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# Carbon emission scenarios of China's power sector: Impact of controlling measures and carbon pricing mechanism

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**Abstract**

The study constructs a low-carbon path analysis model of China's power sector based on TIMES model and presents a comparative analysis of carbon emissions under Reference, Low-Carbon and Enhanced Low-Carbon scenarios, and the main difference of the three scenarios is manifested by policy selection and policy strength. The conclusions are drawn as follows: (1) The peak of carbon emission in China's power sector will range from 4.0 $GtCO_2$ to 4.8 $GtCO_2$, which implies an increment of 0.5−1.3 billion or 14%−35% from the 2015 levels. (2) Introducing carbon price is an effective way to inhibit coal power and promote non-fossil fuels and Carbon Capture, Utilization and Storage applications (CCUS). The carbon emission reduction effects will gradually increase with carbon price. When the carbon price attains to CN¥150 $t^{-1}CO_2$, the $CO_2$ emission can decrease by 36% than that without carbon price. (3) CCUS is one of important contributing factor to reduce $CO_2$ emission in power sector. Generally speaking, the development of non-fossil fuels and energy efficiency improvement are two main drivers for carbon mitigation, but once the carbon price reaches up to CN¥106 $t^{-1}CO_2$, the CCUS will be required to equip with thermal power units and its contribution on carbon emission reduction will remarkably increase. When carbon price increases to CN¥150 $t^{-1}CO_2$ in 2050, the application of CCUS will account for 44% of total emission reduction. (4) In the scenario with carbon price of CN¥150 $t^{-1}CO_2$, power sector would be decarbonized significantly, and the $CO_2$ intensity will be 0.22 $kgCO_2$ $(kW\ h)^{-1}$, but power sector is far from the goal that achieving net zero emission. In order to realize the long-term low greenhouse gas emission development goal that proposed by the Paris Agreement, more efforts are needed to be put to further reduce the carbon emission reduction of power sector. Based on the above scenario analysis, the study proposes four recommendations on the low-carbon development of China's power sector: (1) improve the energy efficiency proactively and optimize the energy structure of power sector gradually; (2) promote the low-carbon transition of power sector by using market-based mechanism like carbon emission trading scheme to internalize the external cost of carbon emission; (3) give more emphasis on and support to the CCUS application in power sector.

*Keywords:* Power sector; TIMES model; Scenario analysis; Carbon peak; Carbon pricing; Policy recommendations

## 1. Introduction

As the Paris Agreement has been reached, countries around the world are moving towards a low-emission and climate-resilient world and the majority prefer to the low-carbon path for development (IPCC, 2014; Du, 2014; Li, 2015). In 2015, the Chinese government announced the Enhanced Actions on Climate Change−China's Intended Nationally Determined Contributions and pledged to peak $CO_2$ emissions around 2030 and strive to peak early (NDRC, 2015). To achieve these targets, we must vigorously press ahead with the low-carbon transformation of economy and society, especially the energy sector.

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The power sector is the largest carbon emitter and non-fossil energy user among Chinese economic sectors. According to preliminary estimates, the power sector produced about 3.55 $GtCO_2$ in 2015, accounting for 38% of the country's carbon emissions from energy consumption. In view of more stringent binding targets for carbon emissions, the Chinese government has adopted a number of policies and measures that remarkably improve the energy structure and energy efficiency in the power sector. The share of renewable generation in total generation increased from 16.1% in 2005 to 22.4% in 2015, while the fuel use per power generation in coal-fired plants fell by 14.9% to 315 gce $(kW\ h)^{-1}$ (CEC (China Electricity Council), 2017; NBSC, 2016a). However, it should not be overlooked that carbon emissions are still taking an upward trend in the power sector. More specifically, the carbon emissions increased by 69% from 2.1 $GtCO_2$ to 3.55 $GtCO_2$ over the ten years (NBSC, 2016b). Given this, only through low-carbon transformation of the power sector can we radically change the high-carbon energy system and achieve low carbon in end users in China.

