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Financial and technical feasibility study of the low enthalpy geothermal system "La Jolla", Baja California Mexico

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ABSTRACT

This study describes a financial analysis of the low-enthalpy geothermal system "La Jolla", located in Baja California, Mexico, based on both reconnaissance and technical studies. The technical feasibility study began with the system exploration to estimate the electric power generating potential using the heat in place model with a Monte Carlo simulation. The calculated energy output was 1 MWe for a 25 year period. Based on both the calculated energy and the physical characteristics of the site, a binary cycle plant was chosen for electricity generation. Profitability was calculated using Net Present Value and Internal Rate of Return. The project risk was obtained from the sensibility analysis of all variables used in the financial parameters calculation. The highest effect on risk comes from tariff price, on the other hand, the lowest effect corresponds to drilling. Projected income was estimated to be 47,000.00 USD per year, requiring an initial inversion of 615,000.00 USD. The time of return of 15 years was calculated, using a 6.8% of interest rate with a 60% private and 40% government investment frame. The NPV was positive, IRR was 10%, greater than 6.8%; therefore, the project may be considered as profitable.

1. INTRODUCTION

In 2016 the Mexican government committed to accomplish the United Nation's Sustainable Development agenda. This agenda includes sustainable energy for everyone ECLAC (2017). The new geopolitical frame requires the government to design strategic actions which guarantee to achieve this goal by 2030. One of the designed strategies is to implement a new model for power cogeneration instead of the previous centralized scheme. One of the objectives is the development of small geothermal power plants near medium and low-enthalpy reservoirs, maximizing social benefits and reducing environmental impact SENER (2016). The low-enthalpy geothermal systems could help to reach the goal as they are all over the country Alemán-Nava et al. (2004).

Considering the abundance of geothermal energy in the country, in the early 90's the Mexican Federal Electricity Commission (CFE) began doing geothermal exploration surveys in the Baja California Peninsula.During that period, the hydrothermal system "La Jolla" was discovered (figure 1). According to the CFE surveys, La Jolla is a low-enthalpy system. Due to the low energy content of the reservoir, it was not considered for power generation Álvarez-Rosales (1993); Gutiérrez-Negrín, (2012). In 2007, Arango-Galván et al. (2011) performed a new exploration campaign to characterize the La Jolla geothermal reservoir for future exploitation.

The objective of this paper is to calculate both the technical and financial feasibility of the La Jolla geothermal system. We performed the technical feasibility study using the results published by Arango-Galván et al. (2011) as a basis for the financial feasibility study. The final results can be used to take decision on investment for exploitation of the resource.

1. 1 PREVIOUS STUDIES

The geology of the zone includes mainly igneous and sedimentary rocks and a lower proportion of metamorphic rocks (the oldest rocks of the stratigraphic column) Allen, et al. (1960); Álvarez-Rosales (1993). Igneous rocks include crystalline sequences from acid to basic composition Gastil et al (1975); Woodford & Harris (1938). Sedimentary rocks belong to the Alisitos and El Rosario formations. Both formations have intrusions of andesitic and granitic dikes related to the Peninsular batholith Álvarez-Rosales, (1993); Payne et al, (2004). Younger rocks are marine sequences and recent volcanic rocks (figure 2).

During Neogene, the subduction of the Farallon plate under North American plate ceased. Then, the rising terrain migrated northwards and formed small divergence zones interconnected by transform faults Angelier et al. (1981); Lonsdale (1989). Such evolution derived into a) the complete transference of the Baja California Peninsula to the Pacific Plate and b) the opening of an oceanic basin in the Gulf of California Martín-Barajas & Delgado-Argote (1995). The main structure in the studied area is the western limit of the dextral Agua Blanca Fault system. This system belongs to the Agua Blanca-Todos los Santos tectonic province Beltrán-Abunza & Quintanilla-Montoya, (2011).

