Turning Policy Promises into Blue Skies

Mixed-Method Assessment of China's Past and Future Air Pollution–Reduction Efforts

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Abstract

High coal consumption resulting from rapid economic growth in China has taken a high toll on Chinese residents' health and China's economy. Many citizens suffer from high rates of air pollution-induced respiratory and cardiovascular illness and premature death. Since the late 1970s, China has been mandating and updating its air pollution reduction policies, many of them targeting emissions from coal burning. These environmental regulations are embedded within a regulatory system with many features of China's former system of central planning. In this system, national regulations, negotiated political agreements, and five-year plans form the basis for the implementation and enforcement of environmental policy. But regulations are often weakly enforced due to poor policy design in which polluters face fines cheaper than compliance costs, and misaligned incentives for government agencies to enforce regulations.

In light of continuing high rates of air pollution, the Chinese government will need to greatly strengthen enforcement if China is to reduce air pollution to the point where the health risks and economic costs of air quality are greatly reduced. Better enforcement would result in deeper reductions in pollution from burning coal. Policy analysis could help guide the Chinese government toward more effective policies. That is the motivation for this research.

In this dissertation I have assessed China's past and current efforts towards preventing and controlling air pollution during a period of rapid economic growth. I first summarized the current status of air quality in China and the costs of pollution imposed on the economy and public health. I then reviewed the institutional and policy designs of China's air pollution regulatory strategies, and identified the key drivers of implementation and enforcement. Finally, using the Pearl River Delta region as a case study, I conducted a mathematical simulation using an integrated assessment model to illustrate the potential effectiveness of the government's proposed Action Plan and consequences of noncompliance.

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Abbreviations

AOD	aerosol optical depth
API	Air Pollution Index
APPCL	Air Pollution Prevention and Control Law
AQI	Air Quality Index
CCP	Chinese Communist Party
CCR	command and control regulation
CEMS	continuous emission monitoring system
CO	carbon monoxide
EIA	environmental impact assessment
ENRPC	Environment and Natural Resources Protection Committee
EPB	environmental protection bureau
EPL	environmental Protection Law
EPSC	environmental protection supervision center
ESP	electrostatic precipitator
FF	fabric filter
FGD	flue-gas desulfurization
FYP	five-year plan (formally, Master Plan for Economic and Social Development)
GAINS	Greenhouse Gas Air pollution Interactions and Synergies
GDP	gross domestic product
GW	gigawatt
IAPI	Individual Air Pollution Index
IAQI	Individual Air Quality Index
IEA	International Energy Agency
IMF	International Monetary Fund
KPI	key performance indicator
kt	kiloton

LNB	low–nitrogen oxide combustion
m ³	cubic meter
MBI	market-based instrument
μm	micrometer
MWTP	marginal willingness to pay
NEPA	National Environmental Protection Agency
NDRC	National Development and Reform Commission
NGO	nongovernmental organization
NO ₂	nitrogen dioxide
NO _x	nitrogen oxide
NPC	National People’s Congress
O ₃	ozone
OECD	Organisation for Economic Co-operation and Development[the OECD]
PM	particulate matter
PM _{2.5}	particulate matter smaller than 2.5 micrometers per cubic meter
PM ₁₀	particulate matter smaller than 10 micrometers per cubic meter
PRC	People’s Republic of China
PRD	Pearl River Delta
SCR	selective catalytic reduction
SEPA	State Environmental Protection Agency
SNCR	selective noncatalytic reduction
SO ₂	sulfur dioxide
TEC	total emission control
VOC	volatile organic compound
WHO	World Health Organization
YRD	Yangtze River Delta

1. Motivation and Research Questions

1.1 Objective

High coal consumption resulting from rapid economic growth in China has taken a high toll on Chinese residents' health and China's economy. High reliance on coal has led to poor air quality in most Chinese cities. Many citizens suffer from high rates of air pollution-induced respiratory and cardiovascular illness and premature death. Since the late 1970s, China has been mandating and updating its air pollution-reduction policies, many of them targeting emissions from burning coal. These environmental regulations are embedded within a regulatory system with many features of China's former system of central planning. In this system, national regulations, negotiated political agreements, and five-year plans (FYPs; formally, Master Plans for Economic and Social Development) form the basis for the implementation and enforcement of environmental policy. But regulations are often weakly enforced because of poor policy design in which polluters face fines lower than compliance costs and misaligned incentives for government agencies to enforce regulations.

China's government has moved toward tightening air quality standards and strengthening enforcement of its environmental laws and regulations. For example, China's State Council released the "Ambient Air Pollution Prevention and Control Action Plan" in September 2013. In this document, the State Council identified ten tasks that local governments need to implement and enforce. Subsequently, the central government modified China's Basic Environmental Law and Air Pollution Prevention and Control Law (APPCL) and updated the Ambient Air Quality Standard.

In light of continuing high rates of air pollution, the Chinese government will need to strengthen enforcement if China is to reduce air pollution to the point at which the health risks and economic costs of air quality are greatly reduced. Better policy would result in deeper reductions in pollution from burning coal. Policy analysis could help guide the Chinese government toward more-effective policies. That is the motivation for this research.

In this dissertation, I summarize the theory of how policy can lead to reductions in pollution. Through publicly available data, I examine the variations in air pollution regulation implementation and enforcement in different regions across China. Using an integrated

assessment model, I evaluate the effectiveness and cost associated with the new air pollution action plan targeting one of China's most economically advanced regions, the Pearl River Delta (PRD).

1.2 Air Pollution Is Hurting China's Population Health and Economy

High levels of ambient air pollution have adverse health effects, which have been documented for all six major ambient air pollutants: sulfur dioxide (SO₂), nitrogen dioxide (NO₂), particulate matter (PM) smaller than 10 micrometers (µm) per cubic meter (m³) (PM₁₀) and PM smaller than 2.5 µm/m³ (PM_{2.5}), carbon monoxide (CO), and ozone (O₃). These pollutants are currently being monitored under China's national ambient air quality standard (World Health Organization [WHO], 2013). Exposure to ambient air pollution is the major environmental risk factor for respiratory infections; adverse pregnancy outcomes, such as preterm birth, low birth weight, and infant mortality; neurological disorders; cardiovascular diseases; chronic obstructive pulmonary disease; asthma; and congenital anomalies (Prüss-Ustün et al., 2016).

Among these pollutants, short-term and long-term exposure to PM₁₀ or PM_{2.5} in diameter is the most dangerous to human health. Ambient air pollution was estimated to result in 3.7 million premature deaths worldwide per year in 2012 because of exposure to PM₁₀ µm or less (WHO, 2014a). Ambient air pollution is the risk factor for a broad range of diseases. Causes of death attributed to ambient air pollution include ischemic heart disease, stroke, chronic obstructive pulmonary disease, acute lower respiratory disease, and lung cancer. New studies show that adverse health effects can happen at very low levels of PM_{2.5} concentrations as well, suggesting the need to update WHO air quality guidelines for both PM_{2.5} and PM₁₀ (WHO, 2013).¹

Globally, exposure to ambient air pollution and the associated health risks is unequally distributed across regions and socioeconomic groups. Industrialization, increasing urbanization, and other social and physical environmental factors contribute to disproportionately high health burdens among citizens of developing nations. According to WHO's database of ambient

¹ WHO air quality guidelines for PM₁₀ are 20 g/m³ for annual average, and 50 g/m³ for 24-hour average at the 99th percentile. The 99th percentile means the 24-hour average air quality standard is met 99% of the time. WHO air quality guidelines for PM_{2.5} are 10 g/m³ for annual average and 25 g/m³ for 24-hour average at the 99th percentile.

(outdoor) air pollution in cities, none of the urban areas in developing countries is meeting the recommended PM₁₀ concentration level of 20 µg/m³ (WHO, 2014b). Eighty-eight percent of the 3.7 million premature deaths mentioned above happen disproportionately in low- and middle-income countries.

A large portion of the premature deaths attributable to ambient air pollution takes place in China. High levels of air pollution in China's cities made China's citizens and economy especially vulnerable to the associated health damage. More than half of the lung cancers associated with exposure to ambient air pollution are estimated to take place in China or other East Asian countries (Lim et al., 2012). The main concern is the effects on health from PM and ground-level O₃, especially serious chronic respiratory and neurological conditions associated with long-term exposure to PM_{2.5}. A study by the Chinese government in 2010 showed that pollution contributed to 1.2 million premature deaths and that more than 500 million Chinese will likely have their lives shortened by at least five years because of poor air quality (Global Commission on the Economy and Climate, 2014). Conversely, if pollution is reduced, health outcomes should improve. When a coal-fired power plant was shut down in Chongqing, neurobehavioral development of newborns improved significantly (Perera et al., 2006).

The economic burden of health damage from ambient air pollution is high in China. Two major World Bank studies (Johnson, Liu, and Newfarmer, 1997; World Bank, 2007) have estimated the economic cost of air pollution in China. Both studies estimated health damage associated with exposure to air pollution at a single point in time. A more recent Massachusetts Institute of Technology study using the Emissions Prediction Policy Analysis—Health model (a multiregional, multisector general equilibrium model) estimated the cumulative impact that past exposures have on total health damage at a given point in time. Although the World Bank study estimated that the damage to human health from air pollution in China was around 4 percent to 5 percent of gross domestic product (GDP) per year between 1995 and 2003, the Massachusetts Institute of Technology study finds an impact of 6 percent to 9 percent of GDP per year between 1995 and 2005 (Matus et al., 2012). Considering the fact that China's energy demand and urban population increased significantly after this period, the cost of ambient air pollution as a share of GDP is likely higher than these figures. On the other hand, the cost associated with cleaning up China's air pollution could prove to be significantly less than this damage (Crane and Mao, 2015).

Poor air quality has and will continue to harm citizens' health and productivity if China fails to reduce air pollution to healthy levels. According to the Ministry of Environmental Protection of the People's Republic of China (MEP), only 21.6 percent of China's cities at or above the prefectural level met national ambient air quality standards in 2015 (MEP, 2016a).²

1.3 Causes of High Pollution Levels in China

To reduce citizens' exposure to ambient air pollution and the associated health impacts, China needs to identify the sources of air pollution. Transportation, seasonal agricultural residual burning, and fossil fuel consumption for power generation and winter heating, especially from coal, are largely to blame for the degradation of air quality. Electricity is the primary form of final energy used by the Chinese economy. Seventy-three percent of electricity generated in 2015 came from thermal generation³ (National Bureau of Statistics of China, 2016). Over the past three decades, China's energy consumption has grown more rapidly than that of any other major country in the world. It is likely to continue to grow (Figure 1.1). Coal remains a critical component of the energy supply despite its negative environmental and health impacts. Coal accounted for 69 percent of China's total energy consumption in 2011 (U.S. Energy Information Administration, undated). In 2013, the electricity sector accounted for 50 percent of total coal consumption (National Bureau of Statistics of China, 2015a). Total power generation capacity has increased by more than a factor of three in the past decade, dominated by coal-fired power plants. Coal burning is a leading source of smog, acid rain, and toxic air pollution, such as SO₂, nitrogen oxides (NO_x), and PM. With the country's rapid economic development, China has become one of the largest emitters of SO₂ since the 1990s, contributing to around one-fourth of global emissions (Lu et al., 2010). In China's three key regions—the Jing-Jin-Ji region, Yangtze

² The attainment of national quality standard here means meeting the standard for all six monitored air pollutants specified by the Ambient Air Quality Standard (Standard ID: GB3095-2012): SO₂, NO₂, PM₁₀, PM_{2.5}, O₃, and CO.

³ The majority of China's thermal power plants are coal-fired power plants. Ninety-three percent of electricity generated from thermal units came from coal-fired power plants in 2014 (China Electricity Council, 2015).

River Delta (YRD), and PRD,⁴ burning coal is responsible for between 50 and 70 percent of PM2.5 pollution (Global Commission on the Economy and Climate, 2014).⁵

Figure 1.1: Total Energy Consumption and Total Coal Consumption, in Thousands of Tons of Standard Coal Equivalent

SOURCE: National Bureau of Statistics of China, 2015b, Table 9-2.

China is likely to continue to urbanize rapidly, which could further increase the number of people living in areas with poor ambient air quality. In the past two decades, 300 million rural residents became urban residents. According to the Chinese National New-Type Urbanization Plan (2014–2020), China aims to increase the urbanization rate from 53.7 percent in 2014 to 60 percent by 2020, while residents with urban status (*hukou*) should account for about 45 percent of the total population, according to the plan (Central Committee of the Communist Party of China and State Council, 2014).

Continued urbanization could increase the demand for more energy-intensive goods, such as air conditioners and personal motor vehicles. Although moving to cities could result in more-efficient use of resources and higher incomes, Zheng et al., 2011, found that the income effect dominates in China. The vast migration has resulted in the very substantial increases in energy

⁴ The Jing-Jin-Ji region includes Beijing, Tianjin, and Hebei Province; the YRD region includes Shanghai, Jiangsu province, and Zhejiang province; and the Pearl River Delta includes nine cities in Guangdong province (Guangzhou, Shenzhen, Zhuhai, Foshan, Jiangmen, Zhaoqing, Huizhou, Dongguan, and Zhongshan).

⁵ Note that these percentages include both primary and secondary PM2.5 emissions. PM2.5 can be directly emitted from sources, but can also be formed from different precursor pollutants such as SO₂ and NO_x.

consumption related to changes in lifestyle. Almost 18 million new cars were added to the road in 2015: car ownership increased fivefold in a decade, reaching 172 million in China by the end of 2015 (National Bureau of Statistics of China, 2016). Despite a slowdown in population growth, the number of households in China is increasing because of falling household sizes. Such reductions mean higher resource consumption per person. China's rapid increase in household numbers and reductions in household size have had significant environmental consequences. For instance, while China's household size has been declining, its per capita house floor area has increased more than threefold from the late 1970s to the present (J. Liu and Diamond, 2005). These trends are common among developing nations, but the large population base and the size of China's economy make government's effort to reduce levels of air pollution harder.

China is not alone in facing environmental degradation during industrialization and urbanization. Industrial nations, such as the United States, Japan, and many countries in Europe, have dealt with similar problems. In the case of the United States, researchers estimated that coal-fired power plants led to \$53 billion of environmental damage each year, 0.3 percent of 2011 U.S. GDP (Muller, Mendelsohn, and Nordhaus, 2011).⁶ Past experiences from developed nations suggest that local environmental problems could improve by replacing dirty coal with cleaner fuels and by installing pollution-control equipment. Clay and Troesken, 2011, concluded that the transition from coal to cleaner fuels, such as natural gas, for cooking and heating has reduced urban PM levels in U.S. and European cities.

The Chinese government has been trying to use pollution controls to reduce ambient air pollutants from the power and industrial sectors for decades. It has mainly targeted SO₂ and soot. By installing and operating pollution-control equipment, SO₂ emissions have fallen (Figure 1.2). However, during the past decade, air pollution in cities has worsened as measured by levels of PM_{2.5} and NO_x. A systematic review of source apportionment studies at the city level provides evidence of the shares of pollution sources in southern and northern China (Karagulian et al., 2015). Figure 1.3 below summarizes the shares attributed to sources of urban ambient PM_{2.5} and PM₁₀ in China. The "Unspecified Source of Human Origin" category is mainly secondary

⁶ The U.S. study used a value of a statistical life of \$6 million, while the World Bank study used a value of a statistical life of \$125,000 (¥1 million at 1:8 exchange rate in 2007). The U.S. study looked largely at PM_{2.5} and O₃. The World Bank study estimated human health impacts, including premature mortality, respiratory and cardiovascular hospital admissions, and incidence of chronic bronchitis, from exposure to PM₁₀ in 2003.

particles formed from unspecified pollution sources of human origin. Secondary particles are formed in the atmosphere through reactions of primary gaseous pollutants (NO_2 , ammonia, SO_2 , and nonmethane volatile organic compounds [VOCs]) (Karagulian et al., 2015). The significant share of secondary particles in urban ambient $\text{PM}_{2.5}$ and PM_{10} make China's task of reducing PM more difficult because it requires targeting multiple precursor pollutants and sectors simultaneously. Thus, compared with Japan and the United States during similar development periods, China's task of cleaning up its air is more complicated.

Figure 1.2: SO_2 Emissions, in Tens of Thousands Tons; and Total Coal Consumption, in Tens of Thousands Tons of Standard Coal Equivalent

SOURCES: National Bureau of Statistics of China and MEP, 2016. Table 4-1; National Bureau of Statistics of China, 2015b, Table 9-2.

Figure 1.3: PM2.5 and PM10 sources in Southern and Northern China

SOURCE: Karagulian et al. 2015

1.4 Political Pressures to More Vigorously Address Air Pollution

Although China has long suffered from poor air quality, the Chinese government did not feel pressure to take drastic actions until preparations for the 2008 Summer Olympics. The international community expressed great concern over air quality during the summer games. Prior to the 2008 Olympics, high-pollution days were often referred to as “bad weather.” Since the Olympics, Chinese residents have much better knowledge about air pollution and its associated health burdens, especially PM2.5. During this same period, the U.S. embassy in Beijing started to monitor and publish PM2.5 data. With improved access to smartphones, Chinese citizens were able to access these data and demanded a government response. Although the Chinese government initially resisted the publication of real-time air quality data, under pressure from the U.S. embassy’s data-sharing initiative, the Chinese government eventually required cities to begin monitoring and reporting PM2.5 concentrations.

1.5 China Is Reforming Its Environmental Regulations

Fearing social unrest due to poor air quality, the Chinese government has laid out ambitious plans to reduce the country’s air pollution levels, especially PM2.5. At the national

level, the State Council announced an air pollution–reduction and –prevention action plan outside the FYP cycle. The action plan set up pollution-reduction targets for various key regions in China. In May 2014, China updated the Environmental Protection Law (EPL) for the first time in 25 years. This amendment gave nongovernmental groups the right to take part in investigating cases of pollution. MEP has strengthened enforcement, including the introduction of daily fines that accumulate, rather than one-time punishments. Fifteen thousand enterprises are now required to publish their real-time emission data for both air and water pollutants.

Ever since the announcement of the State Council’s 2013 Air Pollution Reduction and Prevention Action Plan (The State Council, 2013), many local-level action plans have been proposed. According to the 2013 action plan, concentrations of PM_{2.5} in the Jing-Jin-Ji, YRD, and PRD regions are to be reduced by 25 percent, 20 percent, and 15 percent by 2017 from 2012 levels, respectively (MEP, National Development and Reform Commission [NDRC], and Ministry of Finance of China, 2013). Coal-fired power plants, coal-fired boilers, and industrial furnaces in the three key regions were to install desulfurization, denitrification, and dust-removal equipment by the end of 2015. Regions need to control several air pollutants simultaneously and comply with a cap on their total consumption of coal. The three regions have published air pollution–prevention and –control action plans and inventories of facilities within the four key sectors (power, steel, cement, and plate glass) that require installation of additional pollution-control equipment.

Twelve Chinese provinces (accounting for 44 percent of the country’s coal consumption) have promised to cut coal use in one way or another (Greenpeace, 2014). However, the success of the proposed reductions in emissions depends on the enforcement of reductions in coal consumption and on pollution-control measures. China’s National Bureau of Statistics reported that coal consumption of China dropped by 3.7 percent in 2015 from the previous year (National Bureau of Statistics of China, 2016). This was the second consecutive year of reduced coal consumption; the declines parallel China’s slowing economic growth. The construction of new thermal power plants, on the other hand, continues, seemingly ignoring the downward trend in demand growth for electricity. Even though the vast majority of Chinese cities fail to meet national ambient air quality standards, Chinese businesses continue to construct new coal-fired plants and factories without legal consequences, adding to the problem. In 2015, 51.8 gigawatts

(GW) of coal-fired power generation capacity were added making total coal-fired power generation capacity 880 GW (China Electricity Council, 2016a).

The increase in coal-fired power plants in China could lead to higher emissions of pollutants. First, capacity utilization at China's coal-fired power plants has been declining (Figure 1.4). Lower capacity utilization factors lead to higher emissions. Second, because all power plants operate in competitive electric power markets, generating companies are trying to cut costs as much as possible. Pollution-control equipment has sometimes been the first target for cost control.

Figure 1.4: Thermal Electricity Generation Capacity and Electricity Generation

SOURCES: China Electricity Council, 2015; China Electricity Council, 2016a. Redline indicates average utilization hours of equipment.

1.6 China Faces Problems in Enforcing Air Pollution Regulations

Given its past experiences, the Chinese government is likely to face several obstacles to achieving its goals for reducing air pollution. China's environmental protection and pollution-

control efforts began in the late 1970s, earlier than many industrialized nations at a similar stage of development. Yet, reports on severe levels of air pollution in the major cities indicate continued unsatisfactory levels of implementation and compliance with regulations. The implementation and enforcement of law and regulations have been inconsistent in China mainly because of strong incentives to pursue reported increases in economic output at the expense of increased pollution. Even after the central government increased its efforts to reduce air pollution, anecdotes about delayed implementation and noncompliance appear regularly in the news. In November 2015, residents at Shenyang experienced record-breaking air pollution, with PM_{2.5} concentration exceeded 1,400 $\mu\text{g}/\text{m}^3$ at one point (Phillips, 2015).

