Geothermal energy as a sustainable solution for Peru: perceptions of experts and students to address technological, economic and environmental challenges in Arequipa

Student: Mariana Nalvarte

Capstone Mentor: Nataliya Apanovich

Capstone Instructors: Nataliya Apanovich & Sandra Bernal

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Abstract

Geothermal energy presents a viable solution for sustainable energy development in Peru, particularly in Arequipa, which possesses significant geothermal potential due to its volcanic activity. This study focuses on the perceptions of professionals and students in the sustainable field regarding the social, economic, and environmental challenges of implementing geothermal resources in Arequipa. A qualitative methodology was employed, utilizing perception analysis through interviews with experts and students, alongside a case study of the Achumani Geothermal Project and a comprehensive document review. The results reveal that while geothermal energy can diversify Peru's energy matrix and reduce reliance on hydroelectric power, barriers such as high initial costs and insufficient regulatory frameworks impede its development. The discussion highlights the need for targeted policy recommendations and community engagement to overcome these challenges. Ultimately, this research concludes that harnessing geothermal energy is essential for addressing Arequipa's growing energy demands sustainably and improving local living conditions.

Keywords: Geothermal energy, Arequipa, barriers

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I. Introduction

Geothermal energy is a renewable energy form that is derived from the heat stored within the Earth. Nearly 4.5 billion years ago, the young Earth was a hot, molten sphere of liquid and gas. As it gradually cooled and solidified, it formed a rocky crust, giving rise to the continents. Inside the Earth, magma (molten rock at high temperatures) is continually produced and may rise to the surface. When it cools, it transfers heat to the surrounding rocks (INGEMMET & Peruvian Ministry of Energy and Mines MINAM, 2023).

This heat can be seen in visible forms of geothermal energy, such as volcanoes, hot springs, fumaroles, and geysers. These natural phenomena occur when underground water encounters deep rocks at high temperatures, and this hot water rises to the surface. Geothermal energy is a clean, renewable source of power that is continuously produced and has become crucial in helping satisfy our energy needs (INGEMMET & Peruvian Ministry of Energy and Mines MINAM, 2023).

The importance of geothermal energy lies in its potential to help countries achieve energy independence. By utilizing geothermal energy, many countries can generate their own electricity and provide heating. In the case of Peru, geothermal energy offers great potential for generating both electricity and heating, which could help reduce reliance on external sources of energy such as fossil fuels (oil and diesel), hydroelectric power plants and even coal (INGEMMET & Peruvian Ministry of Energy and Mines MINAM, 2023). To be precise, 36% of energy from fossil fuels and 58% of energy from hydropower (Center for Strategic and International Studies CSIS, 2023).

Peru is particularly rich in geothermal resources. The country has over 500 thermal springs scattered across its territory. According to the Geothermal Map of Peru, the country is divided into six geothermal regions: Cajamarca-La Libertad, Callejón de Huaylas, Churín, Central region, Cusco-Puno, and mostly the Southern Volcanic Belt (INGEMMET & Peruvian Ministry of Energy and Mines MINAM, 2023).

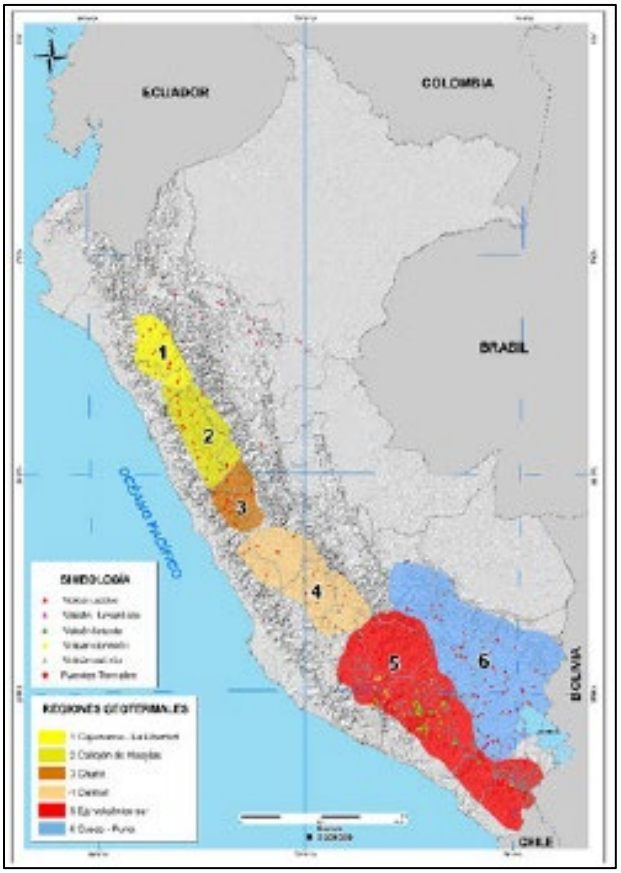

Figure 1: Geothermal Map of Peru (INGEMMET & Peruvian Ministry of Energy and Mines MINAM, 2023).

Among these regions, the Southern Volcanic Belt (Red), which includes the departments (regions equivalent to a state) of Tacna, Moquegua, Arequipa, and Puno, holds the most promise for electricity generation due to its high geothermal potential. This region, part of the Pacific Ring of Fire, is where tectonic plates converge, creating ideal conditions for volcanic activity and geothermal energy. This study focuses on Arequipa to exemplify geothermal potential as well as its limitations.

Geothermal energy in Peru has numerous possible applications. It can be used for district heating to warm entire buildings or neighborhoods, which would be particularly beneficial for the southern regions of the country, where harsh winters and frosts are common. In addition, hot springs provide recreational opportunities, and geothermal energy can also be used in food processing (such as dehydrating fruits and vegetables), greenhouses to heat spaces for growing crops, and in wood product preparation (such as drying wood and paper).

Furthermore, geothermal energy can benefit aquaculture by speeding up the growth of fish, shrimp, and even reptiles (INGEMMET & Peruvian Ministry of Energy and Mines MINAM, 2023).

One of the key advantages of geothermal power plants is that they do not require fossil fuels to generate electricity. Instead, hot water and steam are used to drive turbines, creating a closed-loop system where the steam is re-injected into the Earth. This process does not emit pollutants or greenhouse gases, making geothermal energy an environmentally friendly and sustainable option for power generation. The fact that geothermal plants do not burn fossil fuels means they help maintain clean air and reduce the negative environmental impacts typically associated with energy production.

According to the Geothermal Master Plan, there is a potential of close to 3000 MW. Figure 2 shows the exact potential of all the regions, including the "Southern Volcanic Belt" (the greatest potential) 1600 Mwe/57% of Peruvian's total geothermal potential belongs here.

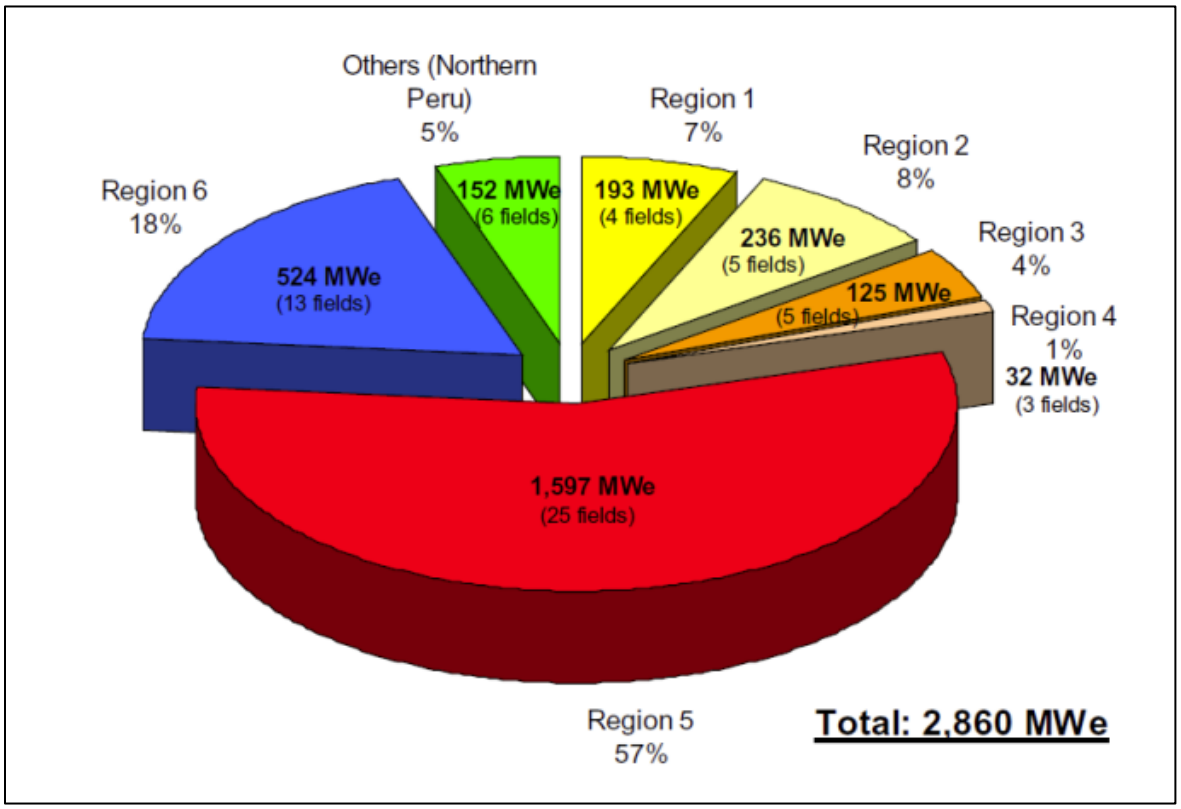

Figure 2: Geothermal Master Plan (Electricity General Directorate, Electricity Concessions Directorate & Peruvian Ministry of Energy and Mines MINAM, 2023).

According to the Geothermal Master Plan, there is a potential of close to 3000 MW. Figure 3 shows the exact potential of all the regions, including the "Southern Volcanic Belt" (the greatest potential.)

For Peru, looking into its geothermal potential could help diversify the country's energy matrix, reducing dependence on imported fossil fuels. This can be researched with the Achumani Project, precisely in the Arequipa Region.

