19. Issues in Greening China's Electricity Sector

Xiaoli Zhao

Introduction

China's electric power generating industry has developed rapidly since the reform era began in 1978 (Figures 19.1 and 19.2). The average annual growth rates of installed power capacity and power generation were 7.8 per cent and 7.9 per cent respectively from 1978 to the end of the last century. This meant that from 1996 China was ranked second in the world for both installed power capacity and power generation. By 2011 China's power generation had exceeded that of the United States, to make China the largest power generator in the world (BP 2015). Installed power generation capacity reached 1,247 GW by the end of 2013, thus also exceeding the United States, according to the *Electric power construction industry annual report 2013* (China Electric Power Construction Enterprise Association 2014). By 2014, power generation had reached 5,649 terawatt-hours (TWh), accounting for 24 per cent of the global total (BP 2015), and installed capacity had reach more than 1,360 GW—22.66 per cent of the global total (China Renewable Energy Society 2015).

The characteristics of China's resource endowments mean it presently relies predominantly on coal. Total installed thermal power capacity increased from 39.84 GW in 1978 to 915.69 GW in 2014. Thermal power generation increased from 211.9 TWh in 1978 to 4,233.73 TWh the same year. Over the past 36 years, installed thermal capacity and power generation have grown the fastest amid China's power mix, in terms of both installed capacity and power generation. By 2014, installed thermal power capacity and power generation accounted for some 70 per cent and 75 per cent, respectively, of the totals. Those shares, and the high scale of production in China, have in turn brought serious environmental externalities.

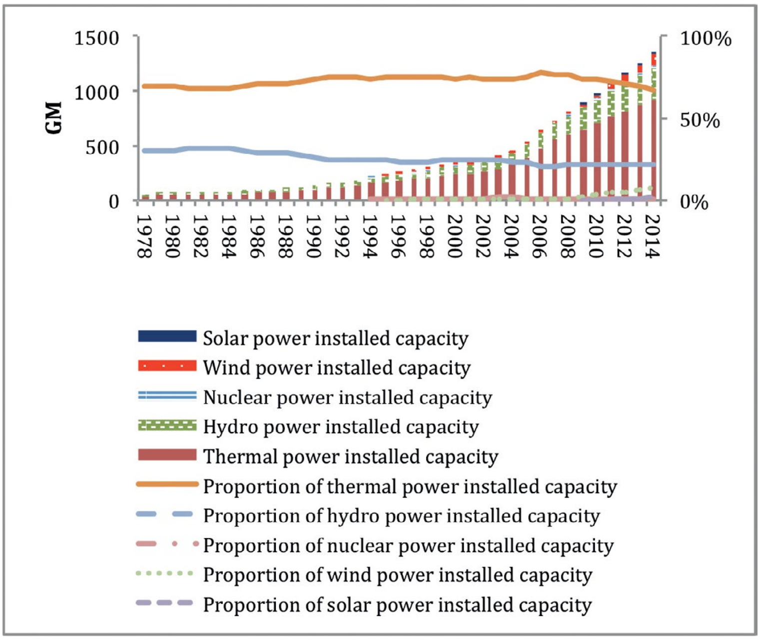

Figure 19.1 Power installed capacity mix in China

Sources: China Electricity Council (2014); NBS (1978–2014).

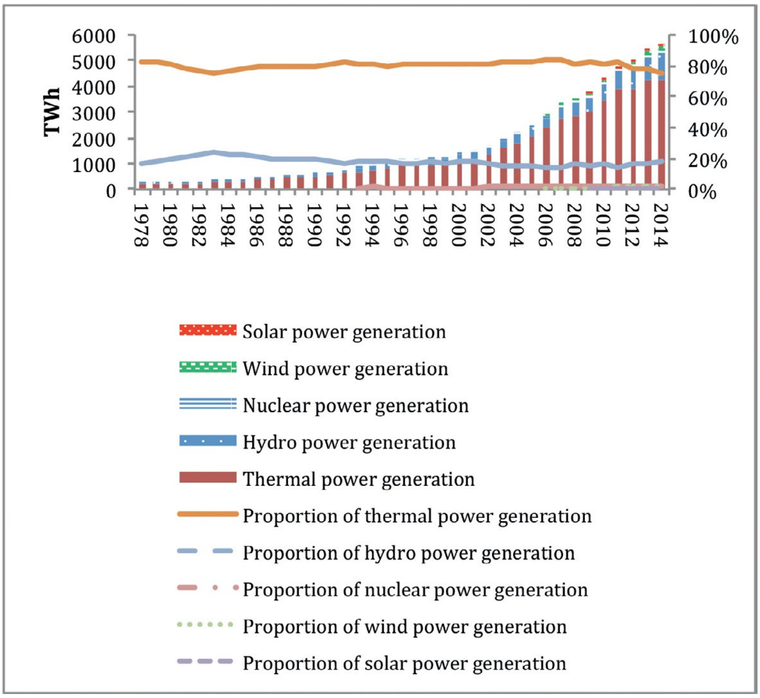

Figure 19.2 China's power generation mix

Source: NBS (1978–2014).

Figure 19.3 shows the share of carbon dioxide emissions for each industrial sector in China. In 2014, the power industry's emissions accounted for half of all carbon dioxide emissions in China. Figure 19.4 shows the changes in three pollutant emissions from China's power industry—smoke dust, nitrogen oxides and sulphur dioxide—and their respective shares in total industrial emissions. As a result of increasing power demand and production, sulphur dioxide emissions from China's power industry in 1999–2006 have fluctuated, from 7.4 million tonnes in 1999 to 13.2 million tonnes in 2006. The rise of sulphur dioxide emissions has been curbed by desulphurisation technology, which was prioritised under the Eleventh Five-Year Plan (FYP). The leading method China uses to achieve this is limestone-gypsum wet desulphurisation (92 per cent), which is accepted practice across a wide range of applications, with a desulphurisation rate, on average, above the 95 per cent level. Accordingly, sulphur dioxide emissions began to drop in 2006, from 13.2 million tonnes to 6.8 million tonnes by 2014.

At the same time, China's broader thermal power emission standards have become increasingly strict, via the *Thermal Power Plant Air Pollution Emission Standards GB13223-1996* and up to *GB13223-2011*, with the aim of reducing the environmental footprint of the industry. As a result, dust emissions decreased from 4.7 million tonnes in 1998 to 980,000 tonnes in 2014 (MEP 1998–2014), supported by improvements in power plant dust removal technology and efficiency. The industry accounted for 39 per cent of total industrial dust emissions in 1998 but only 16 per cent in 2014 (MEP 1998–2014). On the other hand, nitrogen oxide emissions from the thermal power industry increased from 3.6 million tonnes in 1998 to 10.7 million tonnes in 2011. Since the implementation of the Twelfth FYP, there appears to have been a decline to 7.8 million tonnes in 2014. The total emissions of sulphur dioxide, nitrogen oxides and dust rose from 16.4 million tonnes in 1998 to 22.4 million tonnes in 2006, followed by a marked decline to 13.4 million tonnes in 2014.