China's decentralized system of government constrains implementation of clean air policies because environmental regulation and enforcements are fragmented. Responsibilities are shared among the MEP, natural resource management agencies, and the NDRC. There are also regional disparities in terms of pollution-control inputs and outcomes. Part of the regional differences in compliance can be attributed to variations in local and regional policies and differences in implementation. Past studies (Organisation for Economic Co-operation and Development [OECD] Working Party on Environmental Performance, 2006; W. Li, undated; Chang and Wang, 2010; Zusman, 2007) have indicated that the mode of operation of local Environmental Protection Bureaus (EPBs) and their relationships with local and provincial governments create a gap in implementation of environmental policies in China. The ability of EPBs to enforce environmental policies is constrained by conflicts between environmental protection and local economic development goals. EPBs are often caught in the middle of conflicting policy objectives: implementing ministry-level policies, obeying local governments, and responding to citizens' requests. Understanding regional disparities in enforcing environmental regulations and their effects on pollution control would be valuable in helping the Chinese government improve future decision making concerning air pollution.

There is also a poor understanding of the expected effectiveness of proposed policies. In China, successful implementation of regional air pollution controls have appeared to have been most successful during short-term mega events, such as Beijing's 2008 Olympics, Shanghai's 2010 World Expo, and the 2010 Guangzhou Asian Games. In Europe and North America, policies are frequently evaluated on their expected economic benefits and costs. Such a practice is largely missing in China, causing local governments to either hesitate or be overly confident

about compliance with allocated emission-reduction targets. One modeling attempt by the Tsinghua University of China (Global Commission on the Economy and Climate, 2014) indicated that, under current policy, only a small number of cities in China will be able to reduce their average annual PM_{2.5} concentrations below 35 µg/m³ (i.e., the national grade II standard). Most cities in PRD will be able to reduce emissions and concentrations, but major cities within the Jing-Jin-Ji and YRD regions are unlikely to be able to comply with the prescribed concentration level. The study also concludes that, although deploying the best available pollution-control technology will further improve air quality, certain areas (Jing-Jin-Ji and Wuhan) will have to change their energy supply mix as well, if they are to comply with national standards. Although this scenario analysis provides useful insights about the prospects of the national strategy, it does not consider the cost of implementing these strategies, failing to assess to what extent proposed strategies are feasible to fully implement at the local level.

1.7 Research Questions

With the above background in mind, this dissertation aims to conduct a comprehensive analysis of China's efforts in addressing its air pollution challenges to answer the following questions:

- What has China done in the past to reduce air pollution?
- How effective have China's past efforts to reduce air pollution been?
- What are the prospects for the current and proposed strategies in the key regions?

Chapter 2 summarizes the theory of environmental regulations pertaining to air pollution. It provides a snapshot of current thinking on addressing the problem of "externalities." Chapter 3 describes the air pollution challenges China has had and is still experiencing. It characterizes the spatial temporal variation of the air pollution problem by using official and satellite-derived data. Chapter 4 analyzes China's environmental management institutional structure that spans from laws, standards, and China's unique FYPs with special focus on air pollution-related components. Chapter 5 analyzes various policy instruments China has introduced and implemented to achieve the goal of improve the nation's air quality. It emphasizes policy design and implementation challenges that China has faced. Chapter 6 utilizes a scenario analysis to evaluate the extent and cost of proposed strategies to reduce air pollution in China's PRD region.

Chapter 7 provides a conclusion and identifies several issues that could affect the outcome of China's war on pollution.

China is continuing to reform its environmental pollution prevention and control efforts. The policy environment surrounding air pollution control is dynamic; many new regulations and plans have been proposed since 2013. While the account of China's proposed strategies may not be exhaustive in this dissertation, understanding the importance of rigorous implementation and enforcement and that policy changes needed to make this happen would enable Chinese decision makers to set priorities in their strategies, strengthen environmental governance, and lead to real improvement in China's air quality.

2. Theories of Environmental Regulation

China's problems with air pollution are representative of those in many developing nations, especially those that have undergone rapid growth in industrial development. One would think that pollution and the corresponding health costs would spur governments to adopt and implement policies to reduce environmental degradation. However, environmental quality in many developing countries has remained poor.

Below, I summarize current thinking on environmental regulation, mainly based on the theory of externalities. I also identify several economic and policy explanations for why environmental quality in China and other developing countries remains poor.

2.1 The Challenge: Reducing Negative Externalities

Air pollution is a form of negative externality that results from households' or firms' actions that impose costs on others. If polluters do not bear the full cost of air pollution, their products will cost less than they otherwise would, resulting in higher levels of output and consumption of the product than would be the case if all costs of production were incorporated into the market prices. This results in the inefficient allocation of resources; society would be better off if the product price reflected the full cost of producing and consuming it.

Economic theory suggests that the optimal pollution level requires polluters to internalize a cost that equalizes their marginal cost of pollution to the marginal social damage (Cropper and Oates, 1992). Coase argued that polluters and those who suffer from pollution should be able to negotiate a solution or payment that is Pareto efficient if trade in an externality is possible and there are sufficiently low transaction costs regardless of the initial allocation of property (Coase 1960). However, the high transaction costs of reaching a negotiated solution across a large number of polluters and victims generally prevents a Coasian bargaining solution. Thus, societies generally choose to use laws and regulations to induce polluters to control their pollution rather than discharging it without treatment. Laws and regulations usually induce firms and individuals to adopt pollution-control efforts through the use of economic incentives, such as taxes and fees.

In some instances, market-based instruments are employed, such as tradable permits (Stavins, 2003).

The selection and design of policy instruments can be more complicated in developing countries than in more-developed countries, in part because bureaucracies in developed countries are better able to enforce pollution control measures. Problems with monitoring and enforcement in developing countries may require more-careful assessment beyond the choice of instruments (Stern and Coria, 2013; Bell and Russell, 2002). Even the U.S. Clean Air Act, often regarded as a successful example, has taken cautious steps to write regulations and build rigorous checks and balances into the regulatory program to increase the rate of compliance (Bell and Russell, 2002). On the other hand, scholars have pointed out that the economic and welfare costs of environmental degradation can be worse, and the need for cost-efficient regulation is more urgent among developing than developed nations (Stern and Coria, 2013; Greenstone and Jack, 2015).

Comparing environmental quality between developed and developing countries, often reveals stark differences. WHO's latest assessment of ambient air quality across the globe shows that adherence to air quality standards in urban areas is much higher in high-income countries than in low- or middle-income countries (WHO, 2016). Globally, average annual levels of PM_{2.5} in assessed urban areas worsened by 8 percent between 2010 and 2015; this trend is largely caused by worsened air quality in urban areas in low- and middle-income countries (WHO, 2016). With relatively poor air quality, developing countries also face large health burdens. Air pollution is the world's fourth-greatest cause of illness, causing 6.5 million premature deaths every year (International Energy Agency [IEA], 2016).

Do these patterns of consistently poor environmental quality imply that pollution is at socially optimal levels in developing countries? When analyzing why levels of pollution in urban areas in many developing countries are substantially higher than in urban areas in developed countries, a simple correlation between per capita GDP and pollution omits other important factors, such as governance, economic structure, and geographical conditions (Dasgupta et al., 2006). On the other hand, existing studies of marginal willingness to pay (MWTP) among developing countries tend to show significantly lower MWTP for an improved environment than studies of industrialized countries show (Greenstone and Jack, 2015). MWTP

measures the extent to which one is willing to sacrifice income for a marginal increase in environmental quality. If MWTP for better environmental quality is low, the current level of pollution could already have reached its optimum if a social planner values growth more than environmental regulation.

However, scholars have argued that existing studies of MWTP in developing countries may not provide a full explanation of why environmental quality is poor among many developing nations. Greenstone and Jack (2015), provides four possible explanations, reviewing empirical evidence that explains why environmental quality might be low in developing countries and why there is still space for policy intervention: (1) MWTP for environmental quality is low because marginal utility from immediate consumption is higher than the marginal benefits from increased environmental quality, (2) the marginal cost of pollution abatement is high, (3) rent-seeking behavior from the social planner reduces the optimal level of environmental quality, and (4) MWTP may fail to reflect the true willingness to pay because of market failure or cognitive biases. Further, they suggest that, while the demand for environmental quality as a public good may not be significantly different between developed and developing nations, developing nations may be more prone to multiple market failures that lead to failed achievement of the optimal level of regulatory correction (Greenstone and Jack, 2015).

The above framework for understanding poor environmental quality among many developing nations suggests the importance of governance. The theory of environmental regulation described at the beginning of this section assumes that government will design and implement environmental protection policies with the objective of maximizing social welfare. However, the reality often does not reflect such an assumption. The institutions in developing countries may be weak and lack the resources to enforce environmental regulations, which hinders enforcement and monitoring efforts. Two aspects of governance are particularly important in the context of developing countries: the choice of policy instrument and policy implementation.

2.2 Policy Instrument Choices

As countries like Japan and the United States began to take a more aggressive approach to adopting regulations intended to improve air quality in the late 1960s, scholars debated which regulatory instruments were best suited to reduce pollution. The approaches under consideration

fall under two broad categories: command and control regulations (CCRs) and market-based instruments (MBIs). MBIs are policies derived from the theory of externalities, in which governments design and implement pollution control policies with an objective of maximizing social welfare. MBIs correct the market failure by taxing pollution activities to equalize marginal social damage or by setting up a tradable permit system that limits aggregated pollution to the socially optimal level at least cost.

2.2.1 Command and Control Regulations

CCRs set up explicit requirements about pollution-reduction levels or methods. CCRs have been used much more widely than MBIs, tending to dominate most countries' regulatory regimes. Environmental agencies have favored CCRs because they tend to be easier to set and implement. Under CCRs, air pollution is managed by two types of regulations: performance-based standards and technology standards.

Performance-based standards set a uniform emission-control target for polluters regardless of variances in abatement costs. Performance-based standards can be further classified into ambient emission standards and source-based discharge standards. Ambient emission standards define the allowable level of a pollutant in a given region over a specified period of time. Source-based discharge standards set the allowable levels of pollutants that classes of sources can emit over a given time or across a given space.

CCRs can involve the selection of abatement technologies that polluters must purchase, install, and operate or process changes that polluters must employ to comply with emission standards. The selection and cost of these technologies and process changes depends on whether the source is new or old, located in a region that meets or exceeds ambient standards, and various other factors.

Making all polluters meet the same target can be expensive. Regulations can force industries to use a specific technology to comply with standards. A pollution-control technology may not work across all situations. Environmental protection agencies use penalties and sanctions to ensure that industries comply with standards.

While CCRs tend to be less cost-effective than MBIs, they face fewer administrative difficulties, especially when dealing with non-point pollution sources (Goulder and Parry, 2008). On the other hand, CCRs fail to provide incentives for polluters to adopt more-advanced technologies for further reductions in pollution. Firms that adopt better control technologies may be “punished” by being held to more-stringent emission standards (Stavins, 2003).

Many policies currently in place in China employ CCRs. For example, to increase the adoption of desulfurization equipment, Chinese government has introduced technological standards that limit the emissions of SO₂ during the operation of power plants and other industrial facilities. The regulation also identifies specific desulfurization technologies that certain firms must install. The implementation and enforcement of these standards are largely driven by national FYP targets (Schreifels, Fu, and Wilson, 2012).

2.2.2 Market-based Instruments (MBIs)

MBIs are policies implemented to reduce compliance costs polluters face when complying with emission standards (Stewart, 1981; Tietenberg, 1990). In the 1980s and 1990s, in both the United States and the European Union, the rise of benefit-cost analysis requirements forced decision makers to conduct economic analysis of environmental regulations. As more-stringent environmental regulations sometimes made pollution abatement more expensive, both economists and regulators became more receptive to MBIs (Oates and Portney, 2003). MBIs employ financial incentives to achieve similar or the same levels of abatement but more cost-effectively. They rely on the fact that different sources have different marginal abatement costs, which a traditional CCR approach tends to ignore. Under CCRs, it is difficult for regulators to acquire full information of cost differences among pollution sources (Cropper and Oates, 1992).⁷ By leaving the information problem to the market, MBIs can achieve significant cost savings by allowing firms to differentiate their abatement efforts based on costs.

⁷ If policymakers can acquire information about firms' compliance costs and set up different standards for each polluter, CCRs in theory could achieve cost-effective outcomes that are similar to those of MBIs (Stavins, 2003).

Two different types of instruments are commonly used:⁸ through a price mechanism, i.e., pollution charges, or through a quantity mechanism, i.e., tradable emission permits. The choice between the price and quantity mechanism has been subject to debates and assessments (Weitzman, 1974; Pizer, 2006). The price mechanism provides fixed financial incentives to reduce emissions but does not guarantee that emission levels will be capped within the desired level. The quantity mechanism, on the other hand, sets a fixed level of pollution emissions.

As a form of price mechanism, pollution taxes or fees are set to provide a “price” for polluters to internalize marginal social costs associated with their activities and collectively achieve the socially desired level of pollution. Pollution charges aim to induce firms that can reduce pollution at a cost less than the tax to do so. Firms with marginal abatement costs above the tax pay for the right to pollute. The tax rate ideally should be set equal to the marginal social benefit (for example, health benefits) from pollution reduction. Pollution charges should be set up in the form of unit charge or fees on pollution emissions directly rather than on firm’s output or input (Cropper and Oates, 1992).

An alternative instrument to a unit tax on pollution is a unit subsidy on emission-reduction efforts. The tax is a “stick” while the subsidy is a “carrot.” Subsidies to reduce pollution provide the same economic incentive if set equal to the tax level. However, subsidies provide additional profits to polluters, while taxes reduce profitability. In the long run, subsidies will encourage firms to enter the market and can lead to higher production of the polluting good, while taxes will lead to the opposite outcome.

Tradable pollution permits, on the other hand, allow firms to purchase pollution rights within a predetermined emission cap. Under tradable permit programs, government normally sets the total allowable level of pollution and emission permits, which are allocated to firms. The allocation can be free or through an auction. Firms are free to buy or sell permits in order to achieve the lowest compliance costs. Rather than a fixed price (i.e., the tax rate), the cost of pollution permits is determined by market demand and the supply of permits. This feature makes tradable permits more flexible when facing new information about the urgency of pollution reduction (Goulder and Parry, 2008).

⁸ There are two other categories of MBIs: market friction reductions and government subsidy reductions (Stavins, 2003). Market friction-reduction instruments, such as energy-efficiency labeling programs, reduce frictions in market activities. Government subsidy reduction, such as fossil-fuel subsidy-reduction programs, remove subsidies that support practices that damage the environment.

The Chinese government has attempted to utilize pollution levies to control pollution since the very early stage of its attempts to reduce pollution through policy measures. For example, each kilogram of SO₂ emissions faces a pollution discharge levy. However, as will be shown in Chapter 5, the initial design of the policy had many defects. In general, these instruments did not provide large enough incentives for polluters to invest in cleaner production equipment or processes. To encourage coal-fired power plants to install pollution-control equipment, the Chinese government also provided subsidies in the form of a premium on electricity prices to those facilities that installed desulfurization equipment. However, as noted above, subsidies are often less cost-effective than emission taxes and tradable permits as they provide incentives to increase the output of polluting industries (Goulder and Parry, 2008).

The choice of instruments varies across countries. Tradable permits require the country to have a sophisticated regulatory and enforcement capacity, which has hindered the adoption of such instruments among developing countries. Even among OECD countries, the most-popular MBIs are pollution charges which have served to reduce pollution (Di Falco, 2012). The successes of pollution charges were limited among transition economies in central and Eastern Europe but did serve as a source of revenue for environmental protection (Stavins, 2003).

When assessed against a list of policy criteria, no single instrument is superior to another, and the use of a mix of different instruments may be justified when facing multiple market failures (Goulder and Parry, 2008). Despite their obvious differences, the application and success of CCRs and MBIs in terms of pollution reduction are influenced by institutions and rely on strengthening monitoring and inspection activities by government agencies to ensure that various activities indeed abate pollution and that local governments adhere to regulatory obligations. Regardless of how well a policy is designed, its actual effectiveness relies largely on the level of implementation and enforcement. This leads to our next discussion on understanding what factors influence the level of enforcement and why an implementation gap may exist within developing countries that hinders successful environmental regulation.

2.3 Economic Model for Enforcement

Once the policymaker has selected a policy instrument, the next big task is to consider how to design the program to ensure enforcement and compliance. Noncompliance with regulations (not specifically those targeting environmental pollution but breaking the law in general) is influenced by cost–benefit calculations that involve the probability of conviction and the level of punishment for noncompliance (Becker, 1974). From a polluter’s point of view, the decision on pollution abatement is related to the polluter’s evaluation of compliance costs versus savings from noncompliance. To conduct such a calculation, the polluter must consider (1) the probability of a violation at certain abatement levels, (2) the probability of being caught by the regulator if a violation occurs, (3) the probability of being punished if caught because of noncompliance, and (4) the severity of punishment the polluter may incur (Gray and Shimshack, 2011). The OECD (Parker, 2000) has identified three necessary conditions for successful compliance with environmental regulations: (1) the extent to which the targeted group understands the rules, (2) the extent to which the targeted group is willing to comply, and (3) the extent to which the targeted group is able to comply with the rules. A list of causes of noncompliance is shown in Table 2.1.

Table 2-1: Factors of Noncompliance versus Necessary Conditions for Compliance

Necessary Condition for Successful Compliance	Factor That Leads to Noncompliance
Rule comprehension	<ul style="list-style-type: none"> • Rule requirements are too complex.
Willingness to comply	<ul style="list-style-type: none"> • Compliance is too costly. • Overly legalistic regulation ^a • Regulation is at odds with market incentives or cultural practices. • Prior consultation with target group failed or never happened. • Failure to monitor compliance • Procedural injustice • Deterrence failure
Capable of complying	<ul style="list-style-type: none"> • Failures of administrative capacity • Poor choice of instrument • Desired outcome cannot be achieved through the means required.

Source: Parker, 2000

Note:

^a. *Overly legalistic regulation* refers to the situation in which regulators take an overly rule-based approach to compliance. When facing regulators who are overly legalistic in applying rules and punishments, firms may be discouraged from complying (OECD, 2002).

With this framework in mind, implementation and enforcement efforts should focus on (1) increasing the probability of being caught and punished for noncompliance through increased monitoring and enforcement actions, (2) reducing the probability of violation by reducing the cost of compliance through better information and incentives, and (3) making the punishment severe enough so the cost of abatement efforts is lower than the cost of noncompliance. Regulators should also pay attention to the design of the rules and standards to make sure they are clear and specific. It may be necessary to offer compliance assistance to make sure that firms understand the regulator's intention. Empirical evidence shows that rigorous monitoring and enforcements are still the key motivator for polluters to comply with environmental regulations in industrialized nations (Khanna and Anton, 2002; Khanna and Kumar, 2011; Doonan, Lanoie, and Laplante, 2005; Gray and Shadbegian, 2005).

2.4 Why There Might Be Implementation Gaps in Developing Countries

The theory of externalities and the economic model of enforcement provide good frameworks for identifying socially optimal environmental goals, price incentives, and characteristics of good policy design to reduce pollution. However, the determination of standards and policies is never a purely economic endeavor. Rather, determining standards and policies also involves a political process that differs from country to country. While rigorous examination of whether monitoring and enforcement lead to improved environmental outcomes is limited in developing countries (Gray and Shimshack, 2011), implementation and enforcement are likely to be weak in the first place. One would expect that, as latecomers to environmental regulation, developing countries could learn from industrialized countries and avoid the usual develop-first, clean-up-later pathway.

From a policy design perspective, many developing countries have set up regulations that follow proven theory. For example, because of their focus on cost-effectiveness, MBIs tend to be considered more efficient and innovative than traditional command and control approaches. They also, in theory, seem to be better suited to reconciling the goals of economic growth and environmental protection, i.e., reducing pollution at minimum economic cost. Thus, it is not surprising that many developing countries, including China, have adopted market-based policy instruments at an earlier stage of development than industrialized nations. On the other hand, environmental regulatory agencies often find themselves at odds with governments' priorities for

economic growth and suffer from regulatory capacity constraints. Such constraints, which include limited budgets and personnel, lead to poor implementation and enforcement. Thus, these agencies may fail to realize the full potential of the adopted policy instruments. It is therefore not surprising to see the implementation gap resulting from “regulatory leapfrogging” (Rock, 2010) becoming the norm among many developing nations’ environmental management regimes (Marquis, Zhang, and Zhou, 2011).

Blackman and Harrington (2000) provide a detailed review of why environmental regulation may be constrained in developing countries using examples from industrial air pollution control. Four constraints were identified based on their literature review (Blackman and Harrington, 2000):

- 1) The demand for higher environmental quality is inhibited by government preferences for higher rates of reported growth. Environmental advocacy in these countries is less prevalent and less organized, providing less pressure for enforcement.
- 2) Regulatory institutions (including environmental, judicial, legislative and statistical) are weaker.
- 3) Environmental protection agencies face shortages of budgetary and technical resources.
- 4) Regulated sectors are dominated by fragmented and hard-to-monitor firms.