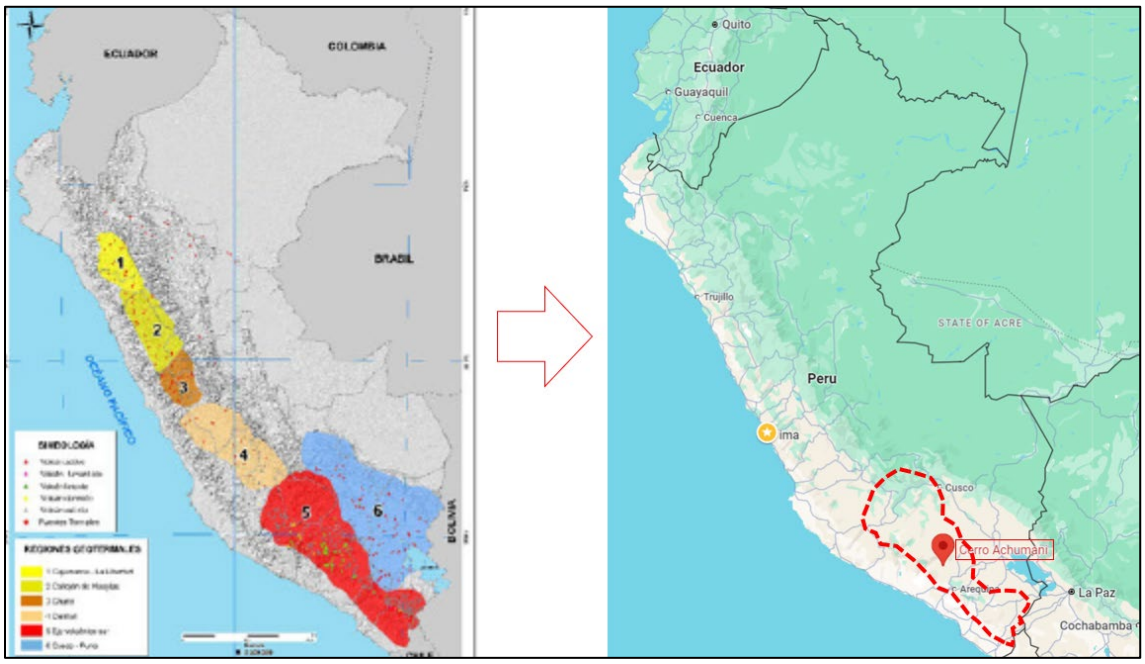

Figure 3: Achumani (Chivay), Arequipa as part of the Southern Volcanic Belt. (INGEMMET & Peruvian Ministry of Energy and Mines MINAM, 2023).

Additionally, using geothermal energy for heating in the high-altitude regions of the Andes would greatly improve the living conditions of people who face the challenges of cold temperatures. This makes continuing geothermal studies and investigations essential to fully exploit this valuable resource. It is a fact that geothermal energy is an abundant, renewable, and sustainable resource that can significantly contribute to Peru's energy needs, reduce environmental impacts, and improve the quality of life, especially in colder regions of the country (INGEMMET & Peruvian Ministry of Energy and Mines MINAM, 2023).

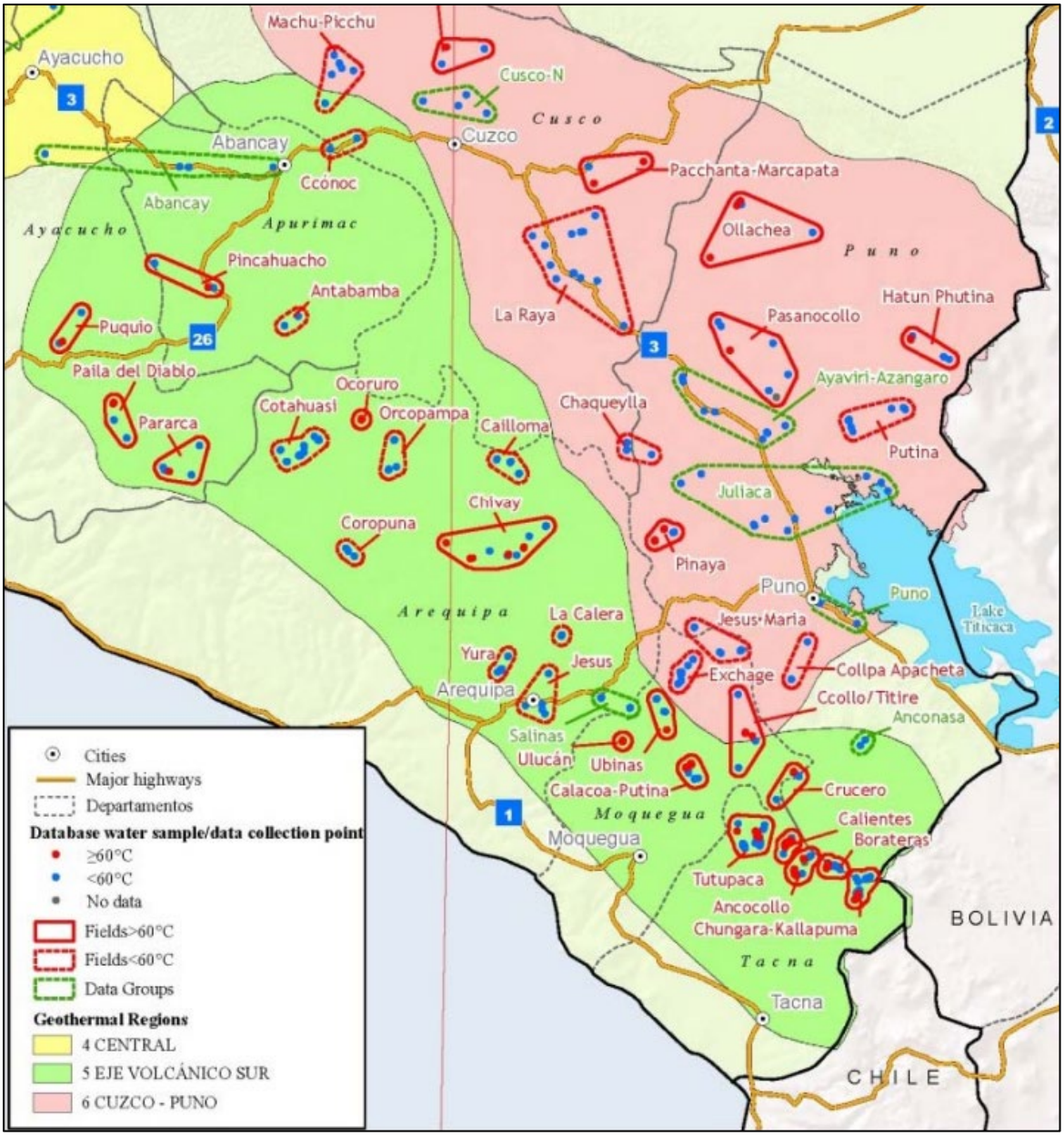

Figure 4: Achumani (Chivay), Arequipa as the region with most data collection points superior to 60°C, in the Southern Volcanic Belt (Engineer Alcides Pacheco & Peruvian Ministry of Energy and Mines MINAM, 2023).

I.I Literature Review

Table 1: Literature Review focused on Achumani Project

Title & Year	Author(s)	Sub-Topic	Main Findings
"Evaluación de la Viabilidad del desarrollo Geotérmico del campo Chivay-Pinchollo en la región Arequipa para generación eléctrica con el fin de diversificar la matriz energética del Perú" (2017)	• Ofélia Arcos • Elmer Francisco • Oscar Soto • Luis Torres	True Viability of Project Achumani	The thesis evaluates the economic and financial viability of the Chivay-Pinchollo geothermal field project in Arequipa, Peru. With a potential of 114 MW and an expected plant capacity of 90 MW, the project requires an investment of $436.9 million USD and a seven-year development period. The study suggests the project is feasible with a minimum auction price of $67.65 USD/MWh, yielding a net present value (NPV) of $57.38 million USD and an internal rate of return (IRR) of 11.01%. The project could enhance Peru's energy security and reduce dependence on external sources.
"Regional Agreement Nº 039-2017-GRA/CR-Arequipa" (2017)	Regional Government of Arequipa		The Government of Arequipa has declared the promotion of private investment in geothermal resource exploration and exploitation as a regional priority. This decision aims to generate electricity from geothermal energy, contributing to economic development, job creation, and the diversification of Peru's energy matrix. The region, particularly the Chivay-Pinchollo geothermal field, has significant potential, with an estimated 497 MW capacity. The initiative supports sustainable development and aligns with national energy policies focusing on renewable energy sources. Additionally, efforts will be made to include geothermal energy in the national renewable energy auctions.
"Empresa privada plantea instalar energía geotérmica en la provincia de Caylloma para electrificar zonas altoandinas" (2020)	Regional Government of Arequipa (Press Release)		Arequipa aims to become a leader in geothermal energy in Peru, with a planned 100 MW geothermal plant in Caylloma by Energy Development Corporation (EDC). The project is expected to generate 1,700 direct and 8,500 indirect jobs, with a total investment of S/ 1,800 million. It will provide electricity and heating to high-altitude areas. The project has completed the exploration phase and will soon begin environmental studies. The government is supporting geothermal development to address energy needs in the south of Peru and boost economic growth.
"El mayor proyecto geotérmico en el mundo lo tiene Arequipa, pero con un futuro incierto" (2020)	Perú Energía News Report	Potential of Project Achumani	The Achumani geothermal project in Arequipa, driven by Energy Development Corporation (EDC), has significant potential, surpassing even the Leyte geothermal plant in the Philippines. With a geothermal reservoir double the size of Leyte's, Achumani could become a world-class facility. The project, requiring an investment of $500 million, could generate 350 MW, powering 385,000 homes in Arequipa. However, its development is delayed due to the lack of a new renewable energy auction, which limits the ability to secure contracts for electricity supply
"Arequipa declara de interés regional la explotación de recursos geotérmicos" (2017)	Rumbo Minero News Report		The Government of Arequipa has prioritized promoting private investment in geothermal resource exploration and exploitation to generate electricity. The region, with its high volcanic activity, holds significant geothermal potential, including the Chivay-Pinchollo field, which can produce up to 150 MW. Peru aims to diversify its energy matrix, focusing on renewable sources like geothermal, which is widely used in countries like the U.S., Philippines, and Indonesia. This aligns with the National Energy Policy for 2010-2040, targeting stable, clean, and renewable energy generation.

I.II Problem Statement

Despite its significant geothermal potential, Southern Peru faces challenges in meeting its growing energy demands sustainably. The region's reliance on external sources for electricity generation creates vulnerabilities in its energy supply.

