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Financial Feasibility Assessment of a Wellhead Geothermal Plant at Nevado del Ruiz Volcano in Colombia

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ABSTRACT

Colombia is close to the initial development of a geothermal project at NRV volcano. Therefore, it is necessary to evaluate the technology of a geothermal power plant that can be installed at this area in order to take advantage, in the short term, of the resource to be extracted. Traditionally in geothermal projects, wellhead power plants with backpressure turbine are the most used for initial stage of exploitation and monitoring the geothermal resource. However, currently there are also wellhead power plants with condensing turbine even below 10 MW, which can be more technically efficient and with better investment returns. The selection of a geothermal power plant will depend mainly on the volume of the geothermal resource, and thermodynamic and physicochemical characteristics of the geothermal fluid. Likewise, it is necessary to evaluate the financial feasibility for a geothermal power plant startup calculating financial parameters such as the net present value (NPV) and the internal rate of return (IRR). This evaluation should take into account the net power production that could be achieved, the domestic financial market where the power plant will be installed and its influence on the investment and operation costs. In addition, the performance of a sensitivity analysis of financial parameters must be complemented with different scenarios that imply some risk in the viability of the project. On this way, the financial feasibility assessment of a wellhead power plant of 5MW net power with condensing turbine is being carried out for the geothermal project at NRV volcano under some technical assumptions, due to there are still no wells drilled to validate them. This analysis is based on the domestic financial market conditions, and the legal and regulatory framework of Colombia.

1. INTRODUCTION

Geothermal exploration around Nevado del Ruiz Volcano (NRV) has taken about 50 years so far. The geothermal field is located in a sector known as “Valle de Nereidas” in the municipality of Villamaria - Caldas, near the city of Manizales, approximately 150 km west of the Colombian capital city Bogotá on an elevation between 3200 and 3600 meters above sea level (m.a.s.l) (Figure 1). The first investigations were initiated in the western sector of the NRV in 1968 by the companies CHEC and ENEL (CHEC, 1968). In 1983 CHEC completed a prefeasibility study and selected three priority zones for exploratory drilling including Valle de Nereidas (CHEC, 1983). Further studies were carried out as a result of the phreatomagmatic eruption of NRV in 1985 and yielded a model of the magmatic and hydrothermal system (Giggenbach et al., 1990). Later, in 1992 CHEC carried out additional geological and geochemical studies in order to schedule an exploratory well, resulting in Nereidas-1, the only exploratory geothermal well known in Colombia drilled by 1997. The geological and hydrothermal alteration descriptions of Nereidas-1 were made by the Colombian Geological Survey (SGC by its Spanish acronym) and published by Monsalve et al. (1998). Between 2008 and 2010, the companies Central Hidroeléctrica de Caldas (CHEC-EPM) and ISAGEN became again interested in a commercial development of geothermal resources in NRV. CHEC-EPM carried out more exploration activities, socio-environmental studies, and new geological and geophysical research in Valle de Nereidas, covering an area of about 60 km^2 (Ormad, 2014). Concurrently, ISAGEN acquired geophysical, geochemical and geological information over an extension of 350 km^2 including two geothermal gradient wells of 300 and 240 meters depth, estimating a depth to Curie isotherm of 2.5 Km and temperature gradients between 160 ºC/Km and 200 ºC/Km (Rojas, 2012). Currently, CHEC-EPM has estimated a preliminary and conservative potential development of 50 MWe, with a plan of drilling five deep exploratory wells to confirm the resources (Lopez, 2018). This seems to be feasible as numerical modelling of heat transfer and rocks thermal conductivity suggest a geothermal potential range between 54 MWt to 130 MWt (Velez et al., 2018).

The NRV geothermal area presents a favorable framework for the existence of an important high temperature geothermal system. The presence of approximately 200 ºC at 1.500 meters depth has already been demonstrated by the well Nereidas-1. Furthermore, González et al. (2015) described a 3D conceptual model of NRV consisting of a convective hydrothermal system that interacts with the magmatic flow that ascends through a tripartite system of magmatic chambers. The flow pattern of the geothermal fluid is structurally controlled by the faults of Nereidas, Rio Claro, Santa Rosa, Samaná Sur and the discontinuity of the prevolcanic basement facilitating superficial manifestations of sulphide, chloride and bicarbonate waters. Geochemical geothermometer calculations indicate that reservoir temperature in NRV can reach up to 260 ºC (Alfaro et al, 2002; Alfaro et al, 2005). Likewise, there is an advanced argillic alteration that benefits the occurrence of a clay cap that restricts the circulation of hydrothermal fluids (Forero, 2012).

