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Impacts of power generation on air quality in China—Part II: Future scenarios

Jianlin Hu[a], Lin Huang[a], Mindong Chen[a], Gang He[b,*], Hongliang Zhang[a,c,**]

[a] Jiangsu Key Laboratory of Atmospheric Environment Monitoring and Pollution Control, Jiangsu Engineering Technology Research Center of Environmental Cleaning Materials, Collaborative Innovation Center of Atmospheric Environment and Equipment Technology, School of Environmental Science and Engineering, Nanjing University of Information Science & Technology, 219 Ningliu Road, Nanjing 210044, China

[b] Department of Technology and Society, College of Engineering and Applied Sciences, Stony Brook University, Stony Brook, NY 11794, USA

[c] Department of Civil and Environmental Engineering, Louisiana State University, Baton Rouge, LA 70803, USA

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ABSTRACT

Power generation is an important source of air pollution in China since it is mostly from coal-fired power plants. Future power generation plans are needed to meet both increasing power needs and air quality improvement. In this study, five future power development scenarios in 2030 were considered. The REF scenario is the base case in which the growth was assumed to follow the existing projection (business as usual). The CAP scenario represents power sector in the trajectory to achieve 80% reduction by 2050 as proposed by IPCC, the LOW scenario reflects low cost of renewable to foster wind and solar development, the PEAK scenario allows China to peak its carbon emission by 2030, while the WEST scenario assumes that the coal power bases build all planned capacity by 2030 and no coal power in Beijing, Tianjin and Shanghai by 2030. Then, impacts of the scenarios on air quality were simulated with the Community Multiscale Air Quality (CMAQ) model in January and August 2030 with unchanged emissions from other sectors and the same meteorology in 2013. The results indicate that air quality gets worse in the REF scenario in both months compared to 2013. The CAP and WEST scenarios generally have larger impacts on pollutant concentrations than the LOW and PEAK scenarios. The four scenarios improve $PM_{2.5}$ total mass and SO_4^{2-} in North China, with maximum decreases of over 100 $\mu g\,m^{-3}$ in January and over 10 $\mu g\,m^{-3}$ in August in the Hohhot area. However, $PM_{2.5}$ total mass and SO_4^{2-} pollution are worsened in Shandong for CAP and WEST scenarios and in Chongqing for LOW and PEAK scenarios. NO_3^- and O_3 get worsened in the four scenarios in large areas of the North China Plain (NCP), East and South China due to more NH_3 available for NO_3^- formation associated with reduction in SO_4^{2-} and aerosol radiative effects on UV radiation for O_3 formation. Power development plans greatly affect air quality in Beijing, with decrease in $PM_{2.5}$ and PM_{10}, but increase in O_3. Reducing NO_x and SO_2 combined with NH_3 should be considered to reduce contribution of power generation to future air pollution in China.

1. Introduction

China has been the fastest developing country in the world during the last a few decades. Associated with fast development of industrialization, urbanization, and motorization, fossil fuel consumption has been dramatically increased. Liu et al. (2015) reported that a 479% growth in coal consumption from 1990 and 2010. Large amount of fossil fuel combustion significantly contributes to emissions of air pollutants such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM), causing severe air pollution problems regionally in China (Chan and Yao, 2008; Cheng et al., 2013; Fu et al., 2008; He et al., 2001; Hu et al., 2014; Huang et al., 2014; Liu et al., 2013; Sun et al., 2014; Tie and Cao, 2009; Wang et al., 2014b) and globally through long distance transport (Lin et al., 2012; Wang et al., 2009). The severe air pollution has been linked to health risks (Huang et al., 2009), visibility degradation (Deng et al., 2008), and climate change (Ding et al., 2013).

The power generation in China has been increasing significantly to support the rapid economic and social development (Yue, 2012). Coal-fired plants contribute about 75% of power generation and become an important source contributor to air pollutions. For example, in 2012 the power sector contributes to 33% of NO_x, 23% of SO_2, and 8% of PM (Huang et al., 2016). SO_2, NO_x, and PM are among the six criteria pollutants regulated by the National Ambient Air

* Corresponding author.
** Corresponding author at: Department of Civil and Environmental Engineering, Louisiana State University, Baton Rouge, LA 70803, USA
E-mail addresses: gang.he@stonybrook.edu (G. He), hlzhang@lsu.edu (H. Zhang).

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Table 1
The general assumptions associated with each of the power generation development scenario.

Scenario	Description	Reference
REF	Reference scenario	Hu et al. (2011)
CAP	Trajectory to reduce 80% on 1990 level by 2050	IPCC (2015)
LOW	Low cost of renewable energy, aggressive learn curve of wind and solar	DOE (2012)
PEAK	Peak carbon emission by 2030	NDRC (2015)
WEST	Assuming the 14 coal-power bases in 7 provinces build half of planned capacity by 2020 and all planned capacity by 2030, No coal in Beijing, Tianjin and Shanghai by 2030	NDRC (2012)

Note: The electricity generation in the REF scenario is from the Scenario 2 by the Intelligent Laboratory for Economy-Energy-Electricity-Environment (ILE4) of the State Grid Energy Research Institute (Hu et al., 2011). In the PEAK scenario as China has nationally determined its actions by 2030 to achieve the peaking of carbon dioxide emissions around 2030 and making best efforts to peak early; to lower carbon dioxide emissions per unit of GDP by 60%–65% from the 2005 level; and to increase the share of non-fossil fuels in primary energy consumption to around 20% (NDRC, 2015). In the CAP scenario, China enhances its efforts to achieve 80% reduction of carbon emission on 1990 level by 2050 as recommended by IPCC (2015). In the LOW scenario, the overnight cost of wind and solar technology is assumed to follow the projections by DOE SunShot and LBNL wind study (DOE, 2012). The coal power base in China locates in Xinjiang, Inner Mongolia, Ningxia, Heilongjiang, Gansu, Shanxi, Shaanxi, Guizhou, and Anhui. In the WEST scenario, we assume coal power is completely phased out in Beijing, Tianjin, and Shanghai by 2020; and half of planned capacity is online in Xinjiang, Inner Mongolia, Ningxia, Heilongjiang, Gansu, Shaanxi, and Shanxi by 2020. And all planned capacity by 2030. Other provinces keep the same capacity (NDRC, 2012; Song et al., 2012).

