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FINANCIAL EVALUATION OF CHACHIMBIRO GEOTHERMAL PROJECT IN ECUADOR

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ABSTRACT

In recent years, the Government of Ecuador has been implementing changes to the energy matrix, as oil consumption represents 76% of total energy use in the country. Hydropower is the second largest source of energy and only a small percentage can be attributed to other forms of renewable energy. Ecuador currently produces 89.16% of its electricity from hydropower, 9.86% from thermal sources which implies more fuel usage and 0.95% from non-conventional sources, which includes energy such as solar, wind and biomass.

In spite of the fact that around 90% of generated electricity is derived from renewables, there is a need to introduce an uninterrupted, or base load source of, energy such as geothermal, which is classified as a green energy source and would decrease the dependence on thermoelectric plants in the country.

In this study, a financial evaluation of the Chachimbiro geothermal project is carried out, being the first geothermal project to be developed in Ecuador. The project is managed, controlled and supervised by the government company CELEC EP. The study describes and analyses the costs, investment, market, prices, installed capacity, generation, conditions and a loan agreement which must be obtained to develop the project.

The project requires a total investment of 107 Million USD and includes two phases: (1) field study phase, this includes the drilling of 5 wells of which 4 are production wells and one a re-injection well, additionally there will be a wellhead of 5 MW; and (2) the construction phase that focuses on the construction of a 25 MW geothermal plant.

In order to determine the financial profitability of the project, financial tools such as the Net Present Value and the Internal Rate of Return were applied, the discount rate was established through the calculation of the weighted average cost of capital and finally the main results were obtained. These results show that the project is feasible.

1. INTRODUCTION

1.1 Background

According to the information shown in Figure 1, CENACE (Centro Nacional de Control de Energía) in its monthly management executive report dated June 2019 states that Ecuador produces 89.16% of its electricity from hydropower, 9.86% from thermal energy sources, and 0.95% from non-conventional sources which include solar, wind, and biomass. In addition, 0.03% of electricity is imported from Colombia (CENACE, 2019a).

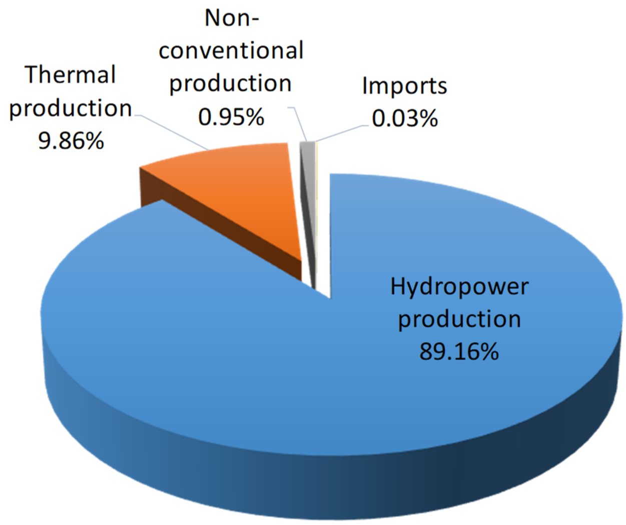

FIGURE 1: Net production of electricity in Ecuador (modified from CENACE, 2019a)

In total, renewables (hydropower and non-conventional sources) account for 90.11% of electricity generation, with associated reduction in pollution or contamination of the environment, replacement of excessive dependence on fossil fuels, reduction of environmental vulnerability and changes to the Ecuadorian energy matrix.

Ecuador's energy matrix is largely dependent on oil, which represented 76% of the country's total energy consumption in 2016, while hydroelectric power was the second-largest energy source. Natural gas and non-hydro renewable fuels account for the remainder of Ecuador's energy mix (US EIA, 2017).

To change the composition of the energy matrix in Ecuador, it has been necessary to identify energy sources that allow the generation of clean electricity. In the last 10 years, the government of Ecuador has given special attention to the non-conventional production of electricity using geothermal energy by reactivating investigations about the advantages of the geothermal resource and implementing the Geothermal Exploitation Plan headed by the Ministry of Electricity and Renewable Energy (MEER) (Beate and Urquizo, 2015).

Research for geothermal resources began in 2011, through the public company CELEC EP (Corporación Eléctrica del Ecuador), which hired the Ecuadorian company SYR (Servicios y Remediación S.A.) to perform initial pre-feasibility studies in the Chachimbiro geothermal prospect which consisted of surface geoscience studies such as gravimetry, magnetotellurics, magnetometry, micro-seismicity, geochemistry and geology.

After several studies in 2013, a geothermal conceptual model was obtained and it was recommended to drill a deep slim hole to verify the temperature gradient.

In 2014, the Government of Ecuador showed interest in accessing concessional loans from the Official Development Assistance loan (ODA) from the Government of Japan to develop the Chachimbiro geothermal project.

Thereby, in 2015, the Government of Japan through its International Cooperation Agency, JICA (Japan International Cooperation Agency), granted the Government of Ecuador its economic assistance through a non-reimbursable technical cooperation, financing the geoscience studies and the first deep exploratory drilling in Ecuador.

At the end of August 2017, Ecuador's first geothermal drilling began, which posed several technical and logistical challenges that were overcome. The drilling of well PEC 1 was completed on November 11, 2017, reaching a depth of 1978 meters, obtaining a temperature of 200°C and permeable rock.

Meanwhile, CELEC EP and JICA continued working on an evaluation mission required to obtain concessional credit for financing the field studies.

In order to perform the concessional credit analysis, involving the field study and construction phase of the Chachimbiro geothermal project, a financial evaluation must be carried out, including costs, conditions, and environmental impact.

1.2 Motivation

Geothermal energy is a clean energy which does not contaminate the environment and which is obtained from the internal heat produced by the earth and transmitted through hot rock, ensuring that the resource is maintained for a long period of time (Blodgett, 2014).

Geothermal energy is a resource capable of reliably providing energy long term and is considered as an alternative in Ecuador, not only for the generation of electricity, but also for direct use in communities that are near the Chachimbiro geothermal project. These communities make a living from industrial processes connected to the agricultural sector, which require energy. Furthermore, the availability of geothermal energy could enable the adoption of new industries in the future.

At a global scale, renewable energies contribute to the generation of jobs, the development of new technologies, and reduce emissions.

According to Gudmundsson (2019), geothermal energy accounts for 0.3% of world electricity generation, which is predicted to increase to 1% by 2030.

According to Morata (2018), Chile was the first country in South America to exploit geothermal energy for electricity generation on a commercial scale, with its first geothermal power plant, Cerro Pabellón, constructed in 2017. The plant was built 4,500 m above sea level.

Chile is a pioneering country in the development of geothermal energy and at the same time became a point of reference for South American countries that plan to develop geothermal energy. Chile's experience will be of great help both for Ecuador and other South American countries.

Now the Government of Ecuador is working on making changes in the energy matrix. Greater focus is given to the production of clean and renewable electricity to curb excessive dependence on fossil fuels and to reduce environmental vulnerability by developing renewable energies such as biomass, wind, solar and geothermal.

1.3 Objectives of study

1.3.1 General objective

The main objective of this project is to carry out the financial evaluation of the Chachimbiro geothermal project to enable the first geothermal exploratory drilling in Ecuador and to change the energy matrix.

1.3.2 Specific objectives

The specific objectives are:

- Define the main assumptions of the project;
- Establish the total investment cost of the project;
- Establish operation and maintenance costs;

- Apply financial tools such as Net Present Value and Internal Rate of Return;
- Obtain discount rate for capital and equity; and
- Analyse the main results obtained through Cash Flow, Balance Sheet, Financial Indices and Sensitivity Analysis.

1.4 Overview of the project chapters

After this introduction, Chapter 2 addresses the methodology used to examine all the factors that influence the financial evaluation of the Chachimbiro geothermal project, such as Net Present Value, Internal Rate of Return, discount rates and Sensitivity Analysis. Chapter 3 gives an overview of the project and highlights the renewable energy resources in Ecuador and the information about the project. Chapter 4 concentrates on describe the geothermal resource, former studies and their results, as well as environmental and social aspects of the project. Chapter 5 covers the financial evaluation of the Chachimbiro project with main assumptions such as: Investment costs, operation and maintenance cost, prices, sales, installed capacity and the main results. Chapter 6 is dedicated to risk analysis with the most important aspects being taken into account. In Chapter 7, other points of view concerning the environmental and social aspects are discussed. Lastly, Chapter 8 provides the conclusions.

2. METHODOLOGY

The methodology used to define the profitability of the Chachimbiro geothermal project includes the application of financial tools such as NPV, IRR, the establishment of the MARR discount rate by calculating the WACC, and finally the evaluation of the results obtained in the cash flow, balance sheet, its financial indices, and sensitivity analysis.

2.1 The Net Present Value (NPV)

Net present value (NPV) is the cash flows obtained from the difference between project revenues and project costs discounted at a discount rate over a given period of time (Björnsdóttir et al., 2016). The NPV is presented as follows:

$$NPV(i) = \frac{A_0}{(1+i)^0} + \frac{A_1}{(1+i)^1} + \cdots + \frac{A_N}{(1+i)^N} = \sum_{n=0}^{N} \frac{A_n}{(1+i)^n} \tag{1}$$

where A_n = Net cash flow at the end of period n;
i = Discount rate or Minimum Acceptable Rate of Return (MARR); and
N = Service life of the project.