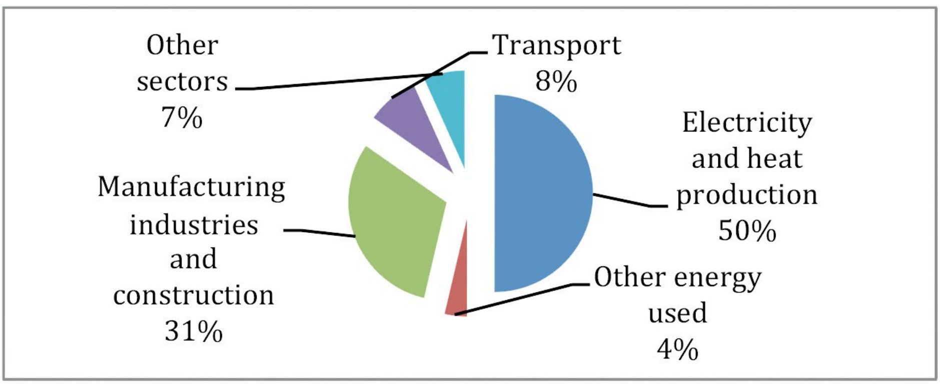

Figure 19.3 Carbon dioxide emissions of various sectors in China

Note: 'Other energy used' includes emissions from petroleum refining, the manufacture of solid fuels, coalmining, oil and gas extraction and other energy-producing industries.

Source: IEA (2014).

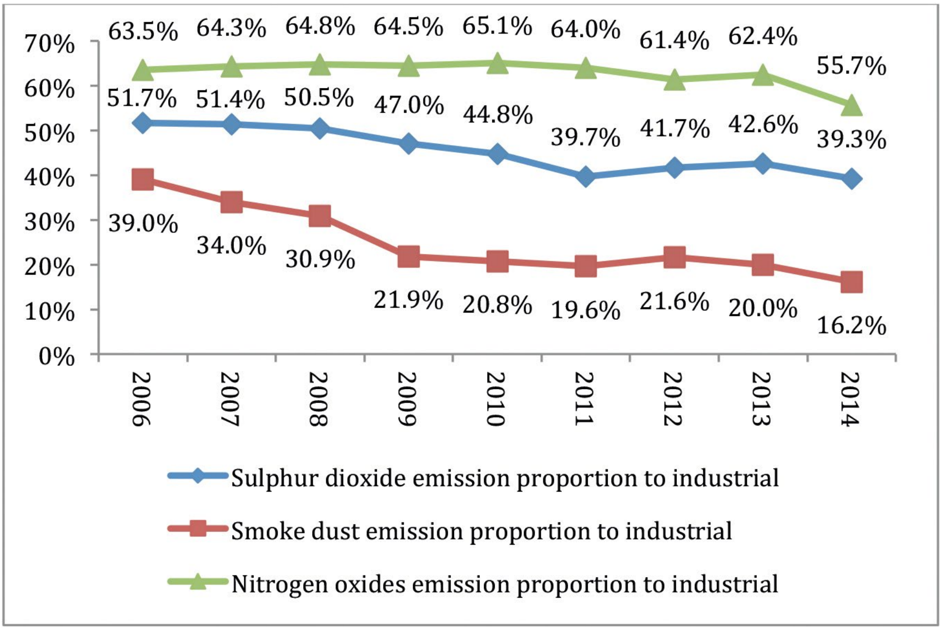

Figure 19.4 Pollutant emissions from China's thermal power generation and their proportion in total industrial emissions

Note: The emissions of sulphur dioxide, nitrogen oxides and dust from the power industry accounted for 34.61 per cent, 13.53 per cent and 37.69 per cent of the national total, respectively, in 2014.

Source: MEP (1998–2014).

Figure 19.5 shows the sulphur dioxide and nitrogen oxides emissions from China's power industry and the US power industry. The nitrogen oxide emissions from China's power industry exceeded those in the United States in 2001, and its sulphur dioxide emissions exceeded those in the United States in 2005. According to the data in Figure 19.6, the carbon dioxide emissions of China's power industry exceeded those of the United States in 2009. According to BP (2015) statistics, however, this transition took place in 2006, which is also when China became the world's largest emitter of carbon dioxide.

The reasons for China's power industry emissions exceeding those of the United States are twofold. First, China's power generation levels reached 5,650 TWh in 2014 (China Electricity Council 2014), compared with 3,880 TWh in the United States (EIA 2014). Second, coal-fired power generation accounts for about 75 per cent of total power generation in China (China Electricity Council 2014)—a much higher share than in the United States, where it is only about 40 per cent (EIA 2014).

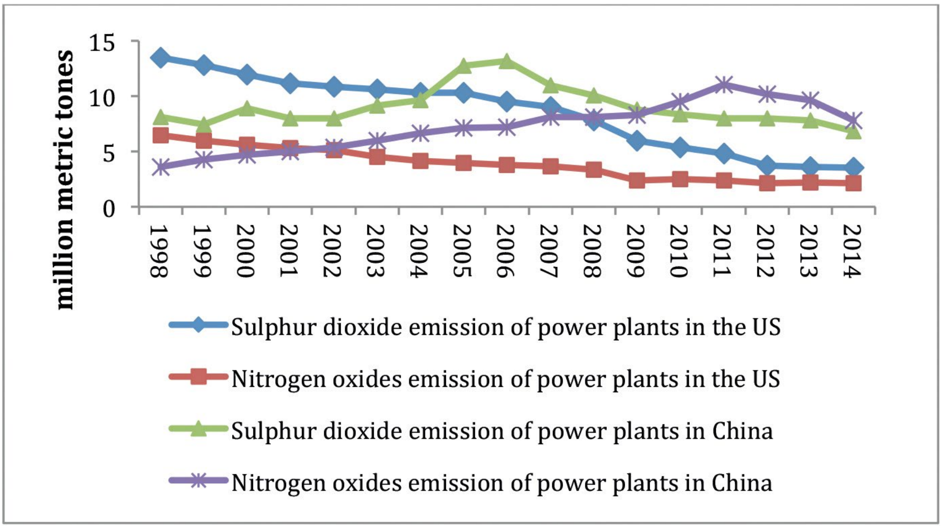

Figure 19.5 Comparison of sulphur dioxide and nitrogen oxide emissions from Chinese and American power industries, 1998–2014

Sources: EIA (1998–2014); MEP (1998–2014).

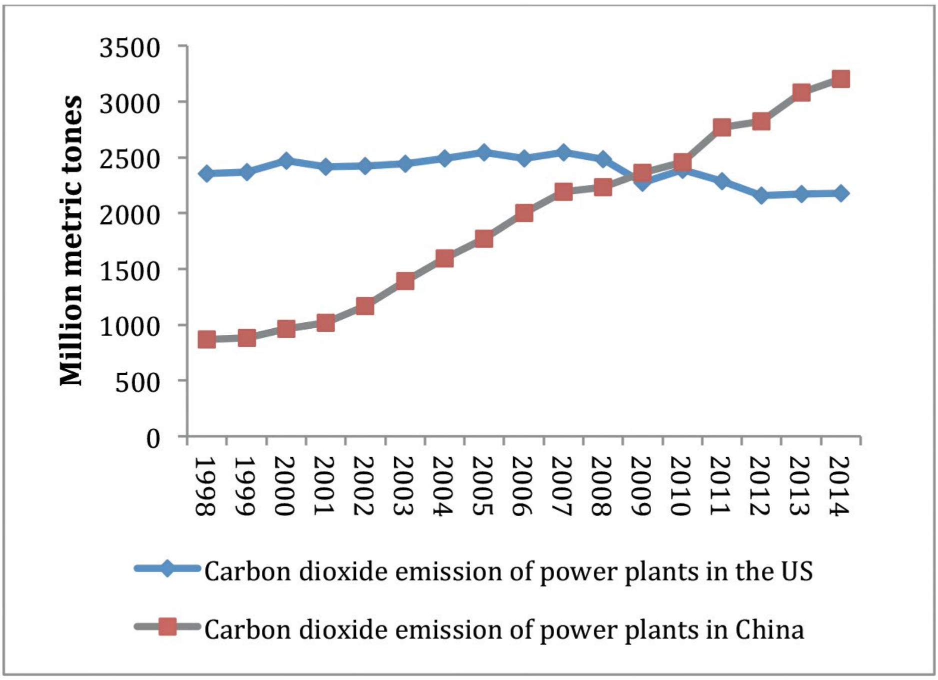

Figure 19.6 Comparison of carbon dioxide emissions from Chinese and American power industries, 1998–2014

Source: EIA (1998–2014); China's carbon dioxide emissions are calculated using data from NBS (1978–2014, 1998–2014a).

