



## Uncertainty modeling of CCS investment strategy in China's power sector

Wenji Zhou<sup>a</sup>, Bing Zhu<sup>a,b,\*</sup>, Sabine Fuss<sup>b</sup>, Jana Szolgayová<sup>b,c</sup>, Michael Obersteiner<sup>b</sup>, Weiyang Fei<sup>a</sup>

<sup>a</sup> Department of Chemical Engineering, Tsinghua University, Beijing 100084, PR China

<sup>b</sup> International Institute for Systems Analysis (IIASA), Schlossplatz 1, A-2361 Laxenburg, Austria

<sup>c</sup> Department of Applied Mathematics and Statistics, Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovakia

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### ABSTRACT

The increasing pressure resulting from the need for CO<sub>2</sub> mitigation is in conflict with the predominance of coal in China's energy structure. A possible solution to this tension between climate change and fossil fuel consumption fact could be the introduction of the carbon capture and storage (CCS) technology. However, high cost and other problems give rise to great uncertainty in R&D and popularization of carbon capture technology. This paper presents a real options model incorporating policy uncertainty described by carbon price scenarios (including stochasticity), allowing for possible technological change. This model is further used to determine the best strategy for investing in CCS technology in an uncertain environment in China and the effect of climate policy on the decision-making process of investment into carbon-saving technologies.

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### 1. Introduction

According to the report from the International Energy Agency (IEA) [1], China ranks the first place in terms of CO<sub>2</sub> emissions by fuel combustion among countries in the world. In recent years, due to the rapid growth of high energy-consumption sectors such as power, steel, cement and chemical industries, China's CO<sub>2</sub> emissions have risen dramatically. A key characteristic of China's energy structure is that coal dominates in energy use, accounting for about 70% in total energy consumption [2], while oil and natural gas constitute a relatively small part only.<sup>1</sup> This situation is expected to last for several decades in the future, mainly due to China's considerable coal reserves. This fact together with the increasingly perceivable need to decrease the global CO<sub>2</sub> emissions imposes great pressure on policy makers and therefore poses huge challenges to China both with regard to energy security and climate change.

Carbon capture and storage (CCS) is considered as an important approach to control CO<sub>2</sub> emissions caused by fossil fuel consumption. The power industry is one of the main CO<sub>2</sub> emissions sectors, in particularly in China. More than 80% of electricity is generated by coal combustion [2], with relatively low-efficiency coal-fired

technology. This indicates that to reduce CO<sub>2</sub> emissions in China, the power industry needs to be considered as one of the first sources. Installing CCS devices in power plants is an attractive option, as it enables further use of abundant coal resources, while at the same time cutting emissions from that combustion by a considerable amount. However, the high cost of CCS and the uncertainty associated with its technological development are obstacles to a fast diffusion of this technology, particularly in developing countries like China. The Chinese government has been strengthening related R&D efforts and some demonstration projects are under construction.<sup>2</sup> From the energy companies' point-of-view, CCS installation is still associated with high cost and could only be considered if it was profitable for the whole value chain. This, however, remains highly uncertain due to the lack of knowledge about the direction of future climate policy.

China's power industry is now confronted by big challenges from increasingly strict environmental policies aiming at the reduction of pollutants. With respect to environmental regulation, the requirement of environmental protection has become much

\* Corresponding author. Address: Department of Chemical Engineering, Tsinghua University, Beijing 100084, PR China. Tel./fax: +86 10 62782520.

E-mail address: [bingzhu@tsinghua.edu.cn](mailto:bingzhu@tsinghua.edu.cn) (B. Zhu).

<sup>1</sup> According to 2007 data, the shares of coal, petroleum and natural gas are 73%, 21%, and 3%, respectively. With respect to renewable energy, hydro power is most developed, accounting for 3%. Nuclear and wind power are under fast development, but still constitute very small shares.

<sup>2</sup> CO<sub>2</sub> capture technology in China has been applied in some industrial sectors such as ammonia, hydrogen and petroleum for several decades. However, R&D of large-scale capture in the power sector just started a few years ago. In 2005, CCS technology was listed in the National Outlines for Medium and Long-term Planning for Scientific and Technological Development (2006–2020), which significantly spurred relevant research. In July 2008, the first demonstration carbon capture project in China has been completed in the Beijing Thermal Power Plant owned by Huaneng Group, with a capacity of 3000 tons of CO<sub>2</sub> captured per year. In the meantime, some other demonstration projects with larger capture capacity are also at different stages of completion.

stricter than before. For example, power plants are compelled to install desulfurization devices by regulation issued in recent years. However, there is currently not such a stringent requirement for China's power industry to reduce greenhouse gas emissions. China is included in the clean development mechanism (CDM),<sup>3</sup> however, and some energy enterprises have benefited from CDM projects. It is still hard to predict whether and when the situation will change and what kinds of policy instruments will be adopted in the post-Kyoto period. Moreover, in a cap-and-trade market, the CO<sub>2</sub> price will fluctuate. In the face of such an uncertain environment, strategic decisions on investment into CO<sub>2</sub> mitigation technology cannot be based on traditional discounted cash flow (DCF) analysis because companies possibly choose to delay the decision rather than immediately make a now-or-never decision by using DCF, as the investment is irreversible, involves high sunk costs and its payoff is uncertain. In order to capture these specific characteristics of the investment decision, real options analysis (ROA) has therefore been chosen for the analysis [3]. Generally, ROA is designed to take three important factors into account: the irreversibility of the investment, the uncertainty surrounding the future cash flows from the investment (here through volatile CO<sub>2</sub> price processes), and the opportunity of timing the investment flexibly (here through adding the CCS module earlier or later in the planning period) [4].