Through the calculation of the NPV, it will be possible to identify if the Chachimbiro geothermal project is viable and if the investment is acceptable or not:

If NPV(i) > 0, accept the investment;
If NPV(i) = 0, remain indifferent to the investment; and
If NPV(i) < 0, reject the investment.

2.2 Internal Rate of Return (IRR)

According to Björnsdóttir et al. (2016), the IRR is the return on capital invested, i.e. the rate that sets the investment equal to zero. It is indicated as $i*$.

The IRR is equal to the rate of return which satisfies the following equation:

$$NPV(i^*) = \sum_{n=0}^{N} \frac{A_n}{(1 + i^*)^n} = 0 \tag{2}$$

Investors generally want to maximize their profits. Their investment policy usually defines a MARR in which case the IRR and the MARR can be used to decide whether a project is feasible or not.

The criteria to decide whether to invest or not are the following:

If IRR > MARR, accept the project;
If IRR = MARR, remain indifferent; and
If IRR < MARR, reject the project.

According to Björnsdóttir et al. (2016), the Modified Internal Rate of Return (MIRR) method does not reinvest all cash flows at the calculated IRR, but all cash flows are reinvested at another rate, that is an external rate of return, and its calculation is done by means of a spreadsheet tool, which is a financial function that returns the modified internal rate of return for a series of cash flows.

The decision rule for MIRR is as follow:

If MIRR > cost of capital, accept the project;
If MIRR = cost of capital, remain indifferent; and
If MIRR < cost of capital, reject the project**.**

2.3 MARR – Equity

For the calculation of the minimum acceptable rate of return on equity, the weighted average cost of capital (WACC) is estimated using the instructions of CONELEC (Consejo Nacional de Electricidad), regulation No. 003/11 (CONELEC, 2011), which establishes a minimum acceptable rate of return of 13%, which is the profitability expected by the owners of the project.

2.4 MARR - Capital

For the calculation of the MARR for the entire project (capital), the method for calculating the weighted average cost of capital (WACC) is applied.

According to Björnsdóttir et al. (2016), to calculate the $WACC$, it is necessary to multiply the cost of each capital component by its proportional weight and take the sum of the results.

The WACC is calculated as follows:

$$WACC = \frac{E}{V} \times Re + \frac{D}{V} \times Rd \times (1 - Tc) \tag{3}$$

where Re = Cost of equity;
Rd = Cost of debt;

E	= Market value of the project equity;
D	= Market value of the project debt;
$V = E + D$	= Total market value of the project financing (equity and debt);
E/V	= Percentage of financing that is equity;
D/V	= Percentage of financing that is debt; and
Tc	= Tax rate.

With the application of the WACC method and with the data mentioned above, the proportional weight for equity and the proportional weight for debt is 30% and 70%, respectively, which in the case of the Chachimbiro project can be expressed as the percentages financed by CELEC EP (Corporación Eléctrica del Ecuador) (30%) and JICA (70%). To each of these portions, the interest rate of cost of equity and debt is applied. Using the WACC method, the MARR for the total project is calculated as 6.5%.

2.5 Sensitivity analysis

Sensitivity analysis is a tool to estimate how much the output values vary in relation to a given change in input parameters, helping decision-makers to make informed decisions.

In the evaluation of the Chachimbiro geothermal project it was calculated how the IRR and the NPV changed in relation to modifications of the input parameters of the sale price, the quantity of sale and the investment cost of buildings, and operation and maintenance costs.

Therefore, since there are no variable costs but only fixed costs, both the price and the amount of sales are charted on the same line.

Based on Björnsdóttir et al. (2016), the most effective way to present the results of the sensitivity analysis is to draw sensitivity graphs. All variables are plotted on the same graph, each as a separate line. The slopes of the lines show how sensitive the output is to a change in each variable; the steeper the slope, the more sensitive the result is to a change in a particular variable.

3. OVERVIEW OF CHACHIMBIRO PROJECT

In this chapter, renewable energy resources in Ecuador and the Chachimbiro geothermal project are described.

3.1 Renewable energy resources in Ecuador

The National Assembly of Ecuador (2015) made reference to article No. 15 of the Constitution of the Republic of Ecuador (2008), which declares that the Ecuadorian state will promote, in the public and private sectors, the use of environmentally clean technologies and alternative, non-polluting and low-impact energy, which translates into efficient use of energy and the use of existing renewable resources.

The Government of Ecuador's objective is to reduce the consumption of fossil fuels such as gasoline, diesel oil, fuel oil and reduced crude oil, which are used for thermal generation, through the construction of new hydroelectric power plants and the development of renewable energy projects such as solar-photovoltaic and wind energy. This will help to reduce pollution of the environment, because these resources are considered unlimited for their ability to regenerate by natural means.

CENACE (2019a) demonstrates that the production of electricity in Ecuador comes largely from hydroelectric production (89.16%), while 9.86% is thermoelectric energy which uses fuel. The remaining 1% are generated from non-conventional energy sources such as solar, wind, and biomass.

The renewable energy projects that are going to be developed in Ecuador are shown in Table 1.

TABLE 1: Renewable energy projects in Ecuador (Enith Carrion, National Coordinator of Renewable Energy Projects, CELEC EP, personal communication, August 20, 2019)

Name	Technology	Power MW
El Aromo	Photovoltaic	200
Villonaco I and II	Wind	110
Bloque de ERNC	Renewable	200
Cardenillo	Hydroelectric	596
Ciclo Combinado Gas Natural	Thermoelectric	1000
Santiago	Hydroelectric	2400

3.2 General information about the Chachimbiro geothermal project

Ecuador is located in the Pacific Belt of Fire, where seismic and volcanic activity is concentrated, so all the geological features of the territory are caused by significant anomalies of terrestrial heat flow.

In the 70s and 90s, through private and state initiatives, the two institutions OLADE (Latin American Energy Organization) and INECEL (Ecuadorian Institute of Electrification) carried out preliminary research to evaluate the potential of various geothermal areas including the Chachimbiro geothermal prospect (Pilicita, 2016).

In 2008, the Ecuadorian government, through its Ministry of Electricity and Renewable Energy (MEER), took up research related to geothermal resources, leading to the Geothermal Plan for Electricity Generation, which was launched in 2010. In 2014, the Government of Ecuador showed its interest by accessing concessional loans, namely the Official Development Assistance (ODA), for the development of the Chachimbiro geothermal project. One year later, in 2015, the Government of Japan, through JICA, granted the Government of Ecuador financial assistance through a non-reimbursable technical cooperation of about 8 Million USD.

At the end of August 2017, the first geothermal drilling started as shown in Figure 2. The well reached a depth of 2000 meters and a temperature of 200°C was documented (CELEC EP, 2017).

FIGURE 2: First geothermal drilling in Chachimbiro project (CELEC EP, 2017)

The Ministry of Electricity and Renewable Energy considers in its Electricity Master Plan 2016-2025 to reactivate and diversify the energy matrix, including the contribution of non-conventional renewable energies such as geothermal, solar, wind and biomass, which reduces the use of energy from fossil fuels that can contaminate the environment (MEER, 2017).

The next step after verifying the resource in Chachimbiro is a field study to evaluate the potential of the existing geothermal resource, to define the design of the power plant, and to seek funding from the Government of Japan through its International Cooperation Agency.

3.3 Location of Chachimbiro geothermal project

The Chachimbiro geothermal project is located in Ecuador, South America (Figure 3), and is the first geothermal project to be developed in the country.

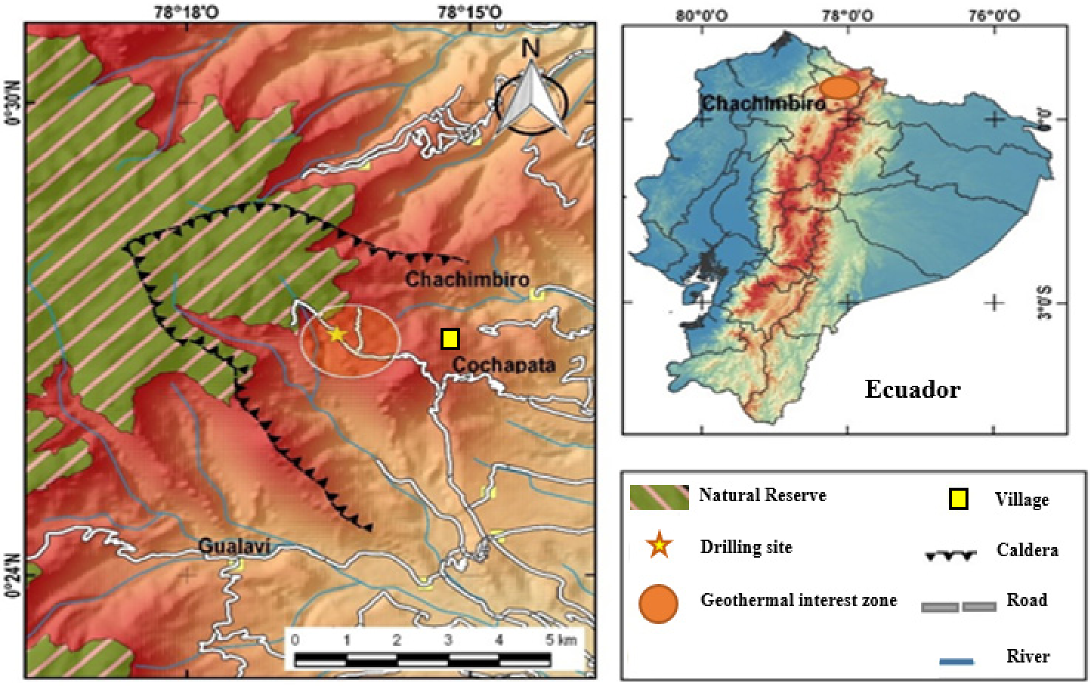

FIGURE 3: Location of the Chachimbiro geothermal project (modified from Lloret et al., 2015)

According to Pilicita (2016), the project is located on the eastern slopes of the western mountain range, approximately 70 km north of Quito, Ecuador's capital, and about 18 km west of Ibarra, which is the nearest major city centre. The area is bounded to the North by the Chota Basin, to the East by the inter-Andean Valley and to the South and West by Cotacachi and Yanahurcu de Piñan volcanoes, respectively.

