Energy 127 (2017) 594–610

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Defer option valuation and optimal investment timing of solar photovoltaic projects under different electricity market systems and support schemes

Cheng Cheng [a], Zhen Wang [a, *], Mingming Liu [a], Qiang Chen [a], Abimelech Paye Gbatu [a], Xiaohang Ren [b]

[a] Academy of Chinese Energy Strategy, China University of Petroleum-Beijing, 18 Fuxue Road, Changping, Beijing 102249, China
[b] School of Mathematical Sciences, University of Southampton, Southampton SO17 1BJ, UK

ARTICLE INFO

Article history:
Received 25 April 2016
Received in revised form
28 March 2017
Accepted 30 March 2017
Available online 3 April 2017

Keywords:
Optimal investment timing
Defer option values
Electricity marketing reform
Government support schemes
Technological progress
Solar photovoltaic project

ABSTRACT

This paper applies the real options method to analyse the defer option value and optimal investment timing for solar photovoltaic projects in China. The main purpose of this paper is to examine investment behaviours under different market systems and support schemes. This paper further investigates the interaction of technological progress and support schemes. Four scenarios are designed, and the corresponding real options models are established. In the case study, we find that electricity market reform enhances the defer option value in the short term but makes the owners of solar PV projects postpone their investment. Nevertheless, the government can stimulate investment by implementing appropriate support schemes. Additionally, the impacts of different support schemes vary according to the market system. The impacts of feed-in tariffs and price premiums are similar in a regulated market but are different in a free market. The price premium scheme greatly promotes the defer option values in the short term, but the feed-in tariff scheme excels in the long term. A feed-in tariff has a greater impact on reducing the expected execution time and its variance than the price premium. In addition, more attractive support schemes are required when the technological level is improved.

1. Introduction

Similar to many other governments, the Chinese government faces a dilemma between developing the economy or protecting the environment. In past decades, extensive economic development has occurred in China, and China has received a tremendous boost to its economy at the sacrifice of its environment [1]. Coal, which provided approximately 67% of China's primary energy consumption during the past 10 years, plays a very important role in this process [2] and meets most of the energy demand that has been induced by economic development. However, the use of coal is associated with considerable environmental pollution. One of the largest sources of air pollution in China is coal combustion [3]. Industrial and residential coal combustion not only cause high levels of $PM_{2.5}$ and NO_X emissions in Central China but are also partly responsible for SO_2 emissions and acid rain in Southern China [1]. In the midst of these challenges, the Chinese government has promulgated several policies to mitigate the environmental pollution problems [4,5]. These policies include (1) strengthening the supervision of environmental governance, (2) limiting coal consumption and promoting the industrial application of clean coal technology, and (3) increasing the application of clean energy, such as natural gas, solar energy, and wind energy. As part of its strategy, the Chinese government aims to achieve 15% non-fossil fuel energy by 2020.

Solar energy is one of the most promising clean energies for China for several reasons. First, China has abundant solar resources [6]; theoretically, solar energy in China could reach an annual output ranging from approximately 6900 to 70100 terawatt hours (TWh) [7]. Second, the cost of solar photovoltaic (PV) power has decreased. As an example, the PV module cost decreased to approximately 4 yuan/peak watt in 2014, which is approximately one third of the cost in 2010 (13 yuan/peak watt) [8]. Third, the domestic demand for solar power devices has continued to increase

* Corresponding author.
E-mail addresses: ccvincente@163.com (C. Cheng), wangzhen@cup.edu.cn (Z. Wang), liumingming@cup.edu.cn (M. Liu), c_sper@163.com (Q. Chen), pagbatu@gmail.com (A.P. Gbatu), domrxh@outlook.com (X. Ren).

http://dx.doi.org/10.1016/j.energy.2017.03.157
0360-5442/

during the past few years. From 2010 to 2014, the cumulative installed PV power in China increased from 0.8 gigawatts (GW) to 28.2 GW [2], yielding a compounded annualized growth rate of 75.7%. Finally, the Chinese government has made several mid-term and long-term plans for solar energy expansion. In the 12th Five-Year Plan for National Economic and Social Development, the Chinese government projected reaching 50 GW of cumulative solar PV power by 2020 [9]. This figure was later increased to 100 GW to promote the development of the clean energy industry and to improve the environmental quality [4]. Several regulations have been approved to facilitate the development of solar energy from different perspectives, including the provision of government subsidies, market reform, public research and development, low rate loans, and the promotion of solar energy systems.