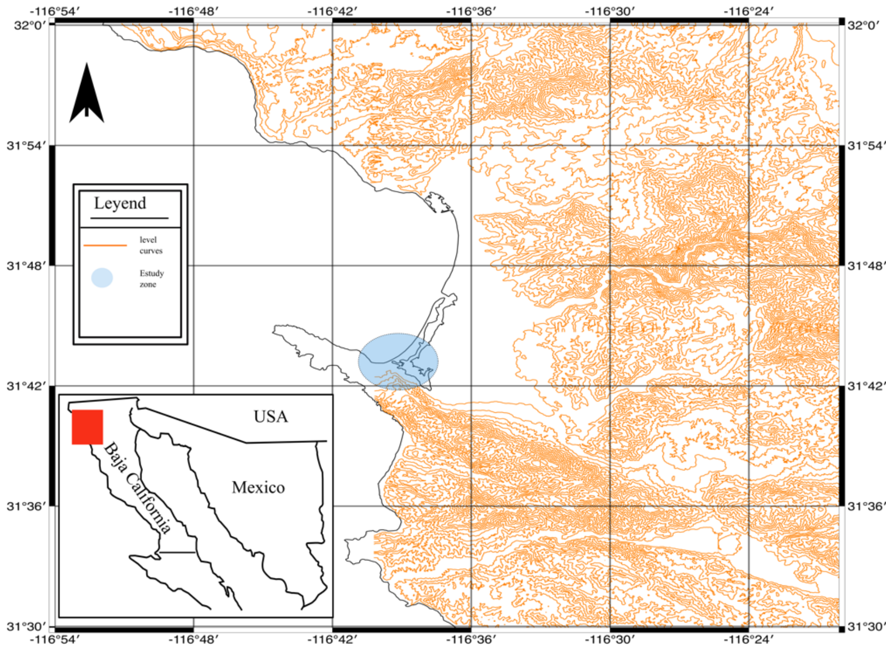


Figure 1 Location of La Jolla geothermal system

1. 2 GEOCHEMICAL AND GEOPHYSICAL SURVEYINGS

Intertidal hot springs are distributed along the northern coast of the Punta Banda Peninsula (figure 1) and represent the main surface manifestations of La Jolla system. Three water samples were collected in the surface manifestations. The chemical analysis was performed by ICP-MS. All samples correspond to sodium-chloride water, and isotopic concentration showed sea water mixing. A lineal mixing model was applied to calculate the Thermal End Member (TEM) Prol-Ledesma et al. (2004) to obtain the chemical composition of the thermal water before mixing with sea water (figure 2).

Geophysical surveys included three Electrical Resistivity Tomography (ERT) profiles. The results indicate the presence of a conductive body at a depth of 80 m (figure 4a). Its relation with the intertidal hot springs suggests that the conductive anomaly corresponds to a hydrothermal source Arango et al. (2011). The geophysical and geochemical information was used to estimate the reservoir temperature and volume (figure 3).

2. METHODOLOGY

The chemical equilibrium of water was tested using the Giggenbach diagram. The reservoir temperature was estimated using geothermometers with the water samples that showed partial chemical equilibrium. We use the chalcedony silica geothermometer to estimate the minimum reservoir temperature Fournier (1979) and Na/K-based geothermometer applied to the TEM for estimating the maximum temperature Fournier & Potter (1982) (figure 4-a).

The volume was estimated based on the ERT profiles Arango-Galván et al. (2011). We integrated and extrapolated the profiles to get one 3D model, using the software Leapfrog®, to estimate the volume (figure 4-a). We used the calculated volume and temperature as input for the Heat in Place model Garg & Combs (2010, 2015), using Monte Carlo method to calculate the potential energy output from the geothermal reservoir. A thermal recovery factor of 10% was used Garg and Combs (2010); Williams (2004, 2014) according with the geology of the zone which indicate the predominance of highly fractured crystalline rocks Allen, et al. (1960); Álvarez-Rosales (1993); Lovekin (2004). Assuming a low-enthalpy geothermal system, a binary plant was the recommended technology for power generation DiPippo (2004), thus, to calculate the whole power generation potential, we use additionally a 20% plant factor Franco & Villani (2009) for 25 years of exploitation as the Mexican Geothermal law states HCU (2012 a)).

