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GEOTHERMAL ROUNDTABLE

ROLE OF GEOTHERMAL ENERGY IN THE DEVELOPMENT OF THE CHILEAN ELECTRICITY MATRIX

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ROLE OF GEOTHERMAL ENERGY IN THE DEVELOPMENT OF THE CHILEAN ELECTRICITY MATRIX

[Logo with the following text: ENERGY CENTER FCFM UNIVERSITY OF CHILE]

[Logo with the following text: ESMAP Energy Sector Management Assistance Program]

[Logo with the following text: FCH CHILE FOUNDATION

July 2018

[PICTURE]

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Introduction and Motivation

The abundant potential of renewable energy sources existing in Chile, including geothermal energy, situates the country in a privileged position to, through a continuous improvement of policies, exploit these energy sources, achieving a more sustainable generation matrix, reducing the price volatility of energy and improving the security of supply through the use of indigenous sources. Recently, we have observed how the high availability of renewable resources has led to an elevated competition and competitive prices in the energy market, it being a powerful tool to meet climate change mitigation objectives.

The local geothermal industry is currently comprised of an operating company, project development companies, services providers, *I+D* centers, universities, and trade associations. Efforts have been made in the exploration of the existing resources in the country, and there is currently enough exploration to encrypt the technically exploitable potential of the explored areas between approximately 1,300 MW and 3,800 MW, for the generation of electricity. The geothermal project development companies have expressed their intention of carrying on with the development of projects, with the purpose of building and operating power generation plants. The high levels of competition in Chile have hampered investment decision-making by geothermal developers, leading some companies to leave the company due to the lack of supply agreements that allow them to make their business strategies viable, despite the high level of investment made and some having discovered extensive fields of geothermal resources.

At the request of the geothermal industry, the Ministry of Energy summoned a public-private instance, denominated Geothermal Roundtable (hereafter "the Roundtable"), with the purpose of evaluating the potential and the opportunities that the development of geothermal poses in the electricity market of the country. On such instance, an analysis was carried out, on the planning and operating level of the electricity system, of the impact of such energy source in the national electricity system. Based on the results obtained from this analysis, public policy measures and instruments could be identified that could support its development. However, this analysis did not include a statement regarding the approval or rejection of the proposed measures. Due to information availability reasons, formation of the Roundtable, available analysis methodologies, and expected term deadlines, the analysis was restricted to geothermal projects for the generation of electricity in high enthalpy reservoirs. Thus, any analysis of the social-environmental type was left out of the scope of the Roundtable, cascading basis business evaluation around a geothermal plant, and the development of low enthalpy geothermal energy.

During the process Chile Foundation acted as technical secretary and organizer, counting with the technical support from the Energy Center of the University of Chile. The Energy Sector Management Assistance Program (ESMAP) of the World Bank has provided the financing for the development of the Roundtable and the studies performed.

The Roundtable, led by the Ministry of Energy, initiated its activities in December 2016 and concluded in December 2017. This report summarizes 12 months of intense work that have included 11 plenary workshops, 2 technical work meetings called *Petit Comités,* along with the analysis and processing of technical information and numerical modeling. In total, 216 CAPEX scenarios have been analyzed, and 648 scenarios for the levelized cost of electricity (LCOE) that characterize different typologies of the development of geothermal projects in Chile, and 12 energy matrix have been modeled, studying the behavior in the short and long-term in each one of them, with different income conditions from the generation of geothermal in the electricity market. This report summarizes such work with the purpose of making it easier to comprehend and spread the voluminous information generated. Herein, the methodology implemented in this participatory process, as well as the main results obtained from the technical analysis and the proposed public policies presented by the members of the Roundtable are exposed.

The results presented show an analysis on the basis of the best information and methodologies available to date. Notwithstanding, given the existent dynamism in the sector in technical, economic, politic and social topics, the detection of new market conditions, along with new information and knowledge, could arise from the revision of the exposed results. If the reader wants to deepen in any of the matters addressed by the Roundtable, the following website of the Ministry of Energy contains all the information – http://www.minenergia.cl/mesa-geotermia.

[PICTURE]

Methodology

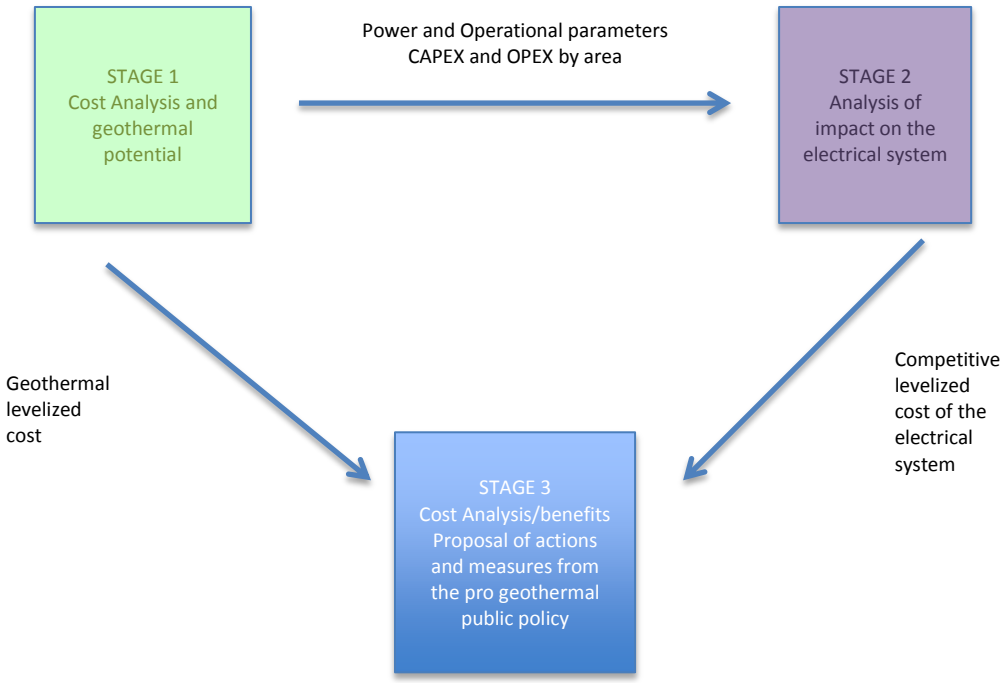
The process of the Geothermal Roundtable was designed contemplating a participation instance between actors and experts on the geothermal sector, uniting efforts with the scientific community, the public sector, the private sector and the public-private sector, in an analysis and discussion exercise that was subdivided in three successive stages, denominated Stage 1, Stage 2, and Stage 3.

Stage 1, has the purpose of defining the current state and development perspectives of geothermal projects in Chile. As of the best available information for identified geothermal areas, the potential developmental geothermal was estimated and determined in detail the investment costs (CAPEX) and operating costs (OPEX) for possible typologies of geothermal projects, considering different sizes of plants, technologies, geographical locations of the projects, depth and average productivity of the wells, among other parameters.

Stage 2, was focused on the main two objectives: 1) determine the levelized cost of electricity that geothermal energy projects must reach to be economically efficient and competitive in the expansion of the electrical system; and 2) identify the elements associated to the introduction of geothermal energy in the electrical system that could translate into benefits to the electrical system, in particular its impact on operating of the system in a context of elevated participation of variable renewable energies.

Stage 3, finalized the process by gathering the results from Stages 1 and 2, with the purpose of analyzing the competitiveness gaps of geothermal energy in the electrical system, as well as evaluating actions from public policy to favor the geothermal development in Chile. In this stage, the participants of the Roundtable proposed a series of measures that were preliminary analyzed and discussed in their scopes and potential impact on the development of geothermal in the country. However, this analysis did not include a statement regarding the approval or rejection of the proposed measures.

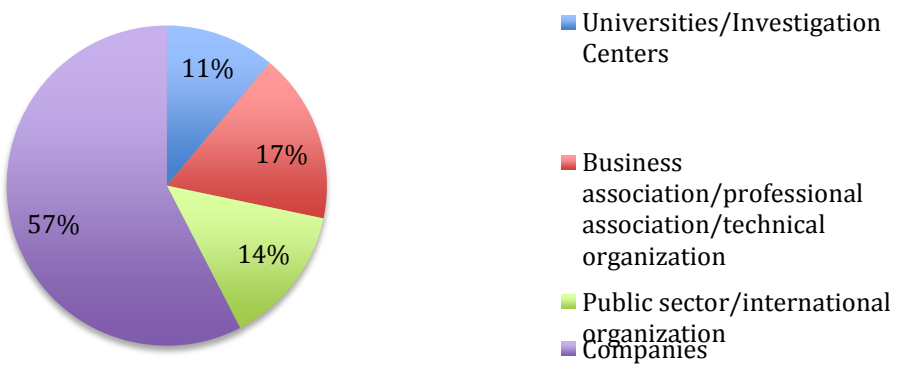
FIGURE 1. METHODOLOGICAL SCHEME OF THE GEOTHERMAL ROUNDTABLE



Description of the Participatory Process

The Geothermal Roundtable gathered in a discussion and analysis process all of the most representative sectors of the geothermal industry in Chile, including competitive public institutions, business associations, geothermal developers, geothermal industry services providers, academic institutions, and professional associations, under the direction of Chile Foundation in the capacity of technical secretary. In total, 41 entities were summoned to participate, of which 34 attended and an average attendance of 21 entities per session was registered, with an average attendance of 38 people in each of the work meetings.

FIGURE 2. METHODOLOGICAL SCHEME OF THE GEOTHERMAL ROUNDTABLE



All the entities that attended the Roundtable contributed actively and permanently, which led to successfully conclude this participatory process. Despite that in several matters several important differences in perspectives and vision from the participants arise, these were resolved making reference to the best available information, which has been one of the main rules applied in the whole process of the Roundtable. Additionally, during a period subsequent to each workshop, the participants had the possibility of making additional comments to those issued in the work sessions and/or contribute with complimentary information supporting their observations and proposals.

All the arguments discussed have been summarized in minutes prepared at the end of each workshop, which are available in the website of the Ministry of Energy – htt://www.minenergia.cl/mesa-geotermia) along with the presentations, data and documents generated or contributed during the discussion.

Stage 1
Methodology of the Analysis

COST ANALYSIS AND GEOTHERMAL POTENTIAL

On Stage 1, multiple national and international references were analyzed, with the objective of determining the current CAPEX and OPEX for geothermal projects limited to the reality of development in Chile. The participating companies of the Roundtable contributed with valuable information and the long-term tendency was analyzed following the behavior of geothermal CAPEX projected by NREL. Once all the information was gathered, a *Petit Comité* along with the geothermal developers was organized and the CAPEX and OPEX values were determined and agreed upon, in addition to high and low CAPEX scenarios, for each cost item. The determined information was further used to determine the LCOE or geothermal projects in Chile.

In parallel, a calendar of the development of projects and of identification of geothermal areas was discussed with the developers, with the purpose of determining the geothermal potential distributed geographically, to be used in the simulations of Stage 2.

Stage 2
Methodology of the Analysis
Impact of Geothermal on the Electrical System

On Stage 2, multiple computational simulations were performed to characterize the possible future scenarios of development of the electrical system, and the integration perspectives of the geothermal energy in the generation matrix. Said simulations have been performed in long and short-term conditions, using tools commonly used in the electrical sector for these purposes and based on assumptions, approximations and criteria agreed on with the participants of the Roundtable. Hereunder, a summary of the most relevant methodological aspects of the simulation processes used.

LONG-TERM PLANNING PHASE: EXPANSION SCENARIOS

The process of simulation of the expansion of the electrical system in the long-term[1] had as purpose to estimate for horizon 2017-2050 possible economically efficient expansion scenarios of the generation and transmission park of the national electricity system, using different assumptions for it. The scenarios have been simulated under the criteria of supplying the demand minimizing the updated current value of the investment costs, operating costs, maintenance, failure and management of the entire elements of the electrical system. The results lead to establish, for each simulated scenario, the competitive levelized cost of electricity (LCOE), which represents the maximum price level that the geothermal generation and other base units can reach for its inclusion in the electrical system may be economically efficient from a centralized optic.

To this effect, it was assumed that the current generation park of the national electricity system is added, as firm investment decisions, the projects declared under

[1] The long-term model detail is available in the presentation elaborated by the Energy Center in the Workshops 4, 4 Additional (4A) (http://www.minenergia.cl/mesa-geotermia/?pa-ge_id=42)

construction by Exempt Resolution CNE Nº914 of December 26, 2016 and the power stations associated with public tenders to supply regulated customers of the year 2016[2]. Successively to these "firm" projects, the selection of the projects to expand the generation matrix was performed by the long-term simulation model, based on potentials of generation from renewable energies determined by the Ministry of Energy for each geographical area, that correspond to an update in the methodology used in the publication Renewable Energies Potentials in Chile (*Potenciales de Energías Renovables en Chile)*[3], as well as type projects associated with thermal power stations. The information defined during Stage 1 of the Roundtable was used for the geothermal potential. Projects for pure storage, as pumping stations or batteries were not considered.

Regarding transmission grid, the simulation model considered a simplified typology of the real system, reducing it to nine bars or geographical areas, and including the transmission works plan under construction.