I.III Description of the Problem

Recent data indicates that Arequipa's total energy production is approximately 770 MW; however, its demand is nearly double this figure. The current energy supply consists primarily of hydroelectric power generated from plants located in central Peru, supplemented by thermal plants that burn natural gas sourced from southern Lima (Figure 5). Hydropower relies on water availability, which can be inconsistent due to changing rainfall patterns, reducing energy production in dry seasons. Natural gas, while abundant, contributes to greenhouse gas emissions, which exacerbates climate change. This reliance on external sources highlights the urgent need for local renewable energy solutions (ESMAP: Peruvian Energy generation and consumption, 2022).

It is also important to consider the correlation between these two aspects. Electricity constitutes 40% of the energy supply and is primarily consumed by the industrial sector (35%) and the residential sector (25%). This indicates that a significant portion of electricity generated is directed toward industrial activities, particularly mining while also meeting residential needs. Natural gas accounts for 30% of the total energy supply and is utilized across both industrial (in mining operations) and residential sectors (for cooking and heating). This dual usage highlights its importance as a versatile energy source.

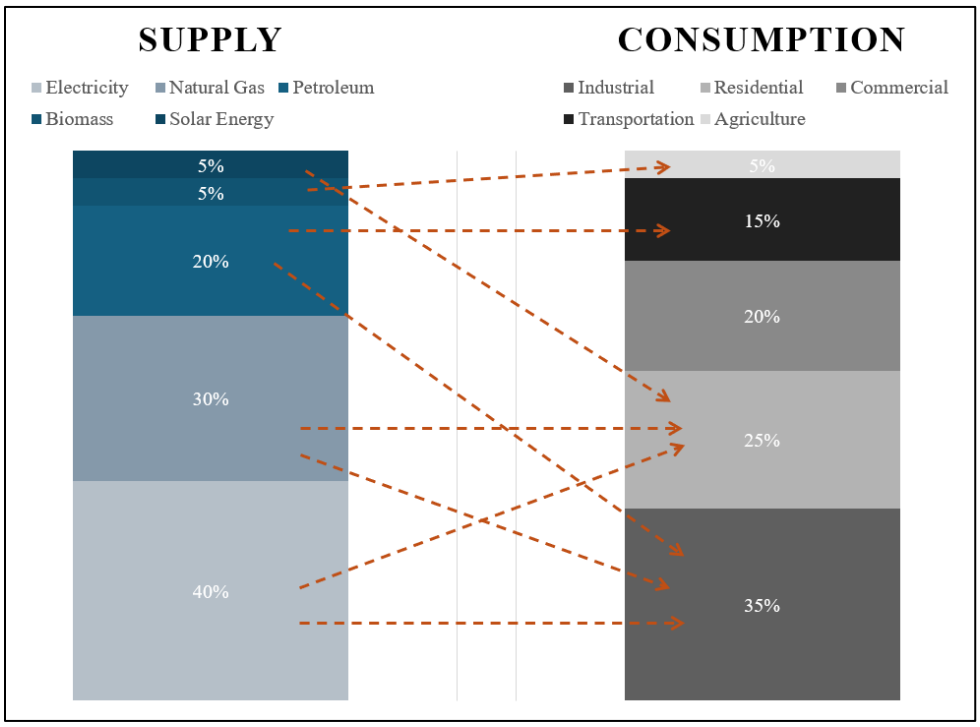

Figure 5: Energy supply and consumption in the city of Arequipa (Peruvian Ministry of Energy and Mines, 2023).

There is a very important focus on geothermal energy and mining. As shown before, the highest sector percentage of energy consumption is the industrial with 35%. Arequipa is a key mining region in Peru, known for its significant mineral deposits, particularly copper, gold, and silver. The region hosts major mining operations, such as the Cerro Verde and Tía María mines, which contribute significantly to the national economy (Piensa Geotermia, 2023; Rumbominero, 2023).

Mining activities in Arequipa have spurred both local development and environmental concerns, with debates over sustainability and the impacts on surrounding communities (Perú Energía, 2023). Arequipa being a mining region, and having the industrial sector as the primary energy consumer, leads to wonder what can geothermal energy do specifically on the mining sector. Some mining activities include some of the applications shown in the Lindal diagram (Figure 6). This diagram is a visual representation of how geothermal energy resources of different temperatures can be used for a variety of applications, including mining ones, indispensable for Arequipa's industries. (Grocentre, 2022).

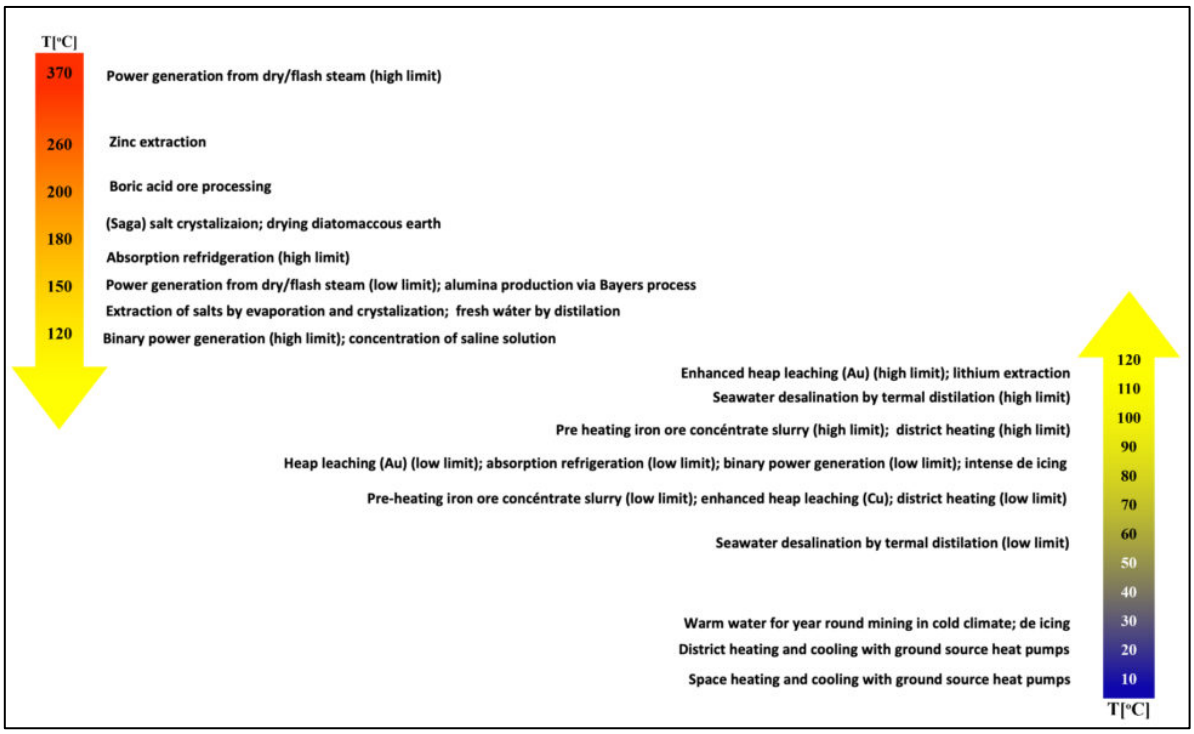

Figure 6: Lindal Diagram – Mining Applications Using Geothermal Resources, Patsa 2015.

I.IV Justification

The growing demand across various sectors underscores the necessity for sustainable energy solutions that can support economic growth while minimizing environmental impacts. Geothermal energy has immense potential to help meet Arequipa's energy needs significantly. According to estimates from Energy Development Corporation (EDC), Peru has a total geothermal potential exceeding 3,000 MW across various regions, with more than half concentrated in southern Peru—specifically Arequipa. If even a fraction of this potential were developed—say around 60%—it could lead to an installed capacity exceeding 1,800 MW from geothermal sources alone. This would position Peru among the top five countries globally in terms of geothermal power generation capacity.

II. Research Question

How the perception of experts native to Peru and students that will soon be proactive in the field can inform stakeholders about the social, economic and environmental advantage of the adoption of in geothermal energy generation in Arequipa?

III. Objective

The objectives are to explore and ultimately demonstrate to stakeholders in the industry with perception of professionals and soon to be professionals in the field how geothermal potential can provide a sustainable solution to Arequipa's growing energy demand, by addressing the barriers and implications, and comprehending why geothermal energy hasn't been yet applied in Arequipa, and to what must happen in order to be able to implement it.

IV. Methodology

For this project, a qualitative approach will be utilized to explore the potential of geothermal energy as a sustainable solution for energy challenges in Arequipa. This approach will allow for a comprehensive understanding of the implications for the application of geothermal energy in Arequipa.

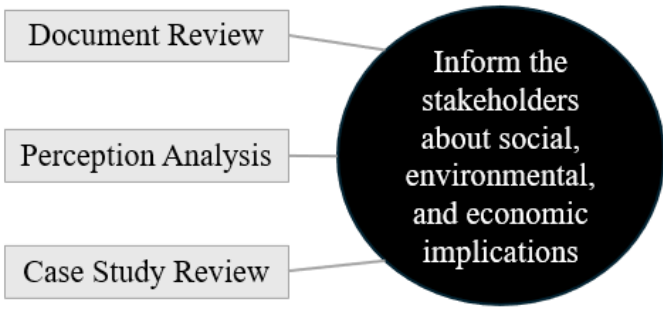

Figure 7: Methodology of the Research.

The research will be divided into three primary methodologies:

IV.I Perception Analysis

The Perception Analysis focuses on gathering qualitative data regarding the attitudes, opinions, and perceptions of a professional (expert on the area) and soon to be proactive professionals (students of environmental engineering and mining engineering that are looking into the future of Peru's potential to renewable resources of energy) toward the implementation of geothermal energy. This section aims to identify the viewpoints of them that may influence the acceptance and adoption of geothermal technologies in the region. By understanding how they perceive geothermal energy, the study is able to highlight potential

barriers to acceptance, public concerns, and opportunities for awareness and education that will be indispensable to inform the stakeholders.

To identify study participants, the author relied on her network within the mining sector and reached out to industry experts, such as engineers, environmental specialists, and faculties of environmental and mining engineering in universities. The final decision was to interview an expert on the field, as well as thirty students of environmental engineering and mining engineering of Universidad Peruana of Ciencias Aplicadas (Lima, Perú) and Universidad Cientifica del Sur (Lima, Perú).

In the case of the interview, it was conducted via phone calls and audio recorded. They were informed about the research purpose and consent for recording was also obtained. This interview follows a structured format, using a set of previously organized questions. The transcribed data are analyzed qualitatively through thematic analysis, by identifying recurring themes, and grouping similar responses to gain insights into the mining sector's energy use and sustainability practices.

