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GEOTHERMAL DEVELOPMENT IN COLOMBIA

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ABSTRACT

Geothermal energy in Colombia is mostly exploited by direct uses, in tourism - bathing and swimming, and minor uses in heating; however, it is necessary to explore the potential of other uses such as power generation. Although Colombia is rich in energy generation, where its main production source is hydroelectric, other sources of renewable energy, such as geothermal energy are strategic to diversify the energy matrix and to increase the reliability associated with hydroelectric power generation.

Initial reconnaissance studies of geothermal resources in Colombia were held in the 1970s, in spite of that, geothermal development in this country is considered incipient, and there is no installed geothermal power capacity yet. Currently, with support of different entities, national and abroad, there are two projects in the prefeasibility and feasibility stages in progress in the country, with 190 MW of geothermal potential in the Macizo Volcánico del Ruiz and Tufiño-Chiles-Cerro Negro areas. Other studies have been developed by the Colombian Geological Survey (SGC), which has conducted reconnaissance and prefeasibility studies in some areas, such as the Paipa, Azufral Volcano, San Diego Maar, Cerro Machín Volcano, and others, in order to increase the knowledge of the geothermal potential of the country.

1. INTRODUCTION

Colombia has a privileged geographical position and a favourable geological setting, because it is located in the Pacific Ring of Fire, an area where the natural temperature of the ground, close to the surface is high due to the volcanic activity associated with features suitable for geothermal exploitation.

Recognition studies supported by the Latin American Energy Organization (OLADE) and the Colombian Institute of Electricity (ICEL) concluded that Colombia has at least nine areas of interest for geothermal electricity generation or direct use of steam for industrial processes or tourism.

Since 2008 and with the support of different entities, ISAGEN has been supporting the Basic Feasibility Study for the Development of a geothermal project in the Macizo Volcánico del Ruiz Volcanic Massif. In addition and in order to develop a Bilateral Agreement signed by Colombia's and Ecuador's Presidents, ISAGEN and Corporación Eléctrica del Ecuador (CELEC EP) began together the prefeasibility studies to develop a geothermal project along the border region between the two countries.

1.1 The current state of energy

Colombia has an installed electricity capacity close to 14,500 MW, from which 9,800 MW are based on hydroelectric power, 4,680 MW based on thermal power and about 18 MW based on wind energy.

The country finds it necessary to develop renewable energy projects that are cleaner and friendlier towards the environment. These are the reasons why the Colombian State has established a National Energetic Plan with the following objectives: Expand and warrant the energy provision; Promote regional and local development; Introduce new sources and technologies of energy generation; Contribute to reduce the greenhouse gas emission and climate change; Promote the use of renewable energy sources. For these reasons the Colombian Government is interested in the study and development of non-conventional renewable energy sources, to diversify the energy matrix and increase the reliability associated with hydroelectric generation.

1.2 Colombian geothermal potential

Volcanism in Colombia is part of a complex tectonic framework generated by the interaction between the South American, Nazca and Caribbean plates. The convergence of the Nazca oceanic plate under the South American collides obliquely in this segment of the Andes at speeds of about 54 mm per year (Trenkamp et al., 2002). This process conform a seismically active zone with trenches and volcanism along the axis of the Central Colombian Cordillera and in the south in Western Cordillera, with at least 15 active volcanoes. Seismological studies have agreed to propose a discontinuous character in the Colombian-Ecuadorian subduction, causing segmentation of Colombian Volcanism in: the north volcanic segment (Volcanic complex Cerro Bravo – Cerro Machín), the central volcanic segment and the south volcanic segment.

