Efficient Methods for Planning and Evaluating Geothermal Projects in Developing Countries Using Real Option Analysis (ROA): A Case Study of Menengai Geothermal Project

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ABSTRACT

Renewable energy projects in developing countries by default should provide a clean and secure energy supply as well as support sustainable economic development. In planning, designing and evaluating a renewable energy project, risks arising from uncertainties such as rapidly changing technologies and host government conditions should be carefully addressed. However, traditional methods for economic assessment are not adequate to support decision-making regarding investments in renewable energy. The use of efficient computational methods provides a rigorous analysis improving the decision-making process. This article demonstrates the application of real option analysis method developed in operational research for the optimum exploitation of renewable resources in the developing countries. A case study involving a geothermal project in Kenya (Menengai Geothermal Project) was conducted to validate and verify the framework. This framework is expected to help developing countries and investors to access Geothermal and other renewable energy projects with high volatility and risk. This study showed that the valuation of geothermal power generation project using NPV method underestimates the value of the project rather than ROA Since the option value (SNPV) was US$79.8million (twice the value of the NPV).

1. Introduction and Background Information

Renewable energy seems to be the solution to meet the growing energy demand and at the same time reduce the carbon emissions and in this regard over 164 countries have national renewable energy targets (REN21, 2014) Renewable energy source shave in common some characteristics that make their development very attractive especially for local use. Some of the advantages advocating the promotion of renewable energy sources are:

➢ Decentralized production and use that results in a more balanced regional development.
Independence from imported fuel.
Minimum environmental impact.
Low operating cost.
Rather simple technology.

However there are disadvantages associated with these renewable energy sources that have to be considered while evaluating its investment (REN21, 2014) such as:-

High risk of a new technology
Very high capital costs i.e. per KWH
Difficulties in matching the supply to the demand thus resulting to extra cost of storage.
Low utilization factor for the installed capacity
Low energy quality and concentration that limits the possible areas
The necessity for parallel use of various energy forms.

Due to global climate change, developed countries have continued to reduce their use of fossil fuels and increase their use of renewable energy (RE). By 2015, as a result of the Kyoto Protocol, RE production reached an estimated 22.1% of global electricity production (IEA, 2016). Total new investment in renewable power was at least US$249.4 billion in 2013 (IEA, 2016). Since 1990, RE generation worldwide has grown by an average of 3.3% per annum: 2.3% among countries in the Organization for Economic Co-operation and Development and 4.5% among other countries. Renewable energy industry has grown in the developing countries which are facing rapid economic growth and energy shortages. The continual decline in prices of RE material and equipment caused by technological advancements have improved the applicability of RE in recent decades. Governments of developing countries have played a role in the growth of the RE market by attracting foreign investors for RE business opportunities, by means of new energy policies such as feed-in tariffs, renewable portfolio standards, deregulation, incentive programs, and public–private partnership models. Despite the positive aspects of RE markets, it is difficult to make decisions regarding RE investments in developing countries. Risks arising from changeable policies, loan rate fluctuations, foreign exchange rates, and inflation are typical examples that illustrate the difficulty of decision-making in RE investment. This paper proposes an efficient computational real options analysis (ROA) framework for the assessment of investments in RE projects of developing countries. The two objectives this paper attempts to achieve are the accurate estimation of uncertainties arising from investment in RE projects of developing countries and the accurate assessment of economic feasibility of these projects. This paper first identifies the key variables to assess the uncertainties that have a direct influence on the project profit. Real Option Analysis is then conducted to yield the option value to decide whether or not the project is economically feasible. The proposed framework enables the government and investors to accurately evaluate geothermal energy projects with regard to the major risks associated with these projects.

2. Problem Statement

Investors, developers, financial institutions and governments commonly assess investments using the net present value (NPV) technique under the condition of definite cash flow. The NPV technique is the most widely used decision-making tool for various investment projects. This traditional approach is known to be quite useful in many projects, but not in the case of highly volatile and uncertain investments like the Geothermal energy projects and other renewable energy sources. Because Renewable Energy projects in
emerging markets entail considerable risk influenced by rapidly changing Renewable Energy technologies and global climate change this traditional method cannot adequately meet the requirement of renewable energy projects in developing countries. NPV has long been authorized as an investment decision technique for energy projects; however, it is considered inappropriate for highly uncertain investment projects because it intrinsically carries the assumption of definite cash flows which is not the case for most renewable energy projects. In this regard these limitations of NPV makes the Real Option Analysis (ROA) the best option as far as Renewable Energy projects are concerned.

