# OPENING NEW FRONTIERS FOR GEOTHERMAL GENERATION IN COLOMBIA, PERU AND ECUADOR: RESOURCE, REGULATION & CAPACITY BUILDING

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## ABSTRACT

Latin America has an enormous potential for geothermal generation along its Andean Cordillera, but this remains largely untapped and can be seen as the largest global geothermal frontier. At present Chile is leading the way with the Apacheta (Cerro Pabellón) project under development (48 MWe to be commissioned in 2017). Other Andean countries like Peru, Colombia and Ecuador could follow soon.

In 2012 and 2014/15 IRENA and the Geothermal Institute assessed the geothermal potential, regulation and human capacity in 5 Andean countries with the objective of supporting their geothermal development. Much of this information remains unpublished. Other country studies were done in the context of the geothermal Master of Energy program at the University of Auckland. This study combines such information.

The paper will discuss Peru, Colombia & Ecuador on:

- Geothermal resource potential & progress;
- Regulation (resource access, electricity market & renewables support, environmental regulation);
- Human Capacity Building;

## 1. PERU

As Peru served as host of the last Climate Change event (COP20) in 2014, the country demonstrated great support for renewable energy. An example of such commitment is the non-conventional renewable energy law which allowed 4 biannual auctions. These auctions brought Peru to a 4.5% installed capacity of renewable energy with power purchase agreements. Certainly, the development of the Camisea gas field at subsidized cost has promoted growth of gas fired thermal generation and the abundance of hydroelectric power on both sides of the Andes has created an oversupply in the market. Nevertheless, Peru continues to grow and the diversification of its energy matrix to renewable energy could develop the geothermal resource,

### 1.1 Electricity market & renewable support policies

Peru's electricity market is driven by the ambition to become an energy hub for Latin America, thanks to the discovery of Camisea Gas, which has an LNG plant that was commissioned in 2010 South of Lima. In 2015, pipelines are in the process of construction to the south of Peru that will supply gas to future thermal plants and a possible second LNG plant. With growing proven gas reserves, Peru has established interconnections with Ecuador and is in discussions to connect to Chile. Peru uses its gas subsidized domestically to fuel the growth of the country in the last 15 years of a sustained 6% growth Y-o-Y. Even so, Peru faces two challenges. Firstly, the generation of electricity is centralized and close to Lima as per Figure 1. Secondly the lack of rural electrification that slows the growth of the middle class of Peru away from the main centres of development.

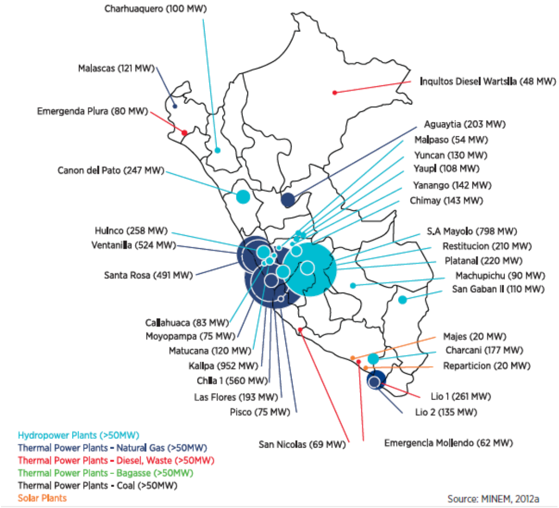


**Figure 1. Existing Power Generation Peru by source (MINEM, 2012)**

Peru has set a law with a target for 5% of the grid capacity to be supplied by renewable energy by 2018 through auctions administered by OSINERGMIN. This is currently on the 4th round in accordance with a biannual schedule, 2009, 2011, 2013 and 2015. With rates from US$60 to US$120/MWh for biomass, from US$100 to US$110/MWh for biogas, US$48 to US$350/MWh for solar, US$38 to US$130/MWh for wind and US$44 to US$75/MWh for hydroelectric energy in the last four rounds for years 2009, 2011 & 2013 and 2015 it offers a competitive environment for electricity on the grid development (NARUC, 2013 and OSINERGMIN, 2016).

Maximum demand capacity continues to grow steadily at 5% having passed 6.7 GWe in 2015. At the same time, additional capacity of renewable energy has grown at 18% of the total additional and committed installed capacity (see table 1).

Due to the (temporary) overcapacity in the system, for geothermal energy to have a future in Peru it will have to compete with a mature industry capable of delivering projects at US$50 to US$75/MWh in the long term, while it will have to compete with US$60 to US$350/MWh of other renewable energy technologies already priced and introduced in the Peruvian market.

| Year | Additional committed Installed Capacity (MWe) | Renewable Energy – MiniHydro-Wind-Solar (MWe) | Percentage of Renewable Energy |
|---|---|---|---|
| 2015 | 926 | 130 | 14% |
| 2016 | 1,828 | 97 | 5% |
| 2017 | 941 | 130 | 14% |
| 2018-2020 | 986 | 508 | 52% |
| Total | 4,681 | 862 | 18% |

**Table 1: Expansion of the Installed Capacity versus Renewable Energy Projects in Peru (Akamine, 2015).**

### 1.2 Resource, ownership and access

Since Peru is located in the Pacific Ring of Fire, a report was prepared in 2012 to produce a master plan to develop the geothermal potential of the country. The Japan International Cooperation Agency (JICA, 2012) report assessed the potential at 2.8GWe with a priority of 640MWe. Despite this large resource estimate not a single exploration geothermal well has been drilled.

