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Business model design for the carbon capture utilization and storage (CCUS) project in China

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ABSTRACT

The high cost of carbon capture has hindered the deployment of carbon capture utilization and storage (CCUS) technology. Due to a dearth of associated engineering practices and business activities, there are currently no broadly viable business models for the large-scale deployment of CCUS technology. Evaluations at the business model level are essential to consider external factors, particularly for projects with a long industry chain and complex relationships among stakeholders, such as CCUS projects. This paper fills a gap in CCUS research by introducing four business models based on the different stakeholders involved in CCUS projects and their varying degrees of integration. Using Monte Carlo simulation, the distributions of return for each stakeholder under the four business models were obtained. The results show that the vertical integration model is the most appropriate choice for CCUS deployment in China during the early demonstration stages due to its lower interest rates and transaction costs. Based on the current cost level of CCUS, subsidy for storage is recommended in the early stage, and reasonable and stable carbon pricing policies (e.g., carbon tax) are conductive to large-scale deployment of CCUS in the long term.

1. Introduction

Carbon capture and storage (CCS) has been acknowledged as an important option to reduce CO_2 emissions in recent decades (Seigo et al., 2014; Leeuwen et al., 2013; Cormos, 2012). In China, CCS based on coal-fired power generation plants is significant because over 65% of the power in China is generated by coal, which produces a large amount of carbon emissions. Thus, China requires the large-scale commercial deployment of CCS technology to achieve its emission reduction goals. However, recently, there has been increasing interest in and expenditures on renewable energy, improved energy efficiency, new nuclear energy sources and lower emissions of fossil fuels, whereas CCS technology has developed slowly (Best and Beck, 2011). Globally, CCS technology is also in a poor state.

According to the Global CCS institute, by the end of August 2017, there were 17 large-scale CCS projects in operation worldwide. The combined CO_2 capture capacity of these 17 projects is approximately 30 million tons per annum (Mtpa). Four more CCS projects are currently under construction and are expected to be in operation by 2020. The current CCS scale is lower than the expected scale proposed by the IEA in 2009, which highlighted the need to develop 100 CCS projects from 2010 to 2020 and store approximately 300 $MtCO_2$/yr (IEA, 2009). Zhou et al. (2010) propose that the high cost of CCS and the uncertainty associated with its technological development are obstacles to the rapid diffusion of this technology, particularly in developing countries such as China. To solve this problem, the utilization of captured CO_2 has been widely discussed in recent years, highlighting the economic value of CO_2.

In this context, the Carbon Sequestration Leadership Forum (CSLF) changed the term 'CCS' to 'CCUS' (carbon capture, utilization and storage) (Rodrigues et al., 2015). Generally, if the economic value of captured CO_2 is high enough to cover its capture and transportation costs, CCUS projects can be profitable. Therefore, the key to CCUS projects is now the CO_2 value chain, which requires a feasible business model because it is not only an emission reduction activity but also a business activity. According to Hayek's spontaneous order theory (Hayek, 1967), business models emerge spontaneously from business activities. However, due to inadequate incentives from the government, few companies will take the initiative to adopt CCUS technology because there is no profit in it, which makes this technology currently

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unfeasible (Višković et al., 2014). In addition, CCUS involves a complicated combination of technologies from industries such as the coal, chemical, power generation, transportation, oil and gas, food, and drink industries. The development of CCUS is limited by a long industry chain, which makes collaboration among industries difficult. Without engineering practices and business activities, it is difficult for a business model for a CCUS project to emerge spontaneously. Hence, there is a pressing need to put forward an appropriate business model for CCUS with corresponding policy incentives that will help the deployment of CCUS projects. However, Kheshgi et al. (2009) noted that there is currently no broadly viable business model for the large-scale deployment of CCS. In addition to its high cost, the lack of a feasible business model for CCUS is now hindering the development of CCUS technology. What is more, many studies predict that the future cost of carbon capture will decrease greatly with increased learning effects (Li et al., 2012; Rubin et al., 2007b),which has been confirmed by engineering practices (GCCSI, 2016). Thus, the adoption of CCUS technology at an early stage is particularly important.

However, to date, major studies have focused on evaluating CCS at the technical level (Rubin et al., 2007a; Spek et al., 2017; Li et al., 2012; Hammond et al., 2011) while little research has investigated the business level of CCUS projects. To fill the above mentioned gaps, this paper aims to design and evaluate business models for CCUS projects from the perspective of cooperation among multiple stakeholders. We propose a full CCUS chain evaluation among multi-stakeholders combined with the business model. The evaluation method can consider multiple uncertainty factors, and thus, the risk distributions of return for each stakeholder can be obtained. Four potential business models that are essential for the future development of CCUS are introduced and evaluated.