4. INFORMATION RESOURCES FOR THE CHACHIMBIRO PROJECT

This section describes the results of the geothermal resource evaluation, the studies and their results obtained before and after the drilling and the potential social and environmental impacts of the project.

4.1 Geothermal resource evaluation

The project is located in the Chachimbiro volcanic complex at approximately 3,525 meters above sea level. There are geothermal manifestations in the form of hot springs, gas emissions and zones of hydrothermal alteration.

In the years 2011-2012, CELEC EP contracted the consulting firm Servicios y Remediación S.A. to carry out the initial pre-feasibility studies for the Chachimbiro geothermal project, which consisted of research work to develop geological, geochemical and geophysical surface studies. According to Beate and Urguizo (2015), the results of these studies are as follow:

- Several mixed chloride bicarbonate hot springs with temperatures above 61°C are found in the area.

- The Quaternary volcanic history indicates a magmatic heat source of long life and evolution. This activity dates back to 500.000 years ago, which is the age of the Huanguillaro andesitic lava flows.
- The youngest activity is the formation of a satellite dome 5,800 years ago, which is located on the lower flanks of the volcano in its North-East.
- The fractures show a structural regime that could provide a favourable environment for the development of a network of highly permeable fractures.

In 2016, a pre-feasibility study of the Chachimbiro geothermal project was initiated with the support of the Japan International Cooperation Agency, which contracted the Japanese Consortium Mitsubishi Materials Techno Corporation (MMTEC).

Finally, from August to November 2017, through the JICA-CELEC EP agreement, the first geothermal well called PEC 1 was drilled in Ecuador.

4.2 Studies and results achieved

After the drilling of a 1978 m deep exploratory well, it was necessary to wait three months for the well to recover and several tests were conducted to measure the pressure, temperature and flow rate.

At the beginning of the drilling activities a large diameter drill bit of 13 ⅜ inches was used and at the end of the drilling the drill bit was 4 ½ inches in diameter. The drill rig had a capacity of 1000 HP (Francisco Astudillo, Specialist Project, Project Department CELEC EP, personal communication, August 25, 2019).

According to Asimbaya (2018), the well encountered four major stratigraphic zones. An argillic alteration zone was identified at shallow depth until at a depth of approximately 1000 m epidote crystals began to appear. From 1200-1978 m, the drilling continued with total loss of circulation. Finally, in the first quarter of 2018, the temperature log indicated a temperature of 200°C close to the bottom of the well.

From the results, it can be concluded that there is a geothermal resource in the Chachimbiro geothermal area, since the main parameters, such as temperature and permeability, have been confirmed.

The next phase of the project consists of drilling 5 wells – that is 4 production wells and 1 reinjection well to determine the characteristics of the geothermal reservoir.

4.3 Social considerations

In the context of the pre-feasibility studies of the Chachimbiro geothermal project, an Environmental Management Plan (EMP) was developed that contained the Community Relations Plan in order to carry out certain activities with the communities close to the project.

There are several communities in the area close to the geothermal prospect with the Azaya and Cochapata communities being the closest.

It was estimated that the Azaya community has around 85 families with approximately 330 people, and the Cochapata Community 25 families with approximately 80 people. The predominant economic activity in these communities is agriculture (Municipality of San Miguel de Urcuquí, 2019).

The activities outlined in the Community Relations Plan were performed based on the environmental registry No. 221218 granted by the Ministry of the Environment.

The activities detailed in the Community Relations Plan are as follows:

- As far as possible, personnel from direct influence area will be hired;
- CELEC EP will provide the owners' authorization for land use to the contractors;
- Meetings will be organized with local leaders prior to the start of work;
- The work places, profiles and services required will be identified with the contractor;
- Activities with public institutions in the areas of health, education and social welfare will be organized;
- Community initiatives in areas such as sanitation, education, and health will be supported on the basis of an allocated budget;
- Houses or hostels that are near the site of Chachimbiro project will be rented for staff thar are going to work in the project; and
- Community environmental care talks will be provided.

The activities that stand out are the following:

The participation of the community in the development of the works has generated 26 direct jobs and 16 jobs performing works such as maintenance of the road, as rangers, or in construction of the project. Further, a group of women from the Azaya community organized and provided food services to the entire team of the Chachimbiro geothermal project.

Workshops were held on tax education, food handling and hygiene as well as training on contracts and workers' rights. Four comprehensive health and dental campaigns were carried out through the Ministry of Public Health and Urcuquí Health Sub Centre, providing care to approximately 110 families in the communities of Azaya and Cochapata.

Through the Social and Environmental Management Department of CELEC EP, environmental training talks were given to the children of the Azaya and Cochapata communities.

An important player is the Yachay Tech University, which is close to the project area and is interested in the continuation of the project, since the university has a geoscience faculty that participates in research programs in the project.

The municipality and local authorities are supporting the project, as well as firefighters, police and local organizations.

4.4 Environmental aspects

During the construction stage and the exploratory drilling of the well, JICA, through the company Mitsubishi Materials Techno Corporation, was in charge of monitoring and complying with the Environmental Management Plan.

On the other hand, according to Ecuadorian regulations about environmental permits, the Ministry of Environment of Ecuador (MAE) states the following: Environmental regulations do not establish environmental regularization of exploratory phase of these kind of projects, of which pre-feasibility and field studies are still required before a decision is made on the construction of geothermal plants. However, the inclusion of good practices and/or Environmental Management Plans are necessary (MMTEC, 2018).

That means that for projects of less than 10 MW or projects in the research stage such as the Chachimbiro geothermal project, it is not necessary to apply for an environmental license, but it is necessary to develop an Environmental Management Plan, which must be reported annually to the environmental authority for information delivery and compliance activities.

According to MAE (2017), the Environmental Management Plan of the Chachimbiro geothermal project is described in the Environmental Registry No. 221218 issued by the Ministry of Environment of Ecuador.

During the pre-feasibility studies phase of the project, it is necessary to comply with the items detailed in Table 2:

TABLE 2: Environmental Management Plan (EMP) for Chachimbiro geothermal project

No.	Items included in EMP
1	Closure plan, abandonment and delivery area
2	Communication and training plan
3	Contingency plan
4	Waste management plan
5	Monitoring and follow-up plan
6	Impact prevention and mitigation plan
7	Rehabilitation plan
8	Community relations plan
9	Occupational health and safety plan

For the field development and construction phase of the 20 MW power plant in the Chachimbiro geothermal project, it is required to obtain an environmental license and make an environmental impact assessment in accordance with JICA guidelines and Ecuadorian laws/regulations.

The preparatory studies for the construction of the Chachimbiro geothermal plant described by MMTEC (2019) detail the environmental impact assessment that has to be carried out, based on the scope of work listed below:

- Confirmation of institutions and organizations related to environmental and social considerations in Ecuador (laws and standards related to EIA, resettlement, gender etc. and gap analysis, roles of each organization).
- Confirmation of project sites from environmental social viewpoints (land use, resettlement etc.).
- Preparation of draft scoping assessment.
- Data collection for impact assessment and monitoring.
- Public consultations.
- Impact assessment and comparative analysis of alternatives.
- Analysis of mitigation measures.
- Elaboration of monitoring plan.
- Preparation of environmental checklists attached to the JICA guidelines (1. geothermal power plant, 2. power transmission and distribution lines).
- Preparation of the draft action plan for resettlement.
- Stakeholder meetings.

5. FINANCIAL ANALYSIS OF THE CHACHIMBIRO PROJECT

In this section the Financial Evaluation of the Chachimbiro Project is presented based on main assumptions such as: Investment costs, operation and maintenance costs, price, sales, and installed capacity.

The profitability model developed by Jensson (2006) is used for the evaluation. The model consists of different excel spreadsheets for summary, investment, operations cash flow, balance, profitability and charts to visualize: Net Present Value, Internal Rate of Return, Cash Flow and Impact Analysis.

Once the main assumptions of the project have been determined, the financial evaluation is carried out applying financial tools such as Net Present Value and the Internal Rate of Return (see Sections 2.1 and 2.2) to estimate the profitability of the project.

