Geothermal potential estimation for direct uses in Peru

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ABSTRACT

This paper pursues to present a first estimate of the geothermal potential for direct uses in Peru and the opportunities for its use according to local economic contexts. Although geothermal energy has been studied in the country since the 1970s and has been used since the Inca period (1400), research has been focused only on evaluating its use for power generation. However, we believe that research and future projects for the use of geothermal energy for heating, agriculture, and industry, among other economic activities, represent a viable alternative for environmentally friendly productive projects focused on the territory's local potentialities.

Peru has a very interesting geological context. The presence of the Andes Mountain Range, resulting from the interaction of the Nazca Plate and the South American Plate, has controlled the geological evolution of the territory, from the Mesozoic era to the present. Likewise, several magmatic and tectonic processes have occurred over time that facilitate the development of geothermal regions in Peru, some of which have higher temperature resources and some evidence for high enthalpy, mainly in the south of the country. However, in most of the territory, geothermal resources are of medium and low enthalpy, more suitable for the direct use of heat.

To estimate the geothermal thermal potential, we used the formula proposed by IGA, including data from the hot springs discharge at the surface, included in the inventory of thermal and mineral springs published by the Peruvian Geological Survey and the Estudio de Factibilidad de las Construcciones Balneológicas de Cajamarca y Churín. Information about thermal wells or ground heat was not considered because it is unavailable. Additionally, the analysis used environmental data published by the National Meteorological Service. All this information was analyzed and processed, and finally, 297 thermal areas were grouped to estimate the thermal potential. The estimated potential for the country was 2,000 MWt, and the Eje Volcánico Sur geothermal region has the greatest potential with around 700 MWt.

Additionally, the paper includes information about the local economic context for each geothermal region, as a starting point for the evaluation of future direct-use projects. Finally, we consider it necessary to deepen and update the estimate made to know in greater detail the true potential of the geothermal region, a task that could be assumed with inter-institutional alliances between the state, academy, local governments, and private organizations.

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 (see figure 1). The presence of the Andean Cordillera (Andean Mountain Range) generates a complex territory, with several different conditions. The elevation ranges from cero to more than six thousand meters above sea level; while the morphology and climatic conditions change from desert regions to jungle areas passing through high mountains.

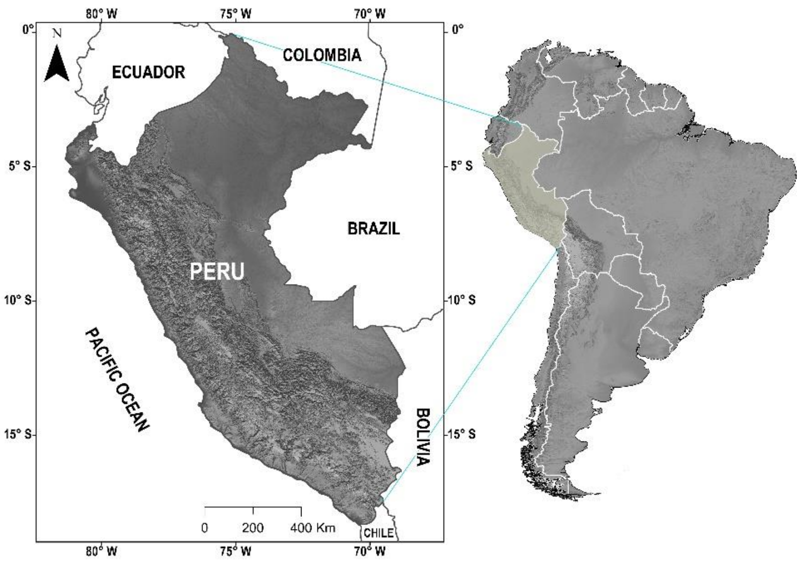

Figure 1: Location map of Peru.

The country is located within the Pacific Ring of Fire, where various geological processes have occurred over time. The subduction of the Nazca oceanic plate beneath the South American plate is the key factor for the formation of the Andes Mountains, and the generation of extensive volcanism, which is currently active in southern Peru.

Various studies and explorations in the field, conducted by government institutions and/or international cooperation agencies, have compiled evidence of the geothermal potential that Peru has. In 2010, the Peruvian Geological Service, INGEMMET (Vargas & Cruz, 2010), identified and classified six geothermal regions, where region five, "Eje Volcánico Sur", is the only one with active vulcanism.

Likewise, one of the most important efforts that integrated a technical, social, and environmental analysis of the possible development of geothermal energy in the country, is the "Master Plan for the Development of Geothermal Energy in Peru", it was a project supported by the Ministry of Energy and Mines and supported by the Japanese government through its cooperation agency called JICA, who published it in 2012. The Master Plan shows the country's total geothermal potential for power generation was estimated at 3,000 MWe. The region with the greatest potential for electricity generation is the "Eje Volcánico Sur", which is in southern Perú throughout the departments of Arequipa, Apurimac, Moquegua, and Tacna, with an estimated potential of 1,600 MWe (JICA, 2012). This planning instrument was socialized at the institutional level, and disseminated with the help of the academy, but unfortunately, no progress has been made yet in its implementation.

Perú has also established a specific legal framework for the development of geothermal power projects and has promoted the investment of private companies in the sector. However, no project has advanced to the exploratory drilling phase.

The direct uses of geothermal energy are not clearly addressed in the existing geothermal legislation and do not have a specific legal framework, but their use, especially for balneology, dates back to ancient times. In fact, many of the country's most famous hot springs facilities are being used since Inca Empire´s time and were probably built in the pre-Columbian period. Additionally, several geothermal manifestations have cultural and social value. For example, volcanoes are considered *Apus* (gods) by the Andean communities; and some hot springs are the scenario of spiritual ceremonies, such as *ayahuasca* in the Peruvian Amazon region.

But can geothermal resources in Peru be used for other activities beyond power generation and balneology? So far, no research has been carried out on the geothermal potential for direct uses, such as heating, food drying, pasteurization, and others. Therefore, the objective of this paper is to estimate this potential, starting by considering the naturally available discharge of hot springs, and evaluating the possibilities of geothermal direct use based on the economic activities that are currently present in the different geothermal regions.

2. LEGAL FRAMEWORK FOR GEOTHERMAL DIRECT USES

Peru does not have a specific legal framework for geothermal direct uses. However, geothermal power generation, the use of thermal water for tourism purposes, and the use of water resources (without specifying their temperature) are contained in the regulatory framework of 3 sectors:

2.1 Energy and Mines

The associated laws and regulations are:

- Law N° 26848, "Ley Orgánica de Recursos Geotérmicos" (1996).
- Supreme Decree N° 019-2010-EM, "Reglamento de la Ley Orgánica de Recursos Geotérmicos" (2010)
- Supreme Decree N° 037-2016 EM, last modification to the geothermal regulations (2013)

2.1 Tourism

In the past 30 years, several regulations for touristic activities have been published, including aspects associated with thermal springs, but only for their specific use for balneology or drinking water; these are:

- Law Decree N° 25533 "Otorgamiento de licencia para el uso de las fuentes de Aguas Minero-Medicinales y el control de su explotación con fines turísticos es de competencia MICTI (hoy MINCETUR)"
- Supreme Decree N° 005-94-ITINCI, "Reglamento de Aguas Minero-Medicinales"
- Supreme Decree Nº 015-2005-MINCETUR, "Modificaciones al Reglamento de Aguas Minero-Medicinales"

2.1 Agriculture

In 2009, the Ministry of Agriculture of Peru, through the Water National Authority, updated and published the water regulation. In these regulations there is a reference to thermal waters but not a specific definition:

- Law N° 29338, "Ley de Recursos Hídricos"
- Supreme Decree N° 001-2010-AG, "Reglamento de la Ley de Recursos Hídricos"

3. GEOTHERMAL DATA GATHERING AND METHODOLOGY

Currently, the country has few studies on the direct uses of geothermal energy. INGEMMET has published an inventory of thermal and mineral springs, with information on location, temperature, chemical composition, and sometimes flow, but these are only surface data. However, this inventory contains the most complete database to date and has been used as the main reference for this paper.

3.1 Methodology

To estimate the thermal potential of hot springs, we used the following equation, as applied in a similar study by Conti, et al. (2015).

$$P_{th} = m_A * c * (\underline{T}_A - T_0) \quad (1)$$

Where:

P_{th} is the nominal capacity of the system, MWt
m_A is the nominal flow rate from the production system (springs), kg/s
c is the specific heat of the geothermal fluid, MJ/kg.K
$\underline{T}_A$ is the average temperature of the fluid from the production system, °C
T_0 is the reference temperature to evaluate the geothermal content supply fluid, °C

In this work, T_0 has been defined as the average ambient temperature, calculated at the regional level considering the elevation and geographical location (northern, southern, or central part of the country, and mountain, jungle, or coast conditions). No geothermal contribution has been assumed to exist when the surface water discharge temperature is below the average ambient temperature for each area.

3.2 Geothermal and environmental data

3.2.1 Hot spring data

The hot springs data used for this study come from the INGEMMET's National Inventory published between 1997 and 2003 (Huamaní, 2000; Huamaní, 2001; Huamaní and Valenzuela, 2003; Steinmüler and Huamaní, 1998; Steinmüler and Nuñez, 1998; Steinmüler and Zavala, 2003).

Additionally, for the Baños del Inca and Churín thermal areas, we have considered the data from the "Estudio de Factibilidad de las Construcciones Balneológicas de Cajamarca y Churín" (AQUATEST, 2007).

All these data have been reviewed and screened according to the following criteria:

- To calculate the nominal capacity, all the springs with data of temperature and flow rate have been considered. Springs without any of these parameters were excluded.
- In thermal areas represented by a cluster of springs, the flow rate was calculated by adding the value of the individual springs, while the temperature value used was calculated from the average temperature of the total number of springs.
- When the value of temperature or flow rate is indicated as **greater than (>)** or **less than (<)**, the value used was the number indicated before the sign.
- The original flow rate is expressed in liters per second, but for the purposes of this paper, we have considered its equivalent in kilograms per second.
- The original temperature is in Celsius degrees, but for the purposes of this paper, we have considered its equivalent in Kelvin degrees.
- Springs with a flow rate value less than 1 l/s (or 1 kg/s) have been excluded from this assessment, because of their marginal potential for geothermal direct-use applications. No geothermal contribution has been assumed to exist when the flow rate is below this value in each thermal area.

3.2.2 Ambient temperature data

The environmental temperature has been taken from the SENAMHI (National Meteorological Institute, https://www.senamhi.gob.pe) statistics for a period of 25 years, from 1995 to 2019. The INGEMMET's hot springs national inventory and the studies on the Cajamarca and Churín thermal areas were carried out within this time frame.

Analyzing the minimum, average and maximum values of temperature, and the changes according to the altitude, we considered for the Andean areas a reference average temperature of 12.6 °C, and for the jungle areas 24.4 °C. There are no hot springs located in coastal areas.

3.3 Processing:

To estimate the thermal potential of the hot spring discharges, we have processed and filtered the database and identified for each geothermal region the corresponding environmental temperature. Here, we have the main highlights of this process:

- The initial data used from INGEMMET´s inventory and the "Estudio de Factibilidad de las Construcciones Balneológicas de Cajamarca y Churín" includes 542 thermal manifestations.
- For the purposes of this paper, we have defined a "thermal area" as a specific zone that includes a cluster of hot springs that may be attributed to a single underground source.
- After data analysis and processing, 297 thermal areas were selected for the estimation of thermal potential.
- A theoretical nominal capacity (thermal potential) was calculated using the data of the 297 thermal areas, which includes all flow rate discharge values (> 0).
- The potentially usable capacity was then estimated considering only the thermal manifestations whose flow rate is more than one liter per second.

4. ESTIMATION OF THERMAL POTENTIAL FROM HOT SPRING DISCHARGES

The estimation of the thermal potential is hereafter presented according to the 6 geothermal regions identified for Peru (see figure 2). To understand the origin and characteristics of the thermal activity, the geological and geothermal background is also briefly discussed for each region.