Assessing the external environmental cost of China's electricity sector

We use a choice experiment (CE) approach to quantitatively evaluate the external environmental cost of China's coal-based power generation.

The CE approach offers a promising opportunity to measure various environmental economic values as it is concerned with modelling choices that vary across a range of characteristics rather than relying on estimated willingness to pay (WTP) for a single option (Ku and Yoo 2010). CE formats have also been applied to a wider range of environmental problems (for example, Adamowicz et al. 1994; Carlsson and Martinsson 2001; Shrestha and Alavalapati 2004). Moreover, a key advantage of the CE approach compared with an alternative method for evaluating external environmental value, the contingent valuation method, is the ability to elicit the marginal value of attributes of the good or service (Hanley et al. 2002). This is useful because many policies are concerned with changing attribute levels, rather than losing or gaining the environmental good as a whole.

In our CE design, we selected four attributes and the relative levels of each one (Table 19.1). This includes three environmental attributes—reduction of carbon dioxide emissions, of PM2.5 (the particulate matter standard for dust emissions) and of acid rain (sulphur dioxide and nitrogen oxide emissions)—and a price attribute, which is defined as the WTP in terms of environmental improvements at the cost of increasing households' monthly electricity bills. The levels of the price attribute were decided through a pre-test and in consultation with an expert at the University of Western Australia. The lower bound is RMB0 and the upper bound is RMB25 per month.

Table 19.1 Description of attributes and levels

Attribute	Description	Level
CO_2	Percentage reduction of carbon dioxide emissions	1–5% (low) 6–10% (medium) 11–20% (high)
PM2.5	Air quality level, corresponding to percentage reduction of dust emissions	Excellent air quality Good air quality Light pollution Moderate pollution Heavy pollution (status)
Acid rain	Distribution of acid rain, corresponding to percentage reduction of sulphur dioxide and nitrogen oxides	No acid rain Light acid rain Moderate acid rain Relatively severe acid rain Heavy acid rain
Bill	Increase in monthly electricity bill	RMB0, RMB5, RMB10, RMB15, RMB25

Survey data were collected from 600 questionnaires containing six choice sets per respondent. There were three types of questionnaires, and 18 sets in total. After removing the incomplete questionnaires, 411 were suitable for analysis, yielding 2,466 observation points (411 effective respondents × six choice sets).

Sampling was distributed across the eastern (145 samples with 35.28 per cent), western (99 samples with 24.09 per cent) and central (167 samples with 40.63 per cent) parts of China, including urban and rural areas. There were 170 samples from urban areas and 241 from rural areas, accounting for 41.36 per cent and 58.64 per cent respectively of the total. The sample was randomly selected so as to reflect a broad population range in terms of education levels, different ages and different income levels.

Among the important elements in the questionnaires were the various alternatives, which were designed by combining the four attributes given in Table 19.1 based on the different levels of attributes. To solve the key problem encountered in CE information overload—that is, too many alternatives with too many complex attributes—we applied the orthogonal main effects design to reduce the number of possible combinations of attributes. The orthogonal main effects design was implemented using the SPSS software 19.0, and 18 choice sets were selected. Previous literature (for example, Susaeta et al. 2011; Lee and Yoo 2009) and expert recommendation informed our decision for each respondent to fill up to a maximum of four to six choice sets. We divided the 18 choice sets into three questionnaires—Questionnaire 1, Questionnaire 2 and Questionnaire 3—each with six choice sets. An example of the choice sets is presented in Table 19.2.

Table 19.2 Choice set examples

Attribute	Plan 1	Plan 2	Plan 3	Status quo
PM2.5	Good	Excellent	Excellent	Moderate pollution
Acid rain	None	None	Light	Relatively severe
Carbon dioxide	6~10%	1~5%	6~10%	0
Bill	RMB25	RMB25	RMB25	0
Please choose	Plan 1	Plan 2	Plan 3	Status quo

Random utility theory (McFadden 1986) is the principle theory for evaluating environmental externalities. The basic indirect utility for respondent n to choose alternative j in choice set t can be expressed mathematically according to Train (2009) and McFadden (1973) (Equation 19.1).

Equation 19.1

$$U_{njt} = V_{njt} + \varepsilon_{njt} \forall j, t$$

In Equation 19.1, U_{njt} is decomposed into a deterministic component, V_{njt}, and a stochastic component ε_{njt}. V_{njt} is the utility of respondent n when he/she chooses alternative j in choice set t. Furthermore, if $U_{nit} > U_{njt}$ for all $i \neq j$ in choice set t, the respondent will choose alternative i over j. Moreover, V_{njt} can be expressed as Equation 19.2

Equation 19.2

$$V_{njt} = V(X_{njt},\ S_n) \forall j,\ t$$

In Equation 19.2, X_{njt} is a vector comprising the attributes associated with environmental quality and S_n is a vector comprising the socioeconomic attributes of respondents.

The random utility model can be transformed between different classes of choice models by varying assumptions about the distribution of the error term (van der Kroon et al. 2014). If the distribution of the error term, ε_{njt}, is assumed to be independently and identically distributed, extreme value distribution for all i, the function of choice probability can be expressed as Equation 19.3.

Equation 19.3

$$P_{nit} = \frac{\exp(V_{nit})}{\sum_j \exp(V_{njt})}$$

Equation 19.3 describes the multinomial logit (MNL) model, which is the most widely used choice model (Train 2009). It is also the most basic of the choice models. The MNL model without interactions is therefore employed as the first step in the analysis.

To explain preference heterogeneity and WTP variations among individuals, it is necessary to consider some individual specific variables (socioeconomic, attitude and experience) (Lim et al. 2014). We applied three different econometric models (MNL, MNL with interaction and random parameters logit: RPL) to analyse respondents' preferences when facing environmental improvement alternatives.

Following Hanemann (1983, 1984), the marginal WTP is specified as Equation 19.4.

Equation 19.4

$$MWTP_{attribute} = -(\beta_{attribute} / \beta_{\cos t})$$

In Equation 19.4, $\beta_{attribute}$ is the coefficient attached to each environmental attribute, which in this study includes carbon dioxide emission reduction, PM2.5 emission reduction and acid rain reduction. β_{cost} is the coefficient of the bill/cost attribute.

We estimate the marginal WTP of each of the three attributes—PM2.5, acid rain and carbon dioxide—along with the 95 per cent confidence intervals estimated using the procedure proposed by Krinsky and Robb (1986). The marginal WTP of each attribute represents the marginal rate of substitution between the cost and each environmental attribute. The marginal WTP can be estimated by taking the average over the sample distribution of $WTP_{attribute}$ coefficients.