5.1 Market survey

Ecuador depends heavily on hydroelectric power generation, which accounts for 89.16% of the current electricity consumption. In order to meet the country's demand for electricity, which is increasing at a rate of about 5% every year, the Government of Ecuador has started to introduce alternative renewable energy resources like geothermal energy, with the aim to reduce the fluctuations of rainfall dependent hydroelectric power supply, as well as to diversify electric energy sources.

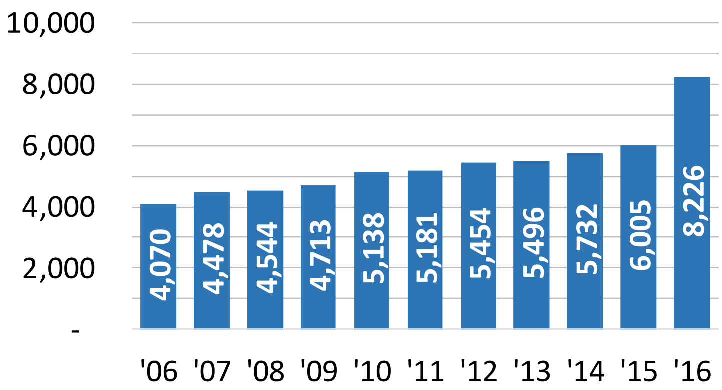

FIGURE 4: Installed capacity in Ecuador 2006-2016 (MW) (modified from MEER, 2017)

The Ministry of Energy and Renewable Energy states in its Electricity Master Plan that in the last 10 years the electricity sector in Ecuador has doubled the installed capacity (Figure 4) from 4,070 MW in 2006 to 8,226 MW in 2016, with the construction of hydroelectric power plants and by replacing 600 MW of thermal energy with the increasing potential of renewable sources of energy (MEER, 2017).

Consequently, renewable energy sources in Ecuador represent 56.41% of the total installed capacity, or 4,640 MW in terms of power, while non-renewable energies account for 43.59% or 3,586 MW.

According to information presented by MEER (2017), the maximum energy demand is 44% of the total installed capacity, requiring 3,653 MW in 2016. For the 56% surplus, the Ecuadorian Government has proposed a program to change the Energy Matrix that includes the substitution of stoves that use liquefied petroleum gas LPG for the massive introduction of electric stoves, electric water heating equipment, the Quito Subway, the Cuenca tramway, as well as reserves to cover low water periods.

The period from October to March is characterized by little rainfall and inevitably requires thermal power generation, which means the use of fossil fuels to ensure energy supply. This source of energy is costly and polluting. Therefore, the Government of Ecuador demands the development of geothermal energy.

Ecuador produces energy from renewable sources, most of which is hydropower. The Government of Ecuador seeks to strengthen its energy matrix by expanding renewable energy sources with the use of clean energy such as geothermal energy.

5.2 Main assumptions

For the financial evaluation of the Chachimbiro geothermal project, it is estimated that the field study and the construction of the plant will be completed within 6 years (2020 to 2025).

The project plan includes the drilling of 5 wells, of which 4 are production wells and 1 a re-injection well. Additionally, there will be a wellhead of 5 MW, so the total installed capacity will be 25 MW.

The investment costs can be divided into 3 groups: Buildings, equipment, and other. The planning horizon is 30 years.

Income tax and depreciations are estimated according to Ecuadorian legislation in force, so that the depreciation percentages for buildings, equipment and other are 5%, 10% and 20%, respectively, and the income tax is 22%.

The MARR for equity and MARR for total capital are established at 13% and 6.5%, respectively, in accordance with the coverage in Sections 2.3 and 2.4.

5.3 Investment cost

The investment cost is divided into the field study phase and the construction phase. The investment for the field study starts in 2020 and ends in 2022, while the investment for the construction phase starts in 2023 and ends in 2025.

Investment costs include civil works, electromechanical equipment, production test, land acquisition, drilling service, wellhead power plant of 5 MW, transmission lines and construction of the power plant of 20 MW.

The total investment cost for the Chachimbiro geothermal project is 106.81 Million USD and is shown in Table 3.

TABLE 3: Investment costs for the Chachimbiro geothermal project

Costs	**Field study phase**			**Construction phase**			**Total MUSD**
	2020	**2021**	**2022**	**2023**	**2024**	**2025**	
Equipment	20.95	6.66	13.19	3.00	3.00	2.64	49.44
Buildings	0.49	0.99	0.99	10.14	10.14	9.22	31.96
Other	8.21	4.40	4.11	4.25	1.90	2.53	25.40
Total investment cost							**106.81**

5.4 Operation and maintenance costs

The operation and maintenance costs are estimated to be 1% of the total investment.

5.5 Installed capacity and generation

According to data provided by Vargas and Püschel (2016), the Cerro Pabellón power plant has a plant factor of 95% and a maintenance period of 2 weeks per year.

Taking this information as a reference, a plant factor of 95% is estimated and a maintenance period of 18 days per year.

The Chachimbiro geothermal power plant will produce 347 days multiplied by 24 hours multiplied by 25 MW: A total of 197.79 GWh annually.

5.6 Price

According to information from ARCONEL (Agencia de Regulación y Control de Electricidad) in its Executive Accountability Report 2018, the current electricity price in Ecuador is on average 3.11 UScents/kWh (ARCONEL, 2019).

CENACE (2019b) in its internal report on Variable Production Costs establishes that the cost of generating energy with thermal plants ranges from 3.5 to 15 US cents/kWh, while ARCONEL (2018) in its report (Analysis and Determination of Electric Energy Public Service Cost) established that the energy produced from water resources fluctuates between 1 and 2.3 US cents/kWh.

Considering the tariff range of hydro and thermal generation, the Chachimbiro geothermal project tariff is determined to be 7 US cents/kWh.

5.7 Loan

The financial structure is as follows: CELEC EP will invest 30% and JICA will finance 70% by means an official development assistance loan. The project will have an interest rate of 1.5%, a loan management fee of 0.2%, a grace period of 10 years and a repayment period of 20 years.

5.8 Main results

In this section the profitability model described by Jensson (2006) is applied to the Chachimbiro geothermal project. The results are based on the Net Present Value and Internal Rate of Return, which are indicators that allow the determination of project feasibility.

The investment required for the project is 106.81 Million USD, allocated as follows: 49.44 Million USD for equipment, 31.96 Million USD for buildings, and 25.40 Million USD for other investment costs. A fixed cost of 1.07 Million USD annually and a tariff allocation of 7.00 UScents/kWh are assumed. The project will require an additional investment in working capital during the first year, estimated at 5 Million USD. See Appendix I for detailed information on the Financial Evaluation of the Chachimbiro geothermal project.

Figure 5 shows the cash flow of the project, which is negative during the first six years due to the purchase of: Materials, drilling services, production tests, wellhead power plant of 5 MW, civil works, transmission lines, land acquisition, pipelines and construction of a 20 MW power plant.

After the investment years, in 2026, Total Cash Flow and capital will have positive inflows. With positive cash inflow, the loan can be covered in total. In accordance with the chart, it is possible to service the loan before the end of the 20 years period because the Total Cash Flow and capital will cover the Net Cash Flow and equity.

The Chachimbiro geothermal project cash flow will be higher in 2035. The Cash Flow and capital is 12 Million USD and the Net Cash Flow and equity is 7 Million USD. In 2054, the Cash Flow and capital will be 10 Million USD and Net Cash Flow and equity will be 6 Million USD. Therefore, it will be possible to service the loan quickly.

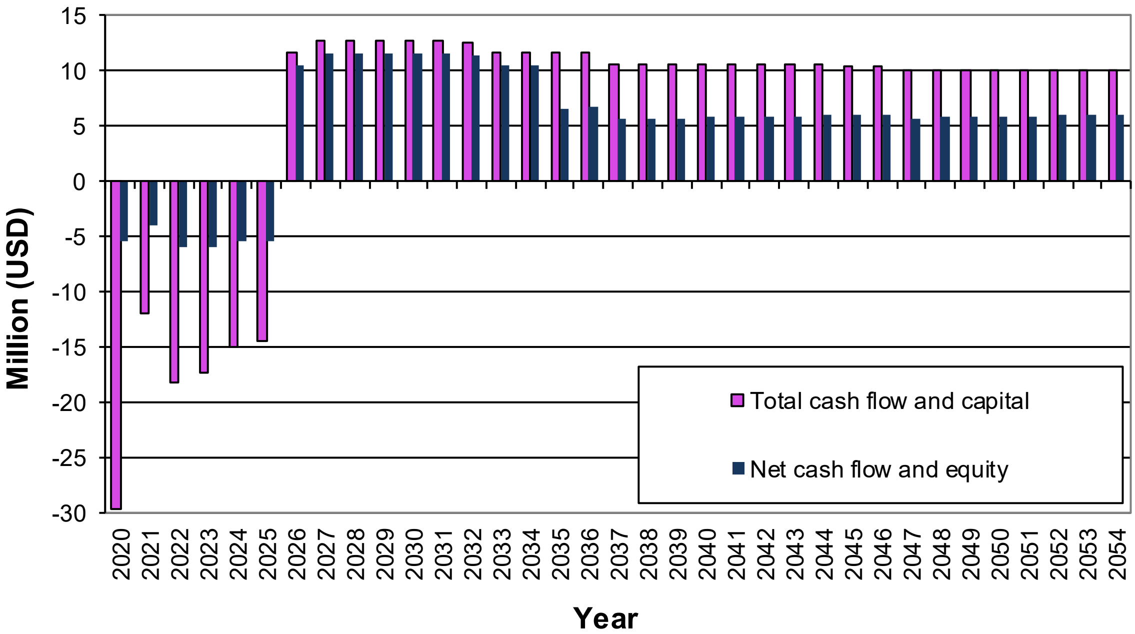

FIGURE 5: Cash flow of the Chachimbiro geothermal project

The main results of the financial analysis of the Chachimbiro geothermal project are shown in Table 4.

