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# Geothermal Energy for Mining in Chile: Current Situation and Opportunities

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## ABSTRACT

Chile is a country with considerable geothermal potential but has had limited development. Considering the world's interest in renewable or alternative energy sources, geothermal energy should be better recognized as a safe, low impact and constant source of clean energy in Chile. The country is known for its high mining activities whose operations continuously depend on conventional fossil fuels. The purpose of this work is to show the current energy landscape of Chile, and explore the benefits of geothermal energy for powering mining operations. Currently, there is one geothermal project at Pampa Apacheta in Chile, which will feed the country's grid. When completed in 2017, the Cerro Pabellón plant in Pampa Apacheta will be the first geothermal plant in South America with an installed capacity of 48 MW. Today, 12% of the country's energy comes from renewable sources, but no geothermal plant delivers energy into the Chilean grid system. The lack of geothermal power production has mainly been due to a weak regulatory framework. The authors point out that mines and geothermal sites can be found in close proximity, especially in northern Chile where many mining sites are located. Energy consumptions of mines are high, for example, approximately of 2.84 MWh per metric ton of copper ore for SX cathodes and 1.98 MWh per metric ton of copper ore for concentrates. Geothermal power plants could help supply the energy requirements for energy intensive mining processes and their facilities.

## 1. INTRODUCTION

Chile is one of the countries with the highest geothermal potential in South America. The Peru-Chile Trench is formed by the collision of the Nazca and South American plates, and the subduction of the Nazca plate is the reason for constant earthquakes and volcanic activities in the area. This is also the reason that Chile presents very favorable opportunities for geothermal energy development, as the country shows many possible locations for exploitation for both low and high enthalpy geothermal resources. Although there exists a promising geothermal prospect and geologic conditions, it has had a very limited actual development. This can be attributed to various factors such as legal, economic and lack of government incentives (Sánchez et al., 2015). Andrew Reed identified the principal barriers for the geothermal sector in Chile were costs and elevated initial risks, lack of a clear and strategic public policy by the Ministry of Energy (Ormad, 2013). According to Reed, this lack of clarity in public policy forces companies to navigate blindly through a situation of high risk capital investment.

Albeit a slow and difficult development process, the first geothermal plant, Cerro Pabellón, is currently being constructed. It is located in Pampa Apacheta and is expected to be producing electricity with a capacity of 48 MW in 2017. The companies that own and are responsible for the advancement of this project are the Italian multinational ENEL and Chilean company ENAP. This site was discovered by CODELCO, a Chilean mining company, while it was carrying out water explorations in the area (Urzúa et al., 2012). Other geothermal spots have also been discovered by mining and commodity related companies while doing explorations for other purposes. This illustrates an interesting point that mining sites can be relatively close to geothermal spots, some of which have turned out to be attractive prospects for developing geothermal energy.

Considering Chile's enormous geothermal potential, it is hard to comprehend that there are still no operational geothermal plants in the country, and the process for its development continues to be difficult and slow. However, this project is the hope of future geothermal projects for the country. This paper explores the current situation of geothermal energy development in Chile, and the principal issues that pertain to the generation of electricity; how the current project may impact the future of this country's geothermal development, what are key objectives in order to install a successful perception of the new plants in the community, and how do we create possible synergies with the geothermal development with mining companies so that the mining sites can be benefitted.

## 2. CURRENT ENERGY SITUATION OF CHILE

10% of all the active volcanoes in the world (IEA Report, 2009) are located in Chile. The potential for electric generation from geothermal sources is estimated between 3,350 MW (ENAP) and 16,000 MW (Lahsen, 1988). The country has experienced three difficult periods of energy supply in the last decade. In 2007-2008, when the import of gas from Argentina was ceased and a heavy drought in the central zone of the country impacted the hydroelectric plants, Chile could only meet 50% of the country's electricity demand.

