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AGEOCOL, a Combined Effort to Promote the Geothermal Energy in Colombia

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ABSTRACT

Different drivers have moved Colombia in the right direction of developing its renewable resources in the last years. These mainly include international commitments to increase the use of renewable energy sources and reduce greenhouse emissions, the need for independence of hydro resources especially during droughts, and the need to supply power to remote communities not connected to the main electrical grid. Geothermal energy is taking its share in this development.

The Colombian Geothermal Association, AGEOCOL, is a nonprofit professional organization with scientific and educational vocation consolidated in 2018. It was established to bring together the academia, government, and industry to promote the use of geothermal resources in Colombia with social and environmental responsibility. Since its conception, AGEOCOL's activities have focused in coordinating efforts and resources to create a unified workforce. Establishing an association and running it has provided numerous opportunities to learn and grow.

This paper presents the context of geothermal energy in Colombia perceived from AGEOCOL, describes the processes followed to establish this association and the academic and scientific activities organized, and discusses the challenges to foster the development of geothermal energy in Colombia in the next years.

1. INTRODUCTION

1.1 Colombia: Geological Context and Energy Overview

Colombia is located to the North of South America, where the Andes Mountains divide into three ranges with two large valleys in between, where Magdalena and Cauca rivers flow to the Caribbean Sea. The orogeny and volcanic activity of the country is largely attributed to the subduction of the Nazca tectonic plate under the South American plate and its location on the Ring of Fire. Because of this tectonic and volcanic context, Colombia is rich in geothermal resources as evidenced by the numerous hot springs. Many of these geothermal sites are located near the current electricity grid to the advantage of development projects in the region (Figure 1). Colombia has an estimate of 48.3 million inhabitants with 84.2% living in cities and towns, and 15.8% living in scattered rural areas. (DANE, 2018). As of 2018, 96.3% of Colombian population had access to electricity, with hydropower being the main electricity generator with 70% of the total, followed by thermo-electric power from gas and coal (18%) (The World Bank, 2019; Salazar et al., 2017). However, hydroelectricity is strongly dependent on climatic conditions and it can be largely affected by droughts associated to the El Niño/Southern Oscillation (ENSO) (Poveda et al., 2011). Thus, base-load energy, such as geothermal, can help to reduce dependency on hydroelectricity and greenhouse emissions related to gas and coal thermal energy.

1.2 Geothermal Potential

Colombia's estimated energy potential for power generation is 2,210 MW from high enthalpy resources and 1,340 MW from low enthalpy sources that can potentially generate using breakthrough technologies (Gawell et al., 1999). This estimation is equivalent to supplying electricity for about 20% country population in 2018.

The only exploratory geothermal well drilled in Colombia was located in the Nevado del Ruiz area (Well Nereidas-1) and showed, locally, low permeability and could not reach the expected depth (Monsalve et al., 1998). The proven potential is still to be confirmed.

The best-studied geothermal regions in Colombia have been the geothermal areas of Paipa, the Chiles–Cerro Negro Volcanic System, the Azufral Volcano, and the Nevado del Ruiz Volcanic System located in the Cerro Bravo-Machín volcanic complex (Moreno et al., 2019). The Nevado del Ruiz area is the only area of interest where research efforts towards numerical modeling of heat transfer at reservoir scale have been deployed (Vélez et al., 2018; Moreno et al., 2018).

The Colombian Geological Survey (SGC by its Spanish acronym) has been conducting geothermal exploration in the following hydrothermal systems located in Figure 1 (Alfaro, 2015):

- **Cerro Bravo – Cerro Machín volcanic complex:** located west of Manizales, it comprises six of the priority areas for geothermal exploration, Nereidas-Botero Londoño (Nevado del Ruiz), Machín, Laguna del Otún, Cerro Bravo, Falla Villa María-Termal and Santa Rosa-San Vicente. Geothermometry measurements estimate reservoir temperatures between 240°C and 260°C.

- **Paipa:** located north of Bogotá. The conceptual model of this geothermal system suggests a possible shallow reservoir in sedimentary host rocks, and a deeper reservoir in basement rocks with a temperature range of 240°C to 260°C.

