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Wellhead Power Plants, an Option to Enhance the "Macizo Volcánico del Ruiz" Geothermal Project

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ABSTRACT

Geothermal projects for electricity production with a central plant present great challenges. Among them are the risks of the exploratory stage, high initial investment, and the lengthy time between exploration and revenue generation. Countries like Colombia, that want to venture into geothermal development, see first-hand how it is even more difficult when it is the first time developing this type of project. As a way to work around these challenges, there are many cases where the use of modular wellhead plants improved the outlook for investment and development of geothermal projects. Installing wellhead plants can accelerate the production of electricity, amortizing the total costs of the project from the start of operation of the first producing well. This document shows the geothermal potential of the "Macizo Volcánico del Ruiz" in Colombia and a little analysis of the use of modular plants to enhance the geothermal project.

1. INTRODUCTION

A growing global energy demand (International Energy Agency, 2019) and pollution problems from the production and use of fossil fuels (Ritchie and Roser, 2019), have led societies to focus efforts on the creation of projects with Non-Conventional Renewable Energy Sources (NCRE). Currently, the Colombian energy matrix is highly dependent on hydroelectricity (PARATEC, 2019)., which are affected by climatic and seasonal conditions. This characteristic puts the country's electricity supply at risk, especially during low level rain seasons, which are becoming more frequent and severe every day, due to climate change (NASA, 2019). Also, while hydroelectric plants supply approximately 68.3% of the electric power, thermoelectric plants generate 30.7% of the electricity of the Colombian energy matrix (ALCOGEN, 2019). Other sources are negligible. Therefore, the high costs of fossil fuels and their polluting effects make thermoelectric plants difficult to maintain over time. Especially since the emission control requirements are constantly increased, to meet the purpose of generating electricity with low environmental impact. The efforts in Colombia to reduce dependence on conventional energy sources are embodied in bill 1715 of 2014, which establishes the procedures and requirements for investments in projects with Non-Conventional Renewable Energy Sources (NCREs) and efficient energy management. This bill provides tax benefits to promote investment in such projects (Congreso de Colombia, 2014).

Geothermal energy is one of the NCREs, which can be defined as thermal energy generated and stored underground. Geothermal energy derives from the original formation of the planet (20%) and the radioactive decay of some minerals (80%) (Bassam, et al., 2013). For electricity production and some direct uses of geothermal energy, the heat of underground aquifers is used. These deposits are heated by the action of hot rock formations near volcanic areas. These resources appear on the surface in hot springs and in fumaroles that discharge water and hot steam (Jutglar and Pous, 2014). According to data collected in 2019, around the world there is an installed capacity of 14,900 MWe (electric generation capacity) to produce electricity from geothermal energy and an installed capacity of more than 71,000 MWt (thermal generation capacity) for the direct use of this energy (Richter, 2019).

Although the production of electricity from geothermal energy does not account for more than 0.5% of the total world production (IEA, 2018), in countries such as Kenya, Iceland, the Philippines, El Salvador, and Costa Rica it represents approximately 51%, 30%, 27%, 25% and 14% of the total electricity produced, respectively (DiPippo, 2016, ThinkGeoEnergy, 2020). This shows that in countries with great potential, geothermal energy can be significant player in the energy matrix.

Colombia is located on the Pacific Ring of Fire and volcanic activity has been reported in its mountain ranges, which is the first indication of the great potential for the use of geothermal energy since it shows that high temperatures can be found at low depths (SI3EA, 2019). This fact was the starting point for the Geothermal Resource Recognition Study in Colombia, done in 1981. The study was commissioned by CHEC ("Central Hidroeléctrica de Caldas") and carried out by CONTECOL, with the participation of the Latin American Energy Organization (OLADE) and the Colombian Electric Energy Institute (ICEL). As a result of this and other studies, four areas with high geothermal potential were determined: Chiles-Tufiño Cerro Negro (Colombian-Ecuadorian border), Azufral (department of Nariño), Paipa (department of Boyacá), "Macizo Volcanico del Ruiz" (departments of Caldas, Tolima, and Risaralda) (CORPOEMA, 2010, Alfaro, 2015, Salazar, et al., 2017).

Earlier, in 1968, CHEC had already begun investigating the geothermal potential of the "Macizo Volcanico del Ruiz". In 1976, under the auspices of the Italian government, an ENEL's commission (Ente Nazionale per l'Energia Elettrica, today ENEL Green Power) was assigned to execute a preliminary study, evaluating the possibility of using the region's geothermal resources. Later, in 1983, CONTECOL (supported by the Italian Geothermal consulting firm) was commissioned to carry out a pre-feasibility study, with refined tests and analysis, which identified the places with the greatest potential within the "Macizo Volcanico del Ruiz", especially the Nereidas Valley in Villamaria Caldas. Based on the study, the decision was to begin the exploratory drilling stage (CONTECOL, 1983).

For this reason, Geoenergía Andina S.A., a CHEC subsidiary company, processed and obtained the environmental license for exploratory drilling works in the Nereidas Valley, with chartering resolution 211 from 1994, issued by the Colombian Ministry of

Environment. In 1997, Geoenergía Andina S.A. drilled the first geothermal well in South America in the Nereidas Valley, assisted by the Parker Drilling company, and under the supervision of Designpower GENZL, the latter in charge of the geoscientific analysis. The budget ran out when the well reached a measured depth (MD) of 1,469 meters. Although its initial target was 2,000 meters, temperatures of almost 200 °C were recorded in depressurized dry reservoirs (see section 2).

