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Analysis of the market penetration of clean coal technologies and its impacts in China's electricity sector

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ABSTRACT

This paper discusses policy instruments for promoting the market penetration of clean coal technologies (CCTs) into China's electricity sector and the evaluation of corresponding effects. Based on the reality that coal will remain the predominant fuel to generate electricity and conventional pulverized coal boiler power plants have serious impacts on environment degradation, development of clean coal technologies could be one alternative to meet China's fast growing demand of electricity as well as protect the already fragile environment. A multi-period market equilibrium model is applied and an electricity model of China is established to forecast changes in the electricity system up to 2030s. Three policy instruments: SO_2 emission charge, CO_2 emission charge and implementing subsidies are considered in this research. The results show that all instruments cause a significant shift in China's electricity structure, promote CCTs' competitiveness and lead China to gain great benefit in both resource saving and environment improvement. Since resource security and environment degradation are becoming primary concerns in China, policies that could help to gain generations' market share of advanced coal-based technologies such as CCTs' is suitable for the current situation of China's electricity sector.

1. Introduction

1.1. General backgrounds

China, with nearly 10% annual economic growth in the past two decades, has already become the world's second greatest energy consumer. As the main domestic energy resource accounting for 70% of energy demand mix (National Bureau of Statistics of China, 2006), coal plays the most important role in China's energy strategy especially for electricity sector. China reserves 1003 billion tons of coal, and coal production has surged since the start of the decade in response to strong demand, reaching 2.3 billion tons in 2006 (International Energy Agency (IEA), 2007). About 46% coal consumption is for generating electricity to meet the rapid demand growth. In the year 2005, China's electricity sector generated 2497.5 TWh, almost two times as the year 2000 (China Electric Power Committee, 2006). At the same time, the installed capacity reaches 517 GW, just behind the United States, ranking second in the world (China Electric Power Committee, 2006). Coal-fired generations account for about 75% of total capacity. It is expected that coal-fired generations will increase at an average rate of 4.9% per year, while total generation is projected to be tripling by the year 2030 (China Energy Research Institute and National Development and Reform Commission, 2004). The surprising expansion requires about 2939 million metric tons of coal then, two times as much as in the year 2005 (IEA, 2007).

However, behind the great achievement, exploration and utilization of large amount of coal at low efficiency in electricity sector has already brought severe problems such as resource depletion and environment degradation. Sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM) and carbon dioxide (CO_2) are caused by direct combustion of coal with weak pollutants control in China's electricity sector. China is now the world's greatest SO_2 emitter and the second largest CO_2 emitter. The emission of SO_2 and energy-related CO_2 reach 26 million tons and 5101 million tons in the year 2005, respectively (IEA, 2007). The trends of China's electricity sector are summarized in Table 1. Currently, about 30–40% of China's territory, especially the southwest, is suffering from acid rain and respiratory system disease are continuously increasing. Moreover, it is predicted that China would surpass the United States to become the world's top CO_2 emitter by the year 2009 (IEA, 2007) and have deeper impact on global warming. Therefore, to eliminate airborne pollutants and to deal with the international requirement of carbon emission

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Table 1
Information of China's energy and electricity sector from the year 2000–2005

Year	2000	2001	2002	2003	2004	2005
GDP (100 million yuan)	99,215	109,655	120,333	135,823	159,878	183,085
GDP growth rate (%)	8.4	8.3	9.1	10.0	10.1	10.2
Energy consumption (Mtce)	1385	1431	1517	1749	2032	2233
Energy consumption elasticity[a]	0.42	0.41	0.66	1.53	1.59	0.97
Electricity generation (TWh)	1347	1481	1654	1903	2197	2497
Electricity consumption elasticity[a]	1.13	1.12	1.30	1.56	1.52	1.32

Based on China's Statistical Yearbook 2006 by National Bureau of Statistics of China (2006).
[a] The elasticity ratio of energy/electricity consumption is calculated as the quotient of the growth rate of energy/elasticity consumption divided by the growth of GDP.