- **Azufral:** this area is located in the southwest of Colombia nearby the city of Pasto. The preliminary conceptual model suggests a reservoir between 2,000 to 2,500 meter depth with a temperature range of 210°C to 250°C or higher.

- **San Diego:** located 95 km north of Nevado del Ruiz Volcano. A potential geothermal reservoir of minimum temperature of 160°C is estimated by geothermometry measurements.

Additionally, the geothermal area Chiles-Tufiño-Cerro Negro located on the boundary with Ecuador, was investigated by ISAGEN and the Ecuatorian government as a Binational Project. There are some other geothermal systems in Colombia inferring a great potential such as Puracé volcano in Cauca and Doña Juana volcano in Nariño.

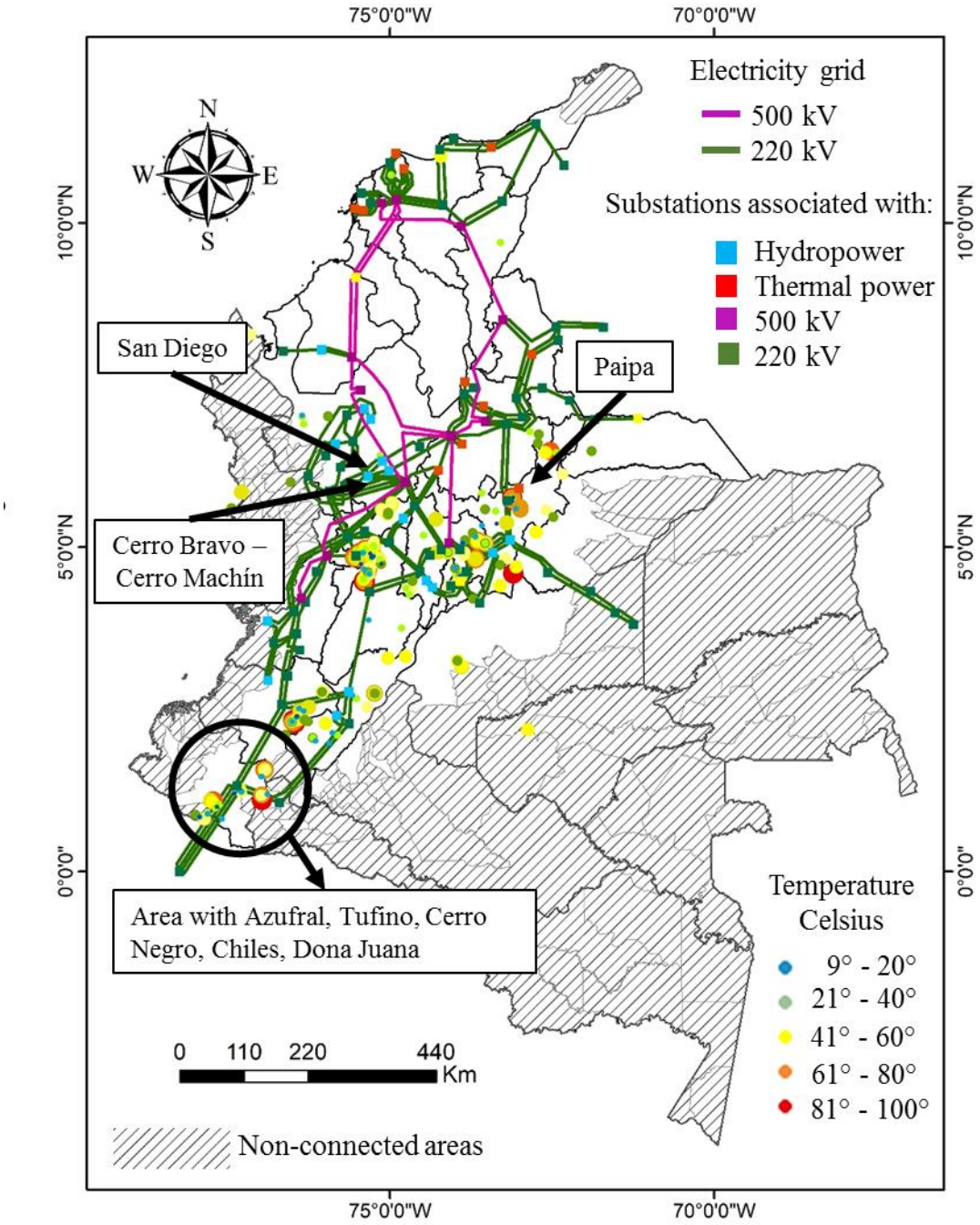

Figure 1: Map of Colombia showing known geothermal manifestations and their temperature, and the location of the national electricity grid. Electrical substations are marked with squares. The white area is the surface covered by the national electricity grid (UPME, 2016).

The geothermal gradient and Curie point depth maps are shown in Figure 2. It is possible to correlate areas of high gradient areas (INGEOMINAS-ANH, 2009) with shallow Curie point depths (Vargas et al., 2016), which also coincide with those locations with the highest geothermal potential.

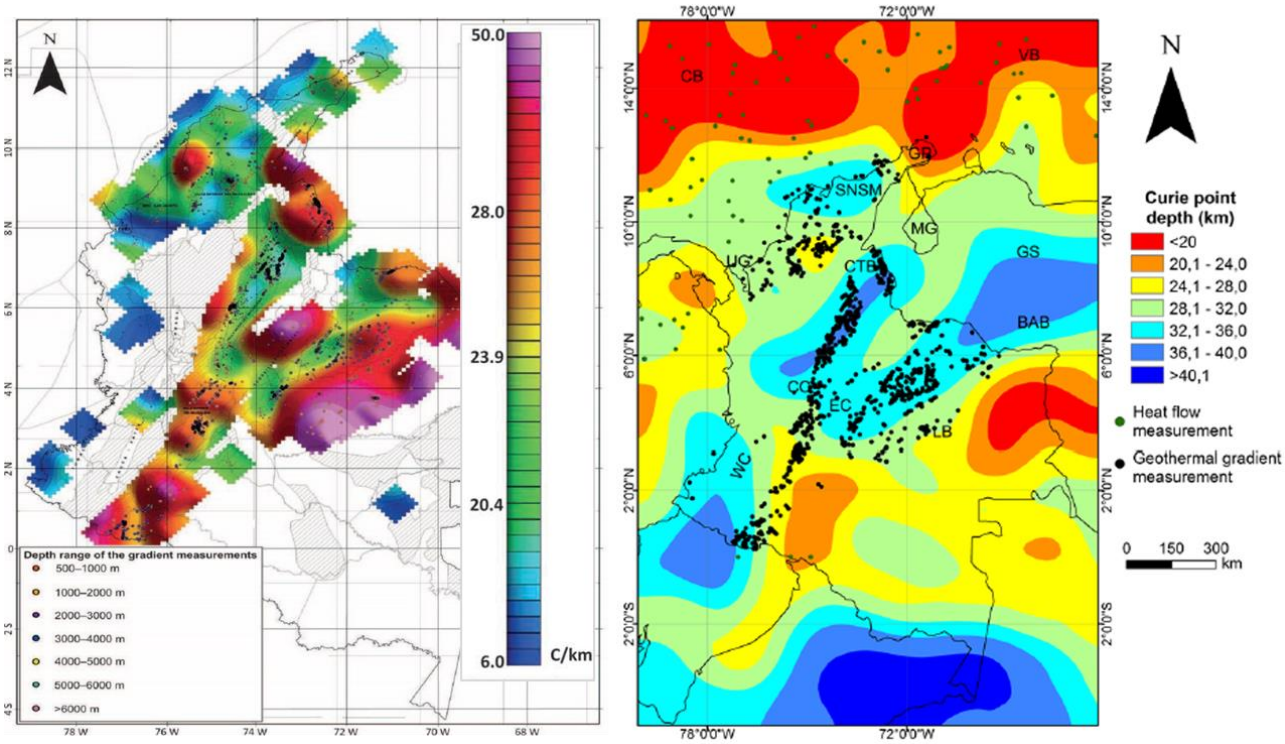

Figure 2: Left: map of geothermal gradient (INGEOMINAS- ANH, 2009). Right: Curie point depth map (Vargas, 2016).