Colombian geothermal capacity is evident in zones around the Chiles, Cerro Negro, Cumbal, Azufral, Galeras, Doña Juana, Sotará, Puracé, Nevado del Huila, Nevado del Ruiz and Nevado del Tolima volcanoes. These volcanoes are quaternary volcanoes, with hot springs, fumaroles, superficial hydrothermal alteration, and other thermal features, that could be evidence of the existence of a geothermal resource, probably with adequate characteristics for being used in power generation. Other non-volcanic areas, which could have some potential, are found in the Los Llanos basin (high geothermal anomaly) and along the Caguan-Putumayo basin and the Magdalena Valley (Vargas et al. 2009) (Figure 1, yellow circles). Colombia's geothermal potential has been estimated at 2,210 MW (Battocletti, 1999), and current installed capacity in direct use is about 14.4 MW, for a total annual use 287.0 TJ/year (Alfaro et al., 2005).

2. BACKGROUND FOR GEOTHERMAL ENERGY DEVELOPMENT IN COLOMBIA

In the past, Central Hidroeléctrica de Caldas (CHEC), Geoenergía Andina (GESA) and entities like the Latin American Energy Organization (OLADE), Planning and Promotion of Energetic Solutions Institute (IPSE), Geological Colombian Survey (SGC previously known as INGEOMINAS) and the Mining and Energy Planning Unit (UPME) have made studies to explore the potential of the geothermal resource, such as:

- Reconnaissance Study of geothermal fields in Colombia and Ecuador (OLADE, AQUATER, BRGM and GEOTÉRMICA ITALIANA, 1979 to 1982).
- Prefeasibility studies for geothermal development in the Tufiño-Chiles-Cerro Negro area (INECEL-OLADE, 1982; OLADE-ICEL, 1986-1987).
- Prefeasibility studies for geothermal development in the Nevado del Ruíz Volcano area (CHEC, 1983; GEOCÓNSUL, 1992; GESA, 1997). Drilling Nereidas-1 Geothermal Well.

FIGURE 1: Geothermal potential zones in Colombia

- Research studies of the geothermal systems in the Azufral and Cumbal volcanoes areas (INGEOMINAS, 1998-1999, 2008-2009; INGEOMINAS - Universidad Nacional de Colombia, 2006).
- Research studies of the geothermal systems of the Paipa and Iza areas (INGEOMINAS, 2005, 2008-2009).

- Additional researches of the geothermal resource in the Tufiño area and the geothermal development plan in Ecuador (MEER, 2008 – 2009).
- Feasibility studies for the generation of geothermal energy in Colombia (ISAGEN-USTDA-BPC-INGEOMINAS, 2008-2009).
- Report of the well PGT-1, perforated in Aguas Hediondas (MEER, 2010).
- Strategic program for the modelling of the hydrothermal-magmatic system of the Nevado del Ruíz volcano (ISAGEN-UNAL-INGEOMINAS, ISAGEN, COLCIENCIAS, 2010-2012).
- Prefeasibility studies to develop the Tufiño-Chiles-Cerro Negro Binational Geothermal Project (ISAGEN-CELEC EP, 2010-2012).
- Modeling of the resistive structure by magnetotelluric studies (ISAGEN-INGEOMINAS-CIF-UNAM-COLCIENCIAS, 2011-2012).
- Prefeasibility studies of the Macizo Volcánico del Ruiz Volcanic. Drilling of three TGW, between 174 to 300 m in depth (ISAGEN-BID-NIPPON KOEI-GEOTHERMAL-INTEGRAL, 2011-2012).
- Catalytic Investments for Geothermal Energy. Complementation of a resistive model, advice and support during exploratory drilling stage (ISAGEN-BID/GEF, 2011-2014).

3. RESEARCH AND EXPLORATION OF GEOTHERMAL RESOURCES

Geothermal research in Colombia is led by entities like ISAGEN, Geological Colombian Survey (SGC), Empresas Públicas de Medellín (EPM) and the Mining and Energy Planning Unit (UPME), which are developing prefeasibility and regulatory studies regarding geothermal use in the country.

The studies developed by electrical companies and government agencies are in the early stages of development (Table 1).