Chile has five independent power grid systems: the Interconnected Norte Grande System (SING), the Central Interconnected System (SIC), the Aysén Electric System, the Magallanes Electric System, and Los Lagos. The total MW and percentages provided by each system out of the total installed capacity in the country is shown in Table 1:

| System | MW | % |
|---|---|---|
| SING | 3,953.6 | 20.19 |
| SIC | 15,468.4 | 78.99 |
| Aysén Electric System | 52.4 | 0.27 |
| Magallanes Electric System | 101.7 | 0.52 |
| Los Lagos | 6.2 | 0.03 |
| Total | 19,582.2 | 100 |

**Table 1: Electric power generation of each electric grid system in Chile**

Table 2 shows the distribution of energy sources as of December 2015, and the distribution in terms of Non-Conventional Renewable Energy (NCRE) and Conventional energy.

| System | Thermal | | Hydraulic | | Eolic | | Solar | | Biomass and Biogas | | NCRE | | Conventional | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MW | % | MW | % | MW | % | MW | % | MW | % | MW | % | MW | % |
| SING | 3,745.6 | 94.7% | 16.4 | 0.4% | 88.9 | 2.20% | 102.7 | 2.6% | - | - | 208 | 5.30% | 3,746 | 94.70% |
| SIC | 7,420.0 | 48,0% | 6,449.1 | 41.7% | 810.0 | 5.20% | 442.5 | 2.9% | 346.9 | 2.2% | 2,040 | 13.20% | 13,429 | 86.80% |
| Aysén | 27.7 | 53.0% | 22.6 | 43.2% | 2.0 | 3.80% | - | - | - | - | 25 | 47.00% | 28 | 53.00% |
| Magallanes | 101.7 | 100% | - | - | - | - | - | - | - | - | 0 | 0.00% | 102 | 100.00% |
| Los Lagos | 5.4 | 87.6% | 0.8 | 12.4% | - | - | - | - | - | - | 1 | 12.40% | 5 | 87.60% |
| Total | 11,300.4 | 57.7% | 6,488.9 | 33.1% | 900.90 | 4.6% | 545.2 | 2.8% | 346.9 | 1.8% | 2,273 | 11.61% | 17,309 | 88.39% |

**Table 2: Distribution of energy sources in each grid system**

As can be seen in the tables, no energy is currently produced from geothermal sources, and only an 11.6% of the country's total energy comes from NCRE. The SING is the system that supplies electricity to the northern Chile where many mines are located, and only 5.3% of this energy comes from NCRE. It is worth mentioning that northern Chile has shown great geothermal potential, and there are several proven sources as mentioned earlier (Sánchez et al, 2015). More than 30% of the SING energy could be supplied from geothermal fields of El Tatio, Surire, Puchuldiza, Orriputunco-Olca and Apacheta (Procesi, 2014).

It is hard to estimate the exact number of geothermal projects currently under review in Chile, as concessions are granted by the government without a thorough examination of the true capacity of a firm to actually implement a project. Therefore, assessing the reality of future geothermal energy generation is complex.

### 3. KEY CHALLENGES

First, an active support by the government in helping move the projects forward has been lacking. Currently, the legal framework in Chile is not helpful for energy projects in general. There are numerous obstacles and confusing regulations that the companies must face, making the projects more expensive and bureaucratic. The process of getting a geothermal project to be approved is exhausting and ends up dissuading companies of investing in Chile. The connection of new projects to the existing grid is being discussed, because it has never been clear how it is done or how it is billed. Research organizations have also had to find their way without government help, such as investment for research. Surprisingly and ironically, Chile is the only country where a geothermal center has been created by applying for governmental grant funds (from Conicyt, Chile's National Commission for Scientific and Technological Research). This center is called CEGA, the Andean Geothermal Centre of Excellence. According to Dr. Diego Morata, the director of CEGA, no coordinated efforts for geothermal exploration and research investigation existed prior to the creation of this center in 2011. In all countries where investigation of geothermal energy has been developed through centers, these have been created by state initiatives, except for Chile. This is one of the great disadvantages that the country has had in respect to others, as there is no support from the government on this topic.

