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How policy choice affects investment in low-carbon technology: The case of CO_2 capture in indirect coal liquefaction in China

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A B S T R A C T

An improved understanding of investment decisions on low-carbon technology will greatly facilitate assessing the effectiveness of carbon emissions mitigation policies. We use the example of implementing CCS (carbon capture and storage) within ICL (indirect coal liquefaction), a controversial technology in China, by constructing a RO (real options) model for the investment decision-making process to assess how different climate policies affect low-carbon technology investors under highly uncertain circumstances. We find that a carbon tax provides the strongest signal for investment and that a market-based measure provides firms with flexibility. Moreover, different types of carbon markets generate substantially different effects on firm behavior, and the CO_2 price level exerts a more powerful influence on investors than market volatility or the policy's implementation date. Considering the regional disparities among the coal-abundant but less-developed provinces and the affluent coastal regions in China, we suggest that a sub-national CDM (clean development mechanism) would complete the current domestic policy framework to balance the development requirement and CO_2 abatement, whereas extraordinary administrative efforts are necessary to raise the current price of CO_2 credits to an effective level, to broaden the carbon market coverage and consolidate the carbon market foundation.

1. Introduction

The commercialization and popularization of low-carbon technologies are critical to the effective reduction of China's CO_2 emissions as part of its essential process of industrialization. Investment in these technologies, however, is fundamentally influenced by national and international climate policies. Although the likelihood of finalizing a comprehensive international climate regime in the medium or long term remains uncertain, a systematic policy that underpins the general target with an integrated consideration of the characteristics of energy resources, security issues and utilization technologies is urgently needed, particularly for China. As a country with abundant coal and relatively scarce oil and gas resources, China has witnessed enthusiasm in the development of coal liquefaction projects since the mid-1990s, which aims to relieve the country's increasing dependence on oil imports. Accelerating the progress of coal liquefaction R&D has been included in the national energy development plan [1–3]. However, some strong critiques are raised against its large-scale application in China, such as its high CO_2 emissions and high water consumption. In addition, other environmental and ecological impacts including land subsidence, damage to the water environment, mining waste disposal and air pollution are also resulted from associated coal mining [4]. The repeated reversals of policy reflect the intense debate on the uncertainty of developing coal liquefaction technology in China. From the mid-1990s to 2006, the central government provided strong support to synthetic oil, which resulted in significant over-investment in coal liquefaction projects. Considering the immaturity of this technology, the central government tightened the policy by forbidding most of the planned projects from 2006 to 2011. However, local governments in coal-rich regions still have strong incentives to invest in this technology to promote the local economy, despite the central government's repeated prohibitions regarding development that is not coordinated with the proper authorities [5–8]. Spurred by the four-trillion-yuan stimulus package implemented to address the impact of the 2008 financial crisis, the rigid policy seems to be loosened to

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Acronyms

CCS	carbon capture and storage
CDM	clean development mechanism
CT	carbon tax
CTL	coal to liquids
DCL	direct coal liquefaction
EAM	emissions allowance market
ECDM	extended clean development mechanism
EUETS	European Union Emissions Trading Scheme
GBM	geometric Brownian motion
ICL	indirect coal liquefaction
NDRC	National Development and Reform Commission
RO	real options

Nomenclature

AM	annual output amounts (ton)
OMC	total cost of operations and maintenance (yuan)
RC	additional cost associated with action (yuan)
SI	accumulated scale of installation (ton yr^{-1})
p	price (yuan ton^{-1})
μ	drift parameter
σ	volatility parameter

some extent, as some of the coal liquefaction projects are allowed again during the most recent years [9,10].