1. Interview with the Specialist:

The specialist for the interview has a Bachelor of Science in Environmental Engineering and a Master of Science in Mechanical and Electrical Engineering degrees. She has led renewable energy and climate change related projects with high social impact locally and abroad. She works as a Developer of New Businesses in a global company specializing in engineering, construction, and renewable energy projects; and she’s in charge of the development and the follow-up of renewable energy projects. She is the ideal candidate for the interview given her expertise, her experience with renewable energy projects (which are extremely limited in Peru) and she has worked for several years for a company that administers three mining companies in Arequipa so she is very well informed of all the aspects mentioned throughout this study.

The interview questions focus on understanding the challenges and opportunities related to geothermal energy development in Arequipa. They aim to explore the technological barriers and potential solutions for implementing geothermal energy, as well as the reasons behind the current low economic feasibility compared to other renewable sources like solar or wind.

The questions also emphasize the importance of environmental sustainability in geothermal projects, seeking input on key environmental considerations. Additionally, the role of government policies in supporting geothermal energy development is discussed, along with the need for collaboration between government, the private sector, and local communities to overcome social, financial, and technical obstacles for successful project implementation.

2. Surveys with the Students:

Environmental engineering and mining engineering students are key, soon-to-be professionals in the field, who will be deciding Peru’s future in geothermal energy. As the next generation of professionals, they will shape how sustainable energy projects are developed, implemented, and managed. Their education gives them the technical know-how and environmental awareness needed to address challenges like minimizing environmental impacts while maximizing the benefits of geothermal energy. These students are trained to think critically about the social, technological, and ecological consequences of energy projects, making their perspectives incredibly valuable in ensuring geothermal projects are not only efficient but also responsible and community friendly. As passionate advocates for renewable energy, they are likely to support geothermal as a clean and sustainable solution to Peru’s energy needs, helping to shift policies and public opinion. Through their research and innovation, they can contribute to improving geothermal technologies and making them more accessible. With their interdisciplinary training, environmental engineering students are equipped to collaborate with experts from various fields, ensuring that geothermal projects are well-rounded and effective. In short, their voices matter because they are the ones who will lead the way in making geothermal energy a central part of Peru’s sustainable future.

The survey questions aim to explore student awareness, opinions, and perceptions about geothermal energy in the context of Arequipa and Peru. They assess familiarity with geothermal energy as a renewable source, its potential contribution to the national energy grid, and its relevance for Arequipa's regional energy needs. The questions also explore perceived barriers to geothermal energy development, such as technological, financial, environmental, and social challenges. Additionally, the survey addresses students' views on the sustainability and viability of geothermal energy in meeting Arequipa's energy demands, as well as their assessment of government support and priorities for successful

implementation. Environmental impacts, carbon emission reductions, and research priorities for advancing geothermal projects are also examined.

IV.II Case Study Review

The Case Study Review is based on the Achumani Geothermal Project in Arequipa, which serves as an exemplary case of geothermal energy development within the region. The Achumani project is an ongoing geothermal exploration initiative that aims to harness the region's abundant geothermal resources for electricity generation and other energy needs. This case study will analyze the technological, economic, and environmental aspects of the project, focusing on its design, implementation, and the challenges faced in its development. The analysis will include a detailed review of the project's objectives, the role of local and national stakeholders, and the lessons learned from its progress.

By examining the Achumani project, this study will provide insights into the practical challenges of geothermal energy deployment in Peru, particularly in a region like Arequipa, which has significant geothermal potential. The case study will also offer valuable lessons for future geothermal projects in the country, highlighting both the successes and the obstacles encountered during the implementation process.

Figure 8: Arequipa's volcanic ground. Photography retrieved from Rumbo Minero, 2017.

The Achumani Geothermal Project is located in the Arequipa region of Peru, led by the Energy Development Corporation (EDC). The project aims to harness geothermal energy from the untapped resources beneath the region to provide a stable and renewable source of electricity. Arequipa currently relies heavily on solar energy for power generation, but geothermal energy presents a more consistent alternative, which has not yet been fully utilized (Regional Government of Arequipa, 2020)

The Achumani geothermal plant, with an estimated capacity of 110 MW, has an estimated Capital expenditure of around $560 million. The project is located in the district of Cabanconde, in the province of Caylloma, south of the Arequipa region (ThinkGeoEnergy, 2020).

The geothermal reservoir supporting the Achumani project is said to be approximately twice the size of the reservoir supporting the Leyte geothermal plant in the Philippines, covering 58 km² compared to Leyte's 29 km² (Eastland Generation, 2021). The Achumani project has the potential to become one of the largest geothermal power plants in the world. Its projected capacity is 350 MW, with an initial aim of generating 100 MW, enough to supply power to around 385,000 households, or approximately 90% of families in Arequipa (ESAN Repository, 2017).

The development of Achumani is expected to require an investment of around $500 million, with a projected timeline of six to seven years. The project is intended to address energy supply issues in southern Peru, particularly in Arequipa, which faces transmission line congestion and a heavy dependence on hydroelectric power (Regional Government of Arequipa, 2020).

"This project would create 1,700 direct jobs and 8,500 indirect jobs and represents an investment of S/ 1,800 million, enabling the provision of electricity and heating in the high Andean areas" (Regional Government of Arequipa, 2020).

The Peruvian government has shown an interest in promoting private investment in geothermal energy to explore and exploit the country's geothermal resources. In South America, countries like Chile and Bolivia have already made strides in geothermal

development, with Chile's Cerro Pabellón geothermal plant representing the first commercial geothermal facility in the region (ESAN Repository, 2017).

The government has also created mechanisms to support renewable energy initiatives, such as financing options provided by international organizations like the Japan International Cooperation Agency (JICA) and the Inter-American Development Bank (IDB) (PIENSA Geotermia, 2020).

The Achumani project will play a role in diversifying Peru's energy matrix, which currently relies heavily on hydroelectric power and natural gas. Geothermal energy offers a high-capacity factor (around 95%), providing a stable and reliable energy source unaffected by seasonal or climatic variations, unlike hydroelectric power (Perú Energía, 2020).

The project has an associated risk: the lack of a new renewable energy auction, which would allow geothermal energy to participate in the national electricity market and secure long-term contracts. This barrier could slow the development of the project (Perú Energía, 2020).

Now, to be exact with numbers, in the hypothetical case that Achumani project became a reality, a series of calculations will be made in order to determine the percentage of Arequipa's energy consumption that will be covered by the project's energy potential. Following the next steps: Convert the geothermal potential (MW) to GWh: The Achumani project's potential is 110 MW (ThinkGeoEnergy, 2020). To find the annual energy production, we multiply by the number of hours in a year (8760 hours).

Geothermal Annual Output (GWh)=110 MW×8760 hours/year=962,600 MWh=**962.6 GWh**

1. Calculate the percentage covered: Now, divide the geothermal energy potential (in GWh) by Arequipa's total energy consumption of 5,240.090 GWh (CIEC, 2021), and multiply by 100 to get the percentage.

Percentage Covered=(962.6 GWh5,240.090 GWh)×100≈**18.4%**

So, the Achumani geothermal project would cover approximately 18.4% of Arequipa's annual energy consumption. Another interesting figure only focusing on housing electricity, according to El Peruano (2023), is that "100 MW can provide electricity to 90% of households in the Arequipa region."

Figure 9: CEO of Private Investment GORE-Arequipa, Dr. Augusto Palaco Toro, informing that the company Energy Developed Corporation Perú (EDC) plans a construction of a geothermal central that generates 110 MW in Achumani, in the province of Caylloma. Photography retrieved from gov.pe (2020).

IV.III Document Review

Document review involves analyzing public reports, case studies, and industry documents related to geothermal energy and energy use in Arequipa. These documents are compilated from web search using key words including: [geothermal energy], [geothermal energy potential in Arequipa], [Achumani geothermal project], [Peru government geothermal energy], among others. By this review, secondary data that provides context and deeper insights into the social, economic, and environmental factors influencing geothermal energy adoption can be gathered. This method will complement the primary data from interviews, survey, and case study analogy, helping to enrich the analysis and provide a more comprehensive view of the challenges and opportunities for geothermal energy in the region. These documents combined with the rest of the literature will be discussed further, interrelating concepts and taking information of each one to get a broader understanding of their content. The four documents reviewed for the research are the following: “Evaluación de la Viabilidad del desarrollo Geotérmico del campo Chivay-Pinchollo en la región Arequipa para generación eléctrica con el fin de diversificar la matriz energética del Perú” (2017), “Energía Geotérmica” (2023), “Regional Agreement N° 039-2017- GRA/CR-Arequipa” (2017), and “Geothermal energy in Perú” (2017).

V. Data Results

In this section, the findings from the research methodologies—Perception Analysis and Case Study Analysis—will be presented. The data collected from these methods will provide a comprehensive view of the potential and challenges of geothermal energy in Arequipa, particularly in the context of the Achumani Geothermal Project. The results will highlight key insights into public attitudes, technological feasibility, economic viability, and environmental considerations that are crucial for the successful implementation of geothermal energy solutions in the region.

V.I Interview and Surveys

The interview leads to the right direction in identifying common themes regarding the general awareness of geothermal energy, the level of support for its development, and any concerns or reservations held by the local population. (Interview transcript in Annex A).

The interview highlights key challenges and considerations for geothermal energy development in Arequipa. She pointed out technological barriers such as the lack of updated studies on geothermal resources, which creates uncertainty for private investors due to the high financial risks of exploration. She emphasized the need for more fieldwork to attract investment and noted that geothermal technology must be adapted to Peru's high-altitude conditions, which adds complexity.

Regarding economic feasibility, she explained that geothermal projects require higher initial investments than wind or solar energy projects. The exploration phase, which can last up to 9 years, involves significant financial risk, especially since resource confirmation only comes after considerable investment. While the costs of geothermal technology have decreased globally, Anaís mentioned that wind and solar remain more competitive due to their shorter development timelines and lower costs.

On environmental considerations, she stated the importance of thorough environmental assessments, especially since geothermal sites in Arequipa overlap with regions of high natural value, such as the Colca Canyon. She also highlighted the need for transparency and community engagement to avoid resistance to projects.

In terms of government policies, she noted that while the regulatory framework exists, it is essential for policies to provide financial incentives, such as tax exemptions or subsidies. She also emphasized the importance of funding educational programs to create local expertise in geothermal energy, which would help avoid delays and ensure proper project management.