The existing regulatory framework has allowed many speculators to obtain geothermal concessions, based on a company's promised investment rather than its ability and capacity to implement an actual project. The ambiguity concerning the idea of potential sharing a single reservoir by many companies is also considered a strong disincentive for all stakeholders (Sánchez et al., 2015).

There are also other issues with the regulatory framework such as the lack of a clear and comprehensive legal framework to regulate disputes between geothermal developers and entities that own the rights to other resources within the concession, inflexible concession requirements on duration and areal dimensions, and environmental impact studies are not uniform and create project delays, which also generate debates with the communities and lead to the project's dismissal. There are a lot of matters that are not regulated and immature, and are left to the good will of the stakeholders involved without striving to promote the development of geothermal energy (Sánchez et al., 2015).

Second, the economic situation of a country is very important. Currently, Chile is not at its economic peak at the moment as it depends strongly on copper and other commodities which have taken a hit in their prices. This may impact on how willing the government can be to invest in geothermal energy, as it is an underdeveloped resource in the country, requiring a large amount of resources that the authorities can consider better allocated elsewhere in this context. However, this may present an opportunity in matters of labor and taking advantage of the lower costs in order to reap the benefits when the economy recovers in the future. Currently, geothermal energy is not profitable with a relatively long payback period. Drilling and explorations are not the highest costs, but the construction costs of geothermal plant and transmission are.

One recent and discouraging event is the case of the Curacautín geothermal plant, in southern Chile. This project was being carried out by Mighty River Power, but was abandoned midway due to high costs. The project had already had large investments and proven resources, having the most productive well ever drilled in South America (PUC, 2016). It was forecasted to be producing 70 MW in 2018 but for now, the project has been suspended. In Chile, the companies themselves are responsible for the connection to the main transmission lines and associated investments, which are sometimes at considerable distances, such as in the case of Curacautín. This is a critical area in which government policies could assist in bringing down the costs. In "Geothermal barriers, policies and economics in Chile – Lessons for the Andes", (Sánchez et al. 2015), the authors estimated a base case LCoE (Levelized Cost of Electricity) of geothermal in Chile around US$ 94,.91/MWh, which was assessed as "near competitive" compared to the average contract price of the main grid (US$ 82.6/MWh). Government policies could have a huge impact in reducing this estimated cost. Chile is in great need of electric power independence, making it an attractive country to invest in for companies who are in the energy business, especially in NCRE given the current worldwide interest in these energy sources.

Third, one of the highest risks of geothermal projects is the handling of communities. In Chile, particularly, this has been an issue with a large number of projects, and in some cases, a bad handling of communities has ended in the shut-down of the initiative. For instance, there is the Hidroaysén project, a hydroelectric plant designed to have a capacity of 2,750 MW. In this case, the project would affect 6 national parks, 11 national reserves, 26 priority conservation sites, 16 wetlands, and 32 private protected areas (Expansión, 2011). Also, it would intervene 6 indigenous Mapuche communities (Ulloa, 2011). This project could have had a huge positive impact on the energy supply of the country, but failed and is still frozen mainly because of a misguided handling of the communities. People in the area were not well informed about the project's benefits and were not involved as part of it. Claudio Meier, a specialist from the University of Concepción who was in charge of reviewing the project for the EIA, found multiple errors in the report, with incomplete and improperly presented information. The plant would alter the Baker and Pascua rivers, which are beautiful, wide rivers, with the Baker having the largest water flow in the country. Such an impact needed a proper study of the reaction and action plans for the acceptance of the project by the community, and a clean, clear presentation of the EIA.