The data obtained from this drilling showed that it was necessary to carry out further studies, to more accurately determine the location of the possible geothermal reservoir and thus drill a second directional well (CORPOEMA, 2010).

In 2009, CHEC EPM group ("Empresas Públicas de Medellín") assembled a team to resume the geothermal project in the "Macizo Volcanico del Ruiz". The team´s task to examine the existing studies, searching for new technologies that could add value to the project (Palacio, 2017). From 2013 to 2016, CHEC and the company Dewhurst Group (USA) carried out geological, geophysical (gravimetry, magnetometry, and magneto-telluric), geochemical, economic, financial, environmental and social feasibility studies of the project that were used to define 3 areas of interest and the projection of a 25MW Flash central power plant. In order to carry out this research, the United States Trade and Development Agency (USTDA) made a generous monetary contribution (Hernandez, et al., 2016). Then in 2016, CHEC and the LaGeo company (from El Salvador) evaluated all the information that had been obtained to date on the project. Also, the expected resource was recalculated using a refined volumetric model. The results of the new model show the feasibility of installing a 65 MW geothermal plant, which this under the technical and geoscientific component of the Dewhurst Group study.

Considering the results quite promising, Strycon Engineering company began updating the environmental impact study in 2016. This study was presented to CORPOCALDAS to satisfy the requirements of the environmental license and thus be able to start the deep exploratory drilling stage. At this point, a geothermal model was integrated and the structures to drill the wells were designed. CHEC is currently waiting for the conclusion of the environmental license update, to perform deep exploratory drilling of 5 wells. The update is expected to be granted in early 2021, taking into account that the environmental license was already approved with resolution 211 of 1994.

Parallel to the efforts of CHEC, in 2008, ISAGEN presented a basic feasibility study for the development of a geothermal project in Colombia (with INGEOMINAS and the USTDA). Based on this study, they focused their efforts on magmatic-hydrothermal modeling for the Geothermal Project in the area of the "Macizo Volcanico del Ruiz", considering it the one with the greatest geothermal potential in Colombia. The results of these and other studies carried out between 2011 and 2014, led ISAGEN to request an exploratory drilling license in 2015. In 2018, the Ministry of Environment authorized ISAGEN to perform a temporary removal of a forest reserve area, for the exploration of the geothermal potential in the "Macizo Volcanico del Ruiz" (Minambiente, 2018). However, when ISAGEN was sold, all its geothermal projects were frozen, not only the "Macizo Volcanico del Ruiz" project but also the Chiles – Tufiño – Cerro Negro binational project (ISAGEN, 2012, Marzolf, 2014, Mejía, et al., 2014, Rendón, et al., 2014)

From the progress of the geothermal project in the "Macizo Volcanico del Ruiz- Nereidas Valley", it can be said that it is at the beginning of the exploratory drilling stage. This is the stage that carries the highest levels of cost-risk, according to the models that establish the phases of a geothermal project. When the drilling stage begins, the costs rise suddenly and the risk remains almost constant, due to the uncertainty about the existence of a viable geothermal reservoir for exploitation. Figure 1 shows the most common stages of a geothermal project (ESMAP, 2012).

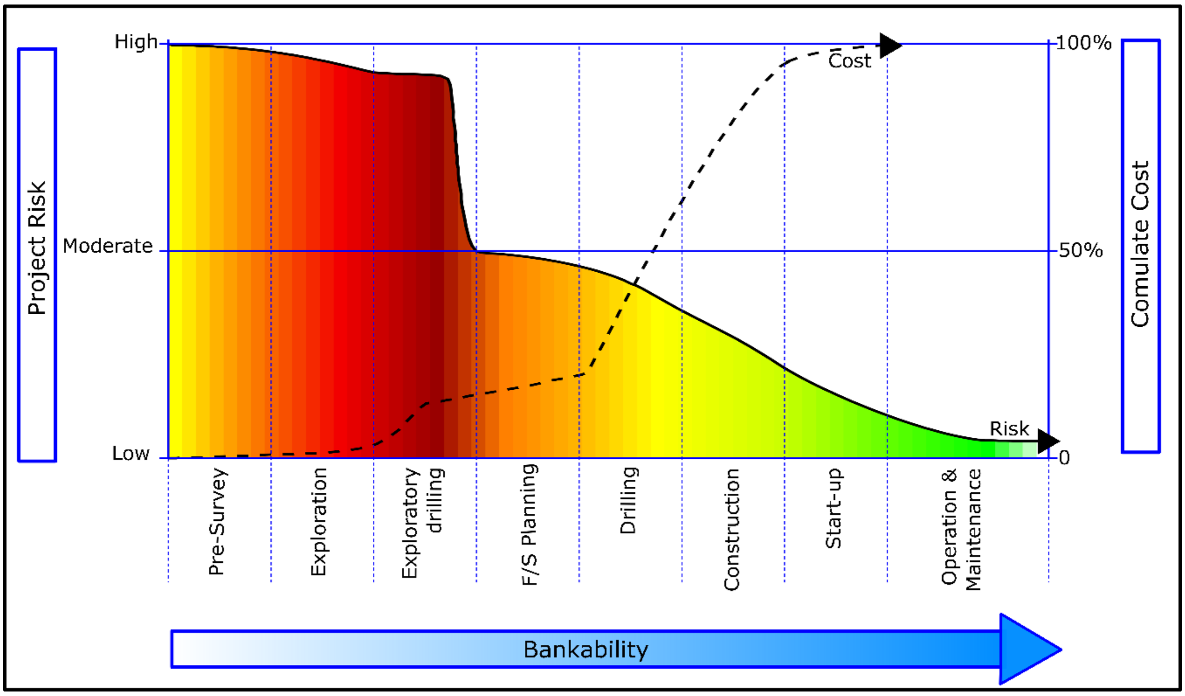

Figure 1: Stages of a geothermal project for large-scale electricity production (> 10MW) (adapted from ESMAP, 2012).

