Cretaceous volcanoclastic and volcano sedimentary rocks; and affected by the intersection of active NNE trending regional strike-slip faults with local E-W faults These varying lithology and structures are likely the due to reasonable regional and local permeability of moderate to high values, favouring the fluid flow between the recharge and discharge zones (García et al., 2019). A drilling target has been estimated between 1,000 to 1,500 m depth. Furthermore, hydrothermal alteration is attributed to high-temperature fluids heated by a main heat source associated with Chiles volcano, which is a moderate size, andesitic to dacitic, stratovolcano active in late Pleistocene. The heat source is reinforced by Cerro Negro de Mayasquer, an active dacitic volcano adjacent to the west (Beate et al., 2015). The shallow part of the geothermal system is capped by a thick conductive layer, which corresponds to an extensive area of hydrothermally altered rocks between 1.5 km to 2.5 km around Chiles volcano. The discharge zone is related to Bicarbonate springs located several kilometres to the east from Chiles volcano. Prefeasibility studies owned by the companies ISAGEN from

Colombia and Electricity Corporation of Ecuador (CELEC-EP), have estimated a geothermal potential of 138 MW (Mejía et al., 2014).

3.8 Dabeiba

This area is located northwest of Bogotá, on the northern part of the Cordillera Occidental. Geochemical analysis indicate that all the surface springs belong to the same reservoir and are in partial equilibrium. Geothermometers suggest reservoir temperature of around 150°C. The deep hydrothermal system is interpreted as hosted by a fractured meta-sedimentary rocks of an extensional Miocene event, and controlled by emplacement of high angle normal faults. The fluid flow is also controlled by the state of stress in the reservoir rock and apparently interact with a magmatic source of a possibly felsic intrusion rich in radioactive elements. The seal rock most likely composed of altered and impermeable Neogene sedimentary units (Gomez, 2019).

3.9 Sedimentary Basins

Relatively high apparent geothermal gradients have been preliminary calculated by the bottom hole temperature (BHT) method in some areas of sedimentary basins (Figure 2A). The highest estimated geothermal gradient (56°C/km) is found in the Eastern Llanos basin. This estimation would not be coherent with the age of the basement composed of the oldest rocks in the territory (Amazonic Craton). The cause of this observation remains unknown. The main areas of occurrence of the hydrothermal systems (Andean region), where the highest geothermal gradient and heat flow regional anomalies are expected, have not been documented by direct temperature measurements, except in the geothermal well Nereidas-1 with an apparent geothermal gradient of about 136 °C/km (Alfaro et al., 2010).

4. LEGAL FRAMEWORK AND NATIONAL POLICY

There are some legal and governmental actions in the last five years that benefit the development of geothermal projects in Colombia. For instance, the law 1715 of 2014 establishes four main incentives to grant energy projects from non-conventional renewable energy sources (FNCER by its Spanish acronym) including geothermal (Colombia, 2019):

- 15 years to deduct 50% of investments from income tax.
- Exemption of the National Value Added Tax (IVA by its Spanish acronym) of 19% for equipment and services.
- Exemption of import duty for equipment not produced locally.
- Up to 20% of accelerated depreciation per year for the investment.

Furthermore, the current government has addressed the next goals in the National Development Plan 2018-2022:

- Definition of a regulatory framework for geothermal projects.
- The SGC will carry out studies to characterize the geothermal potential of Colombia.
- The Mining and Energy Planning Unit of Colombia (UPME by its Spanish acronym) will carry out studies on integrated development and policy strategies around geothermal exploitation.
- The Ministry of Mines and Energy (MME) will establish the area allocation policy, the contractual instruments to develop the exploration and exploitation activities of the resource and the agency responsible of general administration.
- Working groups will be formed by the Ministry of Environment, The National Authority of Environmental License (ANLA by its Spanish acronym), The Regulatory Energy and Gas Commission (CREG by its Spanish acronym) and SGC, to establish the regulatory framework and environmental terms of reference that allow the proper use of geothermal in Colombia, under strict compliance with the conservation of the tropical moorlands as strategic ecosystems.

The above can be translated as opportunities for cooperation agreements and technical advice around topics such as legal definition for using geothermal fluids; how to grant concession areas, pay royalties, ensure sustainable exploitations, and regulate direct uses.

Figure 3 shows the IRR of a financial feasibility exercise for starting up a 15 MW geothermal power plant at NRV since 2023, taking advantage of the incentives offered by the Law 1715 of 2014. It also includes the investment for drilling and is contextualized in the current state of the Colombian energy market. For this case, the levelized cost of energy obtained is US$59/MWh, contrasting with UPME's projection for the energy price of US$70/MWh with annual increments of 1.3% (UPME, 2015).