2. AGEOCOL

2.1 Mission and Vision

AGEOCOL is the result of a joint effort between professionals who have been promoting geothermal energy from their different areas. It was established to facilitate the synergy between communities, government institutions, industry and academia, for the promotion of research, development and use of geothermal resources in Colombia with social and environmental responsibility, under the values of leadership, unity, and solidarity. Its vision is to be recognized in Colombia and internationally as the national organization that supports the deployment of the benefits of geothermal energy throughout the country by carrying out technical and social activities, promoting research and development projects that create employment, and building technical capacity for the sustainable use of geothermal resources.

2.2 Organizational Structure

AGEOCOL has a horizontal organizational structure which aims at empowering each position in its own role and avoids micromanagement. AGEOCOL promotes teamwork, ideas exchange, and collaboration (Figure 3).

The current Board of Directors is comprised by a main board and nine strategic committees. The Executive Board holds the administrative positions who are in charge of legal and financial affairs, and it is constituted by four positions: President, Vice President, Secretary and Treasurer. These four positions are a legal requirement for organizations in Colombia. The strategic committees hold the responsibility of nine different aspects required to fulfill the mission of AGEOCOL, these are memberships, regional chapters, communications, technical contents, logistics, marketing, publications, finance, and The Colombian National Geothermal Meeting (RENAG by its Spanish acronym). Each committee has a leader. RENAG committee is the one in charge of planning and hosting the Colombian National Geothermal Meeting.

All members in AGEOCOL are people working on activities related to research, development, or use of geothermal resources. Paying members receive the status of associate member when registering. Students have a special discount for being enrolled in an educational institution. AGEOCOL welcomes corporate members who support activities, sponsor projects, and have initiatives to develop geothermal expertise. Members who are actively involved with AGEOCOL are granted by the Executive Board the status of Active members which gives them the benefit of being part of the General Assembly, AGEOCOL's maximum authority. Honorary membership is granted to individuals who have provided exceptional services to AGEOCOL or have made significant contributions to the development of geothermal energy in Colombia.

AGEOCOL is actively looking for opportunities and ideas to enrich its members experience by providing benefits, connections, education, etc. Each member is an arm reaching the communities and is priority for AGEOCOL's development.

