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A real options–based CCS investment evaluation model: Case study of China's power generation sector

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ABSTRACT

This paper establishes a carbon capture and storage (CCS) investment evaluation model based on real options theory considering uncertainties from the existing thermal power generating cost, carbon price, thermal power with CCS generating cost, and investment in CCS technology deployment. The model aims to evaluate the value of the cost saving effect and amount of CO_2 emission reduction through investing in newly-built thermal power with CCS technology to replace existing thermal power in a given period from the perspective of power generation enterprises. The model is solved by the Least Squares Monte Carlo (LSM) method. Since the model could be used as a policy analysis tool, China is taken as a case study to evaluate the effects of regulations on CCS investment through scenario analysis. The findings show that the current investment risk of CCS is high, climate policy having the greatest impact on CCS development. Thus, there is an important trade off for policy makers between reducing greenhouse gas emissions and protecting the interests of power generation enterprises. The research presented would be useful for CCS technology evaluation and related policy-making.

1. Introduction

Great attention has been paid to carbon capture and storage (CCS) technology around the world. Although energy efficiency improvement and renewable energy development may play important roles in CO_2 emission reduction, they are not able to completely replace fossil energy or meet world future energy demand [1]. In the foreseeable future (up to 2050), most countries around the world, especially emerging countries with rich coal resources, will still use fossil energy as their primary energy resource [2]. So the development of CCS technology will have a significant impact on the amount of world future greenhouse gas emission reduction, especially for developing countries that use fossil energy as their primary energy resource.

The power sector is the main sector for future application of CCS technology. Theoretically, most of the thermal power stations can be retrofit with CCS technology, especially newly developed IGCC power stations. However, CCS, as a key technology for emission reduction, faces large uncertainties, namely, climate policy, technology feasibility, CCS cost, and fossil energy price. First, regarding climate policy, from the view of the market mechanism for promotion of CCS technology, it is necessary to tax or price emissions from the power sector in both developed and developing countries. However, after several rounds of global climate change negotiations, countries still can not reach mutual agreement on an emission reduction strategy. So the trend of future climate policy, which directly affects the carbon price, is unpredictable. Second, CCS technology is currently in the research and development (R&D) stage, the uncertainty of new technology may have a great impact on the technology investment. So it is hard to predict the investment cost after commercialization. And the investment to promote CCS development is uncertain, too. Also, the storage capacity will concern the feasibility of CCS. It is important to estimate whether there is sufficient storage potential for CCS large-scale applications, and according to the estimation of [3], the storage capacity of oil and gas fields are from 675 to 900 $GtCO_2$, unminable coal seams are from 15 to 200 $GtCO_2$, and deep saline formations are at least 1000 $GtCO_2$, respectively. Third, CCS technology has made it difficult to estimate the CCS future cost. Currently, the CO_2 capture cost is quite high, although this will decrease as CCS technology is commercialized in the future. Basically, the adoption of CCS will result in a decrease in energy conservation efficiency.[1] Therefore, the generating cost of thermal power with CCS will always be higher than that of existing thermal power.

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[1] The adoption of CCS will cause a decrease of energy conservation efficiency: a power plant with a CCS system (including storage path) will consume 10–40% more energy than that of the same installed capacity power plant without CCS. Moreover, the generating cost will increase 10–60%, most of which will be used for CO2 capture and compression [3].

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Fourth, as fossil energy will still dominate future energy consumption, depletion of fossil energy resources may cause fossil energy prices to fluctuate largely. Such price fluctuation will have a great impact on the uncertainty of thermal power with CCS generating cost. Furthermore, CCS technology itself is a time-phased emission reduction solution.[2] All of these uncertainties make the decision of whether to invest CCS technology or not more difficult for power generation enterprises.

This paper applies real options theory to establish a CCS investment evaluation model under the background of global climate change and from the perspective of power generation enterprises. Under a given period of observation, the model evaluates the value of the cost saving effect and amount of CO_2 emission reduction through investing in newly built thermal power with CCS technology to replace existing thermal power. This can help power generation enterprises with the decision of whether to invest CCS technology or not. Four uncertainty factors most relevant to CCS technical and economic evaluation are considered: thermal power generating cost, carbon price, investment in CCS technology deployment, thermal power with CCS generating cost. The model can be used as a policy analysis tool. China is taken as a case study to evaluate the effects of regulations (carbon tax, R&D subsidy and generating subsidy) on CCS investment through scenario analysis. The remainder of the paper is organized as follows: Section 2 provides a literature review; Section 3 contains a description of the model; Section 4 is a case study of implementation of the model in China; and Section 5 presents the conclusions and suggestions for further research.