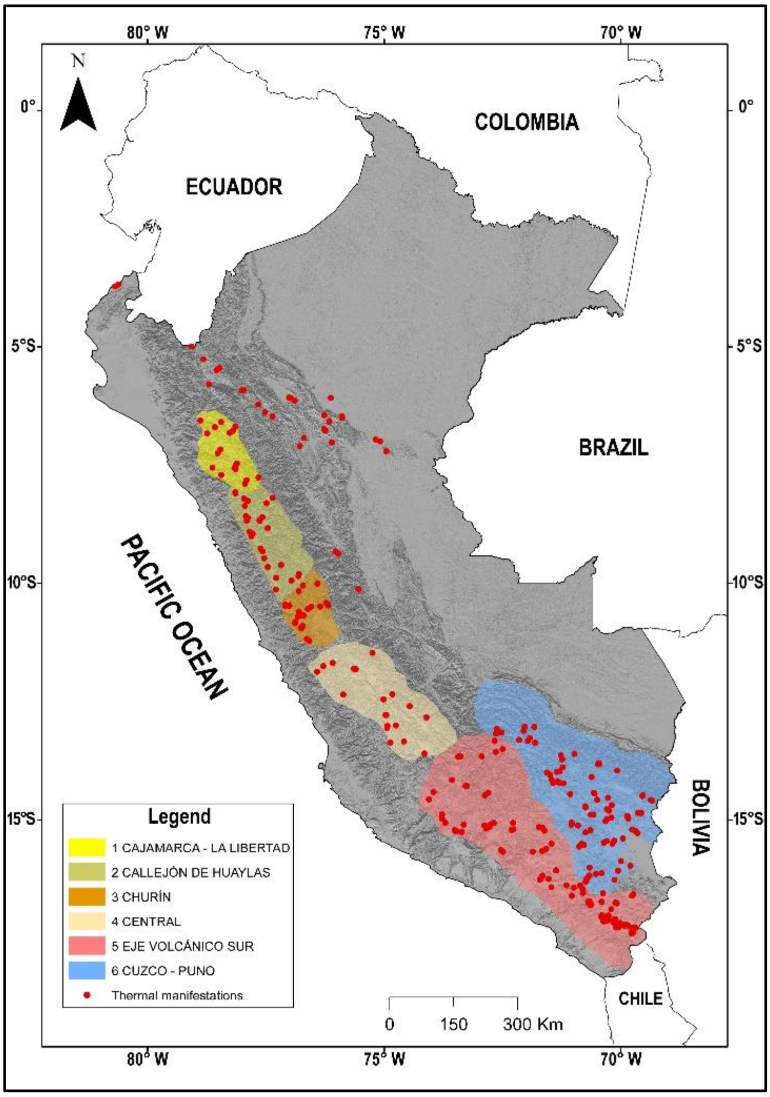

Figure 2: Geothermal Map of Peru (Adapted from Vargas & Cruz, 2010)

4.1 Geological and geothermal background of the country

Most of the power generation with geothermal resources has been developed in countries located along The Pacific Ring of Fire, such as the Philippines, United States, Mexico, New Zealand, and Indonesia, while the development of geothermal direct uses occurs in those same countries but also in other regions all over the world.

In Peru, the tectonic plates trigger volcanic activity, due to magma beneath the Earth's crust that rises toward the surface because of the great pressure it is under, over this long process volcanoes can be formed. Magma is one of the main heat sources 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).

The Peruvian Andes comprise a set of mountain ranges emplaced between the Peruvian-Chilean Trench and the Amazon plain. All the stratigraphy, structure, magmatism, mineralization, seismicity, and thermal phenomena that occurs in the Andes are directly or indirectly the result of the subduction process which at least started in the Jurassic age.

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 geodynamic process that occurred in Peru has developed in two periods clearly identified by the various geological events that occurred in them. The first one was during the Paleozoic, and the second one was with the evolution of the Andean Mountain range during the Jurassic.

Currently In South America, the volcanic chain, as part of the Andes Mountain, is divided into four zones: Northern Volcanic Zone (NVZ), Central Volcanic Zone (CVZ), Southern Volcanic Zone (SVZ), and Austral Volcanic Zone (AVZ) (see figure 3).

Additionally, it is important to remark that in the Northern and Central regions of Peru, volcanic activity ceased 8 million years ago (Marocco, 1980) when the subduction angle started to be more horizontal, forming what we know as the flat-slab segment. Furthermore, the extensive Quaternary volcanism allows the presence of anomalous high heat flow mainly in the southern part of the country, where several thermal surface manifestations such as hot springs, mud pools, fumaroles, and steam sources can be observed.

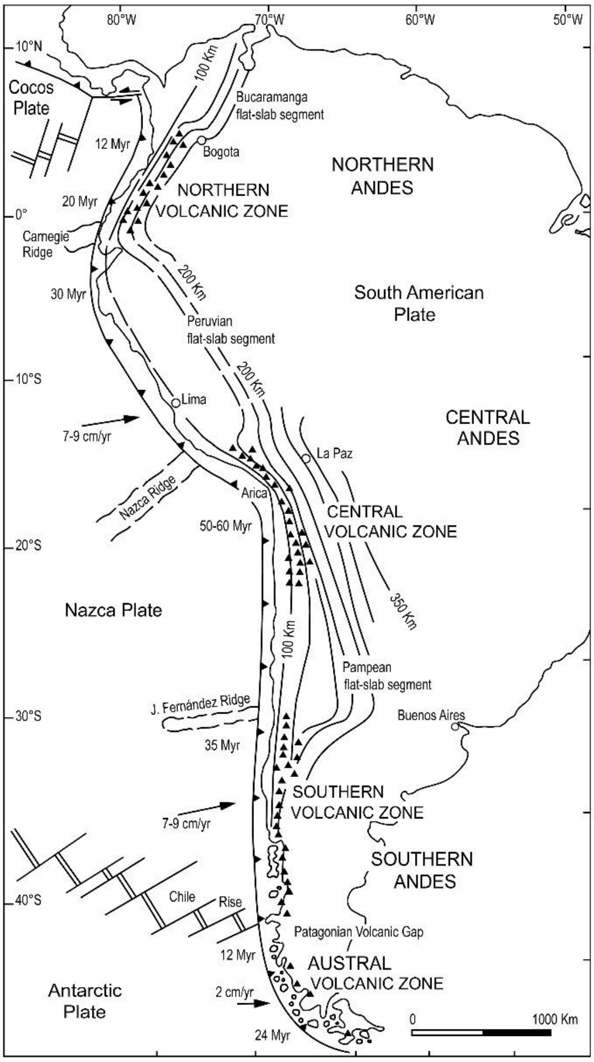

Figure 3: Schematic map of South America and the Pacific oceanic plates, showing the four volcanically active segments in the Andes (Stearn, 2004).

4.2 Geothermal Regions Background and Context

4.2.1 Cajamarca – La Libertad

a. Geological Context

This geothermal region is located in the North of the country and covers approximately 17,668 km^2. It extends through two departments: the southern part of Cajamarca and the northern part of La Libertad and includes around thirteen provinces.

Geologically, the Andean northern cordillera is mainly composed of upper Jurassic – Cretaceous sedimentary rocks deposited in a great NW-SE depression called Cajamarca Basin, described by Benavides (1956) and Wilson (1963). This basin is bounded to the east by the Marañon Geoanticline and to the west by the Olmos Arc. A sequence of Tertiary volcanic deposits (Calipuy Group) unconformably overlay the sedimentary basin and the overall complex is strongly fractured due to the Andean tectonic activity. There is no active volcanism.

In the Cajamarca – La Libertad region, around 20 thermal areas, with the presence of hot springs, have been identified with temperatures between 25°C and 75 °C (see figure 4). All over the region, the hot springs are linked to circulation along deep faults where the temperature of water increases as a result of the geothermal gradient, and in some cases, this deep circulation is favored by lithological control. Several thermal sprigs come from thermal aquifers with good porosity and permeability, mainly constituted by quartz sandstones (see figure 5).

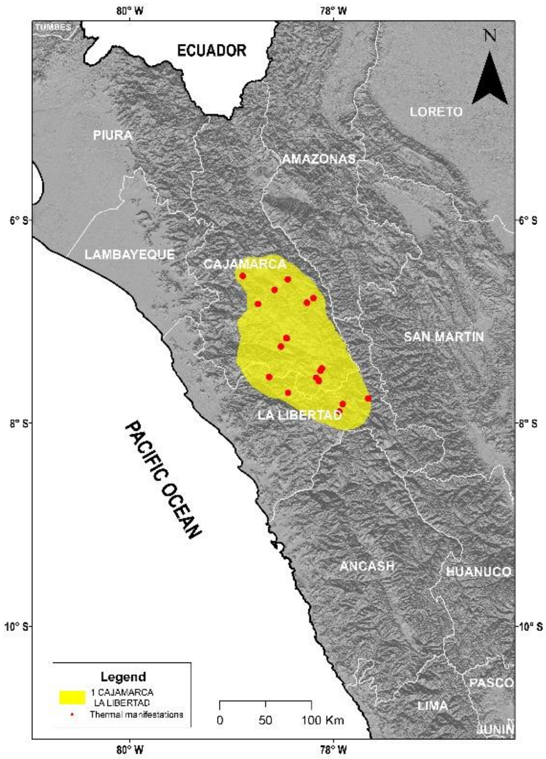

Figure 4: Thermal manifestations in Cajamarca – La Libertad Geothermal region.

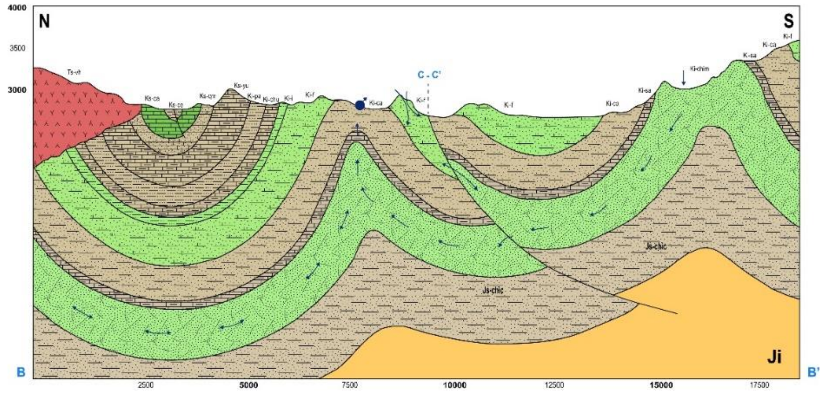

Figure 5: Hydrogeological section in Baños del Inca (Cajamarca) springs (Aquatest, 2007).

b. Local economic characterization

Though this geothermal region extends over the departments of La Libertad and Cajamarca, 80% of the hot springs identified in this paper are located in Cajamarca, so we will focus on the characterization of this department, with the aim of knowing the economic context and local policies that can facilitate or provide opportunities for the future development of geothermal direct use projects.

In Cajamarca, the departmental productive structure is mainly defined by mining and oil activity[1], which presents the highest percentage (15.3%), according to the calculation of the Gross Added Value (GVA), carried out by the INEI. After that, comes the agricultural sector, with 13.1%; and, in third place, the construction sector with 10.7%.

Regarding the mining sector, Cajamarca stands out for the exploitation of gold (the department has the largest proven and probable reserves of this mineral at the national level) and, to a lesser extent, copper (BCR, 2021). Currently, there are more than 5 metallic

[1]The INEI groups one of the economic activities as "Extraction of Oil, Gas and Minerals". However, not necessarily all departments have activities related to the 3 types of resources simultaneously. For example, in one department only mining can be developed, but in the INEI categorization, it will appear as mining and oil.

mining operations in the department, located at more than 4,000 meters above sea level, where temperatures can drop below zero at night or in the coldest winter days. Many of these mining operations are located close to thermal areas (see figure 6), thus there are opportunities for the development of geothermal heating projects to improve the comfort of the mining facilities and reduce the emissions caused by natural gas or diesel-based heating systems.

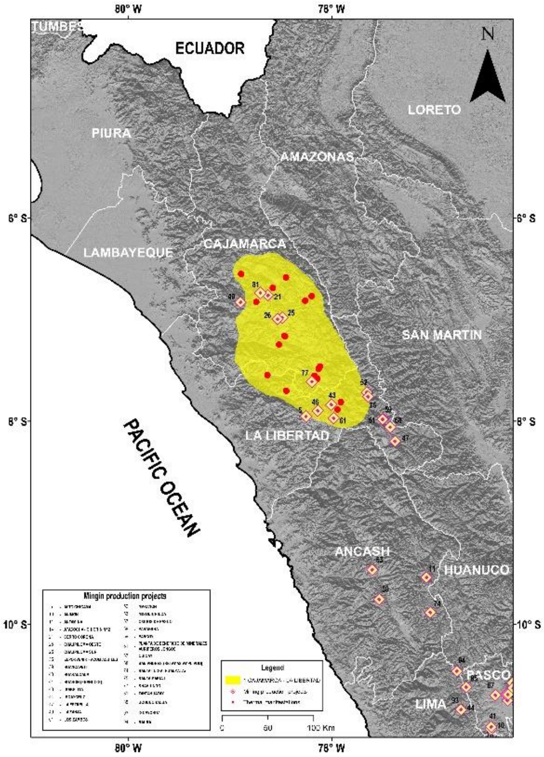

Figure 6: Map of mining operations and thermal manifestations in Cajamarca – La Libertad Geothermal region.

In addition, there is the opportunity to generate social responsibility projects in the benefit of the communities in the area of influence of the mining projects, according to the interests and needs of local stakeholders. It is worth noting that one mining project in Cajamarca appears on the Ombudsman's list of social conflicts[2], therefore, any new initiative must be particularly sensitive to social and environmental safeguards, from its early stages, where geothermal can be integrated as a key element for the creation of social benefits and opportunities.