Abundant solar resources, decreasing manufacturing costs, rapid growth in the demand for solar power devices, and government plans and regulations guarantee that solar energy will become an important energy source in China in the future. Increasing numbers of companies are expected to participate in solar PV projects. However, the levelized cost of electricity for residential solar PV systems (without battery storage) in China is approximately 1.00 yuan/kilowatt hour (kWh) [10], which is approximately 2.5 times more expensive than conventional power generation. Without government subsidies, this high cost results in very low profits for solar PV projects. In addition, solar PV projects have long payback periods and large investments that are characterized by uncertainties. Thus, companies should be cautious about investment timing to avoid losses. Additionally, the Chinese electricity market is undergoing market-oriented reform, in which the deregulation of electricity pricing is particularly important [11]. Therefore, decision makers should be aware of the possible effects of electricity price reform. Moreover, as the impacts of technological progress and support schemes on stimulating investment rely on each other, a quantitative analysis needs to be conducted to evaluate these interactions and how they affect the optimal investment timing of solar PV projects.

In this paper, we apply the real options method to evaluate the defer option value and optimal investment timing of PV projects from the perspective of a private investor. The main goals of this paper are to investigate the impacts that electricity market reform has on the defer option values and optimal investment timing, to analyse the defer option values and investment behaviours under different support schemes and market systems, and to examine the complex relationship between technological progress and support schemes. Four real options models that contain technological uncertainty, economic uncertainty and subsidy uncertainty are established in this paper. The changes in the investment behaviours induced by electricity price reform and different support schemes are observed by comparing the defer option values and the optimal investment timings of the different models. The impacts of the technological progress and support schemes are compared through a sensitivity analysis with respect to the optimal investment timing. The research results are also useful for policy makers and can support recommendations related to support schemes.

The layout of the rest of this paper is as follows. Section 2 discusses the related literature. Section 3 describes the methodology, which contains the economic assumptions, uncertain factors and real options models. In Section 4, an empirical analysis of China, including parameter estimation and scenario analyses, is presented, and Section 5 provides the concluding remarks for the paper.

2. Literature review

Solar PV projects have two distinct features: (1) the investment is irreversible and (2) the investment is not a now-or-never option. These two features grant a firm an option analogous to a financial call option, by which decision makers have the right but not the obligation to invest at a certain time in the future [12]. The net present value assessment does not consider these characteristics, so a real options analysis is applied to address these features. Companies that invest in solar PV projects pay more attention to the growth potential of solar energy. Capital budgeting and long-term planning can be integrated from the real options perspective [13], which will benefit the companies in the long run.

Real options theory can be traced back to 1977 when Myers studied the relationship between corporate debt and its value from the perspective of real options [14]. In the early development stage of this theory, scholars focused on the identification of new option types, their applications in different areas and the development of new methodologies [15]. Generally, real options are divided into five types [12,16,17]: (1) the defer option, in which decision makers wait until a positive environment arises (our analysis studies the defer option embedded in solar PV projects; therefore the option value implies the defer option value); (2) the alter operation scale option, in which decision makers expand or shrink the operation scale in accordance with the market situation; (3) the abandon option, in which decision makers sell the project when necessary; (4) the switch option, in which decision makers change the project's output or input; and (5) the growth option, which requires further investment decisions. Three methodologies are applied to solve real options questions: (1) partial differential equations (PDEs), which are used to solve real options questions under certain boundary conditions [12,18] (the most widely used PDE is the Black-Scholes-Merton equation [19,20]); (2) the binomial tree model, which is easy to understand and apply but can be used only in discrete scenarios [12,21]; and (3) simulation, which can be applied to handle different types of real options [12] (the most useful simulation method is the least squares simulation method [22]).

Hoff et al. [23] were the first to apply real options analysis to solar PV. Since then, many relevant studies have been conducted by different scholars. These studies can be classified into 3 categories, namely, (1) project evaluation, (2) optimal investment timing, and (3) policy evaluation.

Project evaluation is an important application area for real options analysis in solar PV projects. Two methods (the binomial tree model and the simulation method) are commonly applied in these studies. (1) The binomial tree model, used in Refs. [23–25], was first applied by Hoff et al. [23], who set up a simple and instructional model to illustrate the application of real options. Sarkis and Tamarkin [25] extended the work of Hoff et al. [23] by setting up a quadrinomial tree model. Martinez-Cesena and Mutale [24] applied the binomial tree model to assess the value of applying demand response programs in off-grid PV systems. (2) The simulation method was applied in Refs. [26–28]. Martinez-Cesena et al. [26] and Weibel and Madlener [27] focused on the effect of technological impacts on the project value, while Gahrooei et al. [28] concentrated on the demand uncertainties. Unlike these studies, our study applies contingent claims to set up PDEs and to obtain analytical solutions; then, the Monte Carlo simulation method is applied to obtain numerical solutions.

The optimal investment timing is also an important application area. Real options analysis was applied in Refs. [29–31] to study optimal investment timing. The investment uncertainty and electricity price uncertainty are common uncertain factors considered in these studies [29,31]. These uncertainties are very important, but policy uncertainty, which is also an influential factor that affects the economics of solar PV projects, was neglected in their model. Zeng et al. [30] considered investment uncertainty, electricity price uncertainty and renewable energy credit price uncertainty (which belongs to policy uncertainty) in their model. However, the