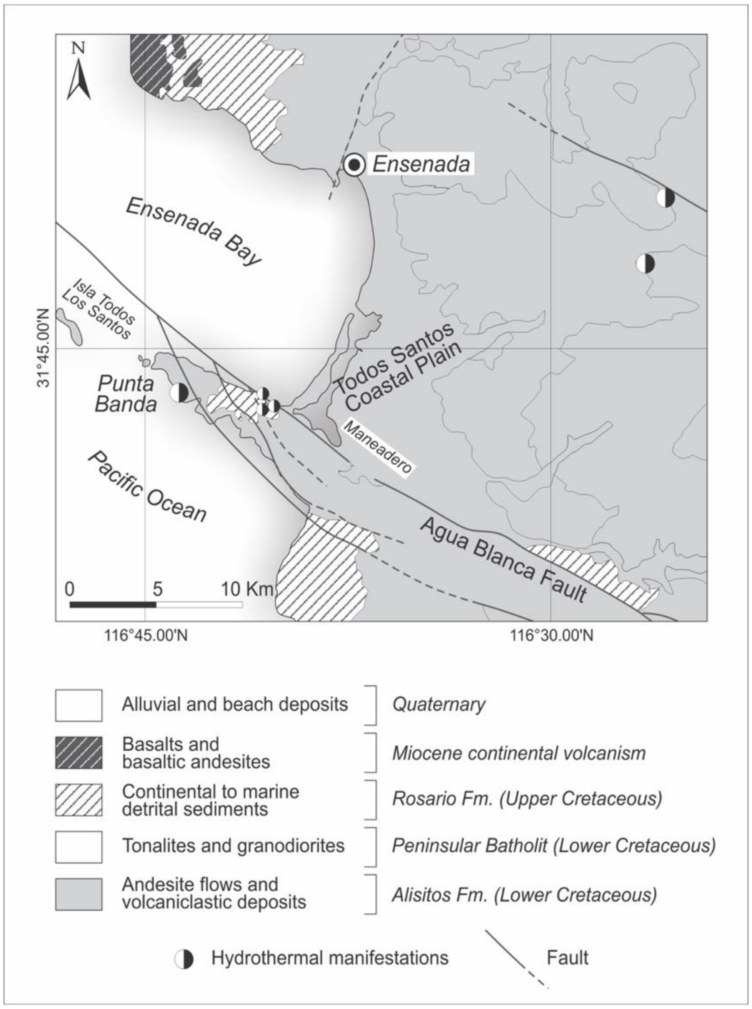


Figure 2 Geologic map of the study zone Arango-Galván et al. (2011).

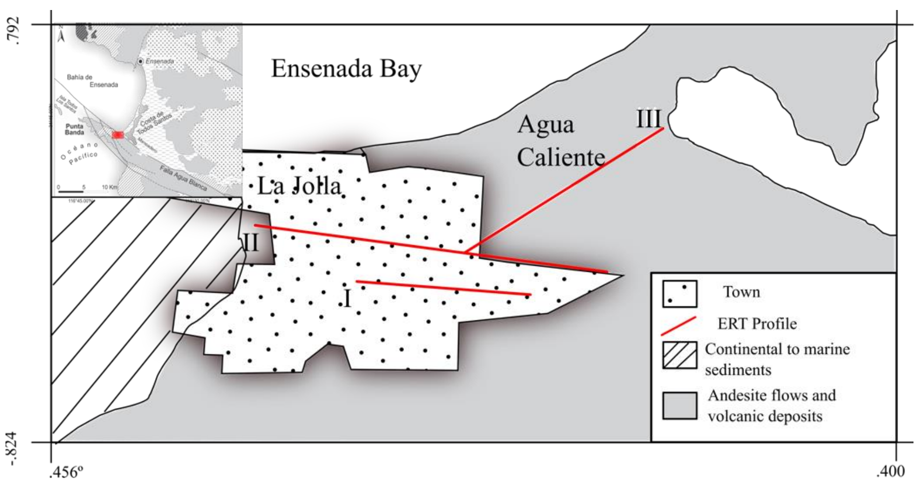


Figure 3 ERT profiles on the study zone Arango et al. (2011). Coordinates are on geographic and it begins with 31.720 and -116.672 respectively.

The financial assessment was performed with the results from the power potential estimation. There is no a standard financial procedure to evaluate the profitability of a geothermal project, so a general financial model for an investment project is proposed:

+Earnings (a)

-Cost of O&M (b)

= Net income (a-b)

-Depreciation of power generation equipment (accelerated).

-Depreciation of drilling and construction (Straight line).

=Before taxing income.

-Rent taxing (ISR).

-Workers accounting on activities (PTU).

=After taxing income.

-Working capital.