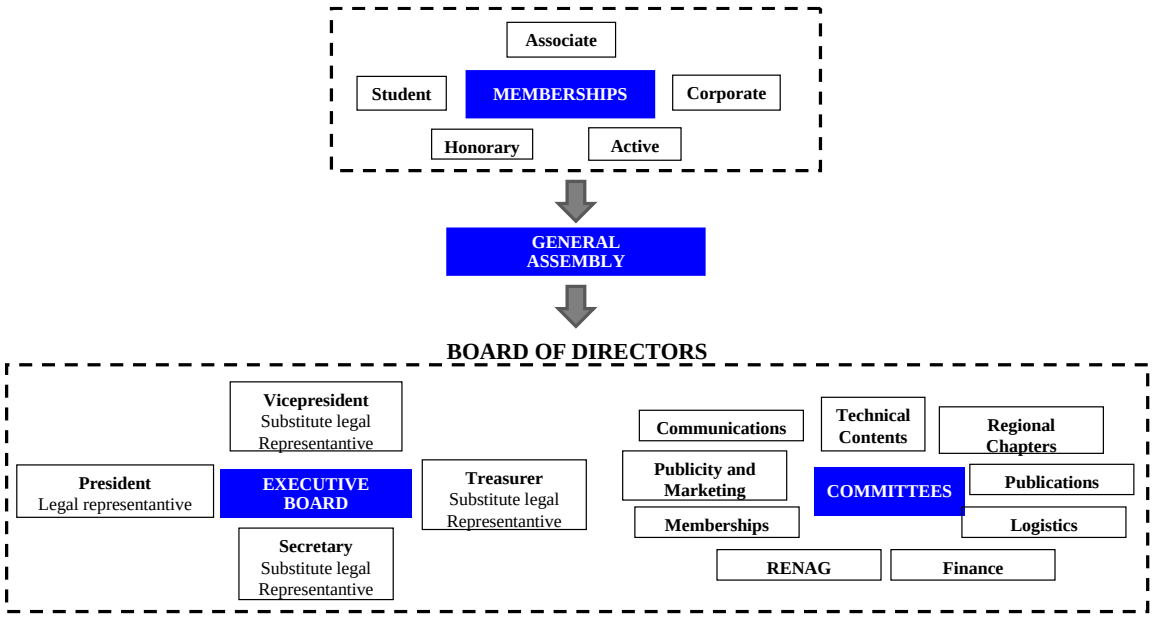

Figure 3: Organizational structure of AGEOCOL 2018-2021.

AGEOCOL's membership was granted as a courtesy to the attendees to the 2017 Annual Geothermal Meeting. Since 2018, the Association has received an increasing number of people interested in joining (Figure 4). Two corporate members have joined with a common interest to use medium temperature geothermal fluids produced by hydrocarbon operations. To date, AGEOCOL counts with over 150 members.

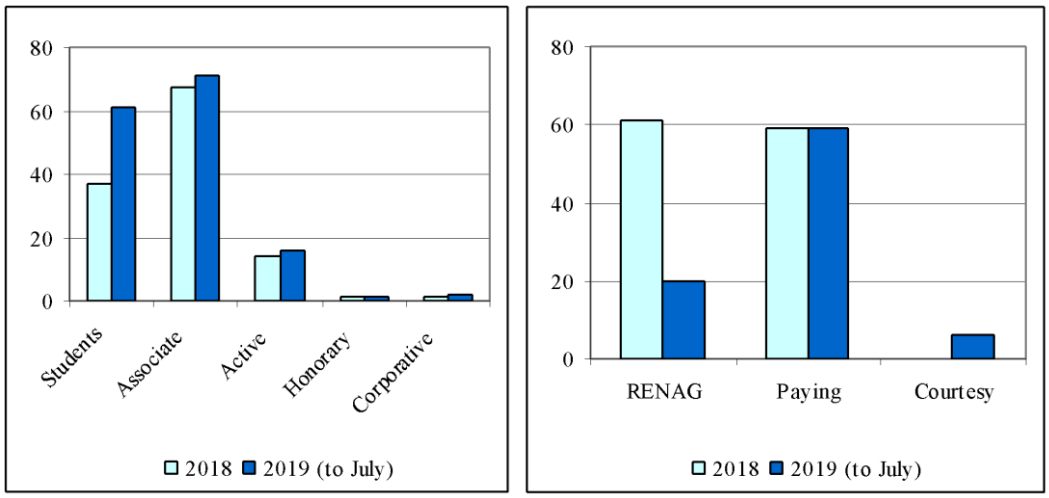

Figure 4: Membership composition of AGEOCOL in 2018 and 2019.

2.3 The Legal Body

AGEOCOL is registered as a nonprofit organization in the Chamber of Commerce of Bogotá, Colombia. To gain legal existence a constituent instrument for AGEOCOL was needed. This required association bylaws, the selection of the Executive Board of Directors and a physical mailing address. Volunteering work in AGEOCOL is inherent to its origin. To produce these documents and fulfill the roles, AGEOCOL counted on people wanting to support another chapter of the geothermal energy in Colombia. For AGEOCOL, this first stage took 2 years.

Following this, AGEOCOL needed new financial settings, which included a Unique Tax Registry (RUT by its Spanish acronym) and a taxpayer identification number (NIT by its Spanish acronym) assigned by the national tax office (DIAN by its Spanish acronym). These procedures may be done personally or through a representative; however, AGEOCOL has assigned legal representation to all members of the Executive Board of Directors for these purposes. Finally, once the certificate of existence was issued by the Chamber of Commerce, a bank account may be opened.

AGEOCOL counted on an exceptional advantage to setting its legal body when using the already existing Colombian Association of Geosciences Students (ACEG by its Spanish acronym). The people participating in the foundation decided to use this association as the base to build AGEOCOL. It saved time and efforts in all this administrative process.