3. Literature Review

Real option Analysis has been applied in the areas of Oil, gas mining, Aviation, pharmaceuticals and semi-conductors (Bøckman & Fleten, 2008) Recently, ROA has been more frequently applied for valuation of RE projects. ROA has been used for various types of RE, including hydropower (Bøckman & Fleten, 2008), wind farms (Martínez & Mutale, 2011), and solar energy (Abadie, 2014). Studies have been conducted to improve ROA methodology for Renewable Energy (C & Lu, 2011). Systematic and comprehensive analysis is increasingly useful for investigating the volatility arising from uncertainties of RE projects. (V, 1999) Developed a real options model for a small hydropower project in Norway, to find the unique trigger price for investing and the optimal size of the hydropower plant. Abadie and Chamorro (Abadie & Chamorro, 2014) developed a real options model to investigate a wind farm project considering the three uncertain factors of electricity price, wind generation quantity, and subsidy in the UK. Lee (Chen & Lu, 2011) demonstrated the effectiveness of ROA for a wind energy project in Taiwan and argued that the value of RE investment increases when underlying price, time to maturity, risk-free rate, and volatility increase. Martinez Cesena and Mutale (EA, 2012) proposed a real options methodology to assess the value of small wind power projects. Policy issues for RE have also been addressed (Hedman & Sheblé, 2006).

The Clean Development Mechanism (CDM) for RE projects is another important issue that has been studied. Additionally, investment in RE projects in developing countries has also been explored (EA, 2012). Particularly, Kurbatova and Khlyap (Venetsanos, Angelopoulou, & Tsoutsos, 2002) and Kaygusuz (Ashuri, Kashani, & Lu, 2011) argued that political and economic factors encourage developing countries to develop RE projects and new energy policies, and that RE strategies be changed with consideration to the increasing levels of future energy consumption. Huenteler (Martínez & Mutale, 2011) suggested the role of donor countries in helping developing countries ease the high uncertainty of feed-in tariff. The uncertainty of project cash flow is much more important in RE projects than in traditional energy projects. Venetians et al. (Venetsanos, Angelopoulou, & Tsoutsos, 2002) developed an evaluation method for uncertainties associated with wind energy projects after deregulation of the electricity market in Greece. Kumbaroğlu et al. (Reuter, Fuss, & Obersteiner, 2012) presented a policy planning model integrating learning curve information on RE technologies into a dynamic programming formulation featuring ROA in a Turkish case. Many researchers evaluated RE projects by taking into account volatility within economic, environmental, and technical factors. Kim et al. (Ashuri, Kashani, & Lu, 2011) Identified three key variables (energy production, tariff, and O&M costs) to understand uncertainty in hydropower projects in Korea, and forecasted the future energy production derived from the projected future precipitation. Zhang et al. [14] suggested a ROA model for evaluating solar photovoltaic (PV) power projects in China, by considering variable factors including CER price, non-renewable energy cost, investment cost, and tariff. Detert and Kotani (Palanichamy & Sundar, 2004) compared coal-based power and renewable energy by
Ngetich, Chebii and Hakizimana

considering the sole uncertain cost of coal in Mongolia. Jeon et al. (V., 1999) Proposed a real option model to estimate optimal subsidy in PV investment, reflecting uncertainties such as tariff, energy production, interest rate, risk premium, risk free rate, and the exchange rate in Korea.