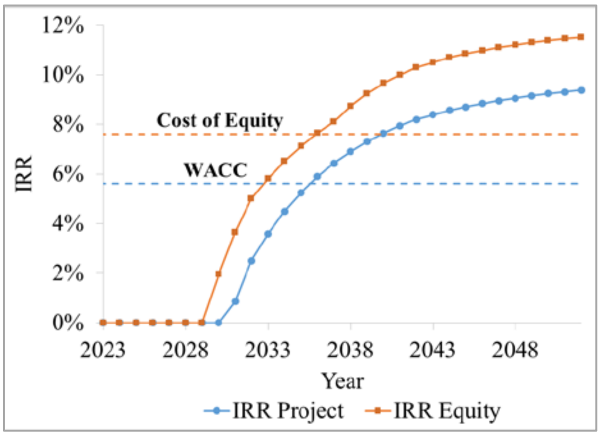

Figure 3: Financial feasibility exercise: IRR Project and IRR Equity to start up a 15 MW geothermal power plant in the coming years at NRV.

5. ELECTRICITY POTENTIAL

Colombian power generation totalled 17.4 GW in July 2019, which supplies 96.3% of its population's electricity demand (UPME, 2019; The World Bank, 2019). This production is mainly hydropower composing 69.7% of the total, requiring an additional base-load energy due to intermittent climate conditions (Poveda et al., 2011). The remaining energy matrix is comprised of thermo-electric power from fossil fuels - 28.9% of the total. Hence, the scenario is clear on how geothermal could play a crucial role for Colombia to move forward to clean resources replacing its base-load of thermo-electric power and in such a way to reduce the carbon emissions. Colombia's geothermal potential has been estimated at 2,210 MW. As already mentioned, it is equivalent to produce around 20% of its electricity demand by using geothermal resources (Gawell et al., 1999; Salazar et al., 2017). However, the exploration and technical knowledge has increased in the last two decades and the proven potential is still to be confirmed.

The Colombian government resolved, through resolutions 4-0590 and 4-0591 of July 9, 2019 the rules for the first renewable energy auction that promotes long-term purchase for power generation projects from FNCER. These projects must have a total power capacity greater than, or equal to 5 MW. The start date of the electricity supply obligations of the contracts awarded will be January 1, 2022 with a term of 15 years. The contracting model type is take-or-pay, which means that the buyer must pay the contracted energy, regardless of whether the marketer consumes it or not, and that the generator agrees to provide a fixed energy to the buyer (MME, 2019). The governmental goal is to increase to at least 1,500 megawatts (equivalent to approximately 10% of the energy matrix) to be produced by FNCER in the next 4 years. To achieve this goal, the MME has contemplated investments for around US$1.5 billion.

6. DIRECT USES POTENTIAL

The exploitation of low and intermediate geothermal resources should be promoted to unlock geothermal resource use in Colombia. Since it is less expensive and quicker to develop a shallow geothermal installation than a power plant, low-enthalpy geothermal applications should be shared with industry, communities, and government. Because of the climatic conditions of the country, where temperature is almost constant through the whole year, heating and air conditioning needs are usually not required at the same location.

Although the geothermal resources in Colombia have been used mainly in bathing and swimming, with an approximately installed capacity of 14.4 MW, several applications in geothermal can be envisioned such as greenhouse heating, heating for industrial processes, and spacing heating and cooling (Alfaro et al., 2005). Using the local availability of water resources (surface and subsurface) and according to environmental regulation, vertical or horizontal loops in ground coupled heat pumps (GCHP), groundwater heat pump (GWHP), and surface water heat pump (SWHP) can be considered (Rafferty, 2001).

Colombia is part of The Iberoamerican Network of Shallow Geothermal Energy (RIGS for its Spanish acronym). This initiative was created at the beginning of 2019 with the goal to facilitate a cooperative framework and activities related to research and development of shallow geothermal energy among the participating countries (including Argentina, Chile, Ecuador, Spain, Mexico, and Uruguay). The motivation of the research groups is to contribute to the installation, development, and integration of geothermal systems for all types of economic activities, thermal conditioning of buildings, both in urban and rural/industrial, using the technologies available in Latin America.

District heating could also be an opportunity to be analyzed for the exploitation of intermediate temperature geothermal resources. In Medellin, La Alpujarra Thermal District is the first of its kind in Latin America, a gas thermal district that provides air conditioning for several administrative and government buildings of the metropolis. It was installed by the company Public Companies of Medellin (EPM by its Spanish acronym) (EPM, 2016). Although it is not working with geothermal resources, it provides significant benefits such as savings in electricity consumption, reduction in equipment investment, maintenance, and operation, in addition to its environmental contribution. Therefore, this vision shows that there is a growing interest in investing in environment friendly projects. Geothermal resources can thus be the option to replace gas for geothermal districts in Colombia.

7. SOCIAL ASPECTS

In Colombia, some work on socializing geothermal in local communities has been conducted successfully. In this paper, the examples from the Sotará volcano, NRV, and Paipa are described.