TABLE 4: Main results for Chachimbiro geothermal project (MUSD)

Profitability model	Total capital	Equity
NPV of cash flow	15	54
Internal rate of return	8%	20%
External rate	7%	15%

The main results obtained for the Net Present Value and Internal Rate of Return are analysed with the following charts.

In Section 2.1 the Net Present Value was discussed together with the criterion to determine whether the project is feasible or not.

As seen in Figure 6, NPV of Net Cash Flow for the equity is recovered quickly, because four years after the power plant construction, in year 2029, the cash flow will be positive. The overall result for the NPV with a discount rate MARR for equity of 13% is 54 Million USD which means that the NPV > 0 and that the project is feasible.

The NPV for the total capital with a discount rate MARR of 6.5%, even though it takes a long period to recover, will reach 15 Million USD.

Figure 7 shows the IRR of the Total Capital which is 8% and for the IRR of equity which is 20%. These values are higher compared to the MARR for Total Capital and MARR for equity which are 6.5% and 13%, respectively. The higher the IRR of a project, the more attractive it is to the investors.

The outcomes for the Chachimbiro geothermal project are: the MIRR for Total Capital is 7% and MIRR for Equity is 15%. These results are higher than the MARR for equity and MARR for total capital. Therefore, the project is feasible.

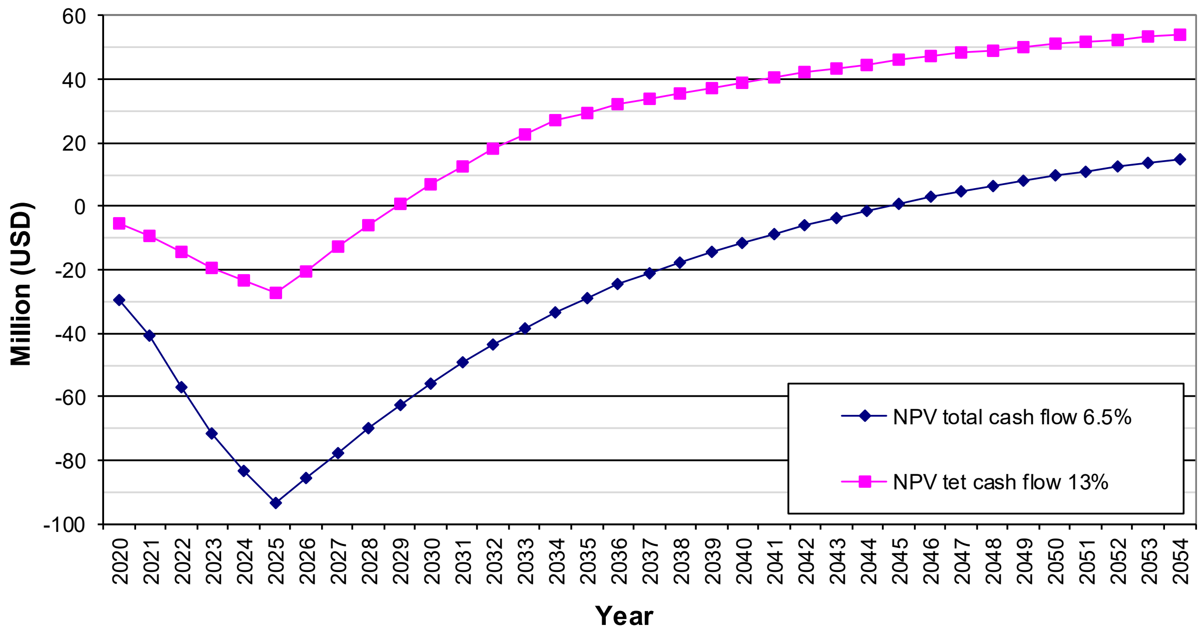

FIGURE 6: Net Present Value for the Chachimbiro geothermal project

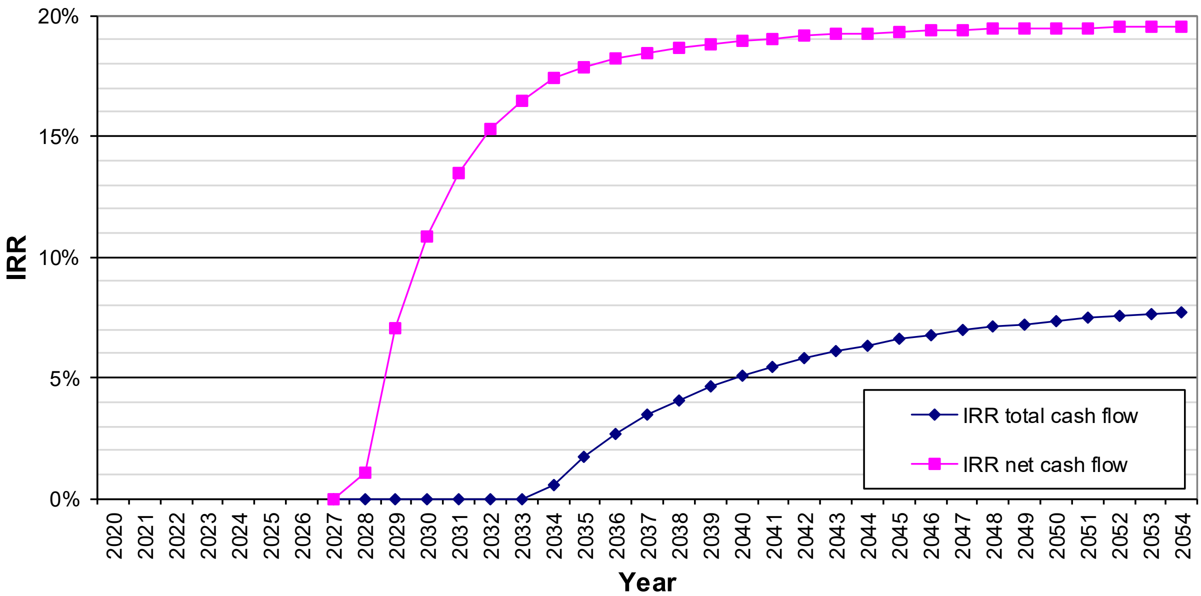

FIGURE 7: Internal Rate of Return for the Chachimbiro geothermal project

5.9 Impact analysis

According to the Asian Development Bank (ADB, 1999), sensitivity analysis is a tool to determine how sensitive the Net Present Value and Internal Rate of Return are to variables such as costs, prices or sales.

As part of this financial assessment for the Chachimbiro geothermal project, the sensitivity analysis was carried out to determine the sensitivity of the IRR for equity to a given change in input parameters such as price, sales quantity, O&M, buildings and equipment costs. The results are shown in Figure 8.

In order to facilitate decision-making, this sensitivity analysis identifies the variables that most affect the economic outcome of the project, as well as the variables that have little impact.

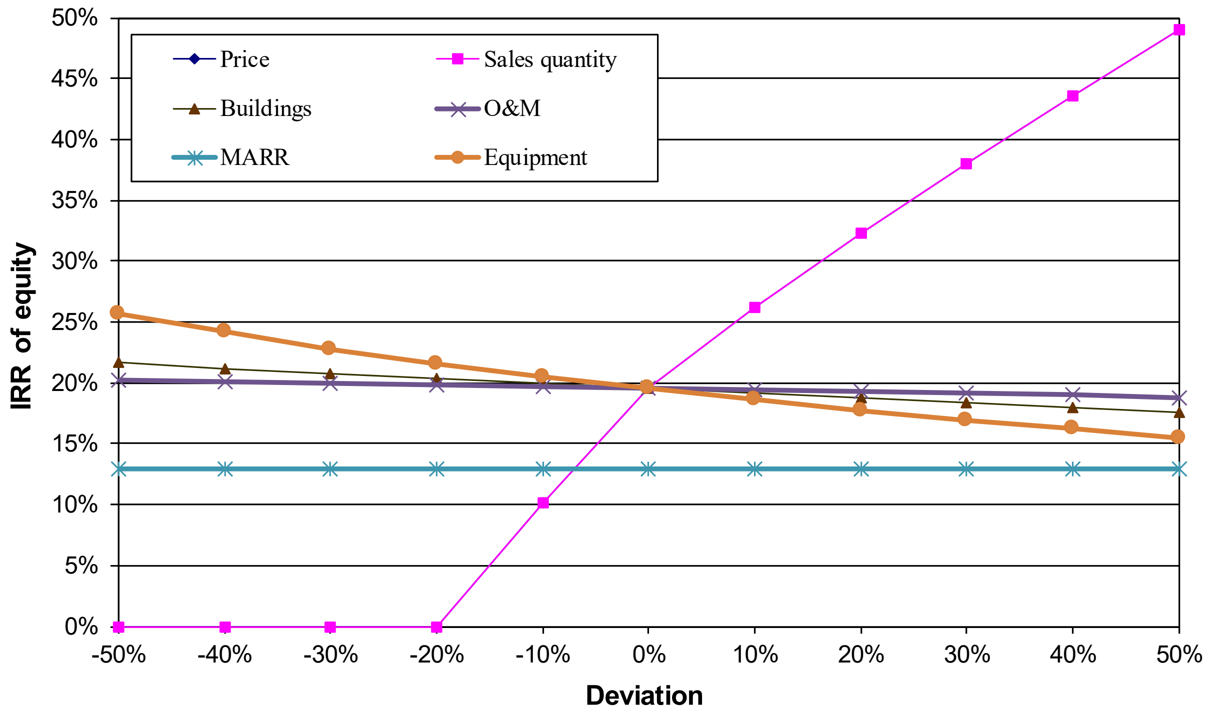

FIGURE 8: Sensitivity analysis for the Chachimbiro geothermal project

The price and the sales quantity are in the same line because there are no variable costs as shown in Figure 8. The line of price and sales quantity is the steepest in comparison to the lines of the other variables (buildings, equipment and O&M).

