Energy 149 (2018) 954–966

Contents lists available at ScienceDirect

Energy

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

Analysis of carbon-abatement investment for thermal power market in carbon-dispatching mode and policy recommendations

Xinhua Zhang [a, b], Hongming Yang [c, *], Qian Yu [a], Jing Qiu [d], Yongxi Zhang [c]

[a] School of Economic and Management, Changsha University of Science and Technology, Changsha 410114, China
[b] Modern Enterprise Management Research Center of Hunan Province, Changsha 410114, China
[c] Hunan Provincial Engineering Research Center of Electric Transportation and Smart Distribution Network, School of Electrical Engineering and Information, Changsha University of Science and Technology, Changsha 410114, China
[d] School of Electrical and Information Engineering, The University of Sydney, Sydney, NSW 2006, Australia

ARTICLE INFO

Article history:
Received 27 July 2017
Received in revised form
31 January 2018
Accepted 9 February 2018
Available online 10 February 2018

Keywords:
Option game
Carbon-abatement investment
Generation market
Policy analysis

ABSTRACT

In this paper, we present a framework that aims to minimise power generation costs while satisfying carbon emission constraints. We then construct a carbon-abatement investment-option game model for asymmetric generation companies. The results show that the investment behavior of generation companies is largely affected by the critical value of the electricity price after carbon-abatement investment (relative decarbonization price). When the relative decarbonization price is lower than the critical value, only generation companies with low emission are motivated to invest in carbon abatement. By contrast, companies with high emission will only make such investments when the relative decarbonization price is higher than the critical value. We find that raising the proportion of competitive electricity will stimulate generation companies to invest in carbon abatement, while the influence of carbon-emission targets on investment behavior is uncertain. Compared with implementing a subsidy, increasing the relative decarbonization price can motivate generation companies to invest in carbon abatement more effectively.

1. Introduction

The Chinese government has already announced their target of reducing greenhouse gas emissions: by the year 2020, the GDP carbon emissions per capita will decline to 40–45% of that in 2005. This has been included as an obligatory target in the long-term planning for national economic and social development. The International Energy Agency survey report notes that China's carbon emissions are mainly derived from the energy industry, primarily coal. At present, coal-fired power generation capacity accounts for about 57.3% of the total generation capacity, and thermal power generation accounts for about 65.5% of the gross generation in China [1]. Therefore, implementing a carbon-abatement policy in the power market is crucial to achieving China's carbon-emission goals [2].

Currently, carbon-abatement measures in the power market can be divided into long-term and short-term categories. The short-term measures are to reduce carbon emission through optimising the carbon-dispatching mechanism, and maximising the use of power from generation units with low emission while minimising the use of power from generation units with high emission. The long-term measures include two aspects. The first is to develop alternative sources of energy generation, such as hydroelectric, wind power or photovoltaics, thereby minimising thermal power generator capacities (especially generating units with high emission). The second is to upgrade existing thermal power generator units to reduce carbon emission per unit: in other words, invest in carbon abatement. Because China's current generation capacity mainly consists of thermal power units and existing clean energy sources have strong seasonal and random factors, to invest in carbon abatement technologies for the existing thermal power units is one of the effective ways to achieve the carbon emission reduction targets in the power industry. The literature of carbon-abatement investment by generation companies focuses on two main aspects. The first of these is the investment strategy of carbon capture and storage (CCS), which optimises investment using the real-

* Corresponding author.
E-mail addresses: xyu7302@163.com (X. Zhang), yhm5218@hotmail.com (H. Yang), yuqian_0215@163.com (Q. Yu), jeremy.qiu@sydney.edu.au (J. Qiu), yongxizhang330@gmail.com (Y. Zhang).

https://doi.org/10.1016/j.energy.2018.02.036
0360-5442/

options method while taking external uncertainties into consideration. Abadie and Chamorro (2008) [3] assume that the carbon price follows geometric Brownian motion and that the electric price is subject to mean-reverting stochastic process. They analyze the CCS investment strategies of generation companies using the real-options method on the basis of an empirical study of the Spanish wholesale electricity market. Considering the uncertainty of the carbon price, fuel price, investment costs and government subsidies, Wang and Du (2016) [4] evaluate the investment strategy in CCS retrofitting for existing coal-fired power plants based on a real-options method. Zhu and Fan (2013) [5] focus on CCS investment decisions considering electricity and carbon price, CCS investment costs and additional operation and maintenance costs, and then solve the complicated model using the least-squares Monte Carlo method. Similar to Wang and Du (2016), Zhu and Fan (2013) [4,5], a CCS investment decision model is proposed by Zhang et al. (2014) [6] that accounts for the uncertainties of carbon price, government incentives, annual operating time, power-plant lifetime and technological improvements. After taking into account uncertainty factors such as technological improvements, electricity, fuel and carbon price, investment subsidy policies and emission reduction rate, Walsh et al.(2014) [7] present two different models to optimise the investment time, based on either the deterministic or stochastic carbon price. The analytical paradigms of Refs. [3–7] are similar, with the main difference being the uncertainty factors. Therefore, the problem-solving processes and results of the above models may vary.