Another important aspect of the exploratory drilling stage is that when it is achieved satisfactorily, the risks reduce by almost half, having invested only about 14% of the project's total value. At this point, it is important to show the barriers to the implementation of geothermal projects, which are found in the literature (Rendón, et al., 2014, ESMAP, 2012), as follow:

- The preliminary exploration phases involve high risks and investments, which require financial assistance.
- The environmental authorities' limited technical and scientific knowledge, which delays the study and authorization of permits for the development of projects.
- Infrastructure limitations and the need for specialized equipment and skilled workforce for the exploration and development of geothermal projects.
- The location of geothermal areas in volcanic zones without appropriate infrastructure, that can allow access and connection to the national electric grid.
- The lack of adequate legislation that allows the development and exploitation of geothermal resources and their efficient and effective participation in the energy market.
- The lack of knowledge in society and specifically in the political sectors about the benefits of geothermal energy development.
- The large supply of hydraulic-powered electricity at lower costs.

Analyzing the information about geothermal projects in Colombia, it may be that the early use of the geothermal resource, starting from the exploratory drilling stage, facilitates the development of this type of undertaking. For this reason, there is an intention of evaluating this possibility for the geothermal project in the "Macizo Volcanico del Ruiz- Nereidas Valley".

2. ESTIMATES OF THE RESOURCE PROPERTIES IN THE "MACIZO VOLCANICO DEL RUIZ" GEOTHERMAL PROJECT.

Firstly, it is necessary to use all available data to estimate the properties of the resource expected to be found in the drilling stage. As mentioned above, perhaps one of the most important tests of the geothermal potential in the Nereidas Valley are the temperature readings made in the well drilled by the CHEC in 1997. Measurements showed high temperatures of approximately 200 °C at the bottom of the well, in depressurized dry reservoirs (Figure 2) (Palacio, 2017).

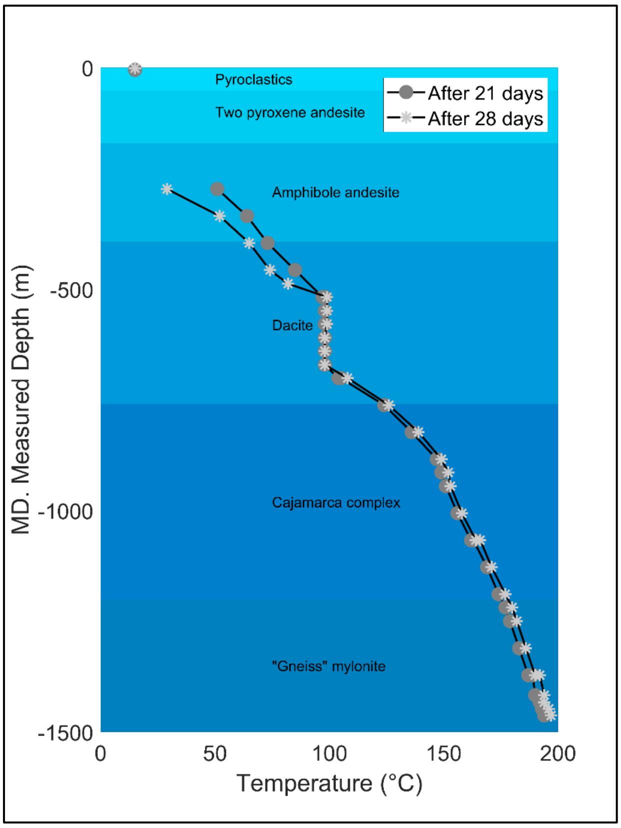

Figure 2: Measured depth (MD) vs. Temperature measurements in well Nereidas 1. Measured depth is the length of the borehole that is different from the true vertical depth (Adapted from Palacio, 2017).

The measurements shown in Figure 2 were taken 21 and 28 days after the completion of the well. Based on the data, extrapolating from the geothermal gradient, temperatures between 230 and 250 °C can be found, for depths ranging from 1700 to 2000 meters. Once the first well was drilled, new geological, geophysical (gravimetry, magnetometry, and magneto-telluric) and geochemical studies were performed, showing that there are underground formations characteristic of a geothermal reservoir. Another important piece of information comes from the geysers and thermal pools that exist in the region (some of them with temperatures above 90 °C).

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After carrying out the geo-thermometric analyzes in water and gases, it is estimated that the original resource may be at temperatures ranging from 240 to 260 °C. These estimates allow us to classify the possible geothermal fluid as a high enthalpy resource, suitable for electricity production (ESMAP, 2012).