Beyond the marginal WTP estimations for individual environmental attributes, this is also needed to estimate the compensation surplus or welfare change in three future scenarios that are compared with the base of the status quo. We calculated the amount of money required to reach a higher level of environmental quality by comparing the utility of any alternative option with the reference alternative. This is called total WTP, which was calculated as in Equation 19.5 (Hanemann 1984).

Equation 19.5

$$TWTP = -(1/\beta_{\cos t})[\ln \sum \exp(V_1) - \ln \sum \exp(V_0)]$$

In Equation 19.5, β_{cost} is the estimated coefficient of cost, V_1 represents the utility of any alternative option and V_0 represents the utility of the reference alternative.

Finally, we obtain the results for the external environmental cost of China's coal-based power generation, which show that respondents have a WTP for the improvement of environmental quality. All the marginal WTPs are significantly positive, indicating that respondents assigned positive values to thermal power environmental improvement. Taking the RPL model results as an example (Table 19.3), the marginal WTP per household for improving PM2.5 levels from moderate pollution (status quo) to excellent air quality, good quality and light pollution is RMB13.3, RMB10.1 and RMB6 per month, respectively. For acid rain levels to shift from severe acid rain to no acid rain, light acid rain and moderate acid rain the WTPs are RMB18.5, RMB13.6 and RMB12.2 per month, respectively; and for carbon dioxide to move from no emission reduction to

high emission reduction (11~20 per cent emission reduction), medium emission reduction (6~10 per cent) and light emission reduction (1~5 per cent) is RMB10.8, RMB9.8 and RMB7.2 per month, respectively.

Table 19.3 Marginal WTP values for MNL, MNL with interactions and RPL

	MNL	MNL with interactions	RPL
PM2.5(Excellent)	16.258*** (12.064, 20.453)	16.105*** (11.850, 20.359)	13.282*** (5.356, 21.207)
PM2.5(Good)	15.7793*** (11.188, 20.371)	15.516*** (11.148, 19.885)	10.110*** (3.193, 17.027)
PM2.5(Light)	5.983*** (1.618, 10.348)	5.894*** (1.788, 10.000)	5.982*** (1.608, 10.356)
No acid rain	17.612*** (10.310, 24.914)	17.614*** (10.625, 24.602)	18.452*** (9.120, 27.785)
Light acid rain	12.580*** (4.986, 20.173)	12.694*** (5.435, 19.952)	13.628*** (6.098, 21.157)
Moderate acid rain	10.254** (2.279, 18.228)	10.124** (2.232, 18.016)	12.178*** (3.993, 20.363)
CO_2 reduction (11%~20%)	9.727*** (4.604, 14.849)	10.011*** (4.935, 15.088)	10.757*** (5.037, 16.477)
CO_2 reduction (6%~10%)	9.010*** (4.082, 13.939)	9.078*** (4.345, 13.810)	9.836*** (4.565, 15.108)
CO_2 reduction (1%~5%)	5.136** (0.729, 9.544)	5.269** (1.036, 9.501)	7.223*** (2.084, 12.362)

** significant at the 5 per cent level
*** significant at the 1 per cent level

Adding up the above estimates, the total WTP for improvements that reach the best-case scenario from the status quo is a monthly amount of RMB40. To equate this to thermal power generation scales, we refer to data from the National Energy Administration (NEA 2015), which suggest the average electricity consumption of a Chinese resident is 6,928 TWh per year. According to the *China family development report* (National Health and Family Planning Commission 2014), there were 430 million households in China in 2014; hence, annual electricity consumption per household is 1,611 kWh per year or 134 kWh per month. From these numbers, we can estimate the total WTP for improvement to the best-case scenario is RMB0.30 per kWh. This indicates that the external cost of thermal power generation in China is RMB0.30/kWh.

To ensure these results are credible, we need to make a theoretical and standard empirical validity check.

The theoretical validity check tests the consistency between the results in this study and the results expected according to theory. According to the data for residential electricity consumption in 2014 (6,928 TWh) and the number

of households (430 million), the average electricity consumption for each household in China can be calculated (134 kWh in 2014). Meanwhile, we know that the residential electricity fee in China is about RMB0.6/kWh; hence, the average monthly household electricity fee in 2014 was RMB80.4. According to this study's results, however, respondents are willing to pay an extra RMB40 to reduce the environmental impacts of electricity generation. Since the premium accounts for about 50 per cent of the total electricity fee per month, it is consistent with the theoretical anticipated scope (no more than 50 per cent).

Empirically, we can also compare our results with those of similar studies. Mahapatra et al. (2012) calculated the environmental cost of thermal power plants in India using a dose-response model. The result was an external cost of RMB0.26/kWh, which is lower than but close to our result. Georgakellos (2010) evaluated the environmental cost of thermal power plants in Greece based on the Ecosense LE method, and found an external cost of RMB0.26/kWh, which is also close to our result. The European Commission (1995) used the ExternE method to calculate the environmental cost of thermal power plants in the European Union, and identified a range of RMB0.23~0.34/kWh. The International Energy Agency analysed the environmental cost of various kinds of power generation in 19 countries and found the environmental cost of thermal power plants is RMB0.20~0.45/kWh. Our result is within the scope of these studies.

The environmental footprint of China's electricity market reform

China's electric utility industry can be characterised by two major reform stages. During the first stage, from 1949 to 1984, the industry (like other energy industries) was treated simply as a means to an end—in other words, as a subordinate sector whose goal was to support the development of the downstream industrial sector. As a result, the performance of the industry itself, and improvements in its management efficiency, received little attention. In general, a highly centralised administrative mechanism was deemed suitable given those instrumental aims.

Stage one of China's market: 1949–84

Within this era, four critical phases can be identified that had a great impact on the management of China's power generation and distribution. The first occurred in the 1950s, when the Soviets had a major influence on the country, leading to a highly centralised administrative mechanism that would dominate the sector for years to come. The second was the disastrous Great Leap Forward period, from 1958 to 1960, during which the Chinese Government required

vast increases in iron and steel production, and energy consumption increased rapidly. The third key phase was the Cultural Revolution, from 1966 to 1976, during which China's economic development was largely blocked and energy demand increased more slowly. The fourth phase was the market reform era that began in 1978. From this time on, China's economy embarked on a rapid development path, but power supply shortages, until the mid-1980s, became increasingly severe.

Throughout the first stage of China's industrialisation phase following opening and reform, electricity prices were held below average costs of production (Huang 2009). This meant it was impossible for the sector to finance its own investment, which ultimately seriously hindered the industry's development. Under the socialist economy of this period, industry and employment were organised around work units (*danwei*), which paid for the electricity used not only at work, but also in the *danwei* housing where workers lived. Electricity was considered an entitlement and, as a result of the very low electricity price, people used power profligately. In a parallel with the government-supplied water pouring out of the taps, which was also essentially unpriced, electricity was simply there to be freely used.

In the mid-1980s, power shortages became so common as to have serious negative impacts on industrial production, and on citizens' living standards. Rationing was implemented and homes and places of work were required to minimise their use of power during the day so that factories would have sufficient power. By the late 1980s, even in large cities, students were often unable to read in university libraries in the late afternoon due to power shortages.

