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Geothermal Energy in Bolivia – Update and Perspectives

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ABSTRACT

The geothermal development in Bolivia started in the 1970s with surface explorations along the Andean Cordillera and demonstrating prospective geothermal potential in some areas: Sajama, Empexa and Sol de Mañana. Six geothermal wells were drilled between 1987 and 1992 in the geothermal areas of Sol de Mañana and Apacheta, as part of the geothermal project Laguna Colorada. Based on evaluation field tests conducted in 1996-1997 and 2012-2013, it was determined that the minimum potential of the field is 100 MWe. By the end of 2018, a contract for the construction of an ORC pilot power plant (5 MWe) was signed and its operation is expected to start by the end of 2023. Likewise, tender documents for the drilling of 25 new wells would be released in 2023, with field operations initiating in 2024. The first 50 MWe unit is estimated to be constructed in 2026, followed by a second 50 MWe unit in 2027. On the other hand, geoscientific studies were carried out in the geothermal area Empexa during the first semester of 2022, the research will provide insights into the potential of the reservoir and the future development of the area. Finally, the government is seeking funding to conduct feasibility studies in the Sajama geothermal area.

1. INTRODUCTION

Bolivia is a landlocked country situated in the middle of South America between the meridian lines 57°26'-69°38' west longitude and 9°38'-22°53' south latitude. The country has a surface area of 1,098,581 km^2 and its population was projected to reach 12 million by 2022. The GDP was 40,703 million USD by the end of 2021, and its economy is based on manufacturing, hydrocarbons, and mining (INE, 2022).

Bolivia has set a goal to raise its total power installed capacity to 4,129 MWe by 2025 and increase the use of renewable energy to 75% in the country (PDES, 2021). Likewise, the country has been investing in a variety of renewable energy sources, including hydroelectric, solar, wind, biomass and it also intends to expand its use of geothermal energy. In this scenario, the country has implemented a number of policies and incentives to encourage the growth of renewable energy, including:

- Net metering allows homeowners and businesses with renewable energy systems to sell excess electricity back to the grid (DS N°4477).
- The creation of a National Energy Fund to support the development of renewable energy projects and a feed-in tariff program that guarantees a fixed price for electricity generated from renewable sources (DS N°2048).
- Exemptions of taxes for renewable energy projects.
- The promotion of rural electrification projects using renewable energy sources and its integration to the National Electricity Grid, energy efficiency and electromobility (PEERR, 2016) (DS N°4539).
- Bolivia has also made strides to increase the efficiency of the energy system, such as by energy-efficient lighting and appliances, and energy-efficient building codes (DS N°3818).
- The Bolivian government also supports the regional integration of energy systems with neighbours, sharing and trading resources such as hydroelectricity and others (Supreme Decree N°2399).
- Bolivia and Japan signed a loan agreement for the construction of the geothermal power plant Laguna Colorada (Law N°904).

Considering the growth of the geothermal in the energy sector, the following actions were taken over the last three years (2020-2022): (i) the Bolivian state-owned electricity company, ENDE, continued the construction of an ORC pilot power plant (5 MWe) in the Sol de Mañana area, the plant commissioning is expected in 2023, (ii) ENDE launched a tender document for "Market feasibility study, conceptual engineering evaluation and business alternatives" for the 100 MWe Laguna Colorada geothermal power plant project (located in Sol de Mañana); once the study is concluded, ENDE will issue a request for proposals for the drilling of 25 additional wells, consultancy services for the construction of a power plant and others, (iii) ENDE conducted geoscientific studies in the geothermal area Empexa during the first semester of 2022; the following steps for the development of the region will be taken into consideration after the conceptual model of the system is complete, and (iv) the Bolivian government and ENDE are seeking for funding to conduct geoscientific (and others) research in the Sajama geothermal area.