By the general law of water, the ownership of water resources belongs to the Republic of Peru and policies are set forth by the Ministry of Energy & Mines (MEM) through the Directorate General of Energy and Environmental Matters (DGAEE). The geothermal law 26848 (1997) defines geothermal resource ownership, concessions and management. The law is managed by MEM and administered by OSINERGMIN. The regulation was last modified in 2013 increasing the geothermal exploration time from 2 to 3 years and defining the 2 different types of exploration concessions: pre-drilling and drilling (see table 2).

By law, companies with concessions are to provide all technical data to OSINERGMIN; the data is then archived by INGEMMET, who is tasked with storing, registering, processing and administering the geoscience data.

| | Duration | Cost | Area |
|---|---|---|---|
| Reconnaissance | Indefinite | 0 | Unlimited |
| Exploration I (Pre-drill) | 2 years (renewable) | 0.001-0.005UIT/Ha equivalent to 6USD$/HA | 20000 ha max |
| Exploration II (Drilling) | 1 year (renewable) | 0.001-0.005UIT/Ha equivalent to 6USD$/HA + Escrow: 1% of application budget, 5% of plant construction budget* | 20000 ha max |
| Exploitation | 30 years (renewable) | 0.001-0.005UIT/Ha equivalent to 6USD$/HA + Escrow: 1% of application budget, 5% of plant construction budget regulatory contribution up to 1% | 1000ha max |

**Table 2: Summary of Regulation: duration, costs and area for geothermal exploration activities in Peru (Akamine, 2015).**

Part of the escrow can be released upon presentation of every 25% of the funds spent on verification of OSINERGMIN.

### 1.3 Regulation of Environmental Impacts

Because of the long history of mining in Peru, the environmental law is mature for mining and large projects. The new law for geothermal energy utilizes the same methodology for environmental assessments to apply for concessions. Nevertheless, issues regarding the lack of technical capability of the geothermal industry, environmental concerns for using laws from different industries and the perceived negative reputation of the quality of environmental assessments for the mining industry could certainly pose some risk that will allow investment to be successful. To solve the issue of technical capabilities and the environmental laws from the extractive industries a new organization National Service of Environmental Certification for Sustainable Investments (SENACE) under the Ministry of Environment was created in 2012. After the government change in July 2016, it was announced that previous responsibilities to certify environmental documents will move from the Ministry of Energy and Mines under the Directorate General of Energy and Environmental Matters (DGAAE) to SENACE.

The negative reputation of extractive industries towards the environmental assessments (Barton, 2015) comes from the possible exploitation of the people who live on the land and although arguments are related to the environmental assessment it is possible that the main issue is a social one. Although there are many examples of companies providing environmental studies to the mining industry, it would be hard to find one with extensive geothermal knowledge.

SENACE has streamlined the environmental process reducing it from an average of 2 years to 7 months and has goals to continue reducing it in the coming years by asking just the necessary information for the analysis and making it transparent in an online system. Geothermal projects would require a preliminary environmental assessment for Exploration Phase II (see Table 2) with a corresponding Declaration of Environmental Impact (DIA) for low impact projects; a Semi-detailed Environmental Impact Assessment (EIA-sd) for moderate impact projects; and a Detailed Environmental Impact Assessment (EIA-d) for high impact projects (MEM, 2013).

### 1.4 Human Capacity Needs and Building

The current landscape for geothermal capacity in the Peruvian government sector includes training from Japan and El Salvador for INGEMMET, OSINERGMIN, MEM, Regional Government and MINAM to the point that they understand the basics of the geothermal industry and use external services for the more complex projects.

Peru has an existing basis of (mining/petroleum) geological sciences and engineering programs, but less than one would expect for the size of these sectors in the Peruvian economy, and little focus or relation to the sector itself. Human capacity building is therefore a challenge because the mining and petroleum industries have forged few links with local training institutes. In fact, the mainly international companies in this sector often focus on in-house expertise building linked to their HQ, creating a level of international job dependence. This can be measured by the number of leading papers written on subjects from petroleum and mining in Peru, by the number of foreigners that come to do the high-level expertise jobs and the lack of local laboratories.

Local universities seem to play a passive role, with no political interest and rather low interest in developing capacities in a technology (geothermal) that is not highly demanded in the country, however they are open to support developing capacities by organizing seminars and workshops with foreign universities/visitors.