For the purposes of this paper, the technical inputs required for a financial feasibility assessment are based on the information mentioned above. Additionally, it is assumed in the near future five wells will be drilled and financed through a grant with the condition of reimbursement in the case of drilling success. Under these assumptions, the implementation of a potential technology will be evaluated, allowing for the initial monitoring of field exploitation and an early generation of electricity. The assessment consists of calculations of the financial parameters' net present value (NPV) and the internal rate of return (IRR) of choosing a wellhead power plant. Traditionally, these types of plants are used at back pressure. However, condensing units also exist and provide greater exergy efficiency than those at backpressure and, despite the higher investment cost, they can also be financially more profitable. For instance, at Olkaria-Kenya geothermal field, 11 units of wellhead condensing power plants can successfully generate a net power of approximately 56 MW (Bardarson, 2016; Chege et al., 2017). The financial feasibility assessment also includes constraints from the Colombian financial, legal and regulatory frameworks and a sensitivity analysis of generation capacity.

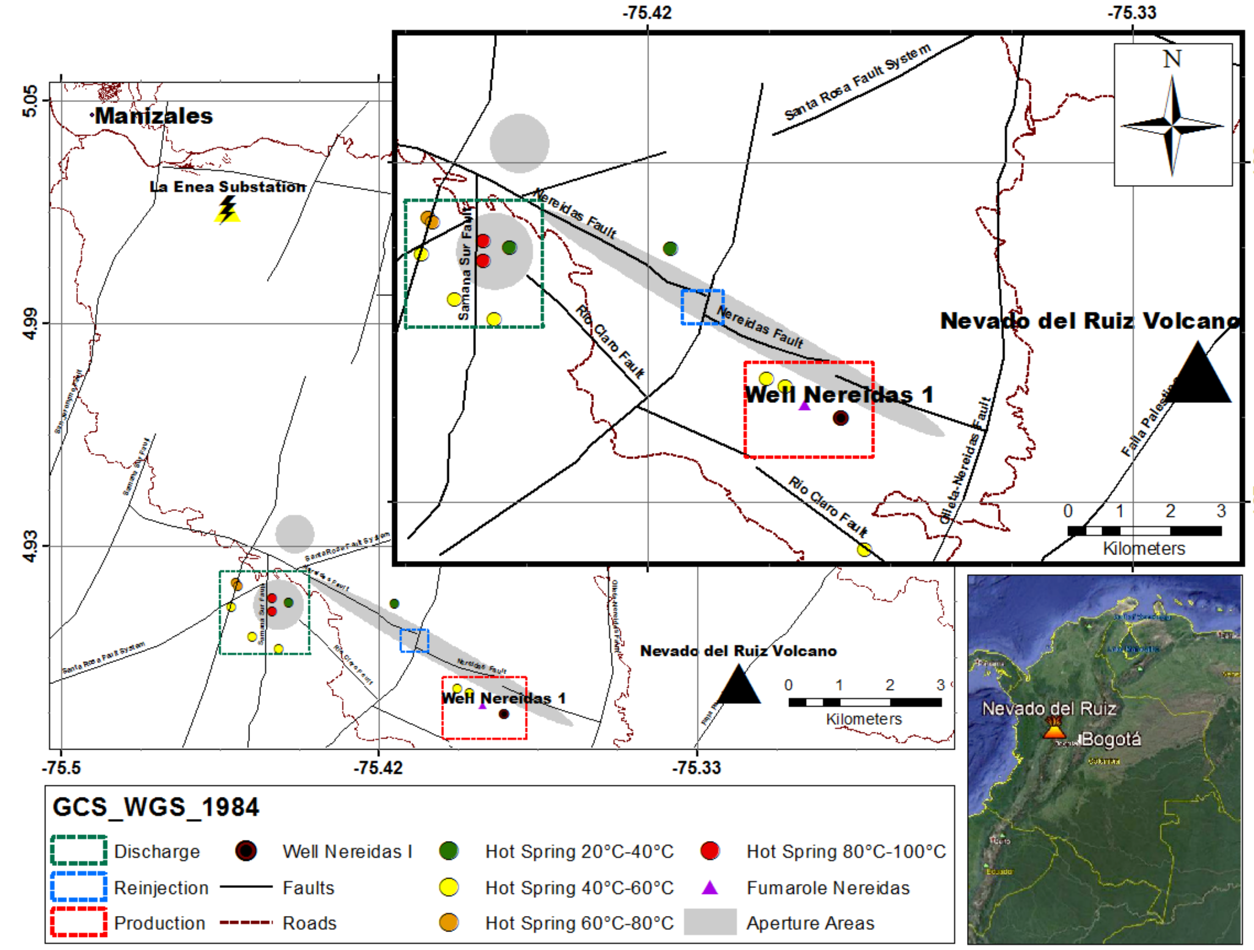


Figure 1: NRV geothermal area. The dashed squares and grey polygons are inferred areas from published information (Alfaro et al., 2002; Mejía et al., 2012; Lopez, 2018). The distance from the production to reinjection area and to the La Enea electrical substation is depicted on the larger image.