2. GEOLOGY BACKGROUND

The major geothermal activity in Bolivia is found in the central Andes area, which is composed of three physiographic units: the Western Cordillera (volcanic arc), the Eastern Cordillera and the Altiplano basin. The Andes are one of the largest active plate-boundary areas formed by the subduction of the Nazca plate (previously Farallon) beneath the South American plate (Pardo-Casas and Molnar, 1987), the plates converge at an ~84 mm/a rate in a WSW-ENE direction (DeMets et al., 1990).

The Bolivian Altiplano is part of the second largest high plateau in the world associated with abundant arc magmatism. The area is covered by large salt flats, quaternary volcanic (andesitic) rocks, Neogene sedimentary rocks and Miocene to Pliocene ignimbrite centers (Allmendinger et al., 1997). The Western Cordillera has been built up by the Neogene to the recent magmatic arc and it is dominated by andesitic to dacitic volcanos and thick ignimbrite sheets (Troeng et al., 1994) built upon Proterozoic-Tertiary metamorphic, igneous and sedimentary substrates, including Precambrian basement (Lamb and Hoke, 1997). The Eastern Cordillera is made up of early Ordovician sediments, mainly shales and it is composed of Cenozoic volcanic and Triassic granitoid bodies and thick sequences (up to 10 km) of Paleozoic flysch-like deposits, with thin (<3 km), folded Cretaceous and Cenozoic sequences. The area is dominated by sedimentary rocks, outcrops of the Precambrian rocks and minor Late Cretaceous deposits (Allmendinger et al., 1997) (Lamb et al., 1997).

The Altiplano is a sedimentary basin at an average altitude of 3,800 m confined by the Western Cordillera and the Eastern Cordillera. The area is covered by Quaternary fill and late Oligocene to recent volcanic rocks, and approximately 500,000 km^2 of late Miocene-Pliocene ignimbrite centers, making the plateau the largest young ignimbrite province on Earth (Allmendinger et al., 1997). The extensive salt lakes of Uyuni and Coipasa, and lake Poopó, are the remnants of once extensive Pleistocene lakes (Servant and Fontes, 1978) (Figure 1).

The first geothermal resources study of Bolivia was conducted in 1976. Along the Bolivian Andes, forty-two major geothermal manifestations (fumaroles, thermal waters, mud pools, geysers and others) have been identified. Following preliminary assessment studies, seven areas were chosen for future geothermal development: Sajama, Empexa, Salar de la Laguna, Volcan Ollague-Cachi, Sol de Mañana (Laguna Colorada), Laguna Verde and Quetena. Three of these fields were considered the most promising: Sol de Mañana, Sajama and Empexa (Figure 1) (Villarroel, 2014).