Environmental regulation in China is prone to all of the constraints mentioned above (Yee, Tang, and Lo, 2016; H. Wang et al., 2003; Marquis, Zhang, and Zhou, 2011). The question to be answered then is the extent to which China can address these challenges by (1) understanding the scale of China’s current air pollution challenge; (2) reviewing China’s environmental governance system and evaluate existing programs against proven theories; and (3) understanding the extent to which the newly heightened environmental regulation improved implementation and, if not improved, the consequences.

3. China's Air Pollution Problem

Before I introduce China's environmental regulatory system with a focus on air pollution control, I summarize current and historical air pollution conditions in China. I first discuss China's current air quality as well as spatial temporal characteristics. I then present historical emissions of SO₂ and NO_x using official statistics. Finally, I use satellite derived data to indicate the change in PM_{2.5} concentration across China during the past decade.

3.1 Current Conditions

Many Chinese cities suffer from poor air quality. Haze and smog events with high PM_{2.5} levels in highly developed and densely populated urban areas have occurred more frequently over the past few years because of rapid economic growth, industrial development, and urbanization over the past few decades. Most cities fail China's own air quality standards. Only nine out of the 113 National Key Environmental Protection cities⁹ meet class II of the National Ambient Air Quality Standard for PM_{2.5},¹⁰ as shown in Figure 3.1 (National Bureau of Statistics of China and MEP, 2015). None of the cities meets the standards recommended by WHO. For all six ambient air pollutants included in the National Ambient Air Quality Standard, only 21.6 percent of China's 338 cities at or above prefectural level met national standards in 2015 (MEP, 2016a).¹¹ Noncompliance is mostly due to noncompliance with PM standards, especially PM_{2.5} standards.

⁹ National Key Environmental Protection cities were initially identified by the Environmental Protection Committee under the State Council in the 1980s (China Environment Yearbook Editing Committee, 1990). Initially, 52 cities, including directly administered cities, provincial capitals, and coastal cities, were identified. Environmental protection efforts were prioritized among these cities; their urban environmental quality is assessed directly by central government. Currently, there are 113 national key environmental protection cities.

¹⁰ The National Ambient Air Quality Standard currently monitors six air pollutants: SO₂, NO₂, PM₁₀, PM_{2.5}, O₃, and CO. Each pollutant faces two classes of limits. Class I applies to special regions, such as national parks. Class II applies to all other areas, such as urban and industrial zones.

¹¹ The attainment of national quality standard here means meeting the standard for all six monitored air pollutants specified by the Ambient Air Quality Standard (GB3095-2012).

Figure 3.1: Average Annual PM2.5 Level of Key Cities in 2014

Source: National Bureau of Statistics of China and MEP, 2015

There are significant spatial and temporal variations in air pollution across China. Yungang Wang et al. reported that the north region suffers from higher concentrations of PM2.5, PM10, CO, and SO₂ than the west and southeast regions (Yungang Wang et al., 2014). The study also found that high-pollution events happen during the autumn in the southeast region and during the spring in the west region. PM2.5 concentrations also show seasonal variability. Concentrations tend to be the highest during the winter because of the combustion of fossil fuels and biomass for winter heating, unfavorable meteorological conditions for pollution dispersion, and secondary sources (Y.-L. Zhang and Cao, 2015). In eastern, northeastern, and southern China, high-pollution days can also be observed during the autumn because of the burning of agricultural harvest residues.

3.2 Historical Situation

China's cities host most of the country's industrial activities. They have made limited progress in mitigating air pollution over the years. China has a long record of battling air pollution, initially focusing on SO₂ and acid rain and now on PM2.5 pollution. China has focused on cutting pollution from power and industrial sources. As illustrated in Figure 3.2, while SO₂ and NO_x emissions have been reduced during the past few years, SO₂ emission levels in 2014 were still on a par with those of 2000, and NO_x emissions were higher than their levels in 2006.

The total volume of industrial emissions¹² was still rising in 2014 and were more than five times their levels in 2000 (Figure 3.3).

Figure 3.2: SO₂ and NO_x emissions over the years, in Tens of Thousands of Tons

SOURCES: China Environment Yearbook Editing Committee, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015

¹² Include SO₂, NO_x, soot, dust, and mercury.

Figure 3.3: Industrial-Waste Gas Emissions, in Hundreds of Millions of Cubic Meters

SOURCES: China Environment Yearbook Editing Committee, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015

Satellite data for PM_{2.5} concentrations show a similar trend. While China did not require official publication of PM_{2.5} monitoring data until 2012, PM_{2.5} data estimated using a combination of Moderate Resolution Imaging Spectroradiometer, Multi-angle Imaging SpectroRadiometer, and Sea-Viewing Wide Field-of-View Sensor aerosol optical depth (AOD) satellite observations provide a unique set of data to analyze trends in PM_{2.5} concentrations (van Donkelaar et al., 2015b; van Donkelaar et al., 2015a). This data set is also immune to potential manipulation from Chinese officials (Ghanem and Zhang, 2013).

The satellite dataset for generating the prefecture level PM 2.5 map and dataset is the Global Annual PM_{2.5} Grids from MODIS, MISR and SeaWiFS Aerosol Optical Depth (AOD), v1 (1998–2012). These data were provided by the National Aeronautics and Space Administration's Socioeconomic Data and Applications Center for years between 1998 and 2012. The original dataset is in raster grids with a grid cell resolution of 0.1 degree. It provides continuous spatial coverage across the globe. I aggregated the grid-level data to the city level to generate PM_{2.5} concentrations for cities at or above prefecture level in China (Figure 3.4). Thirteen data files in GeoTIFF format were downloaded (for all years which data were available between 1998 and 2012).

I processed the data and generated the maps using ArcGIS ArcMap10. I used the model builder tool in ArcGIS to automate the data processing of the 13 files as they each take the same procedure. For each iteration, I took the following steps to process the raster data. First, I used

the Clip tool under Raster Processing to create a new raster file that only covers China. This step reduced the data processing time for future steps. China administrative boundary data were obtained from the GDAM Global Administrative Areas database version 2.8. I used the national administrative boundary shapefile (CHN_adm0) to clip the Global Annual PM2.5 Grids data. I then converted the raster grid to points using the Raster to Point tool under Conversion Tools. Next, I used the Spatial Join tool under the Analysis Tools to spatially join the prefecture level polygon with the point files I generated from step two. The match option chosen for this spatial join is the intercept, i.e. any points that falls within the prefecture boundary. The prefecture boundary shapefile (CHN_adm2) was also from the GDAM Global Administrative Areas database version 2.8. The merge rule was specified as “mean”, meaning the PM2.5 value of points within each prefecture polygon was averaged to generate prefecture level PM2.5 values. Last, a new shapefile was saved for each data file. I also exported prefecture level PM2.5 values into data tables for future analysis.

The resulting national annual average PM2.5 concentration in 2010 was 50 percent higher than in 1998.¹³ Figure 3.4 shows that PM2.5 levels worsened across cities in the northeast and south regions between 1998 and 2012.

¹³ The PM2.5 measure was derived from AOD data, which measure the amount of light extinction through the atmospheric column due to the presence of aerosols. While there is a high correlation between AOD and PM2.5, the relationship can be affected by aerosol vertical distribution, humidity, and aerosol competition. It is reported that satellite-derived PM2.5 values tend to be lower than ground-level measurements with an overall slope of 0.68 (van Donkelaar et al., 2015b).

Figure 3.4: Figure 3.4: PM2.5 Concentration 1998–2000 versus 2010–2012, in Micrograms per Cubic Meter

Source: data generated from Global Annual PM2.5 Grids from MODIS, MISR and SeaWiFS Aerosol Optical Depth (AOD), v1 (1998–2012) dataset (van Donkelaar et al. 2015); map created using ArcGIS; China administrative boundary shapefiles from GADM database of Global Administrative Areas version 2.8.

Using official pollution data, as well as measures of historical concentrations of PM_{2.5} obtained from satellites, we see clearly that China still suffers from severe levels of air pollution, especially PM. Historical emissions and PM_{2.5} measurements indicate that China's past air pollution–reduction efforts have achieved limited results. Data for the past five years show a downward trend in increases in SO₂ and NO_x emissions. However, absolute reductions from historical levels have not been achieved. PM_{2.5} concentration levels across China in the past decade have worsened; this pollutant has the most impact on health. It was estimated that 916,000 deaths in China can be attributed to ambient PM_{2.5} in 2013, making it the fifth-greatest risk factor for mortality in China and accounting for 10 percent of total deaths (Global Burden of Disease from Major Air Pollution Sources Working Group, 2016).

4. China's Air Pollution Regulatory System

The effectiveness of regulations designed to control air pollution has been reduced because of the incentives that Chinese government officials face. In the past, government officials' financial rewards, future promotions, and penalties were not tied to the state of the environment. Since the late 1970s, China has introduced a broad array of laws and programs to prevent and reduce pollution. In this chapter, I introduce China's environmental management system with a discussion of its components related to air pollution. I start with an overview of China's environmental regulatory system including the legal framework, the administrative implementation system, and the importance of environmental policy goals in the context of all government policy goals. I conclude with a more detailed description of key laws, standards, and FYPs related to air pollution.

The research approach taken in this chapter follows the structure used in Ma and Ortolano (2000) which summarized China's environmental regulation system with a focus on water pollution control. However, since the original analysis were done prior to 2000, many changes happened in the institutional set up, legal framework, and the administrative implementation system. I traced the historical evolution of China's environmental legal system, the change of status of MEP, as well as the progress made in China's FYPs with a special focus on air pollution prevention and control.

4.1 Overview of China's Environmental Regulatory System

This overview of China's environmental regulatory system focuses on two broad categories: the policy framework and the system of administrative implementation. Each has its own key actors and hierarchies.

There are three key actors in China's policymaking process: the National People's Congress (NPC), the State Council, and the Chinese Communist Party (CCP). The NPC is China's top law-making body; it approves any revisions to existing laws. The State Council is the leading administrative body and supervises the national ministries. It develops the Master Plan for Economic and Social Development every five years (the FYP) and approves other FYPs and regulations that will be implemented by various ministries. The CCP influences both the

NPC and the State Council through the appointment of top law-making and administrative officials.

The main structure of China's system of environmental regulation previously consisted of "two committees" and "one bureau," (Chang and Wang, 2010). The two committees are the Environment and Natural Resources Protection Committee (ENRPC) under the NPC and the Environmental Protection Committee (ERC) under the State Council. The Environmental Protection Committee under the State Council has the principal mission of coordinating environmental protection efforts among ministries. These two types of committees exist not only at the national level but also at the local level through the people's congress and local government. Since ENRPC belong to the law-making branch while the ERC falls under the law enforcement branch (i.e., the State Council), they play different roles in the environmental regulatory system. *One bureau* refers to the MEP and its local environmental protection bureaus. In 2008, when the State Environmental Protection Agency (SEPA) was elevated to become the MEP, the Environmental Protection Committee was dissolved.

4.1.1 Policy Framework

An easy way of thinking about the policy framework for controlling air pollution in China is to break it into four components:

- laws
- standards and regulations
- complementary policy programs
- FYPs.

The laws provide the framework for managing China's pollution-control regime and give authority to the MEP to regulate pollution. A series of basic and specific EPLs establish organizations and define punishments for noncompliance. Standards and regulations lay out the targets that governments and enterprises need to attain and ways to achieve them. The complementary programs help organizations to meet the standards by providing incentives, punishments, and resources. The national FYP encourages improvements in China's environment through investments and by setting targets for improvements. The FYP is special to China; it does not have a parallel in the Western world. It is not a law, but local governments

must implement it. As such, it is a powerful tool to either aid or inhibit environmental protection in China.

Two types of statutes govern China's environmental protection efforts: "basic laws," i.e., the National EPL that was passed by the NPC's standing committee, and "special laws," which are promulgated by the NPC's Environment and Resource Committee (Ma and Ortolano, 2000; Qi and Zhou, 2013). Often environmental laws are intentionally left ambiguous, which provides room for the State Council, the ministries, and local governments to develop details for implementation. To support the implementation of the National Environmental Law, the State Council and ministries, such as the MEP, can issue other regulations and standards. Administrative regulations introduced by the State Council or other national agencies have the force of law. Provincial and local governments can also develop local-level policies and regulations. However, these laws and regulations issued by subnational people's congresses and local governments must be consistent with national-level laws and regulations; they can be more stringent.

In total, China's legal system has four laws on controlling air pollution: one basic law, i.e., the National EPL, and three special laws, i.e., the APPCL, the Environmental Impact Assessment (EIA) Law, and the Law on Promoting Clean Production. In addition, ambient air pollution standards were established as guidance for the management and evaluation of air pollutant concentrations in China. To achieve ambient air pollution standards, specific emission standards for pollutants and industries are set by the MEP. To provide incentives to comply with emission standards, a list of programs was established that addresses funding, enforcement, and monitoring issues (Ma and Ortolano, 2000):

- EIA
- three synchronizations
- pollution discharge fee system
- discharge permit system
- total emission control system¹⁴
- pollution control within deadlines
- environmental responsibility system

¹⁴ Total emission control system was not among the original list included in Ma and Ortolano (2000). It was introduced in later time.

- assessment of urban environmental quality
- centralized control of pollution.

In Chapter 5, I provide detailed descriptions of the programs most closely associated with air pollution control and an assessment of their implementation status.

As noted above, a unique feature of China's policy framework is the FYPs. The FYPs lay out key national development goals and set public policy priorities. The latest 13th FYP includes 80 chapters organized in 20 sections. It describes China's development strategies, identifies the government's policy focus, and provides guidance for achieving various policy targets in the next five years. Section 10 of the 13th FYP lays out China's strategies to improve the ecological environment between 2015 and 2020. The FYP is not a law but can facilitate the establishment of new laws or point out the need for revision of laws, regulations, standards, and other policy instruments. Complementary FYP plans are developed to break down the national plan by region and sector. Developing the FYP is a dynamic process that can take place throughout the plan period; it is sometimes not finalized until the end of the five years (Lin and Elder, 2015).

FYPs are implemented and enforced through the "target responsibility system" established by a State Council order with a list of key performance indicators (KPIs). That is implemented by the Communist Party organization departments at each level of the government. The KPI can be either veto¹⁵ or binding targets for high-priority development projects or nonbinding targets that are desirable but not mandatory. Traditionally, binding targets have focused on social stability, the one-child policy, and economic growth, while environmental targets have historically been nonbinding targets, good to have but not mandatory. Personnel evaluations are based on achieving KPIs, especially the achievement of veto and binding targets, and determine a bureaucrat's financial rewards, future promotion, or penalties.

4.1.2 System of Administrative Implementation

The system of administrative implementation of China's environmental protection efforts has several levels. The State Council is the highest administrative body and approves the national FYPs. Under the State Council, two ministries share responsibilities for coordinating air

¹⁵ Veto (一票否决) targets are those priority binding targets that must be met. Failure to achieve veto targets could lead to possible termination of local cadres' careers (Van Aken, 2013b). Nonattainment of these targets cancels out all other positive outcomes from other fields, so these targets have veto power in determining a cadre's political future.

pollution–prevention and control efforts at the national and subnational levels. The NDRC is in charge of the planning of air pollution–*prevention* efforts, while the MEP leads the planning of air pollution–*reduction* efforts.

The NDRC is a “super ministry.” It sets and works to implement overarching economic development objectives, as well as energy and climate-change policy. It develops the national FYPs. It also assigns tasks to relevant government entities when implementing national air pollution–prevention and –control strategies.

The MEP is the entity most directly responsible for administering environmental regulations in China at the national level. It has jurisdiction over air pollution issues. The MEP develops environmental regulations and standards for relevant sectors and is responsible for overseeing the implementation of them.

Since the 1970s, the official entities responsible for environmental regulations have gone through a series of increases in status and responsibility to become the current-day MEP. The EPB was first formed in 1982 under the Ministry of Urban and Rural Construction. In 1988, the bureau became an independent bureau directly under the State Council’s Environmental Protection Committee. It was elevated to subministry level and renamed the National Environmental Protection Agency (NEPA). In 1998, NEPA was given full ministry rank and renamed SEPA, and the Environmental Protection Committee was dissolved. However, for years, SEPA did not enjoy full ministerial status. For example, its minister was not a standing member of the State Council (Asian Development Bank, 2012). Finally, in 2008, SEPA was elevated again to become the MEP and a component of the State Council.

Currently, the MEP has 15 departments and one bureau. Among them, the Department of Air Environment Management, the Department of Water Environment Management, and the Department of Soil Environment Management are the three latest departments to be established, in March 2016. These departments replaced the Department of Pollution Prevention and the Department of Total Pollution Emission Control to focus on pollution-prevention and -control efforts for each of these three areas. The Department of Air Environment Management is in charge of national pollution prevention and treatment of pollution from air, noise, light, and fossil-fuel energy sources. The department will develop and implement relevant policies, plans, laws, administrative regulations, and standards. It will also coordinate regional air pollution–control efforts.

Aside from departments, the MEP has 12 regional agencies. Six of them are environmental protection supervision centers (EPSCs), while the other six are nuclear and radiation safety supervision stations. The six regional EPSCs (Table 4-1) were established in 2006 and 2008 to serve as intermediate-level institutions between the MEP and the provincial governments. They are the components of MEP tasked with supervising the enforcement of national environmental laws and regulations and of inspection. However, they largely play a supporting and consultative role because they can neither punish polluters for noncompliance, instruct local EPBs' daily operations, nor mediate between the MEP and the provincial governments (Huan, 2011). The EPSCs are both MEP-affiliated institutions and regional agencies of MEP. This institutional setup has limited the EPSCs' authority to enforce environmental laws and regulations. By law, they cannot interfere in local governments' environmental protection work; they can only supervise and inspect local environmental protection performance (Huan, 2011).

To strengthen the supervision of enforcement, the MEP established a central environmental supervisory group (Central Supervision Group) in 2016. The Central Supervision Group plans to visit all provinces in the next two years and mainly focus on provincial leaders and relevant departments. The content and form of the inspections will be similar to the anticorruption inspections conducted by the Central Commission for Discipline Inspection of the Communist Party of China (CPC). The inspection visits turned out to be fruitful. After a month spent at Hebei (the first stop), the Central Supervision Group was able to resolve 2,856 complaints concerning environmental issues, shut down 200 illegal enterprises, detain 123 people, and conduct administrative interviews¹⁶ with 26 provincial leaders, including the provincial party secretary and governor ("What Kind of Signal Does Central Environmental Protection Supervision Group's Iron Fist Send?" 2016).

Table 4-1: Summary of Regional Environmental Protection Supervision Centers

EPSC	Year Established	Location	Jurisdiction	Number of Staff
East China	2002	Nanjing	Shanghai, Jiangsu, Zhejiang,	24

¹⁶ Administrative interviews or supervision talks (*yuetan*) are now used by central governments to hold local leaders accountable for various issues. The use of talks about environmental supervision have increased in the past few years and proved to be powerful tools to put pressure on local governments (Y. Huang, 2015). During the talks, local officials (both party and government leaders) were asked to respond to issues identified by the Central Supervision Group with deadlines.

	(pilot)/2006		Anhui, Fujian, Jiangxi, Shandong	
South China	2002 (pilot)/2006	Guangzhou	Hubei, Hunan, Guangdong, Guangxi/Hainan	34
Northwest China	2006	Xi'an	Shanxi, Gansu, Qinghai, Xinjiang	25
Southwest China	2006	Chengdu	Chongqing, Sichuan, Guizhou, Yunnan, Tibet	25
Northeast China	2006	Shenyang	Liaoning, Jilin, Heilongjiang	25
North China	2008	Beijing	Beijing, Tianjin, Hebei/Inner Mongolia, Shanxi, Henan	25
Source: Huan, 2011				

MEP coordinates with other ministries when implementing China's air pollution strategies: (1) The Ministry of Finance and Ministry of Commerce develop environmental protection funding strategies together with the NDRC, (2) the Ministry of Science and Technology supports research and development of air pollution-prevention and -reduction technologies, and (3) the Ministry of Industry and Information Technology promotes technology improvement among industries.

While the central government provides broad policy and development guidelines, the day-to-day implementation of laws happens at the local level. *Local-level government* here refers to provincial-level governments (provinces, autonomous regions, and centrally administered municipalities) and below. Above the township level, Chinese government agencies are interconnected through a line and area system (Ma and Ortolano, 2000). For example, local EPBs fall along the *line* of other environmental protection-related agencies above or below it because of their functional connections. They also fall within the same local government's jurisdictional control with other government organizations because of their *area* connections. A city-level EPB reports to both an upper-level agency (provincial-level EPB) in the same functional area and the government of the geographical area (city mayor's office), thus under dual management. There are 14,694 environmental protection entities employing 215,851 staff in China, of which 447 entities employing 17,717 staff were at the national or provincial levels in 2014 (China Environment Yearbook Editing Committee, 2015).

4.1.3 A Holistic Picture

It is important to keep in mind that we cannot view China's environmental regulatory system in isolation from the larger administrative structure. Figure 4.1 provides a holistic depiction of

how administrative units tasked with reducing air pollution and the general environmental protection administrative bodies are embedded within China's existing administrative system. Studies have indicated that the line and area relationship hinders local EPBs' implementation of environmental policies (OECD, 2006; Ma and Ortolano, 2000; Van Aken and Lewis, 2015). Local EPBs often find themselves caught in the middle between environmental protection goals of functional departments and economic development goals of local governments. Since local EPBs are neither institutionally nor financially independent from local governments, their ability to implement and enforce environmental policies is heavily influenced by local governments.

