ANALYSIS OF GEOTHERMAL POWER PLANT PERFORMANCE IN THE CONTEXT OF THE CHILEAN ELECTRICITY MARKET

Luis S. Vargas[1,3], Sebastián Püschel-Lovengreen[2,3]

[1]Department of Electrical Engineering, University of Chile. Av. Tupper 2007, Santiago, Chile.
[2]Energy Center, Faculty of Physical and Mathematical Sciences, University of Chile. Av. Tupper 2007, Santiago, Chile.
[3]CEGA, Faculty of Physical and Mathematical Sciences, University of Chile. Av. Tupper 2007, Santiago, Chile.

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ABSTRACT

Geothermal energy is the upcoming attraction in the Chilean electricity market, due to the announcement of a joint venture between Enel Green Power (51%) and Chile's state-owned oil company ENAP (49%) to launch an EPC contract for the Cerro Pabellón geothermal project in Chile. This is going to be the first geothermal power plant in Chile, and is scheduled to enter into commercial operation by the end of 2017. In this paper a twofold analysis regarding this technology is conducted: the regulatory context and market impact of this new technology. On one hand, the regulatory framework of the Chilean electricity market is analyzed in order to determine the constraints imposed on this particular technology, as well as those characteristics that are recognized and remunerated within the market. On the other hand, an extended analysis of the economic operation of the ongoing project is conducted, identifying its performance in the spot and capacity markets, as well as the impact of entering into long-term contracts (Power Purchase Agreements, PPAs) with large consumers. The latter analysis is based on the long-term hydrothermal scheduling tool used by the Chilean system operator, which is based on stochastic Benders decomposition to account for long-term hydro uncertainty. As renewable energies are growing fast in the country, the analysis focuses on the impact on the project's future profits due to an increasing penetration of variable renewable energy – mainly solar photovoltaic power plants – in the areas surrounding the location of the project. Furthermore, the impact of hydrology is quantified in order to establish the influence of this variable on the project's operational margins.

1. INTRODUCTION

Chile is located in the Earth's largest volcanic chain and this privileged location makes Chile a country with enormous geothermal potential. The potential geothermal electricity production has been estimated to be in the range of 1,500 to 3,600 MW.

1.1 Chilean Electricity Market

The Chilean electricity sector is based on a competitive market with private investment in generation and regulated private investment in the transmission and distribution sectors. In this market, generation developers decide, based on their own private assessment, what, where, when and how much new capacity is needed. There is technology neutrality except for the renewable energy quota (20% by 2025) and any new development must comply with environmental regulation, by application for a license, and there is little or no land use regulation. The authority has a regulatory and supervisory role, aiming to establish criteria that favor economic and efficient expansion of the electricity system. The Chilean electric sector is regulated by the general electric service law.

Generating companies are remunerated mainly for energy, but also, to a lesser extent, for capacity services. Energy refers to effective consumption and is paid for either at marginal cost at the relevant node (the spot market), or according to an agreed Power Purchase Agreement (PPA). Capacity payments reward the generation company for making capacity available to the system. A firm capacity is determined for each power plant and is paid for at marginal system capacity expansion cost, calculated by National Energy Commission (CNE).

Energy sales take the form of financial contracts. PPAs are signed with distribution companies and unregulated clients, and positions are adjusted in the spot market at the marginal cost determined hourly by the CNE for each node. The auction process establishes that distribution companies must back the projected demand of their regulated clients with long term PPAs. The basic mechanism for auctions determines that a generator offers a price and a volume of energy and the auction is cleared at an optimum point that balances cost minimization and demand coverage maximization. Contract prices are passed directly to consumers by means of a pass-through mechanism.

Independent consumers are expected to procure their own supply of electricity independently and select their preferred procurement mechanism, which includes energy auctions. Distributors must contract their needs through auctions, which must be public, open, transparent, and without discrimination. The auctions establish long-term contracts for up to 15 years at a fixed price, and the government sets a price cap for the auctions. The capacity price is also fixed by the CNE (indexed according to CPI) [Palma et al, 2002].

1.2 Renewable Energy Promotion

The official strategy in Chile for promoting electricity production from renewable energy sources is the quota system [Palma et al, 2002]. In this system, Chilean law requires new energy projects to generate an escalating percentage of total energy from renewable sources. The law requires new energy contracts to include 5% generated from renewable sources starting in 2010. The quota of renewable energy will then increase, starting in 2014, by 0.5% each year through to 2025, when generators must secure 20% of power generated from renewable sources.

