ECONOMICS

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DISCUSSION PAPER 14.03

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ABSTRACT

As a large emerging economy, China is exploring to establish a carbon pricing system to mitigate greenhouse gas emissions. The electricity sector which generates the greatest amount of China's carbon dioxide (CO_2) emissions should be covered by such a carbon pricing system. The review of the three main stages of China's electricity market reforms shows that the degree of electricity marketization is relatively low, which might become an obstacle to carbon pricing. This paper develops theoretical and empirical models to analyze the impacts of carbon pricing on electricity supply under two scenarios, namely, marketization and regulation. It is concluded that the electricity market reform is a prerequisite for the development of carbon pricing. Without market-oriented reforms of electricity pricing in China, carbon pricing might lead to a shortage in electricity supply. Potential electricity market reforms to encourage market competition and promote market-oriented electricity-pricing are also suggested.

Key words: Carbon pricing; China's electricity market; Reforms

1. Introduction

During the decade of 2002-2011, the average annual growth rate of electricity production in China was 12%, which exceeded the country’s GDP growth rate of 11% per annum (NBSC 2012). To meet the expanding demand for electricity, various reform measures, such as electricity investment liberalization and the introduction of competition in generation, have been adopted (Xu and Chen 2006). By 2011, China's installed electricity capacity reached 1,063 million kilowatts and was the largest electricity generation market worldwide (Editorial Board 2012). However, coal is still the major source and contributes to about 70% of the total generation mix, which in turn is contributing significantly to China's CO_2 emissions (Kan et al. 2012). In 2007, China already surpassed the USA in energy-related CO_2 emissions (WEO 2006). China's CO_2 emission will be about 10-14 billion tons, and per-capita CO_2 emission will be 7.4-9.8 tons by 2050 according to the projections by Jiang et al. (2010).

In response to the global climate change and energy crisis, Chinese government published a white paper titled *China's policies and actions to address the climate change* and made a commitment to reduce carbon intensity by 40% to 45% below the 2005 level by 2020 (Xinhua News Agency 2011). To ensure this commitment is met, China's 12th Five-Year Plan states that the country will improve its statistical accounting system used to monitor greenhouse gas emissions and establish a sound market of carbon trading. The latter is one of the main policy instruments of carbon reduction (NDRC 2011a). Carbon trading could be regarded as a specific form of carbon pricing. In this market, power generation enterprises are obliged to have emission rights to cover the CO_2 that results from their production, and emissions allowances can be sold and purchased (Kara et al. 2008). A market price for carbon emission would emerge. The “invisible hands” of the market would lead to emission reduction at the lowest cost (Chappin and Dijkema 2009). These changes may have a considerable impact on firms' cost, competitiveness and investment decisions (Grubb and Neuhoff 2006; Laurikka and Koljonen 2006). Thus a series of coordinated reforms are required to cope with those impacts.

The electricity market reform is a useful prerequisite for the development of carbon trading market (Chappin and Dijkema 2009). When the electricity industry is deregulated, the electricity price can reflect the fluctuation of carbon prices, which secures both the profit for the electricity sector and the electricity supply to the end users (Keppler and Cruciani 2010). In the past decade, accompanied by the implementation of carbon trading, electricity markets have been deregulated or in the process of moving toward market liberalization throughout the whole of Europe as well as the United States (Wu 2013). Since 1986, China has made some breakthroughs in electricity market reforms. However, the degree of China's electricity marketization is relatively low and the current electricity price is still regulated by the government, which might impede the development of carbon pricing. Our study discusses the following three questions: (1) How would carbon pricing affect the electricity supply in China? (2) Is the electricity market reform a useful prerequisite for the development of carbon pricing in China? (3) What is the future reform roadmap for China's electricity market?

The paper is organized as follows. Section 2 presents China's carbon pricing instruments. Section 3 gives a brief review on the electricity market reforms in China. Section 4 proposes a model to simulate the impacts of carbon pricing on electricity supply. Section 5 sets out the empirical analysis of China's electricity market to justify the theoretical model. In Section 6, some policy options are proposed for the electricity market reforms. Conclusions are presented in Section 7.

2. Carbon Pricing Instruments in China

By internalizing the negative externalities associated with carbon emissions, carbon pricing can promote cost-effective abatement and deliver powerful innovation incentives. China has implemented a range of policy instruments to facilitate carbon pricing, including the Clean Development Mechanism (CDM), Volunteer Emission Reduction (VER) projects, and pilot Cap-and-Trade. Similar to reforms in other areas, China introduced these environmental regulation tools following the process of *Mo Zhe Shi Tou Guo He* (*Cross the river by touching the stones*) (Chang and Wang 2010).

CDM is a project-based mechanism that allows Annex I countries (developed countries) to meet part of their own commitments under the Kyoto Protocol by investing in emission reduction projects in non-Annex I countries (developing countries). The CDM enabled developing countries to participate in the global emissions market by selling carbon credits. In December 2005, the Chinese government promulgated *the Measures for the Operation and Management of Clean Development Mechanism (CDM) Projects* (NCCCC 2005). By December 2010, 2,738

CDM projects had been approved by China's Designated National Authority (DNA), with 1,032 projects registered and 308 Certified Emission Reduction (CER) projects certified (Wang et al. 2011). The implementation of CDM projects across the country has significantly decreased the emission intensity of CO_2, SO_2 as well as the industrial dust (Jia et al. 2013).

However, China has only limited influence on CER pricing in the global CDM market. To reduce the reliance on foreign CDM investors, the Chinese government was devoted to establish domestic environmental exchange platforms and develop Volunteer Emission Reduction (VER) projects. In August 2008, as China's first environmental exchange platform, China Beijing Environment Exchange (CBEEX) was founded with the approval of the Beijing municipal government, which is a professional market platform for trading various environment equities (CBEEX 2012). Subsequently, the Tianjin Climate Exchange (TCX) and Shanghai Environment Energy Exchange (SEEE) were established (TCX 2012). In the following years, a series of local environmental exchange platforms were set up in nine provinces[1] (NDRC 2011b). However, the development of an environment exchange market was found to lag behind the construction of the exchange platform.

There is a concern about the scarcity of VER demand, which has been the bottleneck of China's carbon trading market (Zhang et al. 2011). At present, most of the domestic enterprises as the main buyers of VER lack the environmental consciousness and social responsibility. Moreover, without compulsory carbon market and the expectation of carbon regulation, these enterprises do not have sufficient motivation to offset and neutralize their carbon emissions. Due to the deficiency of carbon cognition, individuals are less likely to buy VER. During the 2010 Shanghai World Expo, established and operated by SEEE, the World Expo VER platform had been designated as the official platform to carry out VER transactions for enterprises and individuals. However, only a total of 156 VER and 2,552 tons CO_2 emissions were traded at the end of World Expo (Wang et al. 2011). China's VER often serves a symbolic rather than a practical purpose.

In recent years, the policy-makers in China have realized that a compulsory carbon trading scheme will play an important role in achieving the national low-carbon transition. In a compulsory carbon trading scheme, a fixed number of permits is allocated each year to the participants. Participants who with relatively high

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[1] Those nine provinces are Guangdong, Zhejiang, Shandong, Shanxi, Liaoning, Hubei, Hebei, Yunnan, and Guizhou.

abatement costs can continue to pollute by purchasing additional permits on the market, while those who have relatively low abatement costs can take abatement action and sell their surplus permits for a profit. The scheme places an overall ‘cap’ on annual carbon emissions and the trading mechanism allows this cap to be achieved at the lowest cost.

