Developing a Sustainable Financing Model for Geothermal Projects: A Conceptual Framework

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ABSTRACT

Geothermal is vital for sustainable energy systems development in Indonesia. The country is privileged with estimated geothermal reserves equivalent to 29 Gigawatt-electric. However, harvesting such massive potential is precarious since geothermal projects are capital intensive, complex, and sensitive to uncertainties and risks—thus, the projects become a less attractive investment. Moreover, due to deep uncertainties, difficult decisions often have to be made regarding geothermal projects (dis)continuation for financial reasons. Additional governance measures, such as sustainable financing, are required to ensure the viability of the projects in the long run. In order to address this concern, this study proposes a conceptual framework that can be used to develop a sustainable financing model for geothermal projects. Notably, the conceptual framework is developed for exploring alternative financing schemes that are robust and attractive when faced with uncertainties and risks during the projects. For this purpose, the study employs the exploratory system dynamics modeling and analysis (ESDMA) approach and introduces the exploratory financial modeling and analysis (EFMA) approach. ESDMA analyzes geothermal project complexity and explores robust policies under deep uncertainties, while EFMA analyzes the project's financial performance and explores robust-attractive financing schemes under deep uncertainties. Aligning the results from both approaches, a sustainable financing model for geothermal projects is formulated.

CCS CONCEPTS

• Computing methodologies • Modeling and simulation • Model development and analysis

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KEYWORDS

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1 Introduction

Geothermal is vital for sustainable energy systems development in Indonesia. The country is privileged with estimated geothermal reserves equivalent to 29 Gigawatt-electric—the world's largest [1]. The development of geothermal was started back in 1974 by the establishment of the President Decree No. 16, strengthened by the other subsequent decrees (No. 22 in 1981, No. 23 in 1981, No. 45 in 1991, and No. 49 in 1991 to diversify the energy use) [2].

To date, the development of renewable energy in Indonesia still amounts to only 5.8% of the total potential [3, 4]. It is still far below the 23% target of renewables share in the primary energy mix by 2025, where geothermal should contribute up to 7,241.5 Megawatt (MW). Furthermore, the target is raised to 31% by 2050, in which 17,546 MW will be contributed from geothermal. However, harvesting such massive geothermal resources potential for reaching the target is not easy. Up till now, the geothermal power generation installed capacity amounts to only 2,100 MW.

Various factors hinder the development of geothermal resources. They represent barriers in the financial and economic, governance and regulatory, and technical aspects [5, 6]. The financial and economic barriers concerning geothermal projects in Indonesia consist of a mismatch between available financing and the need for sustainable energy projects, insufficient renewable energy subsidy, dynamic changing tariff schemes, continued fossil fuel subsidies, and high risks and costs of exploration and

development. The latter is due to deep uncertainties that are born by the project developer instead of government—which is also a common practice around the world. The regulatory framework and governance barriers are related to policy uncertainties, such as the contradiction between laws and policies, further complicated by a lack of coordination among government ministries and local and central government [7]. Meanwhile, the technical barriers pose the challenges related to uncertainties faced during the exploration and development phases of the project [8].

The elucidation above shows that uncertainties are ubiquitous in all the barriers hindering geothermal development. As a result, geothermal projects become a less attractive investment. Moreover, due to deep uncertainties, difficult decisions often have to be made regarding geothermal projects (dis)continuation for financial reasons. The literature suggests that ignoring uncertainties can lead to missed opportunities and limiting our ability to take corrective action in the future [9], and therefore they cannot be neglected. Correspondingly, additional governance measures such as incentives or sustainable financing are required to overcome uncertainties as well as multiple barriers that exist in renewable energy development [10]. These measures, such as sustainable financing, are of paramount importance to ensure the viability of geothermal projects in the long run. However, they have not been well developed nor even been successfully realized. Research is therefore needed to explore potentially useful methods that can aid the development of such measures and support the policy-and-decision making in geothermal projects under deep uncertainties.