ISAGEN is developing two specific projects: Macizo Volcánico del Ruiz and Tufiño-Chiles-Cerro Negro. (i) The Macizo Volcánico del Ruíz Project is ending the prefeasibility studies and establishing and preparing the contractual documents required for exploratory drilling. (ii) The Tufiño-Chiles-Cerro Negro; Binational Geothermal Project which is in the prefeasibility stage, which consists of geological, geochemical, hydrogeological and geophysical studies; deep slim hole drilling or thermal gradient holes and the design of exploration wells, infrastructure and environmental impact studies.

On the other hand, the Geological Colombian Survey (SGC)'s plan of geothermal research (SGC, 2014) includes reconnaissance and prefeasibility studies in some areas, such as the Paipa, Azufral Volcano, the Nevado del Ruíz Volcano, San Diego Maar, the Cerro Machín Volcano and the Santa Rosa zone. In general, studies have been focused on the acquisition of geophysical information and to update the conceptual models. Moreover, it has projected five thermal gradient wells and one deep drilling well in the Paipa area and another one in the Azufral Volcano area.

Empresas Públicas de Medellín E.S.P. (EPM) and its subsidiary Central Hydroelectric de Caldas S.A. (CHEC) are presently evaluating the geothermal potential within the Nereidas Valley near to the Nevado del Ruiz volcano. Currently, it appears that the survey area has significant geothermal potential.

Likewise, the Mining and Energy Planning Unit (UPME) has advanced some regulatory studies in order to promote non-conventional energy sources, including geothermal, through the elaboration of the geothermal potential map and a study about current state of renewable energy and its development plan (UPME, 2013).

3.1 The Macizo Volcánico Nevado del Ruiz Project

Since 2010 to the present, ISAGEN has developed exploration studies in an area of 200 km^2 around the Nevado del Ruiz Volcano. The activities include a cartographic restitution, 1:5,000 scale, a detailed

structural geology, hydrothermal alteration, fluid inclusion analysis, geochemistry of thermal waters, hydrogeology and geophysics. Overlay anomalies of magnetometric and gravimetric surveys, and the structural lineaments, allowed to identify areas with potentially anomalous thermal gradients near the surface (Figure 2). In 2011, ISAGEN drilled three thermal gradient wells, reaching 300 m in depth (Figure 3).

Table 1: State of current geothermal project develop in Colombia. N.D.: Not defined

Project	Estimated Capacity	Current Status	Inversion (USD)
Macizo Volcánico Nevado del Ruíz	50 MW	Prefeasibility studies is finished. EIA in approbation, by National Environmental Agency Licenses. ISAGEN. 3 TGW perforated 2011-2012.	6 Million
Binational Project: Chiles–Tufiño–Cerro Negro	138 MW	Prefeasibility studies in progress. ISAGEN-CELEC.	4 Million
Paipa	N.D.	Prefeasibility studies. SGC.	N.D.
Azufral Volcano	N.D.	Prefeasibility studies. SGC.	N.D.
San Diego Maar	N.D.	Prefeasibility studies. SGC.	N.D.

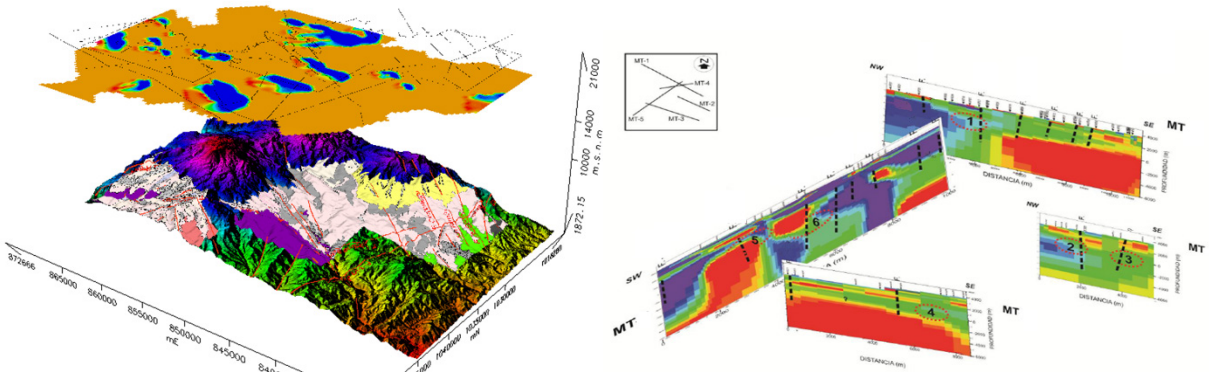

FIGURE 2: Left, 3D modelling with geologic and structural mapping overlap and index overlay anomalies based on geophysics surveys. Right, MT profiles of the Nevado del Ruiz area.