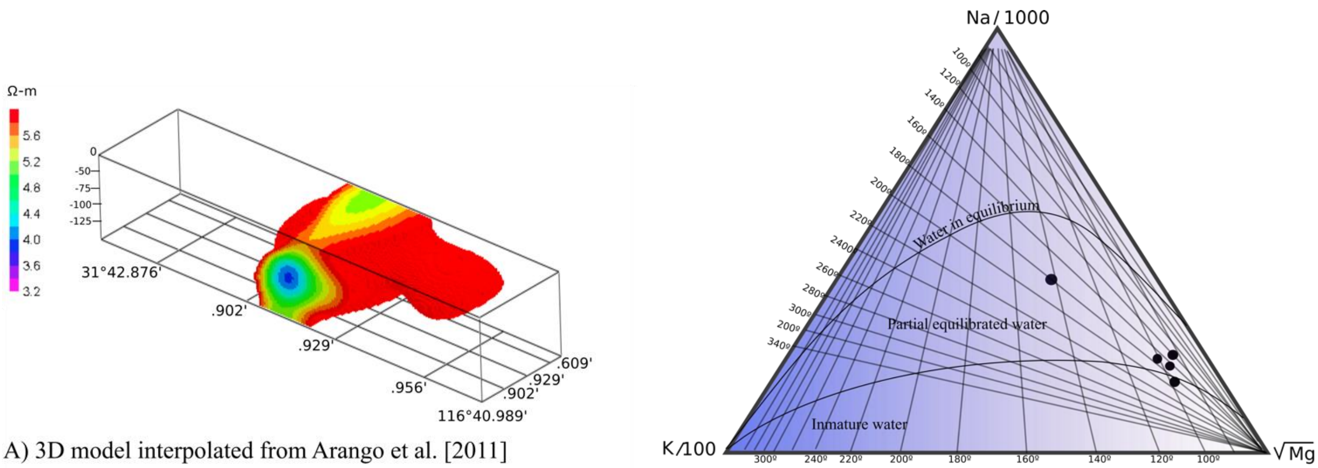
+Depreciation.

=Total Revenues.

In this model, earnings (C_t) were estimated using the model proposed by Mwagomba (2016):

$$C_t = T\left(\frac{\$}{kW}\right) * W_{tnet}\left(\frac{kW}{h}\right) * \eta_g * h_{an}(h) * \eta_{cf}\ , \ldots (1)$$

where the tariff (T) is established by the last power auction in Mexico Forbes (2016); W_{tnet} is the total amount of energy's turbine conversion; η_g is the generation efficiency; h_{an} is the average of working hours over the year by the power plant; and finally, η_{cf} is the capacity factor of the facility. O&M cost was calculated based on the 5% year's revenues. The depreciation of power generation equipment could be accelerated, as stated by the Energy Law in Mexico HCU (2012 b).



A) 3D model interpolated from Arango et al. [2011] resistivity profiles.

B) Giggenbach diagram to show up Arango et al. [2011] chemical samples equilibrium.

Figure 4 A) 3D model to volume estimation. B) Giggenbach diagram to show water-rock interaction equilibrium.

All years of power plant production had different revenues, resulting in a different revenue estimation for each year. Two 120m deep wells were considered for drilling cost estimation. According with the stratigraphy, the wells would penetrate crystalline rocks[1] Allen, et al. (1960); Álvarez-Rosales, (1993). Heat exchangers cost was obtained from a multiplication between values proposed by Ahangar (2012) and heat exchangers area, calculated with this equation Tester et al (2013):

$$A = \frac{\dot{Q}}{U\Delta T}.$$

Net Present Value (NPV) was calculated using all years' total revenues. Discounted payback period showed the number of years necessary to recover the investment. Interest was determined using Weighted Average Cost of Capital (WACC), with value of 6.8%. Finally, we performed sensitivity analysis on three main variables: tariff, heat exchangers areas and drilling cost, from which we were able to calculate the project risk.

3. RESULTS

Potential power was estimated to be 1MW in 25 years of exploitation. This estimation has a 90% probability of success according with the Monte Carlo method. Parameters of the model are shown in Table 1. According to Mwagomba's (2016) model (equation 1); revenues would be 47,000 USD as annual average, with a tariff ranging from 20 to 25 USD per MWh. While drilling costs would be 4,500 USD per two 180m deep wells. Heat exchanger's cost would be 597,000 USD (table 2). The total investment amount required would be approximately 615,000 USD.

Project profitability was shown as VPN. VPN was approximately 4 MUSD, and positive. Having a positive VPN is associated with a high probability of profitability. Investment recovering period is 15 years. Sensitivity Analysis showed that the highest risk variable was the sale tariff. In contrast, the least risk was related to drilling (figure 5).

