Determining the Sustainability of a Community Micro Hydro Power System using Real Options Analysis

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Abstract. Micro hydro power is a clean source of renewable energy that has been utilized for remote communities for electricity generation. The technology is mature and operates the same principle as large hydroelectric power plant but with much lower power capacity. Sustainability relies on the financial and other benefits brought about the micro hydro power plant during its operation. Traditional valuation method is often used to valuate micro hydro projects however it does not incorporate uncertainty factors, specifically unpredictable changes in weather. Real Options Analysis, on the other hand, uses both the Black-Scholes Model and Binomial Tree Method which incorporates uncertainty. The valuation obtained through real option analysis represents the net present value of the project with decision flexibility option for the investor. In this study, real options analysis is applied to a micro hydro power plant to identify its financial sustainability. Head and flow rate are obtained to calculate the capital investment, electrical sales, maintenance, and cost of operating nearby agricultural facilities. Traditional financial valuation method revealed a positive outcome making the project financially viable. However, real options analysis provided a contradicting result indicating the implementation of the project should be delayed.

1. Introduction

Depending on country standard, micro hydro power or MHP mostly belongs to hydroelectric power plant with a capacity between 1kW to 100kW [1]. MHP has been utilized for electricity generation in remote areas in many countries as practical solution for both off-grid and grid connected systems [2, 3]. In the Philippines, MHP has a major contribution to the government's rural electrification program with a potential capacity of 27,000 kW [4]. In Indonesia, MHP accounts for 0.1% of the consumed renewable energy power which accounts for 2,600 KW installed capacity out of a potential of

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143,845.3 kW [5]. In west Malaysia, a total of 109 MHP sites have been identified through a reconnaissance study totalling to 20,400 kW of potential power [3]. Micro hydro power potential is evident in many areas of energy and the factors that affect its sustainability should be identified. One of these factors is the hydrology. The hydrology directly affects the power output of a hydro power plant and therefore ultimately affects the financial benefits in which the sustainability is dependent upon. Zohrabian and Sanders [6] indicate that severe dry season in the California power sector will increase the need for the natural gas power plant to account for losses in hydro power generation. Shadman et al. [7] identified Malaysia, Indonesia, and the Philippines as the potential for MHP and as such should consider drought probability in its planning. Anugrah et al. [8] have also studied the effects of climate change to several MHP installations in West Sumatra indicating power generation changes as high as 15.7%. A clear methodology is therefore necessary for determining the sustainability of the system considering hydrology as an uncertainty factor. Zema et al. [9] have developed methodology to evaluate the feasibility of low head MHP plants installed in irrigation systems. Similarly, another methodology presented by Signe et al. [10] is based on a linear approach to identify the feasibility of the MHP project. Both studies used traditional discounted cash flow methodology to evaluate financial viability of the project. However, discounted cash flow methodology assumes constant cash flow where it is assumed that the power output and hence, the financial benefits are constant throughout the life of the power plant. It is, therefore, necessary to evaluate the project considering the uncertainty of hydrology. Real options analysis provides a suitable evaluation method as it has been used in analysing energy projects characterized by uncertainty. This has been shown in the various case studies by Santos et al. [11] on small hydro power plant with variability of market price as uncertainty, Zhang et al. [12] on solar energy with varying market price and other cost and Barroso and Iniesta [13] on wind energy incorporating public acceptance as uncertainty. This study aims to evaluate the sustainability of a micro hydro power plant incorporating hydrologic uncertainty using real options analysis. The real options analysis results are then compared to the traditional financial valuation method results.