A MT survey consisting of 200 soundings was made and a 3D inverse model has been processed. As a result, a Geothermal Conceptual model was obtained, and five targets for exploratory deep wells were chosen. The selected exploratory wells are 1700 m to 2700 m depth, the expected temperature of the reservoir is about 200°C, which targets some fault zones and a fractured reservoir. Currently, the National Agency of Environmental License is evaluating the Environmental Impact Study (EIA), for exploratory wells, including the design of the wells, platforms and access roads.

The next stage, planned to be executed in the next two years, is drilling exploratory wells and reservoir evaluation, field planning development and plant design. It is expected that construction and operation of a power plant of 50 MW could be ready in 2018.

An important result of the studies performed in association with the Geological Colombian Survey (SGC), the Administrative Department of Science, the Technology and Innovation of Colombia (COLCIENCIAS), and the Universidad National de Colombia, is the institutional strengthening and technical capacity building of the country. Research institutions were provided with modern laboratory and field equipment for geothermal exploration and other applications; received training in geothermal exploration techniques and attended courses and scientific events abroad; and tightened inter-institutional ties. This leads to the creation of shared value for the development of geothermal energy in the country.

FIGURE 3: Left, rig used for TGW 1; Right, cores obtained, mainly andesites with fracture zones and propilitic alteration crossed by calcite veins

3.2 The Binational Tufiño-Chiles-Cerro Negro Project

In the execution of a Binational Agreement signed by the governments of Colombia and Ecuador on July 2010, to study the potential use of the geothermal resource identified at the border between both countries, ISAGEN S.A. and Corporación Eléctrica del Ecuador CELEC EP signed a Technical Cooperation Specific Agreement on April 5th of 2012, for the purpose of proceeding with pre-feasibility studies of the Tufiño-Chiles-Cerro Negro Binational Geothermal Project. The area to be developed extends throughout 49,000 ha, and a potential of 138 MW is expected.

Since 2012 to present, both ISAGEN and CELEC EP have developed activities such as compilation and a review of geothermal exploration studies, project socialization, 1:5,000 scale cartographic restitution, and the shooting of aerial photographs at a 1:15,000 scale. Currently, both companies are conducting with a consultant support the geological, structural, hydrothermal alteration mapping and geochemistry sampling (cold water and gas) for continuing with magnetotelluric studies, elaboration of geothermal conceptual modelling, drilling of slim hole or thermal gradient wells, selection targets for exploratory deep wells, design of wells, platforms and road access and finally preparation of the Environmental Impact Study (EIA).

4. BARRIERS TO GEOTHERMAL DEVELOPMENT

The experience of the evaluation of geothermal projects under development has identified some barriers that are listed in the following paragraph (BID-ISAGEN, 2013):

- Geothermal development requires specialized studies for characterization and exploitation of the resource.
- Colombia has a limited technical and scientific capacity for the development of the geothermal resource.
- Preliminary phases of exploration involves high investment costs and high risks, therefore it requires financial assistance.
- Geothermal areas are located in volcanic zones without infrastructure for access and connection to the National Transmission System (NTS).
- It is necessary to adjust the environmental regulation for the development and exploitation of the geothermal resource and its participation in the energy market.
- It is important to recognize externalities or intangibles that could not be assessed in a typical financial analysis, such as: Reduction of vulnerability of the electrical system against climate change; Complementarity of Hydropower; Reduction of greenhouse gas emissions; Decreasing the demand and consumption of fossil fuels.

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