In a first instance, the participants of the Roundtable considered analyzing six scenarios that would allow to obtain a wide range of levelized competitive future costs (LCOE), including cases of future high and low prices, in addition to medium scenarios. As of the obtained results from the first simulations, the participants of the Roundtable requested simulate a second set of six scenarios to achieve in that way the expected objective in such stage. These new scenarios are composed of a Base scenario (defined by median trends for the relevant parameters) and five sensitizations regarding such Base scenario. By then, the results of the Preliminary Report of the Long-Term Energy Planning Process (*Planificación Energética de Largo Plazo*) (PELP)[4] process were available, carried out by the Ministry of Energy, whereby the Roundtable agreed to perform the new simulations aligning part of the assumptions used in the PELP.

Herein the results of the simulations and analysis performed over the second set of scenarios are summarized, characterized by the different evolution assumptions of the main indicators of the sector, as shown in Roundtable 1, namely: i) projection of investment costs of Non Conventional Renewable Energies (*Energías Renovables No Convencionales)* (ENRC); (ii) projection of fuel costs; (iii) projection of the demand;

[2] The results of the public tender for 2017 have not been included, since the information used for the simulation was up to the end of 2016.

[3] http://www.minenergia.cl/archivos_bajar/Estudios/Potencial_ER_en_Chile_AC.pdf

[4] Report dated June 20, 2017, available at http://pelp.minenergia.cl/

iv) Hydrological contribution; and v) geothermal investment costs. It was decided to take as a simulation criterion the mandatory compliance of the goal established in the Energy Policy – Energy 2050)[5], (70% of the annual generation with renewable energies in 2050), and consider an incremental cost by emissions using the same assumptions used on the process of the PELP. The detail in these projections is attached in Exhibit 1- Assumed projections for the long-term.

Although, part of the participants of the Roundtable expressed the need of incorporating in the simulation an exit schedule of coal-fired power plants (justified by the progressive obsolescence of the facilities and its debated social-environmental sustainability), finally the Ministry of Energy decided not to incorporate this aspect due to the lack of a validated methodology to estimate an exit schedule of power plants and adequately supported base information, having consulted previously and in a prompt manner different international organisms with respect to the existence of a methodology (NREL, IRENA and IEA).

TABLE 1. LONG-TERM SIMULATION SCENARIOS

AREA	Base 1.0	Sens 1.1	Sens 1.2	Base 2.0	Sens 2.1	Sens 2.2
Investment Costs Projection ERNC	Average	High	Average	Average	High	Average
Fuel Cost Projection	Average	Average	Average	Average	Average	Average
Demand Projection	Average	Average		Average	Average	
Hydrological Contribution	Medium*	Medium*	Medium*	Medium*	Medium*	Medium*
2050 Renewable Goal	Yes	Yes	Yes	Yes	Yes	Yes
Incremental costs by emissions**	Yes	Yes	Yes	Yes	Yes	Yes
Geothermal CAPEX ***	50 MW	50 MW	50 MW	100 MW	100 MW	100 MW

* Consider 10% less of hydrological contribution to take into account the effects of climate change
** Consider incremental cost used in PELP, which reaches 20,5 USD/ton by 2037 and 32,5 USD/ton by 2050 (see Exhibit 1- Assumed projections for the long-term)
*** Geothermal CAPEX available in the Report "*Fch_Informe LCOE Mesa de Geotermia*" in the presentations of Workshop 5 in http://www.minenergia.cl/mesa-geotermia/?page_id=42

[5] http://www.energia2050.cl

SHORT-TERM OPERATION PHASE:
OPERATIONAL PERFORMANCE

In this modeling phase of the electrical system, between the six simulated scenarios on the long-term, the participants of the Roundtable selected scenario Base 1.0[6] (Table 1) to be analyzed on detail with the application of models that allow to characterize the operation of the system with hourly resolution. Further, it was agreed to generate a variant of such scenario (Base 1.0 with geothermal energy), forcing the inclusion in the generation matrix of all the geothermal potential identified as available in the modeling term (2017-2050). This variant was generated following the methodology of the Long-Term Planning Phase: Expansion Scenarios (*Fase de Planificación de Largo Plazo: Escenarios de Expansión)*, but this time considering a CAPEX that determines a lower levelized cost of electricity of the geothermal projects that the levelized cost calculated in the Long-Term Planning Phase: Expansion Scenarios. The comparison of the operational performance of both simulated scenarios (Base 1.0 and Base 1.0 with geothermal energy), allowed to infer the impacts and benefits that the income of geothermal generation might generate in the electrical system. Such impacts and benefits correspond to the specific case in which the evolution of the generation matrix and other variables that define the costs of the electrical system behave like the ones considered in scenario Base 1.0, that has been selected as reference for the short-term simulation.

The short-term simulation sought to evaluate the operational performance of dispatch in hourly resolution, including the operative restrictions of the generation units. With this, the technical operability of the resulting matrix of the long-term process was verified, and it was evaluated, from an aggregate point of view (the matrix as a whole), the compliance of the flexibility requirements and of operational reserves product of the massive incorporation of expected wind energy and photovoltaic by the long-term modeling and corroborated by the results of the latest public tenders of electrical supply for regulated customers.

The input information used in the operational short- term models corresponded to the demand projections and the prices of fossil fuels of the PELP. In the same way, the technical parameters of the generation park that the National Electric Coordinator (*Coordinador Eléctrico Nacional)* uses to date were considered, so this consideration can be conservative by virtue of the audit processes, originated by the National Electric Coordinator, could have as a result

[6] Scenario Base 1.0 considers the medium projections for all the parameters that define it.

less restrictive technical parameters for the operation of the electrical system than current ones, as it has been evidenced in some cases. Additionally, the methodology did not consider new technologies like the storage through the use of batteries or pumping stations.

Stage 3 Methodology of the Analysis

Public Policies

In Stage 3 the proposed actions and measures of public policy were analyzed to impulse the geothermal energy, according to the results of Stages 1 and 2.

In this stage, the members of the Roundtable posed concrete measures to incentivize the development of geothermal industry in Chile. Such measures were analyzed based on 5 criterion defined by the Ministry of Energy and the Technical Secretary, with the purpose of comprehending the potential impacts thereof, required resources, implementation terms, and involved institutions. This document gives account of a preliminary analysis and the implications of the proposed measures, along with the terms associated thereof, considering the legal context in force. Thus, the presented analysis is not a pronouncement to approve or reject each of the proposed measures.

Main Results

Stage 1

COST ANALYSIS AND GEOTHERMAL POTENTIAL

CAPEX AND OPEX OF GEOTHERMAL PROJECTS IN CHILE

To characterize the possible configurations of geothermal projects in Chile 7 independent factors among each other were used, which define the main conditions that affect the CAPEX of each project. The considered factors are:

a. Size of the plant (3 types): in gross capacities of 20, 50 and 100 MW.

b. Generation technology (2 types): flash and binary.

c. Location of the project (2 types): northern area of Chile and southern area of Chile.

d. Expected depth of the geothermal reservoir[7](2 types): 1.500 meters and 2.500 meters.

e. Average productivity per well (4 types): 5,0 MW/well; 6,8 MW/well; 8,0 MW/well and 10 MW/well, with an average success perforation rate of 75%.

f. CAPEX unit (3 types): low CAPEX: case with the lowest unit costs of each component of a geothermal project; medium CAPEX: case where the unit costs of reference for each plant of 20, 50 and 100 MW are considered; high CAPEX: Case that integrates the highest unit costs of each component of a geothermal project.

g. Discount rate (3 types): 8%-10%-12%.

[7] From the currently available experience of the companies that have performed geothermal drills in Chile, it turns out that the reservoirs commonly develop in variable depths between 1.500 and 2.500 meters. In the Northern Area only reservoirs with a depth of 2.500 meters were considered and in the Southern Area reservoirs with depths from 1.500 to 2.500 meters are considered.

Additionally, the following criteria was used to describe other cost sources of the geothermal projects:

- Additional investments during the operation or replacement wells: during the lifespan of a plant, 1 replacement well is considered every 4 years, as of the eight year of operation. The wells are drilled until the end of the operation period[8], defined in 30 years. In this financial simplification for the imputation of the replacement wells, the same unit cost per well of the Development Phase is used and the costs of mobilizing the equipment are not considered.

- OPEX – Fixed and operation costs of the geothermal plant: an operation cost of 10 USD/MWh is considered and no distinction is made for flash and binary technology.

- Financial cost during the construction phase: a loan equivalent to the cost of the Construction Phase of the Plant is considered, with an annual financial cost of 4%, in US dollars. It is assumed that the loan is paid in full at the commencement of the operation of the plant.

- Capacity Factor: a gross capacity factor of 90% is used for flash technology and an 80% for binary technology.

The results indicate that the average unit CAPEX for a plant of 20 MW reaches USD 8,8 million per MW, while for a plant of 50 MW and 100 MW reaches USD 6,5 millions per MW and USD 5,7 million per MW, respectively. Thus, the economies of scale are relevant in the extent that the size of the plant increases from 20 to 50 and 100 MW, with a reduction of unit cost of 26% and 35% per MW, respectively.

CURRENT LCOE OF GEOTHERMAL PROJECTS IN CHILE

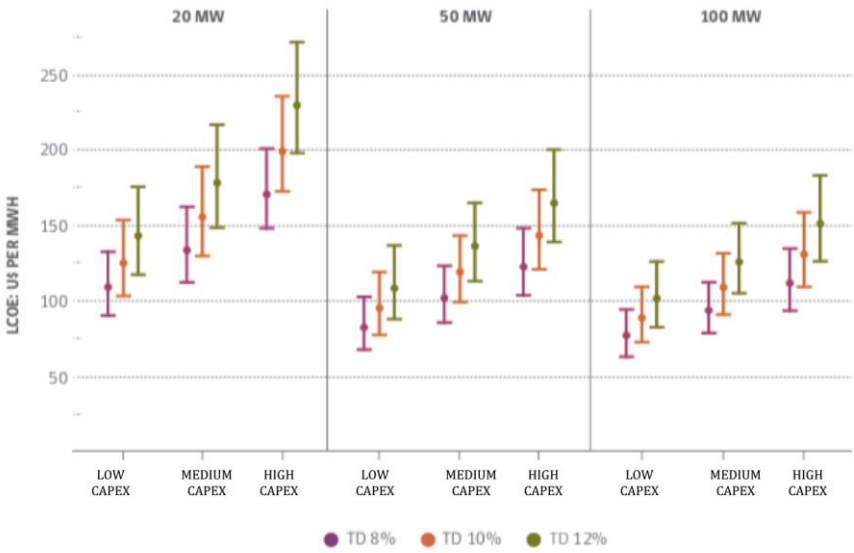
Figure 3 and Table 2 show the ranges of the LCOE obtained in Phase 1 of the Roundtable, arranged by plant size and discount rate, and calculated considering solely income by energy generation; without considering potential income for power[9]. The results shown correspond to a combination of the different

[8] The entire period of operation of the plant is considered, as the drill of 1 well every 4 years is an average value.

[9] In Chile, the income for power are set forth in the Electric Law for all generation plants and where geothermal energy would perceive this income by power, generating a calculation level credit of the LCOE. In the long-term planning analysis of the electrical system performed by the Energy Center, it was estimated that the income by power for geothermal projects, according to the simulated future scenarios for the energy matrix, would be around 6,7 USD/MWh. The non-consideration of income by power for geothermal energy deteriorates its competitive standing with technologies whose power recognition is inferior.

aforementioned CAPEX scenarios, calculated with discount rates of 8%, 10%, and 12%. The average LCOE for a 20 MW plant, considering a discount rate of 10%, is situated around USD 160 per MWh, while for a 50 MW and 100 MW plants it reaches USD 119 per MWh and USD 110 per MWh, respectively. The results reflect the effects of economies of scale in these types of projects, which are strongly affected by the investment in logistics infrastructures and connection to the electric grid.

FIGURE 3. LCOE'S SCENARIO FOR GEOTHERMAL PLANTS IN CHILE (ONLY INCLUDES INCOME BY ENERGY)[10]



[10] Each bar denotes the maximum and minimum limits, and the reference value in Chile, for all the analyzed scenarios by size of the plant category. The discount rates are distinguished by the colors of the bars. The LCOE for projects of 100 MW, considers that the investment decision for the 100 MW is taken at the commencement of the development of the project. The development of the project considers a construction by 50 MW stages each and in series. The second 50 MW stage starts operations 4 years after the first unit. While the graphic shows the results considering a second stage installation with 4 years posteriority, in the industry it is currently possible to consider a lower period between the developments of units, up to 2 years, as has been the case of *Cerro Pabellón*.