At present limited local geothermal capacity exists from the people that El Salvador and Japan trained. Most developers attract their main capacity from abroad.

A national capacity building program would have to be hands-on with a Peruvian project for it to be effective. The project will assure a training ground, a salary for the bet they made and will allow the company to select the highest motivated individuals. A new project would require three types of individuals: administrative support, mid-career technical and fresh-out technical that would need different type of programs (geosciences- engineering, O&M). People in a support administrative role include law, finances, human resources and logistics they will have to learn the differences of the project that would require minimum geothermal energy training. People in a mid-career technical role will need a more directed mentorship program because of the expertise they bring from other Peruvian projects but would need to be coached by an expert geothermal consultant to develop his work plan. The fresh-out technical people will need a program similar to the one offered by the Geothermal Institute[1] and a follow up process with deliverables to keep the learning pace.

A large exploration campaign in Peru of 21 wells in 7 fields would need an organization of about 100 individuals for a 3-year project. The first 6 months includes hiring and contracting of services. The next nine months is the geothermal exploration studies. It would be followed by rig and rig related services contracting and the drilling process. The team would have approximately 20 technical people, 20 support, 25 rig people, 15 rig services, 15 rig support. Though direct employment would relate to 100 people in the industry, the fresh-out training would be around 15 and the mid-career training about 10.

The initial hands-on capacity building could be the training ground for the geothermal development opportunities that this exploration campaign would identify. The capacity building program would not only be class room training, on the job mentoring, but it would also include a series of peer reviewed papers that will put Peru in the radar for geothermal exploration expertise.

## 2. COLOMBIA

Colombia is located in the north-western extreme of South America, working as a connector between the northern and southern hemispheres. In this area, the interactions between the South American, Nazca and Caribbean plates generate a very complex tectonic environment. Three branches oriented in a north-south direction form the Colombian Andes, each one with its own geological and structural characteristics. The volcanic activity, and hence the geothermal potential, is mainly concentrated in the Central Cordillera. Being located on the eastern Pacific zone, the country is subject to naturally occurring climate cycle phases such as El Niño and La Niña.

### 2.1 Electricity Market and renewables support

Due to the topography and population distribution, the electric system of Colombia is divided in the main National Interconnected System (SIN) and the smaller Non-Interconnected Zones (ZNI). The SIN's net effective capacity in 2015 was 16,420 MW distributed between hydraulic (10,892 MW); thermal (4,743 MW, of which gas has 1,548 MW, coal has 1,339 MW, and diesel has 1,247 MW); minor sources, including wind, (698.42 MW); and co-generation (87 MW).

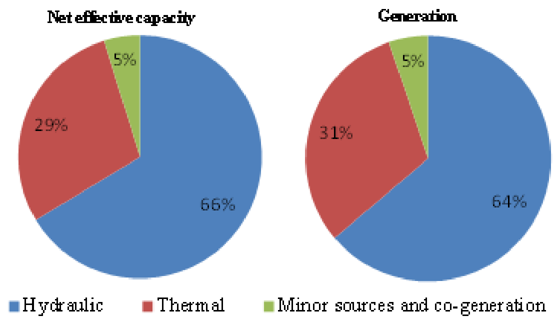


**Figure 2 Colombia-SIN generation & capacity (source XM, 2015)**

The current electric system has evolved since its start in the XIX century. It had a major reform in the 90's, when the National Government restructured the governing entities through the Electric Reform of 1994, aiming to avoid repeating the 1991-1992 rationing of energy caused by El Niño. However, a deficit in the hydric contribution was observed in 2015 causing an increase in the thermal generation and the government intervention in the national energy consumption, i.e., low consumption incentive, to avoid mandatory rationing. The predominance of hydro power still makes the system vulnerable to weather cycles.

The Wholesale Electric Market (MEM) of Colombia includes public and private agents that generate, transmit, distribute and commercialize electricity. It is regulated, administered and supervised by the government as an open, competitive market. As of December 31 2015, there were 56 generation, 12 transmission, 31 operation and 93 registered commercialization companies.

The national government oversees the electricity market. The Ministry of Mines and Energy (MINMINAS) designs the policies through the Mining and Energy Planning Unit (UPME) a special administrative unit with the purpose of planning the sustainable development of the mining and energy sectors. The Commission of Energy and Gas Regulation (CREG) and the Superintendence of Domiciliary Public Services (SSPD) regulate and oversee the agents' participation. The company Expertos en Mercados (XM S.A. E.S.P.) is in charge of market management, operation of SIN, short-term International Transactions of Electricity (TIE) with Ecuador, and the interconnected operation with .

All registered generators participate in the Energy Exchange (short-term) spot market. Dispatch is done on a least cost basis. Generators can also subscribe contracts with commercialization companies, with non-regulated users (those whose demand is more than 0.1 MW or 55 MWh/month), or with other generation companies through (long term) bilateral contracts.