In the case of the agricultural sector, Cajamarca is the main producer of fresh milk and beef at the national level. In addition, the main crops that support the agricultural sector are coffee, cocoa, paddy rice, potatoes, hard yellow corn, starchy corn, and dry grain beans, among others, oriented to the domestic market, with the exception of coffee and cocoa whose orientation is the external market (BCR, 2021). This could trigger the development of geothermal projects related to greenhouses or food drying to improve productivity and the transformation of raw materials, which will increase the income of farmers and local associations/ventures.

In the field of planning and local policies, it is observed that the main planning instruments of the region, such as the Concerted Development Plan[3]: Cajamarca 2021 or the Economic Ecological Zoning (ZEE) of Cajamarca[4] do not include the use of geothermal energy as an opportunity for economic development[5]. This energy is only recognized in the PERTUR Cajamarca - Plan Estratégico Regional de Turismo 2019-2025 (Gobierno Regional de Cajamarca, 2018), which far from representing a barrier, can be seen as a tool to educate regional stakeholders and promote wider use of geothermal energy in the local production chains.

[2] According to the Social Conflicts Report No. 219, May 2020, the Cerro Corona projects appears on the list of conflicts due to socio-environmental causes.

[3]A Concerted Development Plan is the fundamental tool for planned and participatory local management. This is built from the set of opinions, interests and agreements of State actors and civil society, generally after participatory workshops open to all citizens. Additionally, many PDCs were supposed to start their updating processes in 2020 or 2021, but the pandemic made it impossible to convene local actors due to sanitary restrictions due to COVID 19. Therefore, many departments published ordinances extending the validity of the current PDCs.

[4]In Peru, the Ecological and Economic Zoning (ZEE) is a process that aims to identify the different alternatives for the sustainable use of a territory, based on the evaluation of its potentialities and limitations from the physical, biological, social, economic and cultural. It is directed by the Ministry of the Environment, in coordination with local authorities and organizations, and once approved (the ZEE) it becomes a technical and guiding instrument for the sustainable use of a territory and its natural resources, very useful for the of decisions.

[5]The Concerted Development Plan 2010-2021 and the Economic Ecological Zoning mention only solar and wind energy as viable renewable energy alternatives in the region.

Finally, we find that the main use of hot springs in this department is for balneology and tourism. According to the latest figures registered in PERTUR Cajamarca, in 2017 the Baños del Inca Tourist Complex registered 213,115 tourists, becoming the main tourist attraction of the department and one of the 3 most visited thermal complexes in the country.

Likewise, it is worth observing that thermalism is one of the key elements of the tourist vocation of Cajamarca, promoted under the concept of "family rest in nature", and for this reason, it has been explicitly included in the regional vision and goals of the tourism sector:

> "By 2025, the department of Cajamarca is recognized nationally and internationally for being a competitive destination with important tourism products linked to the segments of history, culture, nature, and thermalism, which is characterized by the hospitality of its people, the provision of services quality tourism and has public and private consultation spaces that promote its sustainable tourism development" (Gobierno Regional de Cajamarca, 2018).

For this reason, various hot springs such as Aguas Calientes, Chancay Baños, among others, have been included in the department's future tourism investment projects, which appear in PERTUR 2019-2025.

c. Thermal potential

Using the data available from 20 thermal areas and applying the methodology described in Section 3 above, we have estimated the theoretical thermal potential from hot springs discharges. The results of this calculation show a significant potential of around 392 MWt, where 366 MWt are being used in thermal bathing and healing facilities (table 1)

Locality	Type	Maximum Utilization			Capacity (MWt)
		Flow Rate (kg/s)	Temperature (°C) Inlet	Outlet	
El Cumbe	B	0.5	28.0	12.6	0.60
Pinipata Baños	B	0.5	35.0	12.6	0.62
Bombón	O	1.0	52.0	12.6	1.31
Oscol	B	1.0	31.0	12.6	1.22
Baños Jerez	B	2.0	39.0	12.6	2.51
Doña Ramona	O	2.0	40.0	12.6	2.51
Huaranchal	B	2.0	74.0	12.6	2.80
Aguas Calientes	B	3.0	44.0	12.6	3.82
Chingol	B	3.0	38.0	12.6	3.75
Quilcate	B	3.0	51.0	12.6	3.91
Chancay Baños	B	4.0	40.0	12.6	5.03
Gran Chimú	B	4.0	49.0	12.6	5.18
Yanasara	B	4.0	47.0	12.6	5.15
Maramorco	O	5.0	49.0	12.6	6.48
El Edén	B	5.0	58.0	12.6	6.66
Llanguat	B	6.0	63.0	12.6	8.12
El Tragadero*	B	60.0	70.1	12.6	83.00
La Grama*	B	100.0	45.6	12.6	128.09
Yumagual	B	12.0	51.0	12.6	15.64
Baños del Inca* (Cajamarca)	B	78.0	64.0	12.6	105.91
TOTAL		296.0			392.3

Type B: Bathing and swimming (including balneology)
Type O: Abandoned

Table 1: Thermal Potential of Cajamarca – La Libertad geothermal region.

4.2.2 Callejón de Huaylas

a. Geological Context

This geothermal region includes twenty-two provinces of the departments of La Libertad, Huánuco, and Ancash, covering a total surface of approximately 27,057 km^2.

The major geological feature in this region is The Cordillera Blanca, the highest mountain range in Peru, controlled on its western margin by the NW-SE trending Cordillera Blanca Detachment Fault (CBDF) which is the first active detachment faulting to have been documented within an oceanic/continental convergence zone, above a modern flat slab subduction setting (McNulty and Farber, 2002). The detachment faulting began just after the final phase of continental-arc magmatism in northern Peru, when the Nazca Ridge subduction resulted in the Nazca Plate's flat slab underthrusting (ca. 8 Ma). Buoyant forces associated with this aseismic (hotspot) ridge subduction, are interpreted to have triggered the extensive Cordillera Blanca detachment within a pre-thickened continental crust locally weakened by previous arc magmatism. According to Farber and Hancock (2005), the CBDF is a low-angle normal fault marked by a major, west-facing scarp and by a thick belt of exhumed mylonitic to cataclastic fault rocks.

The Cordillera Blanca is characterized by the presence of many of the highest snow peaks in Peru. Its geological composition ranges from Precambrian formations (Complejo del Marañón), Mesozoic sedimentary sequences (Chicama and Oyón formations, Goyllarisquizga group), and Cenozoic volcanic rocks (Calipuy group, Yungay formation) that unconformably overlays the older formations. Lower Neogene intrusive rocks intersect several of the above-mentioned units.

In this geological and tectonic context, structural elements such as extensive folding and faulting generate extensive fracturing that plays an important role to generate geothermal systems and surface thermal manifestations associated with the deep circulation of meteoric water.

In Callejón de Huaylas, around 30 thermal areas have been identified with hot spring temperatures between 23°C and 90 °C (see figure 7). Based on the geological and tectonic characteristics, Vargas & Cruz (2010) defined three main geothermal areas (Corongo, Caraz and Huaraz) which also show the hottest spring discharges in this region.

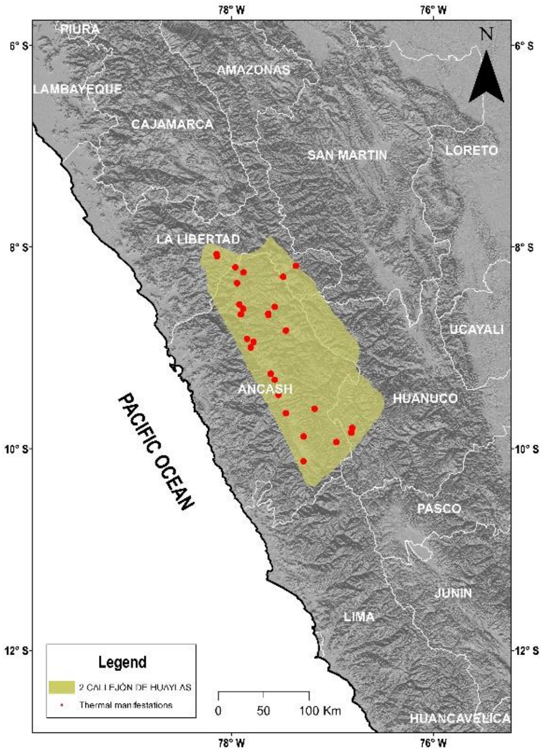

Figure 7: Thermal manifestations in Callejon de Huaylas Geothermal region.

In many hot springs, the water outflow is clearly controlled by faults and fractures, such as in the Aticara hot spring example shown in figure 8 where hot water rises to the surface through fractures in limestones.

Figure 8: Panoramic view of the Aticara hot spring.

b. Local economic characterization

This geothermal region covers part of the departments of La Libertad, Huánuco, and Ancash. 79% of the hot spring identified in this region are located in Ancash, so we will focus on the characterization of this department. In Ancash, the departmental productive structure is determined by mining and oil (45.5%); other services (13.4%); and manufacturing (9.1%), which contribute jointly with 68.0% in the formation of the departmental GVA (Gross Added Value).

In the case of mining, according to the 2020 Mining Yearbook of the Ministry of Energy and Mines, Ancash heads the ranking of departments with the largest proven and probable reserves, for zinc (8.7 million metric tons) and silver (1. 4 million kilograms fine), and it is in sixth place for copper, with 5.9 million metric tons. Likewise, in 2020, Ancash led the production of copper, silver, and zinc, contributing 18.6%, 19.5%, and 39.9%, respectively, of the total national production. In the department there are more than 4 metal mining operations in areas close to hot springs (see figure 9), with facilities located at more than 4,000 meters above sea level, so we find similar opportunities to those previously described for the Catamarca region: geothermal heating for mining facilities and for social responsibility projects in communities near mining operations.

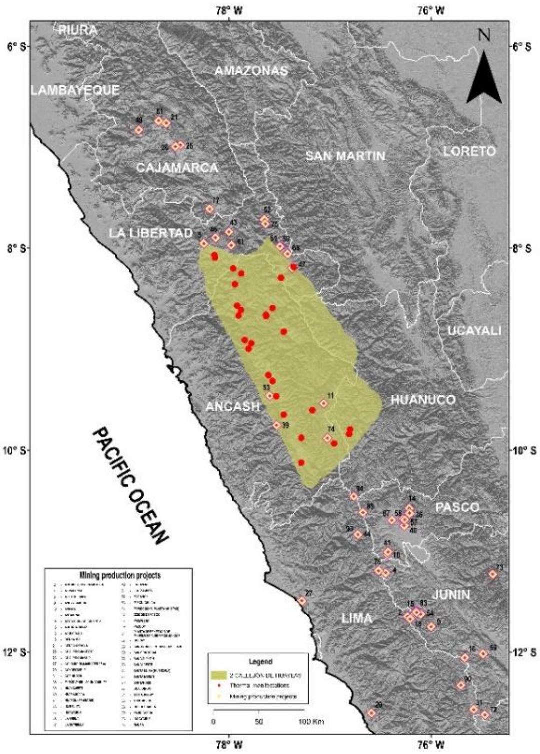

Figure 9: Map of mining operations and thermal manifestations in Callejón de Huaylas Geothermal region.

Three of these mining projects appear on the Ombudsman's list of social conflicts[6] therefore, any new initiative must be particularly sensitive to social and environmental safeguards, from its early stages, where geothermal can be integrated as a key element for the creation of social benefits and opportunities. The manufacturing activity is concentrated in the city of Chimbote (on the Pacific coast), and is mainly represented by the fishing, steel, and sugar industries. The fishing industry is the most important sector with the production of fishmeal and fish oil, and on a smaller scale, canned fish. In 2020, Ancash ranked as the first producer of fishmeal, with 356 thousand tons, 34% of the national production. Despite the existence of significant industrial activities, the lack of hot springs in the coastal zone of Ancash substantially limits the opportunities for geothermal direct use in the economic sector, though the use of the shallow geothermal resource by means of heat pumps is an option to be evaluated.

Regarding policies and local planning, the main planning documents of the department, such as the Ecological Economic Zoning (still pending for approval) or the Concerted Regional Development Plan: Ancash 2016 - 2021, do not include the use of geothermal energy as an opportunity for economic development[7]. Hot springs are only mentioned as part of the diagnosis of the department's heritage system, which includes elements of pre-Hispanic culture and beauties of the natural landscape. This heritage system is related to the tourism potential of Ancash, where hot springs are valued for recreation, health, and the enjoyment of the landscape, as stated in the PERTUR Ancash - Plan Estratégico Regional de Turismo 2020-2029 (Gobierno Regional de Ancash, 2021).

