Geothermal energy in electricity markets and decarbonisation scenarios: The Chilean case

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Abstract. Nowadays geothermal projects must face a challenging competition from variable renewable generation projects, such as PV and wind power plants, almost all over the world, and usually their bidding offers cannot compete with traditional or alternative renewable energies. The efforts of this paper aim towards finding new approaches to assess geothermal energy in order to properly consider their unique technology advantages as well as a longer term for assessing the availability of this technology to strengthen the power systems. The technical feasibility of installing a geothermal-power plant is highly dependent on the availability of an adequate geothermal resource and energy market competitiveness against other technologies. In this work, the geothermal energy role is evaluated in order to achieve the decarbonisation of the Chilean Energy Matrix in different scenarios, including the complementary use of geothermal and CSP units.

1. Introduction
Nowadays decarbonisation is growing rapidly worldwide. In this process, electricity production based on geothermal resources is a natural replacement for fossil fuel-based technologies, as they can provide the same reliability and plant factor as traditional thermal units. However, in competitive markets, due to the current cost of investment and lack of proper recognition to their unique features, geothermal technologies still face important challenges to reach full deployment.

In economies with open markets, the electricity sector is based on competition with private investment in the production sector and, usually, private investment in the transmission and distribution sectors, which are regulated by government entities. In those competitive markets, usually generation developers decide, based on their own private assessment, which projects render the best revenues for their companies. Hence, geothermal projects must compete with other renewable alternatives, such as PV and wind power plants, in order to obtain contracts in bidding processes or competitive bilateral agreements.

In the literature, several studies assess the deployment of geothermal projects worldwide. There are mature methodologies for planning, designing and evaluating geothermal energy projects [1] For instance, in [2] an extensive analysis for accelerating geothermal development in Indonesia is presented. Also, an insightful analysis of different issues for a sustainable energy source, as compared to natural gas-based technology, is presented in [3]. In the decarbonisation strategies, a comprehensive study of Europe Union policies is discussed in [4].

Chile is located in the Earth’s largest volcanic chain of Andes Mountains, which provide a solid base to exploit its enormous geothermal potential. In fact, the potential geothermal electricity production has
been (conservative) estimated to be in the range of 1,500 to 3,600 MW [5].

Regarding the Chilean regulatory framework, it is mostly technology neutral, except for the renewable energy quota (20% of generation by 2025) for non-conventional sources and some private international instruments oriented to reduce the risks in the exploration phase for geothermal projects. In all, the Chilean market is considered a highly competitive one, where the exceptional conditions for solar energy sometimes eclipse the development of other promising technologies. In this regard, the Chilean market is similar to other countries and its experience may also benefit other economies.

During the last year, however, both the government and the private sectors agreed to work in a decarbonisation agenda. As a country, the goal is to phase out gradually all the coal plants by 2050 or earlier. This goal opens an opportunity for the introduction of renewable solutions capable of replacing the base energy provided today by thermal plants. Hence, the purpose of this paper is to analyse the use an impact of geothermal units as coal or thermal plant replacement.

In this work we discuss the current structure of the Chilean energy market and simulate a proposed coal unit retirement schedule with the direct use of geothermal and CSP as substitutes. The exercise illustrates how both the energy matrix and the Carbon Dioxide (CO2) emission index could evolve, as more and more coal plants are phasing out.

2. The Chilean electricity market

2.1. Electricity market

In the Chilean market, generating companies are remunerated mainly for energy. Energy is paid for according to two types of transactions: an agreed Power Purchase Agreement (PPA) and at marginal cost (the spot market). PPAs are signed with distribution companies and unregulated clients, and in the spot market the marginal cost is determined hourly by the Independent System Operator (ISO) at each node of the network.

A very special type of PPA refers to the bilateral contracts with Distribution companies (Discos). According to the law, Discos are enforced to celebrate auction processes in order to find the appropriate provider (generating companies) to serve their projected demand. The basic mechanism for auctions determines that generating companies propose bids with a price and a volume of energy, and the auction is cleared at an optimum economic point.

