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The Valuation of Photovoltaic Power Generation Based on Real Options

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Abstract: This paper provides a decision analysis of photovoltaic power generation investment based on real option theory. The main purpose is to evaluate the investment of photovoltaic power generation under different uncertainties. We consider investment cost, electricity price, carbon price and government subsidies in this model. The result shows that photovoltaic power generation investment values are negative under the existing investment environment in China, and enterprises should not invest in photovoltaic power generation project. The research results would be useful for photovoltaic power generation project evaluation and the related decision-marking.

Keywords: Photovoltaic power generation; Real options; Carbon emission trading; Least squares Monte Carlo approach

1 Introduction

Currently, the world economy relies heavily on fossil energies, according to the BP Statistical Yearbook, the consumption of petroleum and coal reached 4211.1 million tons and 3881.8 million tons in 2014 respectively. As a result, energy shortage and global warming have become two main challenges hindering the sustainable development of the global economy. Among the approaches to address those environmental problems, renewable energy, which is abundant in resource storage and environment friendly in the mean time, is drawing more and more attention of the whole world. The passing one year sees a sharp increase in terms of the global consumption of renewable energies, which is 12% more than that of 2013. Furthermore, China is one of the leading forces in the using of clean energies, with its consumption increasing 15.1% during 2013-2014 [1].

As an effective way to cut carbon emission, photovoltaic power generation is a promising substitution to the traditional electric-generating approaches like thermal power. Moreover, additional benefits can be gained using renewable clean power generation, as carbon emission trading is becoming a future trend in solving the environmental problems. Carbon emission trading mainly has three types: The emissions trading for the Kyoto protocol, EU emissions trading system (EU ETS) and the regional greenhouse gas protocol (RGGI). It is beneficial to both the developing countries and the developed countries. Because the developing countries can get funds from developed countries while helping to reach emissions targets.

Photovoltaic power generation is a project with large-scale, long-cycle and high-risk. Hence it should be carefully evaluated at the beginning, as huge investment is needed to make the project profitable. As the most commonly used method in evaluating the prospect of projects, Net Present Value method (NPV) may not be enough accurate and may lead to some wrong conclusions. In this paper, Real Option Analysis (ROA) is chosen to investigate the investment of photovoltaic power. By real option theory, the actual investment value of photovoltaic power can be given as:

$$V_{ENPV} = V_{NPV} + V_{ROA}. \tag{1.1}$$

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Enterprise making decisions based on ENPV, enterprise should invest in this photovoltaic power station while V_{ENPV} is positive. On the contrary, enterprise should give up investing in this photovoltaic power station while V_{ENPV} is negative.

Real options analysis have been applied in the evaluation of energy and energy-related investment project. Lund [1] estimated the offshore oil project using real option theory, Venetsanos [2] estimated the value of wind power by real options; Suslick and Schiozer [3] applied real option theory in the risk analysis of petroleum exploration and production; Lin [4] make decisions of environment-pollute though real options theory; Shinozaki and Yoshida [5] evaluated the value of CDM project by real options; Naito [6] used real option theory to evaluate nuclear power plant under the release control electricity market; Huang [7] analysed the power generation cost under carbon trading using ROA; Kim [8] discussed the economical feasibility of solar power system under RPS based on real option; Lin [9] evaluate chines solar by real options; Wang [10] using real option theory to evaluate China's biomass power generation projects with policy benefits; Zhang [11] used real option to evaluate the Photovoltaic power generation under energy policy; Biondi and Moretto [12] used the real option method to analysis Italy Photovoltaic plant project.

The paper is organized as follows. In the next Section, the photovoltaic power station investment model was introduced. In Section 3, the model was analyzed with an example. Finally, the conclusion of this paper was drawn in Section 4.

2 Model Description

2.1 Photovoltaic power generation model

The investment cost of photovoltaic power station includes construction costs and operation costs. Obviously, construction costs are fixed cost and operation costs are variable costs. To simplify, we denote installed capacity by η, fixed cost by $S_1(t)$, variable cost by $A(t)$, investment cost by $I((S_1(t), A(t), \eta)$ and investment time is h year. Here, $I((S_1(t), A(t), \eta)$ satisfies with the following hypothesis [13].

