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An uncertainty analysis of subsidy for carbon capture and storage (CCS) retrofitting investment in China's coal power plants using a real-options approach

Huadong Chen, Can Wang*, Minhua Ye

State Key Joint Laboratory of Environment Simulation and Pollution Control (SKLESPC), School of Environment, Tsinghua University, Beijing 100084, China

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ABSTRACT

Carbon capture and storage (CCS) is an attractive option to help reduce China's carbon emission. This paper analyzes the impacts of subsidy for electricity generation on CCS retrofitting investment and carbon abatement in China's coal power plants, considering the coaction of carbon market and subsidy policy. To this end, this paper builds up a real option model, considering carbon prices, electricity prices and coal prices' uncertainties. For decision of CCS investment, we consider two important aspects: whether to invest and when to invest, i.e. CCS investment's potential and timing. Some major findings include: 1) The impacts of subsidy on CCS investment and carbon abatement are affected by carbon market conditions: initial carbon price can determine the magnitude of subsidy's impacts, while carbon prices' uncertainty level can determine subsidy's marginal impacts. 2) Subsidy from \$0.01 to \$0.05/kWh can raise CCS investment potential by 9.66%–39.18%, shorten CCS investment period by 0.39–1.95 years and bring carbon abatement potential of 0.10–1.89 $GtCO_2$, considering different carbon market conditions. 3) With the benchmark carbon market and affordable subsidies, triggered CCS investments in coal power plants have an economical-efficient carbon abatement potential up to 20% of China's carbon emission in 2030.

1. Introduction

China has been making great efforts to control its carbon emission. In its INDC, China promised to lower its carbon emission per GDP by 60–65% by 2030 from 2005 level and peak its carbon emission by approximately 2030. To control China's carbon emission, China's power sector, as the largest carbon emitter, has to make its contribution. In 2013, China's power sector's emission (4.4 $GtCO_2$) had already accounted for 49% of China's energy-related CO_2 emissions, and the coal plants contributed 97% of CO_2 emissions from the power sector (IEA, 2015; Olivier et al., 2015). Moreover, as the coal-dominant energy structure can hardly be changed in the short term, it is very likely that China will continue building coal-fired power plants to meet the growing electricity demand, which will bring along tremendous pressures on GHG emission reduction (Wang et al., 2014a; Viebahn et al., 2015). Thus, in the foreseeable future, China's power sector, especially coal power plants, will remain important contributor of China's CO_2 emission and it is important to control emission from China's coal-fired power plants (Wang et al., 2015).

Under this circumstance, carbon capture and storage (CCS) is becoming an attractive technology option for China's power sector to control its high emissions while simultaneously continuing the utilization of coal. Some arguments have declared against the importance of CCS by arguing CCS as “end of pipe” technology with high energy consumption. Admittedly, energy efficiency improvement and renewable energy development will play roles in CO_2 emission reduction in the long term, but they aren't able to completely replace fossil energy or meet world energy demand, especially in the foreseeable future (Zhu and Fan, 2011; Wennersten et al., 2015). CCS is an important technology option for China to control carbon emission before renewable energy dominates energy structure in China, which will take time. As an illustration of CCS's importance globally, wind generation would need to increase twenty-fold from 2012 to 2040 in the 450 scenario with CCS being unavailable and emission saving by CCS met by wind power (IEA, 2014), and under the goal of halve the CO2 emission (relative to 2005) in 2050, CCS would account for a quarter of the total emission reduction (ADB, 2014c). And in China,

* Corresponding author.
E-mail address: canwang@tsinghua.edu.cn (C. Wang).

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CCS is the only available near-commercial technology which can cut CO_2 emission from fossil fuel-fired plants by 80–90% (ADB, 2014b). As for China's efforts in CCS, over 30 R&D and demonstration projects with billions of RMB investment have been launched since 2006 (MOST, 2011), and China has been working closely with developed world to promote CCS development, including NZEC, COACH, STRACO2 and other projects. Thus, with the importance of CCS and China's growing efforts and experience in CCS deployment, CCS application in China's coal power plants will be an important option to help control China's carbon emission.

The high CO_2 abatement costs are among the most critical challenges for CCS development. One good way to offset these costs in China is to include CCS into the carbon emission trading system. Considering China's development of domestic carbon market,[1] China's national carbon market opens a possible window for promoting CCS retrofitting in China's power sector. However, there is a large gap between high CO_2 abatement costs and low carbon credit prices. The CO_2 abatement costs of CCS are estimated to be \$35–70/tCO_2 (Xu et al., 2010; Huang et al., 2010; Lilliestam et al., 2012), compared with top carbon prices level as \$8–15/tCO_2 in China's pilot carbon markets in 2014. Thus it is essential to provide additional incentivizing policies, to promote CCS investment in coal plants. Subsidy for electricity generation[2] can be preferred, considering China's sufficient experience in subsidies policy for renewable energy. Then there are two questions to be answered before applying subsidies to complement carbon market in promoting CCS investment. The first one is how subsidies will motivate CCS investment with carbon market in position, and the second one is how much subsidy should be provided to trigger desirable level of CCS investment.