China's national agenda now includes such a carbon trading scheme. After the kick-off meeting in November 2011, all the four municipalities (Beijing, Shanghai, Tianjin, and Chongqing), Shenzhen and two provinces (Guangdong and Hubei) were designated to carry out a pilot carbon trading (NDRC 2011b). In June 2013, the first pilot project of carbon trading was launched in Shenzhen (Xinhua News Agency 2013). In the following year, the pilot projects are expected to be launched in the other pilot regions successively. The primary goal of these pilot projects is to establish a trans-provincial or trans-regional carbon trading scheme. Once these pilot projects demonstrate signs of success, carbon trading is expected to be implemented throughout the country in 2015 (NDRC 2011b). In addition, China has some experience of emissions trading. During the period from 1990 to 1994, the former State Environmental Protection Administration (the current Ministry of Environment Protection) organized and supported the pilot trading of sulfur dioxide emissions in six key cities, which intended to explore the policy of atmospheric pollutant emissions trading[2]. Furthermore, the point-non-point source effluent trading in Taihu Lake area was launched in 2002[3] (Wang et al. 2004). These experiences will help China to establish a new carbon emissions trading system.

As a main emitter of greenhouse gases, the thermal power sector was generally covered by the compulsory carbon trading scheme (Perdan and Azapagic 2011). In 2009, the thermal power emissions of China reached 2.3 billion tons, which accounted for more than one-third of the national emissions (Wang et al. 2011). The electricity sector should play a crucial role in China's carbon pricing system.

3. The Reform Process of China's Electricity Market

China's electricity industry was nationalized in 1949 when the People's Republic of China was established. At that time, the total installed capacity of China was 1.85

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[2] The six cities are Baotou, Taiyuan, Guiyang, Liuzhou, Pingdingshan, and Kaiyuan.

[3] The Taihu Lake area covers Shanghai, Suzhou, Wuxi, Jiaxing, Huzhou, Changzhou, and Kunshan.

million kilowatts, and the national annual power generation was only 43 billion kWh (Shen 2005). Considering its importance for China's economy, the electricity industry was protected and monopolized by the Chinese central government. During the period from 1949 to 1985, the relevant generation and power grid assets were fully controlled by State-Owned-Enterprises. The State Development Planning Commission was responsible for predicting electricity demand and planning new generation plants to meet future needs (Xu and Chen 2006). However, these operational mechanisms could not match the country's rapid economic development since the economic reform and opening up started in the late 1970s. To respond to the power supply shortage, various electricity market reform measures have been adopted since the 1980s, including economic reform by opening the power investment financing, institutional reform by separating the government and power enterprises, and competition reform by unbundling the power generation from the power grids (see the Appendix for more details). Based on the evolution of China's electricity market reforms since 1986 (Ngan 2010), the power industry development process can be segmented into three main phases, which are shown as follows.

Phase I: Promotion of fund-raising for investment (1986-1996)

By 1986, the gap in the installed capacity of China amounted to about 14-15 million kilowatts, and 35% of rural households had no access to the electricity grid (Shen 2005). To relieve these electricity shortages, the State Council promulgated the *Provisional Regulations on Promoting Fund-Raising for Investment in the Power Sector and Implementing Different Power Prices* in 1985, which encouraged the investment in power generation industry by local governments, and corporate and foreign investors. At the end of 1997, the balance between the supply of and demand for electricity was achieved. By then, the power shortage, a problem constantly confronting the Chinese government, was effectively brought to an end.

During this phase, the reform policies with the aim of providing incentives for electricity investment yielded two positive results. First, the investment in power generation was successfully financed by both domestic and foreign enterprises. From 1986 to 1996, the net increase of installed capacity achieved up to 400 million kilowatts (NBSC 1996). Second, the state monopoly system had been eroded and replaced by a new market structure composed of multiple investment bodies. However, many new problems arose alongside the progress of electricity market reforms. The strategy of *Provinces as Entities* led to serious local protectionism, which created a barrier to inter-provincial trading of power. Moreover, in order to relieve the regional electricity shortage, a large number of small coal-fired power plants with high energy consumption and heavy pollution appeared. On the contrary, the contemporary policies towards electricity investment impeded the development of hydroelectric power that requires high levels of state incentives, capital, or market guarantees (Shen 2005). These decisions lacked foresight and were made without the full consideration of environmental impacts, not to mention CO_2 emissions.

Phase II: Establishment of an effective market-oriented structure (1997-2001)

The reforms during this period were to solve the organizational structure issues in the electricity industry, especially the separation of government administration from enterprise operation and the establishment of modern corporate structure. In January 1997, the State Power Corporation (SPC) was founded and the Ministry of Electric Power was abolished in the following year, with its administrative functions transferred to the State Economic and Trade Commission (SETC). A new institutional framework was set up within which the SETC and the State Development and Planning Commission (SDPC) functioned as supervisors of the electricity industry. The SPC, which included both power plants and electric grid all over mainland China, was corporatized to provide efficient and reliable electric power supply. In December 1998, the pilots of *separation of power plants from power grids and bidding for on-grid* were carried out in six eastern and central provincial administrative regions[4]. The objective of these pilot programs was to offer viable solutions to break up the vertically integrated monopolies of the electricity industry.

The reforms in this period separated the functions of the government from those of enterprises, through which the regulatory and operational mechanisms of the electricity industry were improved. However, these reforms mainly focused on the central governmental level, while the market-based mechanisms were not established at all on the operational level. Firstly, the power generation, transmission, distribution and sales were still vertically integrated, which impeded the formation of a competition mechanism. Secondly, the power market was segmented across provinces, aggravating local protection and administrative barriers (Zhang et al. 2006). Thirdly, without an effective pricing mechanism, the electricity price could not

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[4] Those six regions are Zhejiang, Shandong, Jilin, Liaoning, Heilongjiang and Shanghai.

reflect the price movements of the factors of production, such as the price of coal.

Phase III: Introduction of competition (2002-present)

In March 2002, the State Council authorized the *Plans of Power Regime Reform* with the following major objectives: (1) to break up the monopoly and introduce the competition; (2) to enhance the efficiency and cut the costs; (3) to establish a rational electricity price formation mechanism and optimize the resource allocation[5]. In detail, the primary missions of the reform plan were to separate the power plants and power grids of the SPC, and to let power plants enter the power grids through a bidding system. By the end of 2002, the installed capacity fully owned or partly owned by the SPC reached 170 million kilowatts, accounting for 47% of that in China's mainland (SERC 2007). The SPC controlled 90% of the nationwide power transmission asset (SERC 2007). As shown in Fig.1, after the electricity “Plant-Grid Separation” reform, the SPC, which included both power plants and electrical grids all over Mainland China, was dismantled and restructured into two grid corporations and five large companies.

