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Peru: Key Factors and a Comprehensive Approach to Develop its Geothermal Industry

Víctor Vargas[1] & Jackeline Reyes[2]

[1, 2] EDC Perú, 335 Manuel Olguín AV. Office 1301, Santiago de Surco, Lima, Peru.

vvargas@edc.com.pe & jreyes@edc.com.pe

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ABSTRACT

Peru mainly depends of two energy sources to produce electricity: natural gas (fossil) and hydropower of large hydroelectric plants affected by climate change. This energy approach puts the country in a position of vulnerability, more accentuated in the southern zone of Peru where a deficit of almost 500 MW currently exists. The southern region of Peru imports almost 80% of its electricity from the center of the country. This generates energy centralism and dependence on transmission lines that affect the competitiveness of local industries and negatively impacts the life of the population because they pay a high price for electricity.

At the same time, the country has a large potential of renewable resources such as geothermal energy located precisely in the southern region where the power deficit occurs. Several thermal manifestations zones can be observed mainly across the Andes Mountains, but the highest temperature features associated with volcanic activity are located in the southern Peru. In the regions of Arequipa, Moquegua, Tacna and Puno at least eight geothermal fields have been identified with an average subsurface temperature around 220 °C and an estimated potential of 850 MW.

In addition to its strategic location, geothermal energy could provide clean base load due to its high capacity factor (>90% vs. 25-35% for solar and wind) and GGE´s low emissions. Also, this technology is compatible with traditions and lifestyle of the communities of the Andean highlands, because in the geothermal industry the resource is not consumed. Sustainably managed, geothermal projects have a small footprint and allow coexistence with the local communities. The geothermal legal framework and regulation have been recently updated, and the government offers incentives to encourage private developers to participate in exclusive auctions for renewable energy projects. Geothermal energy is the most feasible source to provide clean, renewable and sustainable energy for southern region of Peru, contributing to the diversification of the energy matrix and energy security since it is a baseload, indigenous source.

Despite all these advantages and the need to develop geothermal power plants in southern Peru, why is there still no project undergoing an exploratory drilling phase? Is it not enough that there are good resources and investors to build geothermal plants? What other factors should be considered by geothermal developers? This paper seeks to explain this situation from the political, economic, environmental and social point of view, and recommends specific ways in which key decision makers can unlock the Peruvian geothermal industry.

In that sense, to ensure the successful development of the new geothermal industry in Peru, it is necessary to have a comprehensive approach of the project and implement strategic actions that respond to the critical aspects of the particular Peruvian context. This approach should be performed at an early stage to reduce risks that could affect the success of the project. Also, it is important to articulate all the efforts with the main stakeholders, both the communities and the authorities to guarantee the acceptance and support of this new technology and its inclusion as a feasible energy alternative that contributes in a social, environmental and economic way to the development of the country.

1. INTRODUCTION

Peru is located on the west central coast of South America, bordered by the Pacific Ocean to the west, Chile to the south, Bolivia and Brazil to the east, and Colombia and Ecuador to the north. With a total land area of 1.29 million km^2, Peru is the third largest country in South America after Brazil and Argentina.

Peru has a population of 32.5 million people and is one of Latin America's fastest-growing economies. In recent years, the country has achieved significant advances in social and development indicators as well as in macroeconomic performance, with mining being the dominant sector of the Peruvian economy over the past 20 years. This has resulted in very dynamic GDP growth rates, reduction of external debt, and a stable exchange rate and low inflation being achieved. Peru's fast expansion has helped to reduce the national poverty rate from 48.5% in 2004, to 21.7% of its total population in 2017, while extreme poverty declined from 17.4% to 3.8% over the same period (Ernst & Young, 2019).

Since the early 90s, the country has had continuous economic stability and has been one of the region's fastest-growing economies, over the past decade, with an average growth rate of 4.9% in a context of low inflation. Prudent macroeconomic policies, investor-friendly market policies and the government's aggressive trade liberalization strategies combined to create a scenario of high growth and low inflation. Thanks to its strong macroeconomic performance, the main rating agencies – Standard & Poor's, Fitch and Moody's – upgraded Peruvian sovereign debt to investment grade and currently such credit rating isn't at risk. Peru also benefits from strengths such as the fairly large size of its market and its strong financial sector (Ernst & Young, 2019).

With the development of the economy, energy needs have increased proportionally. Peru has a great potential in sources of energy such as: hydropower, natural, gas, solar, wind and geothermal. Historically, the country has been highly dependent on hydropower and at the beginning of this century natural gas started to be a key player. Likewise, since 2011 Peru started to implement the Renewable Energy Resources (RER) auctions mechanism to promote the diversification of the electric matrix.

The current electrical scenario indicates that the total demand of electricity is still sufficient, but projections from the National Interconnected System Financial Operation Committee (COES in Spanish) shows that from 2021 onwards the generation will not cover the growing demand. In this scenario, it is important that the government starts to promote new efficient power generation, developing and using local energy resources, such as geothermal.

In this paper the author´s objective is to explain this scenario from the political, economic, environmental and social point of view, to analyze the current development status of the Peruvian geothermal industry and identify the main key aspects to unlock it.

2. PERU, A COUNTRY WITH GREAT GEOTHERMAL RESOURCES

Currently, there are around 30 countries in the world that have developed their geothermal resources for power generation, and there is another important number of countries with big geothermal potential. Most of the geothermal developed countries are in The Pacific Ring of Fire, such as Philippines, United States, México and Indonesia.

Tectonic plates trigger volcanic activity in this part of the world, due to magma beneath the earth's crust that rises to the top because of the great pressure it is under, over this long process volcanoes can be formed. The magma is the main heat source under the earth's surface, and this is known as geothermal energy (Pambudia, 2017).

The Andean cycle began in the earliest Jurassic in association with the opening of the Southern Atlantic Ocean. Subduction-related magmatic activity had begun along the west coast of the Northern and Central Andes by at least 185 Ma (Pichowaik et al., 1990). In Peru, the Andes Mountains go along the country, and this is associated with the subduction of the Nazca plate under the South American Plate, that started at least 200 million years. In South America, the volcanic chain, as part of the Andes Mountains, is divided in four zones: Northern Volcanic Zone (NVZ), Central Volcanic Zone (CVZ), Southern Volcanic Zone (SVZ) and Austral Volcanic Zone (AVZ) (see figure 1). The southern region of Peru lies in the CVZ.

The Peruvian flat-slab segment (5-14°S) extends between the south of the eastward extension of the Carnegie Ridge (below southern Ecuador) and the subduction of the Nazca ridge below central Peru **(**Stearn, 2004**)**, magmatic activity has decreased in intensity progressively from north to south in this segment in conjunction with the southward migration of the locus of subduction of the Nazca ridge (Hampel, 2002).