Figure 4.1: Institutional Structure of China's Environmental Regulatory System¹⁷

Local governments have incentives to prioritize economic development over environmental protection. By law, the local governments are the state administrative organs under the unified leadership of the State Council and must implement State Council orders. According to Article 59 of the Organic Law of the Local People's Congresses and Local People's Governments of the People's Republic of China (PRC) (NPC, 2011), local governments have the obligation to

¹⁷ Modified based on Schwabe and Hassler, 2016

implement the national plan for economic and social development. Since FYPs are considered State Council orders, the implementation of FYPs is mandatory. Thus, priorities set in the FYPs may trump environmental protection goals specified by national laws and regulations (Young et al., 2015). The good news is that the recent target responsibility system emphasizes environmental protection goals at the local level by including compliance of air pollution controls in the performance indicator system (State Council, 2011).

Besides the formal institutional process, changes in China's environmental regulatory system can be driven by ad hoc responses to crises (Young et al., 2015). Such extreme events can either inhibit or accelerate policy changes. In fact, many major changes to the environmental legal framework, as well as to the administrative structure, have often followed a high-profile pollution incident. The most recent one is the 2013 Airpocalypse, which led China's premier Li Keqiang to declare a "war on pollution" in 2014. In the following years, amendments were made to China's basic EPL, the APPCL, and the national Ambient Air Quality Standard.

4.2 Legislation, Regulation, and National Plans

In the following section, I describe the key laws, standards, and content of the FYPs.

4.2.1 *Environmental Laws*

China's story of environmental protection starts from an anecdote. Former Premier Zhou Enlai sent a delegation to attend the 1972 United Nations Conference on Health and the Environment in Stockholm, Sweden. During this conference, the Chinese representatives criticized developed countries for the deterioration of the global ecosystem and held the capitalist world responsible for remedying these problems (Economy and Oksenberg, 1999). Nonetheless, this conference led some Chinese elites to reevaluate the cause of environmental degradation in China. China's first high-level environmental decision body was formed in direct response to this international conference and eventually led to the efforts to draft China's first EPL.

4.2.1.1 **Basic Environmental Law**

Enacted in 1979 as a trial version and formalized in 1989, the establishment of the EPL set the foundation of China's national environmental legal system. The main content of the law includes objectives, scope, basic principles, measures, and regulations for pollution prevention

and control. It explicitly holds governments at the national, provincial, city, and county levels responsible for environmental protection. It also includes a requirement for an EIA, the “three synchronizations” rule (meaning pollution-abatement equipment to be *designed, built, and operational* at the same time as the new, reconstructed, or extended pollution discharging projects are designed, built, and put into operation), and the collection of pollution levies (NPC, 1989). These three requirements formed the basic management system for environmental protection in China.

Facing increasing pressure to update the EPL to reflect China’s reality, the new EPL took effect on January 1, 2015. The amended law made many positive changes aimed at strengthening implementation and enforcement of environmental regulations, especially at the local level. Key updates include the following (Falk and Wee, 2014) :

1. increased punishment for polluters: The new law specifies under Article 59 that violators will face daily and accumulating fines that start to accrue on the day after the date of the ordered correction. Also, authorities can now order a polluter to suspend or shut down its operations when the polluter discharges excessive amount of pollutants.
2. increased accountability of government bodies: Under Article 26, government officials above the county level will be evaluated on both environmental and economic performance, and evaluation outcomes will be made public. The new law also specified under Article 68 that government officials may face much more-severe penalties for misconducts in their job.
3. increased transparency: Articles 53 and 54 require publication of information related to environmental monitoring, environmental quality, and collection and usage of pollution discharge fees. Information about heavy polluters will also be made public under the requirement of Article 55. Articles 53, 62, and 63 specify that any violations by polluters may be made public. Individuals in charge or other personnel who have failed to abide by the new law can face detention of up to 15 days.
4. public-interest lawsuits: The newly amended law under Article 58 now gives nongovernmental organizations (NGOs) standing to file claims in court against polluters. However, such NGOs must be registered with the civil affairs department at or above the prefecture level and have five or more years of activities focused on environmentally

related issues. The amended law does not grant individuals or organizations the right to sue regulatory bodies that fail to enforce environmental protection regulations.

5. protection for whistleblowers: Article 57 of the new law allows individuals and organizations to anonymously report pollution activities and failure by environmental regulatory bodies to perform their responsibilities.

Overall, the amendment of the EPL addressed many deficiencies of the old law. It is a clear signal from the central government of its interest in strengthening local implementation and enforcement of environmental regulations. Its ultimate effect will require further assessment.

4.2.1.2 Air Pollution Prevention and Reduction Law

The Air Pollution Prevention and Reduction Law is one of the many special environmental statutes that aim to address a particular issue, as illustrated in Table 4-2. These special laws can be classified into three groups: (1) those aimed at preventing and controlling particular types of pollution, (2) those aimed at conservation and utilization of different natural resources, and (3) those related to supporting and promoting environmental management (Qi and Zhou, 2013).

Table 4-2: Examples of Special Environmental Laws

Law Title	Year Passed
Pollution prevention and control	
PRC APPCL	1987 (Revised 1995, 2000, and 2015)
PRC Water Pollution Prevention and Control Law	1984 (Revised 1996)
PRC Solid Waste Pollution Prevention and Control Law	1995
Natural resources conservation and utilization	
PRC Forest Law	1984
PRC Grasslands Law	1988
Environmental management	
EIA Law	2003
Circular Economy Promotion Law	2008

China introduced the APPCL in 1987; three revisions were made in 1995, 2000, and 2015. The 1987 version of the APPCL established basic principles for the prevention and control of air

pollution. The subsequent revision of the APPCL gradually refined the legal basis for air pollution prevention and control in China.

Four major provisions were made in the 1995 revision of the APPCL. The original draft included several potentially contentious issues that spurred opposition from various ministries and regions: a mandatory coal-washing requirement to reduce sulfur and ash emissions from coal, tighter automobile emission standards, a ban on leaded gas, an increase in pollution fee levels, a requirement that pollution fees be based on the total volume of emissions rather than the amount exceeding the standards, and advocacy for dividing cities into three tiered zones with differentiated pollution-control standards (Alford and Liebman, 2001). After heated debate, the final version made key changes in four areas while leaving out many stricter requirements. The first is the inclusion of provisions that required the gradual phase-out of obsolete production methods and equipment. The law called for coal-washing and limited the mining of high-sulfur coal.

The revision also included articles that enabled the State Council to create acid rain and SO₂ control zones (i.e., the “Two Control Zones”). The first zone, the Acid Rain Control Zone, consists of areas with average annual pH values for precipitation less than or equal to 4.5, sulfate deposition greater than the critical load,¹⁸ and high SO₂ emissions. The second zone, the SO₂ Pollution Control Zone, consists of areas with annual average ambient SO₂ concentrations exceeding class II standards, daily average concentrations exceeding class III standards, and high SO₂ emissions. The Two Control Zones policy aims to foster steady reductions in the sulfur content of coal combusted by the power sector. The Two Control Zones are key areas for controlling acid rain and SO₂ emissions in China and receive priority for investment and management to control emissions (Yang and Schreifels, 2003). Lastly, the revision called for phasing out leaded gasoline.

The revision of APPCL 2000 was considered a more successful and smooth experience. It included provisions that ENRPC sought to include in the 1995 revision but failed. It requires the use of total emissions for measuring pollution. It further revised the air pollution fee system. It explicitly states that emissions that exceed standards are illegal. The law also clarifies that all emissions, not just the single pollutant exceeding standards the most, must be subject to fines. To

¹⁸ The critical load of sulfate can be used as an indicator of ecosystem vulnerability from acid deposition. It varies spatially, and exceeding the critical load can lead to long-term damage to the ecosystem (Hao et al., 2001).

target acid rain, the APCL 2000 includes provisions that established a permit system and total emission-control standards for SO₂ emissions in the two control zones. These provisions essentially established a statutory basis for instituting emission trading in China—i.e., the two control zones, emission permits, and the total emission-control standards created the precondition for a tradable permit system (Ellerman, 2002). The 2000 revision calls for more transparency in reporting on environmental problems, requiring regular publication of environmental reports. It also strengthened pollution controls on automotive sources. Finally, Articles 48, 50–54, 57, and 61 gave EPBs the right to impose fines, shut down operations, and impose criminal charges against polluters based on the severity of noncompliance.

The 2015 revision of the APPCL was a much-anticipated amendment following the State Council's 2013 announcement on the Air Pollution Prevention and Control Action Plan, as well as the revision of the nation's EPL the previous year. The new APPCL almost doubled the length of the older version of the law, expanding from seven chapters covering 66 articles to eight chapters with 129 articles. Several major changes were included in the new revision. First, it increased the accountability of local governments in implementing and enforcing air pollution–prevention and –control strategies. It requires cities to regularly develop and release plans to meet national air quality standards. If cities fail to comply with air quality standards, local government leaders are required to develop corrective plans, and new projects will be prohibited from undergoing EIAs. Second, it strengthens air pollution prevention and control through expanded coverage of pollutants and sources. It now covers not only SO₂ and NO_x but also PM, VOCs, and greenhouse gases. It also calls for stricter controls on coal quality and efforts to reduce coal consumption in key air pollution–control regions. It addresses air pollution from various key sources, such as coal-mining, automobiles, marine vessels, agricultural machinery, construction, and food production. Third, the new law now encourages public participation. It heightened the requirement for public information disclosure and explicitly required public input in the planning process. The new APPCL also requires the installation of automated monitoring equipment and real-time publication of emission data. Finally, the amendment establishes a framework for regional air quality management and coordination. The idea of promoting joint prevention and control of regional air pollution was first established by a State Council document, “Pushing Forward the Joint Prevention and Control of Atmospheric Pollution to Improve the Regional Air Quality Developed by the Ministry of Environment Protection and Relevant

Departments” (General Office of the State Council, 2010). The document identified key regions to begin implementing regional air pollution joint prevention and control, as well as reducing key pollutants (i.e., SO₂, NO_x, PM, and VOC) from key industries (thermal power plants, iron and steel, nonferrous metals, petrochemicals, cement, and chemicals). The Jing-Jin-Ji, YRD, and PRD regions were specified in the State Council’s 2013 Air Pollution Prevention and Control Action Plan. The APPCL 2015 provides the MEP the responsibility to identify key regions for air pollution prevention and control while requiring local governments to select a governing body to coordinate regional air pollution monitoring and standard-setting efforts.

4.2.2 National Air Pollution Standards

4.2.2.1 Ambient Air Quality Standards

China has had ambient air quality standards since 1982 with a focus on larger particulates (total suspended particulates), SO₂, NO_x, lead, and benzopyrene. Subsequently, the standard has been updated three times, in 1996, 2000, and 2012. The 1996 version (GB3095-1996) was an expansion and upgrade of the 1982 standard. The 2000 revision set less stringent limits for O₃ and NO₂. In 2012, China announced its new ambient air quality standards (GB3095-2012) and, for the first time, included limits on PM_{2.5} (Table 4-3). The new standards also reduced the thresholds from three classes to two classes, eliminating the least stringent class that covered special industrial areas. Class I applies to special regions, such as national parks, while class II applies to other urban and industrial areas. The Class I standard for PM_{2.5} is comparable to those set up by the European Union and Japan but less stringent than the guidelines recommended by the WHO (10 µg/m³ for annual average and 25 µg/m³ for the 24-hour average). It is also worth noting that both the United States and the European Union further specified the standard in terms of the number of times such standards can be exceeded in a year (European Parliament and Council of the European Union, 2008; U.S. Environmental Protection Agency, 2016).

The implementation of the 2012 standard was phased in based on the following schedule:

- 2012: cities in the three key air pollution–prevention and control regions and provincial capitals (74 of them)
- 2013: key environmental protection cities (113 of them)
- 2015: all prefecture-level cities (338 of them)
- 2016: nationwide implementation.

Table 4-3: Standards for Six Primary Pollutants under GB3095-2012

Primary standards				
Pollutant	Averaging time	Limit		Unit
		Class I	Class II	
SO ₂	Annual	20	60	µg/m ³
	24 hours	50	150	
	Hourly	150	500	
NO ₂	Annual	40	40	
	24 hours	80	80	
	Hourly	200	200	
CO	24 hours	4	4	mg/m ³
	Hourly	10	10	
O ₃	Daily, 8-hour maximum	100	160	µg/m ³
	Hourly	160	200	
PM ₁₀	Annual	40	70	
	24 hours	50	150	
PM _{2.5}	Annual	15	35	
	24 hours	35	75	

To provide an easier-to-understand indication of air quality level, the Chinese government uses an indicator system to evaluate overall air quality. The indicator system associated with the 1996 ambient air quality standards is called the Air Pollution Index (API), while the new index is called the Air Quality Index (AQI) (HJ633-2012). The API included three pollutants (SO₂, NO₂, and PM₁₀) while the AQI also included PM_{2.5}, O₃, and CO. Both the API and the AQI first calculate an Individual API (IAPI) or Individual AQI (IAQI) score for each of the pollutants based on their concentration levels. The final API or AQI is the maximum IAQI among these pollutants. The API or AQI is then classified into several levels with associated color codes ranging from excellent to severe pollution. Table 4-4 shows the concentration levels of each pollutant associated with IAPI or IAQI values. The SO₂ and PM₁₀ concentration levels associated with different index scores are identical between API and AQI. Daily NO₂ concentration levels are more stringent in the AQI standards.

Table 4-4: Comparison of API and AQI, in Micrograms per Cubic Meter

API				AQI						
IAP1	Daily SO ₂	Daily NO ₂	Daily PM10	IAQ1	Daily SO ₂	Daily NO ₂	Daily PM10	Daily CO (mg/m ³)	Daily O ₃	Daily PM2.5
50	50	80	50	50	50	40	50	2	160	35
100	150	120	150	100	150	80	150	4	200	75
				150	475	180	250	14	300	115
200	800	280	350	200	800	280	350	24	400	150
300	1,600	565	420	300	1,600	565	420	36	800	250
400	2,100	750	500	400	2,100	750	500	48	1,000	350
500	2,620	940	600	500	2,620	940	600	60	1,200	500

Note: Values associated with each pollutant are the maximum allowable concentration level associated with IAPI or IAQI value.

Table 4-5: Classification of Air Quality Index Value Comparison

IAP1	IAQ1	1996 Classification	2012 Classification	Attainment status
0–50	0–50	Grade I	Grade I	Attainment
51–100	51–100	Grade II	Grade II	Attainment
	101–150		Grade III	Nonattainment
101–200	151–200	Grade III	Grade IV	Nonattainment
201–300	201–300	Grade IV	Grade V	Nonattainment
>300	>300	Grade V	Grade VI	Nonattainment

A daily average API or AQI less than or equal to 100 indicates attainment of the national air quality standard (Table 4-5). Despite the inclusion of additional pollutants and more-refined qualitative classification of air quality, the new AQI was still considered misleading and less stringent than those of the United States and the European Union (Andrews, 2014). The color-coding and qualification of PM2.5's health impacts are less stringent in China. Nonetheless, the new standard and index system draw a much grimmer picture of China's overall air quality. Prior to the implementation of the new ambient air quality standard, 88.5 percent of China's 113 key environmental protection cities met the standards. The compliance rate dropped to 21.6 percent after the introduction of the new standards (MEP, 2016).

4.2.3 Five-Year Plans

The historical evolution of China's environmental protection and air pollution-prevention and control legislation indicates relatively infrequent responses from Chinese lawmakers to China's pollution situation. Between the late 1990s and early 2010s, China's environmental

statutes went largely unchanged (Figure 4.2). The national FYPs have been driving recent changes in implementation and enforcement, while laws and regulations have remained secondary (A. Wang, 2013). The FYPs and their associated “target responsibility system” provide a clear signal to bureaucrats about promotion criteria, are more flexible than relatively static laws, and are viewed as an effective tool for principal-agent control (A. Wang, 2013). In the next section, I provide a brief history of how environmental protection has slowly become a policy priority among China’s many other development objectives.

Figure 4.2: Evolution of China's Environmental Policymaking

Environmental protection goals first appeared as an independent section in the sixth FYP (1981–1985). Air pollution prevention and reduction–related targets were first published in the ninth FYP (1996–2000). *The National Environmental Protection Ninth Five-Year Plan and 2010 Long-Term Goal* was the first environmental protection FYP that received approval from the State Council for implementation. Beginning with the ninth FYP, the central government established SO₂ emission targets for key sectors and regions. The SEPA began to promote a policy of total emission control (TEC) and established a national SO₂ TEC target. SEPA assigned individual TEC targets to provinces, autonomous regions, and municipalities, while regional governments assigned TEC targets to local governments or pollution sources (Yang and Schreifels, 2003). Table 4-6 illustrates that during the 9th FYP period all of the stated environmental targets were met.

Table 4-6: Ninth FYP Air Pollutant Targets and Achieved Results

9th FYP	Actual 1995, in Tens of Thousands of Tons	Planned 2000, in Tens of Thousands of Tons	Planned Change, as a Percentage	Actual 2000, in Tens of Thousands of Tons	Actual Change, as a Percentage
Soot	1,743.6	1,750	0.37	1,165.4	–33
SO₂	2,369.5	2,460	3.82	1,995.1	–16
Industrial dust	1,731.2	1,700	–1.8	1,092	–37

SOURCES: China Environment Yearbook Editing Committee, 1996, p. 115; China Environment Yearbook Editing Committee, 2001, p. 121.

When the National Tenth Five-Year Plan for Economic and Social Development was first announced, it listed a goal of reducing major pollutants but failed to define which pollutants were deemed “major.” The MEP later provided a list of major pollutants in the National Tenth Five-Year Plan for Environmental Protection in 2001, including 14 national targets, and called for regulations of five major pollutants and solid wastes. It also established a 10-percent reduction target for SO₂ emissions by 2005 based on 2000 levels. The goal took the form of a 20-percent reduction from sources in the Two Control Zones with other regions to achieve reductions by lower levels or even increasing emissions¹⁹ (China Environment Yearbook Editing Committee, 2002, pp. 56–57). Because of rapid economic growth and associated increase in coal consumption, by the end of 2005, reported SO₂ emissions were 28 percent higher than 2000 levels as shown in Table 4-7 (China Environment Yearbook Editing Committee, 2006). Almost all regions exceeded their tenth FYP SO₂ emission targets, and their 2005 SO₂ emissions increased from 6.7 percent to 287 percent over year 2000 levels (Figure 4.3).

Table 4-7: Tenth FYP Air Pollutant Targets and Achieved Results

10th FYP	Actual 2000, in Tens of Thousands of Tons	Planned 2005, in Tens of Thousands of Tons	Planned Change, in percentage	Actual 2005, in Tens of Thousands of Tons	Actual Change, In percentage
SO₂	1,995	1,796	–10	2,549.3	28
Two Control Zones	1,316.4	1,053.2	–20		
Soot	1,165	1,060.3	–9	1,182.5	2
Industrial dust	1,092	898.71	–17.7	948.9	–13

SOURCES: China Environment Yearbook Editing Committee, 2006

¹⁹ Some regions were allowed to increase their emissions by a small percentage.

Figure 4.3: Tenth FYP Target Attainment by Region

SOURCES: Environment Yearbook Editing Committee, 2006, p. 605.

Although the goal for SO₂ emissions in the tenth FYP was not met, the government again set a goal to reduce SO₂ emissions by 10 percent during the 11th FYP, albeit from the higher 2005 emission level. For the first time, the State Council sent a copy of the National Environmental Protection 11th FYP to all local governments and relevant agencies to implement. As opposed to the previous FYP, this time, the SO₂ emission-reduction target was included in the outline of the National 11th Five-Year Plan for Economic and Social Development issued by the NPC. The target emphasized emission reductions in the power sector with a separate emission target set specifically for the power sector, considering it the most important source of SO₂ emissions and the most cost-effective to control. The control of SO₂ emissions during this FYP received significant attention from top-level officials (Schreifels, Fu, and Wilson, 2012). New policy instruments, such as *The Environmental Quality Administrative Leadership Accountability System* that links local leaders' performance evaluation with the attainment of environmental goals were implemented to establish accountability and provide political support.

An interim evaluation by the MEP and the NDRC was conducted for the first time and the results were evaluated and shared with local governments in 2009. A final assessment was conducted by the MEP and the NDRC in 2010. During the 11th FYP period, SO₂ emission reductions were greater than what had been specified by the target, falling 14 percent from 2005 levels. During this period, China also conducted its first national pollution source census, reaching 5.92 million sources and facilities across industry, agricultural, residential, and centralized treatment sources (China Environment Yearbook Editing Committee, 2011).

In the 12th FYP (2011–2015), the government established new goals to further reduce SO₂ emissions by 8 percent and NO_x emissions by 10 percent relative to the 2010 emission levels (Clean Air Alliance of China, 2013). It also expanded the sources that face reduction targets, from industrial and residential to include additional agricultural and transportation sources. According to current inventories, all coal-fired power plants built before 2010 in the YRD region have installed PM-abatement technologies, such as cyclones, wet scrubbers, or electrostatic precipitators.