The most recent studies indicate a 90% probability that the geothermal reservoir supports an electricity power plant, with 65 MWe of installed capacity (LaGeo, 2016). It is estimated that each well can produce between 5 and 4 MWe, which translates into a flow of geothermal fluid that can be between 180-250 tons per hour. The prediction is that the geothermal fluid would be in the form of a saturated liquid inside the reservoir. It should be noted that these estimates are quite conservative when compared with real values of geothermal fields currently in production. For example, in the report of "International Finance Corporation", 2,613 geothermal wells were analyzed around the world and it was calculated an average capacity of 7.3MWe per well (IFC, 2013, DiPippo, 2012).

3. WELLHEAD POWER PLANTS

As mentioned in the first part, the geothermal project in the "Macizo Volcanico del Ruiz- Nereidas Valley" is at the beginning of the exploratory drilling stage, so the decision to carry it out from a financial point of view is quite difficult to make (ESMAP, 2012). Also, in a traditional geothermal project with a central power plant (Figure 1), revenue is only generated after the field has been completed and the geothermal plant has been built.

For these reasons, wellhead power plants were installed in many projects around the world, to enhance the exploration and construction stages, as they have the following advantages (Chege, et al., 2017, Kiptanui and Kipyego, 2016, Bert, 1986):

- Wellhead units take 6 to 12 months to build (faster than a conventional central power plant).
- The anticipation of electricity production also generates anticipated revenue.
- The costs associated with drilling can be reduced as diesel is replaced on the rigs.
- Wellhead plants can facilitate workforce training in operation and maintenance aspects.
- Their costs make them more affordable, easy to install, and cheap to maintain and operate.
- Wellhead units can be portable and can be easily moved to other geothermal areas.
- With this technology, wells can be tapped almost immediately after testing.
- Their design and construction are standardized, making them more reliable.

A great example of successful modular wellhead plants is the Geothermal project in the Olkaria-Kenya field. Although production wells had already been drilled confirming the reservoir's viability for electricity production, KenGen (Kenya Electricity Generation Company) spent more than eight years unsuccessfully trying to finance a central geothermal power plant. Noticing the challenges of the project, KenGen decided to implement a 5MW wellhead unit in one of its wells. The first wellhead plant was installed in 2011 and produced electricity for 18 months. At this point KenGen commissioned GEG (Green Energy Group) to build 14 more wellhead units, considering the success they had with the first one. In 2016 all 15 plants, including the initial modular plant, came into operation, and together they have an installed capacity of 80.6 MW, producing electricity to this day. The solution was so successful that the initial plan to switch from modular plants to a central power plant has been postponed indefinitely (Chege, et al., 2017)

Similar to this case, there are several examples of how the usage of wellhead units boosted geothermal projects (Wallace, et al., 2018, Sutter, et al., 2012, Lund and Boyd, 2019). In addition to this, there are financial and technical studies that compare the use of wellhead units with central power plants or different combinations that link central and wellhead plants in the same field, with different installation times. These studies confirm the advantages offered by wellhead plants. All these studies showed how the addition of modular plants increases the Net Present Value (NPV) of the projects (Long, et al., 2012, Dahlan, et al., 2020, Gudmundsson and Hallgrimsdottir, 2016, Elíasson and Smith, 2011)

Figure 3 shows a comparison between a single Flash central power plant, which had a construction time of 24 months, and a wellhead unit system per well, in which a wellhead unit was installed every 3 months, all in the same hypothetical geothermal field. In this case, the modular plant system not only produces more energy (because each well is optimized) but also has a higher NPV (Geirdal, et al., 2015).

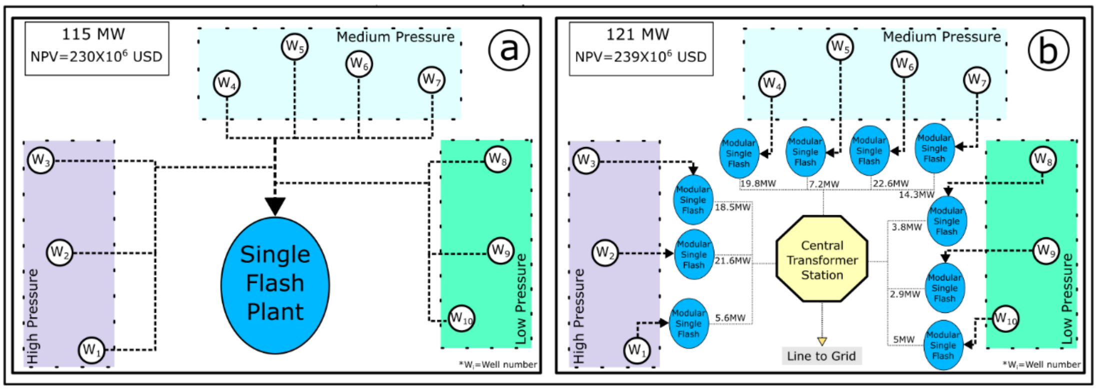

Figure 3: (a) Single Flash plant and (b) Single Flash modular plant system per well. The calculations were made from the same hypothetical geothermal field (created from the data in Geirdal, et al., 2015).

In addition, the data from this study was used for a sensitivity analysis, where it was discovered that a crucial parameter is the construction time of the geothermal power plant. Therefore, when the installation time of wellhead units is analyzed, it must be considered that they gradually come into operation in a staggered manner (Figure 4), unlike a central geothermal power plant that only comes into operation when all works have been completed (wells, civil works, steam pipelines ...).