Previous studies focused their scope in the developed countries only like UK, Korea, Greece, Norway and there are very few that focus their studies on Renewable energy projects in the developing countries like Africa especially East Africa. Renewable energy is characterized by uncertainties influenced by costs during development stage and cash flow during production stage. Typical development costs include site survey, feasibility study, design, and construction. These costs are subject to private risk, as opposed to market (public) risk. Cash flow during the production phase is typically calculated as the net of expected revenue minus production costs (Martín et al., 2011). Cash flow is usually influenced by market risk only (EA, 2012). The Marketed Asset Disclaimer (MAD) approach is applicable to both market and private risks (Hedman & Sheblé, 2006). This approach presents the practical challenge of developing a cash flow model and associated subjective input variables. However, because the MAD approach is applicable to any investment (Reuter WH, 2012), it was adopted in the ROA framework for RE projects. Accordingly, this paper seeks to provide a Real Option Analysis framework applicable to various energy sources of Renewable Energy and also considers the whole process of project investment in developing countries.

Finally recently, the study by (Kim et al., 2018) ROA has been more frequently applied for valuation of RE projects. ROA has been used for various types of RE, including hydropower, wind farms and solar energy. Studies have been conducted to improve ROA methodology for RE. Policy issues for RE have also been addressed. The Clean Development Mechanism (CDM) for RE projects is another important issue that has been studied. Additionally, investment in RE projects in developing countries has also been explored. Particularly, Kurbatova and Khlyap and Kaygusuz studies argued that political and economic factors encourage developing countries to develop RE projects and new energy policies, and that RE strategies be changed with consideration to the increasing levels of future energy consumption. Huenteler suggested the role of donor countries in helping developing countries ease the high uncertainty of feed-in tariff (Huenteler, 2019).

4. Methodology

Previous studies have shown several framework for evaluating energy investment projects. The framework is applicable in accessing feasibility analysis of different Renewable Energy projects. The projects needs critical evaluation due to its volatility and its uncertain nature. Herath and park came up with multiple- stage decision making framework for evaluating project (Herath & Park, 2002). Kodukula & papudesu introduced a four step and six step decision making framework respectively (Kodukula & Papudesu, 2006). ROA for geothermal energy resource projects and other RE in developing countries, is a new and vital framework in the theory of investment decision. Each stage of the framework provide a gateway into the next stage. Strengths and weakness which occur in each stage gives investor time to make timely valuable and informed decision regarding the project. The decision have to contend with; time to invest, abandon for a while, stop a project or to invest in different technology and so on hence investor can make decision that will positively influence the project final value.

The proposed framework has four steps;
**Step 1** is the investment scenario development for a particular RE project considering the specific natural energy source. Here, the project timeline is developed and split into three different phases of planning, design, and construction and operation. These phases are determined by the timing of cash inflow from investor.

**Step 2** is the cash flow development for predicting future cash flow. The main variables identified in this step include energy production, tariff, price of certified emission reductions (CERs), and operation and maintenance (O&M) costs.

**Step 3** is the real options valuation of the RE project. To estimate the volatility of a project's value, a three-point estimation technique (best, worst, and most-likely) is adopted. A compound option model with a binomial lattice structure is also adopted in this step to represent the sequential nature of RE projects.

**Step 4** This is the decision making step where final decision regarding whether or not to invest in the project. The decision is made by comparing the real option value with the NPV. Sensitivity analysis is also conducted to quantify the impact of each variable on the value of the project.

### 4.1 Compound option analysis

Compound option is a complementary approach for risky and uncertain assessments. In risky investments under option valuation, there are three option embedded in the project— the option to expand, delay or abandon an investment after gaining new information or resolving uncertainties. A capital investment includes the planning, design, construction and operation phases, each of which requires a go/no-go decision.

Negative net present value investments destroy value and should not be accepted. The option to delay is in valuation of assets that are not viable today but could be viable in the future. Option to expand scenarios implies that firms make investments that make them lose money in initial stage in the hope to expand into other markets. Taking investment in stages allows investors to decide whether to enter the market in full scale in order to capture economies of scale or to abandon the project.

![Figure 1. Compound valuation](image)

### 4.2 Real Option Valuation

This valuation reformulates the NPV so that the scenarios of great uncertainty, which compose the investments, are considered. Risks from uncertainties affect the volatility of cash
flow. A high level of uncertainties indicates a high level of risk and corresponds with extremely volatile cash flow (Kyeongseok, Hyoungbae, & Hyoungkwan, 2016). These characteristics of uncertainty should be carefully analyzed and understood in order to be minimized at all costs. RE projects in the developing countries are characterized by numerous uncertain factors such as inflation, interest rate, tax, exchange rate, planning cost, design cost, site acquisition cost, construction cost, insurance cost, operation and maintenance cost, change in laws, natural disasters, political instability, CER price, energy production, tariff, and concession periods. However, it is vital to choose the main variables that will have maximum influence on the project's profitability and thus allow investor to concentrate on them to ensure the project is a success.

