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The future of coal in China

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ABSTRACT

As the world's largest consumer of total primary energy and energy from coal, and the largest emitter of carbon dioxide (CO_2), China is now taking an active role in controlling CO_2 emissions. Given current coal use in China, and the urgent need to cut emissions, 'clean coal' technologies are regarded as a promising solution for China to meet its carbon reduction targets while still obtaining a considerable share of energy from coal. Using an economy-wide model, this paper evaluates the impact of two existing advanced coal technologies – coal upgrading and ultra-supercritical (USC) coal power generation – on economic, energy and emissions outcomes when a carbon price is used to meet China's CO_2 intensity target out to 2035. Additional deployment of USC coal power generation lowers the carbon price required to meet the CO_2 intensity target by more than 40% in the near term and by 25% in the longer term. It also increases total coal power generation and coal use. Increasing the share of coal that is upgraded leads to only a small decrease in the carbon price. As China's CO_2 intensity is set exogenously, additional deployment of the two technologies has a small impact on total CO_2 emissions.

1. Introduction

China is the world's largest consumer of both total primary energy and energy from coal (BP, 2016) and is also the world's largest emitter of carbon dioxide (CO_2). Coal accounted for 66% of China's total primary energy consumption in 2014 (National Bureau of Statistics of China, 2015), is expected to account for 50% of the total primary energy consumption by 2030 (He, 2015), and will continue to be a major source of energy until at least 2050 (Chinese Academy of Engineering, 2011). As a carbon-intensive and widely used fossil fuel, coal was responsible for 75% of total CO_2 emissions from fossil fuel consumption in China in 2011 (Mao, 2014).

China is now taking an active role in controlling its carbon emissions by agreeing to peak its CO_2 emissions before 2030 (White House, 2014), and reducing its CO_2 intensity by 60–65% from the 2005 level by 2030 (NDRC, 2015). To contribute to these emission reductions, China has outlined several policies to control total coal consumption and promote cleaner coal use. These directives include limiting the contribution of coal to total energy consumption to a maximum of 65% in 2017 by China's Air Pollution Control Action Plan (State Council of the People's Republic of China, 2013), and capping China's annual coal use at 4.2 billion tons in 2020 (General Office of the State Council of PRC, 2014). In 2015, the National Energy Administration issued the Action Plan on Clean and Efficient Utilization of Coal (2015–2020), detailing plans on a set of clean coal utilization technologies (NEA, 2015). Given current coal use in China, and the urgent need to cut emissions, 'clean coal' technologies are regarded as a promising solution for China to meet its carbon reduction targets while still obtaining a considerable share of its energy from coal (Yue, 2012).

Coal technologies are considered to be 'clean' if they offer an environmental improvement over those currently in use (Watson et al., 2007). 'Clean coal' technologies improve environmental outcomes by using coal more efficiently, or removing undesirable pollutants after combustion in end-of-pipe processes. 'Clean coal' technologies include coal upgrading (e.g. washing and briquetting), highly-efficient coal power generation (e.g. supercritical and ultra-supercritical coal-fired power generation), coal conversion (e.g. coal gasification and coal liquefaction), and coal waste gas clean-up processes (e.g. flue gas desulphurization, denitrification and carbon capture and storage) (Watson et al., 2007; Chang et al., 2016; Zhao and Chen, 2015).

As coal upgrading and more efficient coal-power generation technologies are playing an increasingly larger role, this paper evaluates the impact of these technologies on economic, energy and emissions outcomes in China out to 2035. The analysis employs an economy-wide model with a detailed representation of energy production and simulates a carbon price to meet CO_2-intensity targets in China. The paper finds that clean coal technologies, especially more efficient coal power generation, can reduce the cost of meeting emissions constraints

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in China in the near to medium term. At the same time, near-term investment in coal technologies will increase the costs of meeting more stringent long-run targets that require a move towards low-carbon energy sources. As such, the near-terms benefits of clean coal technologies should be viewed with caution.

This study also complements previous studies that estimate the economy-wide implications of climate policy in China (Li and Lin, 2013; Hübler et al., 2014; Zhang et al., 2015) and research focused on the coal sector (Yue, 2012; Hao et al., 2015; Tang et al., 2015; Yuan et al., 2016; Zhao et al., 2017).

This article has four further sections. Section 2 discusses the USC and coal upgrading technologies evaluated in this paper. Section 3 outlines the modeling framework employed for the analysis, details how the USC and coal upgrading technologies are represented in the model, and outlines the scenarios implemented. Results are presented and discussed in Section 4. Section 5 concludes.

2. Advanced coal technologies

At present, China is facing choices about which coal preparation and conversion technologies should be installed to allow the country to meet its near-term air pollution and climate mitigation goals. This analysis is intended to inform these choices by considering several near-term coal technology options that will have important implications for the country's future carbon footprint. Specifically, we consider coal upgrading and USC combustion for power generation, which are already operating in China's energy system but have scope to expand (NEA, 2015). An important question for this numerical analysis is how these technologies will contribute to reductions in greenhouse gas (GHG) emissions and interact with other energy technologies under climate policies through 2030, the year by which policymakers have pledged to achieve peak CO_2 emissions in China.