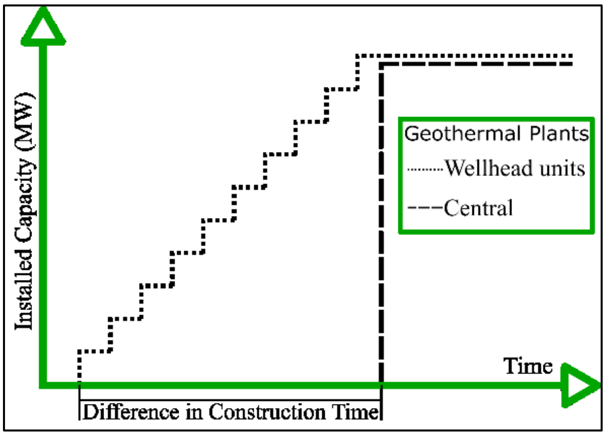

Figure 4: Construction times for wellhead plants systems and geothermal power plants (created from data in Geirdal, et al., 2015).

4. ELECTRICITY GENERATION SYSTEMS

To analyze the advantages of using wellhead plants in the "Macizo Volcánico del Ruiz" geothermal project, thermodynamic calculations were carried out in different electricity generation scenarios, using the estimates that already exist about the characteristics of the geothermal fluid. First, Figure 5 shows the thermodynamic cycles that were used in the calculations; (a) Single Flash with back-pressure turbine, (b) Single Flash with condensing turbine, (c) Double Flash with condensing turbine and (d) Binary power cycle for high enthalpy generation. These are the cycles that were considered adequate for the expected characteristics of the geothermal fluid (DiPippo, 2012, Bonafin, et al., 2018).

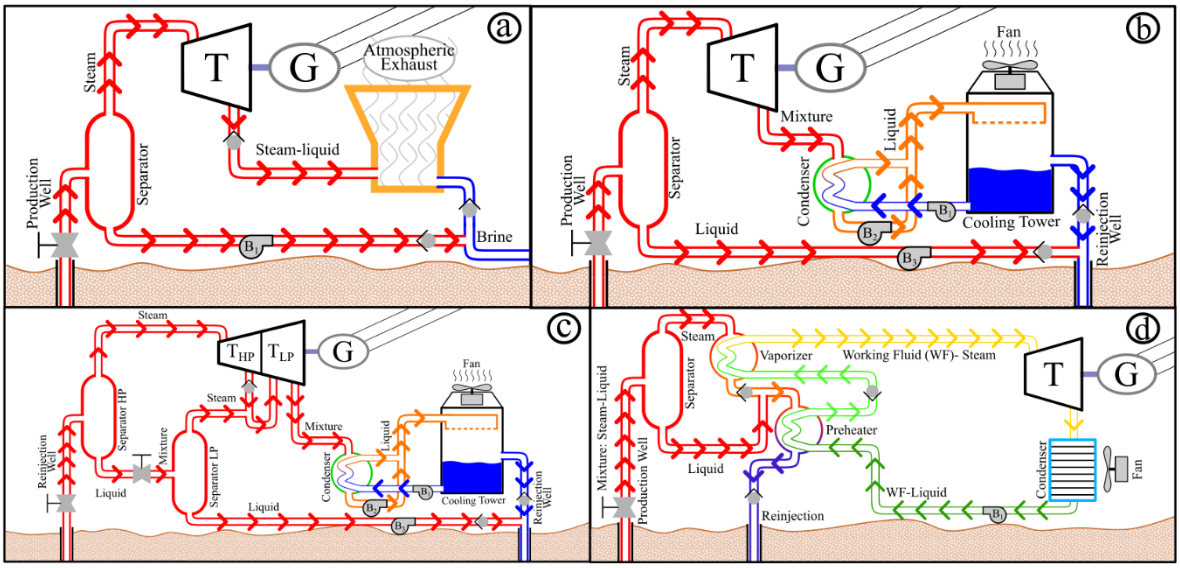

Figure 5: Thermodynamic cycles: (a) Single Flash with back-pressure turbine, (b) Single Flash with condensing turbine, (c) Double Flash with condensing turbine and (d) Binary power cycle for high enthalpy generation.

The estimates presented in Section 2 show that the geothermal reservoir in the "Macizo Volcánico del Ruiz" can support a single Flash power plant with a 65MWe condensing turbine. The studies carried out in the area show that the geothermal fluid is found as a saturated liquid, at a temperature ranging between 240 and 260 °C. In addition to this, it is estimated that each well can have a mass flow that is between 50 and 75 Kg/s. These are the input data for an iterative thermodynamic calculation. From the estimated power of 65MWe, the mass flow and required temperature are calculated, respecting the estimated temperature, flow, and pressure ranges. For this, a thermodynamic calculation structure was used, such as that presented by Professor Ronald DiPippo in his book (DiPippo, 2012). Then using an iterative process of mass and energy balance, the characteristics of each well were calculated, always respecting the mass and temperature flow ranges. Based on data from the literature, the quadratic function was adopted to shape the well curves. This protocol was programmed in an Excel spreadsheet. Based on this, a hypothetical geothermal field of 12 producing wells was created, each well with its estimated productivity curve, which meets the conditions of the fluid expected to be found in the area. These 12 wells can power a 65MWe single Flash central power plant. In Figure 6, the productivity curves for the hypothetical geothermal field are presented.