Hypothesis 1:

$$I(S_1(t), A(t), \eta) = (k_1\eta + b_1)S_1(t)\sum_{t=1}^{h}(k_2\eta + b_2)A(t),\ t, h, k_1, k_2, b_1, b_2 > 0.$$

Most photovoltaic power benefits from electricity and subsidy. We denote profits by $\Pi(S_2(t), S_3(t), S_4(t), \eta)$, anything else, we assume project has little influences on long-term electricity and certificate prices. And profits satisfy with the following hypothesis.

Hypothesis 2:

$$\Pi(S_2(t), S_3(t), S_4(t), \eta) = Q(\eta)(S_2(t) + S_3(t)) + \lambda S_4(t).$$

In addition, $Q(\eta)$ satisfies with the following hypothesis.

Hypothesis 3:

$$Q(\eta) = ab\eta.$$

Assuming that the above uncertain factors which satisfies with the geometric Brownian motion given by:

$$\mathrm{d}S_1 = S_1(t)\mu_1^P\mathrm{d}t + S_1(t)\sigma_1\mathrm{d}z_1^P(t), \tag{2.1}$$

$$\mathrm{d}F_2 = F_2(t,T)\mu_2^P\mathrm{d}t + F_2(t,T)\sigma_2\mathrm{d}z_2^P(t), \tag{2.2}$$

$$\mathrm{d}I = I(t)\mu_I^P\mathrm{d}t + I(t)\sigma_I\mathrm{d}z_I^P(t), \tag{2.3}$$

$$\mathrm{d}S_3 = S_3(t)\mu_3^P\mathrm{d}t + S_3(t)\sigma_3\mathrm{d}z_3^P(t), \tag{2.4}$$

$$\mathrm{d}S_4 = S_4(t)\mu_4^P\mathrm{d}t + S_4(t)\sigma_4\mathrm{d}z_4^P(t). \tag{2.5}$$

2.2 A least squares Monte Carlo approach to option pricing

Assuming that market price risk as follows:

$$\theta_i = \frac{\mu_i^P + \delta_i - r}{\sigma_i}, i = 1, 3, 4, \theta_2 = \frac{\mu_2^P}{\sigma_2},$$

where r is the risk-free rate and δ_i denote dividend yields. By setting

$$\mathrm{d}z_i^Q(t) = \mathrm{d}z_i^Q(t) + \theta_i \mathrm{d}t, i = 1, 2, 3, 4,$$

the above GMB can be written as

$$\mathrm{d}S_1 = S_1(t)(r - \delta_1)\mathrm{d}t + S_1(t)\sigma_1 \mathrm{d}z_1^Q(t), \tag{2.6}$$

$$\mathrm{d}F_2 = F_2(t, T)\sigma_2 \mathrm{d}z_2^Q(t), \tag{2.7}$$

$$\mathrm{d}I = I(t)(r - \delta_I)\mathrm{d}t + I(t)\sigma_I \mathrm{d}z_I^Q(t), \tag{2.8}$$

$$\mathrm{d}S_3 = S_3(t)(r - \delta_3)\mathrm{d}t + S_3(t)\sigma_3 \mathrm{d}z_3^Q(t), \tag{2.9}$$

$$\mathrm{d}S_4 = S_4(t)(r - \delta_4)\mathrm{d}t + S_4(t)\sigma_4 \mathrm{d}z_4^Q(t). \tag{2.10}$$

By using Ito lemma and equation (2.7), it gives

$$\mathrm{d}S_2 = S_2(t)\mu_2^Q \mathrm{d}t + S_2(t)\sigma_2 \mathrm{d}z_2^Q(t). \tag{2.11}$$