Table 2
Emission factors of fossil-fueled electricity generations

	CO_2 ($kgCO_2$/MWh)[a,b,c]	SO_2 (kg/MWh)[a,b,c]	NO_2 (kg/MWh)[a,b,c]	PM (kg/MWh)[a,b,c]
Conv. coal	1186	9.20	4.42	0.93
Adv.coal	1186	0.92	4.42	0.91
Oil	780	2.23	0.72	0.003
Gas (NGCC)	434	0.04	0.29	0.001
SC	913	0.26	4.12	0.48
USC	715	0.19	3.97	0.45
IGCC	718	0.07	0.08	0.003
PFBC	790	0.28	0.39	0.042

[a] Based on China's Statistical Yearbook 2006 by National Bureau of Statistics of China (2006).
[b] Rubin et al. (2007).
[c] Lu et al. (2008).

reduction and to meet the target in the coming post-Kyoto, if China possibly becomes a member, would be huge challenges to Chinese government (China Energy Research Institute and National Development and Reform Commission, 2004).

As a countermeasure, a series of policies is implemented such as developing the increased use of nuclear power, hydro power and renewable power. Nevertheless, considering the resource availability and technology maturity, even if other alternatives achieve their upper limit of development, the situation that coal will still be dominant for power generations for a considerable time in the future would not be changed (Steenhof and Fulton, 2007). In that sense, development of coal-based technologies could become a possible solution.

1.2. Clean coal technologies in China

There are several problems existing in coal-fired generation in China's electricity sector. First, China owns great variation of coal resource and generally, the fuel coal quality is low. China's coal resource is classified as 29% bituminous, 29% sub-bituminous and 16% lignite (Attwood et al., 2003). Moreover, the outdated technology results in low efficiency and serious environment problem. In spite of steadily improving to 33% in the year 2003, coal-fired efficiency of China is still lower than the United States (37%), Western Europe (39%) and Japan (42%) (Zhao and Gallagher, 2007). Under that situation, development of clean coal technologies, which are designed to enhance both the efficiency and the environmental acceptability of coal extraction, preparation and use, was on government's agenda. During the Tenth Five-Year Plan (the year 2001–2005), most clean coal technologies were included in 863 Program and several important tasks were identified. In electricity sector, super critical (SC), ultra-super critical (USC) integrated gasification combined cycle (IGCC), and pressurized fluidized bed combustion (PFBC) are technologies that are being utilized (Lu et al., 2008). The efficiency and emission factors of each clean coal technologies are summarized in Table 2.

Super (ultra-super) critical power generation coupled with pollution-control technology would be a prior choice because it is technically mature and China has mastered the key technologies. Currently, the efficiency of super critical and ultra-super critical is around 44% and 40%, respectively. Compared with other CCT technologies, super (ultra-super) critical power generation can be easier commercialized and manufactured on a large scale. There are many operating units existing around the world and the risks to investors and producers are quite low (US Department of Energy, 2007). Until the year 2005, the capacity of super critical is 11 GW and more than 100 GW is ordered in China. Also, about 20 GW of ultra-super critical is under construction.

As one of the coal gasification technologies, IGCC is considered as the most excellent clean coal technology for its high efficiency, near-zero emission, well adoption to all types of coal, easier connection with carbon capture system and lower water requirement. Also, along with electricity production, IGCC is able to co-produce other commercially desirable products through the coal–gas process. In China's case, due to the reality that fuel coal quality is low and most coal mines are located in the area meeting huge water problem, IGCC is suitable. Research on IGCC in China started form 1970s, and eventually, in October 1997, China's first IGCC demonstration power plant involving two 300–400 MW units is constructed. Until now there are more than 10 new units waiting for approval, which shows the great interest of IGCC by Chinese government. The current barrier to the adoption of IGCC is the high capital cost and low reliability. According to China State Development Planning Commission (SDPC) (1999), there would need to be at least 20% reduction in capital cost for IGCC to be competitive.

By using the fluidized bed combustion technology with higher than atmospheric pressure (5–20 bar), the potential of PFBC plant efficiency could achieve up to 45%. Also, PFBC has the advantages of high SO_2, low-NO_x emissions and the ability to burn low-quality fuels, while the capital cost is lower than IGCC. However, due to the constraints of boiler's material, the real efficiency is difficult to be raised. Also, the process of increasing pressure requires a large