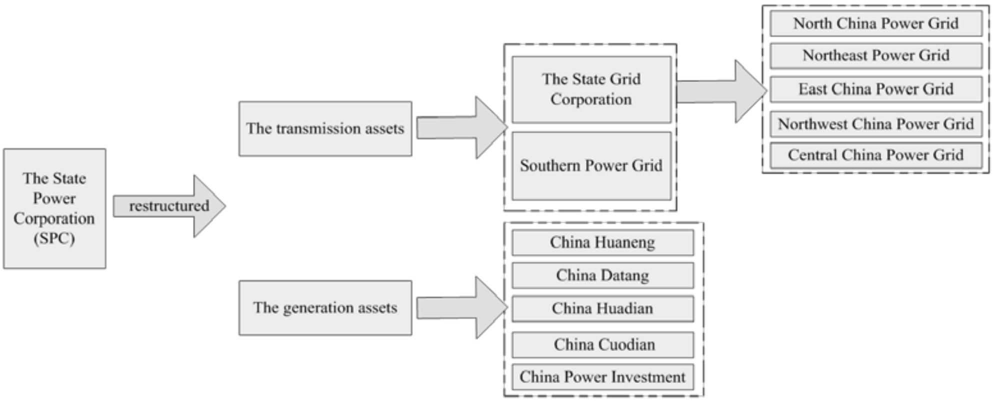

Fig.1 The restructuring of the State Power Corporation (SPC)

Source: Authors' own drawing.

The five major generation companies, namely China Huaneng, China Datang, China Huadian, China Guodian, and China Power Investment, accounted for nearly half of the total installed capacity as shown in Fig.2. By the end of 2009, the total controllable installed capacity of these companies reached 89, 100, 77, 82 and 76 million kilowatts with the market shares of 10%, 11%, 9%, 9% and 9% respectively

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[5] There is a serious debate in the industry and amongst academics about whether competitive market reforms can actually lead to both a price decrease and efficiency improvement. Fabrizio et al. (2007) showed that competitive market contexts have produced slightly more efficient operations in plants, but the impact on prices is much more contentious. Competitive markets pay for risk, and have higher profit margins and serious incentives for exercising market power. The latter is extremely difficult and costly for regulation. Thus, the potential savings may not occur at all. We thank an anonymous referee for his/her contribution to this point.

(Editorial Board 2010). To enhance the efficiency and reduce the electricity price, these companies are expected to compete and sell their power in a nationwide market.

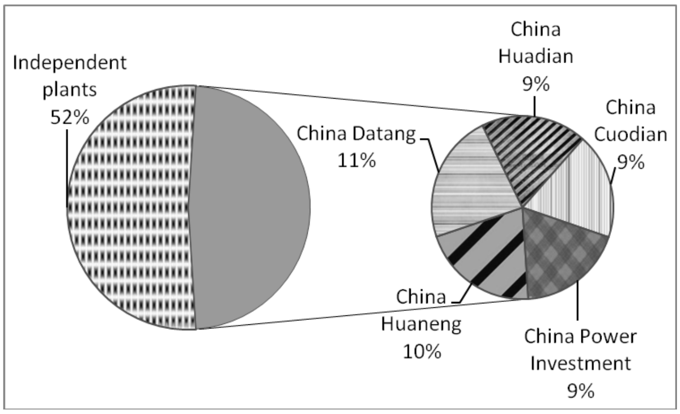

Fig.2 The installed capacity share of the five power generation groups
Source: Editorial Board (2010)

China's electricity transmission is mainly dominated by the State Grid Corporation of China (SGCC), which has five regional subsidiaries, namely, North China Power Grid, Northeast Power Grid, East China Power Grid, Northwest China Power Grid, and Central China Power Grid as shown in Fig.3. SGCC is the largest power transmission and distribution company in China and even in the world. Its operational regions cover 88% of China's landmass providing electricity services for over 1 billion consumers (International Energy Net 2010). By the end of 2011, SGCC had 655,131 kilometers of transmission lines at a voltage of 110 kV and above with the electricity sales amounting to 3,093 billion kWh (SGCC 2012). China Southern Power Grid Corporation (CSPGC), which takes charges of the investment, construction and management of power transmission, transformation and distribution covering China's five southern provinces (Guangdong, Guangxi, Yunnan, Guizhou and Hainan), was based upon the consolidation of the transmission assets of these provinces. It has been serving an area of 1 million square kilometers and a population of 230 million (17% of total population) (Xinhua News Agency 2012). By 2010, the CSPGC with a total installed capacity of 170 million kilowatts achieved the electricity sales of 603 billion kWh (Editorial Board 2011).

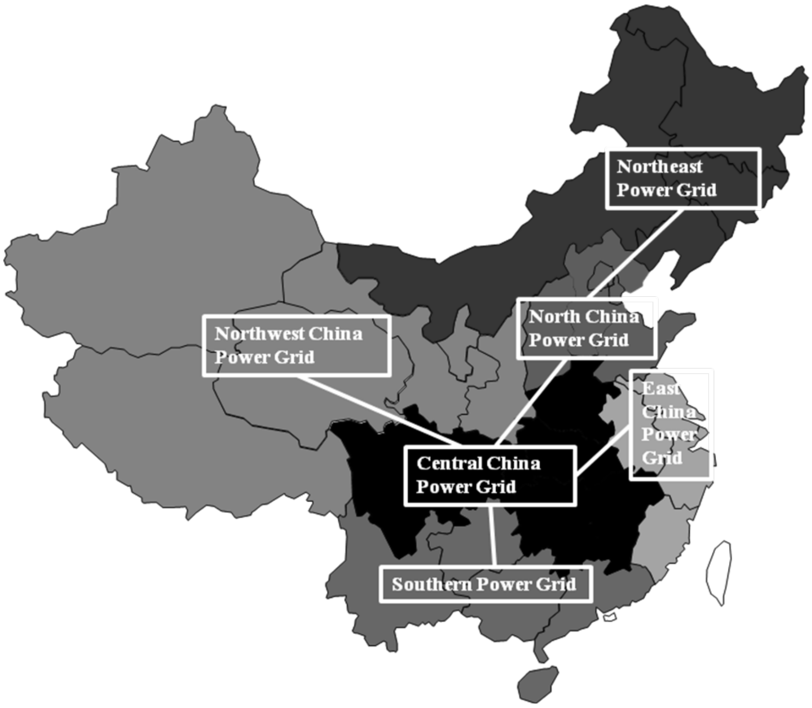

Fig.3 The distribution of the regional power grids
Source: Authors' own drawing.

The above review of China's electricity market reforms shows that electricity shortages have been identified as the main issue over the past decades, which triggered the reforms in the power industry. The current reform roadmap focuses on the transition from a vertically integrated sector to a market-oriented industry. To achieve this goal, a variety of reform measures, such as separating the government from the enterprises, restructuring the enterprises, and introducing competitive mechanisms have been implemented. However, a fair and competitive power market and a market-oriented electricity-pricing mechanism have not been established in China until now.

4. Theoretical Model

Carbon pricing is expected to bring a major change to China's electricity industry, especially to the power generation sector. By introducing a carbon pricing system, there will be a resulting increase in the carbon cost of fossil fuel power generation (Betz and Owen 2010). Carbon cost pass-through is critical to the survival of the generation sector (Kim et al. 2010). However, the current electricity pricing in China is still severely regulated by the government, and the potential impacts of carbon pricing on electricity supply are uncertain. Within this context, we propose a theoretical model of electricity price bidding to explore these impacts. In this model, we should consider several factors such as the mechanism of electricity pricing, and the pass-through of carbon cost to electricity price.