This is why it is so important to understand the needs of the community and seek the acceptance of the people. Geothermal energy is clean, safe, and has a low impact on the environment. These qualities of geothermal energy need to be strongly informed, as Chile has enormous stretches of untouched land, and its people want to conserve this aspect of their country, as well as be affected in a negative way as little as possible by the construction of a plant.

Fourth, there are very limited professionally trained geothermal engineers in Chile and this requires that external knowledge must be brought in. This in turn makes the geothermal projects more expensive and harder to get to move along with the lack of proper investigation and analysis of the attractive sites. Only a few universities in Chile have academic programs associated with geothermal energy and have limited experience due to their short history. Education on this subject must be encouraged, given the enormous geothermal potential in the country and its possible future rise in usage and need for specialized labor.

Finally, geothermal resources are usually located at very remote areas and infrastructure is not readily available at these sites. Therefore, as in the case of former Curacautín geothermal project, which was recently suspended, drilling and other equipment must be transported by air to these places in order to study the fluids and nature of the geothermal sources, and then roads need to be constructed for further works. This makes the expenses of geothermal projects rise, and geothermal energy is not the most profitable and competitive business in the country at this moment, as mentioned above (Sánchez et al., 2015).

**4. CERRO PABELLÓN**


**Figure 1: Cerro Pabellón location**

The Project is called "Central Geotérmica Cerro Pabellón", and as can be seen in Figure 1, is located in Pampa Apacheta in the commune of Ollagüe, El Loa province, in the Antofagasta region in the northern Chile, and it began construction on July 14th of 2015. It boasts to become the first geothermal plant with binary technology built at the highest elevation in the world, of 4,500 m.a.s.l (Rojas, 2015).

Two fumaroles with high steam-discharge rates are located one kilometer north of the summit of Cerro Apacheta at 5,150 m elevation, with measured temperatures of 109° and 118°C. The boiling point at this elevation is 84°C, thus the fumaroles are superheated by 25° and 34°C, respectively.

The 180 m deep PAE-1 well is located in Pampa Apacheta adjacent to the 50 Ka Cerro Pabellón dacite dome at 4,540 m.a.s.l. The well produces a flow of steam with a measured temperature of 88°C, around the boiling point at this elevation.

This reservoir was discovered during CODELCO's explorations for water in the zone. The project contemplates an investment of 320 MUSD and projects a generation plant of 48 MW of installed capacity, and eleven perforation platforms for production wells and reinjection wells. The project will allow the generation of renewable energy, which will contribute to satisfy the rising demand and diversify the energetic matrix of the SING. The generated electricity will be powered into the SING through a single circuit 220 Kv transmission line that will run 73 km from the plant to the El Abra substation.

The geothermal wells have the objective of extracting the geothermic fluid from the reservoir (production wells) and to return the same fluid to the reservoir (reinjection wells) once the thermal energy has been used. This fluid has physicochemical properties and composition similar to brine that differentiate it from shallow, cold waters. These characteristics make this fluid unsuitable for irrigation and inadequate for its consumption, making it ideal for usage for its geothermal potential as it does not present an alternative use as a freshwater fluid. In Antofagasta and in the north of Chile in general, water scarcity is a big problem. Its population has limited access to freshwater, and in Antofagasta particularly, as water presents high levels of arsenic. Mines also use lots of water for their different processes. This water has to be suitable for the processes, and it is usually freshwater coming from different sources. Therefore, it is advantageous that the fluid in question has limited use for other purposes.

The project contemplates the construction and operation of a maximum of 20 geothermal wells, being either production or reinjection, located in 11 individualized platforms. In each platform, a maximum of 4 wells can be perforated. The wells will be perforated until they reach the geothermal reservoir, with an estimated depth of 1,900 to 2,700 meters.