To answer these two questions, this paper builds up a real option model to simulate the process of coal plant owners (we call them CCS investor in the rest of the paper) deciding whether and when to conduct CCS retrofitting investment under carbon market and subsidy policy. Here Supercritical/Ultra-supercritical pulverized coal (SC/USC) plants have been chosen as the representative of China's future coal-fired power plants for analysis, considering their projected large share in the future.[3] With this real option model and different scenarios settings, this paper finds out the impacts of subsidy on CCS investment and carbon abatement, and the subsidy level needed in different carbon market conditions to achieve different carbon abatement potentials.

Following the introduction, Section 2 is the literature review. Section 3 describes the methodology of the real option model and technology & market data in detail. And Section 4 presents the results about subsidy's impact on CCS investment and carbon abatement, and required subsidies for different carbon abatement potentials. Sensitivity analysis is also presented in Section 4. Section 5 is the conclusions and suggestions.

2. Literature review

Since 2008, many studies have used real option theory in the analysis of CCS investment and policy in the power sector, considering different uncertainties. These literature mainly focus on two different types of studies. First, many literature focus on the comparison of different CCS technologies, and the real option theory is used to find out the technologies' economic feasibility. For example, Szolgayova et al. (2008), applied the real option theory to compare CCS investment actions in biomass-fired plants and coal-fired plants, considering uncertainties of electricity market and carbon market. Heydari et al. (2010) extended the uncertainty types by adding the uncertainty of coal prices, and applied a real option theory to compare two different reduction technologies that could be applied in a coal-fired power plant. Zhou et al. (2010) considered the uncertainty of coal prices in a real option theory, in order to compare the impacts of volatile carbon prices on different low-carbon technologies' investment (including CCS investment).

Second, many literature are devoted to the comparison of different policies for CCS deployment, and the real option theory is used to find out how these policies affects CCS investment decision-making process. For example, Zhu and Fan (2011) compared different types of policies for CCS investment, including carbon market, carbon tax, enhanced R&D, generating subsidy and so on, in a real option model. Zhu and Fan (2013) modeled separately the impacts of carbon market and subsidy for carbon capture on CCS retrofitting investment in a real option model and considered both internal and external uncertainties. Wang and Du (2016) applied a real option model to compare the option values of CCS investment under different policies with consideration of uncertainties from carbon prices, fossil fuel price, investment cost and policy.

This paper focuses on the incentivizing policies for CCS retrofitting investment and has several differences compared with previous studies. First, this paper focuses on the policy of subsidies for electricity generation, and comes up with a complete picture about the impacts of subsidy on CCS investment (including CCS investment potential and timing), which has hardly been fully studied before. Second, considering China's promise in launching its carbon market in 2017, this paper considers the coaction of carbon market and subsidy policy, to better simulate the impacts of subsidy. And the impacts of carbon market on subsidy's effects are discussed in detail to help the government determine the best level of subsidy for CCS investment. Third, to better simulate the CCS investment environment in China right now, this paper acquires the latest technological and market data from real CCS demonstration projects in China's power sector, including CCUS demonstration project in Tianjin's power plants by Huaneng's GreenGen Project, Demonstration of CO_2 capture and small-scale EOR utilization in Shengli oil field by SinoPec, CCS demonstration project in Yuhuai power plant by China Huaneng Group, and China's pilot carbon market data.

3. Methodology

3.1. A real option model for CCS retrofitting investments

Here we build a CCS investment model to stimulate the decision-making process of CCS retrofitting investment, based on real option theory. The model used in this study has the following major features. First, this model considers different economic uncertainties from carbon credit prices, coal prices and electricity prices, and Monte Carlo simulation is applied here to address these uncertainties. Second, this model applies a backward stochastic dynamic programming approach to estimate the expected profits of different investment actions at different timing to help investor choose the best invest strategy. Third, this model calculates the option value of CCS investment by calculating the gap between the expected project value in a real option framework and the project value when CCS would never be installed. The details of the model are described in the following sections (see Fig. 1).

[1] China has launched seven pilot carbon trading markets since 2011, and has promised to launch its nation-wide carbon market by the end of 2017. http://news.sohu.com/20150930/n422431506.shtml.

[2] The policy of subsidy for electricity generation allows CCS retrofitted power plants to get a subsidy for every unit of on-grid electricity produced.

[3] Since 2012, all the new coal-fired power plants in China have been SC/USC plants. These SC/USC plants have a lifespan about 3–4 decades, lasting after 2030, and will dominate China's coal-fired power plants. The share of SC/USC plants in coal plants are projected to be 98.5% in 2030 (Zhou et al., 2013).