2. PROJECT CONSTRAINTS

The aforementioned technical parameters are assumed to model the performance of exhaust backpressure and condensing steam turbines. It is also necessary to contextualize the average price of electric power generation in the Colombian energy market, the regulation related to social and environmental aspects, the law that promotes the use of renewable energies, and the interest rates to finance the project.

2.1 Technical Assumptions

The NRV geothermal project has, to date, no confirmed sources to estimate the design parameters of a power plant, therefore the following parameters are assumed according to the previous prefeasibility studies, commonly accepted rule of thumbs and statistics from geothermal wells around the world:

- **Reservoir temperature:** Geothermometer calculations from surface geothermal manifestations indicate that the reservoir temperature can reach up to 260 ºC (Alfaro et al, 2002). For this work, 255 ºC is chosen with accordance to Alfaro et al. (2005).

- **Wellhead pressure:** In geothermal fields around the world, typical wellhead pressures oscillate between 2 to approximately 16 bar. An average value that can be assumed here is 7.0 bar (IFC, 2013). This pressure corresponds to a wellhead temperature of 165 ºC (Klein, 2009).

- **Mass flow rate:** Global statistics suggest 2.27 kg/s as the steam required per MWe in self-flowing wells tapping a reservoir at a temperature of 190°C or more. Additionally, the global average well capacity is 6.8 MWe (IFC, 2013). Based on reservoir temperature estimated from NRV geothermal reservoir, it is assumed that each well could generate a steam flow efficiency around 2.3 kg/s/MW.

- **Elevation:** The NRV geothermal area is located between 3400 to 3600 m.a.s.l. 3450 m.a.s.l. is chosen for the height parameter of this project, as it is the elevation of Nereidas-1 (Monsalve et al., 1998).

- **Non-condensable gases (NCGs):** This parameter is the most significant infuencing factor on geothermal power plant performance. It can vary from less than 0.2 wt% to greater than 25 wt% of the steam. To avoid a considerable decrease in the net power output, it is assumed that 1 wt% of steam are NCGs (Ozcan et al, 2009).
- **Wet bulb temperature:** This is the most important controlling parameter on cooling towers and it can also affect the net power output (Ozcan et al, 2009). By 2008, a minimum annual atmospheric temperature average in the NRV geothermal field was 10 ºC (Ruiz et al., 2008). In the last 10 years, several studies by The Institute of Hydrology, Meteorology and Environmental Studies (IDEAM by its Spanish acronym) on high mountain areas in Colombia (3.000 to 3.700 m.a.s.l.) have shown increases in the temperature of about one degree centigrade per decade (Magoni et al., 2017). Thus, a wet bulb temperature of 11 ºC is chosen.
- **Relative humidity:** The mean annual relative humidity around NRV geothermal area varies from 80% to 94% (Ruiz et al., 2008). The minimum value of 80% is selected considering a possible effect of climate change in the last decade.
- **Reinjection:** It is necessary to estimate a length of the piping system required for reinjection, for costing purposes. There is no public information for this estimation. However, Mejía et al 2012 proposed some aperture areas that favor permeability due to strike-slip faulting (Figure 1). One of the sectors is located around 2 km from the possible production area near the fumarole Nereidas in the north-west direction to the discharge zone Botero-Londoño. On this way, the distance of 2 km is chosen to calculate the cost of reinjection pipeline.
- **Transmission line**: Figure 1 shows the approximate distance from the NRV geothermal area to the nearest electrical substation La Enea at 220 KV, located in the municipality of Villamaría, Caldas (UPME, 2016). The transmission line would have a length of 17 km approximately.

2.2 Environmental and Social Aspects

The Colombian Ministry of Environment and Sustainable Development granted to CHEC-EPM an environmental license since 1994 (Ramirez, 2016). The decree 1076 of 2015 assigned CORPOCALDAS, the Autonomous Regional Corporation (CAR by its Spanish acronym) the responsibility to follow up on the activities required in the environmental license, which includes carrying out an environmental management plan (PMA by its Spanish acronym). The PMA requires a socio-economic and cultural management program. This program has facilitated training, education and awareness for the community surrounding the project (Ramirez and Castaño, 2017) and has also created a positive social perception of geothermal energy as a clean source to produce electricity (Ramirez, 2018). The PMA also includes a Construction and Adaptation Activity Program currently carried out by CHEC-EPM in order to improve 48.21 Km of existing roads, build new 3.5 Km roads, and to provide access to 5 platforms for the exploratory wells to be drilled in the coming years (Lopez, 2018).

The NRV is overseen by SGC through geophysical and geochemistry monitoring networks. Evidence of increasing magmatic activity in the area has been collected since 2007 (Londoño, 2016; Vargas et al, 2017). However, there are no current concerns reported as representative risk factors for the geothermal project. The NRV geothermal area is located about 14 km on the north-west direction far from the Arenas crater that has been presented an increase of ash eruptions over the last years.