The project is sensitive to the price and sales quantity. If the quantity decreases by 10%, the IRR for equity decreases from 20% to 10%, which means that it falls below the MARR for equity, which is 13%. The maximum acceptable decrease in the two variables, price and sales quantity, is 7% in order to obtain at least 13% MARR for equity. On the other hand, when the price and sales quantity increase by 10%, the IRR for equity increases from 20% to 26%, which is well above the MARR for equity of 13%.

The project is insensitive with regard to an increase or decrease in building, equipment and O&M costs. The values remain above 13% MARR for equity.

As shown Figure 8, if the investment cost for buildings, equipment and O&M increases by 10%, the IRR for equity decreases from 20% down to 19%, which is still above the 13% MARR for equity.

However, if the investment cost for buildings, equipment and O&M decreases by 50%, the IRR for Equity is 22%, 26% and 20%, respectively. All these are well above 13% MARR for equity, which means that the IRR is insensitive to these variables.

6. RISK ANALYSIS FOR THE CHACHIMBIRO PROJECT

In this chapter, the risk matrix for the Chachimbiro geothermal project is developed, including the main criteria that the matrix must contain.

The risk matrix is a tool that details in an organized manner the activities of an organization, the level of risk and the controls that will be applied to mitigate the risk, constituting a monitoring and control tool for project management (Dumbrava and Severian Iacob, 2013).

6.1 Matrix of risk analysis

In the risk matrix of the Chachimbiro geothermal project, two factors are applied to measure risk: Probability and impact. The probability and impact variables correspond to one of the qualitative methods of risk assessment titled the impact probability matrix (Dumbrava and Sverian Iacob, 2013). For the evaluation of the possible risks that could arise in the project, a scale of values assigned to both the probability factor and the impact factor was determined as shown in Figure 9.

Risk matrix			**Probability**			
			Low	**Possible**	**High**	**Very high**
			1	**2**	**3**	**4**
Impact	**Severe**	**4**	4	8	12	16
	Critical	**3**	3	6	9	12
	Moderate	**2**	2	4	6	8
	Minor	**1**	1	2	3	4

FIGURE 9: Risk zone assessment matrix for the Chachimbiro geothermal project

The values in the green zone are considered risks of minor impact and it is possible to evaluate the risk, the yellow zone represents an area that corresponds to a moderate risk where the risk can be evaluated and reduced, the critical zone is in the range of 8 to 12 and is an area of high risk in which the risk should be reduced, avoided or transferred. Finally, the zone of extreme risk corresponds to the cell in red colour and describes an event with high probability and whose impact is severe. The response is to reduce the risk, avoid it or transfer it.

Once the variables in the risk matrix have been defined, the different areas involved in the project are analysed, both in the field development phase and the construction phase of the project.

The criteria that have been analysed are: Technical aspects of the field study, finance, cost, political, legal and environmental aspects. They are presented as a summary shown in Figure 10. See Appendix II for detailed information on the risk matrix of the Chachimbiro geothermal project.

		Probability			
		1	**2**	**3**	**4**
Impact	**4**	10. Equipment cost increase 17. Permit for using water	4. Production rates decline faster 11. Define the suppliers 12. Permit for exploration – Field study 13. Permit for using land		19. Fuel spillage during drilling
	3	16. Environmental license	2. Steam flow 9. Drilling service increases the price	3. Scaling and corrosion 5. Drilling	20. High H_2S conc.
	2	14. Regional government 15. Lack of political support for geothermal project	1. Low thermal gradient of drilled wells 6. Project funding by Gov't 21. Earthquakes at any stage	7. Project int'l funding 23. Health risk due to high altitude	
	1		8. Prioritization of other kind of technologies 18. Environmental aspects 22. Local communities around the project		

FIGURE 10: Summary risk matrix for the Chachimbiro geothermal project

The analysis shows that the risks of low impact and probability are related to problems in obtaining the consent of the regional government and the communities close to the project. Additionally, it will be important to carry out an environmental and social impact assessment (ESIA) for the field study phase. This includes all the environmental and social criteria that have been requested by the JICA. Another risk is a change of authorities in the Ecuadorian government or within the company CELEC EP that do not support the renewable energy project. For the risks that are considered low impact, the risk treatment plan is to promote renewable energy because it is a clean energy and to present the project via adequate communication.

Moderate risks that would produce medium consequences or effects have also been considered. In the field study phase, it is possible that after drilling 5 wells, the maximum temperature of 200°C may not be found, or that there is not enough steam flow. The project may experience funding difficulties due to lack of budget for the development of geothermal projects or the costs of drilling services and equipment prices may increase. Negotiation problems with international entities for funding could arise due to political issues that could affect the decision of JICA and government authorities. There may also be environmental risks such as in the issuance of water use permits and obtaining an environmental license, since the entities in charge of issuing permits and licenses may deny them for lack of information about the project. Another environmental risk to consider is earthquakes. These can occur either in the field study phase or during the construction of the geothermal plant, damaging the infrastructure of the project.

In order to mitigate these risks of moderate impact, it has been proposed to carry out constant monitoring and follow-up of the project during drilling. Regarding financing issues on the part of the Government of Ecuador, they should seek financing from international companies such as JICA which offer official development assistance (ODA) loans with low interest rates. In case of earthquakes that may occur during the field study phase and the construction of the plant, there should be an evacuation plan and constant monitoring of the project to avoid damage or contingency. Medical examinations will be performed on people before visiting and working on the project in order to avoid future setbacks.

In the critical zone, the risks are considered high impact and probability. Among the most important are damages that can occur in the casing or the pipelines, a decrease in production, and circulation losses during drilling that would have to be counteracted by cementation. Another important part is the permitting issuance for land use and explaining to the local population the dangers that can occur due to geothermal gases (H_2S) that may emanate around the project area. For handling the risks in the impact zone, it is necessary to select an experienced drilling company. Precise reservoir engineering, as well as constant monitoring and construction of an accurate conceptual model is vital. To identify emission of hazardous gases that may occur in the different stages of the project, a continuous monitoring and alarm procedure has to be set in place.

Finally, one of the most severe risks is spillage of fuel during drilling, which would cause environmental pollution and pose the risk of fire, threatening the project and the communities that are close to it. To mitigate this risk, the regional authorities, together with the federal authorities and stakeholders in charge of the project, should adhere to an appropriate international procedure, including all preventive measures.

7. DISCUSSION: OTHER POINTS OF VIEW

The Chachimbiro geothermal project has become one of the most important geothermal projects in Ecuador, as its energy source is the internal heat of the earth that can be used for the generation of electricity.

This type of energy is considered clean because it is extracted from the earth and the emissions of greenhouse gases are almost nil compared to fossil fuel sources that emit a large amount of toxic gases.

In addition, geothermal offers a high plant factor so that the installed capacity can be used almost continuously, independent of seasonal variations.

Through the introduction of geothermal energy in Ecuador, it is possible to achieve a change in the energy matrix and reduce the amount of fuel used in thermal generation plants. Changing the 9.86% share of electricity produced by thermal power plants using fossil fuels to electricity derived from the geothermal resource would make a dramatic change to the Ecuadorian Energy Matrix.

In 2017, the first geothermal drilling in Ecuador was carried out. Certain environmental aspects outlined in an environmental management plan had to be followed and a request was made for an environmental registration for projects of up to 10 MW, which was granted by the Ministry of Environment. For the phases of field development and construction of the geothermal plant, it is imperative to establish what type of environmental permits and licenses are necessary to develop the project.

Currently, there is no clear environmental legislation for the management and use of geothermal resources. The environmental authorities have not contemplated the implementation of activities related to ESIA for geothermal projects aiming at the construction of a power plant of 25 MW. So far, the only available law is the *Organic law on water resources, usage and exploitation of water* to which the usage of geothermal fluid can be linked. On the other hand, JICA will establish ESIA guidelines in its Preparatory Study for the Geothermal Plant Construction Project in Chachimbiro – Ecuador.

