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Optimal design of subsidy to stimulate renewable energy investments: The case of China

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ABSTRACT

This paper proposes a real options model for estimating the optimal subsidy for renewable energy power generation project by using stochastic process to describe the market price of electricity, CO_2 price and investment cost. Two indicators, i.e., project value and threshold value, are used to derive the optimal subsidy. The least squares Monte Carlo simulation method is used to solve the model. The proposed model is used to empirically evaluate the optimal level of subsidy for solar photovoltaic power generation in China. The results show that carbon emission trading scheme helps reduce subsidy. Unit generating capacity, market price of electricity, CO_2 price and the volatility of investment cost are negatively related with subsidy, whereas investment cost and the volatility of electricity price and CO_2 price are positively related with subsidy. It is suggested that Chinese governments take some measures, e.g., promoting technological progress, establishing a nationwide carbon emission trading market, promoting the competition in renewable energy industry as well as maintaining the stability of CO_2 price and electricity price, to reduce the required subsidy.

1. Introduction

Renewable energy is identified as an important way to cope with climate change, energy shortage and global warming. Many countries have been promoting the utilization and diffusion of renewable energy. Since China is a big country of energy production and consumption, it faces more severe task to increase energy supply and mitigate climate change. However, renewable energy just accounts for about 10% of the total energy consumption in China. In "*China-US Joint Statement on Climate Change*", Chinese government proposed the target of raising the share of non-fossil energy to 20% by 2030.

Encouraging renewable energy investment is recognized as an important step to promote renewable energy in China. However, investors hesitate to invest renewable energy power generation project because of the investment recovery difficulty and high investment risk [1]. Thus renewable energy investors require the guaranteed revenue. It is essential to offer extra economic incentive to renewable energy investors. Renewable energy subsidies, which are designed to promote renewable energy investment by either lowering consumer prices to the ideal range or requiring demand to purchase a certain volume of renewable energy, are important incentive policies [2–4]. Such subsidies may be direct or indirect. Indirect subsidies include research and development (R & D) funding, below-cost provision of infrastructure or services and positive discriminatory rules, while direct subsidies comprise explicit and quantifiable payments, grants, favorable tax rates, feed-in tariff (FIT) and premiums [4–8]. In order to improve the effectiveness of policies and avoid excessive incentive, governments have continuously adjusted the existing subsidy policies. Clearly, the key is to determine the optimal level of subsidy required by renewable energy investors no matter what kinds of subsidy policies are used. At present, on one hand, the pilot carbon emission trading scheme has been launched in seven provinces of China, and a nationwide carbon emission trading market will be established in the near future. On the other hand, the market-based pricing mechanism of electricity and uncertain trend of investment cost in the long run affect the decision-making process of renewable energy investors. Therefore, the uncertainty and complexity of investment environment are greatly increased [9,10]. The optimal level of subsidy should be determined by a more scientific method.

Since 2010, numerous studies have been undertaken to analyze subsidy policies. Table 1 provides a summary of the existing studies by providing their country or region, resource type, research purpose and main contributions. We shall explore the future research trends. First, earlier studies mainly evaluated the effectiveness of multiple subsidy

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Table 1
Summary of studies on subsidy policies.

Authors	Country/ Region	Resource type	Methods	Main contributions
Rigter and Vidican[13]	China	Solar	Net present value method (NPV)	Calculate the exact level of feed-in tariff.
Batlle[4]	EU	Renewable energy (RE)	Goal programming	Present a novel methodology to allocate the RE subsidy cost.
Reichenbach and Requate[14]	_	RE	Game theory and cost-benefit analysis	Investigate the performance of subsidy policies under the impacts of learning by doing, learning spillovers and imperfect competition.
Kim and Lee[15]	–	Solar	NPV and Simulation	Evaluate and optimizing the feed-in tariff (FIT) policies.
Kung[16]	Illinois	Wind	NPV	Estimating the electricity price under the implementation of renewable portfolio standard to achieve a six-year payback on investment.
Kalkuhl et al.[17]	_	RE	General equilibrium model	Evaluate the consequences of renewable energy policies on welfare and energy prices when carbon pricing is imperfect and the regulators seek to limit emissions to a target.
Koseoglu et al.[18]	Germany, US and China	RE	Qualitative analysis	Discuss the allocation of subsidies to research and development (R & D) or to market application of renewable energy.
Lin and Wesseh, Jr[19]	China	Solar	RO (tree)	Evaluate the impact of feed-in tariffs program.
Schmidt et al.[20]	Austria	Wind	NPV and simulation	Assess the effects of fixed and premium based feed-in tariffs on the spatial diversification of wind turbines.
Zhang et al.[21]	China	Wind	Renewable power planning model	Identify the appropriate amount of subsidy.
Quyang and Lin[22]	China	RE and fossil fuel	Cost-benefit analysis, price-gap approach and simulation	Evaluate the impacts of increasing renewable energy subsidies and phasing out fossil fuel subsidies
Quyang and Lin[23]	China	Solar, wind and biomass	Levelized cost of electricity	Analyze the levelized cost of electricity of renewable energies and required subsidies
Zhang et al.[24]	China	RE	Panel regression	Examine the relationship among political connections, government subsidies and firm financial performance of wind and solar manufacturing
Pere and Pablo[25]	EU	RE	Cost-benefit analysis	Examine the cost-effectiveness of combinations of tariffs, investment subsidies and soft loans
Gomez et al.[26]	Brazilian	RE	Levelized cost of electricity analysis	Explore the effects of subsidies on small-scale renewable energy solutions
Chou et al.[27]	Taiwan	Solar	Cost-benefit analysis	Examine the impact of government subsidy on photovoltaic system for industrial users.
Bougette and Charlier[28]	Canada	RE	International quality differentiated duopoly model	Investigate the consequences of a feed-in tariff program
Sun and Xie[29]	–	RE	Game theory	Analyze the impacts of feed-in tariff and renewable portfolio standard
Ramli and Twaha[30]	Saudi Arabia	RE	Qualitative analysis	Analyze the status of renewable energy feed-in tariff
Torani et al. [31]	_	Solar	RO (PDE)	Explore the impacts of innovation subsidies and consumer subsidies
Cucchiella and D'Adamo[32]	_	Biomass	NPV and discounted payback time method	Evaluate the role of subsidies on technical and economic performance of biomethane
Moiseyev et al.[33]	EU	Biomass	Partial equilibrium model	Examine the impacts of subsidies on the wood biomass use for energy
Zhang et al.[34]	China	Wind and solar	Threshold regression	Analyze the impacts of subsidies on the overcapacity of wind and solar energy companies.
Wesseh Jr and Lin[35]	China	Wind	RO (tree)	Evaluate the impact of feed-in tariff
Yu et al.[36]	China	RE	Panel regression	Examine the influences of government subsidies on enterprise's R & D investment behavior
Ritzenhofen and Spinler[37]	German	Wind	NPV and RO (tree)	Assess the impacts of adjustments to feed-in tariff schemes by quantifying the relationship between FIT and the propensity to invest in renewable energy.

Note: RO-real options.