In order to address the concern above, this study proposes a conceptual framework that can be used to develop a sustainable financing model for geothermal projects. Notably, the conceptual framework is developed for exploring alternative financing schemes that are robust and attractive when faced with uncertainties and risks during the projects. For this purpose, the study uses the exploratory system dynamics modeling and analysis (ESDMA) approach [11] and introduces the exploratory financial modeling and analysis (EFMA) approach. The ESDMA approach integrates system dynamics and exploratory modeling used to analyze geothermal project complexity and to explore robust policies under deep uncertainties. Meanwhile, the EFMA approach combines financial modeling with real options and exploratory modeling, employed to analyze the project's financial performance and to explore robust-attractive financing schemes under deep uncertainties.

2 Literature Review

2.1 Geothermal Projects

Geothermal projects are capital intensive, complex, and sensitive to uncertainties and risks. A geothermal project with a 30 MW condensing type of power capacity could require 7–12 years of development, with an investment of USD 65–80 million [12]. The investment cost would be varied, but generally, for 1 MW

geothermal power plant would be USD 5.2 million. Field development and construction accounted for 80% of the total investment of the power plant [13].

Taking a systems perspective [14] to a geothermal project, it resembles a complex dynamics system in which many elements, such as actors, institutions, technologies, are interrelated and change over time. The complexity of geothermal projects provides the meaning of the property of projects that is difficult to understand, hard to foresee, and arduous to keep its overall behavior under control—even when complete information about the project system exists [15]. A geothermal project encompasses all the aspects of project complexity, emphasizing that complexity is generally related to the way the project system is modeled.

The drivers of geothermal project complexity are factors related to project size, project variety, project interdependence, and project context [15]. A geothermal project can be divided into a series of complex development phases before the actual operation and maintenance phase commences. These phases are preliminary survey, exploration, test drilling, project review and planning, field development/full-scale drilling, construction, and start-up and commissioning [16].

In Indonesia, most of the actors involved in geothermal projects govern the power sector, such as the Ministry of Energy and Mineral Resources (MEMR), the Ministry of Finance (MF), Perusahaan Listrik Negara (PLN/State-owned Electricity Company), Independent Power Producers (IPP), and the regional governments. MEMR holds the most central role since it is responsible for developing energy policy, energy planning, and funding and regulation [17]. However, there are often misalignments in coordination and regulation due to conflicting needs and interests between actors [18]. Such misalignments add another complexity to geothermal projects.

2.2 Uncertainty in Geothermal Projects

Uncertainty is a consequence of complexity [19, 20]. Ross [21] eloquently explains uncertainty as a reflection of “the inability to estimate a value exactly.” Different to risk—which can be quantified by using losses and probabilities, uncertainty is difficult to estimate [9]. In general, uncertainty implies that there is both upside potential as well as a downside [8].

There are three dimensions of uncertainty: location, level, and nature [9]. The location of uncertainty is where the uncertainty manifests itself within the systems; the level of uncertainty is about the magnitude of uncertainty, ranging from deterministic knowledge to total ignorance; while the nature of uncertainty refers to the distinction of uncertainty due to knowledge imperfection and due to inherent variability. Figure 1 (adapted from Walker et al. [9]) depicts a framework to characterize the location and level of uncertainty from a systems perspective. The upper part of the framework shows that uncertainty is omnipresent in each element of the system of interest as well as in the system's environment. Meanwhile, the lower part of the

framework visualizes that each element of the system may have a different level of uncertainty.

The uncertainty in geothermal projects is mainly associated with exploration and production for such resources due to the location of natural resources in the subsurface [8]. It encompasses data related to geological, geophysical, temperature, and initial drilling, and how they can inform the early, conceptual ideas of a geothermal reservoir. It influences project risk [8, 22] to be over budget or overtime. As a consequence, the expected financial performance output will be lowered. Further, this will affect the policy-and-decision making in the company or even government.

Uncertainties at the exploration and production stages can be classified as deep uncertainties. Deep uncertainties exist when the probability distributions of some variables in a data cannot be characterized, leading to disagreement in valuing the desirability of alternative outcomes [9].