The law uses a broad definition of renewable energy, and geothermal, wind, solar, biomass, tidal, cogeneration below 20 MW of capacity, and small hydropower projects under 40 MW of installed capacity are all considered 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.

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.

1.3 Chilean Power Network

The Chilean electric power grid is organized in four independent systems. From north to south, they are the Northern Interconnected System (SING according to its abbreviation in Spanish), the Central Interconnected System (SIC), and two medium size systems (under 200 MW of installed capacity) in the extreme southern region.

The SING and SIC systems are the most relevant, as they include nearly 99.1% of the installed generation capacity. The SING system is almost 100% thermal (99.6% thermal and 0.4% hydro), while the SIC system is hydro-thermal with a mix of 42.7% hydroelectric, 55.0% thermoelectric and 2.3% of wind generation capacity. The other two medium size systems in the southern region of the country have approximately 165 MW of installed capacity.

The SIC system is located between Taltal and the Chiloé Island, covering an area of 326,412 km^2 which is 2000 km in length. It supplies more than 90% of Chile's total population and has an installed gross capacity of 15,141 MW as of December 2014. Maximum demand in the year 2014 was 7,536 MW. In this system, almost 70% of the generation is consumed by regulated customers through distribution companies.

The SING system is located between the cities of Arica and Antofagasta, covering an area of 185,142 km^2. It had an installed gross capacity of 4,183 MW as of December 2015, with an annual consumption of 6136 MWh. It provides energy mainly to large non-regulated customers, with mining and industrial customers representing nearly 90% of the total system demand. The generation mix is based mainly on coal-fired power plants (75.4%), followed by natural gas (13.5%) and other fossil fuels such as diesel and fuel oil (6.7%). Also, there is a small and growing renewable generation based on solar (2%), wind (1.2%), cogeneration (0.7%) and hydro (0.4%).

1.4 Cerro Pabellón Project

The Cerro Pabellón project comprises the construction and operation of a 48 MW geothermal power plant, located in the "Apacheta" geothermal concession in Antofagasta region, Chile [CDM, 2012].

The geothermal power plant will be physically connected to the SING System, and its production will come 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 estimated average capacity factor (i.e. based on 8322 hours per year at the rated capacity) of the project power plant is 95 percent. The estimated initial output of gross electricity is 380.000 megawatt-hours (MWh) per year, which is expected to decline as geothermal wells generally undergo minor decline in well productivity with time.

2. MARKET ANALYSIS FOR CERRO PABELLÓN

2.1 System Definition

The long-term market analysis of the Chilean power system involves establishing the market prices and energy production of the power units connected to the system. Since the system has a large component of hydropower coming from reservoirs, finding out prices and production profiles requires the optimization of the use of water stored in the system's reservoirs. For instance, Lake Laja is a major storage area at the top of one of the main watersheds of the country. Its capacity is equivalent to more than 7 TWh, which allows it to be regulated[1] over periods longer than a year.

The mathematical model that allows the optimization of a hydrothermal system over large time frames is known as Stochastic Dual Dynamic Programming and it was proposed by Pereira and Pinto [Pereira et al. 1991]. The model requires 4 major sets of data, namely, the topology of the power system and the parameters of its elements (generators, loads, and lines), the topology of the hydraulic system and its elements, demand profiles as well as fuel price time series for the duration of the analysis.

Based on available information (Brent Index and Henry Hub) about the future evolution of fuel prices comprising Diesel, Liquefied Natural Gas (LNG) and Coal, the incremental cost of generation was calculated for the set of thermal generators in the system. Figure 1 presents the spread of costs and the average trend for each fuel type.

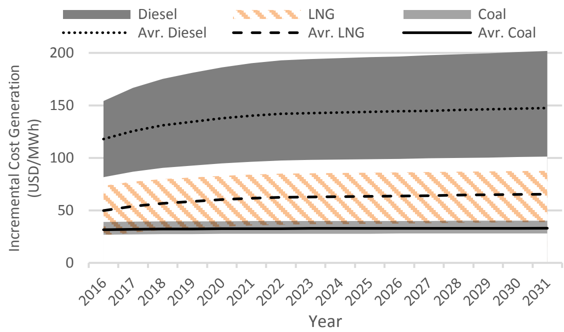

Figure 1: Incremental cost of energy production of thermal technologies (Diesel, Liquefied Natural Gas LNG, Coal).

The demand time series is based on estimates of growth projected by the National Energy Commission in their biannual estimation of future energy prices [CNE. 2016], as well as the information presented by the system operator for the analysis of the expansion of the transmission networks.