Chilean state-owned oil company Empresa Nacional del Petróleo (ENAP) has a share of 20% of the Project, while Enel Green Power, an Italian company, holds the remaining 80% (Revistaei, 2015). The project is forecast for start-up during the first semester of 2017. Once in operation, the plant will be able to produce 340 GWh/year, equivalent to the needs of consumption of 165,000 Chilean homes, and avoiding the emissions of more than 166,000 tons of $CO_2$ per year (Rojas, 2015).

Geothermal energy utilization is not part of the culture of the Chilean community, as in other countries such as Iceland, New Zealand, Japan and the United States. Up to date, the only usage for geothermal energy in the country have been recreational. The success or failure of this plant will have a huge impact on the way people and investors view this technology. Other than problems with construction or the company itself, there are key aspects that need to be considered in order to ensure that this project creates a favorable view of geothermal energy in the country.

For instance, Cerro Pabellón has held meetings with the communities, taking note of their concerns and addressing them in the EIA (RCA Cerro Pabellón, 2012). It has also created a work plan with the communities, also established in the EIA, to communicate and collaborate with the people in order to avoid confusion and misunderstandings, and contribute to an open discussion and transparency. It is also important to stress that a continuous contact with the communities during all the construction and operation phases is crucial. People need to be informed about the progress of different phases of the project and works being done, as the project is impacting on their land and homes. A continuous supply of information and transparency is the key to a successful project. The community continuously needs to feel involved and committed to it.

## 5. EXPLORING THE POSSIBILITY OF POWERING MINING OPERATIONS USING GEOTHERMAL ENERGY

Chile is a mining country and mining is an energy intense industry, so it is logical to look for ways to use geothermal energy to help mining operations. For example, Cerro Pabellón is close to Chuquicamata, El Abra, Gaby, El Tesoro, and Esperanza mines, and also several plants from SQM (SERNAGEOMÍN, 2011). Rather than connecting to the SING which farther away, the power transmission lines could be directly connected to the mines.

Average yearly energy consumptions and production of metric tons of copper ore for four large copper mines in Chile between the years 2003 and 2009 (INE, 2011) are shown in Table 3.

| | Cathodes (SX) | | | Concentrate | | |
|---|---|---|---|---|---|---|
| Mine | GWh | Production (MT) | MWh/MT | GWh | Production (MT) | MWh/MT |
| CODELCO | 1,363 | 480,096 | 2.84 | 542 | 273,291 | 1.98 |
| Collahuasi | 159 | 56,211 | 2.84 | 794 | 400,318 | 1.98 |
| Escondida | 569 | 200,222 | 2.84 | 2,024 | 1,021,380 | 1.98 |
| Los Pelambres | - | - | - | 664 | 334,797 | 1.98 |

**Table 3: Chilean mine sample electricity consumption and production**

Energy consumptions for these mines are very large, however plants such as Cerro Pabellón can supply enough energy for these copper process plants. The data shows consistent amounts of MWh per metric ton of copper produced for the processes of cathodes (SX), which is about 2.84 MWh/MT, and concentrates, which is roughly 1.98 MW/MT. The mines considered are among the largest mines in Chile, which have many different processes in their overall production. Geothermal plants can supply energy for particular processes, plants or facilities, or cooperate in the overall energy usage of the mines. There are many different operations in a mine, especially large mines, that could use particular and separate energy sources from the overall energy supply of the mine. Some production plants or facilities can be individually and exclusively powered by a particular source, such as a geothermal plant, depending on the proximity of the operations to the geothermal site.

Figure 2 shows the indicated, inferred, highly probable and zones of interest for geothermal areas (Aravena et al., 2015) and mine sites (SERNAGEOMÍN, 2011) along the country. The mine sites are of active mines as of 2011 of categories A (400 workers or more) and B (80-400 workers). This map clearly shows the proximity of some mine sites to geothermal sources.