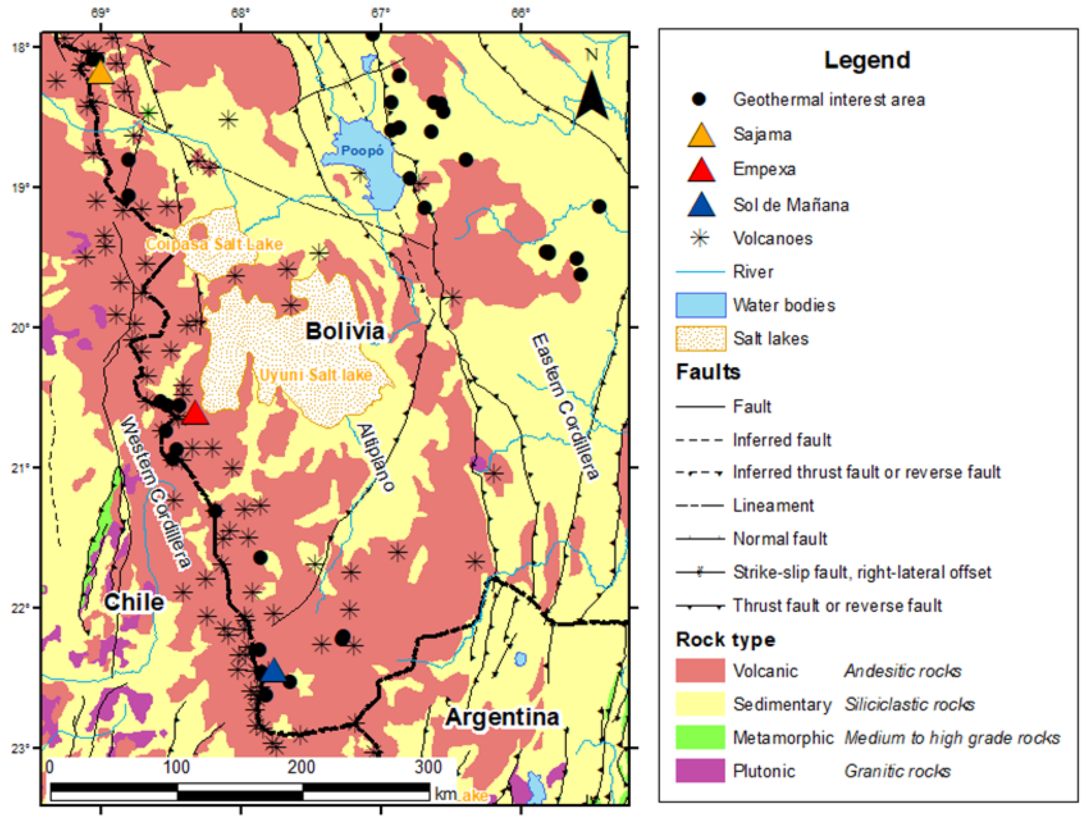

Figure 1. Geological map of the southwest part of Bolivia (modified from Gómez, et al., 2019) and considering the geothermal interest areas studied in 1976 (GEOBOL, 1976). Sajama, Empexa and Sol de Mañana have been considered the most promising areas for geothermal development.

3. GEOTHERMAL RESOURCES AND POTENTIAL

3.1. Sol de Mañana

The Sol de Mañana area has been built up by stratovolcano deposits formed during the Holocene-Miocene and ignimbrites formed during the Pleistocene-Pliocene. The lavas and ignimbrites were formed by partial melting of material from different crustal levels (Kussmaul, 1977). Geoscientific and vulcanology studies conducted between 1976 and 1979, suggested the presence of a high-enthalpy geothermal reservoir in the areas of Sol de Mañana and Apacheta (AQUATER, 1979).

The geothermal well Ap-1 was drilled in Apacheta (next to Sol de Mañana) between 1987 and 1988 and wells SM-01, SM-02, SM-03, SM-04 and SM-05 were drilled in Sol de Mañana between 1988 and 1992. All these wells produced steam except for well SM-04 which is considered an injection well. Reservoir simulations showed a minimum potential of 30 MWe considering the steam produced by wells SM-01, SM-02, SM-03 and SM-05 which are located in an area of about 2.5 km^2. The potential of the field was estimated between 350 and 390 MWe for an exploitation area of 25-28 km^2 (ENDE, 1994).

The Comisión Federal de Electricidad (CFE) of Mexico conducted evaluation tests on the Sol de Mañana wells between 1996 and 1997, and it was concluded that the potential of the field is 120 MWe for 25 years, considering the development of 20 production wells and 7 reinjection wells (CFE, 1997). JICA, West JEC and ENDE conducted tests on the Sol de Mañana wells in 2012 and 2013. It was confirmed that the potential of the field is 100 MWe for at least 30 years (West JEC, 2013).

By the end of 2018, ENDE signed a contract for the construction of an ORC pilot power plant (5MWe) to provide energy to the construction activities in the area and to provide electricity to the small indigenous communities placed in the surrounding areas. The power plant construction would conclude in 2023. Likewise, ENDE launched a tender document for "Market feasibility study, conceptual engineering evaluation and business alternatives" for the 100 MWe Laguna Colorada geothermal project. Once the study is concluded, ENDE would lunch the tender documents for the drilling of 25 new wells in Sol de Mañana and consulting services. The first 50 MWe unit is expected to be constructed in 2026 and the second 50 MWe unit by 2027. In addition, ENDE is conducting environmental studies, focused on biodiversity and flamingo flight pathways, for the construction of a ~170 km of a transmission grid, that will connect the power plant with the National Electricity Grid (SIN).