2.4 Collaboration and Cooperation Agreements

Despite being funded in 2018, AGEOCOL has achieved crucial relationships with national and international institutions. By using cooperation agreements (Memorandum of Understanding - MoU), AGEOCOL aims at integrating and converging efforts to organize technical, scientific, and social activities that allow the exchange of knowledge in geothermal energy and the promotion of and adequate use of resources.

In Colombia, AGEOCOL has signed MoU with Universidad de Medellin (UdeM) and Innosulting (a Colombian company of financial consulting). As successful collaboration inside the Colombian territory, it is worth highlighting the work conducted with UdeM, where the research in the geothermal field has been active since 2015. Since then, three research projects have been developed and concluded with excellent evaluations, eight papers have been published in scientific journals, 2 master's degrees have been concluded with *Institut national de la recherche scientifique* (INRS) in Quebec, Canada and Reykjavik University in Iceland, respectively; while one doctorate is ongoing with INRS. These research activities have been conducted with permanent international collaboration through the project "IGCP636 Characterization and sustainable exploitation of geothermal resources" funded by the UNESCO and International Union of Geological Sciences (IUGS) in the context of the International Geoscience Programme (Blessent et al., 2019). The first annual meeting of IGCP636 project held at UdeM in 2016 has been the opportunity for AGEOCOL's director and UdeM researchers to meet. UdeM has been the first Colombian university to consolidate a robust research group on geothermal energy, with organization of symposiums each semester, paper publication, and a strong international network. Since 2017, geothermal symposiums have been held at several universities across the country, with the goal to promote knowledge sharing about geothermal resources.

AGEOCOL are also part of the Iberoamerican Network of Shallow Geothermal (RIGS) established in January 2019 with duration of 4 years and funded by CYTED (Ibero-American Programme for Science and Technology for development). RIGS is a cooperative framework created to facilitate and channel efforts for activities related to research, development, innovation, and exploitation of shallow geothermal resources in the Ibero-American region. It also aims at contributing to the installation, development, and integration of the subsurface energy exploitation systems for productive activities and thermal conditioning of buildings with heat pumps in urban, rural, and industrial scales. Likewise, RIGS carries out a normative and regulatory analysis in Ibero-American countries that results in boosting the use of geothermal resources and allowing their replication in the region. Members of RIGS come from Argentina, Chile, Colombia, Ecuador, Spain, Mexico, and Uruguay. The leader of the network is the IHLL (Instituto de Hidrología de Llanuras "Dr. Eduardo Jorge Usunoff") in Argentina.

International important cooperation has been established with organizations such as the International Geothermal Association (IGA), the Andean Center of Geothermal Excellence (CEGA by its Spanish acronym) from Chile, the Salvadorian geothermal company LAGEO, and the geothermal company Geoindustry from Spain.

3. TECHNICAL EVENTS

3.1 RENAG: The Unique Annual National Geothermal Meeting

RENAG is an annual event carried out since 2016 in Colombia. One of the great achievements of this conference has been that it creates a convenient atmosphere that facilitated 1) the creation of AGEOCOL, and 2) the formalization of cooperation agreements with national and international institutions and companies.

The work methodology chosen by RENAG answers to the values of participation, debate, and effective conclusion of proposed topics. Each of RENAG participants plays an active role within every activity thanks to an inclusive, dynamic, and participatory space. This is the ideal scenario to positively share projects status, advances, and challenges related to the development of geothermal energy in Colombia. The event has been improving year by year, starting with only one day presentations to adding more days and activities such as discussion panels, discussion tables, short courses, and field trips. Discussion panels are carried out at the end of each session and moderated by an expert, who presents prepared questions and moderates doubts and questions brought by the audience to panelists.