The proposed framework identifies the following as major key variables tariff, O&M cost, energy production, and CER price citing the following reasons, first, economies of developing countries are known to be very unstable characterized by high inflation and interest rates. Thus, it is crucial to consider the variables of tariff and O&M cost, which can reflect high inflation and interest rates. Tariffs however are specified by the power purchasing agreements, which in turn are based on the relevant governments’ RE policy schemes. RE tariff also specify the compensation for initial investment, O&M costs, subsidies provided as investment incentives, and the base price of electricity; these components of the tariff are affected by the inflation and interest rate of the developing economy. CERs under the Kyoto Protocol are a key incentive for investing in RE projects in developing countries. CER price tends to change randomly according to market demand (IEA, 2016), so in order to better control the risk associated with the CER price, it is also selected as a key variable.

As earlier pointed out MAD and the three-point estimation technique was used for the real option analysis of geothermal energy project in the developing countries. The MAD approach allows for the use of the traditional concept of discounted cash flow: the underlying asset value can be calculated from the present value of the most-likely cash flow scenario. The most-likely (moderate) scenario is the situation between the optimistic (best) scenario and pessimistic (worst) scenario. Table 1 shows input variables used to calculate cash flow for RE projects in developing countries. Cash flows for each of the three scenarios are obtained by combining the multiple uncertainties of input variable.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Best case</th>
<th>Moderate case</th>
<th>Worst case</th>
</tr>
</thead>
<tbody>
<tr>
<td>O &amp; M</td>
<td>O &amp; M_best</td>
<td>O &amp; M Moderate</td>
<td>O &amp; M_worst</td>
</tr>
<tr>
<td>Tariff</td>
<td>Tariff_best</td>
<td>Tariff Moderate</td>
<td>Tariff_worst</td>
</tr>
<tr>
<td>CER price</td>
<td>CER price_best</td>
<td>CER price Moderate</td>
<td>CER price Worst</td>
</tr>
<tr>
<td>Combined</td>
<td>Cash flow_best</td>
<td>Cash flow Moderate</td>
<td>Cash flow Worst</td>
</tr>
</tbody>
</table>

If the project is assumed to follow a lognormal distribution, the volatility can be estimated using the following equations (Ashuri, Kashani, & Lu, 2011):-
\[ \sigma = \frac{\ln\left(\frac{S_{\text{opt}}}{S_{\text{pcr}}}\right)}{4\sqrt{t}} \]

Where \( S_{\text{opt}} \) is the underlying asset value under the optimistic scenario, \( S_{\text{pcr}} \) is the underlying asset value under the pessimistic scenario, and \( t \) is the project period. Option values are calculated by the binomial lattice model. Up movement (\( u \)), down movement (\( d \)), risk-neutral probability (\( q \)), and option value (\( C \)) are estimated using the following equations:

\[ u = e^{\theta \sqrt{\Delta t}} \]

\[ d = \frac{1}{u} \]

\[ q = \frac{e^{rt} - d}{u - d} \]

\[ c = e^{rt}[q c_u + (1 - q) c_d] \]

Where \( r \) is the risk free interest rate, \( c_u \) and \( c_d \) are the option values associated with up and down respectively.

**4.3 Application of the proposed framework to a Kenya’s geothermal energy project**

The national government has a set goal of increasing the share of Renewable Energy in its energy mix from 22% in 2015 to over 90% in 2025 in its national Energy Policy (KNBS, 2009). However, lack of public funding many renewable energy projects are implemented by Public Private Partnerships and Independent Power Producers (IPP). Kenya’s foreign investors and government needs an efficient and effective analysis tool that clearly considers all the risks and uncertainties associated with renewable energy in Kenya.

