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Technical, financial, economic and environmental pre-feasibility study of geothermal power plants by RETScreen – Ecuador's case study

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ABSTRACT

A technical, financial, economic and environmental analysis of geothermal power plant developments in the Ecuadorian context was analysed by RETScreen-International Geothermal Project Model. Three different scenarios were considered. Scenario I and II considered incentives of 132.1 USD/MWh for electricity generation and grants of 3 million USD. Scenario III considered the geothermal project with an electricity export price of 49.3 USD/MWh. Scenario III was further divided into IIIA and IIIB case studies. Scenario IIIA considered a 3 million USD grant while Scenario IIIB considered an income of 8.9 USD/MWh for selling heat in direct applications. Modelling results showed that binary power cycle was the most suitable geothermal technology to produce electricity along with aquaculture and greenhouse heating for direct use applications in all scenarios. Financial analyses showed that the debt payment would be 5.36 million USD/year under in Scenario I and III. The corresponding values for Scenario II was 7.06 million USD/year. Net Present Value was positive for all studied scenarios except for Scenario IIIA. The equity paybacks were 3.2, 3.7, 16 and 5.6 years for Scenario I, Scenario II, Scenario IIIA and Scenario IIIB, respectively. Overall, Scenario II was identified as the most feasible project due to positive NPV with short payback period. Interestingly, Scenario IIIB could become financially attractive by selling heat for direct applications. Direct applications, public incentives and clean funding mechanisms are essential for the success of geothermal energy projects in the Ecuadorian context. The total initial investment for a 22 MW geothermal power plant was 114.3 million USD (at 2017 costs). Economic analysis showed an annual savings of 24.3 million USD by avoiding fossil fuel electricity generation. More than 184,000 tCO_2 eq. could be avoided annually. Thus, greenhouse emissions avoided by using geothermal energy would bring out environmental benefits and improve the socio-economic benefits in communities.

1. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) considered greenhouse gas emissions reduction targets in the member states to limit the increase in the global mean temperature and the inevitable effects on global warming and climate change [1]. More recently, the Paris Agreement ambitiously has addressed to limit global warming to no more than 1.5 °C above pre-industrial levels [2]. The use of renewable energy sources to produce electricity plays an important role in the reduction of greenhouse gases [3–6]. By the end of 2017, global energy supply will reach 16,000 million tons of oil equivalent (Mtoe) with renewable energy resources accounting for 15% (2400 Mtoe) [7]. It is estimated that developed and developing countries might require 23,885 Mtoe by 2050 [8]. Although the accuracy of estimating the global renewable energy potential is arguable, the unused global potential of renewable energy resources was estimated to

Abbreviations: FAM, Financial Analysis model; SRAM, Sensitivity and Risk Analysis Models; NPV, Net Present Value; PUGR-E, Plan for the Utilization of Geothermal Resources in Ecuador; UNFCCC, United Nations Framework Convention on Climate Change; IGA, International Geothermal Association; WB, World Bank; MEER, Ministry of Renewable Energy and Electricity; SENPLADES, National Secretary of Planning and Development; CELEC-EP, Ecuadorian Electricity Corporation; INER, National Institute of Renewable Energy of Ecuador; CONELEC, National Electricity Council; SENESCYT, Secretariat for Higher Education, Science, Technology and Innovation; NASA, National Aeronautics and Space Administration; MW, Megawatt; UNEP, United Nations Environment Programme; kW, Kilowatt; kWh, Kilowatt-hour; kg/s, Kilogram per second;; kg/h, Kilogram per hour;; °C, Centigrade degree;; %, Percentage; bar, Bar; kPa, Kilopascal;; USD, United State Dollars;; Mtoe, Millions tons of oil equivalent; GHG, Greenhouse gas emissions; GJ, Gigajoules;; tCO2, Tonnes of carbon dioxide;; Ctv, Cents of dollar; T&D, Transmission and distribution

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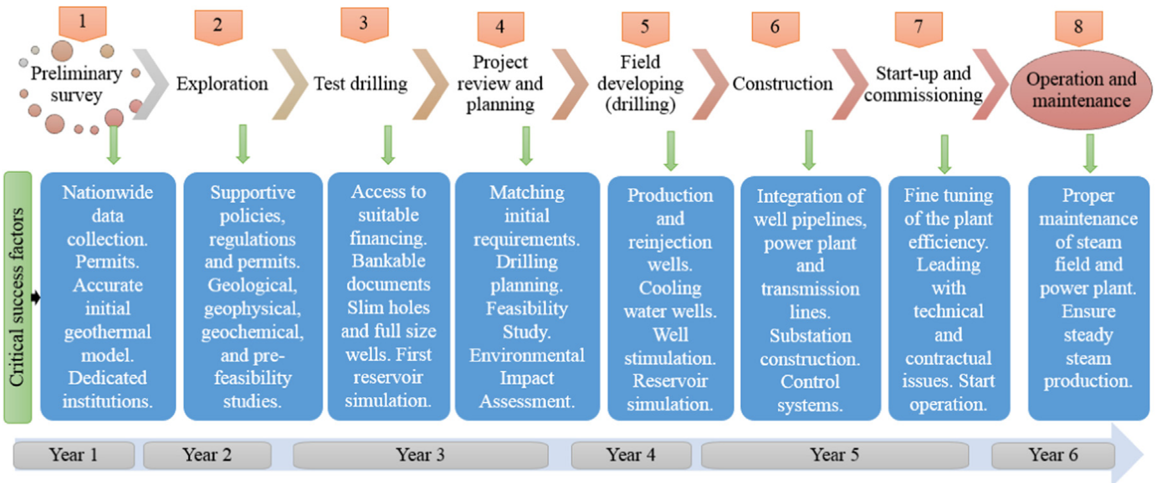