Although there was not, at the time, an absolute target for direct PM_{2.5} emissions, which are finer and have a greater impact than PM₁₀ on human health, China's State Council promulgated a new ambient air quality standard for PM_{2.5} in 2012 (GB 3095-2012) and an action plan for air pollution prevention and control in September 2013 (Clean Air Alliance of China, 2013). To meet the new standards, coal-fired power plants would have to install additional or replace existing PM controls with high-efficiency pollution controls, such as fabric filters (FFs). In 2011, the minister of MEP signed *Total Emissions Control Target Responsibility Contracts* with the heads of 31 provincial governments and eight state-owned enterprises in the power sector to ensure the achievement of the 12th FYP goals (China Environment Yearbook Editing Committee, 2012). The ambient air quality compliance requirement expanded from 113 key environmental protection cities to all 333 cities at or above prefecture level. The plan also required all cities at or above prefecture level to reach class II-level ambient air quality for more than 80 percent of the year.

The 12th FYP for prevention and control of air pollution also emphasized regional air pollution control. It designated major regions for joint prevention and control of atmospheric pollution, such as Jing-Jin-Ji, the YRD, and the PRD. In these designated regions, monitoring systems for regional ambient air quality were required to be established, special emission limits

for air pollutants at the regional level were to be implemented, and simultaneous control of several pollutants was to be conducted. The concentration of PM_{2.5} in the Jing-Jin-Ji region, YRD, and the PRD was required to be reduced by 25 percent, 20 percent, and 15 percent, respectively (MEP, NDRC, and Ministry of Finance of China, 2013). Coal-fired power plants, coal-fired boilers, and industrial furnaces in the three key regions would need to install desulfurization, denitrification, and dust-removal equipment by the end of 2015. Regions would need to control multiple air pollutants simultaneously and faced a cap on their total coal consumption. To date, all three key regions have published air pollution–prevention and –control action plans and inventories of facilities within the four key sectors (power, steel, cement, and plate glass) that require installation of additional pollution-control equipment. However, the effectiveness and feasibilities of these action plans are largely unknown at this time.

The 13th FYP was published in 2016 (NPC, 2016), and the 13th Environmental Protection FYP is still under development as of this writing. The improvement in overall environmental quality, including significant reductions in total emissions of key pollutants, was, for the first time, listed as a national development objective. The 13th FYP also calls for the reform of environmental management systems. Environmental monitoring and inspection activities below the provincial level will be directly managed by provincial-level departments to avoid manipulation of monitoring data at the local level and to reduce local interference in environmental enforcement. The plan intends to develop an enterprise environmental credit history system²⁰ and implement an auditing system to evaluate government officers' past environmental management performance after they leave their current posts.

4.3 Conclusions

Since the late 1970s, China has developed an extensive environmental legal framework on paper. However, the implementation of laws and regulations has been characterized as “notoriously weak,” as evidenced by China’s continued severe pollution levels (A. Wang, 2013). This review of China’s policy framework and administrative implementation system shows that weak enforcement could be explained from three perspectives. First, China’s central government

²⁰ The purpose of the enterprise environmental credit history system is to develop a “black list” of illegal enterprises and make the list available to the public. Enterprises with bad environmental histories will face “punishments,” such as more-frequent inspections; be disqualified from financial subsidies; or face more-stringent requirements for obtaining permits (MEP and NDRC, 2015).

prefers “rule of mandates” rather than “rule of law” (A. Wang, 2013). The implementation of development goals set up in the FYPs was treated much more seriously than laws and regulations. Second, prior to the 11th FYP period, the central government did not make environmental protection a policy priority. This is evident in that environmental quality targets were not listed as veto or hard targets in the KPI system that holds local governments responsible for implementing the FYP. Since attainment of the hard targets of the FYPs is the key determinant of a bureaucrat’s future promotion, it is not surprising that few would risk their future political careers to prioritize the achievement of nonbinding targets. Third, the line and area system (dual management) has limited the power and resources at the local level needed to implement and enforce environmental legislation. Since the EPBs are institutionally and financially under the local governments’ control, local government leaders do not prioritize resource allocation toward environmental goals, unless these goals become mandates that may shape their future careers.

By including environmental targets as binding goals in the 11th FYP, the central government signaled its intention of making environmental quality a focus of central policy. This critical change shifted the responsibility of meeting environmental targets from environmental regulators to the heads of local governments. However, the implementation of KPIs itself is inconsistent across regions and prone to problems within the system itself. Performance outcomes are subject to data manipulation by local officers. The indicator system only evaluates whether a local government passes or fails an indicator but ignores how such a target was achieved. The evaluation is also subject to the influence of *guanxi*, i.e., the personal relationship between the evaluated cadres and their superiors (Van Aken, 2013a). Nonetheless, the ongoing process of reform within China’s environmental regulatory system shows that the central government is actively adapting to new situations on the ground and seeking ways to address the implementation problem.

5. National Environmental Policies to Attain Standards

In this chapter, I assess the relative importance of China's primary regulatory air quality management, compliance, and enforcement policies and their relevance to China's efforts to improve air quality. I provide detailed assessments of five of the nine primary programs and briefer descriptions of the three other programs. Centralized control of pollution control mainly focused on reducing water pollution, thus I will not discuss this program in this dissertation.

The assessments mainly focus on two aspects of the policy program: policy design and policy implementation. The assessment of policy design evaluates whether the design follows established theory, and achieves its intended purpose. The evaluation of policy implementation attempted to use publicly available data to assess the level of enforcement. All of the implementation data came from China Environment Yearbooks. To find evidence of design issues and implementation problems, I also conducted literature review in google scholar with key words combinations such as "China+ environmental impact assessment+ implementation" to gather past assessment studies. There are ongoing efforts to update some of the programs in the coming years to reflect the heightened focus on pollution control. Thus, I also searched official documents and expert commentaries that discuss potential new developments.

China's national government has adopted several policies to enhance the implementation and enforcement of national environmental laws. The most important policies are called the "eight systems" (S. Zhang, 2001; Ma and Ortolano, 2000). Three of them, environmental impact assessments (EIAs), the Three Synchronizations, and the pollution discharge fee system were developed based on the 1979 trial version of the Environmental Protection Law and are therefore called the "Three Old Systems". When the Environmental Protection Law was changed from trial to permanent status in 1989, five additional policies were developed to complement the Three Old Systems. The "Five New Systems" are: the environmental responsibility system, assessments of urban environmental quality, the pollution discharge permit system, centralized control of pollution control, and pollution control within deadlines (S. Zhang 2001). One additional program, TEC, was introduced in the ninth FYP. I will not discuss nor assess the centralized control of pollution control program because it targets water pollution.

- EIA

- Three Synchronizations
- Pollution Discharge Fee System
- Pollution Discharge Permit System
- TEC
- Pollution Control within Deadlines
- Environmental Responsibility System
- Assessment of Urban Environmental Quality
- Centralized Control of Pollution Control

These nine programs focus largely on point sources of pollution. Nonetheless, together, they form a pollution-management framework that covers each stage of the project development life cycle (Figure 5.1). The EIA serves as an ex ante evaluation of potential pollution levels of a project. The Three Synchronizations ensure that the design, construction, and operation of pollution-control equipment follow the plan developed in the EIA. The Chinese government has also attempted to use economic tools to incentivize the implementation of pollution-control strategies. The establishment of the discharge permit system, the discharge fee, and the TEC have created conditions for a market-based pollution-reduction framework. The other three programs, i.e., pollution control within deadlines, environmental responsibility system, and the assessment of urban environmental quality, all serve post implementation evaluation by holding various stakeholders accountable.

Figure 5.1: Framework of China's Environmental Policy Programs

5.1 Environmental Impact Assessment

Introduced in the trial version of EPL in 1979, the central idea of an EIA was to estimate potential adverse environmental effects from a proposed project. Any “new, expansion, and innovation” projects need to develop an EIA report and be evaluated and approved by the MEP (NPC, 1989). Local governments or enterprises responsible for new or modifications of projects need to submit EIA reports to the MEP for examination and approval. Once a project was approved and constructed, the MEP needs to inspect the project and ensure that the completed project does not exceed the pollution level stated in the EIA report.

The EIA was the first administrative measure that was turned into a special environmental law. In 2003, the EIA law was enacted. Elevating the EIA from an administrative measure to a special environmental law clearly demonstrated the central government’s intention of using the EIA as a tool to top projects that emit high levels of pollution. The Chinese government amended the EIA law and implemented it in September 2016. The “Temporary Methods of Public Participation in Environmental Impact Assessment” announced in 2006, and the “Guideline for the Disclosure of the Government Information in Connection with the Environmental Impact Assessment of Construction Projects” in 2013 improved access to information from the EIA reports (Suwanteep, Murayama, and Nishikizawa, 2016). In 2012, the first EIA 12th FYP was developed (China Environment Yearbook Editing Committee, 2012).

The EIA law calls for the application of environmental assessment at the strategic level for spatial and sector-specific plans beyond construction projects. Development and utilization plans related to an area, a river basin, or coastal area and plans related to land use need to include EIAs (Standing Committee of the NPC, 2002). Sector-specific plans related to industry, agriculture, animal husbandry, forestry, energy, water resources, transportation, urban development, tourism, and national resources also need to provide EIAs (Standing Committee of the NPC, 2002). The provisions related to the spatial plan are much less stringent than those related to the sector-specific plans. The law requires that, prior to submitting the plans for approval, the entities writing the sector-specific plans hold public meetings, hearings, or, through other means, collect comments from relevant entities, experts, and the public. The EIA law also identifies elements needed to be covered in the EIA reports for the sector-specific plans.

A list of follow-up regulations was developed to enhance the implementation of the EIA for plans by the MEP and the State Council. They include the Regulation on Environmental Impact Assessment of Planning, Technical Guidelines for the Plan EIA, and Comments on Strengthening the Synergy between Plan EIA and Construction Project EIA. If done effectively, the Plan EIA for the target area or industry should provide guidelines or constraints on construction projects within the area and sector. However, a review of the Plan EIA indicated that EIAs for plans tend to be prepared too late to have a real impact and that the quality of the EIA report is limited by data availability across different planning teams and assessment methodologies (Dusik and Xie, 2009).

The EIA law identifies three types of EIA documents for construction projects in China (Standing Committee of the NPC, 2002):

- For those construction projects that may have a large environmental impact, an EIA report is required and should provide comprehensive EIAs.
- For those construction projects that may cause some environmental impact, an EIA form is required; it should include an analysis of the environmental impacts and special assessment.
- For those construction projects that may cause little environmental impact, an EIA registration form is required; there is no need to conduct an EIA.

The decision of whether a project should submit an EIA report, form, or registration form is made by MEP or local EPBs depending on the size and impact of the projects (Suwanteep, Murayama, and Nishikizawa, 2016). For example, MEP should approve EIAs for projects related to nuclear facilities, classified construction projects, cross-regional projects, and projects that are approved or authorized by the State Council (Standing Committee of the NPC, 2002).

The EIA law requires that the EIA reports and forms be prepared by entities with EIA qualifications (Standing Committee of the NPC, 2002). Before the submission of the EIA statement, the construction entity needs to conduct a public hearing or, through other means, gather opinions from relevant entities, experts, and the public. After receiving the EIA report or form, the MEP and the local EPBs have 60 days (30 days for the EIA form) to review the EIA statement and make a decision on whether to approve the EIA.

The implementation rate of the EIAs, i.e., percentage of construction projects started this year that have conducted EIAs, has remained high since the enactment of the EIA law, close to

100 percent every year (Figure 5.2). The variance in regional implementation of the EIA have been reduced significantly over the years (Figure 5.3).

Such high implementation rates have had their faults. Many EIA entities lend their qualifications to organizations without such permits for profit. According to the MEP data center statistics, there are 981 institutions with qualifications to conduct EIAs as of September 2016.²¹ However, 34,113 EIA reports and 190,363 EIA forms were approved in 2013 alone (China Environment Yearbook Editing Committee, 2014). This means that, on average, each institution would have prepared more than 200 EIAs each year. A joint investigation by an NGO and the *Southern Weekly* in ten provinces with the highest number of EIA entities found that 23 percent of the 600 investigated entities may have involved the sale or embezzlement of EIA qualifications; some entities even resold the qualifications that they had purchased from the original owner (Yue and Shao, 2015). Second, many EIA entities belong to national and local environmental protection agencies, even though the EIA law specifically states that EIA entities should not have any relationship or interest with the administrative department in charge of environmental protection and any other department of examination and approval (Standing Committee of the NPC, 2002).

In the past few years, the MEP has strengthened the management of entities with qualifications to conduct EIAs. The qualification process was governed by the “Measures for the Administration of Construction Projects Environmental Impact Assessment.” This measure was originally announced in 1999, and went through two amendments in 2005 and 2015. It includes detailed requirements on the number and type of engineers required to obtain qualifications, as well as what types of EIA statements (reports or forms) an entity is qualified to draft. The MEP also started to investigate the issue of borrowing and embezzlement of EIA qualifications. The MEP proposed a work plan that requires that all EIA entities that currently belong to environmental protection agencies to become independent by the end of 2016 (MEP, 2015). The implementation will take place through three stages. The first stage involves EIA entities under the MEP (eight of them). The second stage involves entities at the provincial level or entities below the provincial level but not located within the western provinces (274 of them). The last involves entities below provincial level and located within the western provinces. In 2015, 35 EIA entities were disqualified from conducting EIAs (Z. Huang and Cui, 2015).

²¹ Data can be accessed here <http://datacenter.mep.gov.cn/hpzzcx/query.do?talbeName=Hpjg&pageNum=33>

Figure 5.2: Implementation Rate of Environmental Impact Assessment, as a Percentage

SOURCES: China Environment Yearbook Editing Committee, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011.

Figure 5.3: Regional Variances in Environmental Impact Assessment Implementation Rate, as Percentages

NOTE: Each circle represents a provincial-level region.

SOURCES: China Environment Yearbook Editing Committee, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011.

In 2013, the MEP decentralized the approval, inspection, and acceptance rights of the the EIA for certain non-sensitive projects to local EPBs (China Environment Yearbook Editing

Committee, 2014). However, this change led to many concerns that, without national oversight, local EPBs may abuse the power they now have (B. Li, 2013; Kong, 2016).

5.2 Three Synchronizations

The Three Synchronizations policy requires that the design, construction, and operation of pollution-treatment facilities must be incorporated into the design, construction, and operation processes of an entire project. The policy applies to new construction, as well as expansion and modification of existing facilities. The original 1979 EPL required that construction projects could not be approved or used unless appropriate environmental protection and control facilities were inspected and approved by competent departments.

While the EIA focuses on the development of pollution-prevention plans, the Three Synchronization policy focuses on implementation. Project owners are responsible for ensuring the integrity of the design, construction, and operation of pollution-treatment facilities. The environmental administrative authority reviews and approves (or disapproves) and documents the project in an EIA. The authority also inspects and determines whether to accept the project when the construction process is completed. Official statistics indicate that the program achieved a high implementation rate. The implementation rate is measured as the ratio between construction projects that followed the Three Synchronization requirements and passed the environmental protection inspection through one trial after completion, and all construction projects that should follow the Three Synchronization requirements. Thus, the implementation rate measures the combined effect of enterprises following two of the three requirements (design and constructions, but not necessarily operation), as well as the stringency of environmental inspection approval. Figure 5.4 shows that, since the Ninth FYP period, the national average implementation rate was above 90 percent except in 1996. Regional variances in the implementation rate, however, stopped shrinking. In fact, during the later years of the 11th FYP period, implementation rates for some provinces (Shandong, for example) were significantly lower (Figure 5.5). One study found that the implementation rate was particularly low for small enterprises reviewed below the county level (Qi and Zhou, 2013).

Figure 5.4: Implementation Rate of Three Synchronizations, as a Percentages

SOURCES: China Environment Yearbook Editing Committee, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011.

Figure 5.5: Regional Variances in the Three Synchronization Implementation Rate, as Percentages

SOURCES: China Environment Yearbook Editing Committee, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011.

5.3 Pollution Discharge Fee System

The pollution discharge fee system was also introduced in the 1979 trial version of the EPL. There are two types of fee systems. One is related to pollution emissions that exceed the standards. The level of fee for air pollution was based on the number of times that a pollutant discharge volume exceeded the national emission standard. In addition to the fees related to

exceeding the national standards, polluters also pay four other types of fees if they are found to be in violation of standards. They are called the “four small pieces”—namely, (1) a 5-percent annual increase on the unit levy on polluters that have paid the fee for three years, (2) violators of the Three Synchronizations rule or polluters that stop the operation of their pollution-treatment facilities without approval from the EPBs must pay twice the responsible levies, (3) a 0.1-percent-per-day surcharge on late payments, and (4) fines for illegal emissions.

Environmental protection authorities collect fees from enterprises based on monitoring data. Collected fees become part of the local budget as special funding for environmental protection. Up to 80 percent of the collected funding can be used as subsidies for key polluters (i.e., returned to the enterprises that paid these fees as rebates) to reduce their emissions of pollutants. The rest can be used by local EPBs for purchasing environmental monitoring equipment but cannot be used as for the administrative budgets of the environmental protection agencies. Such arrangements provided a stable source of independent funding for local EPBs but also provided incentive for them to focus on charging polluters for fees rather than truly decreasing the pollution levels (Ma and Ortolano, 2000).

In 2003, the State Council enacted the Administrative Regulations on Pollution Discharge Levy (State Council, 2003). Many changes were made in this new regulation from its original form. First, the collection of fees was to be based on the level of total emissions rather than only those exceeding the standard. Levies were to be charged on the total emissions of the pollutants based on the top three emissions. Second, the new regulation changed the collection and allocation procedures for discharge fees. The environmental protection administrative departments of local governments at or above the county level are to identify the types and amount of emissions of pollutants, and issue notifications to the polluters about the fees for which they are responsible. The polluters have seven days to pay the discharge fees through specified commercial banks. Commercial banks deposit collected fees in the national treasury or local treasury based on a set ratio: Ten percent of the collected fees go to the national treasury, while the remaining 90 percent become part of the local government budget as a special fund for environmental protection (Ministry of Finance and SEPA, 2003). Local EPBs must submit annual budgets with each expenditure item justified for social returns and subject to approval from the finance bureau. Third, all of the local fees should be used for pollution prevention and control and technological development and application. After the 2003 update, the total amount

of discharge fees collected more than doubled in two years (Figure 5.6). On the other hand, the number of entities paying the discharge fee has been dropping over the years. The reduction in the number of entities may mean that some enterprises have decided to reduce their emissions rather than pay the fees. However, this also means that the remaining entities would rather pay higher discharge fees than reduce their emissions (J. Jiang, 2014).

Figure 5.6: Discharge Fee Amount versus Number of Entities Paying

SOURCES: China Environment Yearbook Editing Committee, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014. Blue line indicates number of entities paying the fee.

The level of discharge fees has been set far lower than needed to equalize marginal abatement costs to marginal social damage (World Bank, 1999). Many enterprises choose to pay the fees rather than reduce their emissions of pollutants. In the 2003 regulation, waste gas was

charged ¥0.6 per pollution equivalent,²² far below the actual costs of treatment.²³ There are no indications that charging fees based on total emissions reduced the amount of industrial waste gases and industrial SO₂ emissions since 2003 (Figure 5.7). Those countries that have been able to curb pollution discharges by adopting pollution charge systems, such as Sweden and the Netherlands, tend to set the emission fees at very high levels (Stavins, 2003; World Bank, 1999).

²² *Pollution equivalent* is used to represent the amount of pollutants discharged in kilograms. One kilogram of SO₂ equals 1 pollution equivalent. Total pollution equivalents equal total emission of the pollutant (in kilograms) divided by the pollution coefficient associated with each pollutant. For example, SO₂ has a pollution coefficient of 0.95, while soot has a pollution coefficient of 2.18. Total waste gas emission fees would equal 0.6 multiplied by the sum of pollution equivalents of the top three pollutants.

²³ Using recent litigation about illegal waste gas emissions as an example, the estimated waste gas treatment unit cost was ¥5.6 /kg for SO₂, ¥6.8/kg for NO_x, and ¥3.3/kg for soot (Zhen, 2016).

Figure 5.7: Industrial Waste Gas, in 100 million m³ and SO₂ Emissions, in Tons

SOURCES: China Environment Yearbook Editing Committee, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015.

Another implementation issue is related to the collection of the discharge fee itself. Many polluters actually delay or do not pay their pollution discharge fees. Out of the 6,205 key nationally monitored enterprises in 2015, 662 of them did not pay discharge fees; the total value of unpaid fees was ¥696 million (MEP, 2016b). A significant number of steel, cement, and power plants in such provinces as Hebei, Shanxi, Inner Mongolia, and Liaoning failed to pay the required fees. In May 2016, the MEP announced that it would conduct a special audit of pollution discharge and fee-collection activities targeting steel and coal industries, especially their SO₂, NO_x, soot, and dust emissions (MEP, 2016c).