The law defines geothermal, wind, solar, biomass, tidal, and small hydropower projects (under 40 MW of installed capacity) as a common group named Non-Conventional Renewable Energy (NCRE). In addition, Chilean regulation provides for exemptions in transmission charges for new renewable energy sources.

The official strategy in Chile for promoting electricity production from NCRE sources is the quota system [6]. In this system, the quota of renewable energy will increase, starting in 2014, by 0.5% each year through to 2025, when companies must secure at least 20% of their trading from renewable energy sources.

An important feature in the promotion strategy of NCRE is that all technologies must compete for the quota. In other words, price is the only criteria for selecting NCRE projects. Although this concept has fostered the fast deployment of some technologies, mainly solar, wind and hydro, it has not promoted geothermal projects as they cannot compete with solar and wind technologies with the current levelized costs of each technology [6].

2.2. The power grid

The Chilean electric power grid (National Electric System NES) covers an extension of nearly 3100 kms from north to south. It has 24 GW of installed capacity and was formed in 2017 by the unification of two subsystems, the former Northern Interconnected System (SING according to its abbreviation in Spanish) and the Central Interconnected System (SIC). The country also has two medium size systems (under 200 MW of installed capacity) in the extreme southern region. A diagram of the main areas of the NES system is shown in figure 1.
Figure 1. NES System.

The NES system includes nearly 99.3% of the installed generation capacity, which reaches 22375 MW as of March 2018. The generation mix comprises 22% coal, 20% natural gas, 15% hydro (reservoir), 13% diesel, 12% run-of-the-river hydro, 8% solar PV, 6% wind, 2% small hydro (less than 40 MW), and 2% biomass.

The former SIC system covers an area of 326,412 km² which is more than 2000 km in length, whereas the former SING system is located in the north, covering an area of 185,142 km².

2.3. Geothermal projects in Chile
As of today, there is only one geothermal power plant in service in Chile: The Cerro Pabellón. It is located in the northernmost area of the system and entered in operation on September 12th, 2017. This power station comprises a 48 MW geothermal power plant, located in the “Apacheta” geothermal concession in Antofagasta region, Chile [7]. The geothermal power plant is physically connected in the northern part of NES system, and its production comes from a binary cycle power plant comprised of 2 units. The geothermal concession encompasses 11 platforms, for the drilling of a maximum of 207 geothermal wells. The output of gross electricity in 2017 was 63,800 megawatt-hours (MWh).

The variable costs assigned to the operation of the power plant are 2 USD/MWh with maintenance periods of 2 weeks per year, which yields a capacity factor of nearly 95%. Since the technology has a low cost of operation it is always dispatched, except during its maintenance periods, therefore the plant can be classified as being base load. Considering the area where it is connected, no transmission bottlenecks can affect the capability of the project to enter the market (even for larger installed capacities,
hence making the results of this study valid for a larger project). The geothermal unit is the only generator connected to that node and the local load is always higher (close to 90 MW) than the maximum output of the unit. The project’s service life is considered to be 30 years, and there are plans for an eventual expansion of the project to 100 MW in the near future.

3. Decarbonisation scenarios

Literature offers a wealth of scenarios for low-carbon energy projections, which focus on stabilizing atmospheric concentrations of CO₂ at acceptable levels [8]. In the case of Chile, decarbonisation, understood primarily as the retirement of all the coal plants, is viewed as one of the main tools to reach and go beyond the current COP21 commitments and to improve healthy conditions in the locations surrounding thermal units.

The analysis of decarbonisation scenarios uses the SAM model [9], which simulates the performance of photovoltaic, concentrating solar power, solar water heating, wind, geothermal, biomass, and conventional power systems. The Base case is defined from 2017 to 2050, where there are 28 coal power units along the country, which amount 4.9 GW of installed capacity. In the base scenario, the coal power stations are always available, while the increase in energy demand is supplied mainly by solar energy (PV, CSP). The specific model for CSP plants is obtained from [10] and the data for each technology is obtained from [5]. The base scenario is shown in figure 2.