During the choice process of investment opportunity and installed capacity, we should consider the following factors: investment cost, feed-in tariff, carbon price and subsidy. Assuming that investment is infinite, project value $V(S_2(t), S_3(t), S_4(t), \eta)$ is independent of time, and the expected rate of return equals risk-free interest rate, then we obtain the instantaneous profit at dt given by:

$$E[\mathrm{d}V] + \Pi(S_2(t), S_3(t), S_4(t), \eta)\mathrm{d}t = rV\mathrm{d}t.$$

By using ITO formula, we get the following formula:

$$\mathrm{d}V = \frac{1}{2}\sum_{i=2}^{4} \frac{\partial^2 V}{\partial S_i^2}\mathrm{d}S_i^2 + \sum_{i=2}^{4} \frac{\partial V}{\partial S_i}\mathrm{d}S_i = \frac{1}{2}\sum_{i=2}^{4} \frac{\partial^2 V}{\partial S_i^2} S_i^2 \sigma_i^2 \mathrm{d}t + \sum_{i=2}^{4} \frac{\partial V}{\partial S_i}(S_i \mu^Q \mathrm{d}t + S_i \sigma_i \mathrm{d}z_i^Q).$$

Here, photovoltaic power investment value is a solution of the following partial differential equation(PDE):

$$\mathrm{d}V = \frac{1}{2}\sum_{i=2}^{4} \frac{\partial^2 V}{\partial S_i^2}\mathrm{d}S_i^2 \sigma_i^2 + \sum_{i=2}^{4} \frac{\partial V}{\partial S_i} S_i \mu^Q - rV + \Pi(S_2(t), S_3(t), S_4(t), \eta) = 0.$$

Under hypothesis 2, the solution of the PDE can be solved as:

$$V(S_2(t), S_3(t), S_4(t), \eta) = Q(\eta)(\rho_2 S_2 + \rho_3 S_3 + \rho_4 S_4), \quad \rho_i = 1/(r - \mu_i^Q), i = 2, 3, 4.$$

We calculate the option value next, where the definition of the option value can be written as $C(S_1(t), S_2(t), S_3(t), S_4(t))$, and $S_1(t)$,$S_2(t)$,$S_3(t)$,$S_4(t)$ can be denoted as fixed cost, feed-in tariff, carbon price and subsidies respectively. We obtain the following result under risk neutral valuation, where the rate of return is equal to risk-free interest rate:

$$E[\mathrm{d}C] = rC\mathrm{d}t.$$

Hold options value is the solution of the following partial differential equation:

$$\mathrm{d}V = \frac{1}{2}\sum_{i=2}^{4} \frac{\partial^2 V}{\partial S_i^2}\mathrm{d}S_i^2 \sigma_i^2 + \sum_{i=2}^{4} \frac{\partial V}{\partial S_i} S_i \mu^Q - rC = 0.$$

Now, we concern with the changes of subsidy payments by Markov transformation. Assuming that the Markov transformation is independent of the GBM, then geometric Brownian motion of subsidy payments that be modulated by Markov transformation given as:

$$\mathrm{d}S_4 = S_4(t-)\mu_4^P(X(t-))\mathrm{d}t + S_4(t-)\sigma_4(X(t-))\mathrm{d}z_4^Q(t), \tag{2.12}$$

where $t-$ means the left limit of t, $\mu_4^P(X(t-))$ is the drift and $\sigma_4(X(t-))$ is the volatility. Assuming that the market price conversion risk equals to zero or close to zero, and the market price risk under state k is:

$$\theta_4(k) = \frac{\mu_4^P(k) + \delta_4(k) - r}{\sigma_4(k)}, \qquad k = 1, ..., K.$$

We get the subsidy payments by the martingale measure of Q.

$$\mathrm{d}S_4 = S_4(t-)(r - \delta_4(k))\mathrm{d}t + S_4(t-)\sigma_4(X(t-))\mathrm{d}z_4^Q(t), \tag{2.13}$$

where Q is the equivalent martingale measure of P, $r - \delta_4(k)$ and $\sigma_4(X(t-))$ is the corresponding drift and volatility, $\mathrm{d}z_4^Q(t)$ is the independent increments of standard Brownian motions.

