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The implications of CO_2 price for China's power sector decarbonization

Ying Li *, Zofia Lukszo, Margot Weijnen

Faculty of Technology, Policy and Management, Delft University of Technology, Jaffalaan 5, 2600 GA Delft, The Netherlands

HIGHLIGHTS

- We quantify the technical, environmental and economic implications of CO_2 price for China's power decarbonization.
- We examine the interactions between CO_2 prices, fuel prices and CCS technology.
- CO_2 pricing and CCS technology are mutually reinforcing in reducing CO_2 emissions yet keeping the cost effectiveness.
- Higher fuel prices undermine or nullify the effect of CO_2 pricing on the power decarbonization.
- The mandatory targets for RES power generation should be coordinated with CO_2 pricing.

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ABSTRACT

China has shown growing interest in market-based CO_2 pricing and is expected to establish a nationwide emission trading system by 2016. This study investigates the implications of CO_2 price for China's power sector decarbonization up to 2050, incorporating different scenarios of fuel prices and the development of carbon capture and storage (CCS) technology. An adapted low-carbon generation expansion planning (GEP) model is used to determine the least-cost decarbonization pathways. The implications of the CO_2 price are analyzed from the technical, environmental and economic perspectives for 32 scenarios. This study finds that, first of all, a high CO_2 price is conducive to achieve a high degree of decarbonization in a cost-effective way, but only if CCS technology is available. Secondly, higher fuel prices undermine or nullify the effect of CO_2 pricing on the power decarbonization. Thirdly, the optimal share of renewable energy source (RES) power generation depends on its comparative cost-advantage over CCS-integrated power generation in this study, and the cost-advantage is largely influenced by CO_2 prices. Hence, policy makers should coordinate the mandatory targets for RES power generation with CO_2 pricing, otherwise, these targets might become redundant or entail extra costs. The findings can be used for China's policy makers regarding the design of cost-effective power sector decarbonization packages complementing CO_2 pricing.

1. Introduction

China has achieved a remarkable economic expansion during the past three decades, but this has come at substantial environmental costs [1]. The nation today accounts for more than a quarter of global CO_2 emissions and for half of annual emission growth [2,3]. Therefore, its participation is crucial in any global efforts to combat climate change. Besides the international commitments, reducing local air pollution is also of increasing concern to China [4]. Furthermore, most low-carbon technologies entail reduced emissions of particulates, NO_x and SO_2 which are currently responsible for the poor air quality in many cities. Due to these reasons, it has become necessary and urgent for China to embark on transitions towards a low-carbon economy. In particular, the success of China's low-carbon transition hinges on the decarbonization of the power sector, as this sector generates almost 40% of the national energy-related CO_2 emissions [5]. At the same time, the power sector has huge potential to integrate non-fossil fuel-based power especially renewable energy resource (RES) power in the future [6].

Seeking a cost-effective decarbonization pathway for the power sector is challenging, not only due to the diversity of regulatory and technical options available, but also because of the dynamic and uncertain future [7]. Based on past experience, China has come to realize that market-based instruments are indispensable for

* Corresponding author. Tel.: +31 152781588; fax: +31 152783422.
E-mail address: y.li-6@tudelft.nl (Y. Li).

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achieving CO_2 mitigation in a cost-effective way. Before the 12th Five-year Planning (FYP) period,[1] China did not establish policy instruments which were intended for CO_2 mitigation. Hence, most of the CO_2 emission reductions before 2011 were achieved as co-benefits from the state's energy conservation strategies [3]. For instance, during the 11th FYP,[2] 52% of the CO_2 emission reductions in the power sector was achieved by energy efficiency improvement [8]. Next, China's policies have heavily relied on command-and-control regulations, such as the enforced shut-down of small coal-fired power plants [9]. The cost inefficiency caused by these administrative orders as well as the expectations to develop a competitive low-carbon economy have inspired China to adopt more market-based instruments, in which the CO_2 emission trading system (ETS) is currently being developed [10,11]. So far, China has established seven local ETS pilots as macro-laboratories where the ETS can be tested before a national roll out [12].

Instead of focusing on a specific CO_2 pricing mechanism (e.g. the cap-and-trade ETS or carbon taxation), this paper aims to investigate the implications of CO_2 price on the power decarbonization assuming that CO_2 pricing will be adopted nationwide in the future. In theory, introducing a CO_2 price contributes to CO_2 emission reductions of the power sector in three major ways: (1) it shifts power supply towards using less carbon-intensive generation technologies; (2) it promotes the use of non-fossil fuel-based generation technologies; and (3) it provides incentives for innovations in low-carbon technologies, such as carbon capture and storage (CCS) technology [13]. However, the degree to which CO_2 pricing can assist in reducing CO_2 emissions, the technologies needed, and the costs involved are highly uncertain. First, the impact of a CO_2 price on the power decarbonization is influenced by fuel prices which are fraught with high uncertainties. Furthermore, the development of CCS technology and its integration with various fossil fuel-fired generation technologies are uncertain, which complicate the technological choices for the power supply in the future [14,15].

