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The cost of carbon capture and storage for coal-fired power plants in China

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ABSTRACT

This study takes a systematic approach to quantify variability and uncertainty in the cost of carbon capture and storage (CCS) for new pulverized coal-fired power plants in China under a common costing framework and examines the role of economic and policy strategies in facilitating CCS deployment. The CCS cost varies with key parameters including capacity factor, fixed charge factor, coal price, plant location, and CO_2 removal efficiency. Given the probability distribution assumptions for uncertain parameters, results from the probability analysis show that the addition of amine-based CCS for 90% CO_2 capture would increase the plant cost of electricity generation significantly by 58%–108% in comparison with the plant without CCS at 95-percent confidence and result in a CO_2 avoidance cost within the 95-percent confidence interval from $35/tonne to $67/tonne, which is much lower than in other countries. With the nominal assumptions made for the base case study, an emission tax policy to encourage CCS implementation for 90% CO_2 capture at the baseload coal-fired plants requires a CO_2 price of $41/tonne, while a CO_2 sale price of $24/tonne is needed for CO_2-enhanced oil recovery operations to offset the added cost for CCS.

1. Introduction and research objectives

The Paris Agreement on climate change was made in December 2015, with an aim to hold the increase in the global average temperature at or below 2 °C this century (United Nations, 2015). Emissions of carbon dioxide (CO_2), the major contributor to climate change, mainly come from burning fossil fuels. Carbon capture and storage (CCS) is the key technological option to achieve deep reductions in CO_2 emissions from fossil fuel-fired electricity generation systems. Without CCS, the cost of mitigation in meeting the global climate goal could increase by approximately 140% (Pachauri and Meyer, 2014).

China contributed about 28% of global carbon emissions in 2013, mainly from fossil fuel combustion (IEA, 2015a). In China, the energy sector accounts for 32% of the total CO_2 emissions (Li et al., 2015), in which coal-fired power plants provide 75% of the national electricity demand (IEA, 2013). It is unlikely that the heavy reliance on coal for electricity generation will change dramatically in the short term (Korsbakken et al., 2016; Wara, 2007). Therefore, CCS deployment appears important for low-carbon energy in China. In recent years, China has boosted efforts on CCS research, development, and demonstration, featured by 12 large-scale CCS pilot and demonstration projects (Global CCS Institute, 2014). The first industrial-scale CO_2 capture project in China has demonstrated its technical feasibility for coal-fired power plants (Huang et al., 2010).

Information on CCS costs is needed for various applications, such as climate and energy policy assessments, technology assessments and investments, energy system planning, and decision-making at various levels (Rubin et al., 2015). To date, numerous studies have been conducted to estimate the cost of CCS for Chinese coal-fired power plants through deterministic techno-economic estimation (ADB, 2015; Dave et al., 2011; IEA, 2015b; Li et al., 2011; Liang et al., 2009; Wu et al., 2013). However, as illustrated later in detail, there are large discrepancies in major economic metrics for CCS, mainly because of the differences in costing methods and parameter assumptions. Some studies may even directly use the U.S.-based CCS cost to assess the economics of Chinese coal-fired power plants with CCS, which overestimates the CO_2 capture cost because it ignores lower costs of labor, equipment, material, and manufacturing in China (Dave et al., 2011; Global CCS Institute, 2011). In addition, uncertainties in power plant and CCS designs and financial conditions have been widely ignored in the existing cost studies. The major objectives of this study, therefore, are to quantify variability and uncertainty in the cost of CCS for new pulverized coal-fired (PC) power plants in China and to offer rigorous assessments for policy strategies that facilitate large-scale CCS deployment in China. Similar to a previous study on U.S.-CCS (Rubin and Zhai, 2012), we perform a systematic analysis that characterizes variability and uncertainties in power plants and CCS systems and estimates the China-CCS cost under a common costing framework.

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Table 1
Summary of Assumptions and Results for Cost Studies on Chinese Coal-fired Plants.