Coal upgrading technologies refer to coal washing and other coal pre-treatment. Coal upgrading is an important procedure to increase coal utilization efficiency and reduce emissions by decreasing the sulfur and ash content in raw coal and enabling more complete chemical reaction. Coal upgrading will also reduce GHG emissions from coal transportation by removing non-combustible components and ultimately reducing load weight. The share of raw coal that is upgraded is more than 80% in developed countries while only 62% of coal was upgraded in China in 2014 (China Industry Information, 2015). This share is projected to be 70% in 2017 according to China's Air Pollution Control Action Plan (State Council of the People's Republic of China, 2013), and is planned to be above 80% in 2020 (NEA, MEP, MIIT, 2014).

USC combustion is an advanced coal power generation technology which has higher steam temperature and pressure and therefore a higher energy conversion efficiency than conventional coal power technologies. The average energy conversion efficiency of USC units is 48% while the average efficiency of supercritical units is 41%. Due to the rapid development of China's manufacturing industries and the implementation of the 'Replacing Small Units with Large Ones' policy (State Council of the People's Republic of China, 2007), thermal power plants in China are now more reliable and efficient than in previous decades. China has had significant success in advanced coal-fired power generation and energy efficiency development during the Eleventh Five-Year Plan period (2006–2010) and has become a leading country in supercritical and USC power generation technologies

The share of power plants with a capacity larger than 600 MW (MW) is now 36.8% and the average net coal consumption rate – defined as the average coal equivalent consumption for providing 1 kW h (kWh) of electricity by a thermal power plant – has decreased from 370 g of coal equivalent (gce) per kWh in 2005 to 318 gce/kWh (Xie, 2014). China now has more 1000 MW units than any other nation and also has some of the most advanced coal plants with the lowest net coal consumption rate in the world (The Comprehensive Research Group for Energy Consulting and Research, 2015). For example, the Waigaoqiao 3 USC power generation units, in Shanghai, achieved a net coal consumption rate of 276.8 gce/kWh in 2013 (IEA Clean Coal Centre, 2014), compared to 292.5 gce/kWh and 286.1 gce/kWh for the most advance plants in, respectively, Japan and Denmark (Peng and Xu, 2014). New-build coal power plants in China are required to have a net coal consumption rate at or below 300 gce/kWh (General Office of the State Council of PRC, 2014), and an active research program continues to investigate more efficient options for USC power generation. The Waigaoqiao 3 plant has achieved a maximum lower heating value efficiency of 46.5% (Nicol, 2013)

Between 2010 and 2020, all new-build pulverized coal power generation plants with a generation capacity above 600 MW (MW) in China will be supercritical, and half of them will be USC. Consequently, supercritical units will account over 30% of the total power capacity by 2020, which will have a significant impact on the economic and environmental performances of China's power industry (Huang, 2008).

Several other coal-related technologies could interact with deployment pathways for coal upgrading and USC coal power generation, but are not considered in this report. For example, we do not consider end-of-pipe technologies that reduce pollutant emissions such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM). Also, we do not consider coal conversion technologies such as coal gasification. These technologies are not considered in this research as we wish to focus on proposed policies directed at reducing GHG emissions.

3. Modeling framework

The analysis in this paper uses version 2 of the China-in-Global Energy Model (C-GEM) (Qi ei al., 2014; Qi et al., 2016). The C-GEM is a multi-regional, multi-sector, recursive dynamic computable general equilibrium model developed collaboratively by researchers at Tsinghua University and the Massachusetts Institute of Technology as part of the China Energy and Climate Project. The model is designed to simulate existing and proposed energy and climate polices in China and analyze their impact on the deployment of new energy technologies, inter-fuel competition, the environment, and the economy within a global context.

Version 2 of the C-GEM (C-GEM2) has a base year of 2011 compared to base year 2007 used in Version 1 of the model. C-GEM2 uses Version 9 of the Global Trade Analysis Project (GTAP) Database (Aguiar et al., 2016) augmented to include a detailed representation of electricity generation (Peters, 2016) for input-output data for all regions and bilateral international trade data. The C-GEM2 divides the global economy into 19 regions and 21 sectors, as shown in Table 1. As the model is designed to evaluate climate and energy technologies, the model represents energy extraction and production in detail, including eight electricity generation technologies, and separately represents four energy-intensive manufacturing industries. The model is solved for 2011, 2015 and every five years through to 2035. In this study, as outlined in Section 3.1, coal upgrading and USC power generation technologies are added to the C-GEM2 for this study. More details on the C-GEM are provided in the Appendix to this paper.

3.1. Coal upgrading

In 2011, the base year for the C-GEM2, 53.0% of total coal used in China was upgraded (China Energy News, 2012). Decomposing the aggregate number, the share of upgraded coal in total coal used for electricity was 33.0%, and 81.2% of coal used by other industries was upgraded (China Energy News, 2012). In the C-GEM2, production and use of upgraded coal in the base year is captured by the underlying input-output (GTAP) data used to calibrate the model. Without disaggregation of coal types, the model will implicitly assume that upgraded and conventional will be continued to be used in the same