2.3. Domestic Market Conditions

In the last decade, Colombia has implemented crucial legal and regulatory actions to promote the use of sustainable energy. For instance, the Law 1715 of 2014 and the National Development Plan 2018-2022 of Colombia have established the following four main incentives to grant energy generation from non-conventional energy sources including geothermal (Colombia, 2019):

- 15 years to deduct 50% of investments from the companies’ income tax
- Exemption of the national value added tax of 19% for equipment and services
- Exemption of import duty for equipment not produced locally
- Up to 20% of accelerated depreciation per year for the investment

With regards to the price of electricity, the Mining and Energy Planning Unit of Colombia (UPME by its Spanish acronym) projects that the price of electric power generation in Colombia will have an expected growth of 13% for the next 10 years (UPME, 2015). Based on this, the financial assessment is carried out with an electricity price increment of 1.3% per year.

3. ANALYSIS AND RESULTS

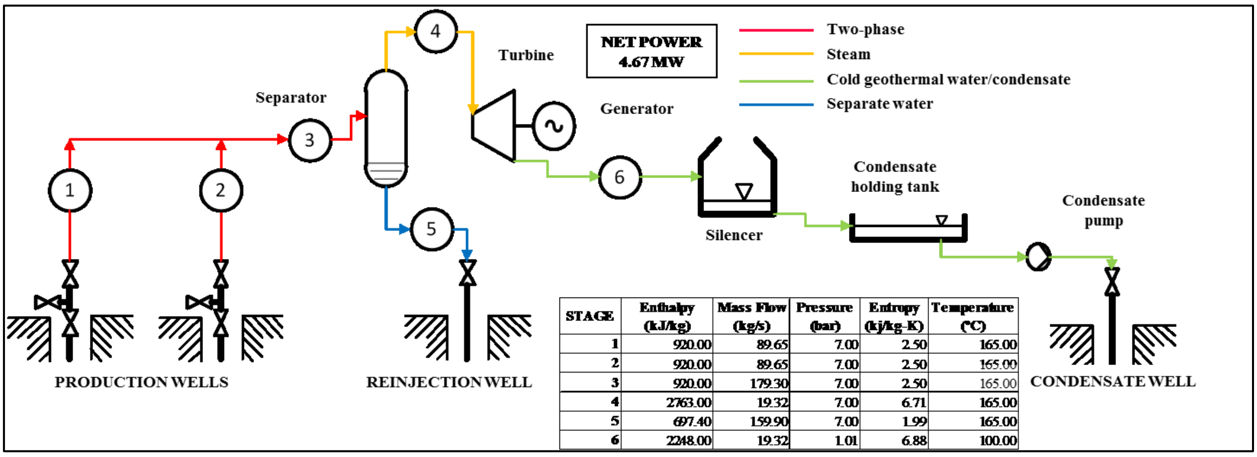
Technical modelling is essential in an investment decision. It implies the responsibility of analysis and selection of the more efficient technology that can generate the power and incomes that make the project profitable. Likewise, the market context and future risk scenarios are mandatory to guarantee the stability and feasibility of the project during its economic life.

3.1 Wellhead Power Plants Performance

Traditionally, the development of wellhead power plants has been based on the use of steam turbine backpressures. However, there are existing solutions of small power plants, even less than 5 MW, with condensing turbine technology. A comparison using ESS (Engineering Equation Solver – Klein, 2009) between this two technologies in terms of performance is essential to identify which one could be financially more feasible.

3.1.1 Backpressure Wellhead Power Plant

Backpressure wellhead power plants are convenient start-up plants due to their low cost and modular construction. These modular plants are portable and allows the early generation of energy from the wellhead while the balance of the well is developed for a larger plant. In this type of power plants, the steam expands through the turbine and is then released into the atmosphere. This is also the simplest type of geothermal plants in terms of operation and maintenance, and has no major restrictions on the percentage of non-condensable gases. However, these plants have the lowest efficiency in the conversion of energy as they require a greater steam flow in comparison with the other technologies available (Sutter et al., 2012). Figure 2 shows the model of using a backpressure wellhead power plant with the technical parameters assumed in the section 2.2 as inputs, resulting of a gross power of 4.86 MW, a net power of 4.67 MW, increasing the steam flow efficiency to 3.97 kg/s/MW.