**Renewables Support**

Geothermal power is a specialized sector, whose development requires an adequate flow of capital and technological investments. Although there are not norms specific for geothermal energy, the Law of Encouragement

[1] http://www.geothermal.auckland.ac.nz/en.html

of the Rational and Efficient Use of Energy and the Promotion of Alternative Energies (URE), No. 697 of 2001 and the law 1665 of renewable energy sources that aims at reducing greenhouse gas emissions and recognizes renewable energies, are applicable.

Incentives to promote the development of alternative energy sources include: income tax deductions on income during 15 years (Law 788 de 2002, Art. 18), VAT deduction on machinery purchases (e.g., Tax Code Art. 424, 428) and on investments in scientific and technological development (e.g., Decree 2755/2003); accelerated depreciation of assets, and legal stability for up to 20 years (e.g., Tax Code Art 428f, Decree 2532/2001) (ISAGEN & BID, 2012).

A recent addition is Law 1715 of 2014 which regulates the integration of non-conventional renewable energies to the National Energy System, and regulates, promotes and encourages activities related to produce and use these resources (Alfaro, 2015). Colombia is contemplating an Emissions Trading Scheme to manage its GHG emission obligations in the energy sector.

### 2.2 Resource, ownership and access

Colombia has an estimate of 2,210 MWe of geothermal potential (Battocletti, 1999). Based on the geological, hydro-geochemical and hydrogeological information, the National Geothermal Reconnaissance Study (2012) selected nine areas of geothermal interest for the exploration of high enthalpy resources: 1- Tufino-Chiles-Cerro Negro, 2 - Azufral, 3 - Paipa, 4 - Cumbal, 5 - Galeras, 6 - Huila, 7 - Doña Juana, 8 - Sotara, 9 – Purace. The study recommended the necessity of performing supplementary investigations to verify the interest in the last three areas. The Nevado del Ruiz and Nereidas prospects are in a more advanced stage (upto 190 MWe).

ISAGEN reported in 2014 the end of the pre-feasibility studies in the Nevado del Ruiz, including 3 gradient wells and the request of the environmental license for exploratory drilling. EPM is working in the Nereidas area, updating pre-feasibility studies with the objective of drilling exploratory wells. Operators expect to prove the resources that would give way to the construction and operation of a 50 MW power plant (Alfaro, 2015; Mejía, et al, 2014) .

Colombian natural resources are covered by the National Political Constitution of 1991. It establishes that the State is the owner of the subsoil and the non-renewable natural resources. Therefore, the State has the power to intervene in the exploitation of its natural resources and to plan their administration and utilization, with the purpose of guaranteeing their sustainable development and conservation.

As there is no specific norm for geothermal exploration or exploitation concessions, the National Code of Renewable Natural Resources and Environmental Protection (1974), is the main legal instrument that regulates (among others) water resources in any state, lands, soils and subsoils, and primary energy resources (including geothermal). It established the methods to access the resources by means of permits, concessions, and partnerships. The code was modified by the Political Constitution of 1991, and by the Law 99 of 1993.

Exploration permits may be granted for up to two years, to be extended in force majeure cases. During the valid period of the study permit, permit holders will have a greater priority than other concession applicants, and also exclusive rights to undertake studies. This permit might even include properties or goods whose exploitation rights have already been granted, if another use will be added along with the one that was previously requested by the applicant, provided the studies do not adversely affect the use that was already granted.

Applicants can request exploitation concessions for any renewable resource of the public domain, except if there are legal exceptions, if they had been reserved for special purposes, if they had already been granted to other parties, if they were granted without a studying permit, or if they have been declared resources that cannot be the subject of new uses, based on technical issues. Denied permits can be reviewed based on new studies.

The legal framework for geothermal exploration and exploitation concessions is a subject of current work by the State in order to promote the geothermal power sector.

### 2.3 Regulation of Environmental Impacts

MINMINAS must formulate, adopt, guide and coordinate the policy for activities related with the integral utilization of all the energy sources of the country. Nevertheless, since 1993, the Ministry of Environment, Housing and Territorial Development is the ruling entity for the management of the environment and non-renewable and renewable natural resources, including geothermal. This Ministry must promote the programs to develop non contaminant technologies for energy generation in substitution of the non-renewable natural resources.

Regional Autonomous Corporations (CARs) are legally capable of managing the environment and renewable resources, therefore they grant licenses for the utilization of thermal waters (defined as waters up to 80°C by the National Code of Renewable Natural Resources and Environmental Protection).

The Environmental License, of mandatory application, is the authorization granted by the National Authority of Environmental Licenses (ANLA) for the execution of a project. It implicitly carries all the permits, authorizations and concessions for the utilization and/or affectation of renewable natural resources. It must be obtained before a project starts and will be valid for all its useful life.

### 3.4 Human Capacity Needs and Building

Among the national governing institutes, there are not many geothermal experts. MINMINAS has few experts in power engineering, environmental sciences and financial analysis. UPME has several professionals specialized in energy technology, CREG has experts in electricity and gas sectors, economics, environmental engineering and GIS. ANLA has a pool of lawyers and environmental engineers/scientists, GIS scientists and experts in the energy sector.