The CVZ includes 44 active volcanic edifices, as well as more than 18 active minor centers and at least six potentially active Quaternary large silicic ignimbrite centers and/or caldera systems (de Silva, 1989a, b; de Silva and Francis, 1991). Likewise, all the geologic evidence such as stratigraphy, structure, magmatism, mineralization and seismicity of the Peruvian Andes are directly or indirectly the result of the subduction process. Further, this process has contributed to the current geological configuration of the country and the genesis of different and various geothermal zones, mainly in the high mountains. As was mentioned before, the magmatic activity is not uniform along all the Peruvian Andes, and according with Fidel, Morche & Nuñez (1997) in Peru there are more than 300 volcanic centers but only seven are active (located in southern regions). The last inventory of thermal and mineral manifestation performed by INGEMMET (Huamani, 2000; Huamani, 2001; Huamani, & Valenzuela, 2003; Steinmüler & Zavala, 1997; Steinmüler & Nuñez, 1998; Steinmüler & Huamani, 1998) have identified more than 500 thermal features along all the country, with the hottest located in the southern region.

Vargas & Cruz (2010) identified six geothermal regions in the country, these are: (a) Región 1 Cajamarca – La Libertad; (b) Región 2: Callejón de Huaylas; (c) Región 3: Churín; (d) Región 4: Central; Región 5: Eje Volcánico Sur; and (f) Región 6: Cusco – Puno (figure 2). In three of these regions specific areas were suggested for geothermal exploration.

The thermal manifestations in the country have three kind of genesis, the first group is related to the geothermal gradient, the second to the presence of active volcanoes and the third group is a mix of the first two. From Región 1 to Región 4, the geothermal systems are interpreted to be low enthalpy with the thermal manifestations having temperatures less than 75°C, mainly neutral and the water features coming from surface reservoirs. In the northern and central areas, the main thermal aquifer for this system is hosted in cretaceous sandstones (Vargas & Cruz, 2010; Sima et al. 2006). Region 6 has higher temperatures manifestations than the previous regions due to the volcanic activity that mainly occurs in the area closer to the CVZ. In the central and western part of this region the geothermal systems are also interpreted as of geothermal gradient origin, hence the geothermal systems are expected to be low and medium enthalpy. The most promissory geothermal region is Eje Volcánico Sur, where active volcanoes as Sabancaya, Tutupaca or Ticsani are located, and is possible to identified hot springs, fumaroles, superheated fumaroles, stem ground areas and geysers reaching boiling temperatures

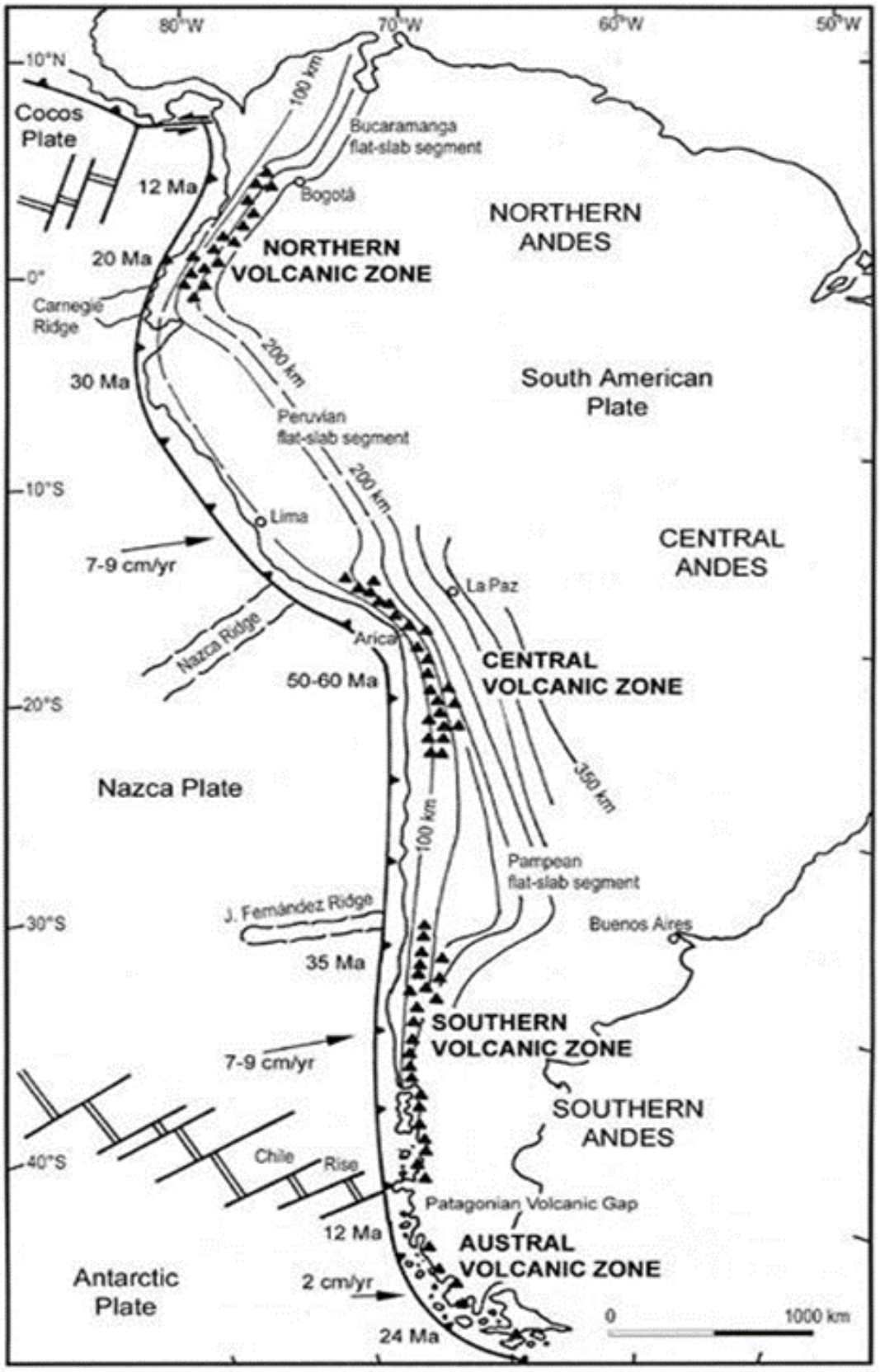

Figure 1: Schematic map of South America and the Pacific oceanic plates showing the four volcanically active segments in the Andes (Stearn, 2004).