Effectively, the current main use of hot springs in this region is for balneology and tourism. The PERTUR Ancash identifies various hot springs, such as Huancarhuaz, Chancos, Monterrey, Chavín, Pomabamba, and Azulmina, among others, as areas for tourism development, and includes a profile of an investment project to improve the services of the Baños de Chancos, including a panoramic viewpoint, the construction of trails and capacity building for tourism service providers.

[6]According to the Social Conflict Report No. 219, of May 2020, the Antamina, Misquichilca, and Santa Luisa projects appear on the list of conflicts due to socio-environmental causes.

[7]The Concerted Development Plan 2010-2021 and the Economic Ecological Zoning mention only solar and wind energy as viable renewable energy alternatives in the region.

c. Thermal potential

Using the data available from 20 thermal areas and applying the methodology described in Section 3 above, we have estimated a theoretical thermal potential from hot springs discharges of around 155 MWt, of which 123 MWt are being used in thermal bathing and healing facilities (table 2)

Locality	Type	Maximum Utilization			Capacity (MWt)
		Flow Rate (kg/s)	Temperature (°C) Inlet	Outlet	
El Pato	B	0.1	44.0	12.6	0.13
Coñoc (La Unión)	B	0.1	38.0	12.6	0.12
Baños	B	0.2	28.0	12.6	0.24
Huandoval	B	0.5	35.0	12.6	0.62
Andaymayo	O	0.5	23.0	12.6	0.59
Villa Fátima	O	0.5	45.0	12.6	0.64
Cueva de los Loros	O	0.5	24.0	12.6	0.60
Azulmina	B	1.0	70.0	12.6	1.38
Chihuán	B	1.0	36.0	12.6	1.24
Tablachaca	O	1.0	50.0	12.6	1.30
Shángol	O	2.0	38.0	12.6	2.50
Huacás	B	2.0	55.0	12.6	2.64
Pomabamba	B	2.5	47.0	12.6	3.22
La Merced	B	4.0	39.0	12.6	5.01
Monterrey	B	4.0	45.0	12.6	5.11
Pacatqui	B	4.0	89.0	12.6	5.85
Rúpac	O	4.0	57.0	12.6	5.31
Aticara	B	5.0	37.0	12.6	6.22
Baños Huarcarhuás	O	5.0	73.0	12.6	6.98
Chavín	B	5.0	41.0	12.6	6.31
Hualcán	B	5.0	39.0	12.6	6.27
Pumapampa	O	5.0	16.0	12.6	5.79
Jocos-Peinado	B	5.0	40.0	12.6	6.29
Cachicadán	B	7.0	65.0	12.6	9.53
Aquilina	B	10.0	77.0	12.6	14.12
Chancos	B	10.0	70.0	12.6	13.83
Cochaconchucos	B	10.0	38.0	12.6	12.49
Olleros	B	10.5	29.3	12.6	12.73
La Pampa	O	15.0	25.0	12.6	17.92
TOTAL		**120.4**			**154.99**

Type B: Bathing and swimming (including balneology)
Type O: Abandoned

Table 2: Thermal Potential of Callejón de Huaylas geothermal region.

4.2.3 Churín

a. Geological Context

This region covers 25,392 km^2, in the departments of Pasco, Huanuco, Lima, and Junin, and includes around eleven provinces (figure 10).

The geological setting is characterized by a sedimentary sequence composed of sandstones, shales, and limestones, which were deposited during the Cretaceous in the Churin basin, which is the narrower basin in the wider West Peruvian Sedimentary Basin (WPSB), and corresponds to the southern extension of the Cajamarca Basin (Wilson, 2000).

In this region, around 28 thermal areas have been identified with temperatures that locally exceed 70 °C (see figure 10). The most important thermal area is Churin which hosts more than 10 hot springs, most of them with flow rates bigger than 15 L/s, and temperatures between 30°C and 60°C.

The hot springs are mostly controlled by tectonic structures and the geothermal systems are associated with the deep circulation of meteoric waters along strongly fractured rocks in correspondence with regional faults (see figure 11). There is no active volcanism.

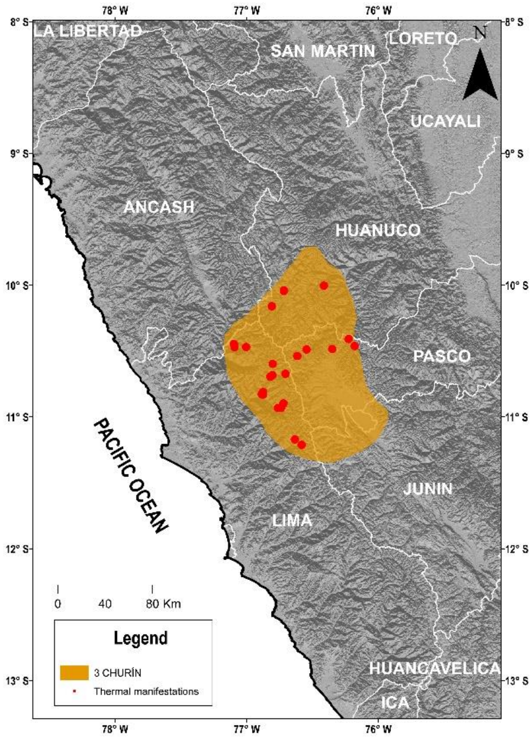

Figure 10: Thermal manifestations in Churín Geothermal region.

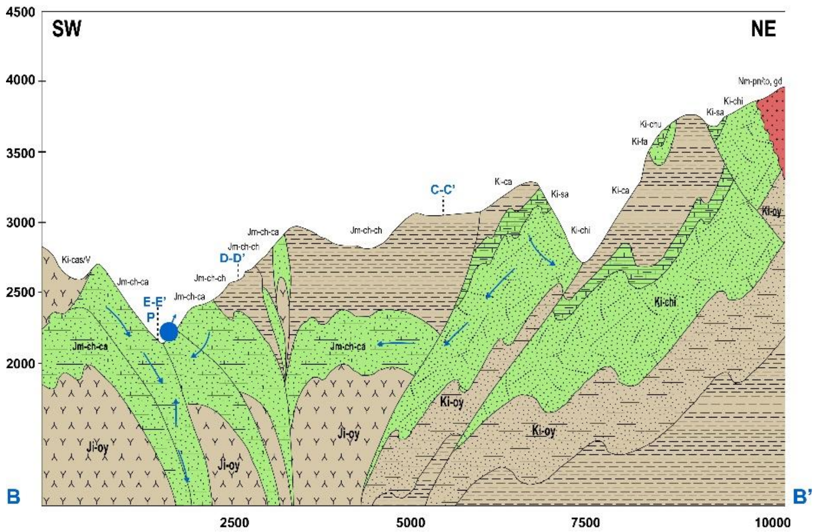

Figure 11: Hydrogeological cross-section of the thermal aquifer in Churín (Aquatest, 2007).

b. Local economic characterization

This geothermal region covers part of the departments of Lima, Huánuco, Junín, and Pasco, but 68% of the hot springs' areas are located in Lima, specifically in Churín, a town located in the northern highlands of this department, so we will focus on its characterization.

Churín is the most important town in the province of Oyón and the district of Pachangara. Although the GVA statistics of the department of Lima, indicate manufacturing and commerce as the most important economic activities (with 17.1% and 12.7%, respectively); in Oyón and Churín the situation is a different reality, since mining, agricultural activity, and services associated with tourism prevail.

The Oyon province hosts 3 important mining operations: Uchucchacua, which produces silver; Iscaycruz, from the Los Quenuales company, one of the most important zinc mines in the country; and Raura from the company of the same name, which produces zinc, and lead and copper (see figure 12), which are a significant source for local jobs. All these mining operations are located above 4,000 meters above sea level, where the climatic conditions are extremely cold at night and in the winter months, so geothermal heating could find interesting development opportunities. Similarly, to the previous geothermal regions, the direct use of geothermal resources can find additional opportunities associated with social responsibility projects, particularly in the Uchucchacua mine which is on the list of social conflicts of the Ombudsman's Office of May 2020.

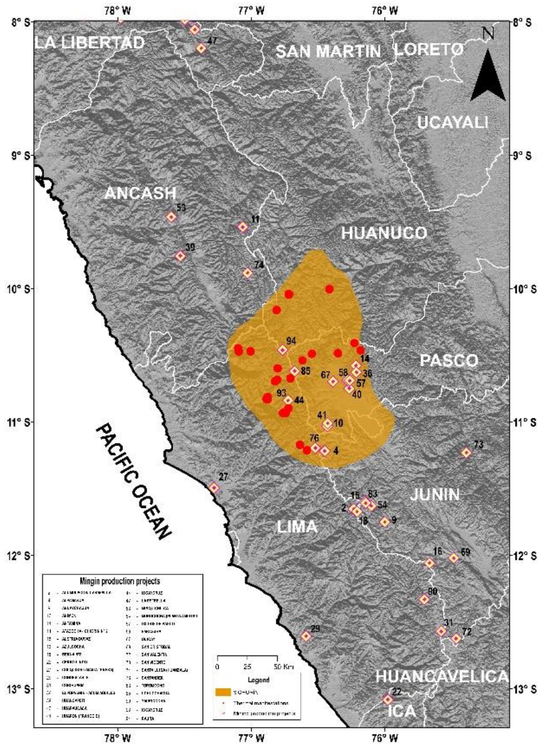

Figure 12: Map of mining operations and thermal manifestations in the Churín geothermal region.

According to the Government Plan for the Province of Oyón 2019-2022, the agricultural activities are characterized by the extensive, raising of cattle and sheep for meat and milk and several crops such as corn, potatoes, oca, and beans. The local farmers face problems related to the impoverishment of the soil, poor quality seeds, crop diseases, lack of labor, and inefficient management of pesticides and fertilizers. For these reasons, agricultural activity is basically for self-consumption, with low levels of technification. Here we find an opportunity for direct use of geothermal energy contributing to the diversification of crops, especially for family and community organizations, through geothermal greenhouses.

The main use of hot springs in this region is for balneology and tourism. According to the latest figures recorded by PERTUR Lima – Plan Estratégico Regional de Turismo 2020 - 2025 (Gobierno Regional del Lima, 2020), in 2018 the Mamahuarmi Thermal Baths, in Churín, registered 221,087 tourists, becoming one of the main tourist attractions of the department of Lima and one of the 3 most visited thermal facilities in the country.

Likewise, the document identifies thermal tourism as one of the most important trends in the diversification of tourist demand in the coming years and includes it as a key factor that determines the tourist vocation of the northern part of the department of Lima. For this reason, thermalism is explicitly included in the long-term vision of the tourism sector:

> "By 2025, the Lima Region is recognized at the national level for being a competitive and safe destination, which applies the protocols for quality care, generating trust in visitors, with segmented and specialized tourism products in the historical-cultural- archaeological, nature, gastronomy, thermalism and experiential experiences, which is characterized by its hospitable population and proud of its identity; and with the concerted organization of its tourist actors who work for the sustainable development of the region." (Gobierno Regional de Lima, 2020).

To achieve this vision, the document proposes the development of projects with Public-Private Associations (PPPs) to improve access to thermal areas and the quality of services for tourists. Likewise, it suggests the implementation of a thermal tourist route in the town of Churín, although it does not define a list of possible investment projects and a corresponding budget.

To conclude this characterization, it is important to mention that 3 of the 4 departments in the Churín geothermal region (Junín, Pasco, and Huánuco) have been prioritized in the Multisectoral Plan for Frost and Cold 2022-2024 since their population is exposed to high or very high risk from this climatic phenomenon that occurs every year between May and September. Geothermal heating could provide sustainable solutions in areas highly vulnerable to frosting and cold events, though specific investigations are needed to evaluate the potential relevance of geothermal heating projects, not necessarily associated with hot springs, but also in locations where accessible geothermal aquifers or conditions for geothermal heat pumps applications are present.

c. Thermal potential

Using the data available from 28 thermal areas and applying the methodology described in Section 3 above, we have estimated a theoretical thermal potential from hot springs discharges of around 179 MWt. Most of this potential, 173 MWt, is being used in thermal bathing and healing facilities (table 3).