Finally, she suggested that collaboration between the government, private sector, and local communities is vital for overcoming the challenges of geothermal development. The government must streamline permits, update regulations, and provide financial support, while also fostering partnerships with universities and local communities to ensure that geothermal projects are both technically and socially feasible.

This interview shows that geothermal energy has significant potential in Arequipa, but overcoming technological, financial, and social barriers will require a coordinated effort from all sectors. Our expert suggests that with the right policies, investments, and collaboration, geothermal energy could become a crucial part of Arequipa's energy future.

Survey Results:

Surveys were conducted through Google Forms. The following graphs show the results to every question, and there was a total of 30 students of Environmental Engineering and Mining Engineering that participated on it.

- Almost three-fourths of the students were familiar with geothermal energy in some degree:

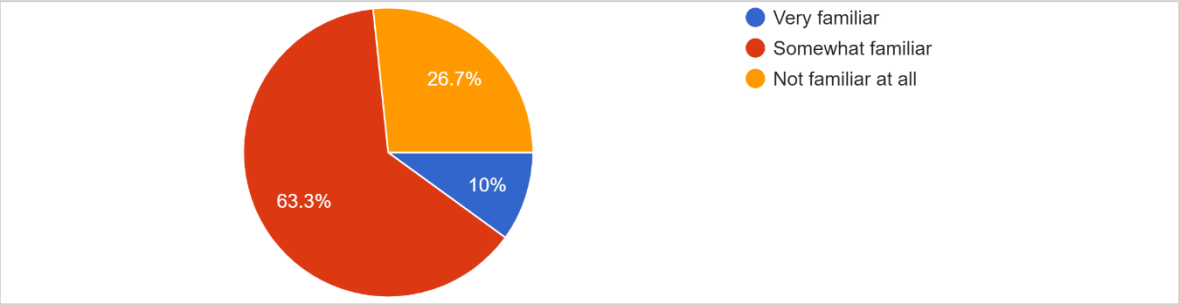

Figure 10: Familiarity with geothermal energy as a renewable source of energy among students.

- 80% of the students believe in the geothermal potential of Peru:

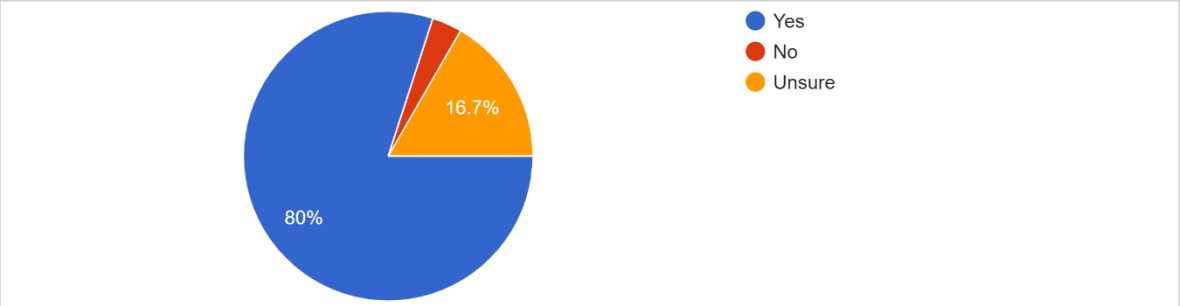

Figure 11: Students' tendency to believe that geothermal energy has great potential in Peru.

80% of the students believe in the geothermal potential of Peru.

- More than 80% of the students are positive this solution might work for Arequipa, Peru:

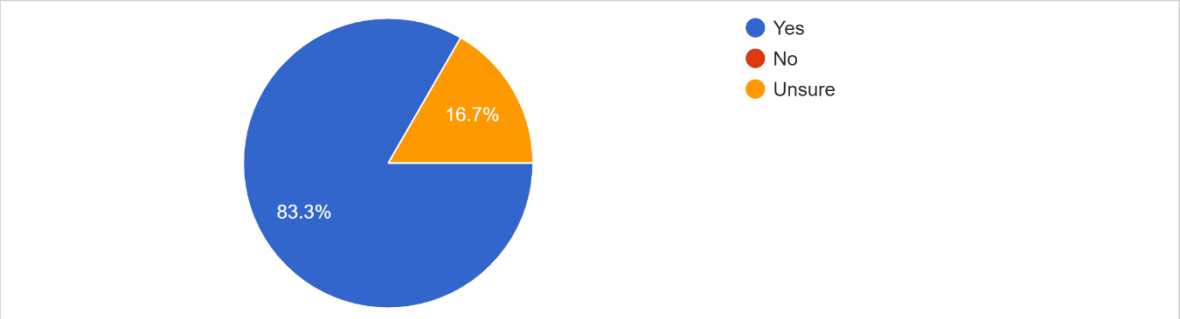

Figure 12: Students' opinion on geothermal potential specifically in the volcanic grounds of Arequipa.

- Almost three-fourths of the students identify lack of investment as our primary issue:

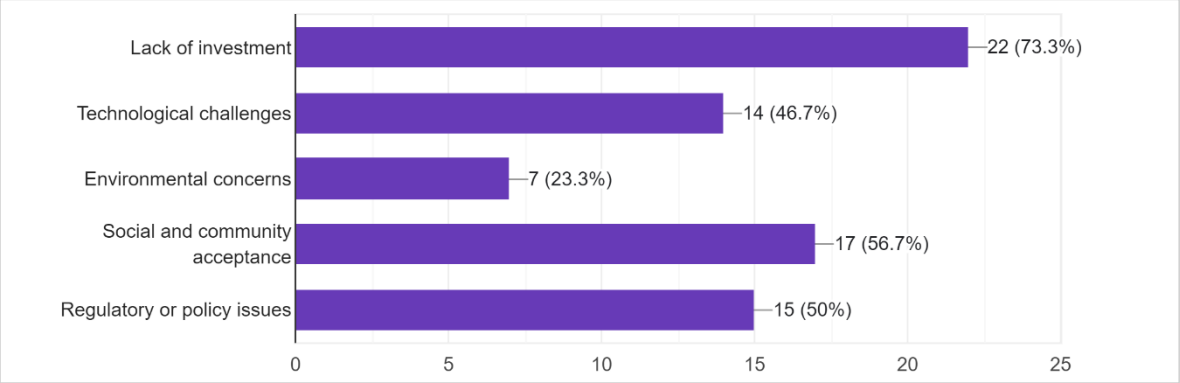

Figure 13: Students' perception on the main barriers to the development of geothermal energy.

- 90% of students, a very high number, think that geothermal energy is a solution for Arequipa specifically.

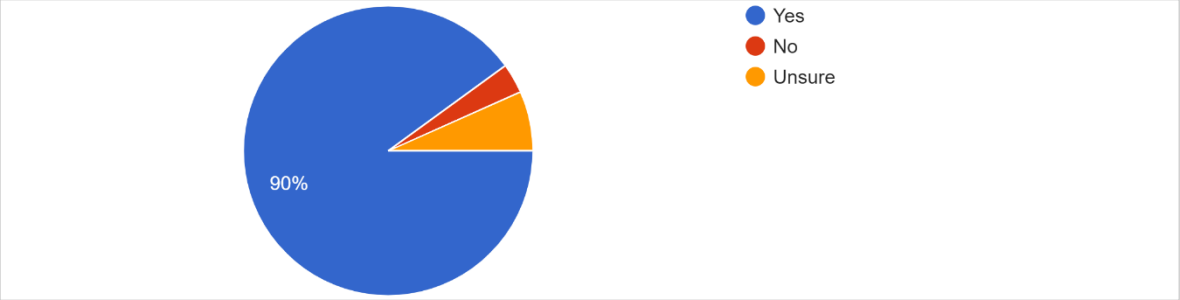

Figure 14: Students' perception on geothermal energy meeting Arequipa's energy demands.

- More than half of the students agree that the government gives weak support for these projects. 70% stand in the weak or no support range.

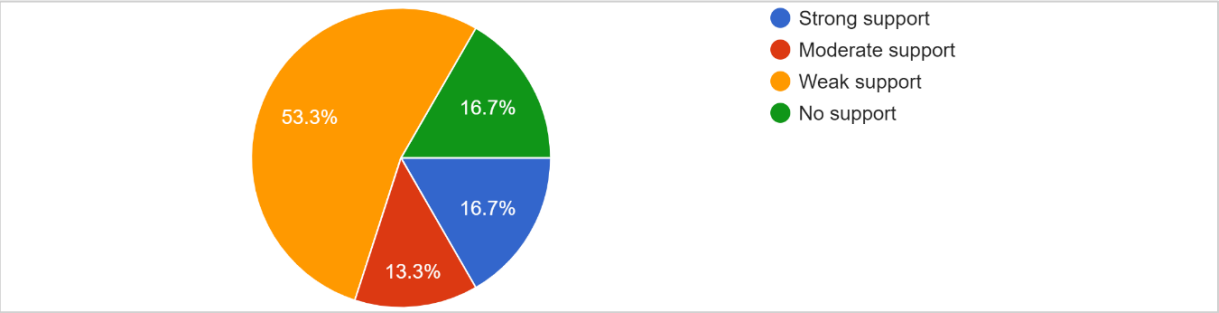

Figure 15: Students' perception of the government's support on sustainable energy sources such as geothermal energy.

- Investment of technology is led by half of the answers as a factor of prioritization:

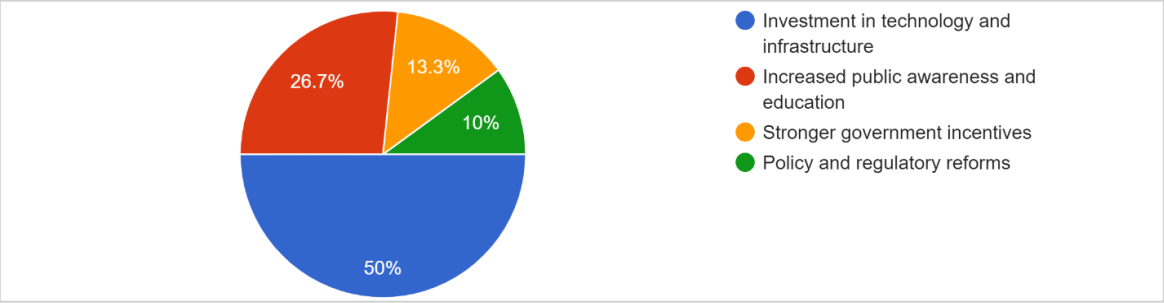

Figure 16: Students' perception of what should be prioritized of the successful implementation of geothermal energy in Arequipa.