2. Real Options Analysis and the Binomial Tree Method
The methodology in this study follows the binomial tree pricing method which reflects the option to decide whether it is best to invest in the project now or to delay up to a maturity date that can be divided into discreet subperiods $\Delta t$ [11]. It is assumed that the price of the underlying asset will have a random behavior of going up by $\mu$, or going down by $d$, at each subperiod $\Delta t$. $\mu$ and $d$ are random coefficients which are dependent on the volatility, $\sigma$, and subperiod length, $\Delta t$. The random coefficients are computed using equation 1 and 2 in which defines the movement of the project value in a two-step binomial tree model shown in Figure 1.

$$\mu = \exp(\sigma \sqrt{\Delta t})$$  \hspace{1cm} [1]

$$d = \frac{1}{\mu}$$  \hspace{1cm} [2]
Each box in Figure 1 denotes each node of the binomial tree, where the upper figures represent the movement of the value of the project being considered. The probability that the value of the project will go up is given in equation 3 while the probability that the value of the project will go down is given in equation 4 where \( r_f \) is the theoretical zero-risk rate of return. On the other hand, the bottom figures in the box solve for the value of the option, \( f \), through equations 5 to 7.

\[
p = \frac{\exp(r_f \Delta t) - d}{\mu - d} \quad [3]
\]

\[
q = 1 - p \quad [4]
\]

\[
f_u = \exp(-r_f \Delta t) [pf_{uu} + (1 - p)f_{ud}] \quad [5]
\]

\[
f_d = \exp(-r_f \Delta t) [pf_{ud} + (1 - p)f_{dd}] \quad [6]
\]

\[
f = \exp(-r_f \Delta t) [pf_u + (1 - p)f_d] \quad [7]
\]

The parameters \( f_{uu}, f_{dd}, \) and \( f_{ud} \) (or \( f_{du} \)) are based on the payoffs of the option on the terminal node where \( S \) is the present value and \( K \) is the option exercise price. It should be noted that the model can be extended to an N-step binomial tree model, and that the value of the option will always start at the option payoffs based on the terminal node of the model [12].

3. Case Study: Application of ROA to an MHP Project Financial Feasibility Assessment

The MHP case study is located in the village of Pilar located north of Cabayog City in the Western Samar Island of the Philippines. The case study has an estimated power output of 72 kW with a head of 62 m based on the average annual flow rate. The project objective is to provide power to nearby agricultural machineries with an estimated power demand \( (P_{ag}) \) of 8 kW operating at \( (T_{ag}) \) equal to 488 hours/yr while the surplus energy will be sold to a local grid.

3.1. Evaluation of present value, \( S \)

The present value \( S \) is based on the revenue generated from electricity produced by the MHP plant and its annual cost. The revenue is a function of average power output \( (P) \), operating hours \( (Hr) \) and tariff rate \( (R) \) as in equation 8. \( P \) is equal to 72 kW while it is assumed that the MHP operates 24 hours per day at 360 days a year. In the Philippines, commercial MHP under the renewable energy service contract will have its selling price fixed at US$ 0.11 per kW-hr for 25 years for this particular case study.

\[
Revenue = P \times Hr \times R \quad (8)
\]

The annual cost for the case study is based on the operation and maintenance cost \( (C_{OM}) \) which is divided to fixed maintenance cost \( (FC) \) and variable maintenance cost \( (VC) \). Depreciation cost \( (C_{DE}) \)
and Cost to operate agricultural machineries ($C_{AG}$) are also included in the annual cost. FC is calculated based on the electromechanical cost ($C_{EME}$) multiplied by a factor $m_1$ in addition to the factor $m_2$ multiplied to the civil engineering cost ($C_{CE}$) in equation 9 [14]. The electro mechanical cost ($C_{EME}$) is calculated based on $P$ and $H$ by equation 10 in US$ [15]. $C_{CE}$ is evaluated as a fraction of the total investment cost ($K$) with the assumption that the ($K$) is the sum of the $C_{EME}$, $C_{CE}$ and, $C_{ED}$; where $C_{ED}$ is the engineering and design cost. $C_{ED}$ is evaluated as a percentage $f$ of $K$ between 5 – 10% [15]. The $C_{CE}$ cost is then calculated using equation 11.

\[
FC = (m_1)C_{EME} + (m_2)C_{CE}
\]  
\[
C_{EME} = 13560 \left( \frac{P}{H^{0.2}} \right)^{0.56}
\]  
\[
C_{CE} = (1 - f)K - C_{EME}
\]  
\[
VC = C_{CE}(r_k)
\]  

VC is the cost incurred by repair or replacement of major components of the power plant. VC can then be evaluated as a fraction of the $C_{EME}$ with a life span $n_k$ in equation 12. Finally, the cost to operate agricultural machinery $C_{AG}$ is the product of $P_{AG}$, $T_{AG}$ and the local grid electricity rate $P_{EL}$.