The issue of adding CCS (carbon capture and storage) to reduce the high CO_2 emissions of ICL (indirect coal liquefaction), one of the two main coal liquefaction technologies, is the subject of the present study. In ICL without capture, producing one ton of fuel emits approximately 7 tons of CO_2 [11]. Adding a CCS module would dramatically reduce these emissions, albeit at an added cost. A critical issue for both the government and project investors seeking to pursue this approach is that the ambiguous climate policy prospects when the Kyoto Protocol expires confer substantial uncertainty on such investments. Assessing the impact of this uncertainty on investment in low-carbon technology has major implications for both investors and policy makers.

There is a wide divergence of opinions concerning the optimal architecture of climate policy. At the country level, a harmonized carbon tax would deliver the simplest price signal, reduce price volatility and avoid the troublesome allocation of emissions quotas among countries [12], but substantial political obstacles exist that may impose relatively high costs on low-income regions. The quantity-based approach, represented by the EU ETS (European Union Emissions Trading Scheme), affords more flexibility in the creation of an equitable distribution of costs among countries [13]; however, this approach may lead to carbon leakage (as would a unilateral carbon tax) and it increases policy uncertainty [14,15]. Consequently, this approach tends to impede large-scale investment and R&D efforts [15]. This deficiency of top-down design might be addressed by the bottom-up establishment of market-based approaches [16]. With respect to this area of investigation, previous studies have explored the effect of market uncertainty on firms' decision-making processes regarding investment in low-carbon technologies, including the assessment of CCS [17–21].

Using the RO (real options) analysis method, the present study attempts to measure the effect of climate policy architecture on the reactions of firms and their corresponding strategic decisions concerning the incorporation of CCS in ICL. Section 2 explains the methodological framework, details of the model, parameters and data. The results of scenario analyses for three potential climate policy choices are presented in Section 3. By drawing the practical implications of applying ICL plus CCS in China, Section 4 discusses the regional disparity and the concept of the sub-national CDM (clean development mechanism). Finally, conclusions concerning investment strategies and industrial policy recommendations are drawn in Section 5.

2. Methods and data

2.1. Analytical framework

This study investigates the process by which decisions are made concerning whether and when an investment is made to retrofit an ICL plant to add a CO_2 capture module in light of uncertain market and policy conditions.

In this study, the market and administrative policies are categorized in terms of the following three mechanisms that affect investment behavior (Fig. 1):

(1) The credit market, represented by the ECDM (extended clean development mechanism) scenario in which the CDM continues to function for China with enlisting CCS in the project inventory. Thus, firms may realize extra profits by selling the emissions reduction credit, earned from the use of low-carbon technology, to firms in other countries that must meet their obligations.
(2) The emissions allowance market, represented by the EAM (emissions allowance market) scenario, features a cap-and-trade environment in which firms whose emissions exceed their quotas must purchase credits from those that pollute less.
(3) The increasing-level carbon tax, or the CT (carbon tax) scenario, represents a situation in which firms are taxed at a certain rate for every unit of CO_2 emissions.

Four indicators are selected to measure the investment strategy response to the specific policy being implemented:

(1) The project value refers to the greatest present value of all future cash flows that could be gained by the ICL investor in executing the optimal investment strategy.
(2) The optimal time for the investment is the time that maximizes the project value (i.e., the present value of future cash flows) plus the future option value (i.e., the option of retrofitting a CO_2 capture system).
(3) The CCS option value is the value of the firm's option to invest in CCS (this option should not be taken for granted; for example, if CCS is not approved under local regulations, the firm will lose the option). The value of this indicator is equal to the project value minus the value of the case in which CCS is never installed.
(4) The response time to policy, or the response time, measures the length of time that the firm waits to add the CCS module after implementation of the climate policy.

2.2. System boundary

The technical process of ICL consists of two major steps: 1) a gasification process that converts coal into a synthesis gas containing carbon monoxide and hydrogen as the main feedstock; and 2) the Fischer–Tropsch process, which synthesizes the cleaned synthesis gas into oil products in the presence of a catalyst. At present, there are more than 20 projects including both of ICL and DCL (direct coal liquefaction) under construction or being planned