Locality	Type	Maximum Utilization			Capacity (MWt)
		Flow Rate (kg/s)	Temperature (°C)		
			Inlet	Outlet	
Gazuna	O	0.1	10.0	12.6	0.11
Picoy*	B	8.0	59.0	12.6	10.70
Rupay	O	0.2	32.0	12.6	0.24
Machaycancha	O	0.5	45.0	12.6	0.64
La Meseta*	B	10.0	33.0	12.6	12.28
Agua de Verruga*	B	15.0	34.6	12.6	18.52
Velo de Novia (Mama Huarmi)*	B	20.0	31.2	12.6	24.41
San José de Baños	B	0.5	73.0	12.6	0.70
Tuntul	O	0.5	16.0	12.6	0.58
Baños de Rabí	O	0.5	49.0	12.6	0.65
Villo	B	0.5	48.0	12.6	0.65
Cabracancha (Baños de Fierro)	B	10.0	47.5	12.6	12.89
Baños de Tingo*	B	10.0	54.5	12.6	13.18
Coñoc	B	1.0	49.0	12.6	1.30
La Juventud	B	10.0	31.0	12.6	12.20
Santa Catalina	B	1.0	38.0	12.6	1.25
Tambochaca	B	1.0	60.0	12.6	1.34
Yahuar Cocha	O	1.5	43.0	12.6	1.91
Baños del Inca (Huánuco)	B	1.7	46.7	12.6	2.19
Huancachín	B	15.0	46.0	12.6	19.24
Huancahuasi	B	8.0	58.0	12.6	10.66
Patón	B	7.0	31.8	12.6	8.56
Shucsha	O	2.0	30.0	12.6	2.43
Víroc	B	3.0	58.5	12.6	4.00
Púllac	B	2.0	19.0	12.6	2.34
Coñoc (San Rafael)	B	4.0	28.0	12.6	4.83
Cunaya	B	4.0	23.0	12.6	4.75
Huayllay	B	5.0	50.0	12.6	6.50
TOTAL		**142.0**			**179.03**

Type B: Bathing and swimming (including balneology)
Type O: Abandoned

Table 3: Thermal Potential of Churín geothermal region

4.2.4 Central

a. Geological Context

This geothermal region is located in the departments of Lima, Junín, Huancavelica, and Ayacucho, where it includes around twenty provinces, covering approximately 45,858 km^2 (figure 13).

This region is in the central part of the country and shows a variety of geological formations where the oldest outcropping rocks are metamorphic and volcano-sedimentary layers of the Paleozoic age (Excelsior, Ambo, Tarma, Copacabana, and Mitu groups). Triassic-Jurassic limestones and sandstones belonging to the Pucara formation, extensively outcrop in the region, underlying Cretaceous sandstones of the Goyllarisquisga Group and Mara Formation. This Mesozoic sedimentary sequence is covered by diverse volcanic rocks, mainly andesite, pyroclastic flows, and breccias of the Neogene age.

Complex faults and folding structures characterize the tectonic setting of this region and control several NW-SE striking sedimentary basins.

At least 20 hot springs occur in this region, mainly associated with sedimentary and volcanic rocks, where major transversal faults control the formation of hydrothermal systems with deep circulation of meteoric waters (Steinmüler, K. & Huamani, 1998) (see figure 13).. The discharge temperature is mostly in the 20-30°C range but can locally reach 50°C.

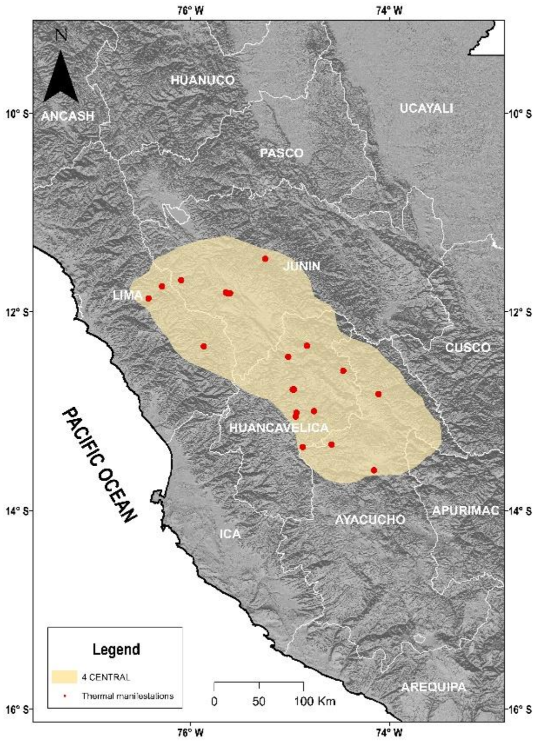

Figure 13: Thermal manifestations in the Central Geothermal region.

b. Local economic characterization

This geothermal region covers part of the departments of Lima, Junín, Ayacucho, and, mainly, Huancavelica. 45% of the hot springs identified in this region are located in Huancavelica, so we will focus on the characterization of this department. The most important economic activities in Huancavelica, according to the calculation of the Gross Added Value (GVA), are the Electricity, Gas, and Water sectors, which had a contribution of 33.5% in 2020, followed by Other Services (17, 4%), Public Administration and Defense (11.8%) and Agriculture, Livestock, Hunting and Forestry (9.3%).

The electricity sector, is mostly represented by the Mantaro and the Cerro del Águila Hydroelectric Power Plants, with a total installed capacity of more than 1,300MW. Thanks to them, Huancavelica, after Lima, is the second most important department for power generation (45% share), and it is the first in hydroelectric generation, with a 33% share of the national electricity production in 2020. Though the contribution of these hydroelectric plants in terms of electricity generation is significant, their impact on the local economically active population (EAP) is very little..

Among the other productive sectors, agriculture stands out, not only for concentrating a large number of jobs in the region (a little over 70% of the EAP), but also for supplying important products to different markets in the central zone of the country, both from the mountain zone, as well as from the jungle zones of the Huancavelica territory. Potatoes, green and dry grain peas, starchy corn, grain barley, and dry grain beans stand out as the major production, oriented to self-consumption and local consumption, and to a greater extent in the cases of potatoes and green grain peas, oriented to the wholesale markets of Huancayo, from where they are sold to be sent to the Lima market. In the livestock subsector, the production of beef, sheep, and pork, as well as milk, stands out, which together accounted for 79 percent of the livestock Gross Value of Production (GVP) in 2020. The beef and milk production alone accounted for about 54 percent of livestock GPV.

In this scenario, the direct use of geothermal energy could contribute to strengthening family production chains or farmer cooperatives through community greenhouses that facilitate the production of seedlings or diversify the diet in areas with little access to fresh fruits and vegetables, contributing to public health and food safety. However, the main planning documents for the region, such as the Concerted Regional Development Plan: Huancavelica 2021, do not promote the use of geothermal energy or hot springs as an opportunity for economic development. As already observed in the previous regions, the main use of the hot springs in Huancavelica is for balneology and tourism. According to the PERTUR Huancavelica - Plan Estratégico Regional de Turismo 2019 - 2025 (Gobierno Regional del Huancavelica, 2019), "hot springs: health and relaxation" have been identified as one of the most important tourism products in the department. it's the main touristic attractions in Huancavelica are the hot springs of San Cristóbal, Baños del Inca, and the ecotourism complex of Las Tres Boas - Villa Cariño. However, PERTUR's Plan acknowledges that this product has not been fully developed, so it is included among the projects requiring public investment to improve services.

To conclude the characterization, it is worth observing that 3 of the 4 departments that make up the Central geothermal region (Junín, Ayacucho, and Huancavelica), have been prioritized in the Multisectoral Plan for Frost and Cold 2022-2024, since their population is exposed to high or very high risk from this climatic phenomenon that occurs every year between May and September. Geothermal heating could provide sustainable solutions in areas highly vulnerable to frosting and cold events.

c. Thermal potential

Using the data available from 20 thermal areas and applying the methodology described in Section 3 above, we have estimated a theoretical thermal potential from hot springs discharges of around 93 MWt. Most of this potential (90 MWt) is being used in thermal bathing and healing facilities (table 4).

Locality	Type	Maximum Utilization			Capacity (MWt)
		Flow Rate (kg/s)	Temperature (°C) Inlet	Outlet	
Uchuraccay	B	0.1	19.0	12.6	0.12
Niñobamba	B	0.3	44.0	12.6	0.38
Baños del Inca (Huancavelica)	O	0.5	27.0	12.6	0.60
Colpa	O	0.5	17.0	12.6	0.58
Coris	B	0.5	50.0	12.6	0.65
Cancaro	B	0.5	20.0	12.6	0.59
Surco	O	0.5	17.0	12.6	0.58
Huahuapuquio	B	1.0	21.0	12.6	1.18
Aguas Calientes	B	1.0	22.0	12.6	1.18
Huachocolpa	O	1.0	25.0	12.6	1.19
Huancavelica	B	1.0	21.0	12.6	1.18
Huapa	B	1.0	19.0	12.6	1.17
Ramón Castilla	B	1.0	19.0	12.6	1.17
Huájal	B	1.0	20.0	12.6	1.17
Yauli	B	1.0	41.0	12.6	1.26
Llocllapampa	O	5.0	26.0	12.6	5.99
Uchubamba	B	5.0	26.0	12.6	5.99
Acaya	B	10.0	29.0	12.6	12.11
San Mateo	O	20.4	25.0	12.6	24.37
Pirata	B	25.0	37.0	12.6	31.12
TOTAL		**76.3**			**92.60**

Type B: Bathing and swimming (including balneology)
Type O: Abandoned

Table 4: Thermal Potential of Central geothermal region.

4.2.5 Eje Volcánico Sur

a. Geological Context

This is the biggest geothermal region in the country, with an extension of approximately 104,498 km^2, that includes around thirty provinces, mainly in the departments of Ayacucho, Apurimac, Arequipa, Moquegua, and Tacna; and in part of Cuzco and Puno.

The geology is dominated in this region by volcanic deposits of the Paleogene to Holocene age. The most important and extensive outcrops belong to the Barroso Group (Neogene) which constitutes a large part of the highlands in this region, and is locally covered by Holocene volcanoes. Fidel et. al. (1997) has inventoried more than 300 volcanic centers in southern Peru, most of them located within this geothermal region, including 12 active, or potentially active volcanoes. Sara Sara, Sabancaya, Misti, Ubinas Yucamane, and Tutupaca are the most important active centers The volcanic sequence overlays a basement composed of Cretaceous and Jurassic sedimentary rocks, extensively outcropping at lower elevations on the western slope of the Andean cordillera from Ayacucho to Tacna.

The structural domain is characterized by the Andean direction, NW-SE, which controls most of the major faults, the formation of sedimentary basins, and the development/alignment of volcanic edifices and calderas. In some specific areas, NE-SW transversal structures are associated with the separation of structural blocks such as the Arequipa and Huaytire blocks. (Steinmüler and Nuñez, 1997; Steinmüler and Zavala 1998).

The extensive and young volcanic activity is associated with several thermal springs and fumaroles, the hottest in the country, that represent the surface expression of potentially large high enthalpy geothermal reservoirs.

Around 80 thermal areas with temperatures that can reach 90 °C have been identified in this region (see figure 14), most of them associated with recent magmatic systems

b. Local economic characterization

This geothermal region covers part of the departments of Apurímac, Ayacucho, Cusco, Arequipa, Moquegua, and Tacna. The largest number of hot springs and correspondingly the greatest potential for geothermal electricity generation in the entire country is concentrated in the departments of Arequipa, Moquegua, and Tacna (JICA, 2012); whose main economic characteristics are summarized in table 5.

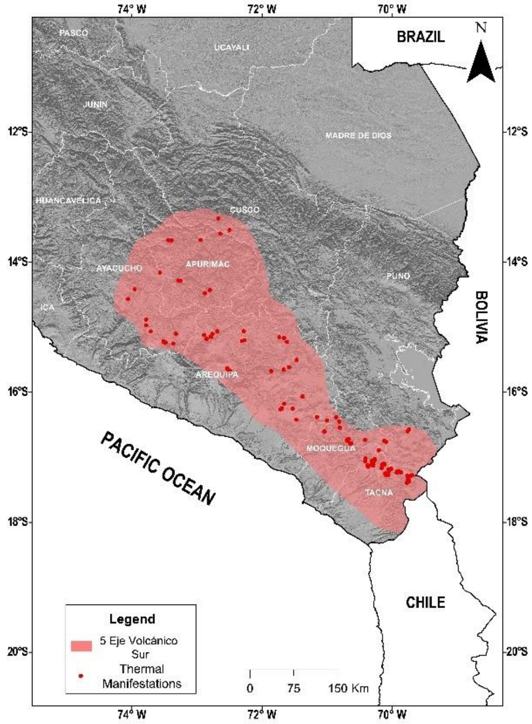

Figure 14: Thermal manifestations in Eje Volcánico Sur Geothermal region.

Arequipa		Moquegua		Tacna	
Mining	31.9%	Manufacture[8]	45.4%,	Mining	50.9%
Other services	18.1%	Mining	28.8%;	Other services	12.6%
Manufacture	10.7%	Other services	6.8%	Trade	7.5%

Table 5: Economic activities with the highest Gross Added Value (GVA). Source: BCR, 2022, BCR 2022b & BCR, 2022d.

Mining is the most important economic activity, with large mining operations such as Cerro Verde in Arequipa (copper and molybdenum), Quellaveco in Moquegua (copper), and Toquepala in Tacna (copper and molybdenum), and several smaller mines totaling more than 15 metallic mining operations[9] (see figure 15). Many of these mines are located near hot spring areas at more than 4,000 meters above sea level, where temperatures can drop below zero at night or in the coldest winter times. Additionally, social conflicts with indigenous communities are present in this region, with three mining projects reported in the list of social conflicts of the Ombudsman's Office[10], As previously mentioned for other geothermal regions, this situation represents an interesting opportunity for the use of geothermal heat in mineral operations, and the development of geothermal initiatives in the framework of social responsibility projects may also be valuable to mitigate social conflicts in areas surrounding mining operations.