By 2014, 16 provinces or cities raised their SO₂ pollution charge standards, some more than ten times the national standard (China Environment Yearbook Editing Committee, 2014). Beijing, for example, raised the SO₂ and NO_x discharge fee from ¥0.63/kg to ¥10 /kg. It also provided more incentives for low emitters (Beijing Environmental Protection Bureau, Beijing Department of Finance, and Beijing NDRC, 2013). Those emitting less than 50 percent of the emission standard need to pay only half of the required fees, while those emitting more than the standard need to pay double. The other governments within the Jing-Jin-Ji region also raised their pollution discharge fees (Table 5-1). The NDRC in 2014 decided to raise the SO₂ and NO_x discharge fee to 1.2 RMB/kg nationwide starting mid-2015 (NDRC, 2014). All provinces, except Tibet, have adjusted their pollution discharge rates to comply with the NDRC guideline.²⁴

Table 5-1: Summary of Pollution Discharge Fee System for the Jing-Jin-Ji Region

City or Province	SO ₂ (yuan/kg)	NO _x (yuan/kg)	Fee Differentiation Mechanism
Beijing	10	10	<ul style="list-style-type: none"> Those emitting less than 50% of the emission standard need to pay only half of the required fees, while those emitting more than the standard need to pay double.
Tianjin	6.3	8.5	<ul style="list-style-type: none"> If the emissions are higher than the standard, the fee rates are doubled. If emissions are between 80% and 90%, the rate is 90% of the original level. Such discounts are provided in increments of 10% with a maximum discount of 60% when emissions are 50% below the emission standard. For example, if emissions are between 70% and 80% of the emissions standard, the rate is 80% of the original level.
Hebei	2.4 starting 2015; 4.8 starting 2017; 6 starting 2020	2.4 starting 2015; 4.8 starting 2017; 6 starting 2020	<ul style="list-style-type: none"> Prior to 2020, if the emissions are less than 50% of the emission standard, the rate will be 50% of the original level. If emissions are higher than the emission standard for a specific pollutant or exceed the standard for total emissions, then the rate will triple. If both standards were exceeded, the rate will become five times the original level. After 2020, up to a 60% discount on fee rates if emissions are 50% below the emission standard.

Sources:

- Beijing Environmental Protection Bureau, Beijing Department of Finance, and Beijing NDRC, 2013
- Tianjin Development Research Center, 2014.
- Hebei Provincial Development Research Center, Hebei Provincial Department of Finance, and Hebei Provincial Department of Environmental Protection, 2014.

²⁴ Information about adjustment of pollution discharge fee standards can be accessed from Bureau of Environmental Supervision, n.d. information portal.

As more-advanced monitoring equipment has become widely applied, the Chinese government has started to validate pollution discharge fees using automated monitoring data. In 2011, the MEP required SO₂ discharge fees for all power plants above 300 MW to be validated using automated monitoring data after data validity checks. In 2013, 538 out of 608 power plants with capacity of 300 MW or above used automated monitoring data to estimate their SO₂ emission charges (China Environment Yearbook Editing Committee, 2014). The NDRC also asked all national key monitoring enterprises to install automated monitoring equipment and use automated monitoring data as the basis for calculating fees (NDRC, 2014).

5.4 Discharge Permit System

Originally aimed at water pollution only, the discharge permit system requires any polluters above a certain size to acquire a discharge permit before they can discharge pollutants. The rationale is to not only limit the concentration of discharges but also constrain the total amounts of pollutants each plant is allowed to emit. The permit is to specify the legally allowable maximum discharge level by concentration. In 1988, the NEPA defined a four-step procedure for implementing the discharge permit system: (1) registration of how and where the pollutants are to be emitted; (2) allocation of pollution amounts in mass flow rates based on total allowable load for the local area; (3) issuance of the permit; and (4) monitoring and enforcement of the permit (NEPA, 1988). The amendment to the APPCL in 2000 formally established the discharge permit system for air pollutants. Despite the fact that the discharge permit system has been mentioned in various special EPLs, it has not been confirmed by legislation; it has been implemented based only on administrative edicts.

If fully implemented, the discharge permit system could serve as a critical link between environmental quality targets and the pollution-control responsibilities of firms. However, many obstacles have prevented it from being effective. First, the current permit system does not cover all polluters. More than 200,000 discharge permits had been issued to businesses by 2014. This accounts for only half of the polluters who are currently paying discharge fees.²⁵ Second, there is no established standard method of measuring actual emissions. Lastly, businesses face no consequences if they fail to register and obtain proper permits because the permit system has not

²⁵ As mentioned in the previous section, roughly 400,000 enterprises paid the pollution discharge fees in 2013.

been formally legalized. Without a clear legal requirement, MEP or local EPBs cannot take enforcement actions.

5.5 Total Emission Controls

TEC for air pollution was introduced in the ninth FYP with emission discharge targets (measured in tons) set for the Two Control Zones. Prior to that, China's pollution control system focused on controlling concentrations of pollutants. To strengthen the implementation of this system, the central government started to assign emission targets to each province since the Tenth FYP. Local governments then allocated emission targets to different industrial sectors through the emission permit system.

The allocation of emission targets follows the guidelines provided by the MEP and is based on the emission levels of the last year of the previous FYP period. For example, the MEP in 2010 provided guidelines for local environmental protection agencies to develop their TEC plans during the 12th FYP period (MEP, 2010). The targets can be both for absolute reductions in emissions or relative reductions (in percentages) compared with the 2010 level. Detailed emission-reduction estimation methods were included in the guidelines for different sectors. Originally, 11 pollutants were included in the TEC system but the number of pollutants was reduced to only SO₂ and chemical oxygen demand (for water pollution) during the 11th FYP period to focus abatement efforts (Schreifels, Fu, and Wilson, 2012).

5.5.1 *Complementary Policies*

Realizing the connection between air pollution control and energy conservation, the Chinese government utilized TEC as the key strategy to minimize new increments of discharges of pollutants. A list of complementary policies, including both command and control and economic incentives, was introduced to achieve goals for total reductions of emissions.

The main strategies under TEC focus on reducing energy consumption, reducing fossil-fuel energy use, and controlling emissions from stationary and mobile pollution sources. The TEC program calls for reducing pollution discharges, accelerated phasing out of small and outdated production capacity, increased installation of pollution-control equipment in key industries, and control of NO_x from mobile sources (Lin and Elder, 2015).

As the power sector emits significant amounts of air pollutants, the State Council and the State Economic and Trade Commission required power producers to phase out small²⁶ generation units in 1997. During the tenth FYP period, the plan was to close down 15 GW of small and inefficient thermal power plants. However, only 8.3 GW were eventually shut down. During the 11th FYP period, the State Council called for the accelerated shutdown of small and high-polluting power generation units (State Council, 2007). The plan followed with close monitoring of implementation and inspection of results. The 11th FYP goal of closing down 50 GW of small and inefficient units was achieved a year and a half ahead of schedule (Meng, 2010). During the 12th FYP period, an additional 28 GW of high energy intensity and inefficient thermal power plant units were phased out (Yichen Wang, 2016). As a result of replacing small, inefficient power plants with larger and more-efficient units, the average coal consumption (in grams) per kilowatt-hour of electricity supplied were reduced by 14 percent between 2005 and 2014.²⁷

To strengthen efforts to reduce emissions of SO₂ and NO_x, the State Council developed plans requiring power plants and other high-polluting industries to install desulfurization and denitrification equipment (Chang and Wang, 2010). Initially, because of high installation and operating costs, installation rates were slow, and some plants installed but did not operate the equipment (Schreifels, Fu, and Wilson, 2012). In 2007, NDRC together with the then-SEPA mandated power plants to install continuous emission monitoring systems (CEMSs), which will transfer real-time data to EPBs and electricity grid companies (NDRC, 2007).

To subsidize the cost of installing and operating this equipment, the same document offered power plants an electricity price premium (0.015 RMB/kwh) equivalent to the estimated cost of pollution-control equipment operations if the plant installs and operates the desulfurization equipment more than 90 percent of the time. The document also indicated two levels of penalties: If the pollution-control equipment is operated between 80 and 90 percent of total generation hours, no price premium would be paid, and a penalty of 0.015 RMB/kwh will

²⁶ Here *small unit* was defined as one with electricity generation capacity below 50 MW. In 2007, the standard expanded to include 100-MW units operating more than 20 years, 200-MW units reaching the end of their life, coal-fired units with unit coal consumption 10 to 15 percent higher than the provincial average, any units that fail to meet environmental emission standards, and other units clearly identified by laws, regulations, or departments within the State Council.

²⁷ Calculated using historical electricity techno-economic indicator data reported in China Electricity Council's 2014 Electricity Industry Basic Statistics (China Electricity Council, 2015).

be imposed; if the pollution-control equipment is operated for less than 80 percent of the total generation hours, a penalty of 0.075 RMB/kwh will be imposed. Currently, separate price premiums were offered for desulfurization (0.015 RMB/kwh), denitrification (0.01 RMB/kwh), and dust-removal (0.002 RMB/kwh) equipment. Power plants are also allowed to franchise installation, operation, and management of pollution-control equipment to third-party companies.

These economic incentives together with heightened enforcement using CEMS significantly increased the installation of pollution-control equipment. Currently, 92.8 percent of China's coal-fired power plants with total capacity of 820 GW have installed flue-gas desulfurization (FGD) units (China Electricity Council, 2016b). Between 2010 and 2015, the installation rate of denitrification units (selective catalytic reduction [SCR] or selective noncatalytic reduction [SNCR] technology) also increased from 12 to 95 percent (China Electricity Council, 2016b). On the other hand, only 31.4 percent of coal-fired power plants have installed dust-removal equipment so as to reduce primary PM emissions.

5.6 Other Programs

The remaining three programs I discuss focus largely on post implementation assessment. They were all designed to provide more “teeth” for the MEP and local EPBs and hold local governments and heads of enterprises more accountable.

5.6.1 *Pollution Control within Deadlines*

Pollution control within deadlines is a policy that sets deadlines for corrective action by enterprises that fail to comply with environmental regulations. If the enterprise fails to fix the pollution problem, it may face fines or suspension of operations. The MEP has also set deadlines for key industries to reduce their emissions of air pollutants in key air pollution-prevention and – control regions. Each EPB compiles a list of violators and sends the list to the local governments. The local government then notifies these enterprises. The EPB assesses the result of the corrective action and compiles a list of enterprises that need to be shut down according to the monitoring data collected through the CEMS. This system works well with pollution control at point sources. However, actual implementation may face interference from the local government, especially if the violator has an important economic presence in the area.

5.6.2 Environmental Responsibility System

To hold local governments and state-owned enterprises responsible for environmental quality within their respective jurisdictions, the environmental responsibility system was created by the State Council in 1996 (State Council, 1996). It identifies the local people's governments as the entities responsible for environmental quality within their jurisdictions. It aims to provide local EPBs more support and to balance the priorities of economic growth and environmental protection. It is implemented in the form of written contracts or agreements with deadlines among heads of local governments or between governmental officials and head of enterprises (Ma and Ortolano, 2000).

A notable recent example is the *Assessment Measures for Air Pollution Prevention and Control Action Plan* (Clean Air Alliance of China, 2014) announced by the State Council that holds people's governments of all provinces and regions responsible for improving air quality within their jurisdictions. Ten indicators were identified that link the ten strategies identified in the action plan: adjustment and optimization of industrial structure, clean production, coal management and oil supply, treatment of small coal-fired boilers, industrial air pollution control, urban dust pollution control, vehicle emission prevention and control, energy efficiency in buildings and heat metering, capital investment in the prevention and control of air pollution, and the management of the atmospheric environment (Clean Air Alliance of China, 2014). Performance is measured on two aspects: (1) achievement of a certain percentage reduction in annual PM_{2.5} or PM₁₀ concentration levels, and (2) implementation of key pollution-prevention and control tasks. Figure 5.8 shows the indicators associated with each strategy. The environmental management for air pollution and air pollution control for the industrial sector account for the largest shares.

Figure 5.8: Key Pollution-Prevention and Control Tasks and Indicator Score

Source: Clean Air Alliance of China, 2014

5.6.3 Assessment of Urban Environmental Quality

Under this system, the environment in selected cities is evaluated annually based on an indicator system. The indicator system covers the areas of air, water, solid waste, noise, and forestation. The resulting overall indicator value is used to identify model cities as a way to motivate local governments to improve environmental quality in their jurisdiction (MEP, 2011).

5.7 Conclusions

Over the years, China has developed a list of programs to implement and enforce its environmental regulations aimed at improving the nation's environmental quality. The programs span pollution prevention to performance assessment. Both command and control and economic incentives are utilized. While environmental quality still relies heavily on the implementation of former strategies, the Chinese government has increasingly sought to take economic incentives and market-driven approaches into consideration.

The combination of TEC, pollution discharge permit, and pollution discharge fee systems have created the foundation for a cap-and-trade system. The TEC targets set the cap on emissions of air pollutants. The pollution discharge permit covers both pollution prevention and pollution-control efforts, and allocates emission rights. The pollution discharge fee serves as the “price” of the emissions.

However, many design and implementation problems hindered the effectiveness of these programs. The low pollution discharge fee provides limited incentives for businesses to take emission-reduction actions seriously. Minimal punishment for noncompliance with these programs weakens environmental protection agencies' grip on the situation. Lack of proper methods and reliable emission information prevents effective use of discharge permit systems and emission targets. While FYP targets and the target responsibility system seem to deliver partial results, integrating the above eight programs into an effective system may deliver similar, if not better, results at lower cost.

6. Prospects for Proposed Strategies in the Key Regions

In the past few years, the Chinese government has significantly increased its air pollution prevention and control efforts. As mentioned in previous chapters, many new regulations and action plans have been proposed. In this chapter, I conduct a cost-effectiveness analysis of the proposed Air Pollution Prevention and Control Action Plan by Guangdong Province with a special focus on the PRD region. This analysis serves three purposes: (1) to understand the extent to which the proposed strategies are likely to achieve air pollution-reduction goals identified by the region, (2) to estimate associated costs and health impacts if the Action Plan is successfully implemented; and 3) to assess the consequences of a non-compliance scenario to highlight the importance of enforcement and implementation. At the end of the chapter, I also discuss the policy implications of this analysis.

Guangdong Province is one of the most prosperous regions in China. It has a population of 107 million and has gone through tremendous economic growth during the past 30 years (Guangdong Provincial Statistics Bureau 2015). The consequences of such rapid economic development has resulted in major degradation of the environment. The region has suffered from high levels of air pollution. In 2013, the annual average PM_{2.5} concentration of Guangzhou were between 38 and 55 $\mu\text{g}/\text{m}^3$ (Department of Environmental Protection of Guangdong Province 2013), significantly higher than the WHO-recommended 10 $\mu\text{g}/\text{m}^3$ average annual concentration level from its 2005 guidelines (WHO 2006). These levels also fails to meet China's own national ambient air quality standard which sets the Class II level at 35 $\mu\text{g}/\text{m}^3$ for annual mean.

If the major metropolitan areas in the PRD region and elsewhere in China are to attain these air quality standards, the provincial and municipal governments need to reduce air pollution from both stationary and mobile sources. One primary cause of China's air pollution is the combustion of fossil-fuels (especially coal) for power generation, steel, cement, and winter heating. In China's three most important economic regions—namely, Jing-Jin-Ji, YRD, and PRD—burning coal is responsible for between 50 percent and 70 percent of PM_{2.5} pollution (The Global Commission on the Economy and Climate 2014). Guangdong would need to reduce combustion of coal by retiring old, inefficient, coal-fired power plants. Other air pollution-reduction strategies include programs to reduce energy demand, improve energy efficiency, and

implement fuel switching. Aside from stationary sources, increased car ownership is keeping NO_x concentration at high levels by offsetting the reductions achieved at large stationary sources in Guangdong and other provinces in China. The number of motor vehicles in Guangdong province rose from 1.7 million to 11 million between 2000 and 2012 (Shao, Wagner, and Yang 2014).

With the above background in mind, this analysis utilizes the Greenhouse Gas Air pollution Interactions and Synergies (GAINS) China air quality simulation model (Amann et al. 2008) at the regional level as the basis for a cost-effectiveness analysis of several existing air quality-control policies in China. This includes the Air Pollution Action Plan for the PRD, which has significant economic and health implications for the PRD region. The GAINS model was developed by researchers at the International Institute of Applied Systems Analysis.

Existing studies of air pollution-reduction policies in China under various scenarios focus largely on global, multinational, or national-level impacts. Subnational level scenario studies and tools are common in developed nations, but are far less common in developing ones. While some of the national-level analyses for China provide useful insights about the prospects of the proposed strategy, they do not consider the cost of implementing these strategies or the regional implications. As a consequence, these studies cannot assess the extent to which proposed strategies are feasible at the local level if they were to be fully implemented.

In Europe and North America, policies are typically evaluated for their efficiency and effectiveness based on estimated benefits and costs. Benefit-cost analysis is largely missing in China. In the absence of this information, local governments either hesitate to act or are overly confident about compliance with allocated emission-reduction targets. Preliminary results from this analysis provide a clearer picture for local decision makers in terms of the associated costs and expected air quality outcomes of planned policies. In addition, this analysis explores the estimated economic and health consequences of less-than-full compliance.

6.1 Methodology

6.1.1 *GAINS Model Description*

This study used the GAINS China (Amann et al. 2008) model at the subnational level to explore the implications of different air pollution-reduction strategies in the PRD region. The

GAINS model is an integrated assessment model that quantifies the effects of technology-based air pollution-control solutions on emissions and concentrations of major air pollutants and greenhouse gases (Amann et al. 2011)²⁸. The GAINS model can simulate air quality impacts from multiple sources of pollutants, and can estimate costs associated with the pollution control strategies implemented and the resulting health impacts. It is a 2D steady-state model, thus it ignores variation over time. Results in emissions, PM2.5 concentrations, and health impacts can be obtained in the form of maps or numerical tables.

Three groups of inputs were required to develop emissions scenarios and estimate their costs (Figure 6.1): 1) an activity pathway, i.e. social development and economic activities that drive energy consumption activity levels in different sectors and with different fuel types; 2) control scenarios, i.e. emissions prevention and control measures applied to different sectors and technologies; and 3) costs associated with pollution-control measures. The first group of inputs represents assumptions about activity levels related to energy use, transportation volumes, and industrial production. The second group of inputs includes various control technologies for different sectors that can achieve policy goals. The last group of inputs represents parameters related to pollution reduction costs associated with different technologies targeting one or more pollutants. It also includes assumptions on local labor costs, interest rates, and electricity costs.

Using the emissions inventory calculated based on inputs of activity levels and control strategies, a GAINS model grid with 1-degree-by-1-degree resolution generates results for PM2.5 concentrations and health impacts. This model resolution is equivalent to 12,000 square kilometer grid cells (at the equator). Such resolution is coarse for subnational analysis and is unable to identify air quality impacts from a particular point source. Other outputs include total pollution reduction costs associated with the implemented control strategies.

²⁸ The model is freely accessible to the public (<http://gains.iiasa.ac.at>). Modification of model inputs and generation of new scenarios require registration and a login.

Figure 6.1: Simulation Approach

6.1.2 Simulation Approach

In my analysis, I used one activity pathway and three control scenarios to generate policy scenarios. Each policy scenario was generated by combining an activity pathway with a control scenario. In each of these policy scenarios, I did not incorporate policies targeting carbon emissions reduction into the analysis. I compared estimated emissions reductions, resultant PM2.5 concentration levels, health outcomes and associated pollution-control costs for three different policy scenarios:

- The first scenario assumes *full compliance* with air pollution reduction strategies proposed in the 12th FYP. Strategies focus largely on controlling emissions of SO₂ and NO_x with some attention to PM2.5 sources.
- The second scenario assumes that, in addition to full compliance with the 12th FYP, *full compliance* is achieved for air pollution-reduction strategies specified in the PRD Action Plan, i.e., *Guangdong Province Pearl River Delta Region Clean Air Action Plan* (People's Government of Guangdong Province 2013) and the *Guangdong Province Air Pollution Prevention and Management Action Plan 2014–2017* (People's Government of Guangdong Province 2014b).

- The third scenario explores the extent to which *incomplete compliance* with the PRD Action Plan but full compliance with the 12th FYP would hinder the air pollution reduction outcome.

I use the third scenario to demonstrate the impact of poor or delayed implementation or enforcement of the Action Plan, drawing on past experiences in China (Xu, Williams, and Socolow 2009; Xu 2011). In fact, some of the policies included in the Action Plan, such as the accelerated introduction of vehicles that comply with the China 5 emissions standard for light-duty vehicles²⁹ in the PRD region, have already faced delayed implementation. China V emissions standard for heavy duty vehicles also faced delayed implementation due to lack of supply of high quality fuel (Q. Zhang, He, and Huo 2012). Although all the coal-fired power plants in the PRD region installed denitrification equipment by the end of 2013 (Xie 2014), five power plants representing 28.5 percent of total capacity in the PRD region were fined by the MEP in 2015 for inconsistent operation of their denitrification and desulfurization equipment (Chen 2015). Such difficulties encountered during policy implementation are not rare in China, and policymakers need to understand the associated consequences. I assume 80-percent compliance rate of policies for the power and industrial sector. A 20-percent noncompliance rate is chosen because it simulates approximately a one-year delay in implementation during a five-year period. Since the Action Plans are implemented between 2014 and 2017, such delay impacts the 2015 and 2020 simulation results.