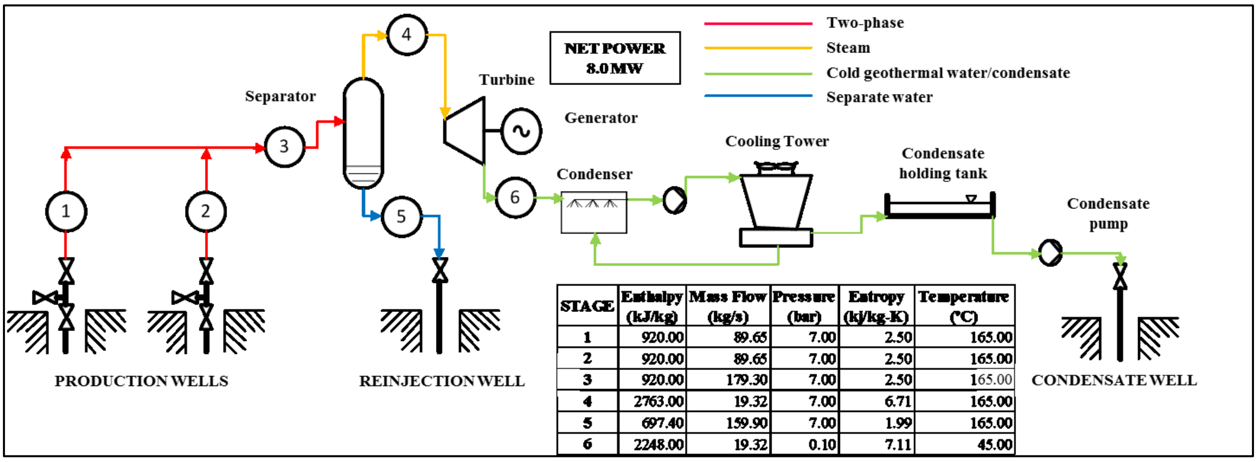


STAGE	Enthalpy (kJ/kg)	Mass Flow (kg/s)	Pressure (bar)	Entropy (kj/kg-K)	Temperature (°C)
1	920.00	89.65	7.00	2.50	165.00
2	920.00	89.65	7.00	2.50	165.00
3	920.00	179.30	7.00	2.50	165.00
4	2763.00	19.32	7.00	6.71	165.00
5	697.40	159.90	7.00	1.99	165.00
6	2248.00	19.32	1.01	6.88	100.00

Figure 2: Process diagram and outcomes for backpressure turbine.

<u>3.1.2 Condensing Power Plant</u>

Condensing power plants are typically large and widely used plants in liquid dominant geothermal fields. However, they currently exist for small power capacity such as 5MW. This type of plant utilises the resource more efficiently than backpressure due to the steam expanding through the turbine at a very low pressure, thus generating more power with the same steam flow rate. Once the resulting steam leaves the turbine, it passes through cooling water sprayers in a direct contact condenser. The heat accumulated is normally released into a cooling tower and then into the atmosphere. Meanwhile, the non-condensable gases are removed from the steam using a two-stage steam jet ejector system and are also released into the atmosphere (Chege et al., 2017; Kiptanui et al., 2016). Despite the higher efficiency, some disadvantages could be associated with condensing power plants due to the need of a greater number of devices such as condenser, non-condensable gas extraction system, cooling tower and more pumps, which demand more internal energy to operate, reducing the final gross power. Figure 3 shows the modelling outputs of the condensing wellhead power plant using as inputs the technical parameters specified in item 2.1. It yields of a gross power of 8.5 MW, a net power of 8 MW, for the steam flow efficiency of 2.27 kg/s/MW.



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3	920.00	179.30	7.00	2.50	165.00
4	2763.00	19.32	7.00	6.71	165.00
5	697.40	159.90	7.00	1.99	165.00
6	2248.00	19.32	0.10	7.11	45.00

Figure 3: Process diagram and modelling outcomes for condensing turbine.

Contrasting the net power obtained from the backpressure and condensing power plants based on the modelling above, backpressure turbines require 75% more steam volume per megawatt than the condensing turbine if the same power output is required. Therefore, the use of backpressure turbines implies to increase the investment in drilling for more wells to obtain more steam. Otherwise, the backpressure unit only can produce 58% of the power output of the condensing turbine with the same steam as shown by the modelling above. These performance modelling outcomes have implications for the financial feasibility of both type of plants which is described later in item 3.2.3.

3.2 Financial Assessment

A project financial assessment includes estimating its initial investment (equity and debt), tax incentives, productivity, operation and maintenance costs, cash flows, and profitability. Furthermore, a sensitivity analysis of different scenarios for the installed capacity and type of technology must be carried out to select and validate the best alternatives for the project (Estevez, 2012).

3.2.1 Cost Breakdown

The results obtained from the exercise of estimating of costs for the project that includes drilling and the installation of a 5M condensing wellhead plant (base case) is detailed in Table 1, with a total cost estimate of 7.76 million US per megawatt (MUS$/MW). For the sensitivity analysis, Table 1 also includes the capital expenditure (CAPEX) for a 5M backpressure unit, and a10 MW and a 15 MW condensing unit. The cost estimate, as recommended by Association for the Advancement of Cost Engineering (AACE International), can be classified as Class 4. Class 4 is related to a number of purposes; in this paper we are looking for the confirmation of technical and economic feasibility (AACE International, 2019).