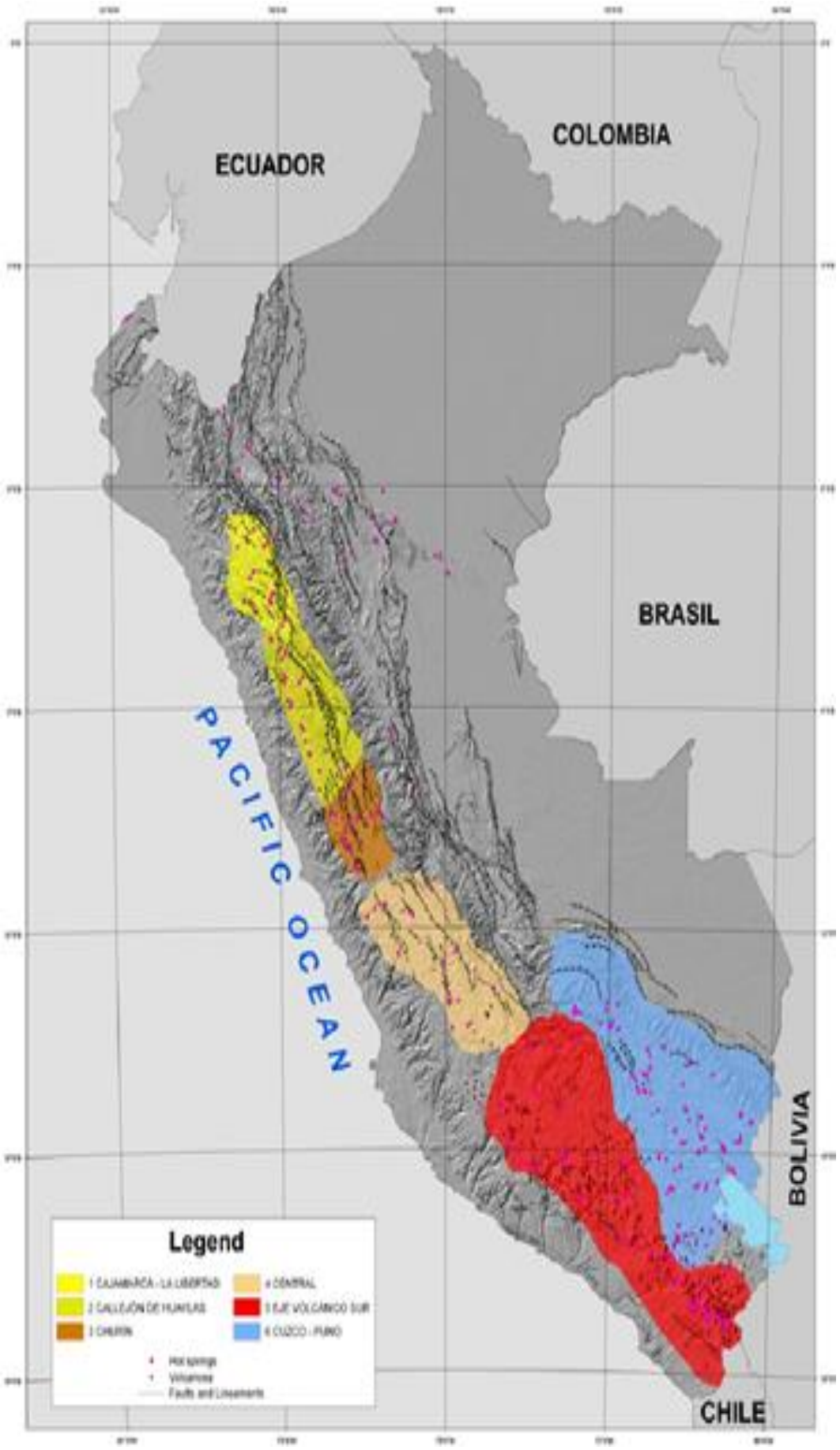

Figure 2: Geothermal Map of Peru showing the geothermal regions defined by Vargas & Cruz, 2010.

In 2012, JICA published the document titled “The Master Plan for Development of Geothermal Energy in Peru”, which is an integral analysis of the energy sector and the possibilities to develop geothermal energy in Peru. This study also includes the technical analysis of 64 geothermal areas along all the country (Figures 3) and establishes a total geothermal energy potential for Peru of 2,860 MW. In the Eje Volcánico Sur the potential estimated is 850 MW (JICA, 2012).

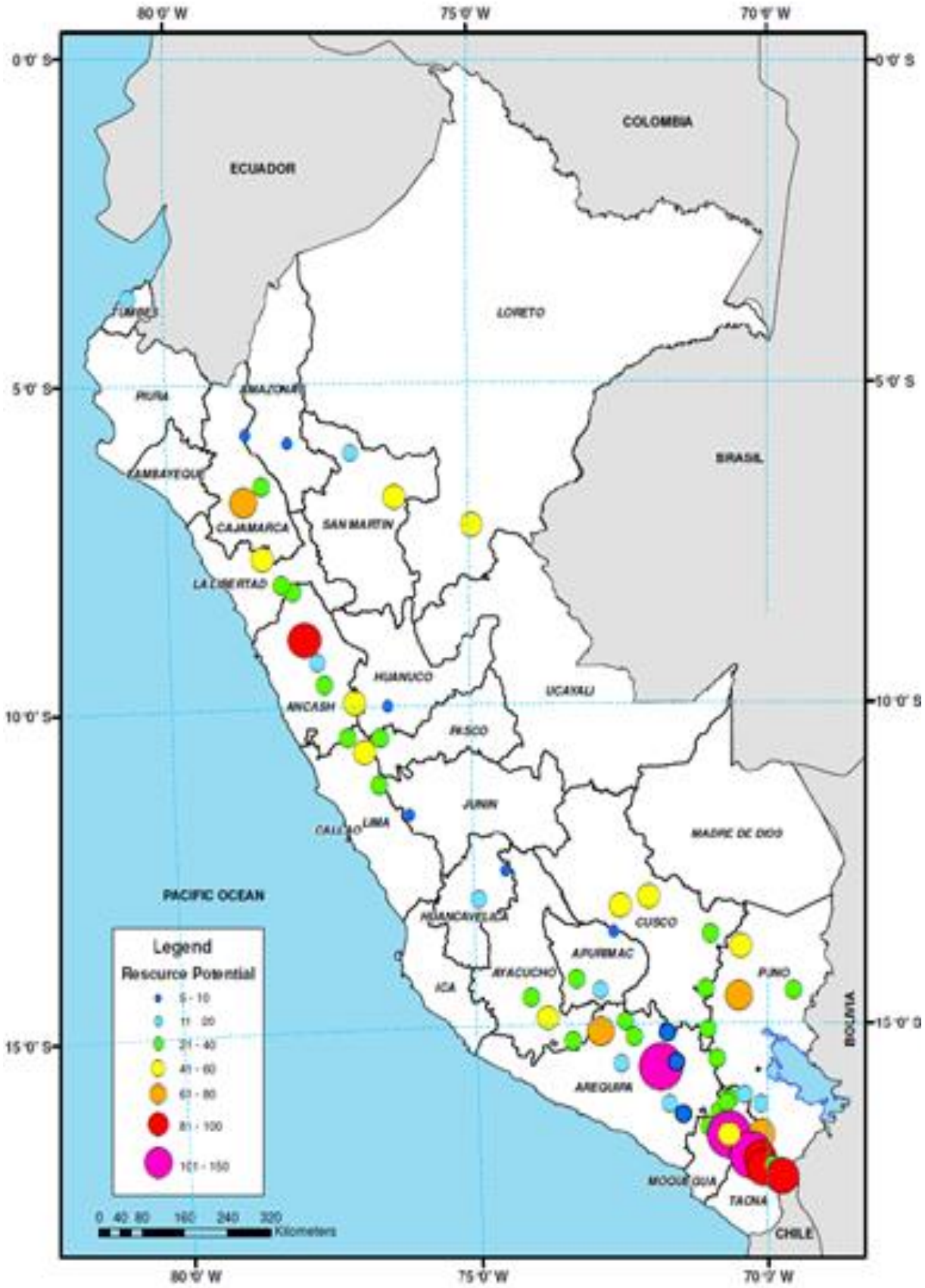

Figure 3: Geothermal Potential Map of Peru (JICA, 2012).