There have been many studies on the low-carbon transition of power sector with the utilization of various models and scenarios, and these studies provided valuable insights into hot topics, such as carbon emission peak, carbon tax, carbon price, influence factors of carbon emission and emission abatement potential (Cheng and Xing, 2016; Wang and Wang, 2016; Liu et al., 2014; Song et al., 2013; Zhang, 2011; Peng and Wang, 2016; Zhu, 2011). The methodologies and conclusions of these studies are instructive for our analysis. Our study constructs a low-carbon path analysis model of China's power sector based on The Integrated MARKAL-EFOM System (TIMES) model, conducts a comparative analysis of carbon emissions scenarios and further, probes into the targets, paths, policies and their effects regarding the control of carbon emissions in the power sector.

## 2. Model and methodology

The TIMES model is an energy system model that can provide detailed technical analysis for long-term, multi-period, and dynamic energy development in a country or region (Loulou et al., 2005a). It is generally used for the study of the entire energy system and also individual-specific sectors such as the power sector. Based on the TIMES model, this study builds the Low-Carbon Path Analysis Model for China's Power Sector which is a refined dynamic linear programming model for power system (Fig. 1). Driven by future power demand, the proposed model objectively describes all aspects of the real energy system, such as primary energy supply, power generation facility operation, power demand, and offers detailed characterization of current or future applicable technologies to form a complete reference energy system (RES) (Loulou et al., 2005b).

The Low-Carbon Path Analysis Model for China's Power Sector simulates future development trends of the power sector on the RES. Under the constraints of energy supply, process capacity, production operation and pollutant emissions, as well as user-defined constraints, the model applies the linear programming method to produce minimum-cost technological combinations and calculates energy consumption and carbon emissions of power system under different scenarios (Liu et al., 2011; Wang et al., 2010).

The analysis sets 2050 as target year with a one-year time interval, and uses China's national historical statistic data from 2007 to 2012 to calibrate the data in the model. In order to clearly present and compare the result for each 5 years, the analysis use year 2010 as the beginning year. The model examines nine energy carriers, namely coal, oil, natural gas, nuclear energy, hydro energy, wind energy, solar energy, biomass energy, and geothermal energy. It depicts a total of 201 existing and prospective technologies in different links of the national power generation system. The model data is divided into five types, including natural sources data, technologies data, emission factor data, system setting parameters and demand data. The first three types of data mainly come from *China Statistical Yearbooks* (NBSC, 2016a), *China Energy Statistical Yearbooks* (NBSC, 2016b) and other publicly accessible data; system setting parameters usually are set by default or by users; and demand data is cited from Liu et al. (2017, 2016).

## 3. Scenario design

### 3.1. Scenarios with different controlling measures

This study sets three scenarios, i.e. reference (REF) scenario, low-carbon (LC) scenario and enhanced low-carbon (ELC) scenario, and by comparing carbon emissions in these scenarios, identifies different paths to carbon emission peak in the power sector and policy implications. In the REF scenario, the power sector is free from additional abatement targets and maintains energy conservation and non-fossil energy development as during the 11th and 12th Five-Year Plan (FYP) periods. The LC scenario strengthens the measures for energy conservation and emissions reduction, and promotes power generation from non-fossil energy sources while intensifying the elimination and replacement of backward coal-fired generators. In the ELC scenario, the power sector is subject to more stringent constraints of carbon emissions, and steps up the control of total installed capacity from coal-fired generators and the large-scale development of renewable energy generators. The demand for electricity will grow, but at different rates in the three scenarios, which reflects the increased efforts of energy demand-side management. To 2050, the per capita power consumption will reach 8500, 7500 and 7000 kW h in the REF, LC and ELC scenarios respectively (Fig. 2) (Liu et al., 2016, 2017; Zhou et al., 2011; IEA, 2014; Wang and Watson, 2010; Zhang and Cheng, 2015; Jiang, 2011). The three scenarios are set and compared, as shown in Table 1.

### 3.2. Scenarios with different carbon pricing

The carbon price scenarios are set by introducing carbon pricing to the above-mentioned scenario, in order to evaluate the effects of carbon price on carbon emissions of the power