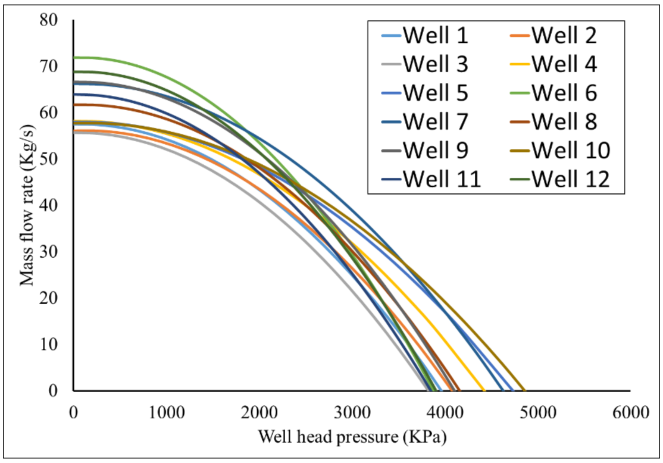

Figure 6: Productivity curves for the 12 wells, calculated for the hypothetical geothermal field.

Based on the curves in Figure 6 and the resource estimates, various electricity generation scenarios with central power plants and wellhead units were evaluated. The thermodynamic calculations depend mainly on the type of cycle (Figure 6) or on the type of system: central power plant or wellhead units (DiPippo, 2012, Bonafin, 2018). These systems and the power generated from the hypothetical geothermal field are shown in Table 1.

Table 1: Geothermal power generation system with central power plants and wellhead units systems.

Electricity Generation System	Total Power (MW)
Single Flash central power plant with condensing turbine (see Figure 6b).	65
Double Flash central power plant with condensing turbine. (see Figure 6c).	72
High enthalpy binary central power plant (see Figure 6d).	96.5
12 single Flash wellhead units with condensing turbine. (see Figure 6b).	71
12 binary high enthalpy wellhead units (see Figure 6d).	97.5
12 single Flash wellhead units with back-pressure turbine (see Figure 6a).	35.6

As shown in Table 1, when the electricity generation technology is changed, a different net power is obtained from the same hypothetical field. For example, with the double Flash central power plant and the high enthalpy binary central power plant, more energy is extracted from the fluid, compared to the single Flash central power plant (DiPippo, 2012).

One of the advantages of wellhead unit systems is that the pressure in each well can be optimized to extract the greatest amount of energy from the fluid (Geirdal, et al., 2015). It is for this reason that the system with 12 single Flash wellhead units, with condensing turbine, produces more electricity than the single Flash central power plant with condensing turbine, regardless of the fact that they start from the same operating principle.

5. FINANCIAL PROJECTIONS

From the generation scenarios presented in the previous section, financial projections were made to calculate the NPV in each case. The costs considered for the power plant options discussed in this study were:

- Costs for pre-feasibility studies.
- Cost for exploratory drilling.
- Cost for planning and design.
- Cost for production drilling.
- Cost for generation plant.
- Cost for substation and transmission.
- Cost for operation and maintenance O&M.

In each generation scenario, it is considered that there is a variation mainly in the costs of the plant, either by size (MW) or by type of technology. The variation by plant size was calculated from the following equation (Sanyal, 2004).

$$C_d = C_C e^{-0.003(P-5)} \quad (1)$$

Where C_d is the plant construction cost (USD/kW), C_C is the base cost that depends on the type of technology (USD/kW) and P is the plant power (MW). The C_C values that were used in each scenario are: for the single Flash power plant C_C = *2,500 USD/kW*, for the double Flash power plant C_C = *2,300 USD/kW*, for the binary high enthalpy plant C_C = *2,835 USD/kW* and for the single Flash plant with back-pressure turbine C_C = *1,853 USD/kW*. These and the other cost values were extracted from the literature (ESMAP, 2012, Salas, 2014).

Table 2 shows the sum of all costs necessary to start up each type of generation system (capital expenditures CAPEX). This value includes the possible costs that may be incurred for the construction of each system, from exploratory drilling to transmission networks.

Table 2: Total CAPEX for the different generation system, including the possible items, from cost of the plant (C_d), plus exploratory drilling, plus transmission networks, etc.

Electricity Generation System	CAPEX (USD)
Single Flash central power plant with condensing turbine.	301,407,558
Double Flash central power plant with condensing turbine.	309,246,481
High enthalpy binary central power plant.	441,756,212
12 single Flash wellhead units with condensing turbine.	336,018,589
12 binary high enthalpy wellhead units.	435,569,994
12 single Flash wellhead units with back-pressure turbine.	169,715,609

For the financial projection, a plant life of 30 years with a capacity factor of 90% was considered (DiPippo, 2012). An electric power sale cost of 67 USD/MWh was estimated, based on conservative projections of the Colombian market and internal estimates of the company, CHEC EPM group (XM, 2020).

In this work, a sensitivity analysis of the Net Present Value (NPV) was also carried out, with the variation of the construction time of the generation system. For central plants this means, that only until this construction time is completed, the plant is commissioned and the useful life begins to run. In the case of wellhead plants, for example, when a construction time of 2 years is considered, it means that each of the 12 units had an individual construction time of 2 months, therefore, after the producing well is ready, every 2 months a wellhead unit comes into operation (construction time, divided by the quantity of wellhead units).

Figure 7 shows the behavior of the NPV, with the variation of the generation system construction time, for the single Flash central power plant with condensing turbine, the double Flash central power plant with condensing turbine and the high enthalpy binary central power plant.

