Real options analysis for photovoltaic project under climate uncertainty

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Abstract. The decision on photovoltaic project depends on the level of climate environments. Changes in temperature and insolation affect photovoltaic output. It is important for investors to consider future climate conditions for determining investments on photovoltaic projects. We propose a real options-based framework to assess economic feasibility of photovoltaic project under climate change. The framework supports investors to evaluate climate change impact on photovoltaic projects under future climate uncertainty.

1. Introduction

Solar power plays an important role as a renewable energy, accounting for 139GW in the 2013 world energy market [1]. Photovoltaic (PV) cells transform solar energy into electricity through a semiconductor junction [2]. PV systems has the advantage of being able to be installed in any place with any size, unlike hydropower and wind power. However, climate-related risks affect the production of solar energy. Two major risk factors in solar power are temperature and insolation changes. Thus, these climate conditions should be considered for optimum investment in photovoltaic projects.

The 2014 fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) predicted that the climate change will alter temperature and insolation in many areas [3]. In PV projects, the energy production is determined by such climate factors as insolation and temperature, and efficiency of the system. Traditional method of economic analysis could not capture the uncertainty latent in PV projects. Therefore, this study proposes a framework to assess economic feasibility of PV projects under future climate uncertainty. Real options analysis is known to have the ability to consider uncertainty of future scenarios. Real options analysis has originated from financial options by Black and Scholes [4]. Trigeorgis [5], Mun [6], and Copeland and Antikarov [7] improved upon this methodology. Real option analysis can consider management flexibility and volatility of project returns, contrary to traditional discounted cash flow [5]. The proposed framework can provide more accurate analysis of the PV project because flexible response to variability of climate factors is systematically factored in.

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2. Framework for investment decisions

2.1 Steps of the framework

Figure 1 shows the three steps of the proposed framework: identification of project conditions (step 1), selection of key variables (step 2), real options analysis (step 3), and decision-making (step 4).

![Figure 1. Real options-based framework for photovoltaic projects under climate uncertainty](image)

2.2 Evaluation procedures in the proposed framework

2.2.1 Step 1. Identification of project conditions

Step 1 is to identify the project conditions and the project goal. The investors want to reduce the impact of uncertainty and obtain economic feasibility. If market declines severely, management could execute the options to abandon or wait or contract. Investors need to identify project period, uncertainties of the project, and economic conditions such as investment costs, project period, discount rate, risk-free rate, operation and maintenance cost (O&M cost), and inflation.

2.2.2 Step 2. Selection of key variables

Step 2 is the selection of key variables for the real options analysis. Although PV projects can be affected by a range of factors, this study considers two major factors: energy production and tariff (electricity selling price). These two factors directly affect the cash flows of PV projects. The potential energy production \( E \) is given by

\[
E = \eta AQ
\]  

where photovoltaic energy production \( E \) in kWh is a function of the overall efficiency \( \eta \), the area of array \( A \) in \( m^2 \), and the insolation \( Q \) in kWh/m² [8]. According to the Representative Concentration Pathway (RCP) 8.5, 6.0, 4.5, and 2.6 scenarios, insolation is expected to increase in 2100 by 3.6%, 2.5%, 1.9%, 1.1%, respectively [9]. RCPs are separated by four pathways. RCP2.6 is a severe relief scenario, RCP8.5 is very high greenhouse gas emissions scenario, and RCP 4.5 and RCP 6.0 are two intermediate scenarios [3]. Tariff is another significant factor for an investment decision in energy markets. Tariff is determined by the market condition which is consisted with supply and demand. Future tariffs are estimated using historical data. In this study, the future tariff is assumed to follow a leaner regression equation.

2.2.3 Step 3. Real options analysis

Step 3 is the real options analysis for the project. Using the electricity production and tariff information generated in the first step, three cases are developed: best, worst, and moderate (most-
likely) cases. The present value of the most-likely cash flow case is the underlying asset value ($S_0$) used for the options analysis. The volatility ($\sigma$) of the project value is estimated using the following equation [10]:

$$\sigma = \frac{ln\left(\frac{S_{\text{best}}}{S_{\text{worst}}}\right)}{\sqrt{t}}$$

(2)

where $S_{\text{best}}$ is the underlying asset value under the best scenario, $S_{\text{worst}}$ is the underlying asset value under the worst scenario, and $t$ is the production period of the project.

The binomial lattice model is used with up movement ($u$), down movement ($d$), risk-neutral probability ($q$), and option value ($C$) represented by Equation (3) – (6) [10].

$$u = e^{\sigma \sqrt{\Delta t}}$$

(3)

$$d = \frac{1}{u}$$

(4)

$$q = \frac{(1+r-d)}{u-d}$$

(5)

$$C = e^{-rt}[qC_u + (1 - q)C_d]$$

(6)

where $\Delta t$ is an incremental time step, $r$ is the risk-free interest rate, and $C_u$ and $C_d$ are the option values associated with up and down movements, respectively.

A real options analysis utilizes management flexibility to try lessen uncertainties such as deferral, abandonment, growth, and multistage. Investors should resolve investment decision. The investment cost is the strike price in real options analysis, which could be implemented when the return is larger than the strike price. Otherwise, investors must wait until the project produces expected return. Real option analysis investigates project value by binomial lattice which solve option model using risk-neutral probabilities [6] (Figure 2).