According to the technical evaluation done by INGEMMET, the explorations carried out as part of the Master Plan study and by the geothermal companies, the most promising geothermal fields are: Tutupaca, Chivay, Putina, Calientes, Borateras, Ancocollo, all of them located in the Eje Volcánico Sur.

3. OPPORTUNITIES FOR GEOTHERMAL ENERGY IN THE PERUVIAN ELECTRICAL MARKET

As a result of the continued economic growth of the country, the demand for energy has also increased, according to Espinoza (2017) the total generation supply in 2016 was 12,000 MW while the total demand was only 6,500 MW. Despite this apparent situation of over supply of electricity, the southern region of the country has a generation deficit of 464 MW. This scenario is the result of the centralization of the power generation, where most of the hydro and thermal plants are located in this part of the country causing an oversupply of 3,481 MW. Even the north of the country has a deficit of 172 MW. Due to this scenario, the southern and northern regions are dependent on a vulnerable system where the cost for transmission services is paid by the consumers.

Peru has an energy matrix highly dependent of two main sources of energy, natural gas and hydropower. During the past few years the country has been developing its renewable energy resources such as solar, wind and biomass projects for generating electricity to the national grid. Despite there being no operating geothermal projects in Peru, geothermal is the only renewable energy source that has its own law and regulation, published in 1997 and 2010 -- Organic Law of Geothermal Resources. This law promotes the development of geothermal resources for generation purposes through private companies. According to these regulations the government is not allowed to undertake exploration or development activities.

Likewise, by Legislative Decree N° 1002 the government has declared as national interest the electrical generation with Renewable Energy Resources (RER), "Promotion of the Investment for Generation of Electricity with Use of Renewable Sources". This regulation has allowed diversification of the energy matrix through a mechanism called "RER Auctions", this process is led by OSINERGMIN. Since 2011, the government has implemented four RER Auctions, but geothermal has not yet been included.

Between 2010 to 2015, several companies applied for authorizations to conduct geothermal exploration, and the General Direction on Electricity granted around 30 areas (MEM, 2016), most of them located in the Eje Volcánico Sur. The results were that only a few of these companies finished the surface exploration work, and to date no deep exploration drilling program has taken place. This loss of interest by the private sector is directly linked to the lack of support from the government. For example, the implementation of the fifth RER auction, including geothermal energy was to take place in 2017 but it is still pending. As a result, many companies have shied away from making early stage investments in exploring geothermal.

Overall, the RER auctions have been the most efficient mechanism to diversify Peru's energy matrix. In the last eight years Peru has passed from two to five sources of generation (Figure 4). This mechanism has contributed to the consolidation of competitive development of solar and wind technologies, and is expected to have the same effect for other clean and renewable sources, such as geothermal. In addition, the RER auctions also have contributed to the decentralization of the electrical generation, because almost all the renewable projects are located in the north and south of the country, with other projects expected to start operation in the next few years. This scenario will contribute to the strengthening of local generation in these regions.

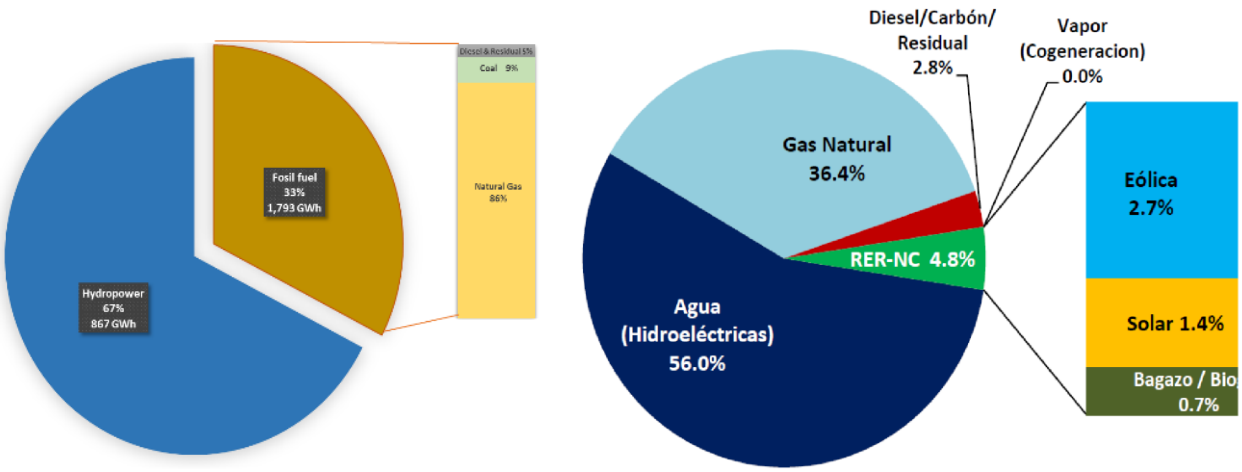

Figure 4: Energy matrix of Peru, 2009 vs 2019 (MEM, 2009 & MEM, 2019).

Geothermal energy represents an opportunity for Peru to continue growing its renewable energy generation using the most efficient sources, contributing to the diversification of the matrix and the decentralization of the generation with a reliable and sustainable energy source (reliable base-load power), mainly in the southern region where the most promising geothermal fields are located.

Aligned to this, in the last few years, some initiatives of local policies have been implemented to accelerate geothermal development in the south. The main are: the "ACUERDO REGIONAL 039-2017-GRA/CR-AREQUIPA", which declares geothermal as a renewable technology of public interest and its exploration and development as a priority for Arequipa region. This document was published on May 2017 and had the support of the Regional Council of Arequipa and the former regional governess. The second initiative was the inclusion of the geothermal development in a regional natural protected area in Tacna (called Vilacota Maure), the region with the greatest potential in the country. This update was published on March 2019 and had the support of the

Environmental Regional Management, the local communities and the former regional governor. Both initiatives are the result of public-private efforts towards the improvement of the political-social scenario, favoring the development of geothermal in Peru.

Finally, it is important to note that in Peru there is no legal framework to regulate the direct uses of geothermal resources. Currently there is legislation only for drinking and recreational uses under the Ministry of Foreign Trade and Tourism, which are the only direct uses that are regulated. This lack of legislation could represent a barrier to the development of geothermal resources, mainly located in northern and central regions where projects for direct uses can be built.

4. SOCIAL ENGAGEMENT AS A KEY FOR THE SUCCESS OF THE NEW GEOTHERMAL INDUSTRY

Social license to operate has become in the last decade a decisive factor for the success or progress of investment projects around the world, due to multiple factors such as the empowerment of social groups, greater access to information and also the bad practices of some industries. Social license is understood as the acceptance of a project within the local community and other interest groups (Wilburn and Wilburn, 2011). In Peru, the absence of this component has generated a scenario of political and social crisis that has impacted our economy. Therefore, it is crucial that the new Peruvian geothermal industry carries out an exhaustive analysis of the social component in order to avoid social conflicts and guarantee the sustainable development of its projects.

Peru is a country with a high rate of social conflicts, which are present because the state, community and private stakeholders have different interests and goals that cause contradictions, lawsuits, and protests occasionally leading to violence. Currently, there are 184 social conflicts (Ombudsman's Office, April 2019) across the country, and 65% of them are related to mining and oil industries. The social conflicts in Peru have produced the loss of more than US$ 62 billion of investment in the last seven years (IPE, 2015), the paralysis of more than 500 thousand jobs per year, and violent confrontations that ended with the death of more than 279 people in the last decade (Ombudsman's Office, 2018).