The Colombian Geological Survey (SGC – formerly INGEOMINAS) is the national entity dedicated to identifying the potential for natural resources. With a group of 3 specialists in geology and geochemistry, and 5 graduate students, it carries out the inventory and the characterization of geothermal areas to define those with the highest potential. Through recent collaboration projects with ISAGEN it has acquired laboratory and field equipment for geothermal exploration.

Currently, there are two generation companies that are developing geothermal exploration projects: the Public Companies of the City of Medellin (EPM) and ISAGEN S.A. E.S.P. EPM is working in the Nereidas Valley. ISAGEN is working in two geothermal areas: Nevado del Ruiz (feasibility stage) and Tufino-Chiles-Cerro Negro (pre-feasibility) with geothermal experts in geology, but also power engineers, financial analysts and GIS scientists (Mejía et al., 2014).

The National University-Bogotá has been recently involved in the geothermal projects with ISAGEN and SGC and received field and laboratory equipment through this collaboration. Together with the Universidad de Caldas, EAFIT, the National University-Medellin, Universidad de los Andes, UIS, Universidad del Norte, Universidad de Pamplona, and the Engineering School of Antioquia, they offer a bachelor degree in Geology. Few of them offer masters and doctoral programs in Geosciences that people can direct to geothermal. Among the offered subjects that can be applied to geothermal development are: geochemistry, geophysics, mineralogy, structural geology, petrography, tectonics, environmental geology, hydrogeology and volcanology.

Various universities offer also degrees in Petroleum Engineering providing a good input for the petroleum industry but also a good background applicable to geothermal (Universidad de America, National University-Medellin, Universidad Surcolombiana, UIS).

Other careers offered by many universities that could be focused to geothermal development include Environmental Engineering, Laws, Economics, and Mining Engineering.

Although there is still a limited technical capability to develop the geothermal resources, the joint work between the operators (ISAGEN, EPM, CHEC), the government and academic institutions (e.g., National University) started in 2008 to reassess the geothermal potential is strengthening this capacity. Around 40 people from the SCS and industry, professors and students, were trained locally and internationally as required for the projects.

Student groups, ACEG Geotermia, and associations, AGEOCOL, are being created and promoted to encourage the union of professionals and the building of technical knowledge and capability in the country.

Training in the areas of geosciences, engineering disciplines, and legal and economic-financial aspects for the exploration and use of geothermal power resources is still needed.

There is still a need for training. Technical personnel need special conditioning to perform tasks at high altitude where the projects are. The good practices and experience of the mining and petroleum industries, especially in engineering, and management, can be translated and applied to accelerate the geothermal development. The government needs to develop the capacity to oversee and issue appropriate regulations for geothermal projects; to assess more variables relevant to geothermal projects to make them feasible, and to develop strategies to get the community involved in the projects in early phases.

## 3. ECUADOR

### 3.1 Electricity Market & Renewables Support

Ecuador has committed to increase the share of renewable energy through the restructuring of its energy matrix including geothermal energy (Glas, 2014; Orejuela, 2014). It has also ratified its commitment for emission reduction targets through the UNFCCC and the Paris Agreement (UNFCCC, 2015).

MEER is the government institution in charge of planning of the entire power sector, and responsible for renewable energy promotion, while ARCONEL acts as the power sector regulator under MEER (Muñoz et.al. 2015). Figure 3 illustrates the structure of the electric sector in the country. MEER provides the guidelines for the power sector based on the 2008 National Constitution enhancing policies for the environment, energy and productivity sector (Albornoz, 2013; Moya & Kaparaju, 2015). These policies include the proposal to change the Ecuadorian energy matrix and detailed plans to secure energy, the environment and natural resources for future generations (Correa et al., 2012; SENPLADES, 2012).

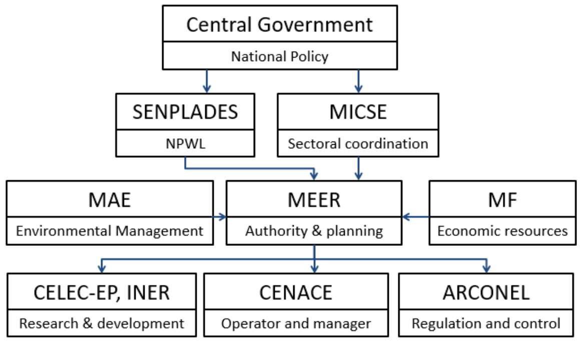


**Figure 3: Ecuador's electric sector structure (Moya, 2015)**

The National Plan for Well Living 2013-2022 (NPWL) establishes the target of reaching 60% renewable energy generation capacity by the end of 2017 (SENPLADES, 2012). Additionally, the Master Plan of Electrification 2013-2022 plans the construction of 25 hydropower projects (4.2 GW), and plans to reach 217 MW between solar, wind and other non-conventional renewable projects (Correa et al., 2012; Muñoz et al., 2015). This strategy seeks to stop relying on fossil fuels for electricity generation, reach a share of 93% of hydropower, 1% of other renewables, and 6% of fossil fuels, and eliminate the imports from Colombia and Peru. Thus, it is clear that hydroelectricity drives the electricity market in the country.