The second aspect focuses on renewable energy investment and its risk analysis, the selection of power generation technology, the retirement of old fossil-fuel-fired equipment, and the policy impact on the low-carbon investment. Masini and Menichetti (2012) [8] investigate renewable energy investment issues from a behavioral finance perspective, and propose a framework for investment decision-making. Fuss et al. (2012) [9] analyze investment strategies under uncertainties, and discuss the investment portfolio risks caused by uncertain factors. In the case of carbon price fluctuation, Fuss et al. (2009) [10] consider the selection strategies of different typical technologies based on fossil fuels, fossil fuels with CCS and renewable energy, respectively. Their analysis shows that energy policy significantly influences the selection of power generation technology. Fuss et al. (2010) [11] discuss the refurbishment and replacement strategies of old fossil-fuel-fired equipment on the basis of stochastic generation technology and fossil fuel prices, and intervention under the government policy. Fan et al. (2010 [12] present a simulation of risk-averse generation companies when making investment decisions under uncertain carbon regulatory policy situations, while Zhou et al. (2014) [13] study the impact of policy on low-carbon technology investment.

Obviously, the above existing literature mainly focuses on the carbon-abatement investment of generation companies from the perspective of the real-options method based on the existing mature carbon market (i.e. carbon price). But this is not in line with China's current situation. China's pilot carbon trading markets such as Shenzhen carbon market have been established since 2013, but the actual carbon trading volume is very low. For instance, the Chongqing carbon market has experienced zero transaction records for several months. China still has a long distance to the large-scale mandatory carbon trading. Although China plans to start a national carbon trading market in 2017, it still takes time to implement emissions trading in the electricity market because of the complexity of the electricity market reform (the implementation of carbon emission rights policy will undoubtedly reduce the market share of thermal power units, whose installed capacity accounts for about 65% [1], and then affect the reliable supply of electricity). Therefore, in view of China's current electricity market, research on the carbon abatement strategies is important in terms of achieving the carbon reduction target. However, the literature on this aspect has not reported.

Compared with the existing literature, this paper has several salient features in the following aspects: 1) In view of the existing electricity quantity allocation, the carbon-emission levels of generating mechanism units have been neglected. This paper has proposed a carbon-scheduling model. The model relates the on-grid power generation to its carbon emission level and the carbon emission standard of the regulatory institution, in order to achieve the carbon emission target without carbon trading markets. 2) In view of technical characteristics of the existing thermal power generating units, this paper has considered the high and low emission power generation units that lead or follow up on carbon emission reduction investments respectively. The existing literature on carbon abatement investment rarely considers the gaming behavior of generation companies. 3) The investment model in this paper is actually an additional investment model. The proposed solution algorithm is derived based on strict mathematical deductions, rather than using the existing classical methods in references such as [14] [15].

Section 2 of this paper presents a framework that aims to minimise total power generation costs under carbon-emission constraints. In Section 3, we establish the carbon-abatement investment-option game model of asymmetric generators. Based on the results, in Section 4 we analyze the carbon-abatement investment decisions of naïve and rational generation companies in a duopoly market using numerical analysis methods, and discuss related investment policy. Section 5 summarises and concludes our findings.

2. Electricity quantity allocation mechanism in carbon dispatch mode

China's current thermal power generation units are mainly coal-fired units, which generally can be divided into two categories: the old generation units with high generation costs and the new generation units with low generation costs. Old generation units have a lower depreciation costs but a higher generation costs per unit, and new generation units have a higher depreciation costs but a lower generation costs per unit. The results indicate that the unit costs of two kinds of generation units are roughly the same. Therefore, the existing on-grid thermal power generation is scheduled according to its basic capacity proportion. Obviously, this kind of power mechanism only considers the costs of the generating units, and does not take the emissions into account. This is clearly inconsistent with the current global emissions reduction requirements.

According to China's "renewable energy law", the clean energy has on-grid priority, at the same time power generation group is forced to guarantee a certain proportion of clean energy (such as 10%) is on-gird in some regions. Moreover, thermal power units are also required to implement the desulfurization and denitration price (the price of desulfurization or denitration devices implies an additional cost of 0.015 yuan/kWh for thermal generators [16]). These measures play an important role in promoting the development of clean energy. This paper considers carbon emission constraints on the dispatch mechanism for thermal power generation. The proposed model can relate the generation company's electricity output to its carbon emission level, so as to achieve the carbon emission standards required by the regulatory organizations.

The carbon emission level per unit of every generation companies is almost the same over the short term. To achieve the established goals of carbon emission, the dispatch center can firstly dispatch the power generated from low-carbon-emission