- Almost all students (95% +) agree that geothermal energy can reduce carbon emissions.

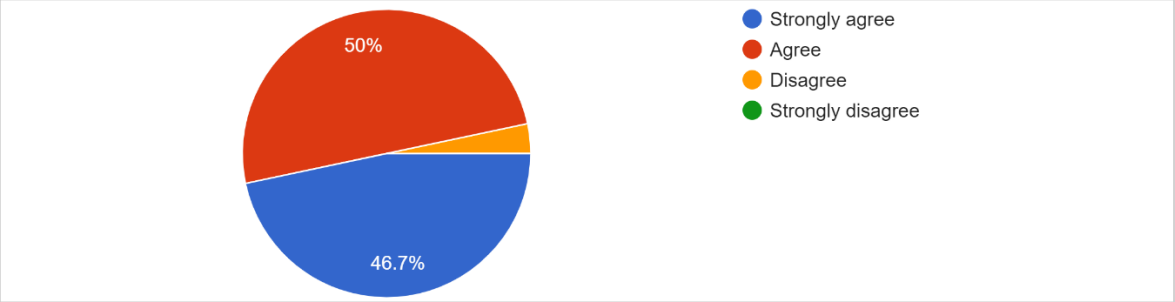

Figure 17: Students' perception of the potential that geothermal energy as a factor to significantly reduce Arequipa's carbon emissions.

- Moderate and high impact lead by more than 70% of students, which implies that they are aware of the environmental implications of geothermal energy application.

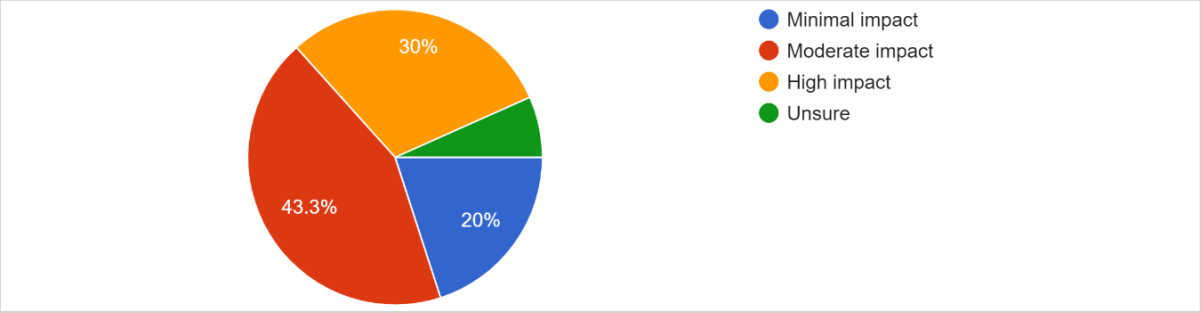

Figure 18: Students' perception of the environmental impact of geothermal energy

- Experimentation on technology and environmental impact are the most important research that students consider.

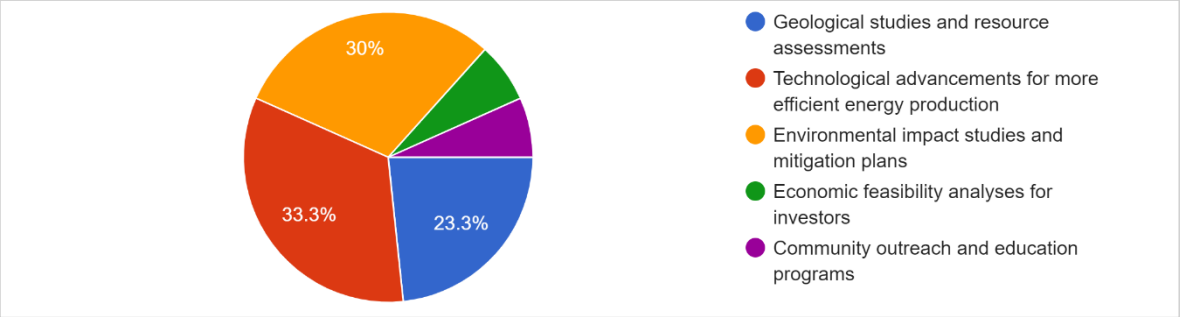

Figure 19: Students' perception of the most important implication to prioritize to accelerate geothermal energy projects in Peru.

The survey results, collected from 30 students of Environmental Engineering and Mining Engineering, offer a comprehensive view of the perceptions and knowledge regarding geothermal energy in Arequipa. Overall, most participants were somewhat familiar with geothermal energy (63.3%), indicating a moderate level of awareness within the academic community, though 26.7% were not familiar at all. This suggests that while geothermal energy is recognized as a potential renewable energy source, it may not be as well understood compared to other more commonly discussed alternatives.

A notable 80% of respondents believe that geothermal energy has significant potential to contribute to Peru's national energy grid, with 83.3% agreeing that Arequipa could specifically benefit from its geothermal resources. This widespread optimism aligns with the growing recognition of geothermal energy's potential, especially in a region like Arequipa, which is rich in geothermal resources.

Identifying the primary barriers to the development of geothermal energy in Arequipa, reveal insights into the challenges faced by the sector. The most significant barrier identified was lack of investment (73.3%), emphasizing that without sufficient financial backing, the development of geothermal infrastructure will remain stalled. This is followed by concerns about social and community acceptance (56.7%), indicating that local support and involvement are vital for the successful deployment of geothermal projects. The issue of technological challenges (46.7%) also stands out, suggesting that the region may lack the necessary expertise or infrastructure to exploit geothermal energy effectively. Regulatory and

policy issues (50%) point to the need for clear and supportive governance to enable the development of geothermal projects, while environmental concerns (23.3%) were noted less frequently, though they remain an important factor in any large-scale energy development.

Students also highlighted investment in technology and infrastructure (50%) as the most crucial factor for the successful implementation of geothermal energy in Arequipa. This is consistent with the earlier response that identified a lack of investment as the primary barrier. The increased public awareness and education (26.7%) also plays a crucial role, as educating both the public and decision-makers about the benefits of geothermal energy could help mitigate social and community resistance. Interestingly, only a small percentage of respondents (13.3%) considered stronger government incentives to be a priority, which suggests that, while important, government action may be seen as secondary to technological and social factors.

About the type of research or development that should be prioritized to accelerate geothermal energy projects, the most important priorities identified were technological advancements for more efficient energy production (33.3%) and environmental impact studies and mitigation plans (30%). These responses indicate that respondents recognize the importance of improving the efficiency of geothermal energy extraction processes, as well as the need to minimize any potential negative environmental effects. Geological studies and resource assessments (23.3%) are also seen as essential for ensuring that geothermal resources are effectively mapped and utilized. Nonetheless, economic feasibility analysis and community outreach programs were seen as lower priorities (6.7% each), which could imply that respondents view these factors as less critical to the technical and environmental aspects of geothermal development.

This survey teaches us several important lessons. First, there is a clear consensus on the potential of geothermal energy in Arequipa and its role in meeting the region's energy needs. However, the development of geothermal energy faces significant barriers, particularly in terms of investment, technology, and public acceptance. The results underscore the importance of securing financial backing and ensuring that the local community understands and supports geothermal projects. The survey also highlights the need for technological innovations and regulatory frameworks that can facilitate the efficient and sustainable

exploitation of geothermal resources. The findings suggest that while there is strong support for geothermal energy, addressing these complex barriers will be crucial to unlocking its full potential in Arequipa. Furthermore, this survey demonstrates that a multi-dimensional approach, encompassing technological, social, and policy-driven solutions, is necessary for the successful implementation of geothermal energy projects in the region.

V.II Case Study Analysis

The projected capacity for Achumani generating 110 MW to serve 18.4% of Arequipa's annual electricity general consumption underscores its importance to regional energy security. The ability to supply power to a substantial portion of the population reflects how geothermal energy can alleviate electricity shortages and reduce transmission line congestion. With a high-capacity factor of 95%, geothermal energy offers a stable, reliable source of power that is not subject to the seasonal fluctuations that affect hydropower, making it an essential addition to Arequipa's energy infrastructure. Also, it is expected that the Achumani geothermal plant initial power plant of 110 MW will be able to supply electricity to 385,000 households, which means almost 90% of families in Arequipa. All of this is based on an investment of 500 million dollars in the project (Peru Energía, 2020).

The legal and regulatory framework for geothermal energy in Peru, established by the Arequipa Regional Geothermal Energy Agreement in 2017, has facilitated private sector interest in geothermal exploration. However, the Achumani project is still hindered by the absence of renewable energy auctions that would allow geothermal energy to participate in the national electricity market. These auctions are crucial for securing long-term power purchase agreements and attracting further investment. Without such a system, projects like Achumani face delays and uncertain financial backing, which could hinder their implementation and development.

The agreement consists of four stages: background, legal context, and alignment with the national strategies (Figure 20).