Fig. 1. Critical Success Factors in the development phase of a geothermal project. Achieving the economic viability of a geothermal project requires rigorous control of costs of each development phase [16,39,40].

be 179,135 Mtoe with geothermal energy accounting for 119,423 Mtoe [8,9]. Thus, development of geothermal energy should be considered as a sustainable alternative to deal with future energy security challenges. In this regard, Ecuador has committed to increase the share of renewable energy through the restructuration of its energy matrix [10,11] to contribute to the UNFCCC and Paris Agreement targets [12,13].

Techno-economic analysis of geothermal projects allows developers, investors and policy makers to have a complete view of the financial pre-feasibility of these kind of highly risky investment decisions [14–16]. Geothermal stakeholders have greatly agreed in the eight development phases of a geothermal power project [16,17]. Fig. 1 shows the critical success factors along the eight development phases to meet in geothermal project developments. Different approaches have been established to study the technical and financial viability of renewables in general [18,19] and geothermal in particular [20–23].

In the case of geothermal projects analysis, there are studies focused in specific phases of the development rather than in throughout the project [24]. Several researchers have previously estimated the cost of well drilling [21,25,26], technical and financial aspects of geothermal power plants [27–30], operation and maintenance costs or annual costs of a geothermal power plant [18–31] and costs of electricity generation in a geothermal power plant [19–32]. Other researcher have evaluated the feasibility of developing hybrid power plants consisting of geothermal and solar [32–36] to produce fuels i.e., hydrogen [18,22,23,34,37,38].

Pre-feasibility studies of geothermal projects helps us to estimate initial and annual costs, saving and production of energy, and focus development prior construction [41,42]. Due to the complexity of these studies, different models were developed [41,43,44]. These modelling tools are classified as pre-feasibility, sizing, simulation and open architecture research tools [44]. For the purpose of this research, RETScreen modelling tool was used. This RETScreen International Clean Energy Project Analysis Software was developed by the Ministry of Natural Resources of Canada in collaboration with National Aeronautics and Space Administration (NASA), United Nations Environment Programme (UNEP), industry partners, and academia [45,46]. It is a free software that can be used to evaluate energy production, life-cycle costs and greenhouse gas emission reductions for various proposed renewable energy technologies [42,44,46]. RETScreen offers a proven methodology focused on the pre-feasibility and feasibility studies, rather than developing a custom-developed methodology [47,48]. This tool has been extensively used to carry out pre-feasibility studies of solar projects [48–56], wind projects [57–60], hydropower projects [61,62], and a geothermal study [63].

Ecuador is committed to increase the share of renewable energy through the restructuration of its energy matrix [10,11,64], including geothermal energy [12,13]. Diversification of the Ecuadorian energy matrix represents an important milestone in the development of its economy throughout the process of changing its energy and productivity matrix. According to the Ministry of Renewable Energy and Electricity (MEER), it is expected that the share of the electricity should be approximately 85% from hydroelectric power plants, 10% from fossil-fuel-fired thermal power plants and 5% from other renewables such as wind and biomass by the end of 2017 [65]. The National Plan of Living Well of Ecuador, developed by the National Secretary of Planning and Development (SENPLADES), aims to make changes to the energy matrix and productivity matrix during the next decade [66]. These changes are supported by the New 2008 National Political Constitution and directed by the Plan of Electrification 2025 [67]. In order to change the productivity matrix, the SENPLADES has identified fourteen productivity sectors and five strategic industries [68], which will affect the structure of the energy matrix by increasing the demand for electric energy in the country. This rise of electricity demand would increase the consumption of fossil fuels due to its demand on fossil-fuel-fired thermal power plants. However, the new energy gap, as a result of the change of the productivity matrix, should be filled with electricity produced in renewable power plants such as geothermal power, considering that there are no current geothermal plants in the country [69,70]. Therefore, geothermal power generation could be a viable option to diversify the electric energy matrix in the country.

The analysis of the technical and economic potential for geothermal development is paramount. Only five of the forty odd active volcanoes in Ecuador were studied due to their potential to generate electricity [70]. Most of these investigations are currently in the exploration stage [69–72]. Furthermore, there are other geothermal prospects to be explored to determine their potential for direct use in industry and agriculture. The Ecuadorian Electricity Corporation (CELEC-EP), a public company, is leading the geothermal development for electricity generation in the country along with cooperation from the scientific and technical support of the National Institute of Renewable Energy of Ecuador (INER), under the MEER [69,70]. The production of electric energy and direct use of thermal energy from geothermal resources in the Ecuadorian context is an option to diversify its Energy Matrix and to support the energy challenges that the change of the Productivity Matrix may produce in the coming years. Geothermal energy harvesting might not only reduce the consumption of fossil fuels, reducing the environmental electricity production impact, but could also create new opportunities of research, employment and positive economic impacts