4. DISCUSSION

Positive values of VPN imply more inflows than outflows, indicating profitability. However, the return period of 15 years for recovering the initial investment could be considered a long period. Financial evaluation of similar geothermal projects produces a period of time to recover the initial investment, which varies from 16 to 19 years Abisa (2002); Ahangar et al. (2002); Mwagomba (2016). Nevertheless, those projects have an initial investment that is 10 times higher, as well as power plant capacity (table 3). In those projects, drilling cost exceeds 1 million USD. Each project required both deep drilling and more than 2 wells. In Maguarichic's geothermal project in northern Mexico, the drilling cost was 100,000 USD. Monroy Parada et al. (2014). This project had only one production well with 300m depth and the installed capacity was 350kW, with limited infrastructure that forbade the use of trucks or drilling machines. This made the construction of the plant more complicated and expensive. Hence, the low drilling cost of "La Jolla" project is a consequence of the shallow depth of the resource. Furthermore, only two wells were considered, one production well and one reinjection well, with the added benefit of proper road infrastructure for the use of heavy machinery.

One important feature of the project is the increase of plant efficiency in 50%. This increase takes into account the repayment of the debt. It should be noted that plant efficiency increases when other projects were constructed in a cascade scheme. Cascade scheme can increase the income more than solo projects by almost three times Rubio-Maya (2016). Nevertheless, Mexico does not have a market for these projects yet, thus neither reinvestment nor earnings were considered for direct use.

Parameter	Value
Minimum temperature (Chalcedony) ETM	153ºC
Maximum temperature (Na/K) ETM	214ºC
Minimum value ($\times 10^6 m^3$)	6.4
Maximum Value ($\times 10^6 m^3$)	8.24

Table 1 Parameters used in the heat in place model.

4.1 FINANCIAL FEASIBILITY

Volume was estimated without the third ERT profile due to a high probability of sea water contamination, which generates noise in data acquisition [Arango-Galván et al., 2011]. Minimum and maximum estimation temperatures were obtained using TEM's concentration

[1] Mexican drilling company Perfocar® gives an estimated cost from 3500 to 4000 USD per 300m deep water wells.

that would correspond to the thermal water before mixing with sea water. As previously mentioned, TEM were processed taking into account mixing of reservoir water and sea water. At this exploratory-phase, using TEM is not too expensive and yields appropriate data for the preliminary evaluation.

Data integration of volume and temperature finished with energy estimation through both a heat in place model and a Monte Carlo method. Results showed a 1 MW estimated energy output suggesting that this energy can be obtained from the reservoir for at least 25 years with minimum risk of damaging the reservoir.

This kind of studies are helpful to make a decision between making an investment or not DiPippo (2012) even if there is no direct evidence of the conditions of the reservoir at depth, which can only be acquired after drilling. To be approved, exploration drilling cost would be 5 kUSD approximately. For comparison, Maguarichic's project drilling cost was 10 times cheaper than the initial investment Covarrubias et al. (2002). Reducing cost on the exploration well is a consequence of exploration wells being thinner and simpler than production ones Ngugi et al. (2013).

Equipment	area/power	price	Cost
Super heater	116	500 $USD \cdot m^2$	58 kUSD
Vaporizer	187	500 $USD \cdot m^2$	93.5 KUSD
Heat recovery	370	400 $USD \cdot m^2$	148 kUSD
Turbine	1000	500 $USD \cdot kW$	500 kUSD
Condenser	600	600 $USD \cdot kW$	360 kUSD
Pump	45	450 USD$\cdot kW$	20.25 kUSD

Table 2 Heat exchanger area and approximate cost.

	La jolla	Malaui Mwagomba (2016)	Maguarichic Covarrubias et al. (2002)	Auachapán Monroy Parada et al. (2014)
Capacity (kWe)	1000	12,000	350	100,000
Investment (USD)	640,000	50,000,000	1,350,000	4,900,000
Income per year (USD)	900,000	6,800,000	12,000	1,670,000
Payback (yr)	15	17	*	1.71

Table 3 Comparison of worldwide projects. *- no available data for payback time in Maguarichic project from CFE:

Once resource exploitation has begun, it will allow the reservoir behavior to be known and its response to exploitation must be monitored for a proper management of the field

4.2 RISK

Risk is the most important factor when an investment projects is planned. In this paper, the fact that drilling effect on risk is very low is a remarkable result. In contrast, tariff is the most important risk variable (figure 5). If possible, selling tariff must be decided with care, otherwise it could become a great impediment for future project development. The tariff reported by Monroy for Ahuachapán is 106 USD/MW-h Monroy-Parada et al. (2014). This price showed a payback period of 1.7 years with 10% interest, making the project more attractive (table 3).

