

Optimal feed-in tariff for solar photovoltaic power generation in China: A real options analysis



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HIGHLIGHTS

- We estimate the optimal levels of feed-in tariffs for 30 provinces in China by using real options method.
- The uncertainties in CO₂ price and investment cost are considered.
- The feed-in tariffs of 30 provinces range from 0.68 RMB/kWh to 1.71 RMB/kWh, and the average level is 1.01 RMB/kWh.

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ABSTRACT

The feed-in tariff policy is widely used to promote the development of renewable energy. China also adopts feed-in tariff policy to attract greater investment in solar photovoltaic power generation. This study employs real options method to assess the optimal levels of feed-in tariffs in 30 provinces of China. The uncertainties in CO₂ price and investment cost are considered. A method that integrates the backward dynamic programming algorithm and Least-Squares Monte Carlo method is used to solve the model. The results demonstrate that the feed-in tariffs of 30 provinces range from 0.68 RMB/kWh to 1.71 RMB/kWh, and the average level is 1.01 RMB/kWh. On this basis, we find that the levels of sub-regional feed-in tariff announced in 2013 are no longer appropriate and should be adjusted as soon as possible. We have also identified the implications of technological progress and carbon emission trading schemes, as well as the importance of strengthening electricity transmission. It has been suggested that the Chinese government takes diverse measures, including increasing research and development investment, establishing and improving a nationwide carbon emission trading scheme and accelerating the construction of electricity-transmission infrastructure, to reduce the required feed-in tariff and promote the development of solar photovoltaic power generation.

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1. Introduction

With growing global concern over the depletion of conventional energy reserves, and the growth of associated environmental protection and climate change mainly arising from the greenhouse gas emissions, many countries have realized the important role of renewable energy. As one of the sources of renewable energy with the greatest potential, solar energy attracts universal attention worldwide. The most important way to utilize solar energy is photovoltaic (PV) power generation. China is abundant with solar energy resources, and has made significant progress in its promotion of solar PV power generation. In 2014,

the newly installed capacity reached 1.06 million kW and the total installed capacity reached 2.805 million kW (National Energy Administration, 2014).

Nevertheless, there is still a big gap between China and several developed countries between the installed capacity and the technological level. Investors continue to hesitate to invest in solar PV power generation projects due to its high costs and the uncertain environment associated with the investment. In addition, the oversize regional differences (see Fig. 1) in the development levels of solar PV power generation creates many adverse effects on the healthy operation of a market system in certain area. Given this situation, the Chinese government has adopted numerous incentive policies such as the feed-in tariff policy, investment subsidies and tax incentives to encourage investment in renewable energy power generation. The feed-in tariff policy is the most important among these incentives. In its document entitled *Notice*

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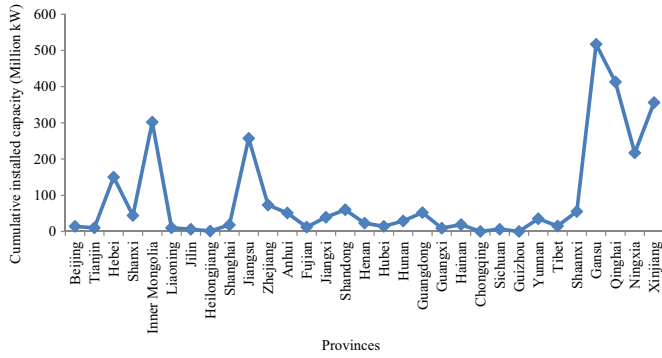


Fig. 1. Cumulative installed capacity of solar PV system by 2014. Source: National Energy Administration.

on perfecting solar PV power feed-in pricing policies, the Chinese government introduced a unified feed-in tariff for solar PV power. The government then determined a sub-regional feed-in tariff policy in 2013. This study contributes to examine whether a sub-regional feed-in tariff is reasonable and seeks to discover the appropriate levels of sub-regional feed-in tariffs. This study also investigates how government should adjust a feed-in tariff in an investment environment of high uncertainty.

A feed-in tariff policy defines a fixed payout for the unit electricity generated by renewable energy. An adequate feed-in tariff can ensure that investors obtain sufficient benefits. At present, the feed-in tariff policy is considered as one of the most effective policies for encouraging investment in renewable energy, and is implemented in many countries (Couture and Gagnon, 2010; Schmidt et al., 2013; David et al., 2013). Determining the feed-in tariff is related to the interests of multiple stakeholders. An appropriate feed-in tariff must be able to attract investors to invest in solar PV power generation project, but should not create an excessive fiscal burden for government and consumers (given that the gap between the market price of electricity and the feed-in tariff is compensated by government subsidy and a surcharge to the consumer). Additionally, numerous factors that affect the determination of feed-in tariff (e.g. investment cost and the CO₂ price) are randomly changing. Ideally, determining an appropriate feed-in tariff would manage these factors scientifically. Thus, determining an appropriate feed-in tariff is a highly challenging task.