4.1 Electricity pricing model

4.1.1 Electricity supply

We assume that the power generation system consists of two groups of plants, which are represented by *a* (efficient plants) and *b* (in-efficient plants) separately. The installed capacity of the i^{th} unit belonging to group j is k_j^i , where $i = 1, 2, ..., n_j, j = a, b$. The corresponding emission rates and the variable costs of production are e_j^i and v_j^i , respectively. Furthermore, we assume $v_a^{i_1} \le v_b^{i_2}, \forall i_1, i_2$ and $e^{i_1} \le e^{i_2}, \forall v^{i_1} \ge v^{i_2}$, that is, the cleaner technology is also the higher variable cost technology (Sijm et al. 2006). A typical example is given by (*a*) the coal-fired power and (*b*) the gas-fired power.

4.1.2 Electricity demand

We assume that power demand is totally inelastic, predictable with certainty and given by a typical load duration curve (Harvey and Hogan 2000; Joskow and Kahn 2002)[6]. We describe the power demand with the load duration curve $D = D(H)$ as shown in Fig.4, where H is the number of hours that power demand equals or exceeds D with $0 \le H \le (H_L = 8760h = 365 \times 24h)$. $D_L = D(H_L)$ is the base-load demand and $D_M = D(0)$ is the peak-load demand, with $D_M = k_a + k_b$ and $D_L = k_a$, that is, the units of *a* and *b* are sufficient to meet the peak demand and the efficient plants *a* can meet the base demand. $\underline{H}$ is the duration hours of the peak-load demand and H_L- $\underline{H}$ is the duration hours of the base-load demand.

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[6] Completely inelastic demand seems to be more appropriate for the power industry, at least in the short-run. Indeed, the aggregate demand should exhibit some elasticity, to the extent that eligible customers are allowed to announce demand bids. Nevertheless, actual observations highlight that the price elasticity of demand is very low (Crampes and Creti 2005). Furthermore, most contributions using auction models assume inelastic demand (such as von der Fehr and Harbord 1993; von der Fehr et al. 2006; Crampes and Creti 2005).

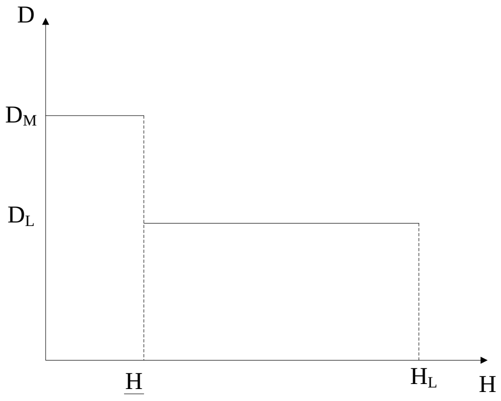


Fig.4 The load duration curve
Source: Authors' own drawing.

Under perfect competition, the power market is organized in the form of first price auctions (Bonacina and Gulli 2007). The generators are paid according to the market-clearing price, that is, the system marginal price equals the highest bid price accepted (Chernyavs'ka and Gullì 2008). The marginal generation unit can be defined as follows: the variable costs v_j^i are ranked by the merit order, that is, $v^i \le v^{i+1}$; when $\sum_{i=1}^{\Upsilon} k^i \ge D$ and $\sum_{i=1}^{\Upsilon-1} k^i < D$ the unit Υ is the marginal generation unit. Given a certain demand, the competitive power price is determined by the variable cost of the marginal production unit, that is, v^{Υ}.

4.2 The impacts of carbon pricing on electricity supply

For simplicity, we assume that the carbon price p^c is given exogenously. Generation units can either use the carbon allowances to cover their emissions or sell them. Hence, the opportunity costs for using allowances must be considered whether they are allocated free of charge or purchased (Bode 2006; Kirat and Ahamada 2011). In line with economic theory, the variable cost of the i^{th} unit belonging to group j is as follows (Sijm et al. 2006):

$$C_j^i = v_j^i + p^c e_j^i \tag{1}$$

The variable costs C^i are ranked in ascending order, that is, $C^i \le C^{i+1}$. The electricity supply function can be defined as follows:

$$S(p) = \sum_{i=1}^{\Upsilon} k^i \tag{2}$$

where p is the electricity price with Υ satisfying $C^{\Upsilon+1} > p$ and $C^{\Upsilon} \le p$. It's clear that the supply function is a monotonically increasing function of price p since p is positively correlated with Υ. Based on equation (2), we can discuss the electricity shortfall, which is the gap between of the electricity supply and demand, driven by the carbon pricing in several scenarios.

Scenario 1: The electricity price is market-oriented

In this scenario, the distributors of electricity (utilities) purchase electric power from competing power suppliers (İşlegen and Reichelstein 2011). Under perfect competition, the electricity prices will fully internalize the marginal carbon opportunity cost (Bonacina and Gulli 2007). For modeling purposes, we take this framework to an idealized extreme by assuming that the electricity prices are fully competitive. If the power demand is at the minimum level (base-load demand), we assume that the marginal generation unit is Υ_1, that is, $\sum_{i=1}^{\Upsilon_1} k^i \ge (D_L = k_a)$ and $\sum_{i=1}^{\Upsilon_1 - 1} k^i < (D_L = k_a)$, by which the electricity price C^{Υ_1} is determined (Ådahl et al. 2006). If the power demand is at the maximum level (peak-load demand), the marginal production unit is assumed to be Υ_2, that is, $\sum_{i=1}^{\Upsilon_2} k^i = (D_M = k_a + k_b)$ and $\sum_{i=1}^{\Upsilon_2 - 1} k^i < (D_M = k_a + k_b)$, and then the electricity price is C^{Υ_2}. The market-clearing price C^{Υ_1} or C^{Υ_2} is the highest bid price accepted. Under the perfect competition, it equals the marginal cost of the marginal unit which fully includes the carbon opportunity cost. Therefore, the electricity supply will be adequate to meet the demand; that is, there is no electricity shortage.

Scenario 2: The electricity price is regulated

The most common industrial structure for electric power services in China remains a vertically-integrated monopoly that is subject to price regulation. The power prices are then based on the firm's historical cost. Specifically, the regulated firm must meet consumer demand at a price that satisfies the constraint that the firm's accounting rate of return does not exceed an allowable rate of return set by the regulator (İşlegen and Reichelstein 2011). We assume that the power price is constrained to be below the regulated price $\hat{p}$, which is determined by the electricity pricing policy. It is assumed that *D* is the base-load demand. When the regulated price $\hat{p} \geq C^{\Upsilon_1}$, there is no electricity shortage. When $\hat{p} < C^{\Upsilon_1}$, according to equation (2), the electricity shortage will reach

$$D_L - S(\hat{p}) \tag{3}$$

where $S(\hat{p})$ is the electricity supply when its price reaches $\hat{p}$.

If it is assumed that *D* is at the peak-load demand level, then, when $\hat{p} \geq C^{\Upsilon_2}$, the electricity supply will be adequate to meet the demands. However, when $\hat{p} < C^{\Upsilon_2}$, accordingly, the electricity shortage will rise to

$$D_M - S(\hat{p}) \tag{4}$$

In summary, if the electricity price is market-oriented, the increase in carbon cost will be compensated for by the electricity price, which secures the profit of power generation plants and the electricity supply for customers. Otherwise, if the electricity price is regulated, the pass-through of carbon cost to electricity price could not occur completely, which might lead to an electricity shortage. To avoid the risk of power shortage, the market-oriented reform of electricity might constitute a useful prerequisite for the development of carbon pricing.