Investment strategy in the power sector has been analyzed by using real options methods before, but only a few of them focus on climate change policies, and it is hard to find any discussion on this issue for developing countries like China. Laurikka [5] presents a simulation model implementing ROA to assess the impact of emissions trading scheme on integrated coal gasification combined cycle (IGCC). The study simulates three types of stochastic variables: the price of electricity, the price of fuel and the price of emission allowances. Yang et al. [6] value real options using a dynamic programming approach for technology investment choices under uncertain climate policy. Three cases for gas, coal and nuclear power investments are considered. Energy prices and the CO<sub>2</sub> price are set to change randomly; for the latter one, a price jump was incorporated to represent policy-related shocks.

All these studies are based on a specific emissions trading system, which cannot be applied directly to the case of China. Furthermore, the absence of technological improvement in those studies implies neglecting one of the most important drivers for low-carbon technology adoption. Kumbaroğlu et al. [7] integrate technological learning curves into a real options framework to appraise renewable energy technologies. Fuss and Szolgayová [8] use a real options model with stochastic technical change and stochastic fossil fuel prices, to investigate their impact on replacement investment decisions in the electricity sector.

Unlike the studies above, this paper attempts to model and analyze climate policy uncertainty in China's energy industry under consideration of technological change and establish a real options model to obtain CCS investment strategies from the point-of-view of a typical energy enterprise, hence providing policy implications for CO<sub>2</sub> mitigation in the coming post-Kyoto period. The paper consists of six sections. Following this introduction, Section 2 presents the methodological framework of the real options model used in the study. In Section 3, the factors of policy uncertainty and technological progress are analyzed. Section 4 describes the features of three representative types of technologies considered. These are a pulverized coal power plant, a wind farm and an IGCC plant. The

data used and the assumptions are explained in detail. The scenarios generated by varying underlying model parameters are analyzed in Section 5. Finally, the policy implications of the results from this real options model and its features as a policy analysis tool are presented in the conclusion.

## 2. Model description

A typical CCS system consists of three parts: capture, transport and storage. The capture part contains chemical devices such as absorber and desorber, accounting for 70–80% of the total cost [9]. These devices can be in-built, when a new modern plant is constructed, or they can be added to an existing plant by retrofitting it at higher cost.

In the model we consider an investor maximizing the sum of his expected discounted profits over the planning period, who faces uncertain climate policy. The real options model determines the optimal timing of investing into a CCS module given that a coal plant already exists. Several possible types of coal plants (and corresponding CCS systems) are analyzed separately. It also derives the corresponding profit distribution resulting from optimal investment. Several scenarios for CO<sub>2</sub> price development (involving both deterministic and stochastic processes) were implemented to reflect different possible policy outcomes and examine their impact on CO<sub>2</sub> mitigation technology investment behavior. In Fig. 1, we show an overview of price assumptions used in the model. Only the CO<sub>2</sub> price is assumed to be uncertain, all other prices are modeled as deterministic. The motivation for an uncertain fluctuating carbon price CO<sub>2</sub> price can be seen for example in a policy resulting in CO<sub>2</sub> credits or allowances being traded amongst firms. We consider the planning horizon equal to the lifetime of the power plant, i.e. 30 years and that the decisions can be done on a yearly basis.

The investor faces an optimization problem of timing the decision to invest into the CCS module so that the sum of discounted expected future profits is maximized. Let  $x_t$  denote the state that the system is currently in year  $t$ , i.e. it tells whether the basic plant, the CCS module or both have been built and whether the CCS module is currently running, let  $a_t$  be the action (i.e. the control) which the decision-maker chooses to undertake in year  $t$ . Possible actions are to either build the CCS module (which is feasible only in case it has not been built yet) or do nothing.  $x_{t+1}$  depends only on the action  $a_t$  and  $x_t$ , with  $a_t$  as an element from the set of feasible actions. The yearly profit  $\pi$  for a given state  $x$  and actions  $a$  can be expressed as:

$$\pi(x, a, P^c) = q^e(a)P^e - q^c(a)P^c - q^f(a)P^f - \text{OMC}(a) - c(a), \quad (1)$$

where  $P^c$  represents the price of CO<sub>2</sub> (or CO<sub>2</sub> credit when  $P^c$  is negative), according to which energy companies could either be penalized by paying for CO<sub>2</sub> emissions required by a stringent policy, or benefit from selling CO<sub>2</sub> credits in a CDM-type market. The variable is created to describe a possible climate policy variation in the future.  $q^e$  and  $q^f$  refer to annual quantities of electricity output and fuel consumption,  $P^e$  and  $P^f$  represent prices of electricity and fuel respectively. OMC refers to operational and maintenance cost, and  $c$  denotes the cost associated with the undertaken action. In case the action is to build the CCS module, it is equal to the expenditure for retrofitting an existing plant with a CCS module. In case the action is to do nothing, this cost is equal to zero.

Based on this profit function, the investor's optimization problem can be formulated as follows:

$$\begin{aligned} \max_{a_t(x_t, P_t^c) \in A(x_t)} & \sum_{t=1}^{30} e^{-rt} E[\pi(x_t, a_t(x_t, P_t^c), P_t^c)] \\ \text{s.t.} & x_{t+1} = F(x_t, a_t(x_t, P_t^c)) \end{aligned} \quad (2)$$

<sup>3</sup> The clean development mechanism is an arrangement under the Kyoto protocol allowing industrialized countries with a greenhouse gas reduction commitment (Annex 1 countries) to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reduction in their own countries.

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