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The valuation of photovoltaic power generation under carbon market linkage based on real options

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HIGHLIGHTS

- Consider the material/labor price fluctuation as a market-linkage to the investment cost.
- The PV subsidy price satisfies with a Markov modulated geometric Brownian motion.
- Get the options value by the least squares Monte Carlo simulation.
- 5 scenarios are presented in the paper including carbon price, electricity price and subsidy uncertainty.
- The result shows that the subsidy is a necessary and key role of PV generation investment.

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ABSTRACT

This paper provides a real option approach to analyze investment value for photovoltaic power generation under carbon market linkage. The primary purpose is to evaluate photovoltaic power generation under uncertainties from the perspective of power generation enterprises. Uncertainties in investment costs, electricity prices, carbon prices and subsidy payments are considered. In addition, the Market Co-movements of investment costs are considered in this study. Dunhuang is taken as a case study to evaluate the value of photovoltaic power generation through scenario analysis. The result shows that the investment value of photovoltaic power generation is negative. Enterprise should give up the investment or delay investment until mature conditions. Moreover, the investment value can be improved by technical improvement, increasing a certain range of subsidy payments, etc. The research presented would be useful for photovoltaic power generation project evaluation and related decision-marking.

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 major challenges hindering the sustainable development of the global economy. Among the approaches to address those environmental problems, renewable energy, which are abundant in resource storage and environment- friendly in the meantime, are 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 substitute to the traditional electric-generating approaches like thermal power. Moreover, additional benefits can be gained by the Clean Development Mechanism (CDM): It is beneficial to both China and developed countries: China can get funds from developed countries when developed countries buy carbon credit of developing countries to reach their emissions targets. China join the CDM in 2002, from 2005 the CDM develop fast and from 2014 China is the largest certified emission reduction (CER) supply country in the world.

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 as the carbon price isn't considered in the

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method, so replaced by Extended Net Value method (ENPV). In this paper, Real Option Analysis (ROA) is chosen to investigate the investment of photovoltaic power. By Real Option Analysis, the actual investment value of photovoltaic power can be given as:

$$V_{ENPV} = V_{NPV} + V_{ROA} \tag{1}$$

Enterprise will make decisions based on ENPV, enterprise will invest PV project when V_{ENPV} is positive, and abandon PV project when V_{ENPV} is negative.

At present, many scholars has devote themselves to the research of energy related, for example, Lund [2] estimated the offshore oil project using real option theory. Ventsanos et al. [3] estimated the value of wind power by real options. Davis and Owens [4] analyzed the optimization of R&D in renewable power by real options. Schwartz [5] discussed the emissions of electricity and R&D by ROA. Suslick and Schiozer [6] applied real option theory in the analysis of petroleum exploration and production. Rmstrong et al. [7] evaluated the irreversible investment project by real options. Lin et al. [8] gave the decisions of environment- pollute though real options. Shinozaki and Yoshida [9] evaluated the value of CDM project by real options. Naito et al. [10] evaluated the nuclear power plant under release control electricity market using real option theory. Lee and Shih [11] evaluated a wind power in Taiwan based on real options. Huang et al. [12] analyzed the cost of power generation under carbon trading using ROA. Kim and Kim [13] discussed the economic feasibility of solar power system under RPS based on real options. Lin and Wesseh [14] evaluated Chinese feed-in tariffs program for solar power generation by real options. Eckhause and Herold [15] gave optimal financing strategies for the CCS in the EU based on real options. Wang et al. [16] evaluated China's biomass power production investment based on a policy benefit real options model. Zhang et al. [17] evaluated PV power generation in China by real options. Biondi and Moretto [18] gave the dynamics of solar grd parity in Italy by real options. Tian et al. [19] proposed a survey on three issues related to Strategic Petroleum Reserves (SPR) policy, and the study proposed a Markov Decision Process model (SPR-MDP). This model is also a stochastic model, it follows that stochastic model has been widely applied in the research of energy related.