5. The Empirical Analysis

In this section, we will utilize the power plants statistics data to estimate the electricity shortfall if the potential carbon pricing system is introduced in China. At present, however, a compulsory carbon market has not been established in China. In this paper, 201 thermal power plants covered by the SGCC service area are taken as simulation participants in carbon pricing and used to verify the impacts of carbon pricing on electricity supply. It is estimated that there were 1.2 billion tons of CO_2 emitted from these plants in 2009, which accounted for over one-sixth of China's total emissions for that year (Editorial Board 2010).

5.1 Data sources and processing

According to the electricity pricing model, we conclude that the generation cost and electricity price are positively correlated while the generation cost and generation hours of the generation unit are negatively correlated. Hence, the variable cost of every thermal power plant can be estimated as follows

$$v_r^i = P_r \frac{\overline{U_r}}{U_r^i} \tag{5}$$

where P_r is the on-grid electricity price in region *r*, $\overline{U_r}$ is the average annual generation hours of the plants in region *r*, and U_r^i is the generation hours of the i^{th} plant in region r.

According to the electricity supply model proposed above, the emission rate and variable cost are negatively correlated. The emission rate of the i^{th} plant can be calculated as

$$e_r^i = E_r \beta \frac{\overline{v_r}}{v_r^i} \tag{6}$$

where E_r is the standard coal consumption per kWh of the power supply in region *r*, β is the emission factor of standard coal, $\overline{v_r}$ is the average variable cost of region *r*, v_r^i is the variable cost of plant *i* in region *r*. The installed power capacity, generation hours, on-grid electricity price, standard coal consumption per kWh, emission factor and total power demand can be found in Editorial Board (*2010).*

5.2 The results and discussion

To distinguish the efficient plants from the inefficient ones, a SOFM (Self-Organizing Feature Map) cluster technique is employed. It clusters data based on an unsupervised learning algorithm (Kohonen 1998). The SOFM consists of two layers: the input layer and the output layer. The input layer contains one unit for each variable (such as the variable cost of each plant) in the data set. The output layer consists of several neurons, each of which has an associated weight vector. The output layer neurons are connected to every unit in the input layer through the weight vectors (Kalteh et al. 2008). The output neurons will self-organize to an ordered map by adjusting their weight vectors and those with similar weights are placed together (Mostafa 2010).

The map can then be used for cluster analysis. We use MATLAB R2008a as our programming tool. The number of output neurons is determined by the desired number of classes, which are 2 (efficient vs. inefficient plants) in this analysis. According to the variable costs of the above 201 plants calculated using equation (5), the efficient plants are separated from inefficient plants by their topology distance in the SOFM analysis. The cluster result shows that there are 105 efficient plants and 96 inefficient plants in the sample. Thus we can calculate the total installed capacity of efficient plants and inefficient plants: $k_a = 148.45$ MKW and $k_b = 159.04$ MKW. According to the electricity demand model proposed above, the peak-load demand is $D_M = k_a + k_b = 307.49$ MKW, and the base-load demand is $D_L = k_a = 148.45$ MKW.

The duration hours of the peak-load demand can be calculated from

$$D_T = D_M \underset{-}{H} + D_L H_L \tag{7}$$

where D_T is the total power demand, and $\underset{-}{H}$ and H_L are the duration hours of peak-load and base-load demand respectively. To meet the total power demand, 1461 duration hours of peak-load supply are needed based on equation (7). Then, we can draw the load duration curve as follows

$$D(H) = \begin{cases} 307.49\text{MKW}, & \text{if } H \leq 1461h \\ 148.45\text{MKW}, & \text{if } 1461h < H < 8760h \end{cases} \tag{8}$$

According to equations (1) , (2) and (5), the variable cost of the marginal generation unit is 0.75￥/kWh under the peak-load. Similarly, under the base-load, the marginal cost is 0.39￥/kWh.

We assume that the compulsory carbon pricing system in China covers these 201 thermal power plants. Referring to the carbon price level of EU-ETS, China's carbon price can be set as 0-250￥/ton (Ellerman and Joskow 2008). Based on equations (1)-(8), we can calculate the electricity shortage and electricity price under the marketization and regulation scenarios.

When the electricity price is market-oriented, the electricity price is determined by the variable cost of the marginal generation unit. However, the merit order of the generation units and the marginal generation unit might change with the introduction of the carbon pricing system. If we assume that the carbon price is 50￥/ton, the variable cost of the marginal generation unit, namely the electricity price is 0.43 ￥/kWh under the base-load. Maintaining the carbon price at the same levels (50

￥/ton), the electricity price is 0.77￥/kWh when the power demand is under peak-load. Accordingly, the electricity price can be calculated respectively when the carbon price is 100￥/ton, 150￥/ton, 200￥/ton, 250￥/ton, as shown in Fig.5. Since the electricity price is determined by the market supply and demand, there is no electricity shortfall in this scenario.

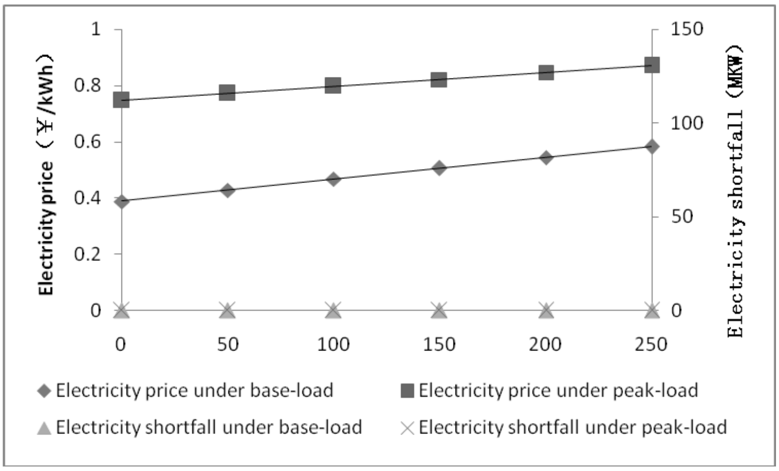


Fig.5 Electricity shortfall and electricity price under the marketization scenario
Source: Authors' own calculations using equations (1), (2), (5), (6), (7) and (8).

In China, the electricity price adjustments are complex and socially sensitive, and usually lag behind the price fluctuations of the fuel used to generate electricity, such as the coal. In general, the frequency of these adjustments will not exceed once per year (Lin 2005). We assume that the regulated electricity price is 0.39￥/kWh, which equals to the marginal cost under the base-load. The total electricity shortfall would be 64.71 MKW when the carbon price was set at 50￥/ton. Similarly, under the peak-load, the electricity shortfall would reach 3.09 MKW with the regulated electricity price equaling to 0.75￥/kWh. Furthermore, the electricity shortfall can be calculated respectively when the carbon price changes as shown in Fig.6. If the carbon price rises from 50￥/ton to 250￥/ton, the electricity shortage increases significantly, especially under the base-load.