Figure 1: Typology of uncertainty from a systems perspective

2.3 Sustainable Financing

Geothermal power generation represents significant, long-term capital, and operating commitments [16]. Consequently, given the magnitude and nature of geothermal power facilities, the financing requirements and considerations involve risk at various levels, complicating and making the ultimate financial outcomes subject to some degrees of uncertainty. It is commonly financed in a series of stages and investor types. The riskiest on early to mid-stages of project development occurs typically financed with equity. As the project proceeds to the construction and operational phases, project risk is reduced, and debt financing is increasingly used [16]. Therefore, the project needs the right financing methods to make it robust and attractive for a different investor type with appropriate risk and return preferences.

Obtaining long-term financing is a critical aspect of the development of any power project [16]. The design of financing schemes consequently is highly dependent on the structure of the venture itself. Large capital projects must obtain a combination of

financing and equity investment from owners or shareholders in order to be built. The developer who controls the business plan and initiates the research and site development process is the core of the project financing decision.

3 Methodology

3.1 Selecting Congruent Methods

As noted above, geothermal projects are capital intensive, complex, and sensitive to uncertainties and risks. These characteristics need to be considered when selecting methods for analyzing geothermal projects. Such methods should be congruent with the characteristics or nature of geothermal projects. Congruency means that the methods facilitate analyzing the complexity of the projects and their financial performance for the policy and decision-making purpose under uncertainties and risks. The system and decision sciences have a number of methods at disposal to investigate complex dynamics projects in such a way, both qualitative and quantitative. The followings are a brief description of the methods used to develop the conceptual framework.

3.1.1 System Dynamics (SD). SD is a modeling simulation method for studying the dynamic behavior of complex systems [23, 24]. Central to SD is the understanding of the system. The terms system refers to an interconnected set of elements that is coherently organized in a way to achieves something [14]. In the SD perspective, a complex system is a high-order and non-linear feedback structure [24]. The evolutionary behavior of a system over time is fundamental in SD, explained in terms of feedback loops and state elements [23]. Thus, the interactions among the elements of the system over time, resulting in dynamic behavior.

The development of an SD model is performed through four steps: conceptualization, formulation, validation, and experimentation. The experimentation is done with the help of computer simulation. Each step possesses a recursive and interconnected manner than a simple linear regression [24]. The ultimate aim of SD is to understand the underlying cause of the dynamic behavior of the system by capturing system structure, feedback loops, and time delays [24]. This makes SD a favorable method for studying complex energy systems such as geothermal.

3.1.2 Financial Modeling with Real Options (RO). RO analysis is an extension of financial modeling analysis. RO has been used as an analytical approach to value flexibility for real assets or projects under conditions of future uncertainty. Unlike the simple net present value (NPV) method used in standard financial analysis, RO treats an investment opportunity in a sequence of options [25]. Its attractiveness is based on the premise that, by creating options, one can maximize the upside potential of a project and, at the same time, minimize its downside effects. RO makes it possible to value the flexibility of making mid-course changes in a decision [26].

RO considers the impact of decisions in uncertain conditions during projects such as delaying, expansion, fluctuating costs, and abandonment [27]. Further, RO not only evaluates the project portfolio under uncertainty but also provides intuitive explanations for various scenario trajectories [25, 27]. This gives benefit for the exploration of long-term financing schemes for a large project such as geothermal.

3.1.3 Exploratory Modeling and Analysis (EMA). EMA refers to a systematic exploration of the impacts of structural, various parametric, and methodological uncertainties on the performance indicators of a simulation model [28]. EMA uses simulation models for 'exploration' purposes rather than for 'prediction'. EMA comprises three major steps: generation of ensemble scenarios, simulation of generated scenarios, and analysis of the simulation results [28].

The first step constructs the scenarios that span the plausible range of model parameters and competing alternative model structures. Full factorial sampling techniques, such as Latin Hypercube, are commonly used in this step [29]. The second step conducts the constructed scenarios. Several analysis techniques can be used for this, such as scenario discovery and global sensitivity analysis. Scenario discovery conducts a backward induction from the simulation results to model structures and parameters, while global sensitivity analysis generates some reference policy with a vast number of input variables [30]. These analysis techniques help in identifying robust alternatives under the condition of deep uncertainties. This is done through computer experiments, aided by utilizing the Python library [31].