**4.3.1 Project case study- Menengai Geothermal Project**

Menengai Geothermal Project is situated within the Eastern sector of the African Rift system, about 180 km Northwest of Nairobi in Kenya. The project aims at meeting Kenya’s rapidly increasing demand for power while diversifying sources of power supply by developing the country’s huge geothermal potential, consistent with Kenya’s green growth vision. More specifically, the project aims to develop the Menengai geothermal steam field to produce enough steam for 400 MW power that will be generated by the private sector as Independent Power Producers (IPP). Table 2 lists the details of the case study project in condition of the moderate (most-likely) case. The total project cost is US$746 million and the project period is 30 years, as shown in Table 2. As mentioned above, four variables most likely to affect the volatility of this project were considered: tariff, O&M cost, energy production, and CER price.

**Table 2. Details of the case study** (GDC 2019)
Though the investment (construction) cost is certainly an important variable, it was assumed to be a fixed factor in this study. The periods of planning, designing, construction and operational is 1, 1, 4 and 30 respectively. Investors have 3 opportunities to make decisions i.e. whether to invest at the planning stage at year 1 and also at year 1 whether to proceed to Design stage and at year 3 whether to construct the geothermal energy project. Based on the ROA framework illustrated in Fig. 1, the RE project was valuated. In step 1, a scenario involving investment timing was developed. The planning cost which includes costs related to preliminary survey, permits, market analysis was assumed to be US$1 million and occurring now (year zero). The result of the planning phase affected the decision to continue to the design phase and determined whether the next step would be taken or the project abandoned. The investment cost of the design phase which involves cost associated with feasibility study, contracts, insurances, well testing and drilling 2 boreholes among other contingencies related to design of the project was US$10 million, and its timing was one year later. Likewise, the result of the design phase affected the decision to invest US$735 million in the construction, operation phase and the steam field development which will be done in 3 years and operate for 30 years. The construction time was three years and the operation period was 30 years.

In step 2 of the ROA framework, the key variables were identified to allow for computation of the projects’ cash flow. Table 5 shows the values of the four variables for each of the three scenarios: moderate, best, and worst. These were later used to estimate the volatility of the project value. However, the moderate case was used to generate the future cash flow used to estimate the current value of the underlying asset. Table 3 shows the cash flow in the moderate case. Revenue was the positive value obtained from the energy production and tariff. Energy production was assumed to be constant throughout the project lifespan. The tariff increased with inflation over time. O&M cost was a negative value that increased over time due to inflation. CER revenue was also estimated to remain constant throughout the project's operation period. The conventional NPV was US$ 39.9 million in the moderate case. In step 3, three-point estimation was carried out to provide a range of values for each of the variables, in each of the best, moderate, and worst scenarios. In the case of tariff, the value for the moderate scenario was increased by 30% to estimate the best-case value, and was decreased by 30% to estimate the worst-case value. Similarly, the O&M cost value in the moderate scenario was increased by 30% for the worst scenario and decreased by 30% for the best scenario. Energy production was assumed to be 76.5% of the maximum capacity (100%) in the moderate scenario, and production in the worst scenario was assumed to be 53.55 %, a value decreased by 30% from that of the moderate case. The efficiency of energy production was estimated taking into consideration operation time, runoff, and machinery.
Table 3. Variables of the case study project under the three-point estimation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Best</th>
<th>Moderate</th>
<th>Worst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity tariff</td>
<td>11.05 usd/kwh</td>
<td>8.5 usd/kwh</td>
<td>5.95 usd/kwh</td>
</tr>
<tr>
<td>O &amp; M costs</td>
<td>0.014 usd/kwh</td>
<td>0.02 usd/kwh</td>
<td>0.026% usd/kwh</td>
</tr>
<tr>
<td>Efficiency of production</td>
<td>100%</td>
<td>76.5%</td>
<td>53.55%</td>
</tr>
</tbody>
</table>

Figure 2. The compound option model of the case study project.