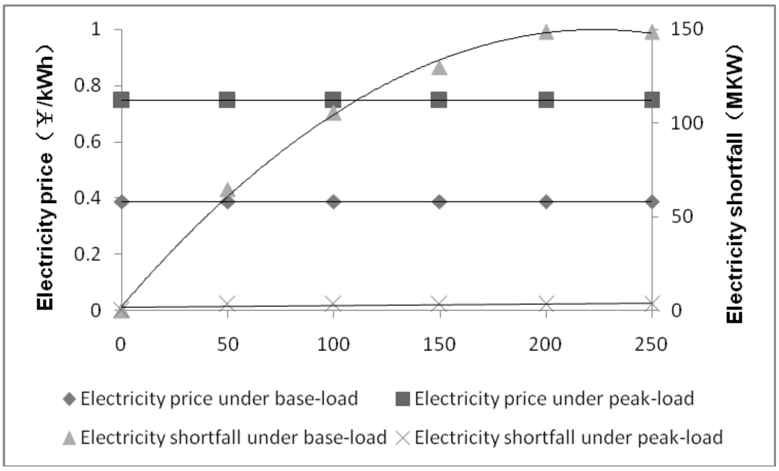
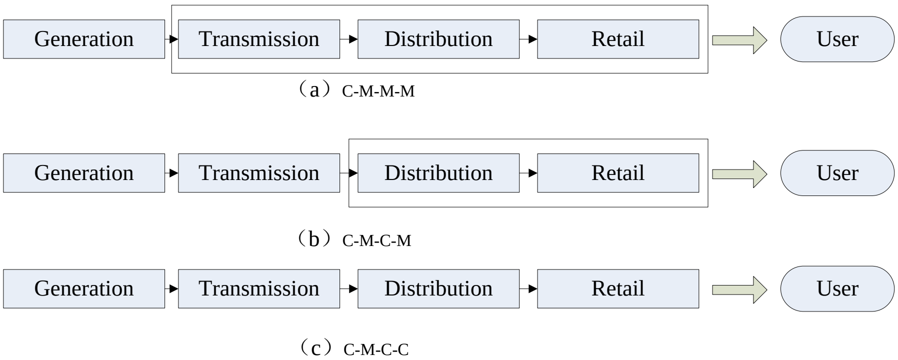


Fig.6 Electricity shortfall and electricity price under the regulation scenario
Source: Authors' own calculations using equations (1)-(8).

In summary, if the electricity price is market-oriented, the electricity price will vary with the carbon price and there would be no electricity shortage. However, when the electricity price is regulated by the government, the electricity shortage would occur with the introduction of carbon pricing. The policy-makers should weigh the consequence of the electricity price rise and the electricity shortage. In China, the negative effects of the electricity shortage may extend beyond that of the electricity price rise (Lin 2005).

6. The future reform roadmap of China's electricity market

To achieve the objective of carbon pricing and to avoid the electricity shortage, it is essential to deepen the electricity market reforms, with the aim of establishing a fair and competitive power market. During the last decades, China made a remarkable progress in electricity sector reforms. However, the transition from a centrally planned industry to a market-oriented industry will be tedious and complicated. It would be extraordinarily difficult to implement the electricity market reforms and establish a carbon market simultaneously, since the carbon price would pass-through into the electricity prices directly, which might lead to electricity price fluctuations under a marketization scenario (Wang et al. 2011). The government should select a limited number of targets and make breakthroughs in some key areas. Prospective electricity market reforms should focus on introducing competition and establishing a market-oriented electricity-pricing mechanism. According to the reform pathway relevant to the privatization and marketization of the power industry in USA and other developed countries (Xu and Chen 2006), we propose a two-step reform for China's electricity market.



（a）C-M-M-M

（b）C-M-C-M

（c）C-M-C-C

Fig.7 The reform roadmap of China's electricity market[7]

Notes: M and C denote monopoly and competition respectively (e.g. “C-M-M-M” denotes that the generation sector is competitive and the power transmission, distribution and retail sectors are monopolistic).

6.1 Separate distribution from transmission and construct a competitive wholesale market

Although the separation of power plants and power grids has been implemented so far, the tariff mechanism is still not market-oriented. The price of electricity is subject to control by the power grid corporation, which stems from the fact that the SGCC or CSPGC is the sole monopoly seller and buyer in the wholesale power market (Fig.7 (a)). To build a market-oriented pricing mechanism, it is necessary to achieve the transition from a single-buyer model (Fig.7 (a)) to a wholesale competition model (Fig.7 (b)); that is, the wholesale market is liberalized (Nagayama 2009). In March 2004, the State Electricity Regulatory Commission (SERC) and SDRC jointly promulgated *the interim measures on the pilot scheme to authorize power consumers to purchase electricity from power-generating enterprises directly* which involved establishing a fair-open power grid and allowing the buyers and sellers to negotiate the prices autonomously. [8]

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[7] Single Buyer model (stage “a” in Fig.7): An independent entity or the transmission utility is mandated to purchase electricity from competing generators and resell this to distribution utilities. Wholesale market model (stage “b” in Fig.7): The wholesale market is market-oriented. Retail market mode (stage “c” in Fig.7): The wholesale and retail markets are market-oriented, in which the power generation, transmission, distribution and sales are offered by different firms.

[8] To implement this policy, a pilot project of large user direct transaction between Fushun Aluminum Plant and Huaneng Yimin Power Plant was launched in October 2009. In the following 2 years, the pilot projects have been extended to other provinces, including Liaoning, Jilin, Fujian, Anhui, Guangdong, and Jiangsu. The direct transaction between large-volume user and power supplier was designed to break with the monopoly purchase and

With the direct trading pilot expansion, a new electricity wholesale market could be established. As a result, a couple of competitive wholesale markets will come into being, namely, one is a trading marketplace monopolized by power transmission companies that are still dominant in the wholesale market and the other is the market for direct transactions between large-volume users and power generators. To construct a competitive wholesale market, China's government should strengthen relevant economic legislation to further encourage users to participate the direct transaction.

6.2 Separate retailing from distribution and establish a competitive retail market

Wholesale competition is a market structure in which the large-volume users have a choice of two or more suppliers from whom they can purchase power. However, small-volume users such as household users have no choice but to purchase electricity from transmission and distribution companies, which is likely to lead to inequality in opportunity. Under direct retail access, a competitive retail market could be developed and consumers could have the choice to purchase electricity from competing power distribution companies, retailers, or directly from the wholesale markets (Woo et al. 2003). In this stage of reforms, the transmission and distribution grids would be opened to power generation companies, retail companies and end users, which mean that the power retailers are separated from the electricity distribution network, as shown in Fig.7 (c).

By introducing retail competition, the electricity price will be determined by demand and supply in the market rather than an individual power supplier. Furthermore, the purchasing cost of electricity suppliers will be delivered to the end consumers; that is, the retail price can reflect the fluctuation of the wholesale price including CO_2 cost. In the retail competition model, the increasing carbon cost will be compensated for by the subsequent power price increase, which secures the profit of the power generation plants.

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marketing. In this transaction system, the power purchase prices are composed of a variety of costs, such as direct bargain price, power transmission & distribution price, and government construction fund (The state established a power construction fund in 1988 which was collected through a surcharge of 0.02 Yuan/KWh on electricity prices. It has been included into power rate in 2000.). Furthermore, the power transmission and distribution price should be sanctioned by SDRC.