Stage two of China's market: Reform

To mitigate the huge imbalance between the quantity of electricity being demanded at below-cost prices and the generating capacity available, from the mid-1980s, the Chinese Government issued a series of important regulatory policies. In 1985, it issued two policy documents entitled 'Interim provision on promotion fund-raising for electricity investment and implementing multiple electricity prices' and 'The measures of implementing multiple electricity prices'. The two policies, the major elements of which are outlined in Ma and He (2008), broadly succeeded in solving the electricity generation shortage. In fact, by the mid-1990s and over the first decade of the twenty-first century, China experienced a surplus in electricity supply (Huang 2009). This was due partly to the rapid growth in supply unleashed by parallel and new investment policies and partly to the fall in electricity demand instigated by the East Asian

Financial Crisis in 1997. Regardless, the excess supply led to strict control of electricity investment by the Chinese Government from 1998 to 2001, which in turn resulted in a renewed electricity supply shortage in 2002 (Huang 2009).

The new period of limited supply was, however, short-lived. The breakup in 2002 of the vertical monopoly held by the State Power Corporation (SPC) prompted a second investment rush in electricity generation in China. In December 2002, the SPC was dismantled and five large mutually autonomous power generation corporations were established. The competition for resources between the five corporations greatly accelerated investment in power capacity in 2003, as can be seen in Figure 19.7.

With rapid growth in electricity capacity, the supply shortage was mitigated to some extent; however, it was not resolved completely until 2011 because of a related shortage in the supply of coal. In sum, during the second half of the twentieth century, China's centralised management of the electricity system led to severe problems in the allocation of energy resources, as would be predicted by standard price theory. By 1985, persistent shortages had instigated various reforms that helped to bring forth new generation capacity. Nevertheless, the continued reliance on government-controlled prices rather than markets led to dramatic swings from power shortages to excess supply and back again.

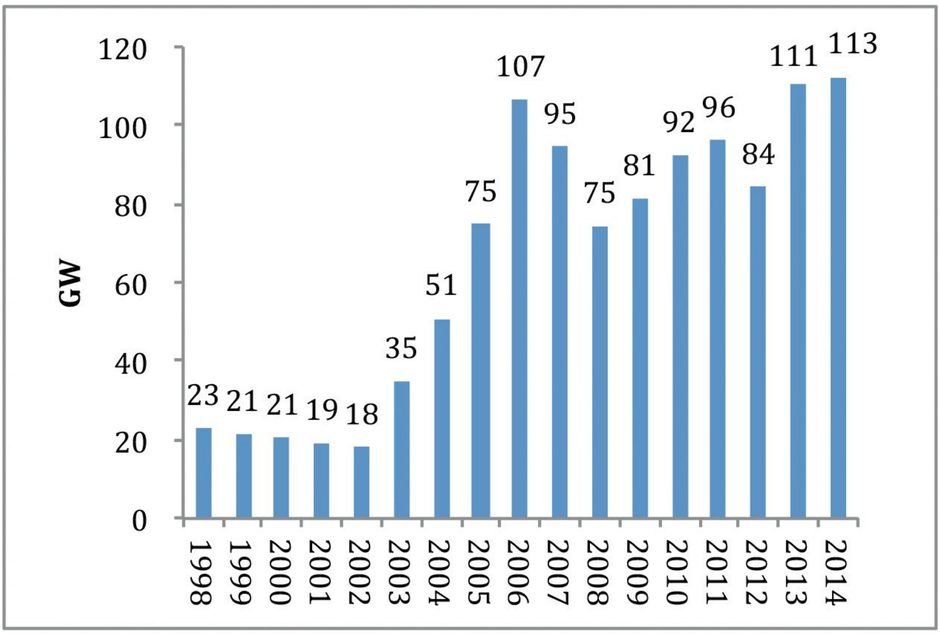

Figure 19.7 Additional power capacity added each year in China

Source: China Electricity Council (2014).

Electricity price reform and its impact on the environment

To resolve the serious shortage pre-1985 in electricity supply, the Chinese Government implemented a pricing system for new power plants under the 'capital and interest price' (in 1985) and 'operation period price' (in 1996) initiatives. The two prices are cost-plus regulation prices (or rate of return prices). Under such mechanisms, profit was guaranteed, greatly encouraging investment in power generation plants. On the other hand, new plants were opportunistic by overstating their cost to get a higher grid price. Moreover, most plants built during that period were high in cost and low in energy efficiency, and thus created serious environmental pollution. Under the capital and interest pricing mechanism, the investment costs could be recovered in a short time. Most investors chose to construct small units because of the lower capital requirements and simpler approval procedures, even though small units were low in efficiency. By the end of 1996, the average thermal power unit capacity was only 46 MW (Ren 2002). More specific data from the China Electricity Council show that by the end of 2014 thermal power unit capacity above 300 MW accounted for about 77.7 per cent of total thermal power capacity; units above 600 MW accounted for 41.5 per cent; and most units with less than 100 MW capacity had been shut to improve energy efficiency.

The Chinese Government has created a yardstick power price (similar to a fixed power price), characterised by a capped power price, since 2004. Up to this point, there had been growing support among both academics and policy practitioners for price-cap regulation as an alternative to rate-of-return regulation in the relative regulatory policy discussions (Baumol and Sidak 1994). Joskow (1991) argued that incentive mechanisms aimed at promoting efficient (and cleaner) supply had focused on 'yardstick' comparisons for specific components of electricity costs.

Electricity investment reform and its impact on the environment

The 'Interim provision on promotion fund-raising for electricity investment and implementing multiple electricity prices' policy document was issued in 1985. Part of its aim was to encourage various investors—including private, local government and foreign investors—to access electric power generation plants. Through this policy and to induce more investment in power generation, the Chinese Government allowed a very high rate of return on power generation plants (Ma and He 2008). Specifically, the rate of return for foreign investors was 13–18 per cent and even 20 per cent (Ou et al. 2009)—much higher than the average at that time.

The most significant in-principle contribution of the 1985 investment reforms was to attract vast capital for power plant construction in a short time. One specific and remarkable effect of this reform, in principle and efficiency, would be the construction of the Ertan Hydropower Station, which started in 1991 and was completed in 2000. Investors in Ertan included the State Development Investment Corporation, Sichuan Investment Group Corporation and Sichuan Electric Power Corporation. The other prominent hydropower station in China is also the largest hydro project in the world: the Three Gorges Project. Much of the investment for this came from the public via the issuing of bonds and stock.

From the mid-1980s, such investments saw a rapid increase in total generating capacity. Within a decade severe shortages in power supply had been nearly eliminated—but only temporarily. Moreover, the economic losses caused by power shortages in the years up to the mid-1990s were huge. In 1993, $27.6 billion of industrial value added was estimated to have been lost to power shortages—the equivalent of 7 per cent of gross domestic product (Li and Dorian 1995). Rapid growth in power generation investment from the mid-1990s, in contrast, prevented the continuation of such huge losses.

Unfortunately, to circumvent complicated central government approval processes and also to minimise risk, the most commonly implemented power generation plants had a capacity of no more than 200 MW. Large-scale generation plants, of 600 MW or more capacity, made up the smallest share of new plants before the mid-1990s (Figure 19.8). From this perspective, the reforms in 1985, while spurring necessary investments in the sector, had a negative impact on the scale-related environmental and economic efficiencies of the industry.