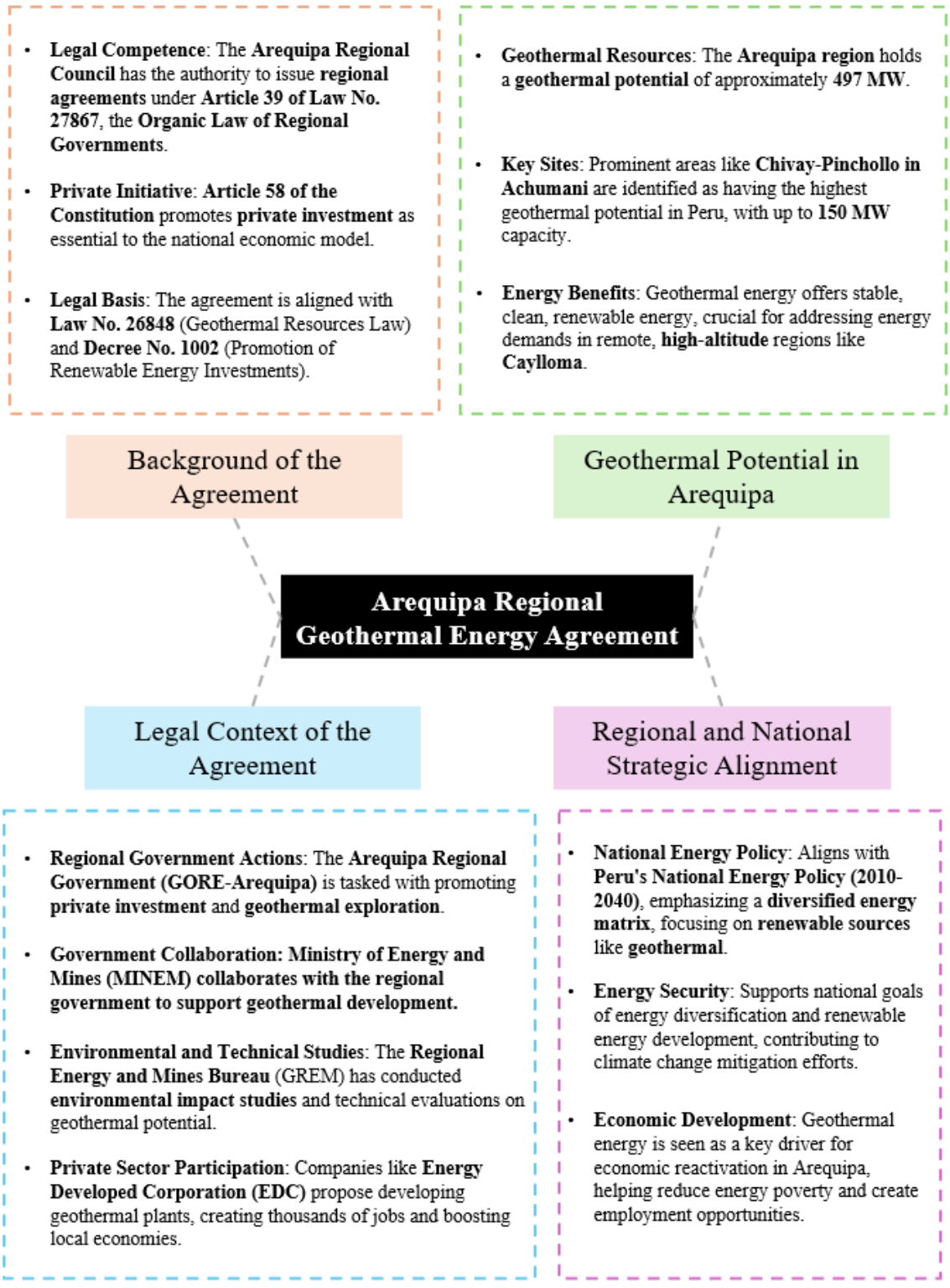

Figure 20: Arequipa Regional Geothermal Energy Agreement. Information retrieved from "ACUERDO REGIONAL Nº 039-2017-GRA/CR-AREOUIPA", 2017.

Despite the challenges stated before, the strategic location of the Achumani geothermal reservoir and its significant energy generation capacity make it a strong contender for reshaping Peru's energy landscape, which is confirmed by the Arequipa Regional Geothermal Energy Agreement. While the absence of a clear development timeline and financial uncertainties have slowed their progression, these barriers can be overcome with further policy alignment and strategic investment, making the project an attractive opportunity for both national and international stakeholders.

The agreement also mentions 5 key actions that have positive consequences, shown below:

Declaration of Public Interest	The agreement declares geothermal energy development as of regional necessity and priority for economic and social development.
Private Investment Promotion	The regional government encourages private sector investment in geothermal exploration and exploitation, highlighting its economic potential.
Coordination with National Authorities	The regional government is tasked with coordinating with MINEM to include geothermal energy projects in renewable energy auctions.
Employment and Regional Benefits	The project is expected to generate 1,700 direct jobs and 8,500 indirect jobs, creating significant local economic benefits.
Environmental and Sustainable Growth	The project will support environmentally sustainable energy production and help mitigate climate change by reducing greenhouse gas emissions.

Figure 21: Arequipa Regional Geothermal Energy Agreement's Key Actions. Information retrieved from "ACUERDO REGIONAL Nº 039-2017-GRA/CR-AREOUIPA", 2017.

The financial requirements of the Achumani project, amounting to $560 million, reflect the scale of the investment needed to unlock the geothermal potential in Arequipa. While Peru's total renewable energy potential exceeds 95,000 MW, the capital required to develop geothermal resources, combined with the risks posed by government policy delays, presents a challenge for investors. However, the willingness of international financial investing institutions such as the Inter-American Development Bank (IDB) and Japan International Cooperation Agency (JICA) to support renewable energy projects indicates that financing options are available to mitigate these risks.

Achumani Geothermal Project represents a promising solution to Peru's growing energy demands and its reliance on vulnerable energy sources. Although there are significant challenges in terms of policy, financial backing, and regulatory approval; the potential of geothermal energy, particularly in Arequipa, offers a sustainable, reliable, and environmentally conscious alternative.

VI. Discussion

This research aimed to explore the challenges and potential of geothermal energy development in Arequipa, Peru, by examining technological, economic, environmental, and social factors.

First, the perception analysis combined insights from an interview with sustainable energy expert and surveys conducted with 30 students from Environmental and Mining Engineering. The findings confirm the significant potential of geothermal energy in Arequipa, with its rich geothermal resources offering a viable solution to the region's energy needs. However, several obstacles must be addressed, including technological limitations, high financial risks, and social acceptance.

Technologically, the lack of updated studies and the need to adapt geothermal technology to the region's high-altitude conditions were identified as major challenges. The exploration phase of geothermal projects, which involves high initial costs and financial risks, further complicates development. Both the interview and surveys emphasized the importance of securing investment and providing financial incentives, such as tax exemptions or low-interest financing, to encourage private sector involvement. Environmental concerns were also highlighted, with the importance of conducting thorough environmental assessments to avoid negative impacts on sensitive ecosystems, such as the Colca Canyon. Social acceptance emerged as another key factor, with respondents stressing the need for community engagement to gain local support for geothermal projects.

The findings suggest that while government policies exist to support renewable energy development, they must be enhanced to offer more specific financial incentives. Collaboration between the government, private sector, and local communities is crucial to ensure the successful implementation of geothermal projects. The study also contributes to

existing theories on renewable energy development by highlighting the need for policies that reduce the financial risks of geothermal projects and foster local expertise.

Perception analysis suggests that geothermal energy offers great potential for Arequipa's energy future, but overcoming technological, financial, and social barriers is essential. A coordinated effort involving government support, private investment, and community engagement is needed to unlock the full potential of geothermal energy. Further research into resource assessments, technological adaptations, and social impacts is necessary to support the sustainable development of geothermal energy in the region.

Secondly, the case study Achumani Geothermal Project in Arequipa began by examining the substantial geothermal potential in southern Peru, particularly in Arequipa, which holds more than half of the country's total geothermal capacity. With a project like Achumani, which could contribute 18.4% of Arequipa's energy consumption, the implications for energy security, economic growth, and sustainability are profound. The findings highlight that the Achumani geothermal project, with its projected capacity of up to 350 MW, is a strategic opportunity for diversifying Peru's energy matrix, reducing reliance on hydroelectric power, and ensuring stable energy supply, particularly in high-altitude regions like Achumani.

The study also answered why geothermal energy has not yet been fully utilized in Arequipa. Despite the large potential, the development of geothermal resources has been hindered by high initial costs, financial risks, and the lack of comprehensive geological assessments. Moreover, regulatory barriers and the absence of a clear mechanism for integrating geothermal energy into the national energy market have slowed progress.

To address these challenges, the study suggests that the government must take concrete steps to facilitate geothermal development. These include updating resource assessments to reduce exploration risks, implementing financial incentives to attract private investment, and fostering stronger collaboration between local, regional, and national authorities. Moreover, aligning geothermal energy projects with national energy policy and creating a stable, supportive regulatory framework will be critical to overcoming financial and bureaucratic hurdles.

From a policy perspective, the findings suggest that Peru's government should enhance its support for geothermal development, including more proactive efforts to create favorable market conditions. This could involve designing specific auctions for renewable energy projects like Achumani, as well as providing long-term contracts that guarantee financial stability for geothermal projects. Additionally, the role of international organizations, such as JICA and IDB, in financing and supporting geothermal energy projects should be further explored to reduce financial risks.

The Achumani Geothermal Project represents a transformative opportunity for Arequipa, with the potential to provide significant economic, technological, and environmental benefits. However, the realization of this potential depends on overcoming financial, technological, and regulatory barriers. The findings suggest that a coordinated approach, supported by updated geological studies, financial incentives, and stronger policy frameworks, is essential for the successful development of geothermal energy in Arequipa.

VII. Conclusions

Finally, based on the previous findings from the Achumani Geothermal Project case study, interviews, and surveys, this conclusion synthesizes the key insights and answers the research questions concerning the economic, technological, and environmental implications of geothermal energy in Arequipa, the barriers to its implementation, and the necessary steps to facilitate its development.

- Economic, Technological, and Environmental Implications of Geothermal Energy in Arequipa:

Geothermal energy in Arequipa offers significant economic, technological, and environmental benefits. Economically, projects like Achumani have the potential to generate thousands of direct and indirect jobs, significantly boosting the local economy. The region's reliance on hydroelectric power and solar energy would be reduced by incorporating geothermal energy, creating a more diversified and stable energy supply. Technologically, the implementation of geothermal energy would enhance Peru's renewable energy capacity. However, challenges exist, including the high initial capital investment required and the need for specialized expertise. Environmentally, geothermal energy offers a cleaner and more

reliable alternative to hydroelectric power, reducing the environmental impact of energy production. Unlike hydroelectric projects, which are highly dependent on seasonal water availability, geothermal energy can provide a stable power source with minimal emissions, contributing to Peru's climate goals.

- Why Geothermal Energy Hasn't Been Applied in Arequipa:

Despite the substantial geothermal potential in Arequipa, geothermal energy has not been fully developed due to a combination of financial, technological, and regulatory barriers. Financially, the high upfront costs of exploration and infrastructure, along with risks related to resource uncertainty, have deterred private investment. The lack of updated geological studies has contributed to these uncertainties, making investors hesitant. Moreover, regulatory barriers, such as the absence of a clear framework for integrating geothermal energy into Peru's energy market, and the lack of renewable energy auctions that include geothermal projects, have slowed progress. The need for a stable regulatory environment and incentives for private companies to invest in geothermal energy is crucial to overcoming these obstacles.

- What Needs to Happen to Implement Geothermal Energy in Arequipa:

To enable the successful implementation of geothermal energy in Arequipa, several key actions are necessary. Firstly, updating geological studies to reduce exploration risks and ensure the accurate identification of geothermal resources is critical. Secondly, the government must implement policies and create financial incentives that attract private investment, such as renewable energy auctions and long-term contracts for geothermal energy developers. Thirdly, better coordination between local, regional, and national authorities is needed to streamline the approval process and ensure that geothermal projects are integrated into the broader energy strategy. Additionally, the government must work closely with international financial institutions to mitigate the financial risks associated with geothermal development. Finally, public support for geothermal energy projects should be fostered through awareness campaigns and consultations with local communities to address concerns and highlight the benefits of geothermal energy.