Quality Standards of China (MEP, 2012). In addition, SO_2 and NO_x can form secondary PM components of sulfate (SO_4^{2-}) and nitrate (NO_3^-), and NO_x is also precursor of ozone (O_3). Previous studies showed that power sector was a major contributor to particulate SO_4^{2-} and NO_3^- in China (Wang et al., 2014a; Zhang et al., 2012a) and inter-regional transport was significant (Ying et al., 2014). It is necessary to consider controlling emissions from power generation to improve air quality. In 2011, the Ministry of Environmental Protection of China revised the Air Pollutants Emission Standards for Coal-Fired Power Plants (MEP, 2011) and lowered the standards for dust, SO_2, NO_x, and etc.

Controlling emissions from power generation faces many challenges. The coal consumption for power generation keeps increasing. Tremendous efforts have been made to reduce emissions from power generation by installing emission control systems of desulphurization, selective catalytic reduction (SCR) or electrostatic precipitators. It was estimated that these techniques reduced SO_2 emissions by 17 million tons in 2010 (Zhang et al., 2012b). As a result, declining trends have been found in the emissions of SO_2 and PM from power generation (Huang et al., 2016). However, the emissions of NO_x, CO, CO_2, and VOC from power generation have been identified to be still growing. NO_x emission has increased by about 10%, and CO, CO_2, and VOC emissions have increased by about 30% from 2008 to 2012 (Huang et al., 2016). Therefore, future development plans of power generation are needed to meet both the increasing power needs and the requirement on air quality improvement, in addition to developing and applying emission control techniques.

In a companion paper, Huang et al. (2016) reviewed the current status of power generation's contribution to air quality in China. In this study, four scenarios for future power generation in 2030 in China were tested against the normal growth case. The future air quality associated with each scenario was predicted using a regional chemical transport model (CTM) in a winter month (January) and a summer month (August) in 2030. The results provide valuable information for designing future power generation development plans to meet the growing power need and improve air quality in China.

2. Method

2.1. Future power emission scenarios

The Multi-resolution Emission Inventory for China (MEIC) developed by Tsinghua University (http://www.meicmodel.org) for base year of 2012 was used in this study. The power emission inventory is a unit-based emission inventory for power plants (Wang et al., 2012). Emission rates of major pollutants from power generation in each province are shown in Table S1. This inventory has been widely used for studies of air pollution in China and its effects globally (Guan et al., 2014; Hu et al., 2015; Lin et al., 2014; Zheng et al., 2015).

Five future emission scenarios of power plants in 2030 were developed based on certain assumptions, as listed in Table 1. The REF scenario is the base case in which the growth was assumed to follow the existing projection (business as usual) (Hu et al., 2011). The CAP scenario represents power sector in the trajectory to achieve 80% reduction on 1990 level by 2050 as proposed by IPCC, the LOW scenario reflects low cost of renewable to foster wind and solar development, the PEAK scenario allows China to peak its carbon emission by 2030, and the WEST scenario assumes the coal power bases build all planned capacity by 2030 and no coal power in Beijing, Tianjin and Shanghai by 2030 (He, 2015; He and Kammen, 2014, 2016). Provincial growth factors for power plants were generated for each scenario (shown in Table 2), and the future emission in were obtained by multiplying the 2013 emissions in Table S1 with the scaling factors. It should be noted that the scenarios used are based on different assumptions from previous studies. Due the transition of China to a more consumption and service oriented economy (China's New Normal), policymakers and power system planners in China should re-evaluate power demand projections and the need for new generation capacity to avoid over-investment that could lead to stranded generation assets.

Other emission inputs to the model include biogenic emissions generated by the Model for Emissions of Gases and Aerosols from Nature (MEGAN) v2.1, open biomass burning generated using an in-house program based on the Fire INventory from NCAR (FINN) from satellite observations (Wiedinmyer et al., 2011), as well as dust and sea salt emissions generated in line during the CMAQ simulations. Details of the models and their settings can be found in previous papers (Hu et al., 2015; Qiao et al., 2015; Zhang et al., 2014). These emissions are kept the same for future scenarios since the purpose of this paper is to see the impacts of power generation.

2.2. Air quality modeling

The Community Multiscale Air Quality (CMAQ) model v5.01 was applied to investigate the impacts of future power generation scenarios on air quality in China. Concentrations of air pollutants in the five scenarios were simulated in January to represent winter episode and August to represent summer episode using a 36-km horizontal resolution domain that covers the entire China. Meteorological conditions in winter generally lead to the highest particulate matter but the least ozone pollution in China; and meteorological conditions in summer lead to the lowest particulate matter but the highest ozone pollution. Therefore by simulating January and August, the highest and lowest impact of changes in power generation on particulate matter and ozone can be assessed.