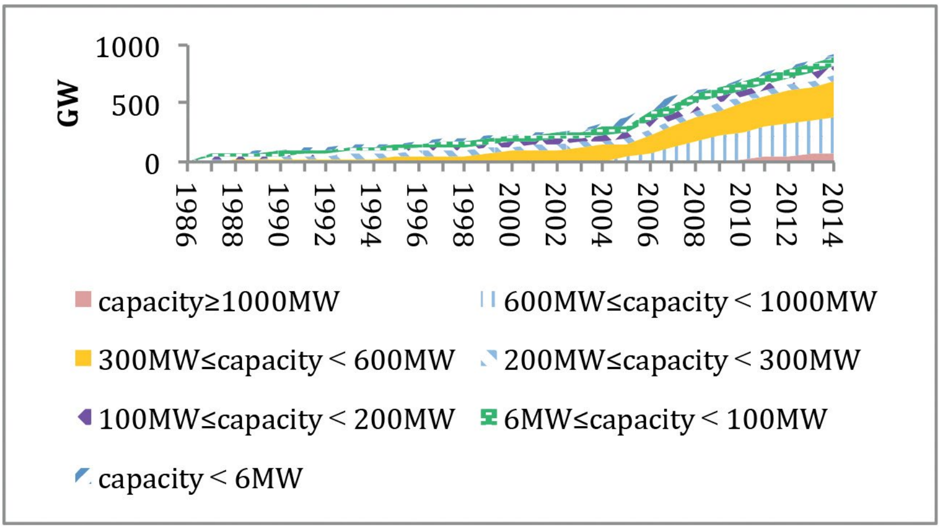

Figure 19.8 Change in size of thermal power generating units

Source: China Electricity Council (2014).

Vertical monopoly reforms and their environmental impact

In 2002, the SPC was dismantled and five big independent power generation corporations were set up: Huaneng Group, Datang Group, Huadian Corporation, Guodian Corporation and Power Investment Corporation. Their assets came from the disbanded SPC and they have been totally independent of the State Grid Corporation since 2003. This end to the vertical monopoly of the sector had the effect of promoting a second wave of investment in power generation in China. From 2003 to 2007, new power plants were established at a rapid rate.

Another reason for ending the vertical monopoly in 2002 was that the efficiency of China's electricity utility had already improved greatly. Alongside those efficiency gains, China's electricity sector had also shifted towards cleaner production. The power plants built after 2002 were mostly large-scale generation units (Figure 19.7). Figure 19.9 shows that since 1997, China's sulphur dioxide emissions from the electric power industry have decreased rapidly, particularly after 2005. These changes are attributed to two factors, the first of which was policy. China's electricity reform after the mid-1990s attached greater importance to the improvement of efficiency (quality) than to increasing power supply (quantity). The second factor was the corporate pursuit of profit. With the enforcement of a yardstick grid price and also competition, corporations with higher efficiency received the greatest benefits. Energy efficiency in power generation has since improved remarkably.

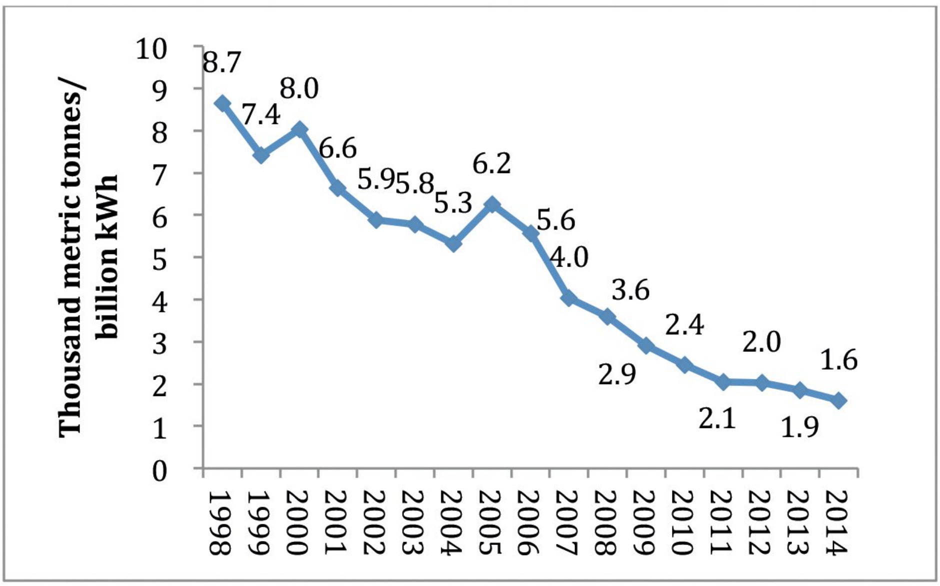

Figure 19.9 Sulphur dioxide emissions from the thermal electric power industry in China

Source: MEP (1998–2014).

China's environmental regulation and its impact on power industry carbon dioxide emissions

China's environmental regulation policies

China has a long history of strong, centralised government, so most of its environmental regulations follow a command-and-control approach. Regulations relating specifically to improving energy efficiency include 'The notice on several issues of improving China's energy efficiency' in 1979, 'The notice on progressively setting up the evaluation institute of integrated energy consumption' in 1980 and 'The specific requirements of energy saving for industrial and mining enterprises and cities (trial)' in 1981.

With regard to environmental protection, *The Managerial Guidelines for Standards of Environmental Protection in China* were promulgated in 1983. This set standards for air, water and soil quality and also for pollutant discharge and environmental monitoring. In the 1990s, as concerns about environmental protection increased, the regulators of China's power sector and other pollution-intensive industries paid more attention to pollutant control. For example, in 1991 China published *Standards for Air Pollutant Discharge from Thermal Power Plants GB13223-1991*, which was revised in 1996, 2003 and 2011. This is a performance-based regulation and the latest revision established several standards for pollutant discharge, including for the upper limit for soot emissions of 30 mg per cubic metre; 100 mg/cu m for sulphur dioxide emissions from newly installed boilers; 200 mg/cu m for sulphur dioxide from existing boilers; 100 mg/cu m for nitrogen oxides; and 0.03 mg/cu m for mercury and its compounds. Technology-based regulations were also ratified during this time to curb pollution from the power industry. For example, 'The division program of acid rain and SO_2 control zones', published in January 1998, required all thermal plants under construction and in future to install desulphurisation facilities (Li and Colombier 2011).

Although not a primary approach, market-based regulation (MBR) was also developed to promote environmental protection in the power industry. For example, in 1982, 'The interim measures on pollution charges' stipulated that firms should pay RMB40 for every tonne of sulphur dioxide or nitrogen oxide emissions above specified standards, and RMB3–10 per thousand cubic metres of sulphuric acid mist, lead and mercury exceeding specified standards. This is a typical pollution charge system. Meanwhile, government subsidies (GSs) were often implemented by increasing the regulated electricity prices. For example, to support power industry desulphurisation and denitrification, China increased the tariff by RMB15/MWh in 2004 and by RMB8/MWh in 2013.

Although these subsidies were not sufficient to cover all pollution abatement costs (Wang et al. 2012), they serve as important economic support for corporate efforts to reduce sulphur dioxide and nitrogen oxide emissions.

In addition to pollution charges and subsidies, two market-based policies have been implemented or attempted: the Clean Development Mechanism (CDM) and the cap and trade system. To promote the development of the CDM, the Chinese Government promulgated 'The operation and management measures of CDM projects (trial)' in 2004. That same year, the first CDM project, the HuiTengXiLe wind farm in Inner Mongolia, began operation. China's CDM projects focus mainly on the power industry. By the end of 2010, renewable energy sector CDM projects accounted for 71 per cent of the total approved projects (Yang et al. 2011).