In my work I conducted the following steps : 1) validation of the calibrated activity pathway embedded in the GAINS China model that includes regional data for the Guangdong Province; 2) development of the control strategies that include full compliance of the 12th FYP, Guangdong and PRD regional Action Plans, and a hypothetical control scenario that delays the implementation of the Action Plans; and 3) identification of actual pollution-control costs in China and an updating of cost estimations generated using GAINS embedded cost parameters.

²⁹ China 5 emissions standard refers to Limits and measurement methods for emissions from light-duty vehicles (GB18352.5-2013) (MEP and Standardization Administration of China 2013). It follows the European vehicle emissions standards precedent. It sets up emission limits for CO, hydrocarbons (HC), HC+NOx, NOx, and PM by vehicle type, mass and engine type (Gasoline versus Diesel).

6.1.3 Scenario Development

Below I provide a more detailed description of mathematical relationships within GAINS and information used to create scenarios and generate results.

6.1.3.1 Activity Pathways

The activity data from 2010 to 2050, including energy sources and fuel types, are based on the down-scaled IEA Energy Technology Perspective 2012 6 °C scenario, i.e. a continuation of existing trends (IEA 2012). The dataset includes energy and climate change targets listed under China's 12th FYP. Emission reduction results were calculated using the 2010 as baseline. Therefore, to provide some measure of validation of the GAINS China model for this particular application, I compared historical Guangdong Provincial 2010 energy consumption data to simulation results generated using the down-scaled 2010 activity data. However, due to data limitations, more detailed breakdowns of fuel use within individual sectors were based on pathways embedded under previous versions of GAINS China activity pathways.

The validation aimed to evaluate whether there were significant differences between the downscaled results and available Guangdong Provincial 2015 Statistics Yearbook (Guangdong Provincial Statistics Bureau 2015) data. By comparison, GAINS estimated total primary energy consumption in 2010 as 6138 petajoules, roughly 7 percent lower than the official data published in Guangdong Provincial Statistics Yearbook at 6541 petajoules³⁰ (Guangdong Provincial Statistics Bureau 2015). Considering the fact that sector breakdowns are not exactly compatible between IEA and GAINS, and the IEA estimates were intended for national level analysis, such differences are hard to avoid. Also, prior to the third National Economic Census (NEC) in 2014, the national total coal consumption statistics has been lower than the sum of individual provincial consumptions (Korsbakken, Peters, and Andrew, 2016). Table 6-1 compares the total consumption of energy and its composition between Guangdong Statistical Yearbook and GAINS estimates for the year 2010. The composition included in the GAINS activity pathway overestimated the share of coal, liquid fuel, and natural gas.

³⁰ Converted from 218,800,500 tons of standard coal equivalent with a conversion factor of 2.93076×10^{-5} petajoule per ton of standard coal equivalent

Table 6-1: Total Consumption of Energy and Its Composition

Fuel	Guangdong Statistical Yearbook Composition, in Percentage^a	GAINS Composition, in Percentage	Percentage Differences from Statistical Yearbook Composition
Coal	48.1	52.9	10%
Liquid fuel	29.1	31.3	8%
Natural Gas	3.7	4.5	22%
Other	19.1	11.3	-41%

SOURCES: ^a Guangdong Statistical Yearbook 2011, Table 7-2

6.1.3.2 Summary of Action Plan policies

In response to the State Council's call for action, the Guangdong provincial government announced a list of policies to support its achievement of specified air pollution reduction targets, including *Guangdong Province Pearl River Delta Region Clean Air Action Plan (2013-2015)* and the *Guangdong Province Air Pollution Prevention and Management Action Plan 2014-2017* (People's Government of Guangdong Province 2014b; People's Government of Guangdong Province 2013), hereafter referred to as the Action Plan.

The Action Plan includes the following targets:

- By 2017, the annual average concentration of PM_{2.5} in the Pearl River Delta must be reduced by 15 percent from 2012 level.
- The annual average PM_{2.5} concentration in Guangzhou, Foshan, Dongguan must be reduced by 20 percent compared to 2012, Shenzhen, Zhongshan, Jiangmen, Zhaoqing by 15 percent, and Zhuhai, Huizhou to fall below 35 µg/m³.
- The air quality of cities outside the Pearl River Delta must meet national standards, with an annual PM₁₀ concentration level lower than 60 µg/m³ and PM_{2.5} levels lower than 35 µg/m³.

To achieve these targets, a portfolio of strategies was also proposed in the Action Plan (People's Government of Guangdong Province 2014a). Table 6-2 summarizes Action Plan strategies implemented in the GAINS China model. The Action Plan covers the period between 2014 and 2017. However, GAINS is currently set up to calculate results in 5 year intervals. Thus,

target values mandated to be achieved after 2015 but before 2017 will be implemented in 2020 in GAINS model structure.

Table 6-2: Summary of Action Plan Strategies Implemented in GAINS

Sources	Target Pollutants	2015	2020
Power Plants	SO ₂	<ul style="list-style-type: none"> All coal-fired thermal power plants at or above 125 MW achieve integrated desulfurization efficiency above 95%.^a Coal-fired plants use coal with sulfur content below 0.7%.^a 	<ul style="list-style-type: none"> All coal-fired thermal power plants at or above 125 MW achieve integrated desulfurization efficiency above 99.1%.^c
	NOx	<ul style="list-style-type: none"> All existing coal fired power plants above 125 MW complete low NOx burner (LNB) and FGD retrofitting, and achieve integrated NOx-removal efficiency above 85%.^a 	<ul style="list-style-type: none"> All existing coal fired power plants above 125 MW achieve integrated NOx-removal efficiency above 85%.^a
	PM	<ul style="list-style-type: none"> All coal-fired power plants in the PRD region meet Thermal Power Plant Air Pollutant Emissions Standard (GB13223-2011) with soot emissions below 20 mg/m³, while those in non-PRD region achieve soot emissions below 30 mg/m³.^a 	<ul style="list-style-type: none"> All coal-fired power plants in the PRD region meet Thermal Power Plant Air Pollutant Emissions Standard (GB13223-2011) with soot emissions below 20 mg/m³, while those in non-PRD region achieve soot emissions below 30 mg/m³.^a
Industrial combustion	SO ₂	<ul style="list-style-type: none"> All industrial boilers with capacity above 20t/h (excluding those using clean energy) should install FGD facilities, reaching integrated desulfurization efficiency above 70%.^a Ceramics, plate-glass, and cement manufacturers using kilns with capacity larger than 7 million m²/year and fuel with sulfur content above 0.5% need to install high-efficiency dust-removal and FGD facilities.^b 	<ul style="list-style-type: none"> All industrial boilers with capacity above 20 t/h (excluding those using clean energy) should install FGD facilities, reaching integrated desulfurization efficiency above 80%.^a
	NOx	<ul style="list-style-type: none"> Coal fired boilers with capacities larger than 35 t/h need to install LNB (removal efficiency at 30%); Coal fired boilers with capacities larger than 65 t/h should install selective noncatalytic reduction (SNCR) equipment (removal efficiency at 60%).^d All industrial boilers with capacity above 20t/h (excluding those using clean energy) should install LNB facilities, reaching integrated denitrification efficiency above 30%.^a Dry cement clinker production lines with capacity larger than or equal to 2,000t/day need to install LNB and SNCR equipment, reaching integrated 	

		denitrification efficiency above 60%. Dry cement clinker production lines with capacity smaller than 2,000t/day must install LNR facilities, reaching integrated denitrification efficiency above 30%. ^b	
	PM	<ul style="list-style-type: none"> • Ceramics, plate-glass, and cement manufacturers using kilns with capacity larger than 7 million m²/year and fuel with sulfur content above 0.5% need to install high-efficiency dust-removal and FGD facilities.^b 	
Transportation		<ul style="list-style-type: none"> • From 2013, Implement National IV Heavy Duty Diesel Vehicle Emissions Standard.^a • From 2015, Implement National V Diesel Vehicle Emissions Standard, and National V Light Duty Vehicle Emissions Standard.^a • Phase out 90% “Yellow Tagged Vehicles”, i.e. those registered prior to 2005.^a • Supply National V Gasoline and Diesel.^a 	100% phase out of “Yellow Tagged Vehicles”. ^a
Agricultural		<ul style="list-style-type: none"> • Open air agricultural residual burning reduce by 80% 	Open air agricultural residual burning reduce by 100%
<p>^{a.} People’s Government of Guangdong Province, 2014b</p> <p>^{b.} People’s Government of Guangdong Province, 2013</p> <p>^{c.} Based on removal efficiency achieved by Guangzhou Hengyun Thermal Power Plant at “ultra clean emissions” level with SO₂ emissions below 20 mg/m³, NO_x emissions below 35mg/m³, and soot below 5mg/m³.</p> <p>^{d.} Guangdong Provincial Environmental Protection Department, 2012</p>			

6.1.3.3 Construction of Control Scenarios

Three control strategy sets were used to construct the three scenarios for this analysis: 1) GAINS embedded control scenario that assumes full compliance of the 12th FYP targets; 2) I constructed a control scenario that assumes full compliance of the Action Plan; 3) I constructed an additional control scenario that assumes 80% compliance of the Action Plan.

The model calculates air quality impacts in the time period between 2015 to 2050 in 5-year intervals for several control strategies based on policies proposed under the *Guangdong Province Pearl River Delta Region Clean Air Action Plan* and the *Guangdong Province Air Pollution Prevention and Management Action Plan 2014-2017* (People's Government of Guangdong Province 2014b; People's Government of Guangdong Province 2013). Since the Action Plans set clear targets for SO₂, NO_x, and PM 2.5, my analysis also focuses on these three pollutants.

Since the structure of the legislative mandates is not entirely compatible with the GAINS model structure, I have 'translated' these policy statements into the sectoral and technology structure within GAINS as much as possible. This allows for development and assessment of several control strategies. However, due to data limitations, some of the Action Plan strategies were not implemented. For example, strategies related to VOC control cannot be implemented in GAINS because the current model structure is not detailed enough to include strategies targeting specific sectors.

Control strategies to meet the requirements of the Action Plans are developed in the following ways. First, the timeline for introducing specific pollution-control measures implemented in the model follows the schedule specified in the Action Plans. Table 6-2 summarizes Action Plan components with associated implementation deadlines that were implemented in the control strategies.

Second, the application of pollution-control measures is intended to meet the emissions removal efficiencies required by the Action Plans. For example, for SO₂ emissions control at power plants, different technologies such as in-furnace limestone injection and flue gases desulphurization (FGD) have different removal efficiencies. To meet removal efficiency targets

specified in the Action Plans, plant operators much demonstrate that the weighted average removal efficiency rates of all control measures is sufficient. Table 6-3 provides an example for power and district heating plants of the relationship between each control technology's removal efficiency, percentage of capacity controlled, and resultant This example shows that by applying In-furnace control on 5% of the power and district heat plants, and wet flu gases desulphurisation on 90% of the power and district heat plants, the resulted weighted average removal efficiency will be 88%.

Table 6-3: Example of calculating removal efficiency based on capacity controlled

Sector	Fuel	Control Measures	Removal Efficiency, in Percentage	Capacity Controlled, in Percentage of fuel use	Weighted Average Removal Efficiency, in Percentage ^a
Power and district heat plants	Hard coal	In-furnace control limestone injection	60	5	88
		No control	0	5	
		Wet flue gases desulphurisation	95	90	

Note: ^a. Calculated as sum product of removal efficiency and capacity controlled

Third, thermal power plants need to meet emissions concentration limitations specified under Thermal Power Plant Air Pollutant Emissions Standard (GB13223-2011) according to the Action Plans. Thus, in addition to evaluating emissions removal efficiency, I made sure that implied emission factors, i.e., weighted average emission factors of relevant control technologies, are in compliance with required emissions standards. Table 6-4 provides an example of calculating implied emission factor based on removal efficiency, capacity controlled, and emission factor after abatement. This example shows that by applying ESP on 22.5% of the power and district heat plants, and HED on 77.5% of the power and district heat plants, the resulted implied emission factor will meet the Thermal Power Plant Air Pollutant Emissions Standard of 20 mg/m³ for key air pollution prevention and control regions.

Table 6-4: Example of calculating thermal power plant emissions standards for particulate

Sector	Fuel	Control Measures	Removal Efficiency, in Percentage	Capacity Controlled, in Percentage of fuel use	Emission factor after abatement, in mg/m ³	Implied emission factor, in mg/m ³ ^a
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Power and district heat plants	Hard coal	Electrostatic precipitator (ESP)	96	22.5	62.2	20
		High efficiency deduster (HED)	99.5	77.5	7.8	

Note: ^a. Calculated as sum product of capacity controlled and emission factor after abatement.

6.1.4 Estimation of Emission Reductions and Atmospheric Dispersion

The emission estimation follows the formula included in the GAINS model. The model estimates the current and future emissions using the following equation:

$$E_p = \sum_k \sum_m A_k ef_{k,m,p} X_{k,m,p}$$

E stands for emissions, p stands for pollutants, k stands for sources of pollution, and m stands for pollution-control and prevention activities. A_k is the activity level of source k; $ef_{k,m,p}$ is emission factors of pollutant p from source k after the implementation of control and prevention technology m (including no control option). $X_{k,m,p}$ stands for the deployment rate of control and prevention technology m for sources k and pollutant p.

The GAINS estimation of PM_{2.5} concentrations for China was calculated using linear transfer coefficients in the TM5 (Tracer Model 5) global chemical transport model at 1-degree-by-1-degree resolution (Amann et al. 2008). TM5 was used to develop reduced form source-receptor relationships that describe the spatial response of an air quality indicator to emissions of precursor pollutants from a source region. The source-receptor relationship has been validated by IIASA researchers for the GAINS Asia model which covers India and China (Amann et al. 2008). A similar approach has been successfully used in support of European Union air pollution policy (Amann et al. 2011). The implemented source-receptor relationship allows calculation of PM_{2.5} concentrations in a relatively short time.

6.1.5 Estimating the Cost of Emissions Reduction

To estimate emissions reduction costs, I considered annualized capital costs, fixed and variable operation and maintenance (O&M) costs, and variations of these costs depending on emissions-control technology and energy source type. Two sets of cost parameters and results can be calculated from the GAINS model, one based on pollution-control costs established in

international markets, and the other based on cost adjustments compatible with local conditions. For international market costs, GAINS embedded calculation assume that there exists a free market for air pollution-control equipment, and all countries can access these products at the same price (Klimont et al. 2002). For local market conditions, the calculation are adjusted based on purchasing power parity and whether the technology is mature enough to allow local manufacturing capacity to exist. Local market costs can be cheaper than those found in global markets.

The cost estimation includes the following steps. First, total capital costs for control technologies are estimated using GAINS-embedded international or local cost parameters. If the information is available, GAINS provides cost parameters for three different thermal capacity sizes. For example, for PM removal, the cost parameters for capacities between 0 to 5 megawatt thermal (MWth), 5 to 50 MWth, and 50 MWth or larger are provided. The capital costs also depend on whether the technology is installed for retrofitting or for a new plant. Second, the capital costs are annualized based on a chosen interest rate. Third, fixed and variable O&M costs are estimated. The annual fixed O&M costs are assumed to be 4 percent of total capital investment. The variable O&M costs include labor, electricity, and sorbents and waste disposal costs. Fourth, unit cost per PJ thermal input is estimated using the following formula.

$$C_{PJ} = \frac{I^{an} + OM^{fix}}{pf} + OM^{var}$$

C_{PJ} stands for unit costs per PJ. I^{an} is annualized capital cost. OM^{fix} and OM^{var} are fixed and variable O&M costs. pf stands for capacity utilization factor, i.e. operating hours per year at full load.

Lastly, the unit costs per ton of pollutant emissions removed is estimated using the following formula.

$$C_{pollutant} = C_{PJ} / (ef * \eta)$$

$C_{pollutant}$ stands for unit costs per ton pollutant emissions removed, C_{PJ} stands for unit costs per PJ, ef is unabated emission factor, and η is the emission removal efficiency associated with different control technologies.

Total annual emissions reduction costs are estimated by multiplying emissions reduced and unit costs per ton pollutant emissions removed. Annual costs estimated from the GAINS model is reported in 2005 Euros which I then converted to 2015 U.S. dollar³¹. The discount rate is assumed to be 10 percent per year. The calculation assumes 20 years of remaining lifetime for existing power plants and industrial boilers or furnaces, and 30 year lifetimes for new plants and equipment.

I conducted a literature review to identify evidence of actual costs of installation and operations of pollution-reduction equipment in China. Sun et al. estimated multi-pollutant-abatement costs of the power sector in the YRD region and collected investment, O&M, and fuel costs data among power plants in the YRD region (Sun et al. 2014). Using cost data for FGD, SCR, fabric filter (FF) and ESP listed in this study, I made adjustments to the abatement costs to reflect actual China market conditions. **Error! Reference source not found.** summarizes the control technologies identified for this comparison. The update used the percentage estimated in column (E) of Table 6-5 to recalculate cost associated with the above mentioned four control technologies where I was able to identify China local costs. Total abatement costs were recalculated assuming cost adjustments for these four technologies while keeping the rest unchanged.

Table 6-5: Comparison of Chinese Actual Capital Costs and International Market Capital Costs of Selected Pollution-control Technologies

Control Technologies	GAINS embedded international market Capital Costs (2005 Euro/kWth) ^a	Chinese Actual Capital Costs (2010 dollar/MW) ^b	Chinese Actual Capital Costs (2005 Euro/kWth) ^c	Actual capital costs as percentage of international market capital costs (%)
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³¹ The conversion of units takes the following assumption into consideration. According to U.S. BEA, the Implicit Price Deflator for 2015 is 109.998 and for 2005 it is 91.988 when 2009 index is set to equal 100 (U.S. Bureau of Economic Analysis 2016). Thus, a 2015 dollar is equivalent to 1.195 2005 dollar. In 2005, 1 U.S. dollar on average equals 0.8041 Euro. Thus, converting 2005 Euro to 2015 Dollar requires multiplying 2005 Euro by 1.195/0.8041=1.4869

(A)	(B)	(C)	(D)	(E)
SO₂ Control				
FGD	49.93	29556.07	8.23	16.5
NO_x Control				
SCR	10.22	18176.98	5.05	49.4
PM Control				
ESP	8.64	14778.03	4.12	31.3
FF	10.49	11822.43	3.28	47.6
Note: <ul style="list-style-type: none"> a. GAINS model included cost parameters for each control technology at different thermal input capacity. Costs listed here assumes power plants with 1800 MWth capacity and a capacity factor of 38%, i.e. roughly 700 MW. The capital costs per kWth could be higher if a smaller capacity was considered. b. Sun et al., 2014, Table 3. c. The conversion of units takes the following assumption into consideration. The energy conversion efficiency was assumed to be 38%. According to U.S. BEA, the Implicit Price Deflator for 2010 is 101.221 and for 2005 it is 91.988 when 2009 index is set to equal 100 (U.S. Bureau of Economic Analysis 2016). Thus, a 2005 dollar is equivalent to 0.91 2010 dollar. In 2005, 1 U.S. dollar on average equals 0.8041 Euro. Thus, converting 2010 dollar/MW to 2005 Euro/kWth requires multiplying 2010 dollar/MW by $0.38 \times 0.91 \times 0.8041 \times 0.001 = 0.000278$ 				

6.1.6 Estimating Health Impacts

The GAINS Asia model contains algorithms and data to estimate months of loss in life expectancy as the health impact metrics. The loss of life expectancy is calculated using population, estimated change in PM_{2.5} concentration, life table with life expectancy by age group, and relative risk factors associated with 10 µg/m³ incremental increases in PM_{2.5} concentration. Within each grid cell, the model apply a relative risk factor to the baseline mortality rate of each age group of a population. It calculates the life year lost due to change in PM_{2.5} concentration for each age group given the life expectancy of the population. The average months of life expectancy loss is then calculated by dividing the total life year lost in the grid cell with the total number of population in the cell. Details about the methodology for calculating health impacts are provided in Mechler, Reinhard, Markus Amann, and Wolfgang Schöpp (2002) and Amann et al. (2008).

The interpretation of health impact estimates requires caution. Although I calculated and mapped the differences in months of life expectancy change between years, and compared them across scenarios, such change can only be interpreted as an indicator of increased or reduced health damage. The interpretation of the absolute value of change between two different years is not straightforward. For example, the months of life expectancy loss at a single grid cell in year 2015 means the average loss in life expectancy assuming the population will be exposed to that

particular level of PM 2.5 concentration for the rest of their expected life. Thus, only the comparison between different scenarios under the same year is meaningful.

6.2 Results

The proposed Action Plans aim to generate additional emissions reductions of SO₂, NO_x, and PM_{2.5}. The plans assume that reductions of these pollutants will in turn lead to further reductions in concentrations of PM_{2.5}. In the following section, I present the results of this assessment. First, estimated emissions reductions are presented for each of the three key pollutants, namely, SO₂, NO_x and PM_{2.5}. Second, I discuss the expected change in PM_{2.5} concentration levels. To help decision makers understand costs associated with installing and operating the prescribed pollution-control equipment, I also present estimates of pollution-control costs.