This paper focuses on investigating the implications of the CO_2 price for China's power sector decarbonization, incorporating the uncertainties regarding fuel prices and the development of CCS technology. This work complements a number of recently published articles in peer-reviewed journals, such as [16–21], which focus on the impact of carbon mitigation policies on China's power sector. In particular, Zhang et al. suggest that a clear and long-term climate mitigation policy should be executed as early as possible to avoid carbon lock-in investment [20]. Wang et al. stress that a continuous and stable carbon mitigation policy is effective in reducing CO_2 emissions and the system costs of the power supply during 2010–2050 [21]. Still, this paper distinguishes itself from others by providing insights into the technical, environmental and economic implications of CO_2 price on China's power sector. In addition, most studies have not paid much attention to the interactions between CO_2 pricing, fuel prices and the development of CCS technology.

We will answer the following questions in this study. Firstly, what are the implications of the CO_2 price for China's power sector decarbonization, in terms of technical pathways, CO_2 emissions and economic effectiveness? Secondly, what is the impact of fuel prices and the development of CCS technology on the three above-mentioned implications? Thirdly, what policy recommendations can be proposed regarding the CO_2 price regulation for China's power sector decarbonization?

The remainder of the paper is organized as follows. Section 2 introduces the context of China's power sector decarbonization. Section 3 briefly describes the research methods used in this study. Section 4 illustrates the data collection. Section 5 analyzes the results of the scenarios. Section 6 discusses the interactions between CO_2 pricing, fuel prices and the development of CCS technology, as well as the policy implications. Final conclusions are drawn in Section 7.

2. China's context of power sector decarbonization

China's power sector is undergoing rapid changes, as fuel markets have been liberalized, emission regulations are put into place and new technologies are being developed. These ingredients closely interact with each other so that the implications of CO_2 price on power decarbonization cannot be assessed without accounting for the impact of fuel prices and generation technologies. This section briefly reviews the current status of the CO_2 ETS, the coal and gas market and the development of CCS technology in China.

2.1. CO_2 pricing: Emission trading system

China has been a dominant carbon credit supplier for the developed countries in the clean development mechanism (CDM), while it has not established a domestic CO_2 pricing mechanism [11,22]. In view of the expected environmental and economic benefits, the ETS (following the European ETS model) was first officially identified as one of the key policy initiatives for CO_2 mitigation in the 12th FYP for National Economic and Social Development [23].

Following the philosophy of "crossing the river by feeling for the stones", major policy changes in China are introduced incrementally and experimentally. The establishment of a CO_2 ETS is no exception. In 2011, seven local ETS pilots[3] were selected by the central government as macro-laboratories to test the ETS and improve its design before being rolled out nationwide. So far, all the seven pilots are operational. These pilots differ from each other in the details of market design, local regulations and implementation [24], while all of them classify the power sector as a top candidate for CO_2 emission trading.

Although the lack of a free market has triggered much debate on the viability of the ETS in China [11,25], the trading of CO_2 emissions so far from the pilots is encouraging. For instance, the total CO_2 emission allocations of the first six pilots (except for the Chongqing ETS) by 2014 amounted to 1115 million tons, which makes China the second largest ETS market just after the European Union [26]. Moreover, all the pilots have actively experimented various measures to boost the market liquidity [27]. Based on the experience of the pilots, China's leading climate officials have suggested a nationwide carbon trading market could be established by 2016, despite many challenges ahead [28].

2.2. Fuel prices

China's efforts to liberalize its fuel markets have so far focused on coal and natural gas. As a result of deregulation of the coal and gas market, opening them up for competition, these fuels are now prone to price uncertainties which will affect the power sector. This paper focuses on the impact of coal and gas price, since other fuels that are relevant for the power sector, such as uranium, remain under tight government control.

Coal price. Since the electricity-coal market was liberalized in 2002, China's coal price has increased steadily, featuring unusual volatilities. The average coal price in 2011 was 126.67 $/ton,

[1] China issues its National Economic and Social Development Planning on a five-year basis. The 12th FYP refers to the year from 2011 to 2015.

[2] The 11th FYP refers to the year from 2006 to 2010.

[3] The pilots are located in five cities, namely Shenzhen, Beijing, Shanghai, Tianjin and Chongqing, as well as in two provinces, Guangdong and Hubei.