Social conflicts in Peru have multiple causes. However, there are transverse reasons such as: the dispute over resources (mainly water), the distribution of benefits (tax for exploitation of natural resources, called *canon*, jobs, etc.), and the pollution caused by extraction activities (Ombudsman's Office, April 2019). In addition, we must consider the complex Peruvian social structure, which includes ethnic and cultural diversity, inequality of opportunities, lack of infrastructure, weakness of public institutions at national and local levels, and corruption in both the public and private sectors. For this reason, it is important that the geothermal developer recognizes these social particularities in order to design an adequate social strategy that does not repeat past mistakes.

Also, it must be taken into account that the social conditions of the areas with geothermal potential are characterized by rural population organized into peasant communities that own communal land. Peasant communities are organizations formed by families that inhabit and control particular territories. They are regulated under the General Law of Peasant Communities (Law N° 24656) approved in 1987. Ownership of communal land is recognized by communities based on rights acquired during the Agrarian Reform, implemented in Peru in the decades of the 1960s and 70s. The limits of communal property are agreed between the communities and are not necessarily legally registered, neither are they dependent on administrative municipal political boundaries (district or provinces). Although they are generally not considered as indigenous people, these communities are autonomous and need to be consulted in decisions about the use of their territories by both public and private actors.

The peasant communities have a *Directiva Comunal* which is elected in public assemblies every two years, and is usually composed of a president, a vice president, a secretary, a treasurer, a prosecutor and a vocal. This may vary according to the statutes of each community. All decisions are taken in public assemblies and recorded in the Book of Minutes of the Community and must have the signature of all the attendees and their authorities as evidence of the agreements made (Congress of Peru, 1987).

Given this social context, geothermal developers must communicate and dialogue with the communities before starting any activity in their area. Therefore, obtaining a geothermal authorization from the state does not automatically authorize them to enter communal lands. Working to obtain a social license is as important, or more, than obtaining environmental certification by the state.

Likewise, if we overlap the regions of geothermal potential on the lands of the peasant communities of the south of the country, we will find that within the Eje Volcánico Sur (Vargas & Cruz, 2010), which has the greatest potential of Peru according to JICA, there are 460 peasant communities located in part of Apurímac, Ayacucho, Cusco, Puno, Moquegua, Arequipa and Tacna regions. The level of expectations from this population tends to increase before the arrival of private investment, because, the lack of access to basic services and the high levels of poverty. According to INEI, 21% of the houses of this regions do not have electricity, and 6% and 5% of the population are in poverty and extreme poverty respectively, while 80% are engaged in agricultural activities.

Table 1: Number of peasant communities per region in Southern Peru. (JICA, 2012 & MINAGRI, 2017).

Region	Resource Potential (MW)	Peasant Communities
Apurimac	40	143
Arequipa	497	90
Ayacucho	129	54
Cusco	167	106
Moquegua	415	28
Puno	292	8
Tacna	568	31
Total	**2,108**	**460**

From the cultural point of view, the communities that live in the Eje Volcánico Sur are diverse in languages and customs. Although, Quechua and Aymara are the most predominant local languages in the south of the country, each of them has developed particular dialects in each region. Thus, the Quechua from Cusco is very different from that of Puno, and the Aymara from this region is totally different from the Aymara of Moquegua. And while it is true that most people in the communities now speak Spanish, their mother tongue is still used in important activities, such as rituals and assemblies, and is spoken by community leaders and decision makers.

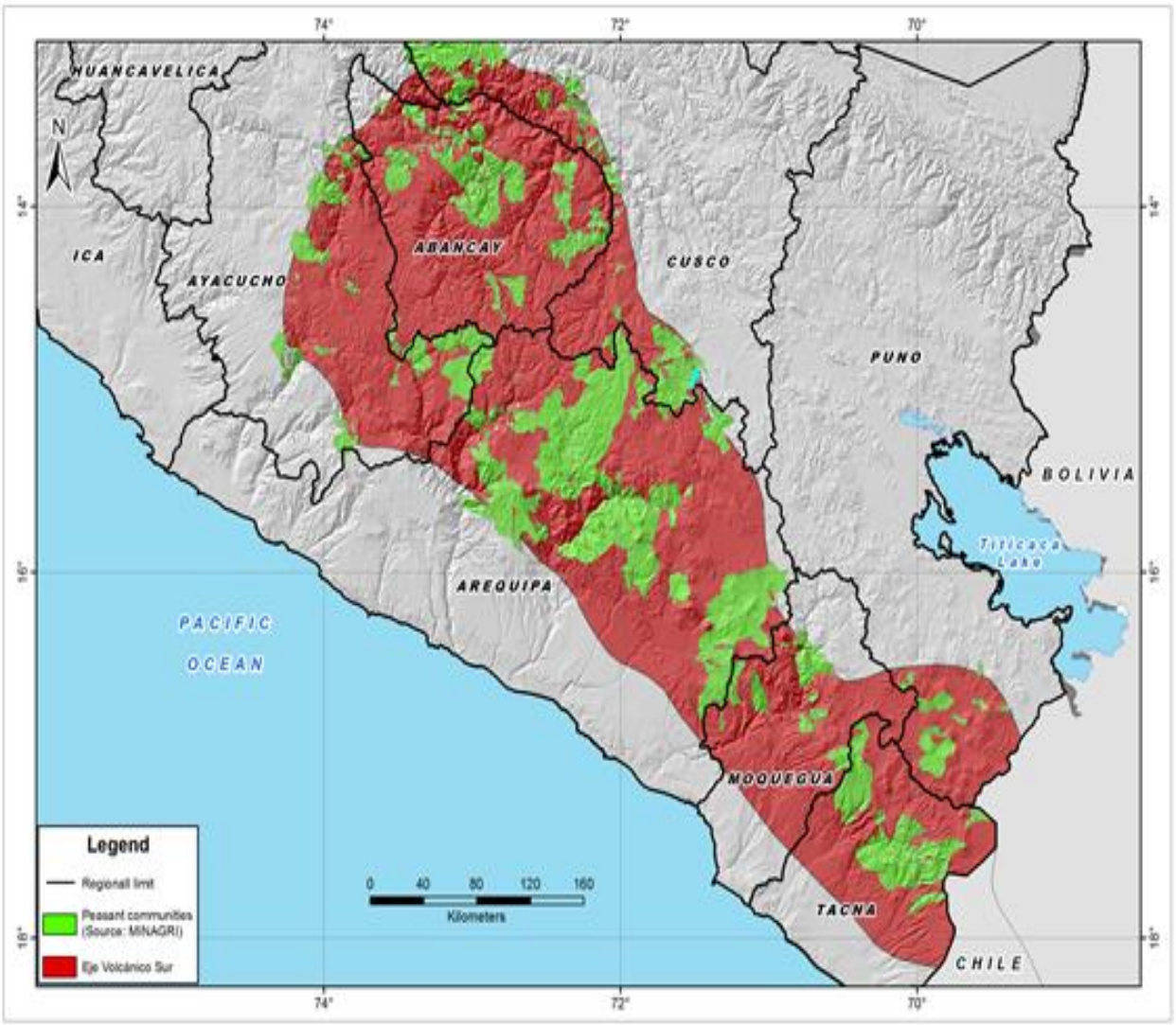

Figure 5: Map of Peasant Communities in Eje volcánico sur. Prepared by the authors with information from Ministry of Agriculture (MINAGRI in Spanish).