In 2015, MEER elaborated the new Organic Law of Public Electricity Service (LOSPEE – from Spanish translation), which establishes mechanisms to promote the efficient use of renewable sources. The promotion of biomass will have pre-eminence in the source of solid waste. Geothermal energy is also defined as a renewable source to be promoted in the Ecuadorian energy mix (MEER & National Assembly, 2015). Regulation of the National Electricity Council (CONELEC, now ARCONEL) No. 004/11 established a feed-in-tariff for the support of renewable energy projects. These rates were for photovoltaic 40.03 US$¢/kWh, for geothermal 13.21 US$¢/kWh, for biomass 11.05 US$¢/kWh, and for wind 9.13 US$¢/kWh (CONELEC, 2011, 2016). However, this regulation and prices for renewables have recently been eliminated and there are now no incentives or special FIT for this sector.

The national Ecuadorian Electricity Corporation (CELEC-EP), is leading geothermal power development in cooperation with the scientific and technical support of the National Institute of Renewable Energy of Ecuador (INER), (Beate & Urquizo, 2015; Lloret & Labus, 2014).

### 3.2 Resource, ownership and access

In Ecuador only five of the more than 40 active volcanoes have been studied and most of these investigations are currently in the exploration stage. The total resource estimate varies from 3,000 to 8,000 MWe for 20-40 active volcanoes (Beate 2015; Lloret&Labus, 2014).

By constitution, the Ecuadorian State is the owner of its natural recourses (National Constituent Assembly, 2008). The MEER is the governing body responsible for issuing permits for reconnaissance and exploration of geothermal resources in the country. Furthermore, the Organic Law of Water Resources applies to the use of hydrothermal water resources; with the National Agency for Water Issues (SENAGUA) as the body in charge of water resources management (Rivadeneira et.al., 2014), and LOSPEE applies in the electricity generation stage. The regulations for exploration drilling are still not well-defined

### 3.3 Regulation of Environmental Impacts

Ecuador recognizes the 'Rights of Nature' in Art. 71-74 of its National Constitution; establishing that 'Every person, community, people or nationality may require the public authority to enforce the rights of nature. Environmental goods will not be subject to appropriation; its production, delivery, use and exploitation shall be regulated by the state' (National Constituent Assembly, 2008). The Ministry of Environment (MAE in Spanish) is the governing body responsible for issuing concessions, permits and environmental licenses for electricity projects. MAE is also responsible for enforcing the Law of Environmental Management (National Congress, 2004). MAE, by Ministerial Resolution No. 0173, has granted accreditation to ARCONEL as Environmental Authority, allowing them to issue environmental licenses for electricity projects, which do not intersect with the national system of protected areas (Betancourt & Moreno, 2014).

### 3.4 Capacity Needs and Potential

Due to the long history of petroleum exploitation, there are strong schools of geological and petroleum engineering and sciences in Ecuador, incl Central University of Ecuador - School of Geology, Mining, Petroleum and Environment (since 1911), the National Polytechnic School - Faculty of Geology, Mining and Petroleum (since 1970) and the Geophysical Institute (since 1983) as the main research centre in Ecuador for the diagnosis and monitoring of seismic and volcanic hazards (Geophysical Institute, 2016). Hence universities and local private and public oil industry have developed a strong capacity regarding drilling, geology, geophysics and geochemistry.

However, IRENA (2014) found a lack of geothermal specialists in the country. Although the National Geological Mining & Metallurgic Institute (INIGEMM) has strong research lines in geological and geomatics cartography, superficial and underground waters, Geographical Information Systems, Sustainable management of metallurgical and mining resources, INIGEMM does not fulfil any specific function as to exploration and development of geothermal resources. In the academia, the Military Polytechnic School (ESPE), the National Polytechnic School (EPN) and the Central University of Ecuador (UCE) should play a vital role for local development of human capacity for geothermal expansion. However, it is clear that there is not strong interest in doing so. ESPE has developed several prefeasibility studies and master theses related to Geothermal energy, including geomatics topography, geodesy and GIS. EPN and UCE both have vast experience in oil and mining exploration, along with geophysics and geochemistry but no additional postgraduate specializations. A framework seems to be missing. MICSE and MEER possess the authority to establish the framework to do so. Present priorities would seem to be in areas of geothermal exploration: geophysics and geochemistry along with environmental licensing and financing for geothermal projects.

As part of the universities, INER possess the high interest in developing geothermal human capacities followed by CELEC-EP. CELEC-EP is currently building geothermal capacity with strong international support from Iceland-UNU-GTP, JICA and LaGeo (4 professionals currently in training). The Institute of Renewable Energy, INER-MEER, has also been working on the development of local capacities along with CELEC-EP (5 geothermal professionals in 2014 (Beate & Urquizo, 2015).