The annual revenue for the MHP case study is 62,938.65 US$. Operation and maintenance fraction for electro-mechanical and civil engineering $m_1$ and $m_2$ is evaluated at 2.5% and 1.5%, respectively which will result to an $FC = 610,989$ US$/yr, $VC = 23,231$ US$/yr, and $C_{AG} = 426$ US$/yr. The calculated stock price ($S$) discounted at 13% results at US$ 384,777.43.

3.2. Evaluation of Exercise price ($K$)

The exercise price of the MHP case study is calculated given $H$ and $P$ using correlated data on hydro sites from the north western region of the UK using Equations 13 and 14 for high head and low head MHP, respectively [15]. The MHP case study falls in the high head category which yields $K = US$ 354,716.3.

\[
K = 25000 \left( \frac{P}{H^{0.35}} \right)^{0.65}
\]  
for heads between 2-30m  
\[
K = 45500 \left( \frac{P}{H^{0.3}} \right)^{0.6}
\]  
for heads between 30-200m

3.3 Time to option expiration, ($T$) and Evaluation of Volatility ($\sigma$)

The MHP case study is based on a commercial hydro power scheme under the Department of Energy Philippines Renewable Energy Service Contract with a 2-year Pre-Development Stage involving preliminary assessment and feasibility study of the MHP project [4]. The volatility is based on the hydrology yearly flowrate variation. For the case study, it is assumed that the rainfall during the commercial phase of the MHP will have similar variation based from rainfall data from the year 1991 to 2015 in Figure 2. Taking the percentage standard deviation of the rainfall will yield to 14.6%.
Figure 2. Philippine rainfall 1991-2015

4. NPV, IRR Payback Period and ROA results of the MHP Case Study

The calculated static net present value of the MHP case study with discount rate of 13% is at US$30,061.17 with a payback period of 7.25 years with an IRR of 14.2%. Figure 3 shows the four-step binomial tree model to analyse the real option.

In Figure 3, the expanded NPV of the project is US$69,265.49 shown in the first decision node. This results in a deferral option value of US$39,204.33 which is higher than the static NPV of US$30,061.17 resulting in a delay option. The 2nd subperiod provides two options of invest or delay. The option to invest or delay is based on the difference of the project value to that of the exercise price. In the 2nd subperiod, the invest option will result in invest or delay options in the 3rd subperiod. On the other hand, the delay option in the 2nd subperiod will result to two delay options in the 3rd subperiod. The delay option in the 3rd subperiod with US$384,583.51 project value will result in an invest or delay option in the 4th subperiod providing a positive outcome for the project. The other delay option in the 3rd subperiod with USD$312,995.9 project value will result in only delay options in the 4th subperiod and ultimately abandon at the final subperiod.

5. Conclusion

The paper has demonstrated the use of ROA and binomial tree methodology as an extension of the traditional financial evaluation methods. For this particular case study, the present value S of US$384,777.43 is only US$39,204.33 of the exercise price K. Although the NPV is positive, ROA results
suggest that the project should be delayed and should be evaluated again with a more favourable condition or with additional information. The ROA results also indicate a relatively high probability of failure as indicated in the abandon option at the 5th subperiod. It is also important to note a critical result in 3rd subperiod where the delay option with the project value of US$312,995.9 will ultimately lead to abandon option. Further studies using ROA should be considered as the financial analysis is affected by the assumptions in obtaining the net present value namely: (1) full power production, (2) fixed power demand and price for agricultural machinery, and (3) fixed discount rate. Both NPV and ROA results may also be attributed to the cost assumptions as the cost equations are based on European data in which may result in higher exercise price $K$. Future studies should then consider other cost estimates and other uncertainty factors.

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