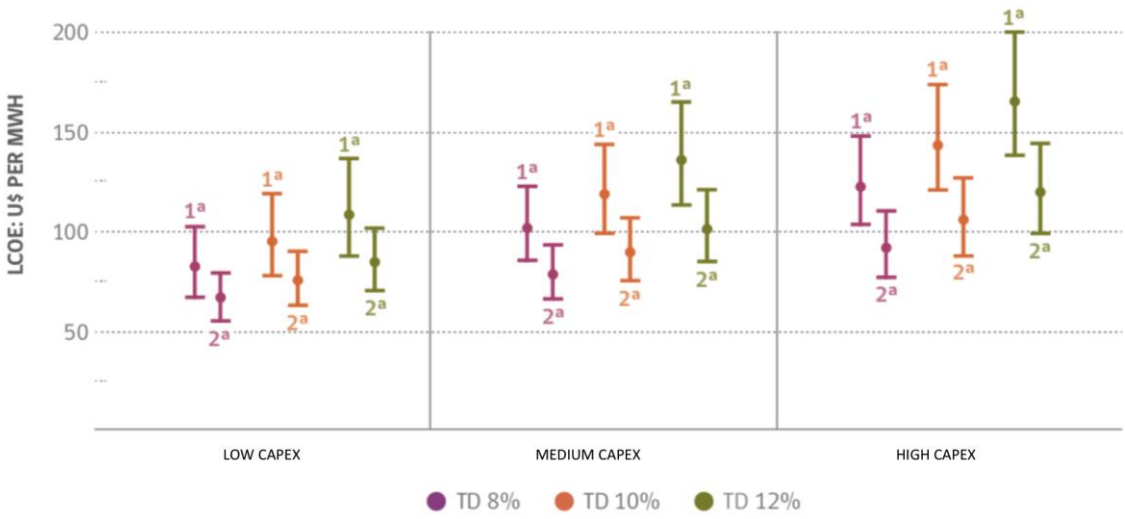
TABLE 2. MIN – MAX AND AVERAGE LCOE FOR GEOTHERMAL PLANTS IN CHILE

LCOE (USD/MWh)	Disc. Rate 8%		Disc. Rate 10%		Disc. Rate 12%	
	Min-Max	Average	Min-Max	Average	Min-Max	Average
20 MW	90-201	138	103-236	160	117-272	184
50 MW	67-148	102	77-173	119	88-200	137
100 MW	63-135	94	72-158	110	82-183	126

To more thoroughly investigate the effects of the economies of scale, the case of a geothermal development of 100 MW was also analyzed, divided in two independent stages of 50 MW each one. In this case the investment for the first unit includes all the habilitation costs and infrastructure of the project, while the construction of the second unit allocates just additional costs[11] for its development, given the exploration of the resource, access routes, camps, transmission network and other infrastructure elements, are already available. The results of such analysis are presented in Figure 4. It is important to note that during Stage 2 of the analysis, this economy of scale effect was represented allocating the investment cost equivalent to the development of two units in series to the geothermal technology.

FIGURE 4. LCOE FOR FIRST AND SECOND UNIT OF 50 MW
(ONLY INCLUDES INCOME BY ENERGY)

COMPARISON LCOE 50 MW VS. ADDITIONAL 50 MW



Note: The first 50 MW units are indicated as "1a" in the figure, and the second 50 MW units are indicated as "2a".

[11] Additional costs for expansion of 50MW: development drill, geothermal plant, steam pipes grid and aqueducts and electricity transformer.

GEOTHERMAL POTENTIAL THAT CAN BE DEVELOPED
OVER THE NEXT 30 YEARS

The evaluations performed during the fist stage of the Roundtable, based on the gathering of information provided by all the participants and in particular by the development companies, have led to identify a set of achievable projects during the term 2017-2050, with a potential around 2.100 MW, which can be visualized in Exhibit 4. It was estimated that 599 MW could be developed by 2030 and additional 1.487 MW during the period 2031-2050.

Table 3 shows the identified capacity, distributed according to the main areas of the national electrical system. This projection was used as a reference parameter to determine the availability of geothermal generation in the long-term modeling exercises of the electrical system.

TABLE 3. INDICATIVE CAPACITY OF ACHIEVABLE PROJECTS IN CHILE
FOR THE PERIOD 2017-2050

Interconnected System	Developable Potential Period 2017-2030	Developable Potential Period 2017-2050
SING North	102 MW	826 MW
SING Central	180 MW	686 MW
SIC	317 MW	574 MW
Total used in the modeling	599 MW	2.086 MW

Stage 2

ANALYSIS OF THE IMPACT OF GEOTHERAL ENERGY ON THE ELECTRICAL SYSTEM OF GEOTHERMAL COST AND POTENTIAL

EXPANSION OF THE NATIONAL ELECTRICAL SYSTEM IN THE LONG- TERM

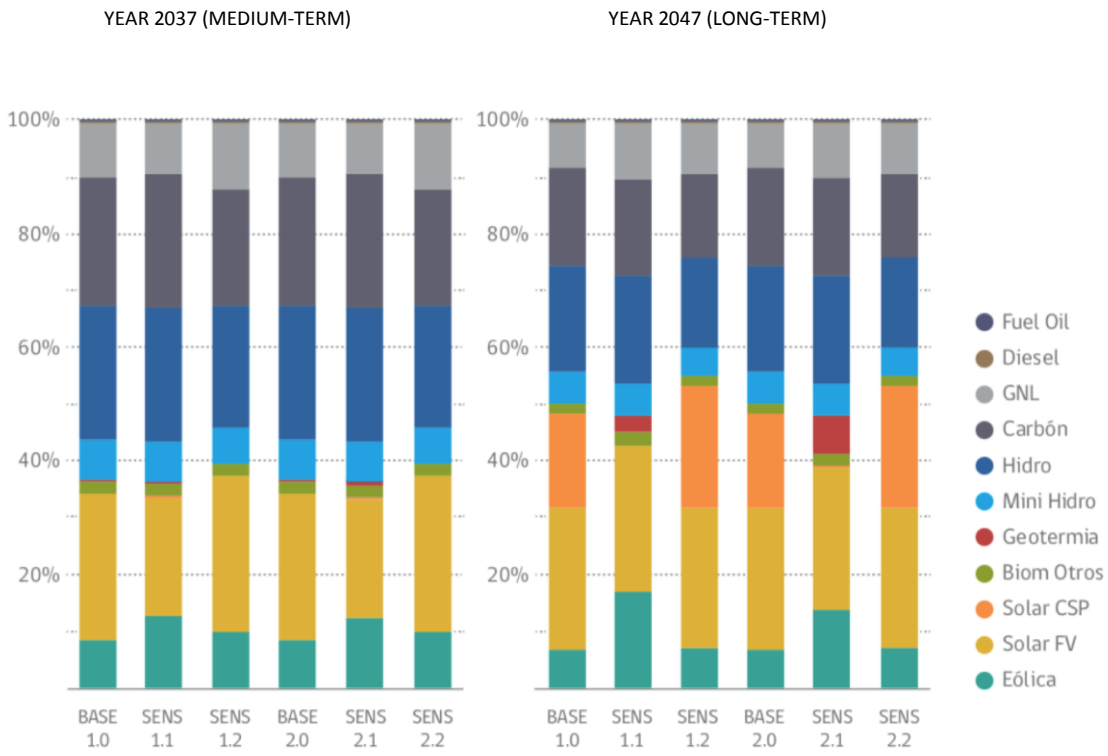
The analysis carried out show that, given the parameterization assumptions used, an important increase in the participation of renewable energies in the future electrical system generation matrix is expected, especially by wind and solar photovoltaic technologies. Such situation was observed consistently in all of the analyzed scenarios. Additionally, there was no evidence of the need to incorporate before the year 2027 additional generation capacity to the works declared under construction and to the new projects awarded during the last years to support supply agreements to regulated costumers.

Figure 5 shows the simulated participation by technology for two years selected as representative of the electrical system conditions in the medium and long-term, 2037 and 2047, respectively. In the medium-term, there is a similar level of renewable generation (around 68%) among the different simulated scenarios (indicated in Table 1), standing out a non-conventional renewable penetration of around 45%. In general, it is observed that the proportion of generation by technology between scenarios is similar, and a greater participation of wind generation is obtained in the scenarios in which a high projection of the investment cost of non-conventional renewable technologies was considered.

In the long-term (in 2047) the overview is a little more varied. Renewable generation would reach participation levels of around 75% (pursuant with the provisions of the Energy Policy 2050), and in the scenarios with medium ERNC investment costs (Base 1.0, Base 2.0, Sens 1.2, and Sens 2.2 – Table 1) an important entry from concentrating solar power (CSP) is observed. In these conditions non-conventional renewable technologies would reach penetration levels above 55%. On the other hand, those scenarios that considered a pessimist projection for the ERNC investment

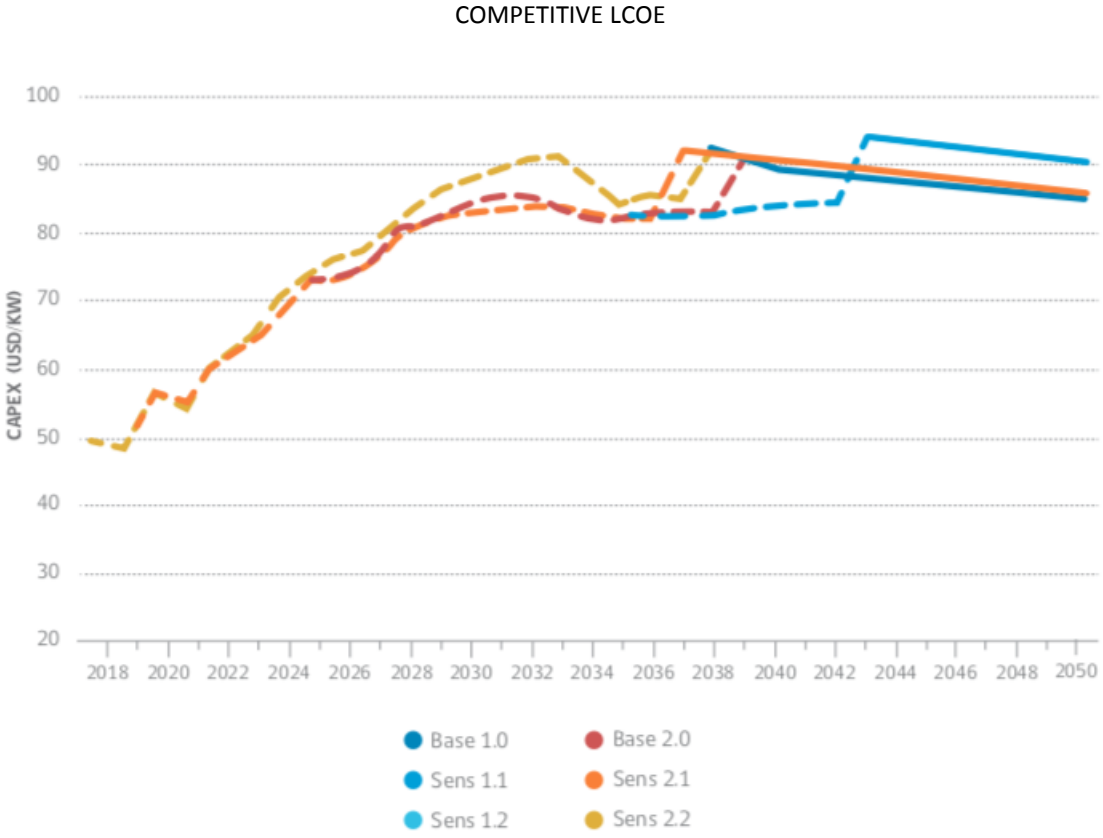
costs (Sens 1.1 and Sens 2.1 - Table 1), equivalent to a cost trend with a slight decrease for wind and solar photovoltaic technology, or without cost reduction over time for CSP technology, suggest the entry of geothermal energy projects and a greater development of wind generation, instead of CSP technology.

FIGURE 5. GENERATION PARTICIPATION BY TECHNOLOGY
TO YEAR 2037 AND 2047 FOR EACH STUDIED SCENARIO



As of the long - term simulation results, the evolution of the competitive electricity levelized cost was determined for each scenario, as shown in Figure 6. Although in the first years such value increases progressively, as of 2027, with the entry of new generation capacity, the LCOE stabilizes between 80 and a little more than 90 USD/MWh with a relatively low dispersion for the set of scenarios.

FIGURE 6. COMPETITIVE LCOE FOR EACH STUDIED SCENARIO
(SCENARIOS DEFINED IN TABLE 1)



The dotted part of the curves in Figure 6 correspond to the years in which no more projects are installed other than those already declared under construction or committed for support of supply contracts (until 2026) or just renewable projects of variable generation (mainly wind and photovoltaic) are installed, thus the levelized cost was calculated as the average marginal cost of the system in the respective year. On the other hand, the continuous part of the curve represents the highest levelized cost among the base generation power stations installed in the system, understanding "base" as those with an elevated plant factor (above 70%).

OPERATIONAL IMPACTS: SHORT-TERM ANALYSIS

One of the objectives of the national electricity matrix projections shown in the previous section was to support the choice, on the part of the Roundtable, of a plausible scenario on which to estimate the impacts on the electrical system of a scenario with greater participation of geothermal energy. The chosen scenario by the participants of the Roundtable as reference for this exercise was Base 1.0 scenario, which corresponds to medium conditions on all the projected variables (demand, ERNC investment costs and fuel costs), for which a variant with a forced entry of geothermal generation was simulated (case Base 1.0 with geothermal energy)[12]. Along with it, two years of interest were chosen over which an analysis of system operation with hourly resolution. The chosen years were: 1) Year 2037, representative of the conditions of the electrical system in the Medium-Term, which is characterized by a high penetration of photovoltaic technology and where the matrix is composed of technologies similar to the current ones; and 2) Year 2047, representative of the conditions of the electrical system in the Long-Term, where a possible significant entry of CSP technology (Figure 5) is observed.

In Figure 7 the installed capacity by technology in the different matrixes chosen for the short-term simulations (Scenario Base 1.0 and Base 1.0 with forced entry of geothermal energy, in the years 2037 and 2047) may be observed. Solar photovoltaic technology is the technology with the greater participation in all the scenarios, while the main difference among the matrixes is on the participation of CSP Solar technology, which enters the system by being a technology that contributes flexibility and has the advantage of providing storage to the energy matrix.