In conclusion, while the Achumani Geothermal Project holds great potential to transform Arequipa's energy landscape, the realization of this potential depends on addressing financial, technological, and regulatory barriers. By improving geological assessments, creating favorable policies, and fostering collaboration among stakeholders, geothermal energy can become a reliable and sustainable energy source for Arequipa, contributing to the region's economic development and environmental sustainability.

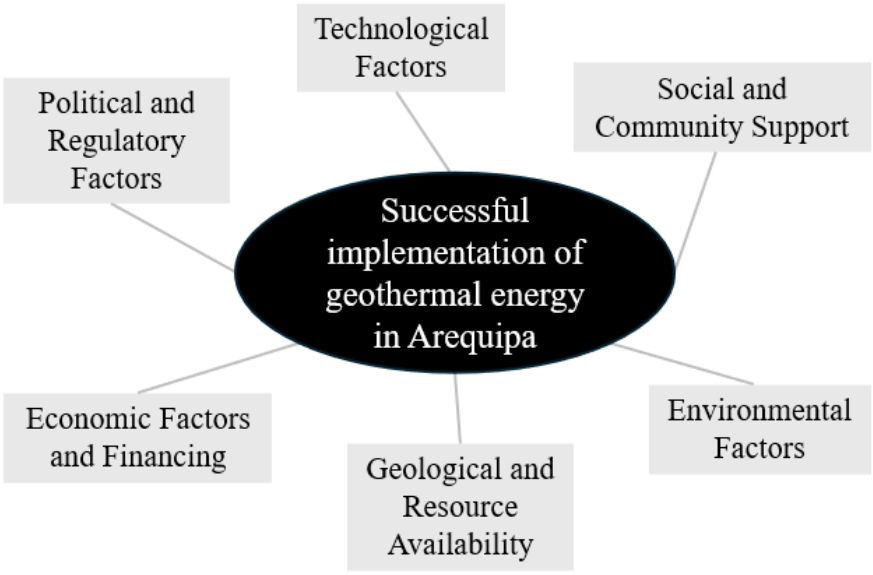

Figure 22: Factors that play a role in successful implementation of geothermal energy in Arequipa.

VII.I Limitations

While this study provides valuable insights, it has several limitations. Primarily, the research relied on secondary sources—public reports, case studies, and industry documents—without access to primary data or direct input from stakeholders such as local communities, government agencies, or private investors. This lack of firsthand data limits the depth of analysis and may not fully capture the on-the-ground realities of the Achumani project or the complexities of its implementation.

Additionally, the rapidly evolving nature of the renewable energy sector, particularly geothermal, means that some findings may quickly become outdated as new policies or technologies emerge. The Achumani project itself remains in a state of flux, with no definitive

timeline or clear governmental support for its development, which makes it difficult to predict the exact long-term impact of the project. This limits the analysis and may not fully capture the realities of the Arequipa Regional Geothermal Energy Agreement or the complexities of its implementation. Additionally, given the rapidly evolving nature of the geothermal energy sector, some findings may become outdated as new policies, technologies, or developments emerge.

Another limitation is the focus on Achumani as a case study. While it offers important lessons for geothermal development in Peru, it represents just one example of what is still a nascent sector in the country. Further research should explore other geothermal projects within Peru to provide a broader perspective on the challenges and opportunities across different regions.

VII.II Future Work

Given the limitations of this study, there are several key areas for future research. This research is a key tool for informing the stakeholders in the industry about implications of geothermal energy. Further research that they will focus on will have to consider:

First, more detailed technical studies are needed to assess the feasibility of the Achumani project. This includes further investigation into resource assessment and the long-term sustainability of the geothermal reservoir. A more in-depth understanding of these technical aspects would help clarify the project's potential to meet the expected energy demands.

Second, future research should explore the socio-economic impact of geothermal energy projects, particularly in rural and indigenous communities. Understanding how these communities perceive the Achumani project and what benefits or concerns they associate with it will be critical to ensuring that geothermal energy development is socially inclusive and sustainable. Research in this area could also explore the economic benefits for local economies in terms of job creation and development opportunities.

Another vital area for future work is evaluating the environmental impacts of large-scale geothermal projects. While geothermal energy is considered environmentally friendly, it is essential to explore the long-term effects on local ecosystems, including land use, water resources, and potential seismic activity. Longitudinal studies that track these environmental

factors will be crucial to minimizing any negative effects and ensuring that geothermal energy remains a viable and sustainable option.

Finally, research should investigate financing models and policy frameworks that can support the development of geothermal energy in Peru. With high upfront costs and significant financial risks, geothermal projects like Achumani require creative financing solutions.

By addressing these areas of future research, stakeholders may see geothermal energy projects like Achumani better positioned to contribute to Peru's energy security and sustainable development. These studies will be essential in ensuring successful implementation and maximizing the long-term benefits for the country and its people.

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Annex

A. Interview with expert
30/11/2024

Full transcript of the interview with Expert (Translated from Spanish):

1. What are the most significant technological barriers to implementing geothermal energy in Arequipa, and how can they be overcome?
   Geothermal energy generation in Arequipa and in Peru in general faces several technological challenges. I can highlight the lack of studies and research necessary to better understand the country's available resources. In 2012, when this master plan for the development of geothermal energy was carried out, some studies were made, but these studies have not been furthered and updated with more field work. These studies should also be more accessible, especially for private investment, since with more information on the resources, private investment can minimize the risks during its exploration phase, since these have very high financial risks.
   When we talk about bringing in machinery, since there is no developed geothermal industry, the first projects will have to import technology and knowledge: human resources. And this technology will also have to be adapted to the Peruvian context, given that in other countries geothermal plants are generally at much lower altitudes, while here in Peru, in the southern region, resources are found at altitudes above 3,000 meters above sea level, which requires an adaptation of the technology and its application.
   To overcome technological barriers, universities and national entities such as INGEMMET and MINAM are beginning to generate more information regarding the availability of current resources and existing reservoirs, as this would attract greater investment, and the risk would be minimized for private companies. On the other hand, it is known that there is already a large investment involved in the exploration stage, and the necessary political incentives should be given to generate this investment, for example, with renewable auctions where geothermal energy is included, and an interesting price is assigned to it so that they are encouraged to invest.

2. How do you interpret the current low economic feasibility of geothermal energy development in Arequipa compared to other renewable sources like solar or wind?

   Geothermal projects involve much larger investments in their initial development phase, such as exploration of the resource through surface studies and then drilling, and this is where the use of advanced technology and technical personnel comes into

play. This exploration phase could take about 5 years, while in the case of wind or solar projects, implementing a project takes 3 to 4 years, so the development time for this type of project is longer, even 7, 8 or 9 years, depending on the exploration.
Then, environmental studies must be done, the geothermal generation concession must be obtained, and a transmission concession must be obtained. So, at the development level, you are going to invest 1 more money in technology to be able to confirm your resource and 2 you are also going to invest more development time in obtaining all the necessary permits for the project to become viable. On the other hand, geothermal projects represent a high financial risk because it ultimately depends on the resource you can confirm and how successful your exploratory phase will be in order to size your geothermal plant based on the resources you find. So, there is a high financial risk because to explore and drill you will have to invest quite a few million, and you will not be certain of the resource until you invest in that initial phase. The investments are large, and this also implies that one assumes financially large debts for which one must request external financing. Although the global trend shows a reduction in the cost of geothermal technology, solar and wind technology are still more competitive.

3. What environmental considerations should be prioritized when developing geothermal energy projects in Arequipa to ensure sustainability?

   It is important that during the development of the environmental assessment, a good characterization of the project area is carried out to identify the environmental, physical, biological and social aspects that may be affected in the different phases of the geothermal project. The determination and assessment of these impacts will lead to proposing the necessary mitigation and compensation measures. It is also important to develop capacities at the level of MINAM specialists or other state entities that carry out the environmental assessment of this type of project. It is also very important to consider the dimension of the social impact of the project since this may be a factor that slows down its development. For example, in Arequipa, the areas of geothermal interest overlap with areas of great natural or tourist value such as the Colca Canyon, so it will be very important to have the real impacts identified and to keep the population well informed.

4. What role should government policies play in supporting the development of geothermal energy in Arequipa?

   Government policies should focus on establishing a clear regulatory framework for the sector: establishing specific laws for geothermal exploration and exploitation, including the issue of permits and environmental standards. In Peru, at least one

regulation has already been approved and the regulatory framework is clear, so perhaps that is not the weakest point. The most important point is that policies should be aimed at providing financial incentives. We know that investment in geothermal projects is very high and that means that very few or no companies want to invest in the drilling phase.

So, mechanisms such as tax exemptions, providing subsidies for low-interest financing, among others, must be created to promote investment. For example, the RER (renewable energy resources) auction that is pending for geothermal projects would help generate investment in these types of projects, given that Peru guarantees a contract for the sale of energy at a fixed price for projects of this type, so that is a great financial incentive that could be carried out. The other is capacity building: funding educational programs for technical training in geothermal energy to create local experts and ensure that these capacities are not only provided in universities, but also in state institutions at the regional and local level so that those who evaluate and supervise the projects have knowledge of how technology can promote the development of these projects instead of paralyzing them or falling into bureaucratic delays.

5. What steps or collaborations between government, private sector, and local communities are essential to ensure the successful implementation of geothermal energy projects in Arequipa, particularly in terms of overcoming social, financial, and technical challenges?

   To ensure the successful implementation of geothermal energy projects in Arequipa, a holistic view is required to be able to face the different challenges. For example, the government must establish a solid regulatory framework and continue to update it, establish clear licenses and permits within reasonable timeframes, and create financial incentives for the initial stage of projects, which generates a lot of pressure. On the other hand, the government could take advantage of external financing from initiatives such as the World Bank or the Inter-American Development Bank that promote the transfer of capabilities or even provide financing for the development of the industry. It could also continue working with universities and research centers to advance in both understanding the resources available in the region and in adopting technologies that are adaptable to local conditions. And no less important, it must have knowledge of the social reality surrounding the projects, so that the benefits and contributions of geothermal energy for local, regional and national sustainable development can be promoted from the different sectors. Finally, finding these synergies between the state, the private sector and communities that seek to establish programs of direct benefit to local communities, addressing their most basic needs where geothermal energy can directly contribute.