Recently, numerous studies have been undertaken to evaluate feed-in tariff policy. Table 1 provides a summary of relevant studies. As seen in the table, previous studies have demonstrated that the real options method is useful for analysing the feed-in tariff due to its capacity to cope with uncertainty and flexibility (Dixit and Pindyck, 1995; Lee and Shih, 2010). The table also demonstrates that previous studies have been mainly conducted in developed countries or regions such as in the European Union, Nordic countries, and the United Kingdom. As a strong supporter of solar PV power, China urgently needs further research focusing on its national conditions. Table 1 also reveals that although most technical and economic factors have been considered in previous studies, the managerial flexibility in investment decisions and the random changes of relevant influencing factors such as investment cost and CO₂ price have not been considered. The table also reveals that previous studies have mainly evaluated the effect and welfare economic aspect of a feed-in tariff policy, but seldom analyse its optimal level, regional differences and variation under different changes to stochastic factors (Fouquet and Johansson, 2008).

The objective of this study is to assess the optimal level of the sub-regional feed-in tariff in China. Given that the province is often recognized as the policy executor in the solar PV industry in China, we use the province as the unit of analysis and investigate the heterogeneity of 30 provinces (excluding Tibet). Considering

the uncertainty characteristics of the investment environment, we use the real options method. The uncertainties in CO₂ price and investment cost are also considered. A method that integrates a backward dynamic programming algorithm and the Least-Squares Monte Carlo method is used to solve the model. The results demonstrate the optimal level of feed-in tariff for 30 provinces. On this basis we can clearly reveal the regional differences of feed-in tariff, and offer an accurate judgment on current sub-regional feed-in tariff policy. The discussion section provides useful information for governments to readjust relevant policies.

The remainder of this paper is organised as follows: Section 2 describes the methodology; Section 3 presents the data; Section 4 presents the results and discusses the findings; Section 5 presents the conclusions.

2. Methodology

2.1. Net present value of a solar PV power generation project

Consider a solar PV power generation project with lifetime L is invested in year t . Assume that the project construction can be completed instantaneously (Kumbaroglu et al., 2008). The project value of this solar PV power generation project is constituted by discounted yearly cash flow over the lifetime and initial investment cost. Given the net present value depends on many factors with stochastic variation, it is reasonable to express the project value by its expectation $E[\cdot]$. Thus, we obtain

$$V_t = E \left[\sum_{i=t}^{t+L} e^{-r(i-t)} \cdot YCF_i - I_t \right] \quad 0 \leq t \leq t_v \quad (1)$$

where r is the discount rate, YCF denotes the yearly cash flow, t_v stands for the last stage of the validity period of investment, and I represents investment cost.

As shown in Fig. 2, the yearly cash flow of a solar PV power generation project YCF_t usually comprises the returns from selling electricity ER_t , gains through selling CO₂ emission allowances CER_t , operation and maintenance costs OMC_t , and tax expenditure Tax_t . Mathematically, we obtain

$$YCF_t = ER_t + CER_t - OMC_t - Tax_t \quad (2)$$

2.1.1. (1) Return from electricity sale

A solar PV power system can convert the radiation energy of sunlight into electricity by using the PV effect of the interface of solar-cell semiconductor materials. The electricity generated by solar PV power system would be input power grid and sold with the feed-in tariff. Once this project investment is completed, the feed-in tariff for the electricity generated by this project would be determined and kept constant within the entire lifetime. It should be noted that the system generating efficiency of a solar PV system gradually decreases with the natural aging of equipment and the accumulation of dust. Thus, the return from electricity sale is expressed as

$$ER_t = Elh \cdot Ge_t \cdot IC \cdot (1 - R^y) \cdot FIT_t \quad (3)$$

$$Ge_t = Ge_{t-1} \cdot (1 - Rr) \quad (4)$$

where Elh denotes the annual effective sunshine hours, Ge_t represents system generating efficiency, IC denotes installed capacity, R^y is the station service power consumption rate, Rr is the annual reduction rate of system generating efficiency, and FIT_t is the feed-in tariff.

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