In this project, tariff was taken from the last Mexican electricity auction. Using tariffs from 15 to 20 USD per MWe, payback was calculated as 15 years, different tariffs yield 5 years as payback period, 3 time less with 10% of interest, tariffs could be changed in the interval from 70 to 20 USD per MWe, effectively modifying the payback period. The Mexican government has created "Clean Energy Certificates" CRE (2016) to mitigate the effect of the low electricity price, which is more a political maneuver. The Clean Energy Certificates are intended to increase the income of renewable energy projects and make them more profitable; nevertheless, certificates would be beneficial only for large power plants. This fact has a negative effect on small power plants, even though a decentralized energy generation scheme is one of the best options to get a complete diversification of the energy matrix, helping to achieve UN objective 7.

The shorter the payback period, the more likely investing capital can be obtained, allowing the development of a cascade scheme to take full advantage of the geothermal resource and decreasing the risk. Heat exchanger area was an important parameter in sensitivity analysis (figure 5). Heat exchange materials must be correctly chosen to ensure the transfer coefficient that the plant requires.

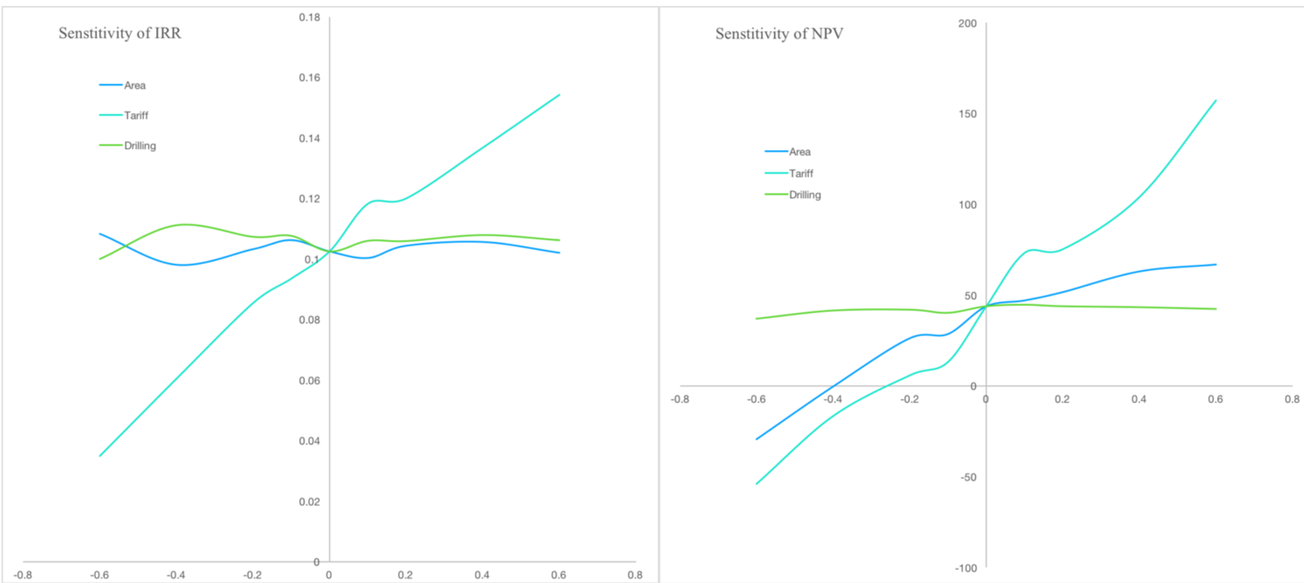


Figure 5 Sensitivity Analysis for both IRR and NPV.

5. CONCLUSIONS

The energy potential of the La Jolla prospect calculated using the heat in place method was 1 MWe with 90% of success probability. This potential could be exploited to power up to 700 houses in the nearby region, where average household energy consumption is 5kW Muñoz et al. (2012). Net income was estimated to be 47kUSD per year with a total investment of 615 kUSD. Assuming that the reservoir has a productive lifetime of at least 25 years, the estimations showed that the NPV was positive. The payback period was considered to be long, but it could be diminished by increasing the energy tariff or including a cascade exploitation scheme. Results show that investing in this reservoir would be profitable, sustainable and beneficial for the local community.

Even though the results are positive, it is still necessary to consider that this evaluation is based on geophysical and geochemical surveys. Further studies using well data are required to do a more reliable risk assessment of the reservoir. Our results showed that the drilling risk is low (with the highest risk coming from the tariff price).

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