![Figure 2. Base Scenario](image)

In the Base scenario some coal generation is replaced mainly by solar-based generation. As shown in figure 2, coal generation stabilizes after 2035 and, by 2050, still represents around 17% of the total energy matrix.

In order to explore other possible projections of long-term energy development in Chile, where the coal generation is voided, the following four future scenarios were considered:

- Normal replacement, without geothermal limitations (GEO_N). In this scenario phase-out time frame for coal based generation is 2040 and no constraints on Geothermal deployment are considered.
- Normal replacement, with geothermal limitations (GEO_CSP_N). In this scenario there is a constraint up to 2000 [MW] for geothermal projects, which has to be provided by CSP technologies.
- Accelerated replacement, without geothermal limitations (GEO_A). In this scenario, a policy to faster the phase-out of coal based generation is assumed. No constraints on Geothermal deployment are considered.
- Accelerated replacement, with geothermal limitations (GEO_CSP_A). In this scenario, a policy to faster the phase-out of coal based generation is assumed. Geothermal deployment is constrained up to 2000 MW.

The corresponding results of the Normal replacement case, with geothermal limitations (GEO_CSP_N), are shown in figure 3.

![Figure 3. GEO_CSP_N Scenario](image)

The constraint of 2000 MW for geothermal projects puts a limitation for annual energy of 16 TWh approximately. The total phase-out of coal based generation is achieved by 2045. Notice that in figure 3, when that geothermal limit is reached in 2044, the increase in demand is satisfied mainly with solar CSP technologies, while the rest of the energy production remains almost constant.

The corresponding results of the accelerated replacement case, with geothermal limitations (GEO_CSP_A), are shown in figure 4.
In this scenario, a policy to faster the phase-out of coal-based generation is assumed. In order to make the scenario more realistic, geothermal growth is constrained up to 2000 MW.

From figure 4 it is clear that coal phase-out starts around 2932 and is fully achieved by 2040. Therefore, electricity production is achieved with 90% of renewable energy by 2040 with approximately 25% based-on hydro, 25% geothermal and close to 45% solar.

Scenario GEO_CSP_A requires to start the investment on geothermal plants 10 years earlier than Scenario GEO_CSP_N, which it will require additional regulatory measures such as retirement plans for coal plants and incentives for fostering the deployment of geothermal and CSP-based technologies.

In figure 5, CO₂ emissions are shown for all the different decarbonisation scenarios.
reduced in almost 85% of the 32gt CO₂ expected for the Base Scenario, and for all the considered decarbonisation schedules. The GEO_CSP_A scenario produces one of the fastest CO₂ reduction trajectories, and by the combination of the geothermal and CSP technologies, we consider is the economically and technically most feasible one.

4. Conclusions

According to the Chilean energy market structure, geothermal projects must compete against other renewables resources in a neutral technology environment. Given today’s CAPEX costs for geothermal projects, there is little space for the geothermal development in Chile, especially if they may depend on open auctions based mainly in energy bids. Regarding the hybridization technologies, in this paper it is shown that geothermal in combination with solar-based generation improve the competitiveness of projects, but they still cannot compete with other renewable projects, such as solar and wind power.

An alternative way to promote geothermal projects is to identify the specific advantageous operational features of geothermal plants when compared to other variable generation. In this line, geothermal power plants are a natural replacement for coal based electricity generation, as they have higher plant factors and can provided a more constant and predictable output as compared with other technologies, such as solar or wind.

Following both government and private decarbonisation expectations, different scenarios considering geothermal units deployment are analysed. We conclude that in all the cases the geothermal technology contributes to both provide a technically feasible operation and large CO₂ emission reductions. The case where geothermal and CSP units are combined correspond, in our perspective, to the most beneficial and economic scenario.

In further work, we will explore not only how these technologies can complement each other, but how the direct hybridization of both can make a more competitive alternative for the development of the electricity market and the energy matrix decarbonisation.

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