Such the identification of robust alternatives is then followed with the selection of the most robust option. The EMA features offer the opportunity to explore robust policies and financing schemes for complex projects sensitive to uncertainties such as geothermal.

3.2 Combining the Selected Methods

Drawing from the methods discussed in the previous section, they are combined to analyze the complexity and the financial performance of geothermal projects. The combination proceeds two approaches, introduced as follows:

1. Exploratory system dynamics modeling and analysis (ESDMA)

The ESDMA approach integrates SD and EMA, used to analyze the complexity of geothermal projects, and to explore robust policies for supporting the projects under deep uncertainties.

2. Exploratory financial modeling and analysis (EFMA)

The EFMA approach combines financial modeling with RO and EMA, employed to analyze the financial performance of geothermal projects investment and to explore robust-attractive financing schemes under deep uncertainties.

The two introduced approaches above will be used as the basis for formulating the conceptual framework.

4 The Proposed Conceptual Framework

The conceptual framework (Figure 2) is formulated by combining the ESDMA and EFMA approaches. The combination is proceeded in three stages: uncertainty definition, policy and financial analysis, and synthesis of the results.

4.1 Uncertainty Definition

The conceptual framework begins with uncertainty definition. This is done by the identification of uncertainties and risks in geothermal projects, covering the policy uncertainty and technical uncertainty. Notably, uncertainties during the exploration and development phases of geothermal projects. As previously noted, the sources of uncertainty in such phases originate from data related to geological, geophysical, temperature, and initial drilling, which are used to model the potential geothermal reservoir. Notwithstanding the available data, different interpretations from similar data often lead to different conclusions, which add further uncertainty. Therefore, what is also important is to formulate uncertainties appropriately in order to translate them into risks.

The uncertainty definition stage is intertwined in multiple ways with the second stage (the policy and financial analysis) represented by bidirectional arrows, and also with the third stage (the synthesis of the results stage) represented by one-directional arrows, shown in Figure 2 respectively. It means that the uncertainty definition must ensure that the relevant uncertainties and risks are well-identified and formulated in the SD model as well as in the financial model.

4.2 Policy and Financial Analysis

The second stage employs ESDMA and EFMA approaches. The stage uses ESDMA for policy analysis and EFMA for financial analysis of geothermal projects. Both approaches can be employed concurrently. Further, since this stage performs policy analysis—for searching robust policy options, the policy analysis framework by Walker [32] is incorporated with ESDMA activities. The policy analysis framework has been widely used in SD studies. Such the framework is compatible with the SD method—notably, in terms of the analytical steps. The tools in policy analysis, such as system diagram, can be used to aid the analysis, thereby mapping the elements that create the complexity of geothermal projects. Methods such as forum group discussion can also be used when building and validating the model.

4.2.1 Using ESDMA for Policy Analysis. The ESDMA approach consists of the development of the SD model representing geothermal project complexity and computational experiments. The SD model development covers the delineation of systems boundary of geothermal projects, analysis of systems structure, which includes actor analysis, outcomes criteria definition, model formulation and validation, and identification of policy

interventions in geothermal projects. Policy analysis tools such as system diagram and actor analysis table are used to aid these activities.

The SD model development is then followed with the computational experiments. Future scenarios are generated based on the identified and formulated uncertainties and risks. This can be done by utilizing a full factorial sampling technique such as Latin Hypercube. Next, the generated scenarios are simulated by using a scenario discovery technique for exploring robust policies. The more the scenarios are created, the more opportunities to explore robust policy alternatives. The outcomes criteria, such as the number of geothermal power generation installed capacity resulting from each policy intervention, are then evaluated for each scenario. The experiments allow for the identification of robust policy.

4.2.2 Applying EFMA for Financial Analysis. The EFMA approach covers financial performance analysis and computational experiments. The financial performance analysis uses financial modeling with RO. It covers the formulation of project cost structure, identification of critical cost factors, setting the target value of performance indicators, defining the option valuation, and identification of plausible financing schemes.