As for cap and trade, under the Eleventh FYP (2006–10), the Chinese Ministry of Environmental Protection (MEP) prioritised the promotion of key pollutant emission trading rights. The MEP specifically selected eight provinces and provincial-level municipalities—Jiangsu, Zhejiang, Tianjin, Hubei, Hunan, Shanxi, Inner Mongolia and Chongqing—as pilot areas for sulphur dioxide emission rights trading. In practice, however, there has been little substantial voluntary trading of sulphur dioxide emission rights. The majority of the few transactions that have occurred have been government facilitated. As for the trading of carbon dioxide emission rights, the first pilot program was set up in Shenzhen in June 2013. By the end of April 2014, six provincial entities had followed in Shenzhen's footsteps: Shanghai, Beijing, Tianjin, Chongqing, Guangdong and Hubei. The trading volume of carbon dioxide emissions, however, accounts for only a limited proportion of national carbon dioxide emissions.

In sum, command-and-control regulation (CCR) still dominates the environmental regulation of China's power industry, although MBR and government subsidy (GS) are rising in prominence. In general, different types of environmental regulations may have different influences on corporate efficiency and environmental performance. In the following subsections, I empirically analyse the impact of various policy shifts in China on the corporate efficiency and environmental performance of the country's power plants. From the results, I offer policy suggestions for promoting the sustainable development of China's power industry with consideration of environmental issues.

Sample and data collection

The data were collected from two major sources: *Electric power industry statistics compiled* (China Electricity Council 2014) and my study group's survey of power plant managers (Table 19.4). China Electricity Council (2014) provides

information on power capacity and coal consumption for 2011 and 2012. To the best of our knowledge, plant-level employee numbers are not publicly available. Therefore, we estimated the number of employees based on the labour quota used in the power industry. Specifically, we followed the 'Labour force quota for thermal power plants' (SPC 1998), the 'Labour force quota for general thermal power plants' and the 'Labour force quota for new thermal power plants' (China Huadian Group Corporation 2008) to estimate employee numbers across all power plants. Three factors play significant roles in this estimation: power plant capacity, when the power plants were established and the capacity of each unit within a power plant. Labour force information in the questionnaire survey was also collected. Specifically, in the questionnaire, respondents were asked to allocate their power plant into one of four capacity-related categories: less than 100 employees, 100–500 employees, 501–2,000 employees and more than 2,000 employees. Labour force information from the survey is used in the regression analyses.

The survey, conducted in 2012, involved questionnaires being sent to 308 power plants in 22 of China's 31 provinces. The sample covers power plants across most regions of China (Figure 19.10). Moreover, the sample covers various sized power plants (Figure 19.2) and all five power corporations. Hence, the sample covers the full range of power plant types in China.

To ensure survey accuracy, the related literature was reviewed (for example, Milliman and Prince 1989; Liu 2009). In addition, we interviewed nine leaders from the China Guodian Corporation, the China Huadian Corporation and the China State Grid Energy Research Institute specialising in issues related to energy savings and emission reductions. Their suggestions and comments helped us refine our questionnaire.

The survey asked plant managers to assess their perceived influence from three policy perspectives—CCR, MBR and GS (the items for capturing the three types of policies are shown in Appendix Table A19.1)—and to note when the power plant was established.

To measure the perceived influence of CCR, MBR and GS, we developed a set of questions using the Likert scale (Likert 1932), which is the most commonly used method for perception measurements (Zhao et al. 2015). Oaster (1989) indicated that a seven-point scale showed the highest reliability. Therefore, the seven-point Likert scale is used in this study.

Table 19.4 Variables and the data sources

	Variable description	Variable name	Data source
Dependent variables	Efficiency change	EF	Calculated by author
	Carbon dioxide emissions	CO_2	Calculated by author
Independent variables	Command-and-control regulation	CCR	Questionnaires
	Market-based regulation	MBR	Questionnaires
	Government subsidy	GS	Questionnaires
Other variables	Power capacity	PC	China Electricity Council (2014)
	Number of employees	SC	Questionnaires and calculated by author
	Power plant age	T	Questionnaires
	Coal consumption	CC	China Electricity Council (2014)
	Power generation	PG	China Electricity Council (2014)

The survey was conducted in two formats: through email and through on-the-spot surveys. Firms were selected according to existing contacts and the questionnaires were distributed to leaders of these firms responsible for making strategy and other management decisions. The second method was an on-the-spot survey. Survey opportunities provided by training courses for leading power firm cadres (who come from all over China) at the North China Electric Power University were also maximised. The topics of these courses focused on firm strategy and management issues. Hence, participants were leaders responsible for making strategy and other management decisions in their firms.

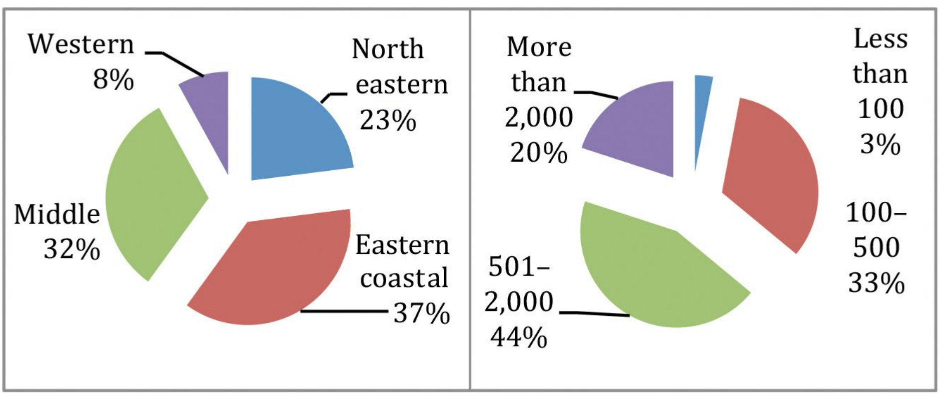

Figure 19.10 Region and size distribution of sampled power plants

Source: Created by the author.

Questionnaires were deemed invalid mainly if there was a non-response to a significant portion of the survey questions or all questions had the same answer. In total, 172 were returned and 137 were valid (for a 55.84 per cent response rate and 79.65 per cent validity rate). Fortunately, invalid questionnaires were randomly distributed across firms, implying that invalid questionnaires do not bring a systematic bias into the evaluation.

Carbon dioxide emissions

Power plant-level carbon dioxide emissions data are not publicly available. We estimated this data based on the method recommended by the Intergovernmental Panel on Climate Change (IPCC). We specifically calculated the carbon dioxide emissions for 137 power plants in China, a selection of which is outlined in Table 19.5.

Table 19.5 The carbon dioxide emissions of sampled power plants

Summary statistics	Carbon dioxide emissions (thousands of tonnes)	Power generation (100 GWh)	Carbon dioxide emissions from power generation (thousands of tonnes/100 GWh)
Mean	8,095.08	56.58	171.64
Median	4,512.29	33.7	140.53
Std dev.	13,371.58	101.10	160.92

Types of environmental regulation

In line with the existing research (for example, Milliman and Prince 1989; Liu 2009; Blind 2012), our chapter categorises environmental regulations into three types: CCR, MBR and GS. CCR is mandatory and allows managers very little freedom. Previous studies (Walley and Whitehead 1994; Liu 2009; Testa et al. 2011) and expert interviews indicate that it is logical to focus on five types of CCR: emission standards, fines, supervision, environmental assessment systems and production technology standards (Appendix Table A19.1). We specifically asked managers to assess the extent to which they were strongly influenced by these five types of regulation.

MBR, meanwhile, sends market signals and firms have flexibility to decide the appropriate level of pollution abatement in response to these signals. Based on previous research (Magat 1979; Downing and White 1986; Milliman and Prince 1989; Walley and Whitehead 1994) and interviews with experts who are familiar with the power industry in China, we focused on three types of marked-based environmental policies: tax credits (tax-exempt financing, one

type of GS), CDM and emissions trading systems (Appendix Table A19.1). We asked managers to assess the extent to which they were strongly influenced by these three types of policies.