Table 2: Percentage of homes with and without access to electric service. Prepared by the authors with information from National Institute of Statistics and Informatics (INEI in Spanish).

Region	With electricity (%)	Without electricity (%)
Apurimac	80.43	19.57
Arequipa	90.27	9.73
Ayacucho	81.35	18.65
Cusco	65.79	34.21
Moquegua	84.29	15.71
Puno	62.96	37.04
Tacna	87.95	12.05
Average	**79.01**	**20.99**

Another aspect to be considered by the geothermal developer is the environmental and social footprint left by other investment projects in the region. Continuing with the example of the Eje Volcánico Sur, where the greatest potential is concentrated in the regions of Arequipa, Moquegua and Tacna, there are 13 social conflicts, 8 of which are related with mining/energy investment projects (Ombudsman's Office, April 2019). This has built a bad image of private companies, generating opposition in the population, because in they assume the companies come to take away resources, abuse people, and leave environmental pollution.

Therefore, the geothermal industry has the mission to build a new image, with different and sustainable practices, and the developer must bear in mind that the company could face a population distrustful of private capital and of foreigners, and thus must be patient in taking time to build strong and sustainable relationships in the long term, based on honesty, trust, fulfillment of commitments and a genuine sense of corporate social responsibility (CSR).

On this last matter, experience teaches us that a philanthropic CSR approach does not contribute to the sustainability of social license, and therefore, to the success of investment projects. On the contrary, the CSR approach must be strategic and planned based on sustainability and according to the needs and expectations of the stakeholders of the geothermal projects and not as a mere marketing or corporate image tool.

Geothermal developers should bear in mind that their projects are located in areas with high levels of poverty and inequality, so their contribution to local development is an ethical but also strategic need for the success of the industry in the country. An alternative is to develop CSR initiatives with the territorial economic development approach that seeks to boost the local economy, by taking advantage of existing endogenous resources in a given territory, creating employment, and local businesses and networks in order to improve the quality of life and welfare of vulnerable populations.

This approach demands a rigorous knowledge of the local stakeholders and of the productive systems and cultural characteristics that govern the territory. This way, strategies based on existing local development policies are articulated and alliances are created with local authorities and organizations so that people become empowered and decide on the path of their own development, in which the company does not become the sole deciding stakeholder, but one more participant at the work table.

Finally, there are features of geothermal generation that can be used in favor of social license, such as its renewable and sustainable nature, or the fact of not depleting the resource but rather recycling it, and returning it to the environment to use again. These are the characteristics that must be communicated and explained in the most didactic methods to the communities in order to find and build shared value based on caring for the environment and respect for Mother Earth.

5. ENVIRONMENTAL STRATEGY: BEYOND PERMITS

While it is true that geothermal energy is a clean and renewable technology, which has been proven over a hundred years for its capacity to improve and to contribute to the environmental sustainability of countries, it should not be forgotten that this industry is new in Peru, a country where environmental issues has been the source of multiple social conflicts.

From the regulator's point of view, the National Environmental Certification Service for Sustainable Investments (SENACE in Spanish), has published a manual identifying eight critical points for the evaluation of Environmental Impact Assessment (EIA) of geothermal power plants. These are: (a) noise during drilling, (b) the impact of the fluid collection and recycling system in the ground, (c) water (availability), (d) gas emissions, (e) groundwater risk pollution due to brine injection, (f) landscape effects, (g) subsidence during exploitation phase; and (h) impact over the geothermal manifestations (SENACE, 2017).

From our point of view, most of these potential impacts can be prevented or mitigated with an adequate baseline, a rigorous groundwater study or the careful isolation of geothermal wells. However, experience teaches us that project developers should place greater emphasis on sustainable water management, since the high Andean areas where the geothermal fields are located suffer from water stress and the communities settled there are mainly dedicated to agriculture and livestock.

While it is true that geothermal projects do not need that much water in the generation process, in drilling activities this is the key resource and its volume will increase according to the number of wells to be drilled. Therefore, it is important to draw up an environmental strategy to prove, both to the authority and to local stakeholders, that geothermal drilling will not negatively impact the availability of water in the basin where the project is located compare with other industries in Peru, like mining or agriculture.

The same applies to the effects of natural geothermal manifestations, such as thermal springs or fumaroles. The geothermal developer should bear in mind that many of these places have tourist and cultural value for local communities and their authorities (figure 6). Moreover, two of the most important geothermal fields in the south are located in special areas of natural or tourist protection. For example, the Calientes geothermal field (100 MW) is within the Vilacota Maure Regional Conservation Area, while the Chivay geothermal field (299 MW) is within the recently created Colca and Volcanes de Andagua Geopark, recognized as the first Geopark in Peru by Unesco (Unesco, 2019).