In addition, there are also many researches about carbon emission related, for example, Tian et al. [20,21] have further study of the dynamic evolutionary system of carbon emissions. Tian and Fang [22] examined the impacts of carbon tax on energy intensity and economic growth in a novel four-dimensional energy-saving and emission-reduction system with carbon tax constraints, and they explored carbon tax pilot in Yangtze River Delta (YRD) urban agglomerations based on a novel energy-saving and emission-reduction (ESER) system with carbon tax constraints besides [23]. Wang et al. [24] analyzed the energy consumption, and carbon dioxide emissions in China. Tsai et al. [25] elucidated the consumption and CO_2 emissions of fossil fuels and low-carbon energy in the US. Above all, the analysis of investment decision by real option theory is mature. But few of these analysis has considered both the effect of carbon market-linkage to investment cost and the Markov property of government subsidy.

This paper aims to the investment value of photovoltaic power generation, and the model was a combination of energy investment analysis and carbon emission analysis. Uncertain factors were described by geometric Brownian motion, and estimated the value by real options method. It is different from previous research that we consider the market linkage of investment cost, then the result could more close to reality. This paper regards photovoltaic power generation project as a options, to get the investment value by a least squares monte carlo method in scenario analysis part. Then, the influences for investment value of each uncertainty factor were studied. This paper provides enterprise a more accurate and flexible evaluation method.

Real Option Approach has been applied in many renewable energy researches. Obviously, PV power generation is no exception. However, the research of PV power generation under interactive market mechanism was rarer than others. It is the main content of this study. Uncertainties are described by geometric Brownian motion in model, in addition, the Market Causality of photovoltaic power generation cost is considered as a extra uncertain factor in this study. This paper takes photovoltaic power generation as a real option, then evaluating the investment value of photovoltaic power generation using Real Option Approach.

The paper is organized as follows. In the next section, we introduce the photovoltaic power station investment model. In Section 3, we analyze the model with an example and analysis of uncertainties. Finally, we give the conclusion of this paper in section 4.

2. Model description

2.1. Model framework

This research mainly adopts real option method of photovoltaic power generation project for evaluation and decision making, evaluates photovoltaic power generation investment and benefits of the project. The model considering uncertain factors as the investment cost, the price of carbon dioxide, internet tariffs and government subsidies. Other considerations to the cost of the investment market linkage, closer to the actual investment. Specific research framework is as follows:

As shown in Fig. 1, firstly, the uncertain factors are classified, pointed out that the uncertain factors including investment cost and investment income, the price of CERs, tariff and government subsidies for investment income. The determination of the in power consumption, investment costs and investment income were decided whether PV investment has profit. Then this paper constructs comprehensive Monte Carlo least squares method and real option model based on the principle to construct the evaluation model of photovoltaic power generation. Finally through the simulating the photovoltaic power generation invest conclusion in Gansu city of Dunhuang province from different NPV method, comparing with the net present value of scientific rationality and linkage analysis of photovoltaic power generation to achieve profitability.

2.2. PV investment model

PV investment cost includes capital expenditures (CAPEX) and operating expenditures (OPEX). We denote installed capacity by η, CAPEX per capacity by S_1(t), OPEX per capacity by $A(t)$, investment cost by $I(S_1(t), A(t); \eta)$, and investment time is h year. Here, $I(S1(t), A(t); \eta)$ satisfies with the following hypothesis [26].

Hypothesis 1.

$$I(S_1(t), A(t); \eta) = \sum_{t=1}^{h}((k_1\eta + b_1)S_1(t) + (k_2\eta + b_2)A(t)), t, h, k_1, k_2, b_1, b_2 > 0 \tag{2}$$

where $k_i\eta + b_i$ denotes the function of installed capacity, $\sum_{t=1}^{h}(k_1\eta + b_1)S_1(t)$ denotes a linear relationship between installed capacity and CAPEX per install capacity, and $\sum_{t=1}^{h}(k_2\eta + b_2)A(t)$ denotes the OPEX per install capacity of h year.

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