N	Development Capacity MW	5	5 (Back Pressure)	10	15
1	**Supervision, contracting fee, commissioning**	$3,480,000.00	$3,965,595.93	$5,545,000.00	$7,035,000.00
2	**Geoscientific studies**	$500,000.00	$500,000.00	$500,000.00	$500,000.00
3	**Expected successful production wells**	$10,000,000.00	$15,000,000.00	$15,000,000.00	$20,000,000.00
4	**Expected successful reinjection wells**	$5,000,000.00	$10,000,000.00	$10,000,000.00	$10,000,000.00
5	**Steamfield plant**				
	Separator stations (1 x 5 MW)	$500,000.00	$500,000.00	$500,000.00	$750,000.00
	Control & instrumentation separator stations	$200,000.00	$200,000.00	$200,000.00	$200,000.00
	Two-phase piping in the pad	$100,000.00	$100,000.00	$100,000.00	$100,000.00
	Lines to separators	$100,000.00	$100,000.00	$100,000.00	$100,000.00
	Main steam lines to power plant	$150,000.00	$150,000.00	$150,000.00	$150,000.00
	Piping from separator stations to reinjection wells	$2,000,000.00	$2,000,000.00	$2,000,000.00	$2,000,000.00
	Reinjection wellhead piping	$150,000.00	$150,000.00	$300,000.00	$450,000.00
6	**Civil works**				
	Land	$250,000.00	$250,000.00	$250,000.00	$250,000.00
	Pad	$2,000,000.00	$2,000,000.00	$2,000,000.00	$2,000,000.00
	Sump	$350,000.00	$350,000.00	$350,000.00	$350,000.00
7	**Transmission lines**	$2,500,000.00	$2,500,000.00	$2,500,000.00	$2,500,000.00
8	**Power plant**				
	Mechanical:				
	Turbine-generator, including lube oil unit, control.	$3,373,895.65	$3,373,895.65	$6,454,409.07	$9,241,540.26
	Surface condenser including Condense piping & cross-over	$1,265,210.87	$0.00	$2,420,403.40	$3,465,577.60
	Gas removal, ejectors, hybrid+coolers+stack	$175,020.84	$0.00	$334,822.47	$479,404.90
	Cooling tower, wet evaporative	$961,560.26	$0.00	$1,839,506.58	$2,633,838.97
	Main + auxiliarys CW pumps and piping	$124,412.40	$0.00	$238,006.33	$340,781.80
	Piping, installation and material	$421,736.96	$210,868.48	$806,801.13	$1,155,192.53
	Compressed air system, cranes, platforms	$615,735.96	$307,867.98	$1,177,929.65	$1,686,581.10
	Electrical & control				
	Main transformer and auxiliary transformers	$345,057.51	$345,057.51	$660,110.02	$945,157.53
	Local connection to the grid	$191,698.62	$191,698.62	$366,727.79	$525,087.51
	HV + MV switchgear	$383,397.23	$383,397.23	$733,455.58	$1,050,175.03
	Motor control cubicles	$172,528.75	$86,264.38	$330,055.01	$472,578.76
	Control & instrumentation	$306,717.79	$306,717.79	$586,764.46	$840,140.02
	Generator relay protection system	$143,773.96	$143,773.96	$275,045.84	$393,815.64
	Cables + trays + terimals + auxiliaries	$383,397.23	$191,698.62	$733,455.58	$1,050,175.03
	Buildings & auxiliaries				
	Site excavation, grating, fencing	$143,773.96	$143,773.96	$275,045.84	$393,815.64
	Turbine hall + electrical annex building	$1,437,739.62	$431,321.89	$2,750,458.41	$3,938,156.36
	Service buildings, staff, workshop, storage	$479,246.54	$143,773.96	$916,819.47	$1,312,718.79
	Fire fighting system	$95,849.31	$95,849.31	$183,363.89	$262,543.76
	Cooling tower basin + pumping pit	$479246.54	$0.00	$916,819.47	$1,312,718.79
	Best Estimated Total	**$38,780,000.00**	**$44,121,555.26**	**$61,495,000.00**	**$77,885,000.00**
	MUSD/MW	**$7.76**	**$8.82**	**$6.15**	**$5.19**

Table 1: Project cost breakdown. Base case 5MW, 5MW backpressure, 10 MW and 15 MW condensing units. The cost exercise was carried out during the Latin American Geothermal Diploma Course, El Salvador, 2017.

As the NRV geothermal area is located on an elevation higher than 3.000 m.a.s.l., the selection of the electrical equipment for this altitude increases the CAPEX. For the base case, the cost for the drilling of 3 wells is included, 2 for production and 1 for reinjection. The estimated cost of the drilling is 15 MUS$ which will be covered by a grant. In case of a successful drilling campaign, 80% of the grant will be paid back. This payback could be financed through a bridging loan, which in this case is assumed to be obtained with the interest of 6%, but it could be a lower value.