The University of Cauca promoted geothermal's benefits to the indigenous community of Yanaconas-Guachicono, located in the foothills of Sotará volcano, municipality of La Vega, department of Cauca. It is a great example of success as currently Yanaconas-Guachicono are interested and looking for support to do research on understanding the geothermal resources around their vicinity for future exploitation projects (Cruz et al., 2018).

In NRV, some activities required in the environmental license for the geothermal project are been done by Caldas Hydroelectric Company (CHEC by its Spanish acronym). It includes training, education and awareness for the community surrounding the project, bringing so far, a positive perception for the locals about geothermal energy as a clean source to produce electricity (Ramirez et al., 2017).

Multiple socializations with the communities of Paipa, including schools, people from rural and urban areas, and governmental entities have been developed simultaneously with the exploration phases. Strategies such as models, banners, technical and informative conferences and field visits with the community have been used, especially in the current time when the geothermal gradient drilling in this area is planned. Despite the continuous socializations, the research work has been in the middle of environmental conflicts related to mining (coal and construction materials) and oil exploration (fracking). Even so, the community in general is aware of the importance of research studies as a way of appropriating their geothermal resources and how to get to defend and use them in the best way.

In addition, a general survey about the perception of geothermal energy has been conducted in a portion of the Colombian population (most interviewed people had a high-education level), and the results were compared with Chile, Canada, Belgium, and France (Lopez-Sanchez et al., 2018). This exercise highlighted that Colombia has the lowest level of knowledge about geothermal energy. Also, no matter the country the respondent belongs to, environmental impacts were considered as the most important issue related to energy.

Furthermore, AGEOCOL, the Colombian Geothermal Association, through symposiums, short-courses, and RENAG, has contributed to foster the sharing of information and knowledge about geothermal energy among the universities, government, and industry. RENAG's technical program has included the following topics: 1. update of geothermal energy in Colombia, 2. exploration and research, 3. legal and regulatory framework, 4. education and capacity building, 5. direct uses, 6. high and middle enthalpy geothermal resources, 7. financial mechanisms, and 8. shallow geothermal energy. This meeting has experienced a steady growth of participants and facilitated the scenario for AGEOCOL to formalize cooperation agreements with Colombian and international institutions. AGEOCOL is actively looking for opportunities and ideas to fulfill its mission of promoting research, development and use of geothermal resources in Colombia with social and environmental responsibility.

8. CONCLUSION AND RECOMMENDATIONS

Colombian geothermal potential is being evidenced by geoscientific studies in some of its areas with volcanic provinces and sedimentary basins. This potential is translated to a possible 20% coverage of energy demand by using geothermal resources. Additionally, legal and public policies and the recent growing interest in Colombia for the development of geothermal projects have been done through initiatives like the Law 1715 of 2014, the inclusion of geothermal in the next four year National Development Plan and the renewable energy auction taking place in the coming months.

In terms of power generation, Colombia can learn from New Zealand not only from geothermal technology but also from the resource management and the electricity market. The spot market structure might help better manage the electricity sources thereby encouraging a positive shift to renewables helping to de-carbon the power generation in Colombia. Colombian market differs from the New Zealand one in its capacity to export electricity to Ecuador and Venezuela and soon to Central America, which allows the grid to perform above the base load for longer hours. A similarity between both countries is the unbundling of the electricity sector in producers, transmission operators, distributors and retailers.

The spreading of geothermal knowledge has been carried out nationally by AGEOCOL through different technical activities as RENAG, creating a good perception from the participants about geothermal resources. AGEOCOL is advising also about the importance of direct uses as an efficient way to socialize to Colombians the benefits of the development of geothermal projects (AGEOCOL, 2018). For instance, New Zealand Geoheat Strategy 2017-2030 aimed at fostering the increase and diversification of the direct use of geothermal heat, could be replicated in Colombia and RIGS. This strategy will create new businesses, convert more industries from fossil fuels to geothermal energy, support regional economic and social development, and increase the uptake of renewable low carbon energy (Climo et al., 2017; Climo et al., 2018). The expertise of New Zealand with respect to geothermal heat pumps could support training of highly qualified personnel in Colombia through some cooperation agreement between government and institutions.

Socialization activities have been also carried out successfully in the indigenous community Yanaconas-Guaicono, NRV and Paipa. Related to this, indigenous and local community affairs is another field where New Zealand can support Colombia. For instance, some of the Colombian Geothermal fields are in ancestral land. However, there is not enough understanding of the cultural significance thermal springs and geothermal fields might have because of the longer period of colonization, which has caused a more pervasive and in most cases irreversible acculturation. Therefore, even though the Colombian government owns all the natural resources, some of them should be legally transferred to the native population. This transfer might have a double effect, increase the sense of belonging to the different nations and potentially lift them up economically because they could potentially receive royalties. It is for instance the cases of Tauhara North, Ngatamariki and Papakainga, New Zealand.

All of the above are some of the reasons for the creation of an active synergy of cooperation between Colombia and New Zealand to foster the geothermal potential of Colombia.

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