The model

We construct the model for environmental regulations on carbon dioxide emissions as follows (Equation 19.6).

Equation 19.6

$$CO_2 = \alpha + \beta_1 CCR + \beta_2 MBR + \beta_3 GS + \beta_4 PC + \beta_5 T + \beta_6 CCR * GS + \beta_7 MBR * GS + \beta_8 SC + \beta_9 AP * SC + \beta_{10} MBR * SC + \beta_{11} CCR * SC + \varepsilon$$

In Equation 19.6, *PC* represents power capacity; *T* is the age of the power plant; *SC* is power plant size; and ε captures other factors that affect efficiency but do not correlate with explanatory variables in the model.

We included age, size and power demand in our regression analyses as control variables. Joskow and Schmalensee (1987) pointed out that the technical profile of generation units, such as age and size, could be potentially significant factors affecting efficiency. Hence, we introduced the age of a power plant into our model and defined it as the calendar year minus the year of initial operation. As for size, we divided enterprises into two groups: power plants with 500 or fewer employees are defined as medium or small enterprises, and those with more than 500 employees are defined as large ones. We coded the size variable as a binary: zero for medium or small enterprises and 1 for large enterprises.

The literature has highlighted that power demand has an impact on carbon dioxide emissions (Declercq et al. 2011; Zhao et al. 2013). We used power capacity to measure this. One notable feature of China's power market is its rapid upgrading due to increasing pressure for energy conservation and emissions reduction, at the same time as increasing power demand. The situation is prominently reflected in the 'build large and shut down the small' policy implemented across China's power industry in the late 1990s. In this context, the focus is on replacing small power units with large ones, which has resulted in capacity change at the plant level in line with increasing power demand. As a result, we chose power capacity as one of our control variables.

Findings

Table 19.6 presents the results of our regression analysis. These suggest that CCR has no significant impact on the dependent variable, carbon dioxide emissions. This may be due to the fact that China's command-and-control environmental regulations on power plants focus primarily on the installation of desulphurisation and denitrification equipment, as well as on the emissions standards for sulphur dioxide, soot and nitrogen oxides. To date, no command-and-control policies for carbon dioxide emissions reduction exist.

Table 19.6 also shows that the coefficients for market-based and government subsidy policies are negative and statistically significant, which tells us that power plants that perceive a strong influence from market-based policies and subsidies have lower carbon dioxide emissions intensity than others.

Table 19.6 Impact of environmental regulations on power plants' carbon dioxide emissions

Variable	Coefficient	Std. error	t-Statistic	Prob.
CCR	0.3623	0.4606	0.7865	0.4335
MBR	–1.0118***	0.3211	–3.1517	0.0022
GS	–1.1396***	0.3241	–3.5163	0.0007
CCR•GS	–0.1529	0.2468	–0.6195	0.5370
MBR•GS	–0.1193	0.1965	–0.6070	0.5453
TIME	0.0433***	0.0105	4.1315	0.0001
PC	0.0162***	0.0021	7.5493	0.0000
SC	2.5187***	0.3867	6.5126	0.0000
CCR•SC	–0.4317	0.5454	–0.7916	0.4306
MBR•SC	0.7416*	0.4019	1.8454	0.0681
GS•SC	1.1480***	0.4032	2.8476	0.0054
C	5.1898***	0.0237	219.1719	0.0000
R-squared	0.2734			
Adjusted R-squared	0.1884			
F-statistic	3.2160			
Prob. (F-statistic)	0.0009			

*** significant at the 1 per cent level
* significant at the 10 per cent level

It is interesting to find that, generally, larger power plants have a higher carbon dioxide emissions intensity than smaller ones. More importantly, the impact of market-based environmental policies and subsidies was somewhat smaller for larger power plants than for small ones. In this study, we measured power plant size by the number of employees. Power plants with more employees, in general, had a longer history. With old facilities, higher carbon dioxide emissions intensity is common, as is the difficulty of lowering emissions in response to market-based environmental policies or subsidies. This is consistent with the time coefficient, which was statistically positive and showed that older power plants have a higher carbon dioxide emissions intensity.

Conclusion: China's electric power industry's green future

China faces a great challenge to improve the quality of its environment while maintaining economic growth at a relatively high level. China's electric power sector is both highly energy and highly emission intensive, especially given the ongoing domination of coal-fired power stations. Greening China's power industry is crucial to realising the national goals for 'green' economic development. From this study, we know that power market reform and environmental regulation play significant roles in the promotion of energy efficiency and emissions mitigation in China's power industry. We found particularly that MBR has an important impact on efficiency improvement and carbon dioxide emissions reduction among China's power plants.

The Chinese Government has realised that expanding market-oriented mechanisms can play an important role in effective distribution of resources, and also in strengthening the role of MBR in the environmental regulations governing the power sector. China has implemented cap and trade for carbon dioxide emissions in seven pilot provinces and cities; however, some improvements should be made to help the system function better. For example, further study is required into how to rationally identify the carbon emission factor, which is crucial for measuring carbon dioxide emissions and deciding the trading amount. Another challenge is to appropriately determine a carbon dioxide emissions quota for power generators. This is critical for controlling the risk of buying carbon dioxide emission rights for some coal-based plants. In sum, MBR in China's power industry is still at a nascent stage, and we need to pay more attention to the use of this type of policy instrument in developing future regulation instead of relying solely on CCR.

Concurrently, China's policymakers need to coordinate different policy instruments. One of the significant characteristics of China's power sector is that most enterprises are government-owned. Moreover, CCR is still an essential

instrument with which to guide power enterprises in green development. It would be interesting and pertinent for scholars and policymakers in China to explore how to better coordinate MBR and CCR to improve future outcomes.

Finally, to promote the green development of China's power industry, improving the share of renewable energy generation is crucial. China's renewable energy generation share in total power generation is currently limited, although this capacity has increased rapidly since 2006. Nonetheless, by 2015, the wind power and solar power generation proportions in total power generation were only 3.3 per cent and 0.70 per cent respectively.[1] Improving the proportion of renewable energy in the power generation mix and reducing dependence on coal should therefore be the choice for China's future power development strategy. To realise such a strategy, again, both MBR and CCR should be coordinated to construct a flexible power system that is suitable for large-scale renewable energy integration, thus promoting continuous greening of China's electric power industry.

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Appendix 19.1

Appendix Table A19.1: Descriptive Statistics of Manager Perceptions of Environmental Regulations

	Items	Mean	SD	Corrected item-total correlat.	α value	Cumulative variance[1]
CCR	Emission standards	4.38	1.687	0.678	0.887	68.990%
	Fines	4.53	1.778	0.752		
	Supervision	4.87	1.726	0.793		
	ESS[2]	5.04	1.750	0.712		
	PTS[3]	5.01	1.646	0.701		
MBR	Tax credits	4.42	1.827	0.500	0.766	82.312%
	CDM	4.34	2.016	0.729		
	Cap &trade	4.04	2.054	0.574		
GS	Subsidy for new technological R&D	3.72	2.135	0.903	0.941	89.543%
	Subsidy for new technical production	3.87	2.050	0.897		
	Preferential loan guarantees	3.84	2.166	0.942		

[1] If the value of the cumulative variance is more than 60%, it is within the scope of what can be considered acceptable (Kaiser 1974).

[2] ESS: environmental assessment system.

[3] PTS: production technology standards.

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