Familiar metrics, such as the NPV, return on investment (ROI), internal rate of return (IRR), profitability index (PI), and payback period (PP) are used for evaluating the financial performance of geothermal projects investment. These metrics are extended by RO for their valuation. In order to do this, relevant variables are

sensitivity analysis that focuses only on a particular input variable, the global sensitivity analysis allows a vast number of combinations of input variables for conducting the scenarios. The more scenarios, the better; in order to give more opportunities for the exploration of robust-attractive financing schemes. The financial performance indicators, such as NPV, which is already extended by RO for its valuation, resulting from each financing scheme option, are then evaluated for each scenario. The evaluation is used to identify robust-attractive financing scheme.

4.3 Synthesis of the Results

The third stage coalesces the results. The aim is to gain insights from the results of the computational experiments. This stage formulates the sustainable financing model by analyzing the results emerge from the ESDMA and EFMA approaches.

Herein, a sustainable financing model is defined as a robust-attractive financing scheme—a financing scheme that is robust and attractive when faced with uncertainties and risks during the projects. Robust and attractive constitute two dimensions determining the sustainability of project financing. The financing scheme is robust when the outcomes and the forecast of the project investment show a long-term and consistent positive financial performance even when faced with various changing scenarios due to uncertainties and risks. Meanwhile, the scheme is considered attractive when there are acceptable long-term financing benefits or returns for the investors to channel their fund into the project. Further, a robust-financing scheme can be achieved when it is aligned with and supported by a robust policy.

Figure 2: The proposed conceptual framework

defined. For instance, ‘the time to maturity’ variable in the NPV analysis is expanded by adding another variable such as ‘the time before the opportunity expires’. The addition of such a new variable gives another option of what decisions have to be made.

Next to the financial performance analysis is the generation of scenarios based on the identified and formulated uncertainties and risks. Full factorial sampling technique such as Latin Hypercube is used for this purpose. Several scenarios are then conducted by using the global sensitivity analysis technique. Unlike traditional

Based on the elaboration above, the results emerge from the ESDMA and EFMA approaches should be aligned. Such an alignment is resulting in a combination of the most robust policy (through an effective and robust policy instrument) and a financing scheme with the most robust-attractive performance.

5 Conclusion and Future Work

Sustainable financing is one key to ensure the viability of geothermal projects in the long run. The conceptual framework

developed in this paper sets the stage for the realization of a robust-attractive financing scheme—so-called a sustainable financing model by embracing deep uncertainties and risks in geothermal projects. In this regard, the conceptual framework has offered a systematic procedure to formulate a sustainable financing model by tailoring the integration of SD, financial modeling with RO, and EMA into two approaches named the ESDMA and EFMA approaches. This paper would be an essential contribution to the application of ESDMA and EFMA approaches in policy and decision studies related to complex energy projects.

Preliminary as it is, the applicability of the conceptual framework should be challenged with real cases. Future work is therefore required to make the conceptual framework applicable for use to realize its purpose. That is, to deliver an alternative sustainable financing model for geothermal projects that can be useful for supporting the policy-and-decision making in geothermal projects faced with deep uncertainties. The proposal is to do this by applying—testing and validating the conceptual framework in actual geothermal projects. To this end, the following research agenda is proposed.

Future work will discuss and elaborate further on the formulation of uncertainty in geothermal projects. Notably, the uncertainty associated with the exploration and development phases. The questions that may arise, such as how the subsurface uncertainty could be better quantified, and what techniques could be used for that. For the macro-level analysis, the conceptual framework will be applied to analyze geothermal development in Indonesia. It will be used to explore robust policies for filling the gap between the targeted and the actual achievement of geothermal power generation installed capacity.

Further, the conceptual framework will be applied to investigate the financial performance of the already on-going and planned geothermal projects. Such the actual projects will be used as the case studies to explore robust-attractive financing schemes fit for improving the viability of the projects in the long run. Since each project has different characteristics, the result from each case may offer insights into different critical success factors for each project type. Finally, future work will derive conclusions from the results of the case studies.

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