The short-term analysis indicate that, for the different configurations of electricity matrixes presented in Figure 7, it is possible to have an economic operation that complies with the reserve requirements for the Frequency Control, in conformity with the Technical Standard of Quality and Service Security (*Norma Técnica de Calidad y Seguridad de Servicio)*, even considering the high level of simulated variable renewable generation.

From the results of the short-term simulations, the total cost of the electrical system for both years and both simulated scenarios was calculated. This is the annual investment value in generation and transmission, adding the annual operating cost (*costo de operación, mantenimiento, y administración)* and the failure cost.

[12] See details of the applied methodology in the chapter Methodology, sub-chapter Short-Term Operation Phase: Operational Performance, of this document.

In addition, and by requirement of the participants of the Roundtable, a valorization of the emissions of atmospheric pollutants was added to these costs, using as reference the projection of the CO2 tax used in the Preliminary Report of the PELP. With these values, the difference on the total cost between scenarios Base 1.0 and Base 1.0 with geothermal energy was calculated, as presented in Table 4.

FIGURE 7. SIMULATED INSTALLED CAPACITY FOR THE YEARS 2037 AND 2047, SCENARIOS BASE 1.0 AND BASE 1.0 WITH GEOTHERMAL ENERGY

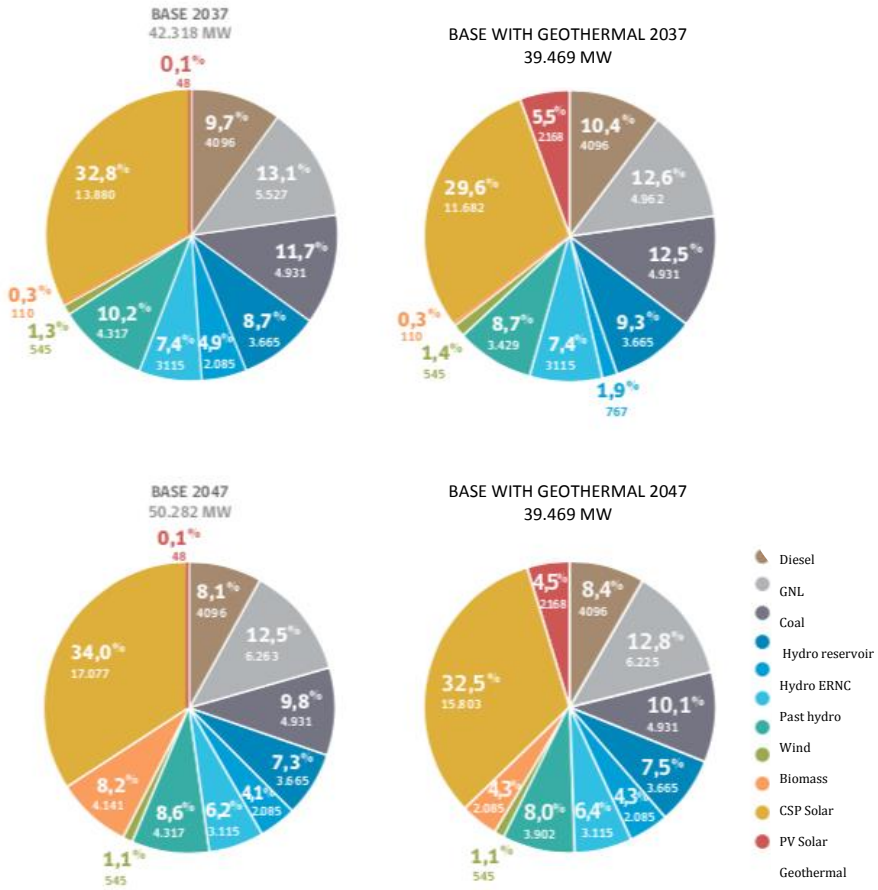


TABLE 4. RESULTS OF THE TOTAL COST OF THE SYSTEM, FOR THE CASES WITH AND WITHOUT GEOTHERMAL ENERGY, FOR THE YEARS 2037 AND 2047

	Matrix 2037			Matrix 2047		
Annual Cost (MMUSD)	Base 1.0	Base 1.0 with Geothermal Energy	Difference	Base 1.0	Base 1.0 with Geothermal Energy	Difference
Annual Operating Cost	2.735	2.336	-14,6%	2.778	2.881	-3,7%
AVI+COMA	2.048	2.479	21,0%	4.796	4.778	-0,4%
CO2 Tax	839	804	-4,7%	1.188	1.198	0,8%
Annual Total Cost	5.622	5.619	-0,1%	8.762	8.857	1,1%

Under the simulated conditions, the incorporation of geothermal energy in the system did not modify significantly the total cost of development. However, in the year 2037 (medium-term) with a generation park that continues to be characterized by traditional technologies, but with a high participation of photovoltaic solar technology, it is appreciated that the incorporation of the geothermal energy induces a reduction of the operating cost in a 14,6% and a reduction of a 4,7% of the emissions.

For its part, for the year 2047 (long-term) with a generator park dominated by a high penetration of ERNC, that has a higher energy managing capacity, the incorporation of geothermal energy would increase the operating cost in a 3,7% and would maintain the emissions with a slight increase around a 0,8%.

Other relevant aspects resulting from the short-term simulation exercise, agreed by the *Petit Comité*, are the following:

- The modeling exercise was delimited to the characteristics with which the National Electric System currently operates and a potential offer of projects considering technologies that are currently operating or under construction in Chile. With these assumptions, it was obtained as a result that the requirements for additional capacity of the electric system could be covered almost exclusively with renewable energies.

- For the simulated scenarios, it has been possible to identify, for the medium and long terms, an increase in the flexibility requirements of the national electrical system, determined by the high level of participation that renewable energies reach with significant hourly variability, in particular the photovoltaic solar energy.

- According to the obtained results, within an approximate horizon of 20 years, it is possible to assert that such flexibility can be provided through the participation of the existing traditional park, if it is maintained in operation without major modifications. In the event that the thermal park (specially coal) reduces its participation (see Exhibit 3), either by obsolescence, low competitiveness, or public or private policies decisions, it would be required to replace its contribution with technologies that have the capacity to contribute to operating flexibility. This could be an opportunity for geothermal energy, as well as for other technologies (CSP, hydroelectricity with regulation capacity, batteries and pumping, and demand control).

In a horizon over 20 years, the increase in the system demand and the participation increase of renewable energies with hourly variability generates the need of increasing the flexibility levels of the national electrical system, regardless of the future situation of the already installed thermal park.

PROVISION OF FLEXIBILITY TO THE SYSTEM BY GEOTHERMAL UNITS

The topic of flexibility of the system was subject of extensive discussions among the participants of the Roundtable, in which it was stressed that geothermal energy is capable of contributing to the flexibility and security of the system, in case that such operating mode is considered in the design stage of the plants. Such considerations would not require a major investment cost according to the opinion exposed by the geothermal industry in the development of the Roundtable.

On this respect, the World Bank requested a study from the consulting company Mannvit[13] with the purpose of describing the ability of the geothermal plants of providing complementary services. Such study shows the capacity of geothermal units to participate in the services of tension and frequency control, as well as also the black start capacity (independently for 3-5 MW small units and with the support of diesel units to fuel the auxiliary consumption in the case of larger units). The study deepens in the technical characteristics of these types of units, in terms of its minimum power of operation, ramp capacity, and minimum time of operation and out of service.

[13] Available at http://www.minenergia.cl/mesa-geotermia/?page_id=12

These characteristics were incorporated in the short-term analysis, where less participation of geothermal energy as a service provider of frequency regulation was observed, mainly during the hours of photovoltaic generation. Such provision coincides with the cut hours of photovoltaic generation, where in these operating conditions the valorization for the frequency control services could eventually get to zero (high reserve surpluses for frequency regulation product of an operation close to technical minimum by the hydraulic and thermal units).

CAPEX TO ACHIEVE A COMPETITIVE POSITION IN THE CHILEAN ELECTRICAL MARKET

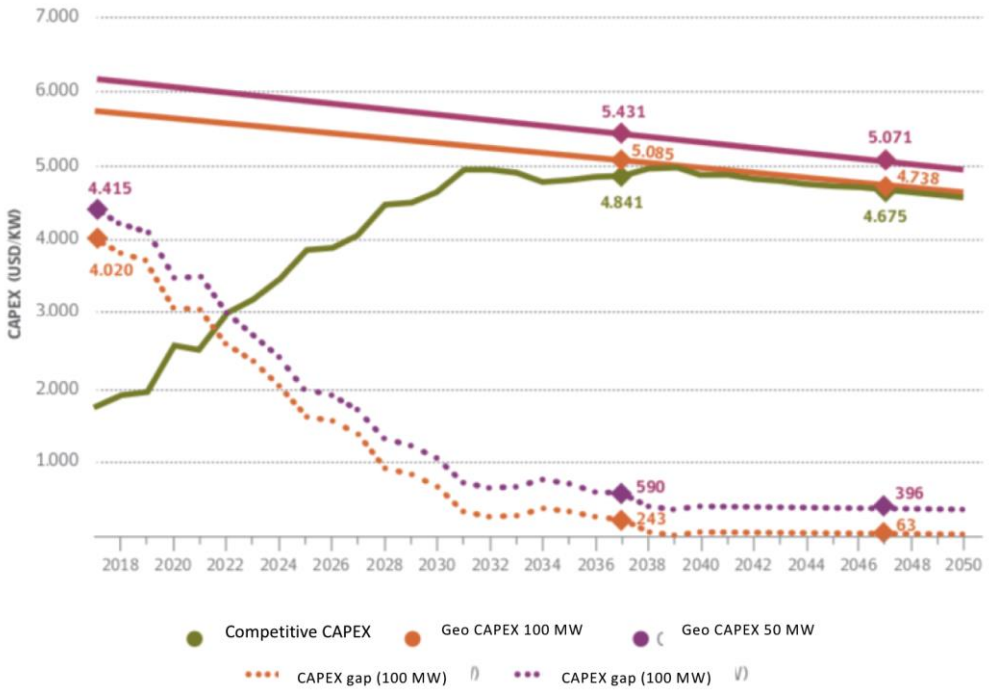
As of the competitive levelized cost obtained in the Long-Term Planning Phase, the maximum CAPEX that the projects based on geothermal energy should reach was determined, in order to be competitive, if the expansion conditions of the electrical system under scenario Base 1.0 (development technology) are verified. The difference between this value and the geothermal CAPEX determined in Stage 1 of the Roundtable, allows quantifying the economic gap that geothermal energy would face in the modeled period of time (2017-2050).

Figure 8 shows the evolution of the estimated medium CAPEX[14] for geothermal projects of 100 MW and 50 MW. Given these results and under the simulation conditions of scenario Base 1.0, it was identified that geothermal energy could achieve a competence condition by reaching a CAPEX around a 4.800 USD7kW installed, against other technologies of similar attributes regarding its plant factor.

[14] The evolution of CAPEX has been estimated by adapting to the Chilean context the geothermal market trends published by NREL, which are detailed in the LCOE Report (see reference in Table 1).

FIGURE 8. EVOLUTION OF THE COMPETITIVE CAPEX OF THE ELECTRICAL SYSTEM AND OF THE CAPEX OF GEOTHERMAL TECHNOLOGY

COMPETITIVE CAPEX VS GEOTHERMAL CAPEX



In particular for the case of a 100 MW plant, in the year 2037 a CAPEX gap of 243 USD/kW is observed, equivalent to a 5% of the expected CAPEX for geothermal energy in that year and an LCOE equivalent to 3,5 USD/MWh. For the year 2047 the CAPEX gap reduces to 63 USD/kW, which is equivalent to approximately 1% of the expected CAPEX for geothermal energy in that year and an LCOE of 1,0 USD/MWh. Considering that CAPEX and LCOE of the different development technologies are also subject to uncertainty, the values shown here give account of the competitiveness of geothermal energy in such horizon.

It is important to note that the size of the gap against other base technologies (like coal, GNL, CSP, among others), as of 2037, is comparable to the “contingency” item that is used for projects. Thus, it is estimated that geothermal projects could result competitive as of such date depending on the positions regarding the risk that different project developers could take. Reaching this level of competitiveness would depend of many factors where, according to the information provided by the participants of the Roundtable, it is assumed that geothermal energy could decrease its costs through the development of the national market of industry and related services,

and also as a consequence of possible technological or operating improvements that occur at the international level.

Stage 3
PUBLIC POLICIES

PROPOSAL OF ACTIONS AND MEASURES PRO GEOTHERMAL ENERGY

Considering the results and analysis derived from Stages 1 and 2, different measures that could impulse through public policies destined to support the development of electric generation project that use the geothermal potential of Chile were posed and discussed in the Roundtable. The proposals were prepared by the Chilean Geothermal Association (*Asociación Chilena de Geotermia)* (ACHEGEO) and by the Geothermal Council (*Consejo Geotérmico)* and widely evaluated and discussed in two plenary workshops of the Roundtable. The analysis presented in this document gives account of a preliminary analysis and of the detection of the implications product of the proposed measures, along with the terms associated to them, considering the legal context in force. Thus, the presented is not a pronouncement to approve or reject each of the proposed measures.