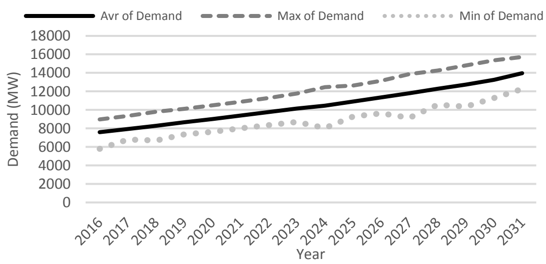

Figure 2: Expected yearly growth of minimum, peak and average demand for the next 15 years.

[1] Amount of water that is stored or released from storage in a period of time

The aggregated demand trend presented in Figure 2 is distributed over a reduced system representing 30 nodes of the power grid. The nodes are connected by a transmission system that considers maximum flow constraints, as well as losses and the reactance parameters of each link. It is important to underline that currently the power system consists of two isolated systems (SIC and SING), that are going to be connected together in 2017, through an AC transmission line represented by the link between the nodes Los Changos and Cardones in Figure 3.

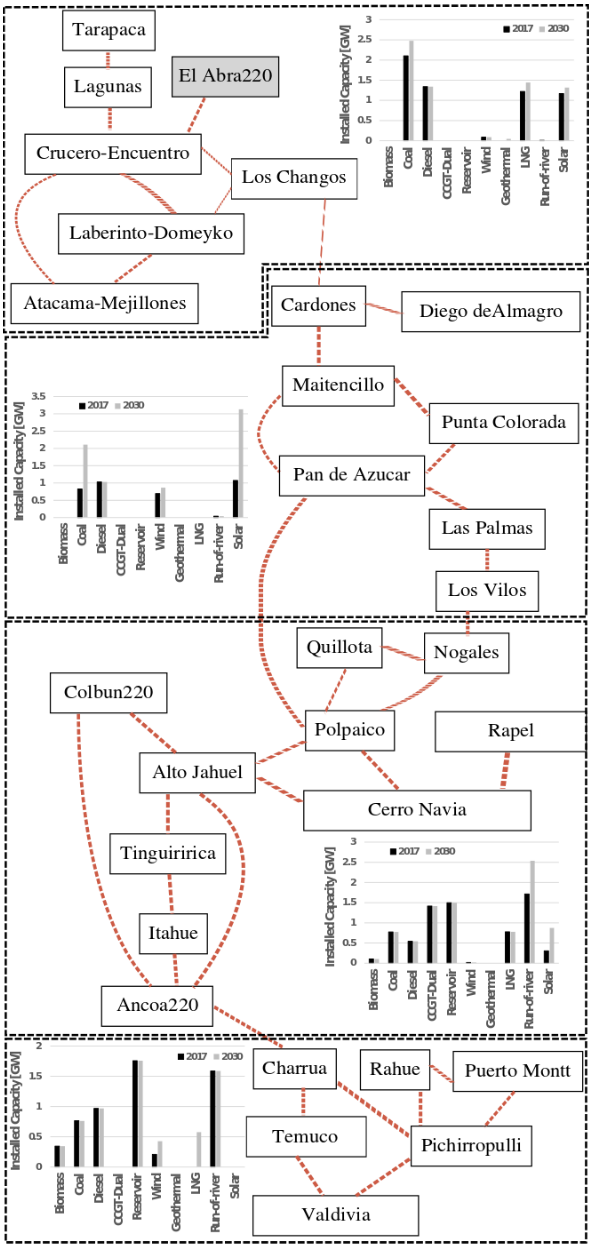

Figure 3: Reduced grid representing the Chilean interconnected system. Installed capacity by technology by area.

The expected mix of generation in the system in 2030 consists of more than 450 units that includes 9 hydro reservoirs and 140 run-of-river generators; 45 biomass units, 32 wind power plants, 84 solar photovoltaic projects and 1 geothermal site. The remaining 300 units are thermal power plants (including Diesel, LNG, Coal). The installed capacity evolution by technology between 2016 and 2031 is presented in Figure 3. The capacity is aggregated in 4 representative areas of the system where each has a different primary energy potential. In this context, geothermal energy is included only through the Cerro Pabellón project. This decision comes from the fact that the expansion studies conducted by the Ministry of Energy, with the support of the Energy Centre at the University of Chile [Ministerio de Energía, 2016], expect only a marginal incorporation of this technology under current assumptions about the system regulatory framework and performance.