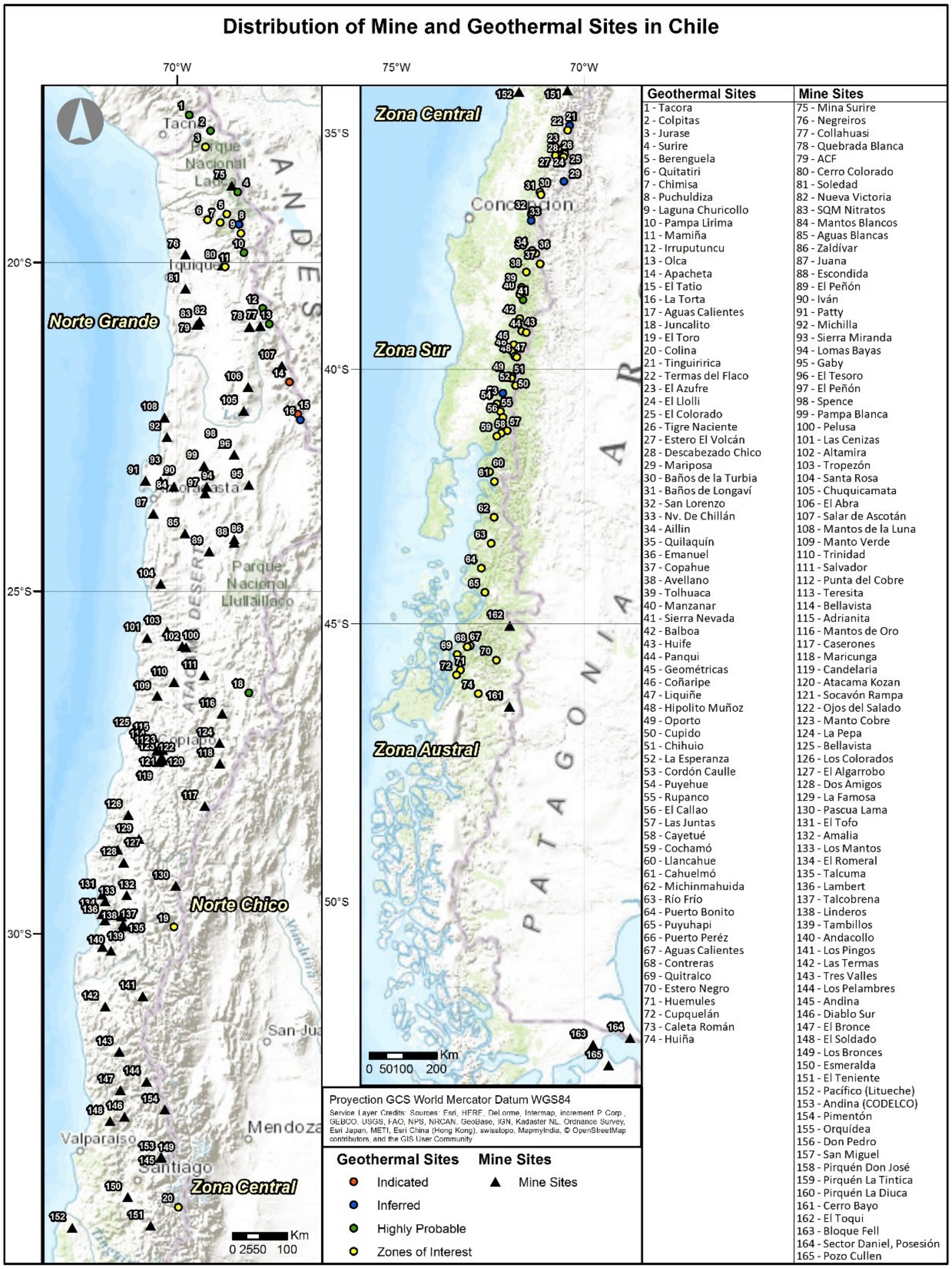


**Figure 2: Distribution of Mine and Geothermal Sites in Chile (Aravena et al., 2015, SERNAGEOMÍN, 2011)**

As can be seen from the map, possible synergies are mostly located in the northern region of Chile, as it shows the largest concentration of mine sites. Towards the south, there is a large amount of geothermal zones of interest, which are based on geothermal exploration at a regional scale and surface geothermal features (Aravena et al., 2015). Some close connection points of interest are summarized in Table 4.