The JICA guidelines for environmental and social considerations and Ecuadorian laws/regulations that have to be taken into account in this project are: 1) Environmental and social considerations that include impacts on human health and safety, as well as on the environment, which are transmitted through air, water, soil, waste, and water usage; and 2) Social impacts with respect to employment and working conditions (MMTEC, 2018).

Geothermal energy is considered an environmentally friendly energy, with low associated emissions of greenhouse gases such as CO_2.

8. CONCLUSIONS

The Government of Ecuador is exploring new ways of electricity generation by utilizing renewable energy sources, such as geothermal energy, that do not pollute the environment. Geothermal energy can be used long term and is not as costly as thermal energy, which is reliant on fossil fuels.

In the medium term, the aim is to reduce fuel consumption in thermal generation plants, which are costly and polluting.

The financial evaluation presented in this report has determined that the project is feasible. The NPV with a discount rate MARR for equity of 13% is 54 Million USD, the NPV for Total Capital with a discount rate MARR of 6.5% - even though it takes a long period to recover - will reach 15 Million USD. The MIRR for the Total Capital is 7% and the MIRR for equity is 15%. These results are higher than the MARR for equity and the MARR for Total Capital.

A risk matrix was developed, with different risk factors being established. It was determined that the most severe risk is fuel spill during drilling. To mitigate this risk the regional authorities, together with the federal authorities and stakeholders in charge of the project, must adhere to an adequate international procedure, including all preventive measures.

The realization of the Chachimbiro geothermal project would reduce the dependence on, and consumption of, fuel used in thermal generation plants by utilizing the clean energy of a geothermal resource.

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APPENDIX I: Financial evaluation of Chachimbiro geothermal project

Assumptions and Results							**MARR for Equity**			**13%**	**Planning Horizon**			**30 years**	
Assumptions:							**MARR for Total capital**			**6.5%**					
		2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**Total**
Investment:	**MUSD**														**MUSD**
Buildings	100%	0	1	1	10	10	9	0	0	0	0	0	0	0	**32**
Equipment	100%	21	7	13	3	3	3	0	0	0	0	0	0	0	**49**
Other		8	4	4	4	2	3	0	0	0	0	0	0	0	**25**
Total Investment		**30**	**12**	**18**	**17**	**15**	**14**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**107**
Financing:															
Working capital (Inv from Op)		5	0	0	0	0	0	0	0	0	0	0	0	0	**5**
Total financing		**35**	**12**	**18**	**17**	**15**	**14**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**112**
Equity	100%	30%													
Loan repayments	100%	20	years												
Loan interest	100%	1.5%													
							OpStart								
Operations:		**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	
Sales quantity	100%	0.0	0.0	0.0	0.0	0.0	0.0	197.8	197.8	197.8	197.8	197.8	197.8	197.8	Gwh/yr
Sales price	100%	0.0	0.0	0.0	0.0	0.0	0.0	0.07	0.07	0.07	0.07	0.07	0.07	0.07	USD/kwh
Variable cost	100%	0													
Fixed cost	100%	1.07	MUSD/year												
Inventory build-up (MUSD)					0										

Other Assumptions:		
Debtors	1/12	of turnover
Creditors	1/6	of variable cost
Dividend	30%	of profit
Income tax	22%	of Taxable profit
Depreciation buildings	5%	
Depreciation equipment	10%	
Depreciation other	20%	
Loan management fee	0.2%	

Main Results:	**Total Cap.**	**Equity**
NPV of cash flow	14.96	54.22
Internal rate of return	8%	20%
External rate	7%	15%
Internal value of shares after 30 years		**4.8**

Breakdown of Costs:		
Variable Cost	0	0%
O&M Cost	31	8%
Paid Taxes	49	12%
Repayment	78	19%
Interest	26	7%
Paid Dividend	53	13%
Cash Account	167	41%
	405	**100%**

FIGURE 1: Main assumptions and results

Investment

Year (20xx):		**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
Investm and Financing		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Investment:																			
Buildings		0	1	1	10	10	9.2	0	0	0	0	0	0	0	0	0	0	0	0
Equipment		21	7	13	3	3	2.6	0	0	0	0	0	0	0	0	0	0	0	0
Other		8	4	4	4	2	2.5	0	0	0	0	0	0	0	0	0	0	0	0
Total		**30**	**12**	**18**	**17**	**15**	**14.4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Booked Value of Fixed Assets																			
Buildings		0	1	2	13	23	32.0	30	29	27	26	24	22	21	19	18	16	14	13
Equipment		21	28	41	44	47	49.4	45	40	35	30	25	20	15	10	5	0	0	0
Other		8	13	17	21	23	25.4	20	15	10	5	0	-2	-2	-2	-2	-2	-2	-2
Total		**30**	**42**	**60**	**77**	**92**	**106.8**	**95**	**84**	**72**	**60**	**49**	**40**	**34**	**27**	**21**	**14**	**13**	**11**
Depreciation																			
Buildings	5%	0	0	0	0	0	0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Equipment	10%	0	0	0	0	0	0	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	0	0
Other	20%	0	0	0	0	0	0	5.1	5.1	5.1	5.1	5.1	1.74	0	0	0	0	0	0
Total		**0**	**0**	**0**	**0**	**0**	**0**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**8.3**	**6.5**	**6.5**	**6.5**	**6.5**	**1.6**	**1.6**
Financing:																			
Equity	30%	10.4	3.6	5.5	5.2	4.5	4.3	0	0	0	0	0	0	0	0	0	0	0	0
Loans	70%	24.3	8.4	12.8	12.2	10.5	10.1	0	0	0	0	0	0	0	0	0	0	0	0
Total		**35**	**12**	**18**	**17**	**15**	**14.39**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Loans:																			
Drawdown		24.3	8.4	12.8	12.2	10.5	10.07	0	0	0	0	0	0	0	0	0	0	0	0
Repayment	20				0	0	0	0	0	0	0	0	0	0	0	0	3.9	3.9	3.9
Principal	0	24.3	32.7	45.5	57.7	68.2	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3	78.3	74.4	70.4	66.5
Interest	1.5%	0	0.4	0.5	0.7	0.9	1.02	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1
Loan Mngmt. Fees	0.2%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Year (20xx):	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**Total**
Investm and Financing	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	
Investment:																		
Buildings	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**32**
Equipment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**49**
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**25**
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**107**
Booked Value of Fixed Assets																		
Buildings	11	10	8	6	5	3	2	0	0	0	0	0	0	0	0	0	0	
Equipment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	
Other	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-3	
Total	**9**	**8**	**6**	**5**	**3**	**1**	**0**	**-2**	**-2**	**-2**	**-2**	**-2**	**-2**	**-2**	**-2**	**-2**	**-4**	
Depreciation																		
Buildings	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	0	0	0	0	0	0	0	0	0	**32**
Equipment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.86	**50**
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.74	**29**
Total	**1.6**	**1.6**	**1.6**	**1.6**	**1.6**	**1.6**	**1.6**	**1.6**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2.6**	**111**
Financing:																		
Equity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**34**
Loans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**78**
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**112**
Loans:																		
Drawdown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Repayment	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	**78**
Principal	62.6	58.7	54.8	50.9	47.0	43.0	39.1	35.2	31.3	27.4	23.5	19.6	15.7	11.7	7.8	3.9	0	
Interest	1.0	0.9	0.9	0.8	0.8	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.3	0.2	0.2	0.1	0.1	**26**
Loan Mngmt. Fees	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.2**