3.2. Empexa

The geothermal area of Empexa is located between the volcanic complex Picoloro-Huallcani-Milluri and the Uyuni Salt Lake (Figure 1). The stratigraphic sequence is made up of sediments of volcanic origin from the Miocene to recent age formations. The area is covered by dacitic and rhyolitic products from the last volcanic activity in the Quaternary period and morainic deposits associated with glacial phases. The rhyolites formed by fractional crystallization of andesites and dacites suggest the presence of a magmatic chamber of great dimensions. Two principal fractures system have been identified: the older with W-NW and N-NE directions and the youngest with a NE-NW direction (Scandiffio and Cassis, 1990).

Between 1977 and 1980, geoscientific surveys conducted in the area suggested a resource temperature around 230°C-240°C at 800 to 1,000 m depth. In addition, six gradient wells (60 to 165 m) showed a gradient temperature higher than 60°C/100m in the zone. Volumetric reservoir assessments suggested a field potential between 10 and 15 MWe (JOGMEC et al., 2011).

During the first semester of 2022, ENDE conducted geoscientific studies in the zone. The conceptual model of the system would provide insights into the future development of the zone.

3.3. Sajama

The geothermal area of Sajama is located in the western part of the Sajama volcano, the highest peak in Bolivia (Figure 1). The area is formed by lavas and pyroclastic rocks built upon ignimbrite sheets originated from Tertiary to Quaternary stratovolcanoes. Two major conjugate fault structures have been identified: the older with NS-EW direction and the youngest in NW-SE/NE-SW direction. Geothermometers applied to the thermal and natural waters show a reservoir temperature between 230 and 250°C (Scandiffio and Rodriguez, 1990).

Currently, the government of Bolivia and ENDE are seeking funding options to conduct geoscientific studies in the area and develop a novel conceptual model of the system.

4. ELECTRICITY MARKET

The Bolivian state-owned electricity company, ENDE, controls the production, transmission, and distribution of electricity in Bolivia. The National Electricity Grid (SIN) is composed of 5,919 km of transmission grids which provide 95% of the total electricity in the country. Eight of the nine departments of Bolivia are connected to the SIN (CNDC, 2021).

The energy matrix of Bolivia depends highly on hydrocarbons, particularly natural gas. At the end of 2021, 61.1% (6,084.8 GWh) of the total gross energy generated came from fossil-fueled plants, mainly gas plants (53.6% combined cycle plants, 7.0% gas plants and 0.5% diesel), while 32.4% (3,232.9 GWh) were produced from hydropower plants (19.0% dam and 13.4% run-of-river plants), and 6.5% (648.5 GWh) came from renewable sources (3.5% solar, 1.8% biomass and 1.2% wind) (Figure 2). The total gross power generation was 9,966.2 GWh in 2021, about 8.2% higher than the electricity generated in 2020 (CNDC, 2021).

Additionally, Bolivia had 3,589.74 MWe of total installed power capacity in 2021. 2,496.03 MWe are from fossil-fueled plants (46.00% combined-cycled plants, 22.44% gas plants and 1.09% diesel generators), while 20.47% are from hydro plants (12.61% dam, 8.31% run-of-river) and 10.00% from renewable power plants (4.60% solar, 3.56% wind and 1.84% biomass) (CNDC, 2021). Table 1 shows the present production of electricity in Bolivia, considering geothermal, fossil fuels and other renewable sources of energy and Figure 2 shows the power install capacity and the power generation, considering all different types of power plants in the country. In 2021, the installed capacity increased to 195.55 MWe, considering the addition of combined cycles and wind power plants.