Parameter[a]	IEA (2015b)	Liang et al. (2009)	Li et al. (2011)	Wu et al. (2013)	Zhao et al. (2008)	Dave et al. (2011)	ADB (2015)	Renner (2014)
Reference plant without CCS								
Gross power output (MWg)		600		600	1200	600	600	
Net power output (MW)	1000		1000		1126	570	570	
Net plant efficiency, HHV (%)[p]	42[b]	41[b]	41[b]	38[b]	39[b]	41	41	42[b]
Capacity factor (%)	85		75	100	64			85
Cost year	2013$	2006$	2010$	2010$	2006$	2010$[c]	2014$[d]	2011€[e]
Discount rate (before taxes) (fraction)	0.10[f]	0.06–0.10		0.06				
Fixed charge factor (fraction)	0.102	0.073–0.106	0.120	0.066				
Coal price ($/GJ)(HHV)[p]	4.2		4.9	4.6		3.6[b]	3.3[b,d]	3.5[b]
Construction time (years)	4	2			3	2		4
Plant TCR[p]								
(reported $/kWnet)	947[g]	611[g]	664[g]	1106	519[g]	688[g]	794[g]	
(2013$/kWnet)[q]	947	694	684	1139	589	709	782	
Plant VOM ($/MWh)[p]	63.6[h]					33.9		
Plant FOM ($/MWh)[p]	4.07	6.09	5.92	4.62			18 M$[i]	
Plant LCOE[p]								
(reported $/MWh)	81.6				34.6	42.8	52	
(2013$/MWh)[q]	81.6				39.3	44.1	51.2	
Same plant with CCS								
Total CO_2 removal efficiency (%)		83[j]	~84[k]	90		90	90	90
Capacity factor (%)				100				85
Net power output (MW)		567				412	389	
Net plant efficiency, HHV (%)[p]				27		30	28	33
CCS T & S cost ($/t$CO_2$)[p]		7.4–14.9					13% VOM	3.3 ($/MWh)
Plant TCR ($/kW-net)[p]				1780[l]		1275	1430	
Added plant TCR for CCS ($/kWnet)[p]			398–445[m]	674		587	636	
Plant VOM ($/MWh)[p]								
Plant FOM ($/MWh)[p]			3.1–3.5[m]	11.7			21 M$[i]	
Plant LCOE[p]								
(reported $/MWh)						63.5	99	
(2013$/MWh)[q]						65.4	97.5	
Added plant LCOE for CCS ($/MWh)[p]						21.3	46.3	
Cost of CO_2 avoided								
(reported $/tonne)			39–47	61[n], 40.7[o]		30	53	
(2013$/tonne)[q]			40–48	63[n], 41.9[o]		31	52	

[a] The blank cells indicate that there are no data available from the reviewed papers.
[b] A 0.93 conversion factor provided by the U.S. National Research Council (2000) for coal in China was used to adjust the reported lower heating value to the higher heating value.
[c] The author indicated an exchange rate of August 2010 between CNY and AUS$ as "present". The exchange rate between CNY and USD (6.77 CNY/USD) at that period was applied.
[d] An exchange rate of 6.14 CNY/USD was applied to convert the reported data.
[e] Unless noted, a conversion factor of 0.719 (EUR/USD) was applied in this column to convert values on a 2011 USD basis.
[f] The IEA report presented three scenarios, only the scenario with a discount rate of 10% was included here.
[g] That was defined as investment cost by the IEA, including the overnight cost and interest during construction. That was defined by Liang et al. and Li et al. as initial capital outlay (fixed capital) plus working capital. Total plant investment capital was defined by Zhao et al. representing overnight cost plus other engineering cost, contingency and interest during construction. Capital investment cost as defined by Dave et al., including the interest during construction. Total overnight capital expenditure was defined by the ADB report.
[h] The estimated fuel cost was 35.7 $/MWh in the variable O & M costs.
[i] Only the total fixed O & M value on the absolute basis was given in the report.
[j] The removal efficiency was assumed in this study.
[k] The CO_2 emission rate was reported to change from 743 g/kWh to 122 g/kWh with CCS deployment.
[l] The value was assumed by the author.
[m] The two bounds stand for a 60% and 67% extra cost for reference plants with and without CCS ready hub respectively.
[n] This was phrased as "a carbon price required to justify the CCS investment for PC plants". The estimation was made based on the case of the 2010 investment.
[o] Projected value for 2030.
[p] HHV = Higher Heating Value, TCR = Total Capital Requirement, VOM = Variable Operation and Maintenance cost, FOM = Fixed Operation and Maintenance cost, LCOE = Levelized Cost of Electricity, T & S = Transport and Storage.
[q] The costs from different studies were converted to 2013 year US dollars using the Chemical Engineering Plant Cost Index. However, please note that the application of the index to non-US countries might bias estimates to some extent.

2. Review of cost studies on chinese coal-fired power plants

Numerous studies have reported cost estimates for Chinese coal-fired power plants (ADB, 2015; Dave et al., 2011; IEA, 2015b; Li et al., 2011; Liang et al., 2009; Wu et al., 2013; Zhao et al., 2008). Among the factors that affect the overall cost of a PC plant with CCS, plant type and size, capacity factor, and CO_2 removal efficiency are the major plant design parameters, while discount rate, fixed charge factor, and fuel price are the major financial and economic parameters (Rubin et al., 2007; Rubin and Zhai, 2012; Zhai and Rubin, 2013). The plant levelized cost of electricity (LCOE) generation and the cost of CO_2 avoided are the two most common cost metrics used for CCS assessments. Table 1 summarizes the major assumptions and results from recent cost studies of Chinese PC power plants by researchers from different agencies including the International Energy Agency (IEA), the Asian Development Bank (ADB), and Imperial College London. To make a comparison, the reported costs were adjusted to 2013 year dollars using the Chemical Engineering Plant Cost Index (CEPCI) ("Plant Cost Index – Chemical Engineering Magazine," 2016).

Among these existing studies, the reference plants are supercritical