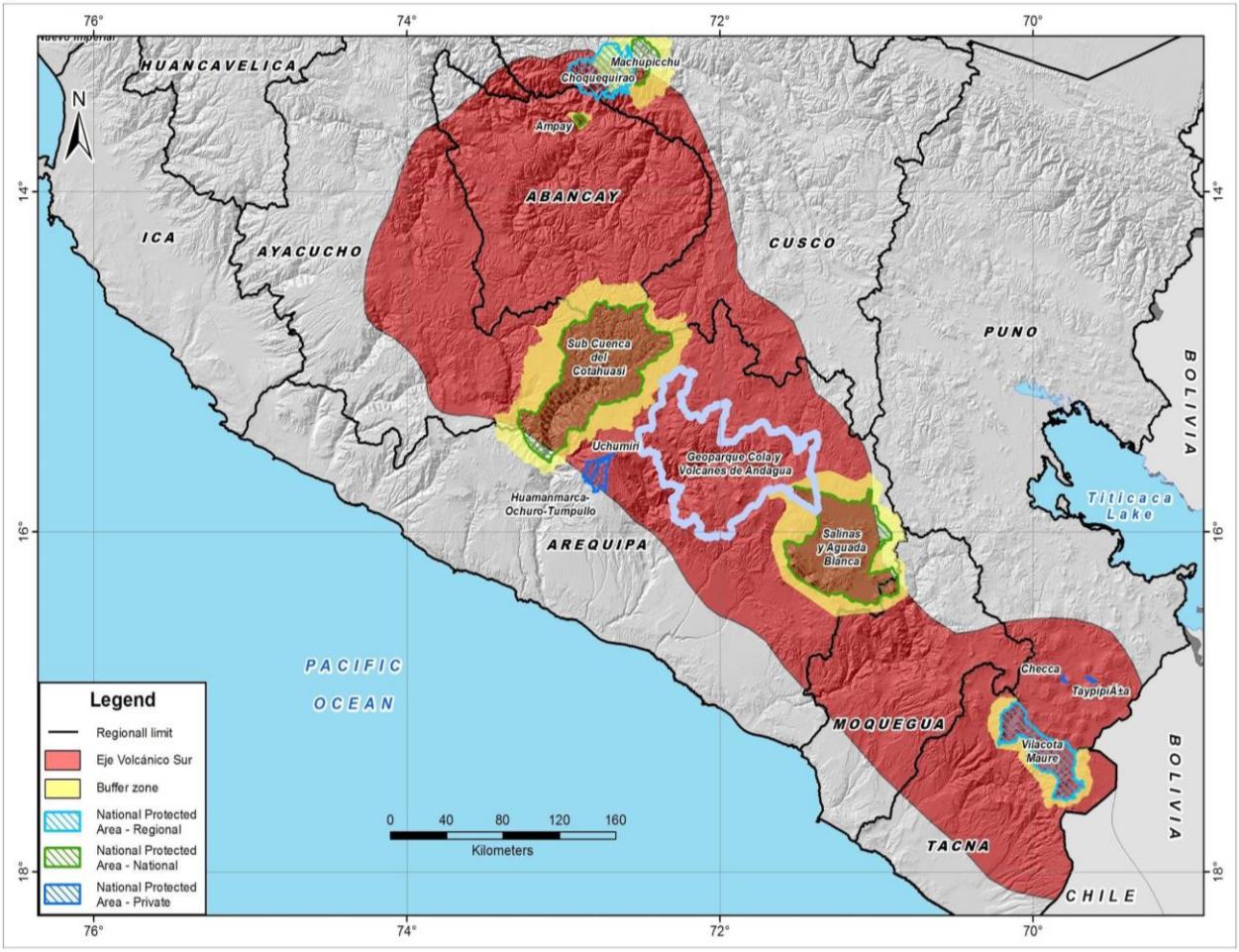

Figure 6: Map of natural protected areas located in the Eje Volcánico Sur. Prepared by the authors with information from National Service for Protected Natural Areas and Peruvian Geological Survey (SERNANP and INGEMMET in Spanish).

Therefore, management and monitoring of the geothermal reservoir is critical in order to avoid the disappearance of geothermal manifestations due to generation activity. Likewise, it is important to develop an environmental strategy that not only guarantees the developer may obtain certification by the state, but is responsible for generating allies to work together for sustainability with, for example, the Ministry of the Environment, the Regional Basin Councils, the managers of natural protected areas, etc.

Finally, an opportunity for the Peruvian geothermal industry is to demonstrate its contribution to the reduction of greenhouse gas emissions agreed by 195 countries in the Paris Agreement signed in 2015. As a country, Peru is undertaking to reduce 30% of its emissions by the year 2030 and has developed a strategy of adaptation and mitigation to climate change in order to reach that goal. According to figures from the Ministry of the Environment, 26% of our emissions come from the energy sector (MINAM, 2016), so that the increase in generation with non-conventional renewable energies could help achieve the percentage of emissions reduction.

In this sense, geothermal energy is presented as an ideal alternative, because not only would it help to produce less greenhouse gases, but it would make possible the development of other renewable technologies, granting the electric system energy security while increasing the renewable mix with solar and wind. Therefore, geothermal energy is not only a *nice* option, it is also necessary because it is impossible to increase renewable generation or achieve 100% renewable energy without providing a base load and reliability to the Peruvian electrical system.

6. RISK MITIGATION MECHANISMS, AN OPPORTUNITY FOR GEOTHERMAL IN PERU

The geothermal industry is not new, it has more than 100 years of development with a global potential of 70 to 80 GW (Bertani, 2009). In 2015 the installed capacity was 12.6 GW (Bertani, 2015) and at the end of 2018, it is estimated at 14.6 GW (ThinkGeoenergy in Pettitt, 2019). Several challenges, including geothermal resource risk, inadequate regulation, high exploration costs, lack of infrastructure, or limited technical expertise, and others, need to be faced by the geothermal industry in countries like Peru. There are also environmental and social issues that need to be addressed for a sustainable development. In this context, it is also important to mention that the most well-known and critical barrier for geothermal development is the high resource risk, which in several cases have stalled the investment in geothermal projects. Reviewing the global experience, the success of the geothermal development in some countries is apparently related to government support (Robertson-Tait, Jayawardena, Berman, & Huttrer, 2015).

Figure 7 shows the conceptual view of all the stages and the risk of each one including the range of capital investments. The highest risk is related to the stage I & II, and the uncertainty is considerably reduced after drilling and testing when the available and commercial resource has been confirmed. Also, in this stage the financial viability for the projects is better determined.

To move forward the geothermal industry, a possible and feasible solution for the critical issues described above, the Risk Mitigation Mechanisms (RMM) includes four main schemes. Robertson-Tait, Jayawardena, Berman, & Huttrer, (2015) and ESMAP (2016) have made a description and comprehensive analysis of them:

6.1 Government acting as geothermal developer

This scheme includes through state-owned enterprises and government-backed entities. The government plays the role of developer, from development to operation of the project. Here, the public sector takes the risk in all phases of geothermal development. It is noteworthy that over 3.25 GW of global capacity is owned by the government. Examples of this are those in Costa Rica, El Salvador, Indonesia, New Zealand, and others.