2.2 Characterization of the Cerro Pabellón geothermal project

The Cerro Pabellón project is being developed in the northernmost area of the system. It will be connected to the bus-bar known as El Abra, highlighted in grey in Figure 3. The installed capacity proposed for the geothermal unit is 48 MW. There have been some press releases about an eventual expansion of the project to 100 MW, but for this study the original capacity is modelled. Since the technology has a low cost of operation it will always be dispatched, except during its maintenance periods. 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 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 ca. 95% the plant can be considered as being base load. The power plant is expected to start operation by the end of 2017. The project's service life is considered to be 30 years.

2.3. Long term performance of the system

The software used to conduct the long-term hydrothermal coordination is known as PLP, which is the tool that the Chilean system operator uses to calculate the opportunity cost of the water stored in the reservoirs and to analyze the long-term trends of the system. The optimization was run in a 64-core machine on Ubuntu Server 16.04 using CPLEX 12.6. Considering a tree with 55 scenarios, 186 stages and 6 blocks of demand per stage, the optimization process took 1.5 hours.

The results of the scheduling process include various sets of data, namely: prices, line flows, output of units, water releases, for each demand block in every stage and in every scenario. In order to build the time series of income for Cerro Pabellón it is necessary to analyze the behavior of the marginal prices at its connection node. In Figure 4 the average prices among the 55 scenarios for 4 representative nodes are presented, including the average trend for El Abra. Additionally, both the time series for maximum and minimum prices at the latter node are presented, in order to introduce the degree of spread that the results display, due to the hydrological uncertainty.

For any given year between 2017 and 2031 (time scope of the simulation), the amount of energy that the geothermal unit produces is approximately constant (ca. 400 GWh/year), and so are the operation costs (ca. 0.8 million USD/year). Thus, it is clear that the profile of spot profits for the geothermal unit will follow the trend of marginal prices at the node El Abra.

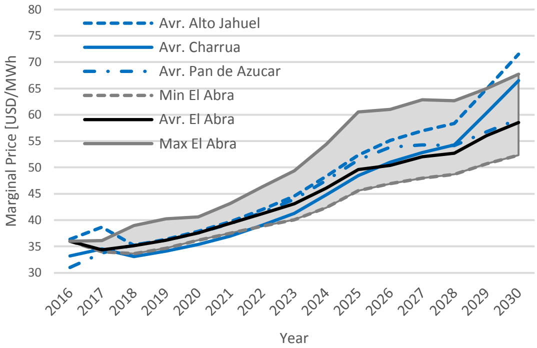

Figure 4: Average price trends for 4 buses in the system, and spread of prices for El Abra.

2.4. Spot incomes for Cerro Pabellón

The spot profits can be calculated as the energy sales in the spot market minus the costs to produce each unit of energy.

Figure 5 presents the annual distribution for spot profits. It is important to take into consideration that both the incomes and costs have not been discounted to a reference year. Since the optimization considers 55 scenarios, there are 55 yearly profits for each year. For a better understanding of the results, they are clustered in 5 quintiles, each representing a probability of occurrence of 20%.

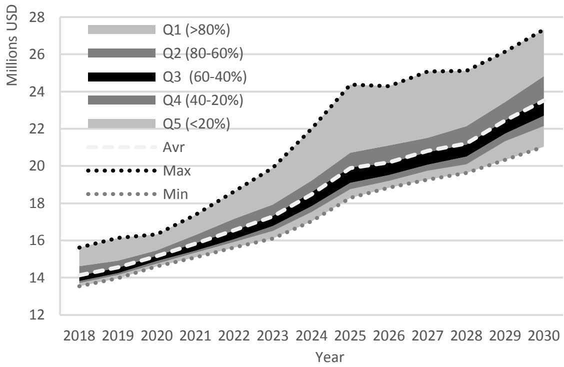

Figure 5: Non-discounted spot profit distribution by year

Since the project has an expected service life of 30 years and the optimization period accounts only for half of that period, it will be necessary to work with a representative annuity for the profits in the first 15 years. In order to calculate the annuity a cost of capital of 10% is used. The first step is to calculate the net present value (NPV) of the future profits by actualizing the future cash flows to 2016, which in turn will allow a comparison with the capital expenditures arising from the current construction of the power plant. After finding the NPV of the spot profits for each scenario, it is possible to annualize them through the application of the capital recovery factor; this factor is calculated using the same rate of return and period as for the calculation of the NVP of the spot profits.