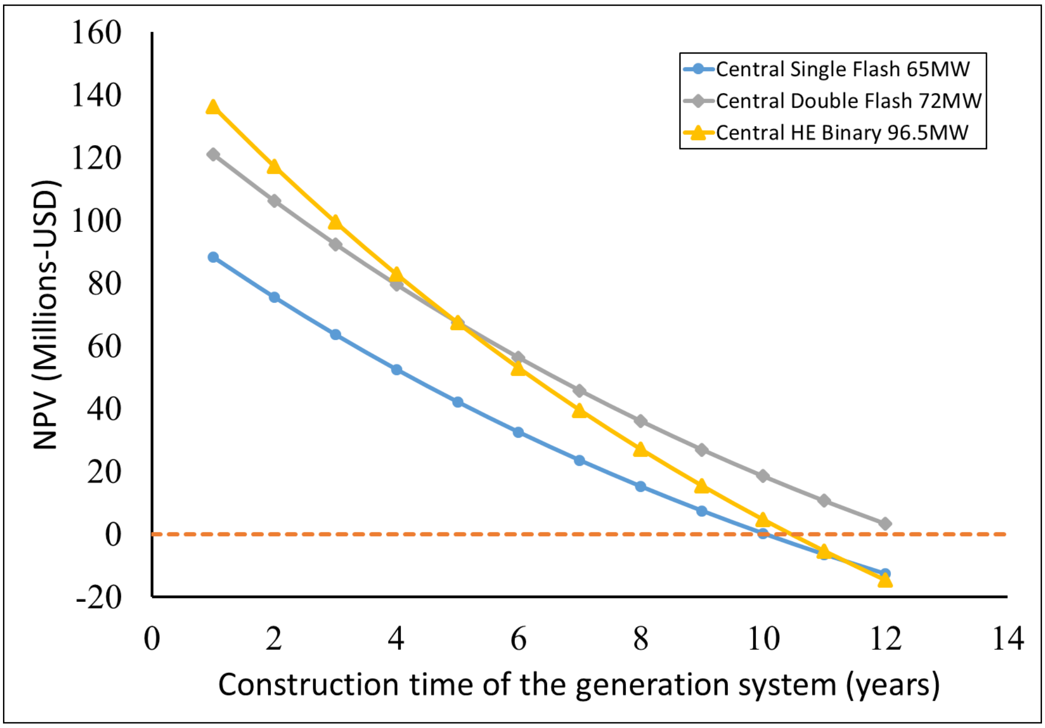

Figure 7: Behavior of the NPV with the variation of the generation system construction time, for the scenarios: single Flash central power plant, double Flash central power plant and high enthalpy (HE) binary central power plant.

The data in Figure 8 shows how the increase in the construction time of the plant can severely affect the NPV of the project, to the point of making it unviable (NPV <0). It is also interesting to see how these delays in the completion of the plant eliminate advantages that exist in short construction times, for example, the binary power plant is the most attractive when the construction time is less than 3 years, but when the time increases, the double flash plant has a better NPV.

Continuing with the analysis, Figure 8 shows the NPV values for the generation scenarios where the field is developed with single Flash wellhead units with condensing turbine, binary high enthalpy wellhead units and single Flash wellhead units with back-pressure turbine. The curve of NPV vs. construction time of the single Flash central power plant is show, to serve as a reference.

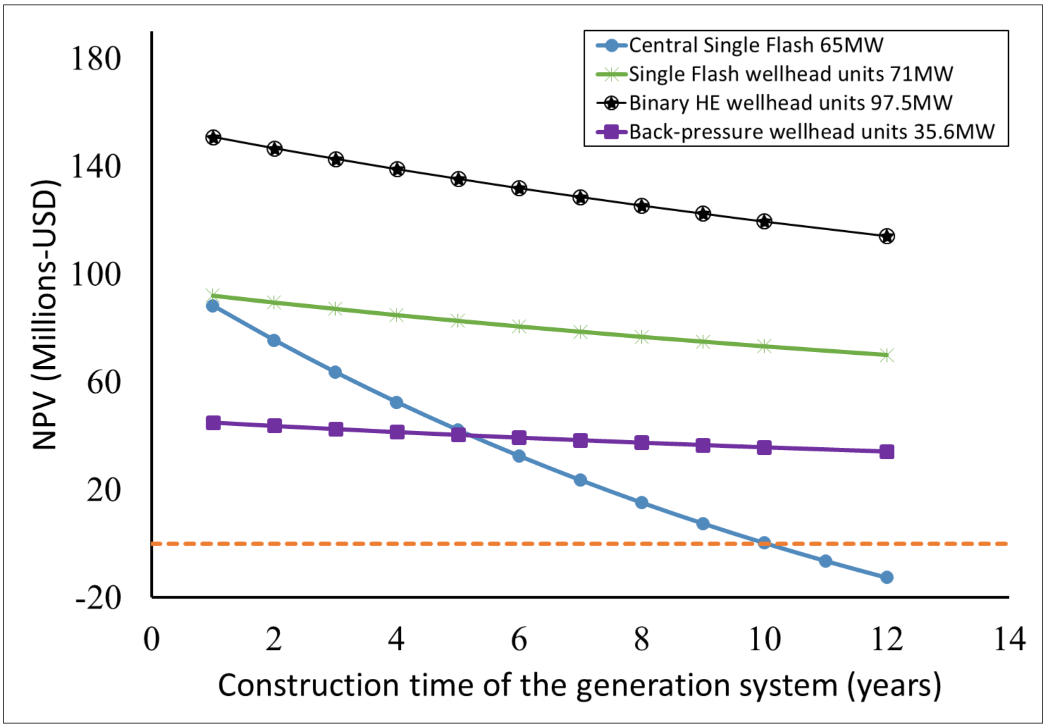

Figure 8: Behavior of the NPV with the variation of the generation system construction time, for the scenarios: single Flash central power plant, single Flash wellhead units with condensing turbine, binary high enthalpy wellhead units and single Flash wellhead units with back-pressure turbine.