Regarding local policies and planning, geothermal is considered as a development option only in the Concerted Development Plan (CDP) of the Tacna department, as summarized in table 6.

The main use of hot springs in the three departments is for balneology and tourism, therefore thermalism is considered in the following planning documents: PERTUR Arequipa - Plan Estratégico Regional de Turismo 2021- 2026 (Gobierno Regional del Arequipa, 2021), PERTUR Moquegua - Plan Estratégico Regional de Turismo 2019- 2025 (Gobierno Regional del Moquegua, 2021) and PERTUR Tacna - Plan Estratégico Regional de Turismo 2019- 2025 (Gobierno Regional del Tacna, 2021), as summarized in table 7.

[8]Mainly linked mining processing.

[9]According to MINEM, we have the following metallic mining units in production: Chaccuille, Veta Dorada, Belén, Doble D, San Juan, Gran Arcata, Orcopampa, San Cristóbal, Tambomayo, Alpacay, Cerro Verde and El Santo in Arequipa. Mariela, Cuajone and Quellaveco in Moquegua. And Toquepala and Pucamarca in Tacna.

[10]According to the Social Conflict Report No. 219, of May 2020, the Cuajone, Quellaveco and Toquepala projects appear on the list of conflicts due to socio-environmental causes.

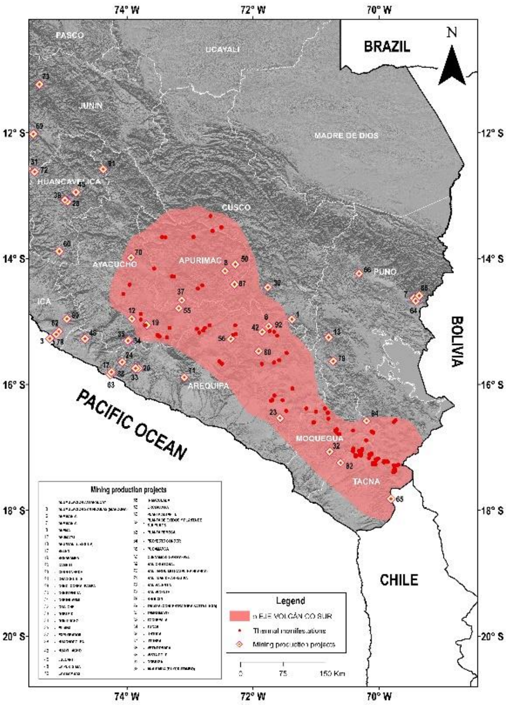

Figure 15: Map of mining operations and thermal manifestations in Eje Volcánico Sur geothermal region.

Arequipa	Moquegua	Tacna
Arequipa Concerted Development Plan 2013 – 2021	Moquegua Concerted Development Plan 2003 – 2021, updated to 2009	Tacna Concerted Development Plan towards 2021
Geothermal is not mentioned	It contemplates non-conventional energies as a development strategy, but only includes solar energy.	It does recognize the geothermal potential: “(Tacna) has five promising geothermal zones of high enthalpy, located above 4000 meters above sea level, with geothermal manifestations such as hot springs, fumaroles and geysers with high temperatures that in some cases reach up to 90°C on the surface, and in depth above 200°C calculated through chemical geothermometers.”
None mention the direct uses of geothermal energy, for balneology or tourism, for example.		

Table 6: Geothermal energy in the Concerted Development Plans of Arequipa, Moquegua, and Tacna.

Arequipa	Moquegua	Tacna
PERTUR Arequipa 2021 - 2026	PERTUR Moquegua 2019 - 2025	PERTUR Tacna 2019 - 2025
● Recognizes the importance of wellness tourism, which includes the thermal springs (p. 58). ● Identifies the hot springs of Yura, La Calera, Chacapi, Huancarama, Luicho, Chancharay, Lucha, among others, within the main resources and tourist circuits of the department (p. 76). ● It includes hydrotherapy as an opportunity to diversify the tourist offer and identifies 9 main circuits and the profile of the thermal tourist (p. 115). ● It includes areas with hot springs in the list of prioritized or complementary public investment projects (p. 204).	● Recognizes the balanced traveler (who makes use of hot springs) as one of the profiles in tourism trends (p. 38). ● Identifies the hot springs of Cuchumbaya, Ullucán, Putina, Puente Bello, among others, within the main products and tourist circuits of the department (p. 53). ● It includes as an action of strategic objective 1: "promote the formalization of the hot springs of Cuchumbaya and Coalaque" (p. 85). This contemplates the formalization of the use of thermal waters and studies to promote its tourist use, within its Action Plan (p. 87).	● Recognizes hot springs as one of the attractions of the Vilacota Maure Regional Conservation Area (p. 43). ● Recognizes the importance of wellness tourism, which includes the thermal (p. 50). ● It identifies the hot springs of Pachía, Ticaco, among others, as the tourist products with the greatest demand (p. 75). ● It identifies the Geothermal Valley of Candarave as part of the tourist offer with potential, emphasizing the need to improve access roads and local tourist services (p. 77). ● Includes areas with hot springs in the list of tourism investment projects (p. 183).

Table 7: Hot springs in the Regional Strategic Tourism Plans in Arequipa, Moquegua, and Tacna.

To conclude the characterization, it is worth mentioning that in this geothermal region the department of Puno has been prioritized in the Multisectoral Plan for Frost and Cold 2022-2024, since its population is exposed to high or very high risk from this climatic phenomenon that occurs every year between May and September. The development of geothermal heating projects can provide a sustainable solution, not only in areas surrounding thermal springs but also in other areas where studies are required to identify the appropriate geothermal resources and define the feasibility of their use.

c. Thermal potential

Using the data available from 80 thermal areas and applying the methodology described in Section 3 above, we have estimated a theoretical thermal potential from hot springs discharges of around 737 MWt, of which 176 MWt are being used in thermal bathing and healing facilities (table 8).

Locality	Type	Maximum Utilization			Capacity (MWt)
		Flow Rate (kg/s)	Temperature (°C) Inlet	Outlet	
Q. Chungara (sect Inf)	O	0.0	24.4	12.6	0.01
Baños Lucha	B	0.1	47.0	12.6	0.13
Puica	B	0.1	54.0	12.6	0.13
San José	O	0.1	31.0	12.6	0.12
Baños Geronta	B	0.1	69.0	12.6	0.14
Ubinas	B	0.1	29.0	12.6	0.12
Tintasma	O	0.2	20.0	12.6	0.23
Baños Santa Clara	B	0.2	41.0	12.6	0.25
Cuchumbaya	B	0.2	49.0	12.6	0.26
Banos Cencuyo	B	0.3	37.0	12.6	0.31
Hualalachi	B	0.3	20.0	12.6	0.35
Andapampa	B	0.3	52.5	12.6	0.39
Baños de Yura - Agua Nueva	O	0.3	31.0	12.6	0.37
Baños de Yura - Agua Riveros	O	0.3	30.0	12.6	0.36
Baños El Inca (Colca)	B	0.3	44.0	12.6	0.38
Chacaray	B	0.3	57.0	12.6	0.40
Río Mirmaca	O	0.3	49.7	12.6	0.39
Tincua	B	0.3	48.0	12.6	0.39
Baños Paraiso	B	0.4	39.0	12.6	0.50
Baños Taurisma (Baños Coñec)	B	0.4	32.0	12.6	0.49
Juntupujo	O	0.4	40.9	12.6	0.50
Humaroco	B	0.5	30.0	12.6	0.61
Viques	B	0.5	25.0	12.6	0.60
Chuchuhuanca	B	0.5	33.0	12.6	0.61
Colpar	B	0.5	32.0	12.6	0.61
Sengata	O	0.5	41.0	12.6	0.63
Agua termal Sauceda	O	0.5	28.0	12.6	0.60
Ccacahuara	O	0.5	62.0	12.6	0.67
Pincahuacho	B	0.7	62.0	12.6	0.94
Q. Chungara (sect sup)	O	0.9	60.3	12.6	1.21
Lapaca	B	1.0	43.0	12.6	1.27
Larcay	B	1.0	49.0	12.6	1.30
Santo Tomás	O	1.0	33.0	12.6	1.23
Banos Conicmayo (Maripujo)	B	1.0	36.0	12.6	1.24
Ccollpa	B	1.0	29.0	12.6	1.21
Huacuya	B	1.0	60.0	12.6	1.34
Chilota	O	1.0	37.0	12.6	1.24
Huallaquere	O	1.0	22.0	12.6	1.18
Agua mineral Chorro	O	1.0	10.0	12.6	1.13
Coracorane	O	1.0	23.2	12.6	1.19
Pampas Chillicolpa y Samuta	O	1.1	38.5	12.6	1.38
Baños Chacapi-Yanque	B	1.5	69.2	12.6	2.07
Quiane	O	1.5	53.7	12.6	1.97
Acopallpa	O	1.7	48.7	12.6	2.20
Paila del Diablo	O	1.7	76.7	12.6	2.40
Baños de Yura - Pozo 1	B	1.8	30.6	12.6	2.19
La Calera	B	1.8	34.0	12.6	2.22
Tacalaya Norte	O	2.0	24.3	12.6	2.38
Pusa Pusa	B	2.1	54.8	12.6	2.77
Kovire	O	2.1	41.2	12.6	2.65
Socosani	O	2.2	28.3	12.6	2.66
Baños Huancarama	B	2.5	48.5	12.6	3.23

Locality	Type	Maximum Utilization			Capacity (MWt)
		Flow Rate (kg/s)	Temperature (^oC) Inlet	Outlet	
Punta Perdida-Pastogrande	B	2.5	42.0	12.6	3.16
Agua termal Vizcacha	B	3.0	31.0	12.6	3.66
Huanuscucho	B	3.0	31.0	12.6	3.66
Río Maure	O	3.1	50.8	12.6	4.04
Sicolaque	O	3.7	65.5	12.6	5.05
La Calera (chivay)	B	4.0	68.0	12.6	5.50
Aguas termales Crucero	O	4.0	58.0	12.6	5.33
Ccocho	B	5.0	41.0	12.6	6.31
Ccolpapampa	B	5.0	47.0	12.6	6.43
Agua termal Poqpoccollo	B	5.0	33.0	12.6	6.14
Qda. Azufre Chico	O	5.7	39.9	12.6	7.17
Qda. Azufre Grande	O	6.2	72.2	12.6	8.63
Ccónoc	B	10.0	41.0	12.6	12.62
Aguas Calientes	O	10.0	33.0	12.6	12.28
Baños Calachaca	B	10.0	36.2	12.6	12.42
Borateras	O	11.8	81.9	12.6	16.91
Sondajes	O	12.1	27.9	12.6	14.60
Sayasayani	O	12.5	72.5	12.6	17.42
Qda. Ancocollo	O	13.3	74.5	12.6	18.64
Río de Calientes	O	15.2	75.4	12.6	21.36
Río Callazas	O	18.2	29.8	12.6	22.11
Tacalaya Sur	O	18.4	46.2	12.6	23.61
Ccoñas puquio	B	20.0	18.0	12.6	23.31
Baños Luicho	B	20.0	42.0	12.6	25.32
Baños Josla (Pampamarca)	B	30.0	36.0	12.6	37.22
Putina	O	57.3	84.3	12.6	82.67
Ulucán	O	79.2	71.4	12.6	110.00
Vilacota	O	125.0	61.2	12.6	168.27
TOTAL		**555.3**			**737.03**

Type B: Bathing and swimming (including balneology)
Type O: Abandoned

Table 8: Thermal Potential of Eje Volcánico Sur geothermal region

4.2.6 Cusco – Puno

a. Geological Context

This region covers approximately 100,721 km^2, in the departments of Cuzco and Puno, and with a small portion in Arequipa and Moquegua. It includes around thirty provinces.

Due to its extension, this region embraces two main geological sectors: the Andean Cordillera and the Altiplano. Its northern portion shows a NW-SE trending tectonic domain (Andean direction), and it is mainly composed of sedimentary rocks, like sandstones, limestones, and shales whose age spans from the Paleozoic to the Holocene. The geological setting is characterized by Abancay Deflection, which is an important set of E-W and NE-SW regional faults inherited from the Permo-Triassic rift system, that cut the main Andean direction, that has controlled the geological evolution in this part of the Andes (see figure 16) (Carlotto, et. al. 2006).

During the Permo-Triassic the core zone of the Abancay Depression received significant accumulation of continental sediments and some marine transgressions, as evidenced by the 200 m thick fossiliferous limestone in Vilcabamba (Cárdenas et al., 1997) or in Cachora-Huanipaca (Carlotto et al., 1999). Successively, until the Cretaceous, The Abancay core zone evolved into a structurally elevated block limited by the NE-SW Puyentimari-Rancahua Fault (FPR) and Patacancha-Tamburco Fault (FPT) systems. A large part of the previously deposited sediments, of the Mitu Group, were removed by erosion during this period.