Figure 6 presents the results for the distribution of the annuity representing the profits of the first 15 years of spot transactions. The number to bear in mind is an annual average of 14.6 million USD of profits.

There are three more elements that are important to discuss: first, the incomes due to capacity payments and secondly, the additional payment that a renewable project can get from the scheme to support renewable energy development in Chile. The third element that is important to consider is the effect that Power Purchase Agreements can have on making a project viable.

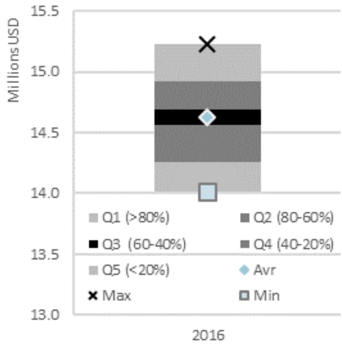

Figure 6: Annuity of 15-year spot profits referenced to year 2016

2.5. Capacity payments, renewable energy transactions and long term contracts

The Chilean electricity market has two additional sources of income for a geothermal project. Capacity payments are necessary to make investment viable in the context of a wholesale market operating under a marginal cost pricing system, based on the actual incremental costs of operation for each power plant. With only the energy income none of the units operating in the system would recover their investment and operation costs. The clearest example to verify the imbalance is a peaking unit: when it is operating it is simultaneously setting the marginal price of the system. This means a peaking unit never produces profits due to its production of energy, and hence lacks the necessary income to cover the initial investment expenditures.

Following the calculations conducted by van Campen et al. [van Campen et al. 2016] the annual capacity payment for a 48 MW geothermal power plant like Cerro Pabellón, facing a power price of 8 USD/kW/month, is close to 2.4 million USD.

In 2010, Chile introduced a mechanism to promote renewable energy investments based on imposing a minimum quota of energy that has to be covered by renewables. The mechanism includes a way for renewable companies to bilaterally transfer their quota to other companies who lack it. The average transfer price currently is close to 4 USD/MWh. With a generation of 400 GWh/year, Cerro Pabellón could generate a further 1.6 million USD/year of cash.

At this point, the potential aggregated annual profit for Cerro Pabellón yields, for the best scenario, is less than 20 million USD. Considering the characteristics of the project (location, access, exploration), it is expected that the investment costs for the binary power plant that is being developed will approach the upper limit of the cost range per unit of capacity usually considered for this technology, i.e., over 5000 USD per kW, or 240 million USD for the greenfield project. By means of the capital recovery factor it is possible to estimate an investment annuity of 25.5 million USD, considering the discount rate of 10% and a time horizon of 30 years.

These rather rough approximations show an imbalance between the annualized capital expenditures and the potential profits.

In this context, the ability to enter a long term power purchase agreement (PPA) could help harmonize the cash flow. The spot market in Chile is reserved only for generating companies; they can sell energy there and buy energy from it to fulfil their contracts. If the system has no transmission bottlenecks, similar prices are found in the nodes of the system. A generator selling its production to the spot market at its connection node and buying the same amount of energy in other nodes of the system to cover their contract liabilities would equalize its spot position. Then, instead of a spot income, it will collect the income resulting from the conditions of its long-term contract(s).

The owner of Cerro Pabellón recently announced the existence of a contact where it was established a selling price of 120 USD/MWh. This leads to an annualized energy profit of ca. 40 million USD, allowing the investment costs to go up to 7000 USD/kW while keeping the project profitable under a discount rate of 10%. Under current market conditions (with long term contract prices in the range 50-80 USD/MWh) the contract price achieved by Cerro Pabellón does not seem to be a rule, but rather an exception. Future geothermal developments will depend on lower investment costs and/or the capability of geothermal companies to enter into contracts with strike prices over 100 USD/MWh in order to make the projects viable.

3. CONCLUSION

According to the Chilean quota system geothermal projects must compete against other renewables resources in open auction processes. Since the levelized energy cost for geothermal technologies are higher than hydro, solar and wind, there is little room for successful competition in auctions for geothermal projects in the near future.

Thus, in order to ensure the economic viability of geothermal projects, the companies must obtain bilateral contracts with other players in the market, which is a rather challenging road.

Another alternative way to promote geothermal projects is to identify the specific advantageous operational features of geothermal plants when compared to other variable generation. A possible path to explore here is to value the high plant factor of geothermal plants as compared with other technologies, such as solar or wind. In fact, variable generation needs back-up in order to work properly, and so if the regulation process values the ability of a power plant to supply permanent and reliable energy it could give geothermal developers a good opportunity to increase their revenues.

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