Figure 8 shows how the NPV of wellhead systems are less sensitive to construction time, because the start-up is staggered. In contrast to this, the NPV of central plants is more sensitive to construction time, because any delay in the plant's entry into operation translates directly into a delay in the entry of the first project revenues (see Figure 8).

The results in Figure 8 show how in the case of wellhead system, the choice of generation technology is quite relevant. For example, more electricity is generated (97.5 MW) with the binary wellhead system, when compared to the single Flash wellhead plant system (71 MW), and that makes the binary plant system have a higher NPV. In addition, this advantage is practically maintained despite the increase in the construction time of the system.

Figure 9 shows the results of NPV vs. construction time for all scenarios. This figure can be used to select the type of generation system to be implemented, depending on the construction time that is established in the project execution schedule.

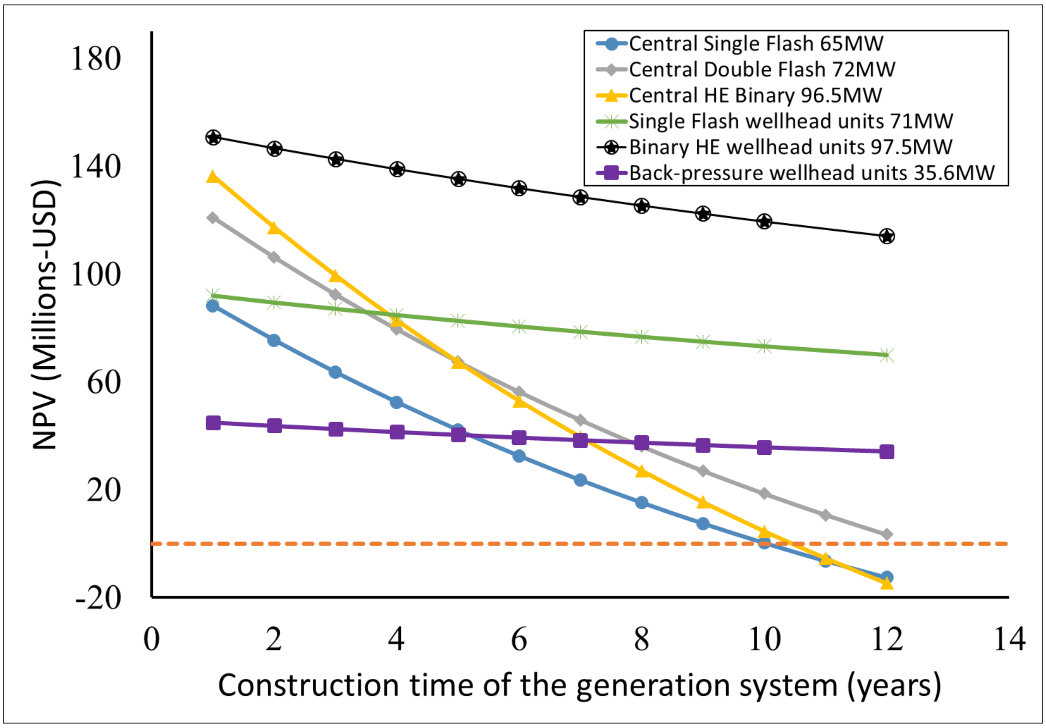

Figure 9: Behavior of the NPV with the variation of the generation system construction time, for all generation scenarios.

This analysis is relevant when choosing what type of electricity generation system to implement. Since in countries with little experience in geothermal energy, the construction time may be uncertain. For example, in the Cerro Pabellón project in Chile, the central power plant was put into operation approximately 5 years after several delays (high enthalpy binary central power plant, 48 MW) (Enel, 2012). Figure 9 shows that two wellhead systems could have been a better option in this case, as they have a higher NPV with a construction time of 5 years (binary and single flash with condensing turbine). Finally, it can be said that it is possible, taking into account that in the Olkaria field in Kenya, a total construction time of 4 years was reached for 14 wellhead units (about five single Flash wellhead units every 16 months, equivalent to 25 MW in total) (Chege, et al., 2017).

6. CONCLUSIONS

After having reviewed the history of the "Macizo Volcanico del Ruiz" geothermal project, it was observed that it has the state of the art in geothermal studies with satisfactory results, which allows continuing with the exploratory drilling phase (DiPippo, 2016).

The information presented in Figures 7, 8 and 9 shows how the construction time of the generation system becomes quite relevant when choosing the type of plant to be implemented in the project. Contemplating the possibility of delays or uncertainties about the execution of the construction stages, it may be better to implement systems with wellhead units that are not as sensitive to increased construction time.

The data presented not only shows the economic advantages generated by the inclusion of wellhead power units in geothermal projects, but also the increase in electricity production by optimizing the pressure-flow relationship of each well.

This work is currently under development, so further analysis is needed on the inclusion of modular wellhead plants in the "Macizo Volcanico del Ruiz" geothermal project.

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