3.2.2 Project Financing

Table 2 summarizes the input parameters used in the financial model for the base case and the additional scenarios.

Plant size	MW	5	5 (Back Pressure)	10	15
Plant capacity factor	%	93.0	93.0	93.0	93.0
Electricity generation per year	MWh/year	39105.0	39105.0	76580.0	114870.0
CAPEX - Investment	MUS$	38.8	44.1	61.5	77.9
Grant	MUS$	15.0	15.0	15.0	15.0
CAPEX after 20% of grant	MUS$	35.8	41.1	58.5	74.9
Equity - Cost of equity - *Ke*	%	7.6			
Equity share	%	53.0			
Debt: Average cost of debt - *Kd*	%	6.0			
Debt share	%	47.0			
Debt maturity period	years	15.0			
Debt grace period	years	2.0			
Corporate tax	%	34.0			
Tax Exemption	years	10.0			
WACC after tax	%	5.6			
Depreciation	years	20.0			
Operation and maintenance	US$/MWh	8.0			
General cost: Insurance, sales	US$/MWh	3.8			
Transmission cost	US$/MWh	0.0			
Resource decline	%	0.0			
Inflation	%	2.0			
Construction period	years	4.0			
Energy price	US$/MWh	70.0			
Energy price increase per year	%	1.3			
Life of the project	years	30.0			

Table 2: Financial input parameters. Base case, 5MW backpressure, 10 MW and 15 MW condensing units.

The parameters are explained below:

- **Financial structure:** The capital structure for the NRV project is assumed to be 53% equity and 47% debt.
- **Interest rate:** The nominal interest rate on the debt is set at 6.0% over 20 years.
- **Taxes, incentives, fees:** Only the corporate tax of 34% was considered for the cash flow calculations, which will be paid to the government after year 10. By this time 50% of the investments will have already been deducted from the income tax, according to the incentives offered by the Law 1715 of 2014.
- **Project timeline/financing needs:** The project is set with a 30 years outlook for generating revenue. Additionally, 4 years of construction is assumed. The debt maturity period is 15 years with a grace period of 2 years.
- **Operation and maintenance:** It includes the direct cost and chemical stimulation cost of the wells.
- **Inflation:** It corresponds to an average annual inflation rate in the United States of around 2% as the financial modelling is carried out in US$.
- **Depreciation:** It relates to the main equipments of the power plant. 20 years are chosen as the benefit of the Law 1715 of 2014 related with the income tax exceeds the 20% of accelerated depreciation per year.
- **Energy revenues:** The energy price and sales are based the wholesale spot market of Colombia at US$70/MWh when operation starts, with an annual increment of 1.3% (UPME, 2015).
- **Weighted Average Cost of Capital (WACC):** The calculation of *WACC* for the project considered the equity cost *Ke* and the debt cost *Kd*. This is calculated as follows:

$$WACC = We * Ke + Wd * Kd * (1 - Tc)$$

In the above calculation, We is the equity share, Ke is the cost of equity, Wd is the debt share, Kd is cost of debt and Tc is the corporation tax or law tax that must be paid for the gross income of the project. Kd is based on the current interest rates on the financial market of Colombia for this type of project (Central Bank of Colombia, 2019). The calculation of *Ke* is based on the Capital Asset Pricing Model, CAPM, with the following data:

- **Risk free rate**: US Treasury bond rate for 30 years equal to 2.58% (United States Department of the Treasury, 2019).
- **Equity risk premiun**: 5.93%.
- **Beta, unlevered beta and other risk measures:** The industry is power with an unlevered beta of 0.3 (Damodaran, 2019).
- **Country risk rate:** For Colombia the country risk premium is equal to 3.0%.
- **Company size premium rate:** A rate of 1.2% is added to *Ke*.

3.2.3 Results

The valuation modelling is based on discounted cash flow. The Free Cash Flow (FCF) is used for the financial valuation of the entire project, with *WACC* as the discount rate. For investors, the model uses the Equity Cash Flow (ECF) discounted with the equity cost of capital *Ke*. The financial ratios or indicators included in the model are the Net Present Value (NPV), the Internal Rate of Return (IRR), the Levelized Cost of Energy (LCOE), the Debt Service Coverage Ratio (DSCR) and the Payback.

NPVs for the different scenarios of generation capacity are shown in Figure 4, based on the given conditions of the NRV project. The additional financial outcomes are presented in Table 3. The results indicate that the base case and the 5MW backpressure unit are not profitable. Furthermore, it should be taken into account that the drilling cost, which affects profitability, is already included in this financial exercise. The small power plants are recommended for an early stage when the steam is available while a larger plant is constructed. The scenario without drilling costs favored the financial feasibility of the 5MW plants (Kiptanui et al., 2016). However, an increment in the installed capacity to 10 MW or 15 MW shows that the NPV Project and NPV Equity are positive, which means a value creation even without deducting the investment for drilling.