Regarding Photovoltaic power generation investment as a real option, then estimate project value by the least squares Monte Carlo [14].

$$V_{ENPV} = V_{NPV} + C(S_i(t_i)).$$

The enterprise should invest the photovoltaic power when V_{ENPV} is positive or abandon photovoltaic power when V_{ENPV} is negative.

3 Case study

Most photovoltaic power is $10MW_P$ in China, Gansu has rich solar resources, annual total of the solar radiation reaches $4800 - 6400mJ/m^2$, and the reserves of solar resources is 67 trillion kwh, Dunhuang, which is a city in the western of Gansu, has abundant solar resources. The enterprise wants to build a photovoltaic plant in Dunhuang, the relevant parameters are given in the Table 1:

Table 1: Model parameter values

Parameter symbolic	Parameter	Value
I	Photovoltaic power generation cost	20300 million
A	Photovoltaic power generation operating cost	259.22 million/year
	Photovoltaic power generation equipment repair	3248 million
	Photovoltaic power generation debt cost	947.3 million/year
η	Photovoltaic power generation capacity	1.8 million kwh
S_2	Electricity price	0.9 yuan/kwh
S_3	Carbon Price	1.92 yuan/ton
S_4	Government subsidy	0.1-0.5 yuan/kwh
r	Risk-free rate	5%
n	Number of simulations	2000
T	Investment period	25 year
$CERS$	$CERS$	16565 ton

The result shows that the NPV is -7974.05, and the enterprise should abandon invest based on NPV theory. In fact, there are much uncertainties in Photovoltaic power generation. NPV theory is not suitable for this project. However, real options theory is effective for this project. Therefore, we estimate the investment value of the photovoltaic power by real options theory. The number of simulations are set to 2000 and the investment time are divided into 1000 intervals. Simulation results are shown in figure 1 and figure 2.

Figure 1 and figure 2 show that simulates paths of cash flow and optimal stopping time. According to the above model, we calculate the option value by the least squares Monte Carlo simulation method. We get the option value which is $C = 3760.7$, $V_{ENPV} = -4216.35 < 0$. The enterprise should give up investment in photovoltaic power station. Although the result is the same by using two different methods, uncertain factors are taken into account by the real option theory. Thus, real option theory is better than net present value theory.

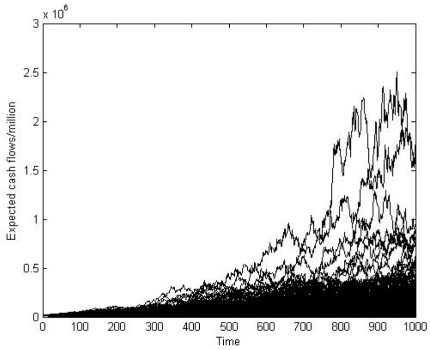

Figure 1: The simulation of PV power generation cash flows

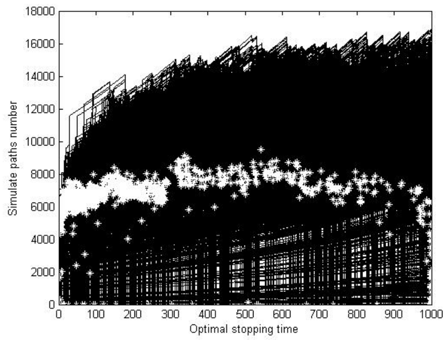

Figure 2: The simulation of optimal stopping

4 Conclusions

This paper established an evaluation model of photovoltaic power under uncertain factors based on real options theory. In this model, we concentrate on the following four factors: investment cost, electricity price, carbon price and subsidies. Considered with uncertain factors by geometric Brownian motion, the model is resolved by the least squares Monte Carlo simulation. After the above analysis, we discussed a case of photovoltaic power in Dunhuang. We found that the option value was 3760.7 and the investment value was -4216.35. Since the investment value is negative under the existing circumstances, enterprise could not have any profitability. In order to avoid losses, enterprise has two choices: one is to give up the investment and the other one is to delay investment until mature conditions.

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