The technical programs of RENAG have been mainly around the following topics:

- Update of geothermal energy in Colombia
- Exploration and research
- Legal and regulatory framework
- Education and capacity building
- Direct uses
- High and middle enthalpy geothermal resources
- Financial mechanisms
- Shallow geothermal energy

The first RENAG was held in Bogotá in 2016, with special spotlight on the state of the art of geothermal energy in Colombia and under the theme "Joining Efforts". This event gathered stakeholders of geothermal energy in Colombia from government, academia, industry, public and private institutions, and concluded with a general discussion about the future challenges. In 2017, RENAG was held under the theme "Unlocking our geothermal energy potential" in Manizales near Nevado del Ruiz volcano, which hosts the best known geothermal system of Colombia. In this year AGEOCOL was officially presented. In 2018 and again in Bogotá, RENAG was held with the theme "Bringing together government, industry, and academia to define a road map to 2030 for the geothermal development in Colombia". This meeting saw a high international participation of experts and a regulation workshop that stirred the status of the regulatory framework and clarified the participation of AGEOCOL in this field. RENAG - 2019 is being held in Medellin and hosted by UdeM under the theme "Development to Action".

RENAG has not only brought discussion around Colombia but also contextualized the global panorama of geothermal energy, with the participation of experts from countries such as Canada, Chile, El Salvador, Guatemala, Iceland, Italy, Mexico, Kenya, and New Zealand. For instance, discussions have been upon the challenges, opportunities and solution proposals that the Colombian government must address based on energy demand, environmental protection, and research requirements, and have been supported by international experts.

3.2 Geothermal Symposiums and Short-Courses

Since the mission of AGEOCOL is promoting technical and social activities capacity building for the sustainable use of geothermal resources, geothermal conferences, short-courses, and talks have been organized in the last years in several universities across the country, mainly organized by the leaders of regional chapters across the country, as shown in Table 1.

Table 1: Main academic and scientific events organized by AGEOCOL members.

Held at	Date	Name of the event	Type
Universidad de Medellin	November 2014	Characterization and exploitation of geothermal resources	Symposium
Universidad Nacional, Bogotá	May 2017	Geothermal day	Symposium
UIS	May 2017	Geothermal day	Symposium
EAFIT	May 2017	Geothermal day	Symposium
Universidad de Medellin	June 2017	Numerical modeling of heat transfer in porous and fractured geological media	Short-course
Cali	July 2017	Geothermal resources from a geophysical perspective	Symposium
Universidad de Medellin	September 2017	Second geothermal day: an international vision	Symposium
EAFIT	November 2017	Magnetotelluric exploration	Symposium
Universidad de Medellin	April 2018	Antioquia Geothermal day (inauguration of "Antioquia" regional chapter)	Symposium
Servicio Geológico Colombiano-Bogotá	May 2018	Geothermal day Topics: State of geothermal energy in Colombia, financing, project management and research	Symposium
Universidad del Valle-Santiago de Cali	May 2018	Geothermal day Topics: Energetic matrix, shallow Geothermal and technical-financial evaluation	Symposium
Universidad de Medellin	November 2018	Fourth geothermal day: geothermal and groundwater, a space to learn and share knowledge	Symposium
Universidad Nacional	November 2018 – May 2019	4 talks organized by the Research Group on Volcanology and Geothermics of Universidad Nacional about volcanology, and earthquakes associated to volcanic activity	Talks
Universidad Pedagógica y Tecnológica de Colombia	January 2019	Geothermal day Topics: Research in geochemistry and software development GQ analyzer	Symposium
Universidad de Medellin	February 2019	Course on hydrogeochemistry	Short-course
Universidad Pedagógica y Tecnológica de Colombia	May 2019	First basic course on analysis and hydrogeochemical simulations	Short-course
Universidad de los Andes	May 2019	GSA Earth Day Topic: Geothermal Exploration, direct use in oil fields and financing for geothermal development.	Symposium
Universidad de Caldas	June 2019	Manizales Geothermal day (inauguration of "Eje Cafetero" regional chapter)	Symposium

3.3 Field trips

Field trips are usually organized at the end of each RENAG, to increase the knowledge of Colombian geothermal systems, which are mainly located in remote areas that cannot be easily and quickly accessed by researchers working in other cities. The goal of RENAG field trips is therefore to offer an opportunity to meeting attendees to visit regions of geothermal interest. In RENAG 2017, the Nereidas region, close to the Nevado del Ruiz volcano, was the selected destination, while in RENAG 2018, the geothermal area around the city of Paipa was the goal of the field trip.