The southern part of this region embraces part of the Andean Altiplano (figure 17), which is an intramountain basin extended between Peru and Bolivia, and it contains two main lakes, Titicaca and Poopó.

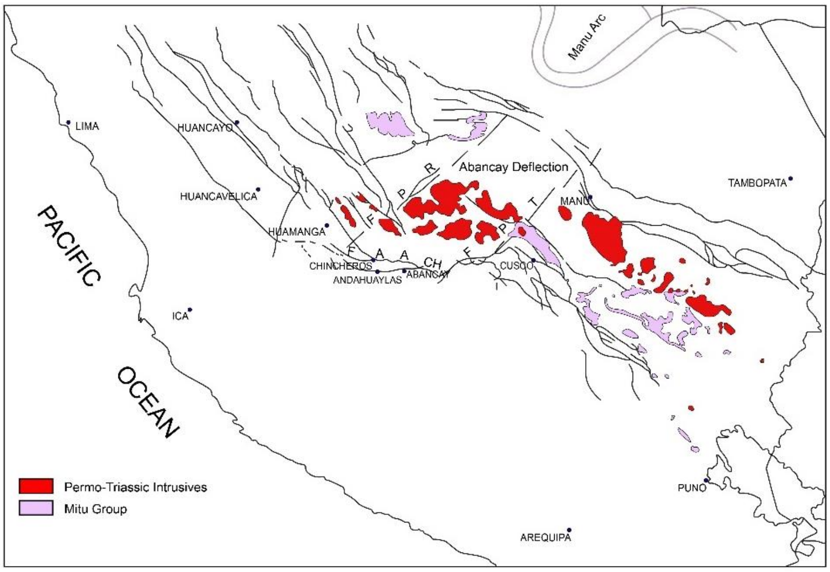

Figure 16: Main Structures related to the Abancay Deflection

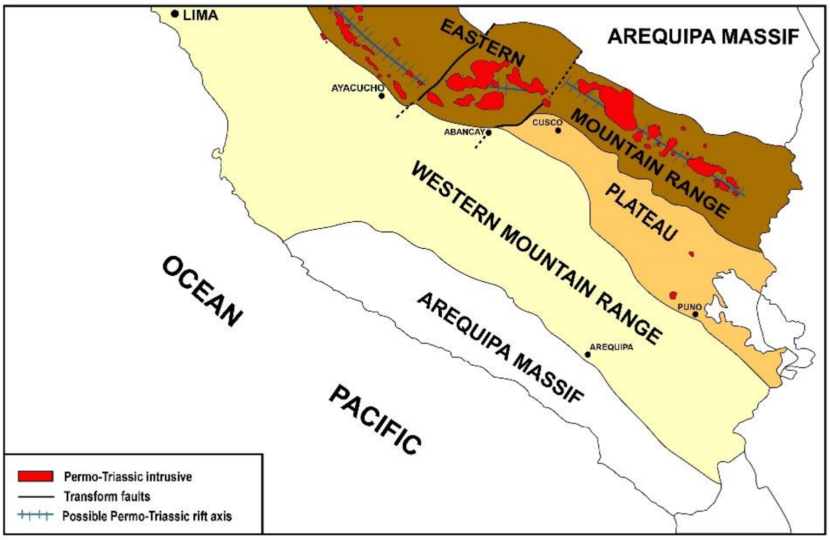

Figure 17: Location Map of the Altiplano and the Abancay Deflection.

The formation of the Altiplano basin started in the Pliocene, with the deposition of fluvial and lacustrine sediments, then evolved during the Quaternary with several types of continental deposits, including glacial and interglacial sediments in its external portions, close to the adjacent mountain ranges, fluvial deposits and lacustrine sediments and evaporites in the lower central portions of the basin (Lavenu, 1991).

Between 2 and 3 Ma ago, a compressive tectonic phase associated with NW-SE to E-W shortening stresses affected the Upper Pliocene deposits in the Altiplano with the formation of folds and reverse faults. During the Quaternary, a second compressive deformation phase resulting a N-S shortening produced additional deformation of the Pliocene deposits, with several reverse faults. Finally, an extensional tectonic event occurred along the boundary areas between the Altiplano and the Western and Eastern Cordillera, creating N-S to N20°E extensional faults (Lavenu, 1991).

This region includes around 91 thermal areas with temperatures that can reach 90 °C (see figure 18). The highest temperatures in hot springs have been registered in the western areas close to the active volcanic range (highlands of Arequipa, Moquegua and Tacna) which the presence of heat sources, like magmatic chambers, are in contact with deep aquifers or by fractured or faulted zones leading the heat towards the shallow aquifers. Some of the hot springs in this region have a magmatic or volcanic origin.

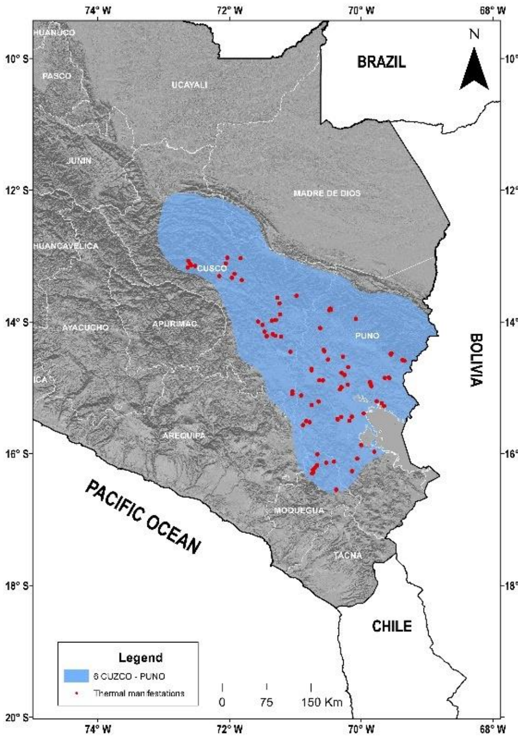

Figure 18: Thermal manifestations in Eje Volcánico Sur Geothermal region.

b. Local economic characterization

This geothermal region, and has been identified as having the second-highest geothermal potential in the entire country (JICA, 2012). Most of its territory is in the departments of Cusco and Puno, whose main economic activities are summarized in table 9.

Cuzco		Puno	
Mining and hydrocarbons	46.2%	Agriculture, livestock and others	18.5%
Trade	6.9%	Trade	11.2%
Construction	6.4%	Public administration	9.2%

Table 9: Economic activities with the highest Gross Added Value (GVA). Source: BCR, 2022a & BCR, 2022c.

The different geographic conditions and availability of natural resources determine a diverse economic context in these two regions, Cuzco has a strong mining economy and according to the 2020 Mining Yearbook (MINEM, 2020), has proven copper reserves amounting to 2.5 million TMF; gold, 39 MT, and silver, 1.0 million TMF, among the main ones. The most important mining operations are Antapaccay (US$1.5 billion investment) and Constancia (US$1.7 billion investment and 15.3 years of commercial life) (see figure 19), which started commercial production in 2013 and 2015, respectively. Likewise, the department of Puno is home to the Camisea gas field, one of the most important energy resources in the country, since a good percentage of electricity generation depends on it. The proven reserves of natural gas and natural gas liquids are estimated at 10.0 trillion cubic feet (TPC) and 506.7 million standard barrels (MMSTB), respectively.

On the other hand, Puno presents a different economy. Being the Altiplano department par excellence, it has a wealth of natural pastures that allowed the development of extensive agriculture and cattle ranching. This department allocates quinoa, organic coffee, and cañihua to the international market, and livestock fodder (alfalfa, oats, and barley forage) to the regional internal market. Likewise, Puno plays an important role in the national production of alpaca meat and fiber, with a participation of 46.9% and 61.6%, respectively. In addition, dairy products deserve special attention, due to the dynamism of dairy production in the districts of Mañazo, Acora and Asillo, in addition to the already consolidated Azángaro, Melgar, and Taraco.

This is therefore a region that offers diverse opportunities for geothermal direct-use applications, ranging from heating in mining and domestic facilities, to heating of greenhouses, or sheds for alpacas, which is a livestock species seriously affected by the frosting and cold phenomenon.[11]..

[11]Frosts are a recurring atmospheric phenomenon in the high Andean areas of Peru, generally located at more than 3 thousand meters above sea level, where the ambient temperature drops to levels below 0°C (zero degrees Celsius), with greater intensity during the period from May to September.

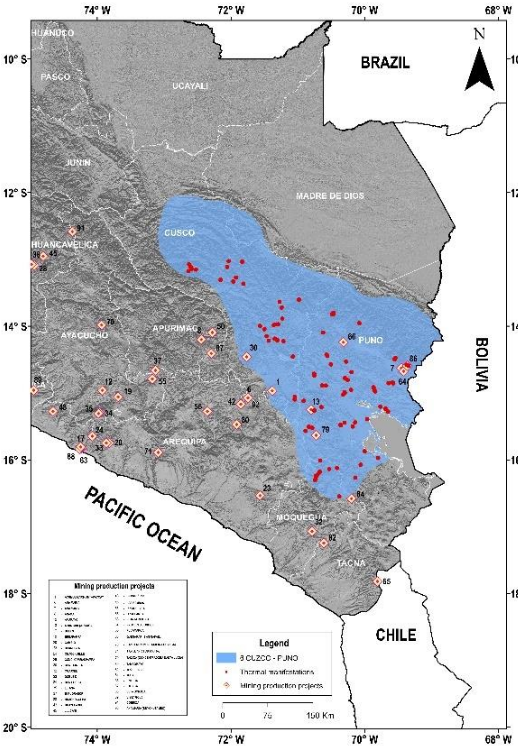

Figure 19: Map of mining operations and thermal manifestations in the Cusco – Puno geothermal region.

Regarding local policies and planning, both the departments of Cusco and Puno have the geothermal or thermal sources mentioned in the most important local policy documents of, such as the Concerted Development Plans (PDC), as summarized in table 10.

Cuzco	Puno
Strategic Concerted Plan for Regional Development , Cusco to 2021	Regional Concerted Development Plan to 2021
Hot springs or geothermal energy are not specifically mentioned but are generically included within the strategic actions: "Promote electrification with an emphasis on rural areas and the use of renewable energies" (p. 116).	Hot springs are part of the inventory of tourist resources. Among the potentialities of renewable energy, reference is only made to hydropower.

Table 10: Geothermal energy in the PDCs of Cusco and Puno.

Similarly, to all other geothermal regions of Peru, the main use of hot springs in these departments is for balneology and tourism. Thermalism is considered in Regional Strategic Tourism Plans for both Cusco and Puno, as indicated in table 11.

Cuzco	Puno
PERTUR Cusco 2019	PERTUR Puno 2021 - 2026
● Identifies the hot springs of San Pedro, Aguas Calientes, Colcamayo, and Lares among others, within the main resources and tourist circuits of the department (from p. 113).	● Recognizes the balanced traveler (who makes use of hot springs) as one of the profiles in tourism trends (p. 38). ● Identifies the hot springs of Moho, Putina, and Puente Bello, among others, within the main potential tourist attractions of the department (p. 76). ● It includes areas with hot springs in the list of prioritized investment projects (p. 150).

Table 11: Hot springs in the Regional Strategic Tourism Plans in Cusco and Puno.

To conclude the characterization, it is important to mention that both Cusco and Puno have been prioritized in the Multisectoral Plan for Frost and Cold 2022-2024, since their population is exposed to high or very high risk from this climatic phenomenon that develops every year, between May and September.

c. Thermal potential

Using the data available from 91 thermal areas and applying the methodology described in Section 3 above, we have estimated a theoretical thermal potential from hot springs discharges in the Cusco-Puno geothermal at around 331 MWt, of which 200 MWt are being used in thermal bathing and healing facilities (table 12).