Table 1. Present production of electricity in Bolivia

Energy source	Geothermal		Other Renewables		Fossil Fuels		Total	
	Installed Capacity (MWe)	Gross Electrical generation GWh/yr	Installed Capacity (MWe)	Gross Electrical generation GWh/yr	Installed Capacity (MWe)	Gross Electrical generation GWh/yr	Installed Capacity (MWe)	Gross Electrical generation GWh/yr
In operation in December 2021	0.00	0.00	1,093.71	3,881.40	2,496.03	6,084.80	**3,589.74**	**9,966.20**

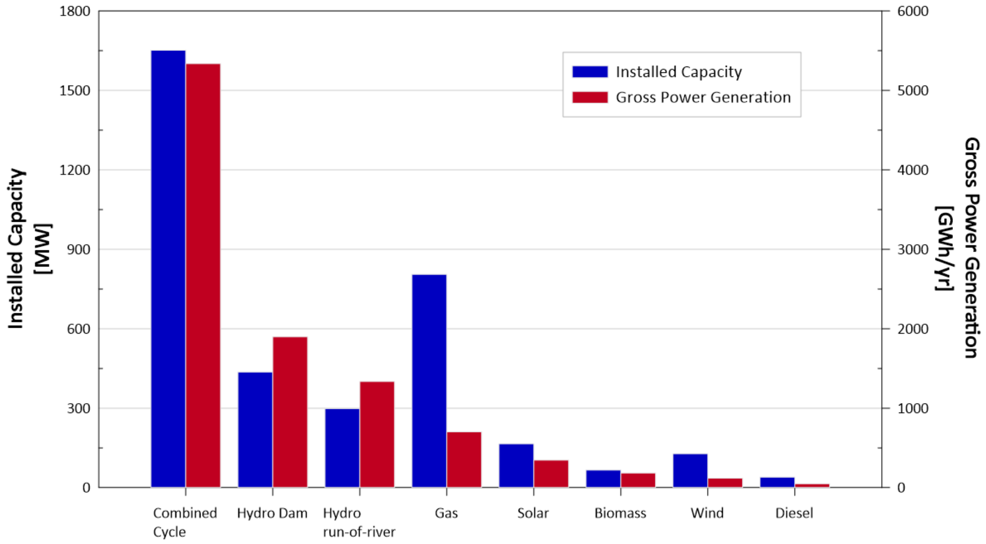

Figure 2. Total installed capacity and total gross power generation considering different types of power plants in Bolivia.

5. CONCLUSIONS

The government of Bolivia has set ambitious targets for increasing the use of renewable energy in the country, intending to generate 75% of the country's electricity from renewable sources by 2025. However, the country is facing some challenges in achieving this goal, such as a lack of infrastructure and investment. In addition, the economic crisis and the COVID-19 pandemic can also affect the progress of the renewable energy sector.

Even though only three geothermal areas have been studied in Bolivia, the future growth of geothermal energy appears promising. The policies established by the government are encouraging the use and development of renewable energies, and the first geothermal power plant in the country (Pilot Power Plant Laguna Colorada) could start operating in 2023, providing energy to the small communities located in the surrounding area. In addition, the agreements subscribed between Bolivia and Japan will expand the activities in Laguna Colorada with a 100 MWe geothermal power plant, by 2027. These power plants will be connected to the National Electricity Grid (SIN) through a ~170 km transmission line.

In addition, the Bolivian government and the National Electricity Company (ENDE) are looking for options for the development of the geothermal areas Empexa and Sajama, these projects are intending for promoting the use of geothermal energy in rural areas and the mining sector, which could help to reduce energy costs and increase energy security.

Finally, a geothermal map of the country must be created through the exploration, identification, and confirmation of potential geothermal areas in the Andes and the east part of the country. The use of low-enthalpy resources for heating, green-houses, balneology-bathing and others could promote economic development in rural areas by providing a reliable and low-cost energy source for businesses and industries.

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