Using the MAD approach, the cash flows in the moderate scenario were discounted back to a present value using the risk-adjusted interest rate for calculation of the asset value at the present time. The current value of the underlying asset in the moderate scenario was US$737.5 million. The yearly volatility of project return was estimated to be 14.32% using Eq. (1). The use of Eq. (1) required making assumptions regarding the underlying asset values under the optimistic and pessimistic scenarios (Fig. 2). The up movement (u), down movement (d), and risk-neutral probability (q) were estimated to be 1.1540, 0.8665, and 0.6794, respectively, by using Eqs. (2)–(4). The compound option values of the case study project were calculated using the binomial lattice and Eq. (5). The option value (strategic net present value; SNPV) of the project was estimated to be US$79.8 million. Investors could make various investment decisions at each node of the binomial lattice. The three investment decisions were US$1 million for the planning phase, US$10 million for the design phase, and US$735 million for the construction and operation phase. At the current time (node 1), if the start-up cost were larger than the option value the project should be abandoned. However, because the initial investment cost is only US$1 million, the project is worth pursuing. If the market uncertainty does not disappear by the end of the design phase, the project should be abandoned and the investment for the construction and operation phase declined. Otherwise, the project would continue. At node 2, execution of the option at the expense of US$10 million to fund the design phase would generate an option for the construction and operation phase. This would produce the option value of US$79.8 million. However, at node 3, the economic situation is not favorable for the investment, so the project is abandoned. At year 2, the investor makes a final decision regarding whether to advance to the phase of construction and operational. If the project turns out to be economically feasible, as shown at nodes 4 and 5, the investment is executed. When examining nodes 4 and 5, node 4 presents a more ideal situation, as the option value is US $48.2 million, with the cost of US$140.1 million. At node 5, the option value is only US$ 1.3 million. However, at node 6, representing the worst case, the project is considered to be unfeasible and investing in the construction is declined.
The project NPV calculated in the traditional way was US$ 39.9 million under the moderate scenario. Since the SNPV was US$79.8 million (twice the value of the NPV) the real option premium was US$39.9 million. In step 4, for sensitivity analysis of the four key variables affecting the option value of the case study project, a Monte Carlo simulation of 100,000 iterations was conducted. Each variable was assumed to have a triangular probability distribution, with the maximum, minimum, and mean parameters assumed to be equal to the best, worst, and moderate values. The sensitivity analysis showed that tariff (52.4%) was the most influential factor, followed by energy production (40.5%), CER price (4.0%), and O&M cost (−3.1%). The sensitivity outcomes of tariff and energy production totaled more than 90%, meaning that these two factors strongly impacted the option value of the project as shown in figure 6. However, O&M cost negatively influenced the option value. In brief, the sensitivity analysis of the case study showed that investors must focus their attention on improving tariff and energy production to effectively increase profitability.
This study showed that the valuation of geothermal power generation project using NPV method underestimates the value of the project rather than ROA. The ROA method assesses projects based on options in the implementation of a project. In ROA approach where we only executed the project if best scenario occurred, we obtain better value of the project and risk has been reduced. The main objective of this study was to also assess the uncertainties associated to geothermal energy development in the developing countries and how it affects its feasibility in these regions whereby ROA framework has been considered the best tool to serve this purpose. This study considered the following key variables that directly influence the projects’ profitability: tariff, energy production, CER price, and O & M cost in a geothermal project in the developing country. The ROA uses these key variables to yield results that will lead the investor to a proper and informed decisions regarding the investment. The decision makers and the investors with this framework have an opportunity
to fund or abandon the project at each project stage as long as the market uncertainty could be manageable.

It’s definitely clear that this proposed framework properly reflects the uncertainties and also assess the economic viability of the project. The case study of Menengai geothermal project provided a meaningful findings. The framework is an effective tool for assessing the investment’s economic feasibility, since it considers the uncertainties associated with renewable energy projects in developing countries. Compound option model was designed to consider multistage investment timing for the planning, design, and construction phases. To maximize the profit of RE projects in developing countries, investors should take into account the following order of priority among the variables: tariff, energy production, CER price, and O & M cost.

However, the limitation of this study is that it lacks more accurate quantification of project uncertainty due to lack of information on how uncertainties on RE projects in developing countries will fluctuate with climate change, environmental policies and the economic status. Therefore, as a recommendation for future research, then a more accurate quantification of a project uncertainty will be an important area to consider to allow for better management of risks and uncertainties of RE projects in developing countries.

REFERENCES