Consequently, the criteria defined and used by the Ministry of Energy for the evaluation of the proposals were:

i. Qualitative impact of the proposed action in the national geothermal sector. With this criterion an attempt was made to determine if the proposed measure could have a relevant incidence in the decision of geothermal project development.

ii. Need for regulatory changes to implement the measure, with the intention of defining if the proposed measure could be implemented within the regulatory framework in force or requires, necessarily, of any regulatory change.

iii. Dimensioning of economical resources involved for the implementation of the proposal. The amounts lower than USD 100.000 were considered low financial resources, medium between USD 100.000- USD 1.000.000; and high over the USD 1.000.000. It is about, mainly public resources, depending of the implementation scope of the proposal.

iv. Time of implementation of the action.

v. Required institutionality for the implementation of the proposal. In this point the required public institutions in the treatment of the measures are indicated.

The summary of the analysis of the proposals, carried out based on such criteria, is presented in Table 5.

SPECIFIC ANALYSIS OF THE MEASURES

A summary of the analysis made from the discussion held in the workshops of the Stage 3 of the Roundtable and the documents with clarifications and precisions received afterwards is presented below. The documents with the proposals in detail presented by the Geothermal Council and ACHEGEO are available in the web site of the Ministry of Energy[15].

A. PROPOSALS OF THE GEOTHERMAL COUNCIL

PROPOSAL 1: MODERNIZATION OF PAYMENT BY SYSTEM CAPACITY

Contents of the Proposal: The proposal seeks to modernize the payment by capacity (or, in the Chilean electrical market, payment for "power"), opening the discussion regarding the currently used procedure for the determination of the price of the capacity attribute, as well as the one used for the payment allocation among the different generators, with the objective of having a mechanism adapted to the new energy technologies and the current and future needs of security, which provides a stable long-term price signal, particularly given the future flexibility requirements identified in the exercise performed in this Roundtable.

Analysis: Payment for power sufficiency set forth in the Supreme Decree 62, is still being reviewed to maintain coherence with the rest of the regulatory modifications of the sector, in particular with the SSCC Regulation and with the Operation Coordination Regulation.

[15] Reports "EDC_Minuta Final de Análisis de Medidas Desarrollo Geotermia v3-revCMM", "PROPUESTA DE MODIFICACIONES LEGALES PARA IMPULSAR EL DESARROLLO DE LA GEOTERMIA ACHEGEO", "Propuesta Políticas Públicas Geotermia_221117_CG" and "Consejo Geotérmico_Clarificacio-nes_Propuestas PP_151217", disponibles en el apartado Presentaciones Taller en el link http://www.minenergia.cl/mesa-geotermia

Modifications to the power payment scheme can also affect the rest of the electrical market structure, thus could imply substantial changes in the current legislation and, eventually, some modifications to the Electrical Services General Law (*Ley General de Servicios Eléctricos)* (LGSE) could be required.

There was a point of view on the part of the industry regarding that within the scope of the revision of Decree 62, the power signal was designed to make investments viable. Furthermore it was complemented that presently the regulation that delivers such decree is insufficient for that purpose and thus, is being object of review by the authority, and that the complementary services in itself, are not investment signs in generation means, rather, signs to carry out investments in specific equipment.

From the point of view of the five evaluation criteria previously indicated:

1. Qualitative impact of the proposed actions in the national geothermal sector: could be medium to high, but depends of the competitiveness of geothermal energy in relation to other technologies of similar attributes.

2. Requirement of regulation changes to implement the measures: could be medium or high, it will depend if regulatory or legal changes are needed, thus the need of a review of the entire electrical market structure.

3. Dimensioning of the resources involved for the implementation of the proposals: low to medium, depending on the regulatory review.

4. Time of implementation of the actions: at least 12 months, if it were only about adjustments at the regulatory level. If, in addition, there would be the need to modify the sectorial legislation, the term could extend at least 12 more months.

5. Required institutionality for the implementation of the proposal: Government – Ministry of Energy, National Energy Commission (*Comisión Nacional de Energía)-*, the industry, and eventually, the National Congress.

PROPOSAL 2: BLOCKS THAT INTRODUCE SECURITY DEMANDS IN THE ELECTRICITY PUBLIC TENDERS

Content of the Proposal: The proposal seeks to allow the incorporation of criteria to differentiate offers with specific attributes in the public tenders of electrical supply to regulated costumers, for example through the design of blocks that introduce security demands in the Electricity Public Tenders regulated by articles 131 and further of the LGSE, or specific criteria of the award of these public tenders, in a way that, without implying an arbitrary discrimination, allows to generate a balance between non manageable and manageable technologies, and at the same time allows to pursue the competence objectives, security and diversification foreseen in the mentioned regulation.

Analysis: A preliminary analysis, allows establishing the current regulatory frame, under certain conditions, could allow incorporating criteria to differentiate offers with specific attributes. As of an interpretation of the legal frame of the electrical sector, it is possible to sustain that it would be possible to define supply blocks for generation with specific attributes if: 1) in a near future[16], the application of the award criteria presently used in the public tenders that could translate into greater supply costs for the regulated clients (for example an increase in the complementary services costs paid by them); and 2) from the security perspective referred to by article 72-1 of the LGSE, the existence of a real sufficiency risk for the supply period, that redounds in greater prices for the regulated clients.

It is important to indicate that, according to the analysis of the LGSE carried out by the Ministry of Energy and the CNE, the ultimate end of the public tender is to supply with the least supply cost the consumptions of the clients subject o price regulations, considering the criteria of economic efficiency, competence, security and diversification (article 131 bis of the LGSE).

The literal analysis of the referred Article 131 bis of the LGSE would imply that the word diversification it uses, would limit to the compliance of the ERNC obligation set forth in Article 150º bis of the LGSE. On that regard, in the medium-term, and according to estimations carried out by the Ministry of Energy, no risk of compliance of such obligation product of the results obtained in the public tender processes of supply to regulated costumer is foreseen.

[16] By near it refers to the term contemplated in each public tender to initiate the supply.

For its part, the concept of security used in the frame of the public tender, references to the existence of enough generation to supply the demand of regulated clients. This concept could consider the aforementioned energy sufficiency, as well as the "service security", in other words the maintenance of the quality of the electrical service according to the provisions set forth in the Technical Standard of Quality and Service Security (*Norma Técnica de Calidad y Seguridad de Servicio)* (NTSCS).

The analysis performed gives account that, while no arguments are posed that indicate that the results of the future public tenders cause greater costs to the regulated clients by requirements of "service security", the compliance of the standards established by the NTSCS must be ensured by providing the Complementary Services. This matter is regulated in the LGSE, which sets forth mechanisms for auctions and public tenders to attend to the security and quality of service problems in the short and medium-term, respectively.

In synthesis, to attend to this proposal two situations must be distinguished:

- If an engagement is detected in the security and quality of service standards in the short and medium-term, then will proceed to carry out auctions or public tenders associated with the provision of complementary services (SSCC), according to the provisions of the LGSE.

- If it is detected that the application of the criteria used in the public tender supply processes may redound in greater supply costs, for example, because of the existence of greater costs for provision of SSCC, under the mechanisms that the law contemplates, a review of the aforementioned criteria could be generated, that allows to analyze offers with specific attributes.

Finally, and regarding the inclusion possibility of this proposal in a public tender, it is indicated that the formal entity where the aforementioned conditions could be analyzed correspond to the Public Tender Report elaborated by the CNE, which the industry or anyone interested, can make technical observations to its content. It is in the referred Report where the criteria, that according to law, determine the public tender process or processes, are included.

From the point of view of the five criteria defined by the Ministry of Energy:

1. Qualitative impact of the proposed actions in the national geothermal sector: medium to high, and it will depend of the geothermal competitiveness with regard to other technologies with similar attributes.

2. Regulatory changes requirement to implement the measures: low. A preliminary analysis, gives account that potentially a public tender as indicated can be justified, subject to the analyzed conditions.

3. Dimensioning of the involved resources for the implementation of the proposals: low.

4. Actions implementation time: low, less than 1 year.

5. Required institutionality for the implementation of the proposal: CNE and distribution companies.

PROPOSAL 3: EVALUATION REPORT OF GEOTHERMAL RESOURCES TO OPT TO THE POSTPONEMENT MECHANISM OF THE COMMENCEMENT OF SUPPLY OR EARLY TERMINATION OF THE CONTRACT

Content of the Proposal: This proposal has as objective to make a modification to the basis for the public tender of supply for regulated customers, regarding the optional mechanism of early cancellation of the contract or extension on the supply term, in case that the geothermal resource does not have the originally expected characteristics. The proposal consists in replacing the current exigency of a report of proof of well by a report of evaluation of geothermal resources elaborated by a qualified third party, according to the criteria of the "Canadian Geothermal Code for Public Reporting" or the "Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves".

Analysis: In the scope of the energy Public Tenders for regulated costumers, the access to geothermal projects was facilitated in a way that they could in part mitigate the risk associated with the exploration phase of the resource and the development of the geothermal field. This way, in the basis of the public tender, special conditions were created for the geothermal projects allowing exercising the early abandonment clause of the contract or reprogramming of the date of commencement of the supply, in the event of failure in the exploration and development of the geothermal field.

To opt to these special conditions, the geothermal offeror must accompany the petition with an approved report by the Ministry of Energy, certifying the existence of the geothermal resource by means of proof of production of a geothermal well. The postponement option of commencement of supply and the early termination of the contract justified in the non-existence of the primary energy resource is exclusive of geothermal, not having this option generation means based on other primary sources.

Under these conditions a geothermal offeror may:

a. Not opt to the special condition for geothermal, adhering to the same conditions of postponement or early termination of the supply contract that projects of any other technology have. In this case the postponement on the commencement of the supply or early terminate the contract using the justification of insufficiency of the geothermal resource will not be possible.

b. Opt to the special condition, being able to adhere to the postponement or early termination of the contract clauses by not finding sufficient geothermal resource.

Notwithstanding, the special condition exposed in numeral b), could result impractical or inapplicable for an offeror who has not yet executed its deep drilling program, in situation where there are other means to deliver the guarantees that the process requires for its application that can be delivered much earlier than executing such deep drilling program. Precisely, after applying criteria like those established in the "Canadian Geothermal Code for Public Reporting", the "Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves", the "Geothermal Resources and Geothermal Reserves", the criteria of the Risk Mitigation Reserve (*Fondo de Mitigación de Riesgo)* of the BID (for its acronym in Spanish) for geothermal projects (MiRiG), or other similar ones, a clear signal could be obtained to establish if the special condition of the postponement clause applies or not.

In this regard, it further results convenient, to review if in the context of the Law of Relevant Persons (*Ley de Personas Competentes)* that applies in the mining sector, exists feasibility to incorporate or extend the mechanism to the geothermal sector.

From the point of view of the five evaluation criteria:

1. Qualitative impact of the proposed actions in the national geothermal sector: Medium. The direct effect it would have is the facilitation of the presentation of offers for offerors that promote geothermal projects in the supply public tenders.

2. Requirement of regulatory changes to implement the measures: low. Change in public tender basis.

3. Dimensioning of resources involved for the implementation of the proposals: low.

4. Time of implementation of the actions: short, less than 1 year.

5. Required institutionality for the implementation of the proposal: CNE, Ministry of Energy.

PROPOSAL 4: TAX PROVISIONS OF INTEREST FOR GEOTHERMAL ENERGY

Content of the Proposal: The presented proposal seeks to establish tax and customs nature incentives applicable to geothermal projects, such as:

- Customs duties exemption to capital assets.
- Exemption of rates and guarantees for the temporary entrance to the country of drilling equipment.
- Exemption of VAT on the import of capital assets.

Analysis: These three exemption mechanisms are already in force in a generic form for energy and mining projects, and apply for geothermal projects; it is noted that the *Cerro Pabellón* project used these tools. However, it is proposed to perform improvements in its application procedure, in a way in which the particularities of the geothermal projects are considered. These improvements would imply some legal and regulatory modifications.

From the point of view of the five evaluation criteria:

1. Qualitative impact of the proposed actions in the national geothermal sector: low, the proposed option is in force, although it could be improved.

2. Requirement of regulatory changes to implement the measures: high. In case a special tax regime for geothermal projects is intended legal approval would be required for its establishment, which implies the proper difficulty for the approval of this kind of regulations. The aforementioned, notwithstanding to the discriminatory element of its exclusive definition for these types of projects.

3. Dimensioning of resources involved for the implementation of the proposals: low.

4. Time of implementation of the actions: more than 2 years.

5. Required institutionality for the implementation of the proposal: Ministry of Energy, Ministry of Finance (*Ministerio de Hacienda)*, Ministry General Secretary of the Presidency (*Ministerio Secretaría General de la Presidencia),* National Congress.

PROPOSAL 5: DEVELOPMENT POLES AND GEOTHERMAL ENERGY

Content of the Proposal: It is proposed that, within the framework of the Transmission Law (*Ley de Transmisión)*, geothermal areas are considered potential candidates for Development Poles.

Analysis: The Development Poles are contained within the legal framework in force and during 2017 the first process of definition of candidates to development poles took place, in charge of the Ministry of Energy. The process, by which a Development Pole is determined, is regulated and it is the result of a long-term simulation of the national electric system, similar to the one performed by the Geothermal Roundtable. In the process, all the potentials of renewable resources are used as background, among them those of geothermal energy, and are located geographically as part of the evaluation process.

In the Law, the definition of a Development Pole is: "It is understood as development poles those areas territorially identifiable in the country, located in the regions in which the National Electrical System is based, where the existence of resources for the production of electric energy originating from renewable energies, whose utilization, using a sole transmission system, results in the public interest for being economically efficient for the electrical supply, shall comply with the environmental and land-use planning legislation". For this effect, the results of an optimization model are used to justify the potential poles that result to be economically efficient for the electrical supply.