Locality	Type	Maximum Utilization			Capacity (MWt)
		Flow Rate (kg/s)	Temperature (°C)		
			Inlet	Outlet	
Pampilla	B	0.2	32.0	12.6	0.24
Agua mineral Tacamani	O	0.3	15.0	12.6	0.35
Ccolpani	B	0.5	42.0	12.6	0.63
Yanatile	O	0.5	42.0	12.6	0.63
Ichuña	B	0.5	42.0	12.6	0.63
Lucco	O	0.5	42.0	12.6	0.63
Agua mineral Qanqari	O	0.5	15.0	12.6	0.58
Agua mineral Vila Vila	O	0.5	12.0	12.6	0.57
Agua termal Ácora	O	0.5	65.0	12.6	0.68
Ccollpapampa	O	0.5	54.0	12.6	0.66
Chupahuito	O	0.5	63.0	12.6	0.68
Collpapampa	O	0.5	23.0	12.6	0.59
Jarpaña	O	0.5	26.0	12.6	0.60
Ozoco	O	0.5	12.0	12.6	0.57
Ventitane	O	0.5	60.0	12.6	0.67
San Pedro de Buena Vista	O	0.8	14.0	12.6	0.92
Agua mineral Minasmocco	B	1.0	17.0	12.6	1.16
Agua termal Pahtana	O	1.0	32.0	12.6	1.22
Aguas Calientes-Machu Picchu	B	1.0	39.0	12.6	1.25
Baños Pampacancha	B	1.0	47.0	12.6	1.29
Baños termales Machacancha	B	1.0	37.0	12.6	1.24
Aguas Calientes-Jesús María	O	1.0	52.0	12.6	1.31
Agua medicinal Chimpa Jarán	B	1.0	18.0	12.6	1.17
Agua mineral Huamanruro	B	1.0	15.0	12.6	1.15
Agua mineral Salcedo	B	1.0	17.0	12.6	1.16
Agua termal Cuyo Cuyo	B	1.0	50.0	12.6	1.30
Agua termal El Ruedo	O	1.0	36.0	12.6	1.24
Aguas termales Libertad	O	1.0	41.0	12.6	1.26
Choque Chambe	O	1.0	28.0	12.6	1.21
Paqcha	B	1.0	21.0	12.6	1.18
Putina Punku-San José	B	1.0	55.0	12.6	1.32
Qatsile	O	1.0	36.0	12.6	1.24
Exchage	O	1.5	31.3	12.6	1.83
Qotini	O	1.5	37.0	12.6	1.87
Baños geomedicinales Ccaccatu	B	1.8	22.0	12.6	2.13
Agua medicinal San Pablo	B	2.0	19.0	12.6	2.34
Agua mineral Chilca	O	2.0	19.0	12.6	2.34
Aguas termales Uyurmire	B	2.0	37.5	12.6	2.49
Choquecancha	B	2.0	88.0	12.6	2.92
Urpipata	B	2.0	43.0	12.6	2.54
Ácora (Chiuchire)	O	2.0	15.0	12.6	2.31
Agua mineral Sequén (Chullunquiani)	O	2.0	22.0	12.6	2.36
Agua termal Cachichupa	O	2.0	36.0	12.6	2.48
Agua termal Coline	O	2.0	39.0	12.6	2.51
Agua termal Ocuviri	B	2.0	28.0	12.6	2.41
Agua termal Uchu Uma	B	2.0	52.0	12.6	2.62
Aguas calientes Bolognesi	B	2.0	44.0	12.6	2.55
Andaymarca	B	2.0	24.0	12.6	2.38
Collpa Apacheta	B	2.0	54.0	12.6	2.63
Macarí	O	2.0	15.0	12.6	2.31
Putina Punku-Alvarizani	O	2.0	47.0	12.6	2.57
Quilca Punku	O	2.0	58.0	12.6	2.67
Sasabin Punko-Huayllatoc	O	2.0	48.0	12.6	2.58
Untu Uma-San Luís	B	2.0	38.0	12.6	2.50
Pichacani-Santa Rosa	O	2.5	16.0	12.6	2.89
Agua mineromedicinal Marcani	B	3.0	22.0	12.6	3.55
Aguas Calientes-Río Jaruma	B	3.0	51.0	12.6	3.91
Aguas termales Ccahuaymayo	B	3.0	50.0	12.6	3.90
Baños Pacchanta	B	3.0	63.0	12.6	4.06
Ccomunto	O	3.0	25.0	12.6	3.58
Quellomayo	B	3.0	52.0	12.6	3.92
Uchullucllo	B	3.0	32.0	12.6	3.67
Yanaoca - Uccurmina	B	3.0	22.0	12.6	3.55
Agua termal Calachaca	O	3.0	49.0	12.6	3.89
Agua termal Juriruni	B	3.0	27.0	12.6	3.61
Agua termal Vidal Lama	B	3.0	47.0	12.6	3.86
Aguas Calientes-Pinaya	B	3.0	81.0	12.6	4.29
Baños termales W. Molina	B	3.0	47.0	12.6	3.86
Chacatira	O	3.0	55.0	12.6	3.96
Orcco Putina	B	3.0	46.0	12.6	3.85
Putina Cuyo	B	3.0	18.0	12.6	3.50

Locality	Type	Maximum Utilization			Capacity (MWt)
		Flow Rate (kg/s)	Temperature (°C) Inlet	Outlet	
Tolapalca	B	3.0	45.0	12.6	3.84
Puente Ccollo	O	3.3	79.7	12.6	4.70
Agua mineral Poccpoca	B	4.0	17.0	12.6	4.64
Baños termomedicinales Marcapata	B	4.0	63.5	12.6	5.42
Aguas termales Ollachea	B	4.0	70.0	12.6	5.53
Agua mineromedicinal Ccaylla	B	5.0	22.0	12.6	5.91
Agua termal Chaqueylla	B	5.0	54.0	12.6	6.58
Aguas calientes La Raya	B	5.0	52.0	12.6	6.54
Agua termal Infiernillo	B	5.0	38.0	12.6	6.25
Aquina	O	5.1	36.0	12.6	6.33
Aguas termales Hatun Phutina	B	5.5	59.0	12.6	7.35
Pasanoccollo	O	7.0	75.0	12.6	9.83
Agua mineral Ccollupata	B	8.0	12.0	12.6	9.12
Baños termales Lares	B	8.0	39.0	12.6	10.03
Salineras de Maras-Pichingoto	O	8.0	31.0	12.6	9.76
Pirín	O	10.0	8.0	12.6	11.24
Aguas termales Huayna Putina	B	11.0	50.5	12.6	14.32
Comermocco	O	13.0	18.5	12.6	15.18
Agua mineral Comopuquio	B	15.0	20.0	12.6	17.61
Balneario Pojcpoquella	B	20.0	36.0	12.6	24.81
TOTAL		**266.0**			**331.49**

Type B: Bathing and swimming (including balneology)
Type O: Abandoned

Table 12: Thermal Potential of Cusco – Puno geothermal region.

4.2.7 Other thermal areas

a. Geological Context

Outside the six geothermal regions described above, there are around 29 thermal areas, mainly located in central and northeast Peru, in the transition zone between the Andean Cordillera and the Amazon lowlands. These thermal areas occur in diverse geological contexts, with hot springs commonly discharging from quaternary non-consolidated deposits, and mostly associated with NW-SE structures and regional faults. The genesis of the thermal waters in most of these areas is likely related to deep circulation, but further studies are needed to understand the presence of these springs that in certain sites have temperatures close to the boiling point.

b. Thermal potential

Using the data available from 29 thermal areas and applying the methodology described in Section 3 above, we have estimated a theoretical thermal potential from hot springs discharges of around 83 MWt, of which, 37 MWt are being used in thermal bathing and healing facilities (table 12).

Locality	Type	Maximum Utilization			Capacity (MWt)
		Flow Rate (kg/s)	Temperature (°C) Inlet	Outlet	
Aguas Calientes-Contamana	O	0.5	84.0	12.6	0.70
Agua Salada	B	0.1	22.0	12.6	0.12
Qda. Juiz-Prusia	O	0.1	20.0	12.6	0.12
Los Hervideros	B	0.1	35.0	12.6	0.12
Colpar	B	0.5	25.0	12.6	0.57
Rentema	O	0.5	26.0	12.6	0.57
Salinas	B	0.5	20.0	12.6	0.56
El Almendral	B	0.5	35.0	12.6	0.62
Chazutayacu	O	0.5	35.0	12.6	0.59
Gramalote	O	0.5	26.0	12.6	0.57
San José	O	0.5	43.0	12.6	0.61
Corontochaca	O	1.0	25.0	12.6	1.15
Baños Termales San Mateo	B	1.0	41.0	12.6	1.21
Agua Sulfurosa La Bella	B	1.0	24.0	12.6	1.19
Aguas Termales Sulfurosas Paucarhuasi	B	1.0	41.0	12.6	1.21
Baños La Shayna	B	1.0	25.0	12.6	1.15
Yanayacu	O	1.0	48.0	12.6	1.24
Las Jeras	B	1.2	37.0	12.6	1.43
Picurohuasi	O	1.5	63.0	12.6	1.96
Pucayacu-Huallaga	O	2.0	56.0	12.6	2.55
Pucayacu-Achinamiza	O	2.5	50.0	12.6	3.12
Chaquil	B	3.0	23.0	12.6	3.41
La Urmana-Sacanche	B	3.0	39.0	12.6	3.61
Troncomocho	O	3.0	48.0	12.6	3.76
Canchahuaya	O	5.0	64.0	12.6	6.54
Michina	B	7.0	26.0	12.6	8.05

Locality	Type	Maximum Utilization			Capacity (MWt)
		Flow Rate (kg/s)	Temperature (°C) Inlet	Outlet	
Tocuya	B	10.0	28.0	12.6	11.58
Santa Clara	O	10.0	49.0	12.6	12.46
Shamboyaquillo	O	10.0	32.0	12.6	11.75
TOTAL		**68.5**			**82.53**

Type B: Bathing and swimming (including balneology)
Type O: Abandoned

Table 13: Geothermal Potential of thermal springs located outside the main geothermal regions.

5. CONCLUSIONS

a. Based on the information available from 297 hot spring areas, a total thermal discharge potential of around 2,000 MWt. has been estimated for Peru. This potential includes only the heat available at the surface from the natural discharge of hot springs and represents a minimum value for geothermal direct-use. It could be significantly higher if works (excavations, drilled wells) are performed to artificially increase the extraction of hot water from the subsoil, in sites where appropriate investigations demonstrate such extraction is technically and economically viable

b. The analysis of the estimated thermal potential indicates that the Eje Volcánico Sur has the higher value of thermal potential available on the surface all over the country. Cajamarca - La Libertad region is the second one, even when in this region there are only 20 thermal areas. This is because the hot springs in this region have the highest flow rate value, around 100 L/s.

c. From the analysis of the data, it is observed that in geothermal region Cajamarca – La Libertad, the number of thermal areas is 20, which has a total supply of thermal water of around 300 L/s. While region Eje Volcánico Sur, with 80 thermal areas, provides a total supply of around 550 L/s. This is due to the fact that the hot springs in region Cajamarca – La Libertad have a higher flow rate due to the highest precipitation that occurs in the northern part of the country, which benefits the recharge of the thermal aquifers. Therefore, even though region Cajamarca – La Libertad is not the one with the highest thermal potential in the country, it is a good place to start direct-use projects due to the large supply of thermal water.

d. The only direct use of geothermal energy in the country is for balneology, tourism, or recreation. This is also the only use or potential application recognized in planning public documents, such as the Regional Tourism Plans. The results of this study indicate that 60% (1,200 MWt) of the total hot spring discharge in the country is being used for balneology or recreation, while 800 MWt (40%) is still unexploited.

e. The geothermal regions that currently take the most advantage of the thermal potential of their hot springs for balneological, tourist, or recreational purposes are Churín (which uses 97% of its potential in 22 thermal areas), Central (which uses 97% of its potential in 16 thermal areas) and Cajamarca – La Libertad (which uses 93% of its potential in 16 thermal areas). While the geothermal regions that take the least advantage of their geothermal resources are: Eje Volcánico sur (which only uses 24% of its potential in 43 areas), Cusco – Puno (which uses 60% of its potential in 200 thermal areas), and Callejón de Huaylas (which uses 79% of its potential in 22 thermal areas). The thermal use in hot spring areas outside the main geothermal regions is 44% in 37 thermal areas.

f. In 66% of the geothermal regions, the mining sector plays a very important role in the local economy, either by generating jobs or through the payment of taxes (surface leases and royalties). Therefore, it constitutes a stakeholder that could become an investor or financier of future geothermal pilot projects for direct use, either for its own benefit (heating its facilities) or for the benefit of its partners in areas of influence. However, a strategic social management and communication strategy must be considered to avoid any social conflict and ensure that direct-use geothermal projects have a positive impact on people's lives and the local economy.

g. The desktop review conducted in this study indicates that there is a demand for heat from various sectors of the local economy in the six geothermal regions, be it the mining sector to heat its facilities, the agricultural sector to improve its production, with greenhouses for farmers; or housing, to improve the living conditions of the population most vulnerable to climatological phenomena, such as frost or cold. However, with the current information, it has only been possible to identify synergies with the mining sector, where projects are located in areas close to thermal springs. For a better analysis of development possibilities in the agricultural, domestic and district heating, and other sectors, further studies based on fieldwork are necessary.

h. Geothermal, as an energy resource, is included in only one of the local planning policies (PDC Tacna). This evidences the need to educate and strengthen the articulation between the authorities and the technical agencies of the State in charge of promoting the development of renewable energy applications. If decision-makers are not aware of geothermal energy and its possible applications beyond electricity generation, the development of direct uses may be limited.

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