Furthermore, five AGEOCOL members attended the Short Course "Reservoir III on Geothermal Reservoir Characterization: Well Logging, Well Testing and Chemical Analysis" held in El Salvador in September 2018 and hosted by the Salvadorian geothermal company LAGEO.

4. FUTURE CHALLENGES OF THE GEOTHERMAL INDUSTRY IN COLOMBIA

One of the goals of the association is to strengthen knowledge in direct uses and support research in the country that allows the development of this type of applications. AGEOCOL believes that shallow geothermal energy is the path for the positioning of geothermal energy in Colombia. Through the RIGS network, this goal may be easier achieved. The first annual RIGS meeting is scheduled in October 2019 in Argentina, and it is a good opportunity for a collaborative work towards this goal, taking advantage of experience in the other participating countries (Argentina, Chile, Ecuador, Spain, Mexico, and Uruguay).

Another task is to build a Geothermal Information Geoportal, whose purpose is to inform the Colombian geothermal community and the public in general about the acquired data and the information processed through research projects led by AGEOCOL, governmental entities (open data), and private companies (agreements). This Geoportal will constitute a repository of information focused on all the edges of Colombian geothermal industry and academia.

During workshops, discussion panels, and conference at RENAG in 2018, the attendees and AGEOCOL members identified five current critical points for the development of geothermal energy in Colombia: 1. quantification of the geothermal potential with known uncertainty, 2. human capacity building, 3. relationship with communities, 4. regulatory framework, and 5. public policies. AGEOCOL signed a declaration towards Colombian society proposing actions to overcome these five main barriers to the development of geothermal energy in Colombia (AGEOCOL, 2018). AGEOCOL proposed strategic actions to work on these points such as coordinating working groups, connecting research institutions to undertake relevant studies, promoting technical training sessions, socializing studies results within the communities, academia, and government, and exploring paths to take part of public policy making. AGEOCOL today is in the position of promoting interconnection between institutions, and supporting the information flow. It provides a platform for technical training and debate and has a base of members from different circles of Colombia's society. Being a volunteers-based association, AGEOCOL relies completely on the active participation of its members in the activities and the leadership to perform the strategic actions. Therefore, maintaining a membership growth, motivating the contribution of the active members, improving the systems of benefits for the active participants are the challenges to be faced.

5. CONCLUSION

In conclusion, Colombia certainly has a promising future in harnessing and developing geothermal potential. Geothermal manifestations and preliminary investigations are indicators of such potential, which is located close to the national electricity grid. The actual potential is still to be quantified, several studies are being conducted with such end.

AGEOCOL, as a nonprofit organisation intends to promote the development and use of geothermal resources. To achieve this, the Association has been established on the bases of volunteering workers who attend the many different areas of need. Its members are at the core of the results and are a prime target for AGEOCOL's administration.

One of AGEOCOL's achievements has been the promotion of cooperation agreements with national and international organizations. The Universidad de Medellin is a prime point for the introduction of geothermal energy into the academia and also a focal point to develop connections with RIGS network to promote the use of low enthalpy resources. Other agreements include national companies (e.g., Innosulting) and international organizations (IGA, CEGA, LAGEO, Geoindustry).

AGEOCOL is committed to building the technical capacity of the country in geothermal energy. This is the reason to organize and support symposiums, short-course, field trips, and RENAG every year. AGEOCOL wants to consolidate as a space for positive discussion, information sharing, and wide support for the different actors involved in the development of geothermal energy.

AGEOCOL faces many challenges to date. Within the association, there is a need to widen the benefits for our members to motivate them to the action. AGEOCOL aims at enhancing the understanding of direct uses and possible applications in the country and consolidating the geothermal information to ease its access and use, and pursuing the strategic actions proposed to cover five critical aspects for the geothermal development in the country: 1) knowledge of Colombian geothermal potential, 2) human resources available, 3) community integration, 4) regulatory framework, and 5) public policy. Any initiative that lead AGEOCOL in these paths is welcome and supported.

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