FIGURE 2: Investment

Cash Flow

Year (20xx):		**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
Cash Flow																			
Operating Surplus (EBITDA)		**0**	**0**	**0**	**0**	**0**	**0**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**
Debtors	0	0	0	0	0	0	0	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1	1.2	1.2	1.2	1.2
Debtor changes			**0**	**0**	**0**	**0**	**0**	**-1.2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Greditors	1/6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Creditor changes			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Financing - expenditure		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cash flow before tax		**5**	**0**	**0**	**0**	**0**	**0**	**11.6**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**
Paid taxes			0	0	0	0	0	0	0	0	0	0	0	0	1	1.1	1.1	1.1	2.2
Cash flow after tax		**5.0**	**0**	**0**	**0**	**0**	**0**	**11.6**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**11.7**	**11.7**	**11.7**	**11.7**	**10.6**
Interest & loan man fee		0	0.4	0.5	0.7	0.9	1.0	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1	1.2	1.2	1.1	1.1
Repayment		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.9	3.9	3.9
Net cash flow		**5.0**	**-0.4**	**-0.5**	**-0.7**	**-0.9**	**-1.0**	**10.4**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**11.6**	**11**	**10.5**	**6.6**	**6.6**	**5.6**
Paid dividend			0	0	0	0	0	0	0	0	0	0	0	1.0	1	1.2	1.2	1.2	2.4
Cash movement		**5**	**0**	**-1**	**-1**	**-1**	**-1**	**10**	**12**	**12**	**12**	**12**	**12**	**11**	**9**	**9**	**5**	**5**	**3**
Cash flow ratios:																			
Debt service coverage					0	0	0	9.9	10.9	10.9	10.9	10.9	10.9	10.9	10.0	9.9	2.3	2.3	2.1
Loan life cover ratio:																			
NPV of cash flow	1.5%				46	47	47	48	37	25	13	25	37	49	60	71	81	92	101
Principal					58	68	78	78	78	78	78	78	78	78	78	78	74	70	67
Loan life cover ratio					0.8	0.7	0.6	0.6	0.5	0.3	0.2	0.3	0.5	0.6	0.8	0.9	1.1	1.3	1.5
Critical value					1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Year (20xx):	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**Total**
Cash Flow																		
Operating Surplus (EBITDA)	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**371**
Debtors	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	
Debtor changes	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-1**
Greditors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Creditor changes	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Financing - expenditure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Cash flow before tax	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	**374**
Paid taxes	2.2	2.2	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.7	2.7	2.7	2.7	2.7	2.8	2.8	2.8	**49**
Cash flow after tax	**10.6**	**10.5**	**10.5**	**10.5**	**10.5**	**10.5**	**10.5**	**10.5**	**10.4**	**10.1**	**10.1**	**10.1**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**325**
Interest & loan man fee	1.0	0.9	0.9	0.8	0.8	0.7	0.6	0.6	0.5	0.5	0.4	0.4	0.3	0.2	0.2	0.1	0.1	**26**
Repayment	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	**78**
Net cash flow	**5.6**	**5.7**	**5.7**	**5.8**	**5.8**	**5.9**	**5.9**	**6.0**	**6.0**	**5.7**	**5.7**	**5.8**	**5.8**	**5.9**	**5.9**	**6.0**	**6.0**	**221**
Paid dividend	2.4	2.4	2.4	2.4	2.4	2.4	2.5	2.5	2.5	2.9	2.9	2.9	2.9	2.9	2.9	2.9	3.0	**53**
																		0
Cash movement	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**4**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**167**
Cash flow ratios:																		
Debt service coverage	2.1	2.2	2.2	2.2	2.2	2.3	2.3	2.3	2.4	2.3	2.3	2.4	2.4	2.4	2.4	2.5	2.5	
Loan life cover ratio:																		
NPV of cash flow	110	119	128	136	145	153	162	170	178	185	193	200	207	214	221	228	235	
Principal	63	59	55	51	47	43	39	35	31	27	23	20	16	12	8	4	0	
Loan life cover ratio	1.8	2.0	2.3	2.7	3.1	3.6	4.1	4.8	5.7	6.8	8.2	0	0	0	0	0	0	
Critical value	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	

FIGURE 3: Cash flow

Profitability

Year		20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Profitability Measurements																			
NPV and IRR of Total Cash Flow																			
Cash flow after taxes		5	0	0	0	0	0	12	13	13	13	13	13	13	12	12	12	12	11
Total capital		-35	-12	-18	-17	-15	-14	0	0	0	0	0	0	0	0	0	0	0	0
Total cash flow and capital		-30	-12	-18	-17	-15	-14	12	13	13	13	13	13	13	12	12	12	12	11
NPV total cash flow	6.5%	-30	-41	-57	-71	-83	-94	-86	-77	-70	-63	-56	-49	-43	-38	-33	-29	-25	-21
IRR total cash flow										0%	0%	0%	0%	0%	0%	1%	2%	3%	3%
MIRR total cash flow												0.0%	0.0%	1.1%	2.3%	3.2%	3.9%	4.5%	4.9%
NPV and IRR of net cash flow																			
Net cash flow		5	0	-1	-1	-1	-1	10	12	12	12	12	12	12	11	10	7	7	6
Equity		-10	-4	-5	-5	-5	-4	0	0	0	0	0	0	0	0	0	0	0	0
Net cash flow and equity		-5	-4	-6	-6	-5	-5	10	12	12	12	12	12	12	11	10	7	7	6
NPV tet cash flow	13%	-5	-9	-14	-19	-24	-27	-20	-13	-6	1	7	13	18	23	27	30	32	34
IRR net cash flow									0%	1%	7%	11%	13%	15%	17%	17%	18%	18%	18%
MIRR net cash flow									0%	6%	10%	12%	13%	14%	15%	15%	15%	15%	15%

Year	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	Total
Profitability Measurements																		
NPV and IRR of Total Cash Flow																		
Cash flow after taxes	11	11	11	11	10	10	10	10	10	10	10	10	10	10	10	10	10	325
Total capital	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-112
Total cash flow and capital	11	11	11	11	10	10	10	10	10	10	10	10	10	10	10	10	10	214
NPV total cash flow	-18	-14	-11	-9	-6	-3	-1	1	3	5	7	8	10	11	13	14	15	
IRR total cash flow	4%	5%	5%	5%	6%	6%	6%	7%	7%	7%	7%	7%	7%	7%	8%	8%	8%	
MIRR total cash flow	5.3%	5.6%	5.8%	6.0%	6.2%	6.3%	6.4%	6.5%	6.6%	6.7%	6.8%	6.8%	6.9%	6.9%	6.9%	6.9%	7.0%	
NPV and IRR of net cash flow																		
Net cash flow	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	221
Equity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-34
Net cash flow and equity	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	187
NPV tet cash flow	36	38	39	41	42	44	45	46	47	48	49	50	51	52	53	54	54	
IRR net cash flow	19%	19%	19%	19%	19%	19%	19%	19%	19%	19%	19%	19%	20%	20%	20%	20%	20%	
MIRR net cash flow	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	

FIGURE 4: Profitability

APPENDIX II: Risk Matrix of the Chachimbiro geothermal project

Ref.	Risk factor	Description	Probability	Impact				Evaluation	Risk treatment plan
				HSE	Cost	Time	Operation		
FIELD STUDY – TECHNICAL									
1	Low thermal gradient in drilled wells	Drilling of 5 wells, the wells maximum temperature is less than 200ºC	2		2			4	To develop the project step by step
2	Steam flow	Low steam flow, overestimating the resource	2		3			6	Step-by-step project development and constant monitoring of wells
3	Scaling and corrosion	Damage in casing and pipelines, and decrease in the production	3		3		3	9	Geochemical analysis of the fluids and use of inhibitors
4	Production rates decline faster	Fast production decline could be caused by limited porosity or changes in permeability after production starts	2		4		4	8	Accurate reservoir engineering, constant monitoring and building of a conceptual model for the project
5	Drilling	Losses during drilling or cementing	3		3			9	Select experienced drill-ing company, loss handl-ing material to be avail-able prior drilling, and sufficient water supply
FINANCE									
6	Project funding by Government	Difficult funding from government because of lack of budget to develop geothermal projects	2		2	2		4	Mostly after the exploration stage: Communication and support of national agenda. Seek funding from ODA enterprises because they offer lower interest rates
7	Project international funding	Difficulty in funding, political issues could affect decision of JICA and governm. authorities	3			2		6	Ensure all - inclusive negotiation and proposal

Ref.	Risk factor	Description	Probability	Impact				Evaluation	Risk treatment plan
				HSE	Cost	Time	Operation		
FINANCE									
8	Prioritization of others kinds of technologies	Government aims to develop another type of renewable energy	2		1			2	Promote renewable energy because it is a clean energy
COST									
9	Drilling service increase the price	Oil market could increase the price per barrel of petroleum	2		3			6	Establish drilling contract and fix the unit prices
10	Equipment cost increase	High demand of equipment for drilling and materials in the international market	1		4	4		4	To have a budget to perform the procurement on time
11	Define the suppliers	There are many suppliers in the market which offer goods and service at very high prices	2		4			8	Establish procurement methods
12	Permit for exploration - field study	Difficulties and delays in getting a permit for exploration license	2			4		8	Meetings with officials and hire a legal consultant
13	Permit for using land	Difficulty in getting a permit for land use	2			4		8	Allocated persons for the land acquisition process, start the process early (at least 12 months before exploration)
POLITICAL AND LEGAL									
14	Regional government	Problems getting regional government consent	1			2		2	Involvement and support from national government, enhance communication
15	Lack of political support for geothermal project	If there is a change of authorities, the new government may not support the ideas of the previous government	1			2		2	Introducing the project with adequate communication
ENVIRONMENTAL									
16	Environmental license	The Ministry of Environm. could deny the project's environmental license for lack of information on geothermal development projects	1		3			3	To perform meetings with official personnel of Ministry of Environment to introduce information about geothermal projects
17	Permit for using water	The Ministry of Water can deny the use of the water resource during the drilling and operation of the plant	1		4			4	Drilling of shallow wells in the project area for water

Ref.	Risk factor	Description	Probability	Impact				Evaluation	Risk treatment plan
				HSE	Cost	Time	Operation		
ENVIRONMENTAL									
18	Environmental aspects	Acceptance of the ESIA for exploration (field study)	2	1				2	Approval of the ESIA by JICA for development of the Chachimbiro geothermal project
19	Fuel spillage during drilling	Contamination of the environment, risk of fire	4	4	4			16	Use proper containment procedures and adhere internat. procedures
20	High H_2S concentration	Potential harm to locals due to geothermal gasses around project area	4	3				12	Constant monitoring and alarm procedure in project area
21	Earthquakes at any stage	Damage the power plant and the infrastructure	2	2				4	Earthquakes in the vicinity, must have an evacuation plan and constant monitoring
22	Local communities around project	Problems getting acceptance of the local communities	2	1				2	Introduce a social engagement plan (benefits of the society from the project): Electricity, jobs, education, other compensations etc. Special discussion with organisations opposing the project.
23	Health risk due to high altitude	People in poor health could have problems due to less oxygen in the air	3	2				6	Medical exams before visiting and working on the project