## 4. SUMMARY & CONCLUSIONS

The Andean region is the largest undeveloped geothermal region in the world. Chile has been leading the way and finally the first geothermal power project (Apacheta – 48 MWe) is under construction to be commissioned in 2017.

Peru, Ecuador and Colombia also have large geothermal potential. Due to different electricity markets and policy/regulation approaches, each is following their own geothermal pathway (see comparison table in Annex-1).

Each country has large potential for (cheap) hydropower, but Peru is now working on FiT/NCRE-auctions in a drive to install/diversify into more (non-hydro) renewable generation.

Geothermal human capacity in the countries is limited. Each also has a large petroleum/gas sector (in contrast to Chile), which can provide a basis for expertise/capacity building. Ecuador also has a good university/training sector for petroleum geology and engineering. Colombia and especially Peru seem to lack this, relying more on imported expertise.

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## REFERENCES


Akamine A; Reducing the risk for geothermal energy investment in Peru; University of Auckland Geothermal Institute - MEnergy Project, November (2015)

Albornoz, E.; The new Ecuador's electric sector (El nuevo sector eléctrico ecuatoriano); Quito (2013).

Alfaro, C.; Improvement of Perception of the Geothermal Energy as a Potential Source of Electrical Energy in Colombia , Country Update (pp. 19–25)- (2015).

Barton, A; A Global/Local approach to Conflict Resolution in the Mining Sector – The Case of the Tintaya Dialogue Table – Thesis Masters of Arts in Law And Diplomacy, Tufts University (2015).

Battocletti, L; Geothermal resources in Latin America and the Caribbean. (1999).

Beate, B., & Urquizo, M. (2015). Geothermal Country Update for Ecuador: 2010 - 2015 *Proceedings World Geothermal Congress* (2015).

Betancourt, B., & Moreno, A.; Estructura del sector eléctrico en el Ecuador (2014).

CONELEC.;. Feed in Tariffs regulation No. CONELEC – 004/11 (2011).

CONELEC.; Regulation of unconventional renewable energy (Regulación of energías renovables no convencionales).- (2016).

Correa, R., Glas, J., Poveda, R., Albornoz, E., Ruiz, S., Muñoz, P., Chávez, A.; Master Plan of Electrification (Plan Maestro de Electrifiaccion) - (2012).

Geothermal Institute, NZAID; Geothermal Capacity Building Study; Ministry of Foreign Affairs & Trade (MFAT), Wellington (2012).

Glas, J.; "El cambio de la Matriz Productiva es para todos los ecuatorianos", manifestó Jorge Glas, Vicepresidente de la República (2014).

IRENA (International Renewable Energy Agency), Geothermal Institute; Capacity Needs Assessment Studies for Bolivia, Chile, Colombia, Ecuador and Peru (2014; unpublished).

ISAGEN, & BID; Notas para la investigación y desarrollo de proyectos geotérmicos en Colombia (2012).

JICA; Japan International Cooperation Agency, & West JEC; The Master Plan for Development of Geothermal Energy in Peru (2012).

Lloret A., Labus J.; Geothermal development in Ecuador: history, current status & future. *Geothermal training programme, 1*(1), 1-11. (2014).

MEER, & National Assembly; Ley Orgánica del Servicio Público de Energía Eléctrica (2015).

Mejía, E., Rayo, L., Méndez, J., & Echeverri, J; Geothermal development in Colombia. In Short Course VI on Utilization of Low- and Medium-Enthalpy Geothermal Resources and Financial Aspects of Utilization. Santa Tecla, El Salvador (2014).

MEM; Ministerio de Energía y Minas; Perú Electricity Subsector – Promotion Document; Lima (2012).

MEM; Ministerio de Energía y Minas; Balance Nacional de Energía 2012; Lima, Peru (2013).

Moya, D., & Kaparaju, P.; *Obstacles and strategies of achieving geothermal energy target of 1000 MW in Ecuador: a techno-political overview.* Proc 37th NZGW (2015), Taupo, NZ; (2015).

Muñoz, M., Lopez-Peña, A., Kieffer, G., Khalid, A., & Ferroukhi, R.; Renewable Energy Policy Brief - Ecuador. (2015)

NARUC: Peru: Public Bid for Renewable Energy, National Association of Regulatory Utility Commissioners; Lima (2013).

National Congress.; Ley de Gestion Ambiental (2004).

National Constituent Assembly; Constitucion Nacional de la Republica del Ecuador (2008).

Orejuela, V.; Perspectivas de la matriz energética de electricidad en el Ecuador (2014).

Osinergmin; Generacion Electrica con Recursos Energeticos Renovables No Convencionales en el Peru, Osinergmin (2014).

Osinergmin;"Perú: Soluciones para un mercado eléctrico de alto crecimiento - Promoción de energías renovables y competitivas" (2016).