| Geothermal Site | Mine Site | Approximate Distance (km) |
|---|---|---|
| Surire | Surire | 8 |
| Berenguela | Surire | 50 |
| Mamiña | Cerro Colorado | 8 |
| Olca | Collahuasi | 20 |
| Apacheta | Salar de Ascotán | 25 |
| Juncalito | Mantos de Oro | 50 |
| El Toro | Pascua Lama | 75 |
| Colina | El Teniente | 60 |
| Tinguiririca | El Teniente | 70 |
| Estero Negro | El Toqui | 60 |
| Huiña | Cerro Bayo | 60 |

**Table 4: Close mine and geothermal sites**

The physical proximity between geothermal and mining sites is very beneficial for a co-development, especially the expensive cost of transmission lines could be shared. Today, many mining companies would like to deliver an image of being sustainable, and partnership with a clean energy source such as geothermal is hugely beneficial for this purpose to show a commitment to the environment and to the creation of better initiatives. An example of this type of synergy is Centinela Mine, from the AMSA group, the main national private mining group. Antofagasta Minerals SA designed a thermosolar plant with the sole purpose of supplying electricity to the mine, in order to contribute to sustainability of the project. The plant substitutes 55% of the total diesel required in the heaters of the Sx-Ew plant, reducing 4% of the total $CO_2$ emissions of the entire mine operation. It is equal to a plant of 3 MW (IIMCH, 2014). It is the first project of this nature at a national level in the mining industry. Another example is Gabriela Mistral (Gaby) Mine, which uses the energy by a thermosolar operated by Energía Llaima SpA and Arcon-Sunmark. Codelco, the owner of Gaby, has replaced nearly 80% of the diesel that it used to haul in trucks 2.6 km to the mine (MCh, 2015).

Other usage of geothermal energy to the mining industry are possible, some examples are: enhanced heap leaching, in desalination processes, space heating and cooling in operating mines and direct heating and cooling from abandoned mines (Patsa, 2015). There are several mines that could profit from constant temperature fluids, such as RT, El Abra, Quebrada Blanca, Cerro Colorado, and Collahuasi, which use Electrowinning as part of their copper production process. Other processes that might benefit from a continuous flow of steady heat is leaching by bacteria.

In the south, other possible connections with other industries are viable for geothermal plants. For example, Tolhuaca is close to Forestal Curacautín and Forestal Venturelli, which are wood producing companies. Other industries in the south that could benefit from a synergy with a geothermal plant are agricultural and the fish industry, which need energy and also have processes that are run at constant temperatures.

## 6. CONCLUSIONS

Chile is a country that has an enormous geothermal potential, but there are no operating geothermal plants to date. A huge need of energy is and will be present. One geothermal project is currently underway, Cerro Pabellón in northern Chile, being forecasted to be in operation in 2017. This project is the key in creating a precedent in the country, and to create a favorable environment for the reception of future geothermal projects.

Some of the main challenges with a consistent geothermal development are the complicated legal framework, unfavorable economic situation and a trust building with the communities. These are all essential for the success of the projects. It is critical for the future of geothermal energy in the country to create incentives for better public policies and a clear regulatory framework that can provide companies with a better understanding of the risks and situation encompassing the projects.

A synergy between geothermal plants and particular industries, such as mining, is an interesting opportunity to explore, as it enables supplying the energy requirements of different processes or facilities that can be beneficial to the companies in ways of costs, reduction of carbon emissions, and independency. A huge benefit is also an image of commitment to the environment, which is a strong focus of today’s businesses.

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