7. Conclusions

We proposed theoretical and empirical models to examine the impacts of carbon pricing on electricity supply in China. It is found that if the electricity price is market-oriented, the electricity price will vary with the carbon price and the electricity shortage would not occur. If the electricity price is regulated by the government, the pass-through of carbon cost to electricity price could not occur completely, which might lead to an electricity shortage, especially under the base-load. We thus argue that a carbon pricing system should be implemented at the start of the coordinated reforms of market-oriented pricing in electricity. However, such reforms could be easily overlooked when related market mechanisms have not yet been fully established in China.

To exploit the potential benefits associated with carbon pricing and avoid the occurrence of electricity shortage, China should deepen electricity market reforms. For this purpose, in this paper, we endorse a gradual approach towards further reforming the country's electricity sector. In particular we recommend a two-step strategy for deepening the reforms by constructing first a competitive electricity wholesale market and then a competitive electricity retail market.

Finally, we are concerned with the fact that our model relies on some simplistic assumptions such as an inelastic electricity demand and a simple bidding model. If we relax those assumptions, the model could yield more interesting results which would be more informative for decision-makers.

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References

Ådahl A, Harvey S, Berntsson, T (2006) Assessing the value of pulp mill biomass savings in a climate change conscious economy. Energy Policy 34(15):2330-2343

Betz R, Owen AD (2010) The implications of Australia's carbon pollution reduction scheme for its National Electricity Market. Energy Policy 38(9):4966-4977

Bode S (2006) Multi-period emissions trading in the electricity sector—winners and losers. Energy Policy 34(6):680-691

Bonacina M, Gulli F (2007) Electricity pricing under ‘‘carbon emissions trading’’: A dominant firm with competitive fringe model. Energy Policy 35(8):4200-4220

Chang YC, Wang NN (2010) Environmental regulations and emissions trading in China. Energy Policy 38(7):3356-3364

Chappin EJL, Dijkema GPJ (2009) On the impact of CO2 emission-trading on power generation emissions. Technological Forecasting & Social Change 76(3):358-370

Chernyavs'ka L, Gullì F (2008) Marginal CO2 cost pass-through under imperfect competition in power markets. Ecological Economics 68(1-2):408-421

China Beijing Environment Exchange (CBEEX) (2012) Memorabilia. http://www.cbeex.com.cn/article/gywm/dsj (In Chinese)

China National Climate Change Coordination Committee (NCCCC) (2005) Measures for operation and management of clean development mechanism projects in China. http://www.ccchina.gov.cn/en/NewsInfo.asp?NewsId=5370 (In Chinese)

Crampes C, Creti A (2005) Capacity competition in electricity markets. Economia Delle Fonti di Energia e dell'Ambiente 2:59-83

Editorial Board (2010) China Electric Power Yearbook 2010. China Electric Power Press, Beijing (In Chinese)

Editorial Board (2011) China Electric Power Yearbook 2011. China Electric Power Press, Beijing (In Chinese)

Editorial Board (2012) China Electric Power Yearbook 2012. China Electric Power Press, Beijing (In Chinese)

Ellerman AD, Joskow PL (2008) The European Union's emissions trading system in perspective. Pew Center on Global Climate Change, Washington, DC

Fabrizio KR, Rose NL, Wolfram CD (2007) Do markets reduce costs? Assessing the impact of regulatory restructuring on US electric generation efficiency. American Economic Review 97(4):1250-1277

Grubb M, Neuhoff K (2006) Allocation and competitiveness in the EU emissions trading scheme:

policy overview. Climate Policy 6(1):7-30

Harvey S, Hogan W (2000) Nodal and zonal congestion management and the exercise of market power. Mimeo, Harvard University

International Energy Net (2010) State Grid Corporation committed to promoting electricity generation from renewable energy sources. http://www.in-en.com/article/html/energy_0924092436564237.html (In Chinese)

İşlegen Ö, Reichelstein S (2011) Carbon capture by fossil fuel power plants: An economic analysis. Management Science 57(1):21-39

Jia RY, Guo XM, Marinova D (2013) The role of the clean development mechanism in achieving China's goal of a resource-efficient and environmentally friendly society. Environment, Development and Sustainability 15(1):133-148

Jiang B, Sun ZQ, Liu MQ (2010) China’s energy development strategy under the low-carbon economy. Energy 35:4257-4264

Joskow PL, Kahn E (2002) A quantitative analysis of pricing behavior in California’s wholesale electricity market during summer 2000. The Energy Journal 23:1 -35

Kalteh AM, Hjorth P, Berndtsson R (2008) Review of the self-organizing map (SOM) approach in water resources: Analysis, modeling and application. Environmental Modeling & Software 23:835-845

Kan HD, Chen RJ, Tong SL (2012) Ambient air pollution, climate change, and population health in China. Environment International 42:10-19

Kara M, Syri S, Lehtil A, Helynen S, Kekkonen V, Ruska M, Forsström J (2008) The impacts of EU CO2 emissions trading on electricity markets and electricity consumers in Finland. Energy Economics 30(2):193-211

Keppler JH, Cruciani M (2010) Rents in the European power sector due to carbon trading. Energy Policy 38(8):4280-4290

Kim W, Chattopadhyay D, Park J (2010) Impact of carbon cost on wholesale electricity price: A note on price pass-through issues. Energy 35(8):3441-3448

Kirat D, Ahamada I (2011) The impact of the European Union emission trading scheme on the electricity-generation sector. Energy Economics 33(5):995-1003

Kohonen T (1998) The self-organizing map. Neurocomputing 21(1-3):1-6

Laurikka H, Koljonen T (2006) Emissions trading and investment decisions in the power sector—a case study in Finland. Energy Policy 34(9):1063-1074

Lin BQ (2005) The development of China's power industry: Process and supporting reforms. Management World (8):65-79 (In Chinese)

Mostafa MM (2010) Clustering the ecological footprint of nations using Kohonen's self-organizing maps. Expert Systems with Applications 37(4):2747-2755

Nagayama H (2009) Electric power sector reform liberalization models and electric power prices in developing countries. Energy Economics 31(3):463-472

National Bureau of Statistics of China (NBSC) (1996) China Energy Statistical Yearbook 1996. China Statistics Press, Beijing (in Chinese)

National Bureau of Statistics of China (NBSC) (2008) China Energy Statistical Yearbook 2008. China Statistics Press, Beijing (in Chinese)

National Development and Reform Commission of China (NDRC) (2011a) Outline of the 12th Five-Year Plan of national economic and social development of the People's Republic of China (In Chinese)

National Development and Reform Commission of China (NDRC) (2011b) The notice about carry out carbon emissions trading experimental work. http://www.sdpc.gov.cn/zcfb/zcfbtz/2011tz/t20120113_456506.htm (In Chinese)

Ngan HW (2010) Electricity regulation and electricity market reforms in China. Energy Policy 38(5):2142-2148

People's Net (2011) The energy intensity of China fell by 19% during the 11th five-year plan. http://politics.people.com.cn/GB/1026/16250184.html (In Chinese)

Perdan S, Azapagic A (2011) Carbon trading: Current schemes and future developments. Energy Policy 39(10):6040-6054