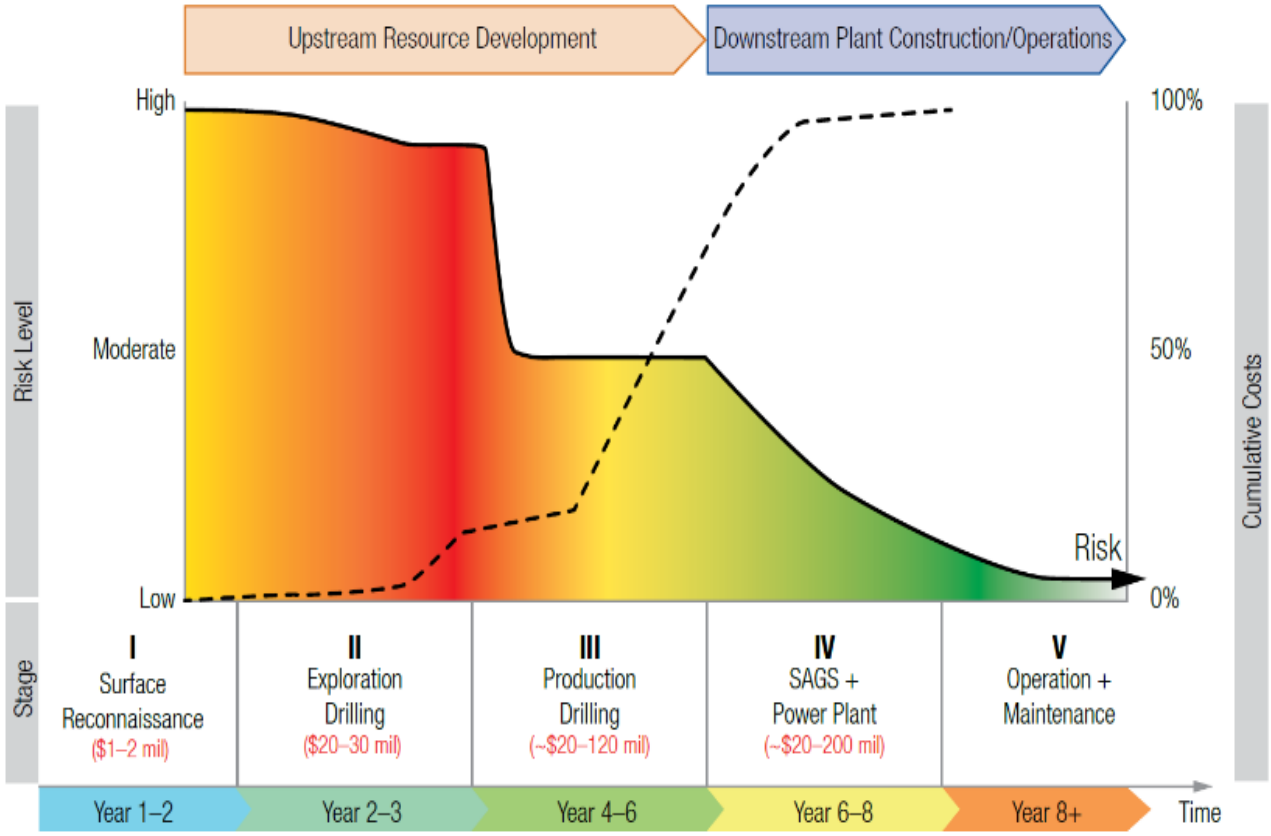

Figure 7: A Conceptual Representation of Risk during the Development Stages of a Geothermal Development (adapted from ESMAP Geothermal Handbook, World Bank, 2012, in ESMAP, 2016).

6.2 Cost-shared exploration drilling

This as a mechanism to mobilize private investment in the drilling phase, where agreements for cost-shared drilling between the government and private companies can also leverage public resources to mobilize private funds. Here, this could primarily be undertaken in two ways: (a) government leads the exploration (before the development) and then transfers the rights to a private company to complete and operate the project; and (b) private companies are responsible for the development of all the stages of the project, but the government share costs of the high risk exploration stage (deep drilling). It has been estimated that around 3.0 GW of geothermal capacity has been catalyzed through different kinds of cost-sharing risk mitigation schemes. Examples of this kind of development can be found in the USA, Kenya, New Zealand, Japan and others.

6.3 Geothermal resource risk insurance

This measure seeks to pool the exploration risks across a portfolio of development projects by insuring the productivity of a well prior to drilling. This way some or all the losses would be covered if certain pre-specified goals are not achieved. This scheme is seldom used, and only a few tens of megawatts have been installed.

6.4 Early-stage fiscal incentives

These are not a specific risk mitigation mechanism, but some incentives can include exemption from duties, tax credits, etc. To help the reduction of up-front cost of geothermal exploration.

Currently, in Peru there is only one Risk Mitigation Fund available, it is called "Geothermal Development Facilities for Latin America - GDF", which has the objective of encouraging public and/or private investment for geothermal power development in Latin America, and the funding is available for the following activities: (i) geoscientific surface studies to determine the optimal location of reservoir-confirmation wells at the most promising geothermal prospects, and possibly include developing complementary studies on the environment or engineering; and (ii) drilling and testing of reservoir-confirmation wells at the most promising geothermal prospects to assist developers in securing financing for subsequent development phases. In the first case, the awarded project will receive a grant of € 600,000 and in the second one, is a loan of € 5,800,000. They are currently in the third call, and only one project in Peru has been awarded with a grant.

According to ESMAP (2016), implementation of any resource risk mitigation scheme should include assessment of the challenges described in the previous sections and take into account the impact of these challenges on the country in the success of the geothermal development projects. In the case of Peru, as mentioned before, the social and environmental aspects are the critical path for many projects, as well as the lack of knowledge about geothermal by the main decision makers in the government.

Finally, it's been observed that 3 of the mechanisms described above are focused on reducing the risk to prove the existence of a commercial geothermal resource through the drilling, but even with a successful drilling campaign, there is no guarantee for the commercial operation of a geothermal project.

It seems that there is a gap in the main objective of the risk mitigation mechanisms, because they directly associate the success of the drilling with the possibility to install a certain amount of MW (i.e. MiRiG in Chile or Risk Transfer Financing Program for Geothermal Energy in Mexico). But, the confirmation of the resource is only the first step. Subsequently, the developer must overcome other critical aspects until reaching power generation. That's why, in the developer's point of view, the risk mitigation mechanisms must help prove a business case to allow the development of the geothermal industry in countries where it is new or is starting (i.e. Peru or Chile). For that reason, it's necessary to articulate and enhance the mechanisms from the drilling to the next stage, analyzing the integrality of the project, and considering other criteria, such as electrical infrastructure facilities, market conditions, the awarding of a PPA, etc.

7. CONCLUSIONS AND RECOMMENDATIONS

Peru has great geothermal potential as shown by the thermal manifestations distributed across the country. In the northern and central regions, it is possible to develop direct uses of geothermal resources, which includes the bath and recreational uses currently in place. The Eje Volcánico Sur is the most promising region for power generation. For that reason, most of the authorizations for exploration were filed and granted in this region. However, no project has moved forward to the deep exploration stage because of the risks associated with the tariff, electricity market, regulation and politics. These have slowed the progress of the geothermal industry in recent years.

An alternative to mitigate the lack of efficient electricity generation that the country will experience from 2021 is to promote geothermal generation in the south of the country, which will also contribute to energy decentralization and system security. In order to have this geothermal development completed on that date, it is necessary to call the fifth RER auction to take place in 2019.

Geothermal developers must build competitive financial models and include advocacy political strategies in their development plans in Peru. Likewise, to articulate the geothermal development with other transversal policies, such as the reduction of greenhouse gases, the development of the vulnerable populations in the regions. That would facilitate the start-up and gain allies in favor of this new industry.

Due to the great impact caused by the lack of a sustainable social license in Peru, the strategies on reasonable and acceptable corporate social responsibility and social management must be considered as key investment to ensure the development of geothermal projects. In order to achieve a sustainable social license, it is recommended to: start a relationship with the communities from an early stage of the projects, design the social strategy taking into account the cultural, demographic and social particularities of the area, build harmonious relationships based on honesty and the fulfillment of agreed commitments, conduct a thorough analysis of social risks, incorporate social marketing strategies to position geothermal energy, and build, in a concerted manner, local economic development initiatives that generate shared value.

Most of risk mitigation mechanisms for geothermal development have an economic and technical approach, but do not include other factors that involve risks for the developer, especially in countries like Peru. Also, these mechanisms can be the trigger to develop a Peruvian geothermal industry, as happened in other countries. It is important to identify not only the risks related to the geothermal resource, but also other risks that impacts the project. Other risks include limited technical knowledge by the implementing authorities, accurate environmental management, social conflicts and social license, and others. So, it is recommended that risk mitigation mechanisms be implemented from an integral point of view, articulating with other financing mechanisms related to these kinds of projects, such as: Green Climate Fund, Sustainable Development Goals Fund, and others.

Finally, global organizations in favor of geothermal energy, such IGA, could carry out advocacy activities in global organizations, such as the United Nations Conference of the Parties, to include geothermal as a key strategy to mitigate climate change and reducing emissions in countries located in the Ring of Fire and other areas with important geothermal resources.

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