2. Literature review

There has been a lot of research on the advancement of CCS technology, including CCS technology improvement [4–9], impact analysis of potential CCS effects to the atmosphere [10], CO_2 transportation pipeline design [11], property calculations of a CO_2 mixture [12] and, techno-economic analysis of CCS demonstration project [59]. These studies exemplify the current focus of CCS study on improving technology in terms of economic feasibility and applicability.

Some research has focused on CCS policies and regulations, including policy and regulation design for CO_2 storage and public acceptance of CCS [13–15], and driving factors and barriers of CCS application in developing countries [16,55].

Furthermore, in some energy-economic system models, CCS technology had been introduced as a potential emission reduction technology to estimate the impact of CCS application on the socio-economic system and reduction in greenhouse gas emissions, including the MIT Emissions Predictions and Policy Analysis (EPPA) model [17], Energy Technology Systems Analysis Programme TIMES Integrated Assessment Model (ETSAP TIAM) model [18], Model of Investment and Technological Development (MIND) [19], MESSAGE-MACRO model [20] and, US MARKAL-TIMES [21].

Real options approach is suitable for the evaluation of large-scale investment projects with large uncertainties. Myers and Turnbull [22] and Ross [23] were the first to introduce a "real" financial options pricing approach. McDonald and Siegel [24] first developed a real options valuation model, using the option pricing approach to solve it. Brennan and Schwartz [25] introduced a real options approach to natural-resource investment decisions. After that, real options approach has been applied more and more in the evaluation of energy investment [26–29].

For power investment projects, real options approach can consider the uncertainties of the market environment, generating fuel prices, environmental factors, electricity demand and supply, and so on [30]. Therefore, the real options approach would be useful for evaluation of advanced generating technologies. Real options approach can evaluate the substitution effect (generating cost saving effect) of renewable generating technology to fossil fuel generating technology [31,32]. Real options approach can also consider the uncertainty of climate policy in the evaluation of generating technologies [33–35]. Real options approach has already been applied for evaluation of integrated gasification combined cycle (IGCC) generating technology [36] and an distributed generation system [37–39], and so on.

Some researchers have already applied real options approach to evaluation of CCS investment. Abadie and Chamorro [40] and Fuss [41] both established real options models to evaluate the value of thermal power retrofit with CCS technology respectively, considering the uncertainties of European Union (EU) electricity and carbon prices. The model in [40] finds the optimal investment rule for thermal power retrofit with CCS technology, solved by the binomial lattice method using the Spanish electricity market as an example. And the model in [41] solved by Monte Carlo simulation. Fleten and Näsäkkälä [42] considered the uncertainties of electricity prices and natural gas prices, applying a real options approach to analyze the value of operating flexibility and the abandon option of natural gas generating projects. The model computed the upper and lower bounds on plant values and investment threshold levels, and also analyzed the effects of emission costs on the value of installing CO_2 capture technology. Heydari et al. [43] have considered the uncertainties of electricity, CO_2, and coal prices and developed an analytical real options model to value the choice between two emissions reduction technologies available to a coal-fired power plant. The model valued the option of investing in either full CCS (FCCS) or partial CCS (PCCS) technology, and the results showed that the optimal stopping boundaries are highly sensitive to CO_2 price volatility. Based on the research of [33], Zhou et al. [44] have incorporated carbon price uncertainty in a real options model and analyzed the CCS investment strategy in China's power sector. Their paper has discussed the best strategy for CCS investment in China and the effect of climate policy on the investment decision-making process of carbon-saving technologies.

This paper takes a specific view to evaluate the CCS investment and has several differences with previous research. First, it has investigated the cost saving effect between thermal power and thermal power with CCS, which will result in relative cost saving cash flows between them, and the real options evaluation model is build on the relative cost saving cash flows. Second, it has considered the CCS technology uncertainty, especially the uncertainties during CCS technology deployment. Third, as CCS technology is highly related to fossil energy consumption, it has considered the impact of thermal power generating cost on thermal power with CCS generating cost.[3] Fourth, it takes CCS as a time-phased emission reduction solution and investigates the emission reduction amount and cost saving value of CCS in a given period, also the given period is divided into two stages: stage one is the time needed to complete the CCS deployment; and stage two is after the enterprise has completed the CCS investment and starts receiving cost saving cash flows.

[2] Compared to alternative energy (renewable energy and new energy), CCS is a time-phased emission reduction technology. It has been developed to reduce greenhouse gas emissions from consumption of fossil energy. The development of alternative energy not only reduces greenhouse gas emissions, but also will somewhat ease the potential energy crisis caused by the depletion of fossil energy in the future.

[3] Although both emission reduction technologies, there is a significant difference between CCS and renewable energy. That is, the uncertainty of fossil fuel prices directly affects CCS generating costs, but will not happen to renewable power generation.