In the Long-Term Energy Planning Process (PELP) developed during 2017 the geothermal areas identified by the Roundtable were considered as candidates to development poles. The criteria used in such process to define if an area is a development pole or not, are the following:

a. Technological: wind, geothermal and hydroelectricity.

b. Need for solution: without proximity to the existent transmission.

c. Temporary: set in force between 2025 and 2044.

d. Feasibility: it is recommended in several simulation scenarios (at least 3).

e. Efficiency: size relevant for the system.

The results of the final report of PELP (December 5, 2017), indicate that in this evaluation process, no development poles for any type of technology were found.

With this result, in 5 more years, the Ministry of Energy will perform a new evaluation to define possible development poles. From the point of view of the five evaluation criteria for this proposal, in this Final Report its application has been dispensed with, as it is a measure already in operation.

PROPOSAL 6: RISK MITIGATION RESERVE FOR EXPLORATION

Content of the Proposal: Seek the mechanism to institutionalize a funding model between the Inter-American Development Bank (*Banco Interamericano de Desarrollo)* (BID) and the State of Chile, with the participation of the Ministry of Energy, Ministry of Finance, and CORFO, with the purpose of distributing the risks of the exploration stage and of incorporating the private financial sector in the development of the geothermal industry. Likewise, the grant of a broad non-objection letter, for the funding of geothermal projects by the green funding entities.

Analysis: From the proposal it is understood that what is sought is the search of international cooperation funds to maintain an instrument like the Geothermal Risk Mitigation Reserve (MiRiG) [17] permanently in force, which translates in the institutionalization of this funding model of projects. In this sense, the role of the State is limited to manage with donors the prevision of funds for the mechanism.

From the point of view of the five evaluation criteria:

1. Qualitative impact of the proposed actions in the national geothermal sector: medium, the sole reduction of the exploratory risk does not resolve the problem entirely for the development of projects, but can be complementary to other measures.

2. Requirement of regulatory changes to implement the measures: low, it is mainly managing.

3. Dimensioning of resources involved for the implementation of the proposals: low, if considering it done with external funding from international cooperation.

4. Time of implementation of the actions: more than 1 to 2 years.

5. Required institutionality for the implementation of the proposal: CORFO, Ministry of Energy, and international cooperation.

[17] Geothermal Risk Mitigation Reserve. Instrument funded by the Clean Technology Fund (CTF) for Chile and implemented by the Inter-American Development Bank (BID), which coves part of the failure risk in the exploration and the development of geothermal fields

PROPOSAL 7: CREATION OF AN EXPERT COMMITTEE FOR THE DESCARBONIZATION FROM THE ELECTRICITY MATRIX

Content of the Proposal: Creation of an expert committee for the study, design of a work plan and search for mechanisms that allow to plan for a progressive reduction of coal as a source of electric generation in the long-term, specially considering the context of the generation of "base energy", in which this fuel has broad preeminence in our electrical system.

Analysis: The impact of a measure like the one indicated for fostering the geothermal industry would depend of the competitiveness of geothermal energy with regard to other energy technologies. However, the industry poses that in the extent of the existence of a public policy destined to descarbonize the electricity matrix, the other analyzed measures in this Final Report will have greater impact in the development of geothermal.

The executed proposal transversally impacts the whole generation sector and its total costs structure. The participants of the Roundtable stated that this type of matter is something that could be incorporated among the specific topics to be analyzed by the Permanent Advisory Committee for Climate Change (*Comité Consultivo Permanente sobre Cambio Climático).*

From the point of view of the five evaluation criteria:

1. Qualitative impact of the proposed actions in the national geothermal sector: medium. Depends on the competitiveness of geothermal energy with regard to other technologies with similar attributes.

2. Requirement of regulatory changes to implement the measures: low. It is not required for the creation of a committee with the mentioned duties.

3. Dimensioning of resources involved for the implementation of the proposals: low for design and development of a work plan.

4. Time of implementation of the actions: 1 to 2 years work.

Required institutionality for the implementation of the proposal: Ministry of Environment (*Ministerio de Medio Ambiente),* Ministry of Energy, Ministry of Finance, Industry, Academy, Ministry of Economy, Civil Society.

PROPOSAL 8: DEVELOPMENT PLAN OF THE GEOTHERMAL INDUSTRY (CORFO COMMITTEE)

Content of the Proposal: The proposal aims for the creation of a Committee CORFO, dedicated exclusively to geothermal energy, following the guidelines of the Development Committee of the Solar Energy Industry (*Comité de Desarrollo de la Industria de la Energía Solar)* (formal committee, established by the Governing Board of CORFO, with an organizational structure and with public funding). The purpose of this proposal is to carry out a detailed study of the state of the art of the geothermal industry in Chile, as well as to formulate development, competitiveness and productivity proposals. This Committee would give follow up to the Geothermal Roundtable.

Analysis: The Committees CORFO, have exclusive dedication, generally have a governing board integrated by Authorities and industry representatives and the academy, and are established by agreements of the Governing Board of CORFO, ratified by the Comptroller General of the Republic (*Contraloría General de la República).* These types of committees have a commencement date, but not of termination, possess institutionality and an annual operation budget with tax charge. Its role is not regulatory.

From the point of view of the five evaluation criteria:

1. Qualitative impact of the proposed actions in the national geothermal sector: it cannot be determined *a priori,* for which the formulated proposal does not contain details over the activities that this Committee could foster.

2. Requirement of regulatory changes to implement the measures: medium. Requires the creation of a new institutionality (CORFO Committee). Requires the approval of the Governing Board of CORFO, to then go to the Comptroller.

3. Dimensioning of resources involved for the implementation of the proposals: medium or high. Permanent public investment while the respective Committee exists and would depend of the actions of the Committee.

4. Time of implementation of the actions: 1 year minimum in the creation and undetermined operating period.

Required institutionality for the implementation of the proposal: CORFO, Ministry of Energy, Industry, Ministry of Economy, Ministry of Finance.

PROPOSAL 9: ELABORATE A DEVELOPMENT PLAN OF DIRECT USES OF GEOTHERMAL ENERGY

Content of the Proposal: The proposal aims to elaborate a development plan of direct uses of geothermal energy, focused on the generation of sustainable local projects, along with the Ministry of Economy, the Tourism Sub-Secretary, the Regional Governments and Local Communities.

Analysis: To be able to carry out the evaluation of this proposal it is necessary to precise the scope and measures it would imply. Regarding this proposal it is relevant to contextualize that the Ministry of Energy, with the support of the World Bank and the Clean Technology Fund, in the framework of the "Technical Assistance Project for the Development of Sustainable Geothermal Energy" (*"Proyecto de Asistencia Técnica para el Desarrollo de Energía Geotérmica Sostenible"),* is already executing a program whose general purpose is to promote the development of direct use applications of geothermal resources for the self-consumption in different energy sectors. The work lines are regulatory, diffusion and education to the communities, lifting of potential information, and feasibility analysis of different applications. The different studies and publications performed in this context are found in http://energiaabierta.cne.cl/estudios.

From the point of view of the five evaluation criteria for this proposal, in this Final Report its application has been dispensed with, as it is a measure already in operation. In addition, the proposed measure would not be within the analysis domain defined for the Geothermal Roundtable, circumscribed to geothermal projects for the generation of electricity with high enthalpy reservoirs.

PROPOSAL 10: IMPULSE PROGRAM FOR THE ANDEAN GEOTHERMAL ENERGY

Content of the Proposal: The proposal orients to the creation of an impulse program to geothermal energy and the generation de new knowledge regarding the particularities of the geothermal Chilean resources (Andean). All this with the purpose of providing technological innovation in the different development stages of the projects, contribute to improve the competitiveness of the geothermal industry and to train highly specialized human capital in the different aspects of the industry.

Analysis: The elaboration process and study of this program can be framed within the proposal regarding the creation of a CORFO Committee (Proposal 8),

as well as within the work scope of the Center of Excellence in Geothermal of The Andes of the University of Chile (*Centro de Excelencia en Geotermia de Los Andes de la Universidad de Chile*) (CEGA) and the National Commission of Technologic and Scientific Investigation (*Comisión Nacional de Investigación Científica y Tecnlógica)* (CONICYT).

From the point of view of the five evaluation criteria for this proposal, in this Final Report its application has been dispensed with, because of a lack of greater precision over the type of actions that could result, it is not possible to evaluate its possible impact, institutionality and required resources.

B. PROPOSALS FROM THE GEOTHERMAL COUNCIL AND ACHEGEO

PROPOSAL 11: MODIFICATIONS TO THE LAW Nº 19.657 OVER GEOTHERMAL PUBLIC TENDERS

Content of the Proposal: The Geothermal Council as well as ACHEGEO, posed the need of carrying out modifications to Law Nº 19.657, over geothermal energy public tenders, with the purpose of incorporating changes oriented to impulse the development of the industry. This matter was also one of the objectives of the Energy Agenda (from the year 2014).

The ACHEGEO proposal details several proposed changes to the Law, such as:

- Sole concession.
- Previous admission exam.
- Shortened terms.
- Elimination of possible sources.
- Limitation of third party claims.
- Form and capacity of the concessions.
- Exclude from the public tender system the direct use of geothermal.
- Early indigenous consult (ideally for sole concession).

Analysis: The majority of the proposed changes coincide with modification projects to the Law that have already been considered by the Ministry of Energy, evidencing a convergence in that aspect. Within 17 years of the Law Nº 19.657 being in force, it has become necessary to review its content and pose some improvements. During the year 2015, there was a work by the Ministry of Energy in update matters of the

Geothermal Law, but the text was not presented for its discussion in the parliament, due to legislative priorities in that moment.

From the point of view of the five evaluation criteria:

1. Qualitative impact of the proposed actions in the national geothermal sector: low - medium.

2. Requirement of regulatory changes to implement the measures: high. Change to Geothermal Law.

3. Dimensioning of resources involved for the implementation of the proposals: low.

4. Time of implementation of the actions: more than 2 years.

5. Required institutionality for the implementation of the proposal: Ministry of Energy, Ministry General Secretary of the Presidency, and National Congress.

The Geothermal Council subsequent to the presentation of the measures, stated that those measures that would result more effective for the industry in its current stage are those that have incidence over the investment signs, in a way in which this are grasped by the developers of geothermal projects (proposals Nº1 and Nº2) and those that facilitate the competence of technology to access funding (proposal Nº3).

TABLE 5. EVALUATION OF PRO-GEOTHERMAL ACTIONS AND MEASURES

(CONTINUES ON THE FOLLOWING PAGE).

Nº	1	2	3	4	5	6
Proposal	Modernize payment for capacity	Blocks that introduce security demands in the electricity public tenders	Evaluation report of geothermal resources to opt to the postponement mechanism of the commencement of supply or early termination of the contract	Tax provisions	Development Poles and Geothermal	Risk mitigation reserve for exploration
Proponent	Geothermal Council	Geothermal Council	Geothermal Council	Geothermal Council	Geothermal Council	Geothermal Council
Qualitative Impact	Medium-High Depends on the competitiveness level of geothermal regarding other technologies of similar attributes	Medium-High Depends on the competitiveness level of geothermal regarding other technologies of similar attributes	Medium	Low Currently in force, susceptible of improvements	Currently implemented	Medium Exploration risk reductions do not solve the problem completely
Need for regulatory changes	Medium or High if modifications to LGSE required	Low	Low Requires modification in the public tender specifications	High In case a special regime not contemplated in the law is sought	Currently implemented	Low
Dimensioning of resources for implementation	Medium-low depends on type of modification	Low	Low	Low	Currently implemented	Low
Terms	1 year in case of regulatory modifications. 2 or more years for legal modifications	< 1 year	< 1 year	< 2 years	Currently implemented	1-2 years
Required institutionality	Ministry of Energy, National Energy Commission, National Congress and the industry.	CNE and distributor companies	CNE and Ministry of Energy	Ministry of Energy, Ministry of Finance, SEGPRES, National Congress.	Currently implemented	CORFO, Ministry of Energy and International Cooperation

(CONTINUED FROM PREVIOUS PAGE).

Nº	7	8	9	10	11
Proposal	Creation of an expert committee for the dscarbonization of the electricity matrix	Geothermal industry development plan (CORFO Committee)	Geothermal direct uses development Plan	Impulse program for the Andean geothermal energy	Modifications to Law 19.657 about geothermal public tenders
Proponent	Geothermal Council	Geothermal Council	Geothermal Council	Geothermal Council	ACHEGEO and Geothermal Council
Qualitative Impact	Medium-High Depends on the competitiveness level of geothermal regarding other technologies of similar attributes	Cannot be determined *a priori*	Currently in development	Cannot be determined *a priori*	Low-Medium
Need for regulatory changes	Low Not required for the creation of a committee with such duties.	Medium Requires a new institutionality (CORFO Committee), Requires approval from the Governing Board of CORFO and Comptroller.	Currently in development	Cannot be determined *a priori*	High Changes to Geothermal Law
Dimensioning of resources for implementation	Low For the design and development of the work plan.	Medium High Permanent Expense during the operation of the Committee depends of the actions of the Committee.	Currently in development	Cannot be determined *a priori*	Low
Terms	1-2 years	1 year minimum in the creation and undetermined operating period.	Currently in development	Cannot be determined *a priori*	>2 years
Required institutionality	Ministry of Environment, Ministry of Energy, Ministry of Finance, Industry, Academy, Ministry of Economy, Civil Society.	CORFO, Ministry of Energy, Industry, Ministry of Economy, Ministry of Finance.	Currently in development	Cannot be determined *a priori*	Ministry of Energy, SEGPRES, National Congress.