![Figure 2. Binomial lattice approach for real options analysis](image)

2.2.4 Step 4. Decision-making

Step 4 is the step for decision making. If the option value of each node of the binomial lattice is larger than 0, the project is worth investment; otherwise, the project better be abandoned. The result is a good indicator as to the project profitability and a guidance to reasonable selection and execution of the project.

3. A case study of a PV project in South Korea

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A PV project is developed inside a thermal power plant in South Korea with the capacity of 1MW in 2016 and start to operate from 2017. As previously mentioned, step 1 is to identify the project condition.

Table 1. Identification of project conditions.

| Factor                  | Value                                      |
|-------------------------|--------------------------------------------|
| Investment cost         | US$ 2.73 Millions                          |
| Capacity                | 1 MW                                       |
| Efficiency              | 15%                                        |
| Power loss              | 5%                                         |
| O&M cost                | Yearly 0.7% % of the investment cost       |
| Risk-adjusted discount rate | 10.0%                                  |
| Risk-free interest rate | 5.0%                                       |
| Tax rate                | 27.5%                                      |
| Climate change scenarios| RCPs                                       |
| Development period      | 1 years (2016)                             |
| Production period       | 20 years (2017 - 2036)                     |
| Option model            | Option to abandon                          |

Table 2. Information of technical specifications and climatic conditions in case study.

| Category          | factor          | Specification                |
|-------------------|-----------------|------------------------------|
| Technical data    | Module type     | Single-crystalline silicon   |
|                   | Module size     | 1,580L*802W*46T (mm)         |
|                   | Number of module| 6,240 pieces                 |
|                   | Mounting type   | Ground                       |
|                   | Angle of the panel position | 30%                     |
| Climatic conditions| Average outdoor temperature | Spring 12.5 °C               |
|                   | Daylight hour per year | 2,105 hours                 |
|                   | Daylight hour per day  | 5.76 hours                  |
|                   | Average humidity   | 69%                          |
|                   | Average days of yellow dust | 6.5 days               |

Table 1 shows the project conditions of the case study. The case study of PV project is designed for an average annual generation of 1,246.3 MWh in 2017. However climate uncertainty may alter the energy production and tariff may sharply fluctuate. Thus, we investigate the economic feasibility and establish the strategy for investment of the PV project under climate change.

In this study, the type of option is abandonment. Option to abandon is used to select the go/no-go investment decision for obtaining economic feasibility under climate uncertainty using real options analysis. The PV project will be operated for 20 years. However the investor has an option to abandon and resale the asset to the land owner within five year from start of operation at the 50% of investment
cost. Table 2 shows the information of technical specifications and climatic conditions in case study [11].

In step 2, the key variables were selected to develop the project cash flows. Table 3 shows the values of the two key variables for each case: moderate, best, and worst. These values were utilized to create three scenarios of cash flows. The underlying asset was generated through the moderate scenario of the future cash flow. The insolation increase of 3.6% by 2100 on the basis 2010 under RCP8.5 is converted to the best case of annual increase rate of 0.040%. The worst case is 0.012% in RCP2.6. The moderate case is the average value of 0.026%. In case of tariff, we could simulate future tariff during the project period using historical data between 2004 and 2015. However, Schröder et al. [12] found that investment and O&M costs of PV power will be less than a third of the current cost by 2050. Although the tariff of the renewable energy such as wind and PV energy declines due to rapidly changing technologies, the historical data of KPX [13] shows the increase during 12 years as shown in Figure 3. Linear regression was used for simulation of future tariff during the project period. The best case of tariff is assumed to be 200% and worst is 50% of the moderate value.

Table 3. Key variables of the case study project under the best, moderate, worst cases.

| Variable                        | Best       | Moderate  | Worst   |
|---------------------------------|------------|-----------|---------|
| Tariff                          | T × 200%   | T × 100%  | T × 50% |
| Energy production (annual increase) | 0.040%    | 0.026%    | 0.012%  |

Figure 4 shows the revenues in the three scenarios: best, moderate, worst scenario. The volatility of the project was calculated by present value of underlying asset under the best and worst scenarios.
Using step 3, we conducted the real options analysis. Figure 5 shows the binomial lattice calculation which yielded the underlying asset values and option values between 2016 and 2021. Investors have the right to abandon and resell the PV power asset and will obtain 50% of the investment cost. US$1.36 million is the fixed salvage value for the next five years.
In step 4, investors may decide to use the American put option for maximizing project value. The abandonment option can be exercised at any time up to the expiration date. Depending on the outcome of the binomial lattice, the option value of US$ 2.86 million would make the project economically feasible in the year 2016. If the project uncertainty is clear, the project will continue. If the project becomes unprofitable, investors could exercise the abandonment option from 2018 to 2021, as shown in red boxes in Figure 5. The traditional net present value (NPV) of the project was US$ 0.28 million; but the option value was US$ 2.86 million. This result means that the project was quite feasible in case that the abandonment option is included in the project value.

4. Conclusions

This study proposed a framework that copes with the uncertainty of climate change for PV projects. The contributions of this study to the body of knowledge are three-fold. First, the proposed framework can help investors find proper investment strategy in PV projects. Second, the proposed framework can be extended to predict the energy production under different climate scenarios. Third, real options analysis has an advantage to reflect management flexibility to exercise options until project value become positive in PV projects.

Our study is confined to only major factors such as tariff and energy production. Other technical and socio-economic factors that could determine the economic feasibility of PV projects were not considered. Notwithstanding, the outcomes of this study gives an idea for a role of government. Governments can provide abandon and resale options to investors for improved economic feasibility of PV projects.

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