This study is organized as follows: Section 2 reviews the literatures about business model analysis in the energy sector, and the current CCUS business framework. Section 3 introduces the cost accounting method used in this study and the designs of four business models based on different types of cooperation among stakeholders. Section 4 describes a simulation and discussion of the cost and benefit results, followed by a conclusion in Section 5.

2. Literature review and current CCUS business framework

2.1. The business model in the energy sector

Business models affect firms' possibilities for value creation and value capture (Amit and Zott, 2001). There is no generally accepted definition of the term "business model". Because this concept is considered at different levels by researchers, its definitions differ (Stewart and Zhao, 2000; Mayo and Brown, 1999; Morris et al., 2005; Zott and Amit, 2010). In this paper, we adopt the definition of Zott and Amit (2010): "the business model is a structural template that describes the organization of a focal firm's transactions with all of its external constituents in factor and product markets". This definition focuses on a firm's exchanges with external stakeholders rather than on its administrative structure.

Many studies in the energy sector involve discussions about business models. Several studies have investigated the business models of energy service companies (ESCos) (Pätäri and Sinkkonen, 2014; Suhonen and Okkonen, 2013; Pantaleo et al., 2014) Though a growing number of studies apply the business model concept as an analytic tool (e.g., He et al., 2011; Kley et al., 2011; Loock, 2012; Shrimali et al., 2011; Richter, 2013), to the best of our knowledge, most of the literatures about CCS are focused on tech-economic evaluation (Rubin et al., 2007a; Spek et al., 2017; Li et al., 2012; Hammond et al., 2011), while little researches have been done from the CCS business model perspective which includes a firm's exchanges with external stakeholders.

2.2. Development of CCUS

CCUS has been widely discussed in recent decades and is regarded as a sound option to permit the ongoing use of fossil fuels while reducing CO_2 emissions (Wu et al., 2016). Carbon capture is a costly and energy-intensive process; with the average cost of CO_2 capture of over US$30/t (Rubin et al., 2007a; Spek et al., 2017; Li et al., 2012). A large-scale CO_2 transport network is required for CCUS, and this can only be achieved viably using pipelines or shipping (Parliamentary Office of Science and Technology (POST), 2005). Hammond et al. (2011) noted that shipping is more economical than piping for the transport of CO_2 over long distances (> 1000 km). The most attractive and mature geological option to utilize the captured CO_2 is enhanced oil recovery (EOR), which has been widely used in the US (Hammond et al., 2011). EOR can make a profit by the sale of the extra oil captured due to CO_2 injection. Despite receiving considerable attention, there has been slow progress on CO_2 storage in this decade due to its high cost. Moreover, there are broad and complex stakeholder relationships among the different industries involved in CCUS technology, which makes it difficult to achieve widespread cooperation. Therefore, there is no broadly viable business model for the large-scale deployment of CCS technology (Kheshgi et al., 2009).

According to the Global CCS Institute, by the end of August 2017, 17 large-scale CCS projects were in operation. Although the post-combustion capture method demonstrates a significant potential for CO_2 emission reductions (Hammond et al., 2011), there are only two large-scale CCS projects applied for power generation using this method, and most of the projects are applied in industries such as natural gas processing, fertilizer production, synthetic natural gas and hydrogen production by adopting industrial separation method. EOR is an attractive geological option as 13 projects employ EOR as their primary storage type. For details on these projects, see Appendix A.

2.3. Current business framework of CCUS projects

The business framework of current CCUS projects is summarized in Table 1.

Uthmaniyah's CO_2 EOR Demonstration Project can be summarized as a vertical integration model. This model has strict requirements for the degree of integration of the energy company; the energy company should have a capture source and a storage/EOR site as well as transportation facilities. Some projects in China, such as the Yanchang Integrated Carbon Capture and Storage Demonstration Project and the Sinopec Shengli Power Plant CCS Project, currently share similar characteristics.

The business model of the Quest CCS project can be summarized as a joint venture model. In addition, the business models of the Snøhvit CO_2 Storage Project in Norway, the Petrobras Lula Oil Field CCS Project in Brazil, and the In Salah CO_2 Storage Project in Algeria are similar to the Quest business model.

The Coffeyville Gasification Plant is a typical project in that the capture, transport, utilization and storage processes are operated by a third-party company whose business model can be summarized as a CCS operator model. Currently, the Great Plains Synfuel Plant, the Weyburn-Midale Project in Canada, and the Enid Fertilizer CO_2-EOR Project in the United States have similar features in their business models.

The Val Verde Natural Gas Plants can be defined as a CO_2 transporter model as there is a third party in charge of the transportation part. This business model has a relatively long history with a mature industrial chain because of the benefits of large-scale carbon dioxide flooding. In addition, the Shute Creek project has similar features in its business model, with three companies in charge of the transportation part of the project and five companies using the captured CO_2 to enhance oil recovery through the injection of CO_2 in acid gas injection wells.