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Conclusions

The Geothermal Roundtable had as purpose to establish the current state of the geothermal projects in Chile, identify the gaps for it to become an economic alternative for the development of the electrical sector of our country, detect advantages of its incorporation in the operation of the electrical system and identify possible measures to achieve a greater use of this energy source.

The main conclusions of the Geothermal Table are presented below:

- The medium range of the developable geothermal potential in Chile for the period 2017-2050 is estimated around 2.100 MW, with a potential of around 600 MW in the period 2017-2030 and of 1.500 MW for the period 2031-2050.

- The average CAPEX unit in Chile for a geothermal plant of 20 MW currently reaches USD 8,8 millions per MW, while for a 50 MW plant and 100 MW reaches USD 6,5 millions per MW and USD 5,7 millions per MW, respectively. Relevant economies of scale were identified as the plant size increases from 20 to 50 and 100 MW, observing that the unit cost decreases by 25% and 33%, respectively.

- The LCOE for a 50 MW, medium CAPEX geothermal project and a discount rate of 10% varies between USD 100 / MWh and USD 140 / MWh, while remaining in the range of USD 85-125 / MWh in case of consideration a discount rate of 8%. The cost drops to USD 75-110 / MWh for the case of a second 50 MW project located in the same geothermal field as an existing geothermal plant.

- Under the simulated conditions geothermal energy does not modify in a significant way the total costs of the system, for the year 2037 (in 20 years). With a generating park based on current technologies, it could lower the operating cost (14,6%) and the emissions of greenhouse gases (4,7%), while in the year 2047 (in 30 years), with a generating park with more flexibility contribution, could increase the operating cost (3,7%) and the emissions of greenhouse gases (0,8%).

- According to the obtained results, in the resulting matrix for the year 2037 the required flexibility in the electrical system can be obtained with the existing traditional generation park. Taking into account that the thermal park (especially coal) reduces its participation in the matrix, either due to obsoleteness, low competitiveness, public policies or private decisions, it will be necessary to gradually replace technologies that have the capacity to provide operational flexibility. On the other hand, and for a future horizon, the increase in the demand of the system and the increase in the participation of renewable energies with significant hourly variability will generate the need to increase the flexibility levels of the national electrical system, regardless of the future situation of the already installed thermal park, setting an opportunity for geothermal energy to provide flexibility to the system.

- The CAPEX gap between the geothermal projects of 100 MW for the simulated electrical system is of 243 USD/kW and 63 USD/kW for the years 2037 and 2047, respectively. The LCOE gap is of 3,5 USD/MWh and 1,0 USD/MWh in the resulting matrixes of the evaluation years.

- The short-term operation simulations give account that the service provision of frequency control by the geothermal units would be produced in hours with the presence of solar cuts, where the valorization of the provision of this type of resources could be rather lower (high reserve surpluses for frequency regulation product of an operation close to technical minimum by the hydraulic and thermal units).

Under the assumptions considered in the selected scenario in the Geothermal Roundtable for the simulation of the electrical system (scenario Base 1.0, see Table 1), geothermal energy could achieve a competence condition by reaching a CAPEX around 4.800 USD/kW installed, against other technologies of similar attributes like natural gas (GNL, for its acronym in Spanish) and solar concentration (CSP). This, taking into account that such technologies also exhibit uncertainty, either in their cost structure (CSP) and/or availability and their primary input price (GNL). Such competitiveness level can be reached lowering their costs through the local market

development of the industry and services, and also through possible technological or operational improvements.

Proposals for measures of different kinds were raised to deepen their penetration. Some of the proposals made by the actors have already been implemented or are in the process of being implemented, while others require a technical and political consensus. These are:

1. Modernize the payment by capacity, opening the discussion regarding the mechanism of payment by power.

2. Incorporate criteria to differentiate offers with specific attributes in Supply Tenders to Regulated Costumers.

3. Include a third party geothermal resources evaluation report to opt to the early cancellation mechanism of the contract or extension in the supply term in the Supply Public Tenders to Regulated Costumers.

4. Tax provisions of interest for geothermal energy.

5. Incorporation of geothermal areas as possible candidates to development poles within the Transmission Law framework.

6. Search of international cooperation funds to maintain a Geothermal Exploration Risk Mitigation instrument permanently.

7. Creation of an expert committee for the descarbonization of the electrical matrix.

8. Creation of a CORFO committee dedicated exclusively to geothermal energy.

9. Elaborate a direct use of geothermal energy development Plan.

10. Develop a geothermal Andean impulse program.

11. Modification to Law Nº 19.657 about geothermal public tenders.

The performed evaluations regarding the possibilities of geothermal insertion within the expansion of the electrical system, the results obtained regarding the existing economic gaps for the development of the geothermal potential in the electricity generation matrix on the long-term, the conclusions extracted regarding the benefits and advantages of the incorporation of geothermal energy in the electrical system operation and the proposed measures to deepen its penetration, are the main products of the work of the Geothermal Roundtable and are presented in this document for the consideration and evaluation in their merit by the authorities.

The results presented in this document, give account of an analysis based on the best information and methodologies available by the year 2017. However, given the existent dynamism in the sector either in technical, economical, political and social topics, the detection of new conditions in the market, along with new information and knowledge, could suggest the review of the exposed results.

Acronyms

ACHEGEO: Chilean Geothermal Association

AVI: Annual Value of the Investment

BID: Inter-American Development Bank

CAPEX: Capital Expenditures

CNE: National Energy Commission

COMA: Operating costs, maintenance and management

CORFO: Production Promotion Corporation

CSP: Concentrated Solar Power

ERNC: Non-conventional Renewable Energy

ESMAP: Energy Sector Management Assistance Program

GIZ: International Cooperation German Agency

IEA: International Energy Agency

IRENA: International Renewable Energy Agency

LCOE: Levelized Cost of Electricity

LGSE: Electrical Services General Law

MiRiG: Geothermal Risk Mitigation Reserve

NREL: National Renewable Energy Laboratory

NTSCS: Technical Standard of Quality and Service Security

OPEX: Operating Expense

PELP: Long-Term Energy Planning Process

SEGPRES: Secretary General of the Presidency

SIC: Central Interconnected Secretary

SING: Grande North Interconnected System

SSCC: Complementary Services

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Exhibits

Exhibit 1
SUSPECTED PROJECTIONS FOR THE LONG-TERM

INVESTMENT COSTS PROJECTIONS OF RENEWABLE TECHNOLOGIES

The projections and initial values of the investment cost of renewable technologies have been gathered from the Preliminary Report of the Long-Term Energy Planning Process (2017). In case of the initial cost, the considered reference is the following:

- National Energy Commission, << Cost Report of Generation Technologies >>, March 2017. [Online]. Link: https://www.cne.cl/traficacion/electrica/precio-nudo-corto-plazo/.

- On the other hand, for the projection in time of these costs, the aforementioned report considers the following references:

- National Renewable Energy Laboratory, <<2016 Annual Technology Baseline>>, Golden, CO, 2016.

- Lazard, <<Lazard's Levelized Cost of Energy Analysis – Version 9.0>>, 2015.

- S. Teke, S.Sawyer and O. Schäefer, <<Energy Revolution: A Sustainable World Energy Outlook 2015>>, 2015.

- Bloomberg New Energy Finance, <<LCOE Costs for Brazil>>, from 2030 Market-Outlook Americas, 2014.

- Bloomberg New Energy Finance, <<H1 2016 Global Levelised Cost of Electricity Update>>, 2016.

- Bloomberg New Energy Finance, << H1 2016 LCOE AMER Outlook>>, 2016.

- Bloomberg New Energy Finance, <<Q1 2017 Global PV Market Outlook>>, 2017.

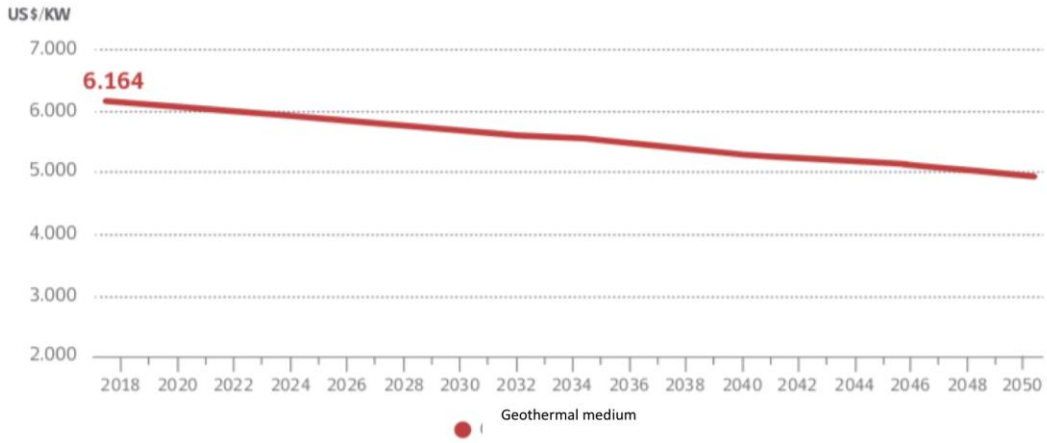
- International Energy Agency <<Energy Technology Prospective>>, 2016.

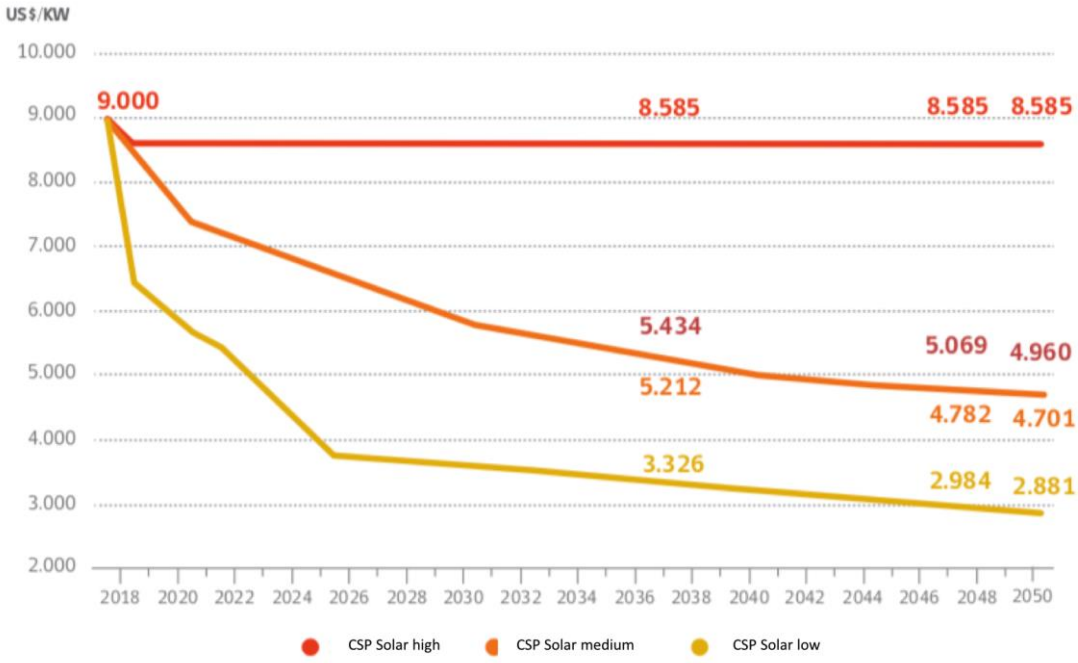
- US Department of Energy, <<SunShot Vision Study-Annex>>, 2012.

A summary of these projections for photovoltaic solar technologies, wind, geothermal energy and CSP solar is shown in the Figure 9 and Figure 10, where the values corresponding to the year 2037 and 2047 are also indicated.

FIGURE 9. INVESTMENT COSTS PROJECTION FOR WIND AND PHOTOVOLTAIC SOLAR TECHNOLGY.

FIGURE 10. INVESTMENT COSTS PROJECTION FOR GEOTHERMAL AND CSP SOLAR TECHNOLGY.