Rivadeneira, G., Rivas, L., & Pozo, H.; Ley orgánica de recursos hídricos, usos y aprovechamiento del agua (2014).

SENPLADES; Plan Nacional del Buen Vivir (2012).

Servicio Geológico Colombiano; Investigación y Exploración de Recursos Geotérmicos. Subdirección de Recursos del Subsuelo. Bogotá, diciembre (2012).

UNFCCC.; Ecuador's Intended Nationally Determined Contribution (INDC) - (2015).

van Campen, B. Rai, K: *Geothermal Policy and Regulation - Cases from Chile, Kenya, New Zealand and the Philippines*; Geothermal Institute; *International Renewable Energy Agency (IRENA);* August (2015a).

van Campen, B. Rai, K, O'Sullivan, J; Capacity Building Assessment Methodology; Geothermal Institute; *International Renewable Energy Agency (IRENA);* April (2015b)

XM. Información operativa y comercial, Colombia (2015).

**Annex 1 Comparison table Geothermal in Peru, Colombia, Ecuador**

| | *Peru* | *Colombia* | *Ecuador* |
|---|---|---|---|
| **1. Electricity Market & support policies** | 6.7 GWe installed capacity (2015); mainly hydro and local gas; 5% pa growth rate with subsidized gas prices<br><br>Relatively open power market (prices <US$50/MWh)<br><br>5% NCRE-target 2018 through 'technology auctions' with average 2015 Prices US$ 37 (wind) - US$78 (biomass)/MWh for renewable auctions (no geothermal auctions yet) | 15.5 GWe installed capacity; ca 65% hydro, 35% thermal (gas &coal)<br><br>Liberalized electricity market with firm energy payments. All generators and technologies competing freely.<br><br>Plenty of cheap hydro resources backed up by gas and coal in case of droughts.<br><br>No FiT or NCRE-prices, but growing support for Renewables to meet international GHG emission obligations. Considering an Emissions Trading Scheme | Around 5,2 GWe installed capacity (2016), with 52% hydro generation (down from 72% in 2000). Aim for 60% renewables by 2017 (including large hydro)<br><br>Regulated electricity market with a Master Plan of Electrification<br><br>Separate plans to reach 217 MWe renewables (incl geothermal) by 2022. |
| **2. Resource & Progress; Ownership & Access** | Upto 2.8 GWe.potential, but much high up in Andes remote from demand. 640 MW potentially economic resource (JICA, 2014);<br><br>State ownership with new geothermal law allowing exploration & production by private & international companies.<br><br>High bonds for drilling permission seen as barrier.<br><br>Mainly international developers with many (7+) exploration projects, indicating high temperature resources; no drilling yet<br><br>Present lull in activities. Possible projects with mining sector; | Total Resource Potential upto 2,210 MW (Battocletti, 1999)<br><br>3 projects in (pre)-feasibility stages (ca 190 MWe) by private, Colombian power companies (Isagen, EPM)<br><br>Geothermal resource is state-owned, but regulations (1999) with concessions for private access.<br><br>Regulations being reviewed by the government in light of renewables drive. | Geothermal potential could reach 3,000 MWe to 8,000 MWe 20-40 of the active volcanoes (Beate, 2010).<br><br>Currently, of the eleven prioritised prospects in the PUGR-E only four have reached the prefeasibility studies up to pre-drilling stage (Moya, 2015)<br><br>State ownership with options for private (international) developers, but national CELEC-EP leading geothermal power development. |
| **4. Human Capacity building** | Reasonable base for geological sciences and engineering, but little industry focus.. Strong, existing gas/petroleum sector but few related university/training programmes;<br><br>Questions around strength of universities to set up geothermal programmes. Will need state/donor driver to get momentum going;<br><br>National Geological Survey buildings capacity with help from JICA and LaGeo; other regulatory and environmental authorities would need training support<br><br>Developers could build on geoscience, engineering and drilling experience in the gas/petroleum sector, but also largely controlled by international companies;<br><br>A national geothermal training programme could also be built with hands-on training in conjunction with a national/JV development programme, with training priorities in geosciences, reservoir engineering and drilling; | Limited human capacity in Government. Growing research and practical geothermal expertise in Colombian Geological Survey.<br><br>Several universities have strong geosciences, - engineering and petroleum programmes with a growing interest in geothermal specializations.<br><br>National power companies ISAGEN and EPM are working on 3 as developers and building growing expertise, with support from international agencies like IRENA and IADB. | Long history and good basis for expertise and training in petroleum geosciences, engineering and drilling.<br><br>Universities have the potential, but little interest in setting up geothermal programmes. MEER has regulatory mandate to build a framework for geothermal capacity building<br><br>INER and CELEC-EP are currently building geothermal capacity with strong support from international assistance such as Iceland-UNUGTP, Japan-JICA and El Salvador-LaGeo,<br><br>Present piority areas for training are geosciences for exploration. . |