Shen JF (2005) The market reform of China's electricity industry. Xinhua Press (In Chinese)

Sijm J, Neuhoff K, Chen Y (2006) CO2 Cost Pass Through and Windfall Profits in the Power Sector. Climate Policy 6(1):49-72

State Electricity Regulatory Commission (SERC) (2007) Problems and prospects of market-oriented reforms of China's power industry (In Chinese)

State Grid Corporation of China (SGCC) (2012) Company profile. http://www.cet.sgcc.com.cn/web/company/profile (In Chinese)

Tianjin Climate Exchange (TCX) (2012) Exchange Introduction. http://www.chinatcx.com.cn/tcxweb/pages/gywm/wm_exchange_resume.jsp (In Chinese)

Von der Fehr N, Fabra N, Harbord D (2006) Designing electricity auctions. RAND Journal of Economics 37(1):23-46

Von der Fehr N, Harbord D (1993) Spotmarket competition in the UK electricity industry. Economic Journal 103 (418):531-546

Wang XJ, Zhang W, Huang YN, Li SJ (2004) Modeling and simulation of point-non-point source effluent trading in Taihu Lake area: perspective of non-point sources control in China. Science of the Total Environment 325(1-3):39-50

Wang YG, Ge XA, Shao SY, Li YD (2011) China's pathway towards carbon emissions trading scheme: International experience & China's practices. Economic Management Press (In Chinese)

WEO (2006) World energy outlook (WEO). Paris, France: International energy agency

Woo CK, Lloyd D, Tishler A (2003) Electricity market reform failures: UK, Norway, Alberta and California. Energy Policy 31(11):1103-1115

Wu YR (2013). Electricity market integration: Global trends and implications for the EAS region. Energy Strategy Reviews 2(2):138-145

Xinhua News Agency (2011) China's policies and actions to address the climate change (2011). http://news.xinhuanet.com/2011-11/22/c_111185426.htm (In Chinese)

Xinhua News Agency (2012) China Southern Power Grid Corporation. http://www.gd.xinhuanet.com/zt12/qsgd/2012-03/04/content_24823039.htm (In Chinese)

Xinhua News Agency (2013) The first pilot project of carbon trading was launched in Shenzhen. http://news.xinhuanet.com/fortune/2013-06/20/c_116227291.htm (In Chinese)

Xu SF, Chen WY (2006) The reform of electricity power sector in the PR of China. Energy Policy 34(16):2455-2465

Zhang C, Shuklab PR, Victor DG, Heller TC, Biswas D, Nag T (2006) Baselines for carbon emissions in the Indian and Chinese power sectors: Implications for international carbon trading. Energy Policy 34(14):1900-1917

Zhang FW, Guo Y, Chen XP (2011) Research on China's power sector carbon emissions trading mechanism. Energy Procedia 12:127-132

Appendix: The chronology of China's electricity market reforms

Date	Event
February 1979	Ministry of Water Resources and Electric Power were withdrawn. Meanwhile, Ministry of Electric Power Industry was founded.
March 1982	Ministry of Water Resources and Ministry of Electric Power Industry were merged into Ministry of Water Resources and Electric Power again.
May 1985	The State Council issued the notification of *Provisional Regulations on Promoting Fund-Raising for Investment in the Power Sector and Implementing Different Power Prices*.
September 1987	The State Council proposed *the Twenty-word policy* of electricity reform and development, including Separation of Government Administration from Enterprise Operation, Provinces as Entities, Interconnected Power Grid, Centralized Dispatching, and Fund-Raising for Power Construction.
April 1988	Department of Energy was founded to take the place of Ministry of Coal Industry, Ministry of Petroleum Industry, Ministry of Nuclear Industry as well as Ministry of Water Resources and Electric Power.
October 1988	China Electricity Council (CEC) was founded.
July 1991	China Southern Power Pool Company was established.
January 1993	State Council Gorges Project Construction Committee was founded. Later in the same month, Enterprise Group of Electric Power Industry was formed to integrate the northeast, north China, central China, northwest and east China power grids.
March 1993	7 ministries such as Department of Energy were withdrawn, while Ministry of Electric Power Industry and other 5 ministries were established.
December 1995	The *Electricity Law of the People's Republic of China* was passed in the 17th Session of the 8th National People's Congress, and came into force on April 1, 1996.
June 1996	National Grid Construction Co., LTD was founded.
January 1997	State Power Corporation was formally founded.
March 1998	Ministry of Electric Power Industry was withdrawn, with its business functions transferred to State Economic and Trade Commission.
September 1998	The State Council approved *Position Papers of the Regulations on Stopping Implementation of Buying Power Consumption Right*, which indicated that power shortages came to an end.
October 1998	The policy of *two reforms and one unified price* were officially started.
December 1998	The pilots of *Separation of Generation from Grid and bidding for on-grid* were carried out in 6 provinces and municipalities including Zhejiang, Shandong, Shanghai, Liaoning, and Heilongjiang.
May 1999	State Economic and Trade Commission issued *Position Papers of the Reform on Doing Well the Job of the Separation between Government and Power Enterprises*.
June 2001	The *implementing scheme on power institutional reform of separation of government from power enterprises and generation from grid* was issued.
February 2002	The State Council promulgated the *Notification of Plans of Power Institutional Reform*.
December 2002	State Power Corporation was restructured into two grid corporations (State Grid and China Southern Power Grid) and five large companies (China Guodian Corporation, China Huaneng Corporation, China Huadian Corporation, China Datang Corporation and China Power Investment Corporation.).
March 2003	State Electricity Regulatory Commission was founded, which meant that the separation of politics and supervision was started.
July 2003	*China's Power-Pricing Reform* was promulgated.
March 2004	The policy of *benchmark on-grid electricity tariff ca*me into being.

December 2004	National Development and Reform Commission promulgated *the Coal-Electricity Tariff Linkage Mechanism.*
February 2005	*Electricity Regulatory Rule* was promulgated.
March 2005	Three implementation measures, such as *Interim Measures of on-grid Electricity Pricing Management, Interim Measures of Transmission and Distribution Electricity Pricing Management and Interim Measures of Sale Electricity Pricing Management,* were formulated, which matched *China's Power-Pricing Reform*.
February 2006	The task of electric power system reform was defined during *the 11th Five-Year Plan*.
June 2006	With the second implementation of *the Coal-Electricity Tariff Linkage Mechanism* e, electricity price of thermal power enterprises was increased by 1.5%-5%.
January 2007	National Development and Reform Commission issued *Interim Measures of Additional Income Allocation on Renewable Energy Price.*
March 2007	National Development and Reform Commission issued *the Notification on Reduction on-grid Electricity Pricing to Promote the Shut-down of Thermal Power Units with Small Capacity*.
September 2009	State Electricity Regulatory Commission issued *Annual Electricity Regulatory Enforcement Report in 2008*.
October 2009	*Some Position Papers on the Advancement of Electricity Price Reform* (Opinion Solicitation Draft) was jointly worked out by National Development and Reform Commission and State Electricity Regulatory Commission. At the same time, a pilot project of large user direct transaction between Fushun Aluminum Plant and Huaneng Yimin Power Plant was launched, which symbolized that the pilot direct transactions were officially launched between power consumers and generation enterprises. Later, *the Notification of Some Questions on Normalizing Electricity Transaction Pricing Management* was issued.

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