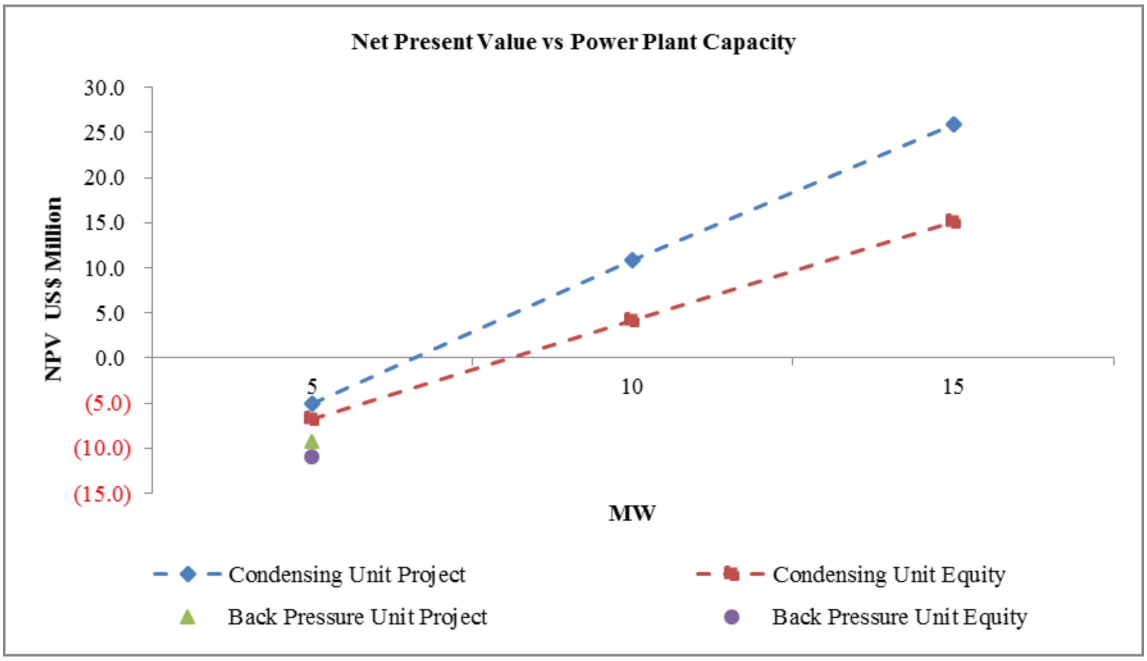

Figure 4: NPV versus generation capacity for the base case, 5MW backpressure unit, 10 MW and 15 MW condensing power plants.

Results	**MW**	**5**	**5 (Back Pressure)**	**10**	**15**
Project IRR	%	4.17	3.32	7.65	9.38
Equity IRR	%	4.47	3.10	8.94	11.51
LCOE	US$/MWh	97.02	107.91	67.34	58.54
DSCR	Average	1.60	1.30	2.20	2.50
Project Payback	years	No	No	11.00	13.00
Equity Payback	years	No	No	16.00	10.00

Table 3: Financial results of the Project and the Equity for base case, 5M backpressure unit, 10 MW and 15 MW condensing power plants.

4. CONCLUSION AND RECOMMENDATIONS

The current status of the NRV geothermal project allows for an analysis of the early use of steam that can be obtained from the first wells. The conceptual model let to intuit technical conditions suitable for the use of a condensing wellhead power plant. Additionally, public policies and the recent growing interest in Colombia for the development of geothermal projects generate a convenient atmosphere for the review and improvement of the legal and regulatory frameworks that facilitate the installation of geothermal power plants. Both the aforementioned outcomes of the financial assessment and the technical conditions support the case of the NRV geothermal project. The results indicate the profitability of the project with an early development around 10 MW, which not only covers the costs of the plant but also the drilling. Therefore, it is recommended to maintain the execution plan of the use of the grant for the first wells. If steam is found, the installation of a condensing wellhead unit is recommended for the early delivery of power, while further exploring and expanding our knowledge of the NRV geothermal system. It is also recommended to evaluate the installation of smaller condensing power plants, such as 5 MW, with a better approximation to the Colombian market to assume the drilling cost to be included in the cost computations for a larger conventional power plant. It should be noted that small condensing power plants have a better technical and financial performance than backpressure units with similar turbine size.

The financial assessment also suggests a review of tax incentives and regulatory framework to improve the profitability of geothermal projects in Colombia. For instance, the income tax of Law 1715 of 2014 showed that, in the first 10 out of 15 years, 50% of the investments had already been deducted from the project incomes. Consequently, the 20% of accelerated depreciation per year for the investment could not be taken advantage of. In addition, the use of power purchase agreement (PPA) type contracts is recommended to reduce the risk of energy sales.

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