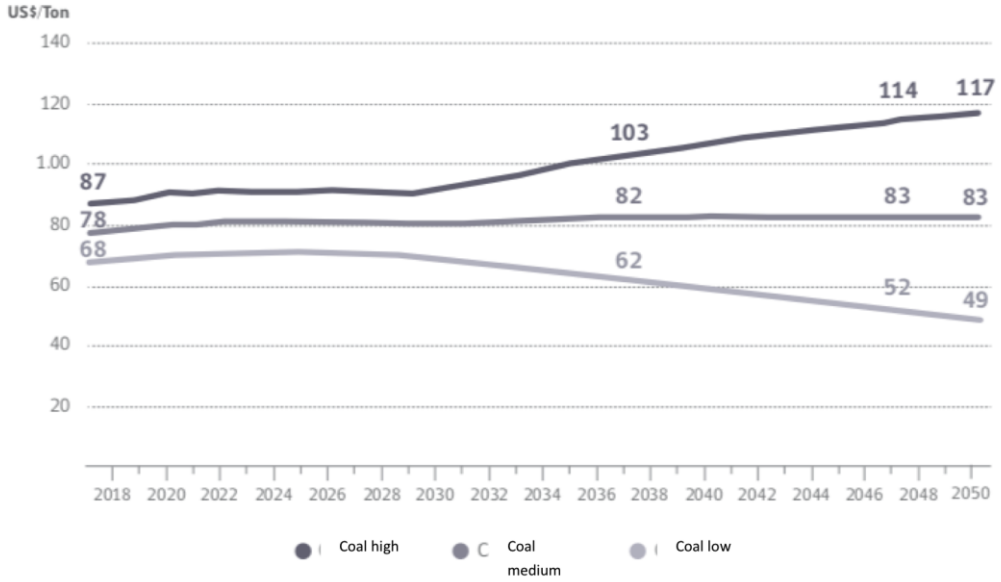


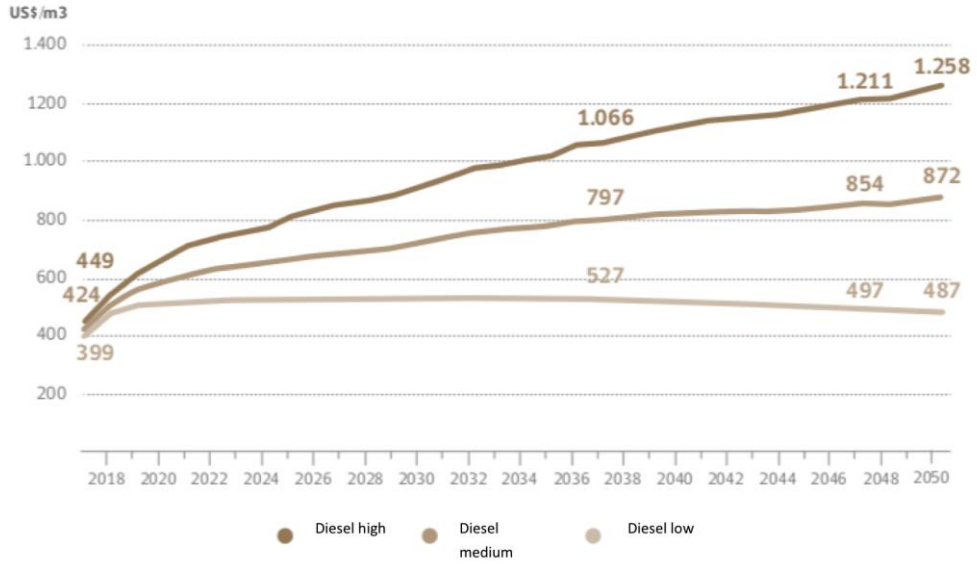
PRICE PROJECTION OF FOSSIL FUELS

The price projections of fossil fuels have been gathered from the Preliminary Report of the Long-Term Energy Planning Process (2017). The reference to project these prices corresponds to the Annual Energy Outlook 2017, published by the Energy

Information Agency[18]. In Figure 11 a summary of the projections for coal, diesel, are presented, while in Figure 12 the projections for GNL are presented, indicating the values for the years 2037 and 2047.

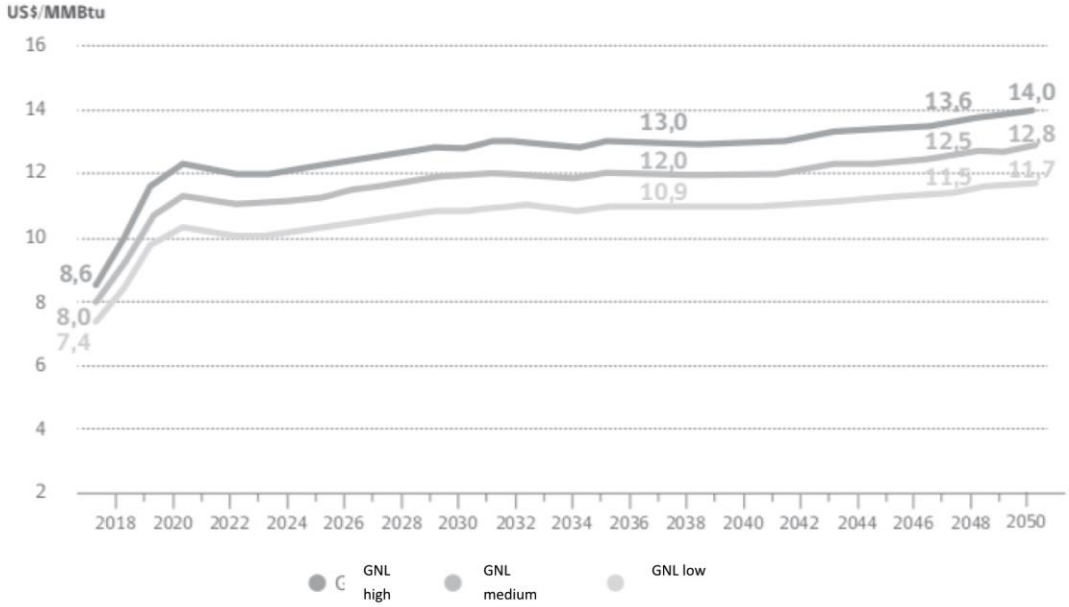
FIGURE 11. PRICE PROJECTION OF FUEL FOR COAL AND DIESEL





[18] https://www.eia.gov/outlooks/aeo/tables_ref.cfm.

FIGURE 12. PRICE PROJECTION OF FUEL FOR GNL.



COST PROJECTION OF ENVIRONMENTAL EXTERNALITIES

According to the background presented in the Preliminary Report of the Long-Term Energy Planning Process (2017), the Scenario of High cost of environmental externalities was considered. For effects of the applied methodology, the cost of environmental externalities has been included in the model as a proportional cost to the emissions of each thermal power station, and its projection is built on the following:

i. In the year 2017, the cost has a value of 5US$/TonCO2 and then grows in a linear form until it reaches a value of 14US$/TonCO2 in the year 2030. These 14US$/TonCO2 correspond to the resulting value to the year 2030 of the study "Analysis of potential impacts derived from the implementation of coal tax to thermal generation plants in Chile" (*KAS Ingeniería & Castalia*, 2016).

ii. Then, between the years 2030 and 2050, the cost increases linearly until it reaches a value of 32,5US$/TonCO2. This value corresponds to the social price of coal published in the report "Estimation of the Social Price of CO2" (Ministry of Social Development, 2016).

Such track, and the particular values for the years 2037 and 2047, is presented in Figure 13.

FIGURE 13. COST OF ENVIRONMENTAL EXTERNALITIES.

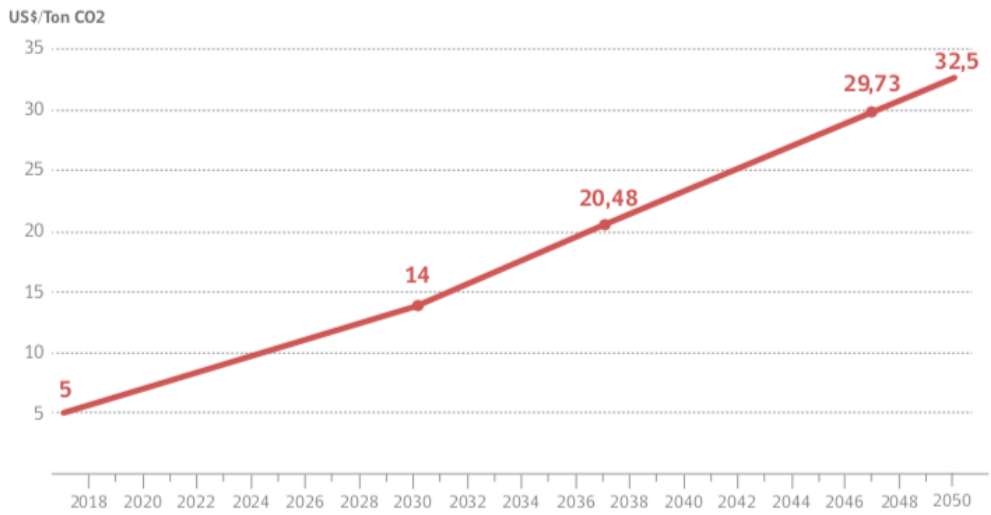


Exhibit 2

GEOTHERMAL PUBLIC TENDERS

TABLE 6. PUBLIC TENDER DETAIL TO JANUARY 2018

	Exploration	Exploitation
Valid Public Tenders	11	12
Expired public tenders with Exclusive Right to obtain Exploitation	7	N/A
Applications	1	13
Nº of concessionaires	5	8

Updated and detailed information about public tenders, holders, and public tenders applications of geothermal energy, as well as the records to visualize them in a geographical information system, is found in the following link: http://www.energia.gob.cl/energias-renovables

Exhibit 3
DESCARBONIZATION AGREEMENT

Regarding the development of new thermal power stations based in coal, or to the future operation of power stations of this technology currently in operation, it is important to note that, subsequent to the plenary work term of the Geothermal Roundtable, the Government of Chile and the companies members of the Association of Generators of Chile (*Asociación de Generadoras de Chile)*: AES Gener, Colbún, Enel and Engie reached the following agreement in January 2018:

1. The aforementioned companies are committed not to initiate new developments of coal projects that do not have carbon capture and storage systems or other equivalent technologies as of this date.

2. A Work Group will be created to analyze, in the context of the objectives of the 2050 Energy Policy, the technological, environmental, social, economic, safety and sufficiency elements of each plant and the electrical system as a whole, between others, that allows to establish a schedule and the conditions for the programmed and gradual cessation of the operation of coal-fired power plants that do not have carbon capture and storage systems or other equivalent technologies.

3. The Ministry of Energy will coordinate this Work Group to which all relevant institutions will be invited in this process.

Exhibit 4
GEOGRAPHICAL DISTRIBUTION OF
THE GEOTHERMAL POTENTIAL

Attending entities
TO THE GEOTHERMAL ROUNDTABLE

Entities	Characteristics	Representatives in the Geothermal Roundtable
ACERA	Business Association	Darío Morales; Carlos Finat
ACHEGEO	Business Association	Fernando Allendes; Pietra Salvatori
Customs Agency Patricio Sesnich y CIA	Private Entity	Patricio Sesnich
Amawta Geoconsultores	Company	Jorge Clavero
World Bank	International Entity	Paolo Bona; Patricia Marcos Huidobro
CEGA	Investigation Center	Diego Morata; Diego Aravena
Energy Center of the University of Chile	Investigation Center	Marcelo Matus; Rodrigo Sepúlveda; Sebastián Gwinner; José González
College of Engineers	Professional Association	Cristian Hermansen
Collahuasi	Company	Verónica Cortez; Leopoldo Gaegger
National Energy Commission	Public Sector	Martín Osorio; Sebastián Romero; Cristián Luhr
Geothermal Council	Business Association	Gonzalo Torres
National Electrical Coordinator	Private Entity	Alex Santander
EDC	Company	Joshua Carvachi; Carolina Rodríguez; Camila Manzano; Leonardo Carrasco; María José Irarrázabal; Guido Machiavello; Jaqueline Reyes; Franklin Acevedo; Víctor Vargas; Matías Lewin, Jerónimo Carcelén
ENAP	Public Company	Rodrigo Bloomfield, Ljubomir Tomasevic; Rodrigo Lobos; Andrea Sabignoso; Mario Tellez
Enel Green Power	Company	Sandro Bruni, Guido Cappetti; Paola Hartung
Energía Andina	Company	José Manuel Soffia
Exergy	Company	Francesco Oppici
Chile Foundation	Private Public Entity	Érika López; Fernando Coz; Carlos Jorquera; Ana María Ruz; Marisol Silva; Paulina Suazo; Olaya Cambiaso; Nicolás Correa; Jorge Morales; Eugenio Evans; Aurelio de Diego
Geolog	Company	Raúl Moyano
Geomarket South	Company	Adrián Bereilh

Geothermhydro	Company	Harpa Harasdlodóttir
Magallanes Energy Services	Company	Alejandro Doberti; Jorge Morales
Ministry of Energy	Public Sector	Francisco Martínez-Conde; Carlos Suazo; Luciano González; Rubén Muñoz; Christian Santana; Camila Vasquez; Elizabeth Soto; Javier Bustos; Cristóbal Muñoz; Stefano Banfil, Juan Ignacio Alarcón; Monserrat García; Carlos Toro
MRP Geotermia	Company	Rudgier Trenkle
Petreven	Company	Andrea Guglielmetti; Pasquale Simari
Schlumberger	Company	Juan Véliz; Juan Rivera
SERNAGEOMIN	Public Sector	Carolina Honores
Serviland	Company	Diego Gaytán
Sumitomo	Company	Carlos Espinoza
Transmark Chile	Company	Carolina Wechsler; Macarena López; Jan Erik Otten; Frederik Kam
Turboden	Company	Domenico Ravera
Ultramar	Company	Juan Francisco Rodríguez
University of Chile	University	Ronald Fischer; Luis Vargas; Tomás González
Santa Maria University	University	Mauricio Villarroel
Wellfield	Company	Carlos Araya; Juan Bascur

[PICTURE]

[Stamp with the following text: Ministry of Energy

Government of Chile]

PICTURE

[Logo with the following text: ENERGY CENTER FCFM UNIVERSITY OF CHILE]

[Logo with the following text: ESMAP Energy Sector Management Assistance Program]

[Logo with the following text: FCH CHILE FOUNDATION