6.2.1 *Short Term Emissions Reductions*

If additional measures specified in the Action Plans were implemented, the PRD region would be able to achieve further SO₂ emissions reductions compare to implementing the 12th FYP by 2015. As illustrated in **Error! Reference source not found.**, the Action Plan will reduce SO₂ emissions by 145 kilotons (kt) or 17 percent. Most of these reductions come from installing desulfurization equipment in power plants, industrial boilers, and from improving industrial processes.

Figure 6.2: SO₂ emissions and sources of emissions reduction by scenario

According to the Guangdong Provincial Statistical Yearbook, in 2014, 762 kt of SO₂ were emitted (Statistics Bureau of Guangdong Province 2014) compared to the 835 kt of SO₂ emissions estimated by GAINS for 2015, assuming implementation of the 12th FYP policies beginning in 2010. Considering the fact that *both* the 12th FYP and the Action Plan have been implemented during this period, such comparisons indicate the potential for noncompliance. GAINS estimated SO₂ emissions assuming full compliance with *both* the 12th FYP and the Action Plan are below 700 kt.

Implementation and enforcement of environmental legislation have been challenging in China. Past experiences in controlling SO₂ emissions in power plants in China reflect the ongoing struggle. Since the early 2000s, the Chinese government has been using FYP targets to encourage the installation and operation of SO₂-control equipment, in particular, SO₂ scrubbers. At first, government incentives made rapid deployment of scrubbers feasible from a cost perspective (Xu 2011). However, many of these scrubbers were actually not being operated properly (Xu 2011). The Chinese government has made efforts to resolve this issue by realigning

financial incentives and requiring the installation of continuous monitoring systems. It further requires that these data be transferred in real time to the government (Xu, Williams, and Socolow 2009). Past studies have shown that, in China, both the probability of detecting noncompliance and the penalties imposed on violators are low. By providing stronger financial incentives and requiring real-time monitoring data, the Chinese government was able to improve the probability of compliance with its environmental policies (Xu 2011). On the other hand, there are still concerns related to the operation and management of CEMSs and the quality of real-time monitoring data (X. Zhang and Schreifels 2011).

In terms of NO_x emissions, the PRD region should be able to achieve further emissions reductions beyond what it could achieve implementing only the 12th FYP by 2015. As illustrated in **Error! Reference source not found.**, according to the GAINS model, the Action Plan should be able to achieve additional NO_x emissions reductions of 299 kt or 27 percent. Most of these reductions would come from installing denitrification equipment in power plants and industrial boilers, and from improving industrial processes and introducing more fuel-efficient road vehicles.

Figure 6.3: NOx Emissions and Sources of Reduction by Scenario

Similar benefits could be observed for PM_{2.5} emissions as well (**Error! Reference source not found.**). The PRD region installed more dedusters in power plants; banned open-air burning of wood, coal, and waste; and significantly controlled volatile organic carbon (VOC) emissions. As a result, under the Action Plan scenario, according to the GAINS model, PM_{2.5} emissions should have been further reduced by 54 kt PM_{2.5} or 13 percent beyond estimates of emissions reductions from the 12th FYP by 2015. Most of these further reductions come from installing fabric filters in power plants; banning open-air burning of agricultural waste; and more stringent emissions control on road transportation.

Figure 6.4: PM2.5 Emissions and Sources of Reduction by Scenario

6.2.2 Meeting Short Term Targets

The PRD region is subject to air pollution-reduction targets from various levels of governments and policymakers. The estimated key air pollutant emissions levels from the GAINS model were evaluated against the *2015 and 2020 Emission Reduction Targets/Ranges for the PRD Region endorsed by the government of Hong Kong and Guangdong* (Hong Kong Information Service Department 2012). These are illustrated in **Error! Reference source not found.** Both the 12th FYP and the newly proposed Action Plans would enable the PRD region to meet the proposed SO₂ and NO_x emission-reduction targets specified for 2015 and 2020. However, it is evident that the Action Plans could potentially introduce much deeper emissions reductions in the short run.

Figure 6.5: SO₂ and NO_x Emissions Reduction against Targets

6.2.3 Long-term Implications

While the analysis suggests that the Action Plans could bring about the desired air pollution-reduction in the short- term, it is also useful to understand the longer term implications of this analysis. **Error! Reference source not found.** summarizes the sectoral breakdown of emissions sources for SO₂, NO_x and PM_{2.5} between 2010 and 2030. For SO₂ emissions, the Action Plan could lead to substantial reductions by targeting the power sector. However, from 2015 forward, more attention to industrial sources such as industrial boilers and industrial processes could further curb emissions of SO₂. For NO_x emissions, the Action Plan could bring larger reductions from the power and industrial sectors. However, in the longer term, the transportation sector will be the key source of emissions. For PM_{2.5} emissions, while the Action Plan would significantly reduce emissions from the power sector, industrial sources and the residential sector would require more attention for future emission-reduction efforts.

Figure 6.6: SO₂, NO_x, and PM_{2.5} Emissions by Sector

As illustrated in **Error! Reference source not found.**, the red line represents projected emissions of SO₂, NO_x, and PM_{2.5} if only the 12th FYP strategies are fully implemented, while the blue bar represents emissions if the Action Plans is also implemented. The Action Plans could constrain a rebound of future emissions driven by economic growth and increased urbanization. This observation indicates that air pollution-control will require a continuous effort to extend beyond any short-term success.

Figure 6.7: SO₂, NO_x, and PM_{2.5} Emissions by Scenario

Note: Red lines represent emissions from the 12th FYP scenario. Blue bars represent emissions from the Action Plan scenario.

6.2.4 Air Quality Impacts

The projected reductions in emissions overall indicate promising results from the Action Plan, if it is implemented. It is the reductions in concentrations of PM_{2.5}, in particular, that would have the most significant impact on human health. There is no official statistics on the PM_{2.5} concentration level in Guangdong or PRD region for the year 2010. One study shows that in 2010, the annual average concentration of PM_{2.5} in Guangzhou was between 35 and 63 $\mu\text{g}/\text{m}^3$ with the highest daily concentrations reaching 271 $\mu\text{g}/\text{m}^3$ (Liu et al. 2013). By comparison, the GAINS model projected a baseline PM_{2.5} concentration on the higher end of the above-mentioned range near the Guangzhou area. Figure 6.7 illustrates the projected changes in concentrations of PM_{2.5} across the policy scenarios if only the 12th FYP is implemented in comparison to the Action Plan for the PRD by 2020. Implementing the Action Plan would result in reductions of 20 to 25 $\mu\text{g}/\text{m}^3$ in PM_{2.5} concentrations while implementing the 12th FYP

would lead to only 15 to 19 $\mu\text{g}/\text{m}^3$ of PM2.5 concentration reduction among the central areas of the PRD region, i.e., in Guangzhou, Shenzhen, Dongguan, and Foshan cities.

Figure 6.8: Changes in Concentrations of PM2.5 by Scenario, in $\mu\text{g}/\text{m}^3$

6.2.5 Costs of Pollution-control

To project implementation success, it is important to understand the costs of installing and operating pollution-control equipment proposed under various strategies. There is a substantial difference between abatement costs under international and local cost assumptions. Compared with GAINS international market cost assumptions, the actual costs in China for FGD, SCR, EAP and FF are 16.5, 50, 31, and 48 percent of GAINS assumed costs based on calculations shown in 6-5. After adjusting the abatement costs for these technologies with actual Chinese market cost data, the total abatement cost would equal €4 billion in 2005 euro rather

than €6.2 billion in 2005 euro projected by GAINS as shown in Table 6-6. According to these limited comparisons, actual implementation and operational costs of key abatement technologies in China are likely to be lower than international market costs.

Table 6-6: Abatement Cost Break Down in Millions of 2005 Euros

Costs	International	China Capital Cost as Share of International Market Cost, in Percentage	Adjusted Value
SO₂ total	1,928		458
Of which FGD	1,761	16.5	291
NO_x total	2,843		2,600
Of which SCR	480	49.4	237
PM total	1,421		906
Of which ESP	216	31.3	68
Of which FF	700	47.6	333
Total abatement	6,192		3,963

In 2015, implementing the Action Plan specified air pollution-control strategies would have cost between €4 billion and €6.2 billion in 2005 euro or \$5.8 billion to \$9.2³² billion in 2015 U.S. dollar. Thus, air pollution-control strategies proposed under the Action Plan would cost the region between 0.5 and 0.8 percent of its 2015 GDP at ¥7.2 trillion in year 2015. Such costs are hard to ignore, especially when regional political leaders are trying to maintain Guangdong's economic position in China relative to its many other provincial competitors.

6.2.6 Health Impacts

For the year 2015, ambient air pollution will lead to a loss in statistical life expectancy of 41 to 55 months if only the 12th FYP strategies were implemented near the center of PRD region. These statistics would be reduced to 40 to 43 months if additional Action Plan strategies were implemented. As illustrated in **Error! Reference source not found.**, additional efforts to reduce air pollution could lead to around three months of avoided loss of life expectancy in the center area of the region in 2020. Meaning, if the population in 2020 were exposed to the level of PM2.5 concentration resulted from full compliance of the Action Plan for the rest of their

³² The conversion of units takes the following assumption into consideration. According to U.S. BEA, the Implicit Price Deflator for 2015 is 109.998 and for 2005 it is 91.988 when 2009 index is set to equal 100 (U.S. Bureau of Economic Analysis 2016). Thus, a 2015 dollar is equivalent to 1.195 2005 dollar. In 2005, 1 U.S. dollar on average equals 0.8041 Euro. Thus, converting 2005 Euro to 2015 Dollar requires multiplying 2005 Euro by 1.195/0.8041=1.4869

expected life, they can avoid three months of loss in life expectancy, compare to the same population who were exposed to the level of PM2.5 concentration resulted from full compliance of 12th FYP only.

Figure 6.9: Health Impact by Scenario

6.3 Discussion of Noncompliance Scenario

While the above results suggest improvements in the PRD's future air quality are possible if the actions under the 12th FYP and the Action Plan are implemented, the assumption of full compliance is optimistic. I have created a third scenario that assumes 80 percent compliance rate with the Action Plan proposed strategies. This means that 20 percent of the intended installation does not happen. **Error! Reference source not found.** summarizes the results of this scenario for each of the three key air pollutants. For all three pollutants, missing 20 percent implementation leads to a significant increase in pollution emissions. The failure to fully comply in the power and industrial sector leads to significantly higher SO₂ and NO_x emissions; this is not the case for PM_{2.5}. In the case of NO_x, noncompliance leads to almost double the amount of emissions in the power sector than in the scenario of full implementation of the Action Plan.

Figure 6.10: SO₂, NO_x, and PM_{2.5} Emissions by Scenario and by Sector

As a consequence of significantly increased emissions of air pollutant, the estimated reductions in concentrations of PM 2.5, as illustrated in Figure 6.10, is around 18 $\mu\text{g}/\text{m}^3$ in the central area of the PRD region, 2 $\mu\text{g}/\text{m}^3$ lower than the magnitude under the scenario in which the Action Plan strategies are fully implemented. The analysis illustrates the potential negative consequence of failed enforcement of government policies. As discussed in the next section, the potential health consequences of noncompliance will have a direct impact on people's quality of life in this region.

Figure 6.11: PM2.5 Concentration Differences by Scenario, in $\mu\text{g}/\text{m}^3$

Figure 6.14 compares the estimated health impacts in terms of change in life expectancy loss between the full compliance and 80 percent compliance of the Action Plan scenarios. Full compliance of the Action Plan strategies will lead to between 38 and 40 months of loss in life expectancy in 2020 in central area of PRD. If the local EPBs in the PRD fail to enforce the proposed strategies, the expected loss of life expectancy will be increased to between 40 and 42 months in 2020, around 2 months of increased loss in life expectancy. While there are uncertainties associated with these estimates, the point is clear: Even a 20-percent level of non-compliance is likely to lead to significant impacts on people's health.

Figure 6.12: Health Impact Differences by Scenario, in Months

6.4 Conclusions

The above analysis examines the likely effectiveness of increased government efforts towards solving the PRD's air pollution challenges from several perspectives. A list of currently proposed strategies was identified that may be implemented on top of the National 12th FYP. After translating these strategies into GAINS inputs, GAINS was used to estimate emissions

levels and concentrations of PM_{2.5}. Results showed that when assuming full compliance, the PRD region could achieve its desired environmental outcomes except in its central area near Guangzhou and Foshan. The costs associated with full compliance are significant, running between 0.5 and 0.8 percent of the region's 2015 GDP. When using actual Chinese cost data, I find that actual implementation costs may be lower.

The analysis of the impacts of a noncompliance scenario demonstrates the magnitude of negative consequences decision makers could expect if they fail to enforce and monitor implementation. Results showed that even a 20 percent noncompliance of the Action Plan would lead to higher emissions, nonattainment of the national PM_{2.5} concentration standard, and 2 additional months of loss of life expectancy for residents within the PRD in 2020.

This study has limitations. The spatial resolution of the grid is too coarse to provide more detailed regional variations. Some of the Action Plan strategies were not able to be implemented in the GAINS model, thus the cost estimation is likely an underestimate, so are the estimated reductions in PM_{2.5} concentrations and associated reductions in health damage. There are uncertainties associated with the emissions estimation as well, as this model did not take a detailed bottom-up approach to estimate emissions from individual sources.

Despite these limitations, the message is clear. Improving air quality will require continuous efforts to constrain emissions. The necessary emission-control technologies are widely available in China, and Chinese companies have wide experience operating these technologies. The Chinese government has already implemented a large number of policies addressing air pollution through the 12th FYP, the PRD Action Plan, and other regional incentives, demonstrating its intention to significantly reduce air pollution levels. At the same time, past experience shows problems in proper implementation and enforcement of the legal mandates.

This study illustrates the consequences of successful and delayed implementation of these mandates, highlighting the importance of timely and stringent enforcement. Enforcement of the law requires a well-maintained and geographically representative monitoring network. Only with consistent, credible monitoring data can the effectiveness of policies be evaluated and adjusted as necessary to achieve air quality standards.

7. Conclusions

In this dissertation I have assessed China's past and current efforts towards preventing and controlling air pollution during a period of rapid economic growth. I first summarized the current status of air quality in China and the costs of pollution imposed on the economy and public health. I then reviewed the institutional and policy designs of China's air pollution regulatory strategies. Finally, I conducted a simulation to illustrate the potential effectiveness of the Action Plan and consequences of noncompliance using the PRD region as a case study.

I made several unique contributions through this dissertation. First, by conducting a detailed review of historical evolution of China's environmental regulatory system, I gained new insights about drivers of policy change, implementation, and enforcement. Second, by assessing policy instruments and programs implemented to attain air pollution standards, I identified design problems and implementation challenges. Third, the case study of PRD region is a rare analysis of cost and effectiveness associated with implementing air pollution policy in China.

In Chapter 1, I identified several factors that have led to China's poor air quality. China experienced unprecedented economic growth over the past three decades. High levels of industrial production and heavy coal consumption have brought with them severe environmental degradation, particularly of China's air. Income growth has led to higher demand for and consumption of energy, which has more than offset the benefits of improvements in energy efficiency. Combined with lax implementation and enforcement of environmental regulations, China failed to achieve significant air pollution reductions until Prime Minister Li Keqiang declared a "war on pollution" following a severe pollution incident experienced by residents of Beijing in 2013.

According to the theory of externalities summarized in Chapter 2, environmental regulation should be designed to make polluters internalize the cost of the environmental damage they cause. Policy designs to control pollution include two types of policy instruments: command and control regulations and market-based regulations. While in theory, market-based regulations are generally superior to command and control in terms of inducing polluters to adopt the least-cost means of reducing pollution, when assessed against different institutional and political backgrounds, this is not always the case. Theory does emphasize the importance of

understanding local institutions and effective implementation and enforcement to ensure that a policy's potential environmental benefits are fully realized.

Chapter 4 pointed out that, over the years, China has developed a comprehensive environmental legal system that is based on one basic environmental law and several special environmental laws that cover different pollution sources. It also includes pollution prevention and control programs. Updates to these laws, have, however, been infrequent and tend to be triggered by environmental crises. China has set more stringent ambient air quality standards based on an improved understanding of pollution sources and their health impacts. The current standards include six pollutants. Chinese cities are striving to meet the new Class II national standards for PM_{2.5}, which have been set at 35 ug/m³. While Chinese government has strengthened ambient air quality standard, the color coding system used to provide qualitative assessment of air quality for Chinese residents can be misleading as the level of PM_{2.5} that is considered unhealthy elsewhere in the world can be categorized and colored as moderately polluting. China has also developed a corresponding set of environmental regulations to attain these air quality standards.

Despite these modifications and the expansion of the regulatory legal system, the attainment of environmental goals has largely been achieved through “rule of mandates” rather than “rule of law”. My analysis of China's environmental regulation administrative structure finds that China's environmental protection agencies operate in a difficult, although improving political environment. The MEP was elevated from a bureau within another ministry to an independent ministry under the State Council in 2008. However, the local EPBs are still neither institutionally nor financially independent from the local governments, making the implementation and enforcement of environmental regulations by the EPBs largely dependent on the local leader's political agenda. By including environmental targets into the FYP target-responsibility system, the central government has shown its desire to emphasize environmental pollution prevention and control. The elevation of environmental targets from non-binding to binding targets serves as a tool to hold local leaders accountable for environmental quality within their jurisdictions, and has also provided incentives for local leaders to provide resources to support environmental protection activities.

The analysis in Chapter 5 indicates that China still has deficiencies in the design and implementation of its programs to attain environmental quality standards. The EIA, the Three

Synchronizations, the TEC system, the Discharge Permit system, and the Pollution Discharge Fee system are the key programs that if implemented effectively could potentially prevent and control air pollution from project planning to operation. However, each of these programs has both design problems and implementation challenges. Failure to enforce any of them means added risk of generating excessive amount of pollution. Since 2015, China has been taking steps to improve the policy design of the EIA, the Discharge Permit System and the Pollution Discharge Fee system. These upgrades are promising, but are subject to implementation risks.

Since the declaration of the “war on pollution” in 2013, China has identified key regions for heightened air pollution prevention and control efforts. More stringent pollution reduction targets were imposed on the Jing-Jin-Ji, YRD, and PRD regions. This call to action was the first outside China’s regular FYP cycle, indicating an extremely urgent need to take action. My simulation of the effects of this call to action on emissions in the Pearl River Delta indicates that if local government can effectively implement the pollution prevention and control strategies that have been identified, emissions could meet government standards. According to the analysis, rapid reduction of air pollution in the short run has long term environmental and health benefits. However, if targets are missed, even by a small percentage, environmental damages and health impacts will be substantially higher.

Ever since 2013, government efforts to follow up on implementation of air quality programs have been extensive. A target for improving environmental quality was introduced as a FYP target. It has been elevated from a non-binding to a binding target. The 13th FYP now includes protection of the natural environment as a priority target, holding local government leaders accountable for improving environmental quality within their jurisdictions. Amendments were made to the nation’s basic and some of the special environmental laws related to reducing air pollution. The government has introduced more stringent air quality standards that cover a wider range of pollutants. The central government has also actively sought to update various policies and programs that target implementation and enforcement of environmental regulations by provincial and local governments.

With these positive developments in mind, the following discussion focuses on issues and trends in need of further improvement and government attention. The discussion follows the structure of the dissertation itself, starting with a discussion of environmental regulatory institutions and policy design, followed by prospects from the PRD case study. While not

comprehensive, this discussion is intended to highlight priority issues that Chinese decision makers will need to consider when developing future strategies.

7.1 Institutions

By including environmental quality as a binding target in the 12th and 13th FYPs, the central government has signaled its heightened focus on improving the nation's environment. The central government still favors a traditional top-down approach that takes the form of a target responsibility system to hold local governments accountable for policy goals. Such a choice is not surprising, as it worked for enforcing the one-child policy. Experiences during the 11th and 12th FYPs periods (from 2005 to 2015) showed that tying a cadre's future political career to environmental performance can serve as an effective incentive.

7.1.1 *Limitations of Enforcement through FYPs*

Rule by FYP, however, can be problematic. First, the FYP is subject to the inherent weaknesses of the indicator system used to enforce it. The indicator system evaluates only whether a local government passes or fails an indicator, but fails to capture how such a target was achieved. For example, local governments in various regions used temporary power cuts as a means to achieve emission-reduction targets toward the end of the 11th FYP (Jiang 2010). Such an approach can be costly. Rolling blackouts not only reduced productivity but also led to higher operating costs for the impacted firms (Fisher-Vanden, Mansur, and Wang 2012). As governments expand the number of polluting entities targeted to include smaller polluters, the grip that local governments have on enforcement will be diminished. The remaining polluting equipment that needs to be replaced or phased out is not owned by large enterprises. Verifying policy implementation will be challenging for a local government and administrative costs are likely to increase.

7.1.2 *Rule of Law*

The Chinese government will need to consider further strengthening the rule of law with respect to environmental protection. The amendments to the basic environmental law and the Air Pollution Prevention and Control law were a good start. The changes provided more opportunities to use litigation in the courts as a way to hold polluters accountable. Although the number of cases is still limited, environmental litigation against polluters has yielded

significantly higher numbers and amounts of fines and penalties in recent years compared to the past (Wong 2015). However, under current law, only a limited number of NGOs have the qualifications and capacity to bring lawsuits against polluters. The extent to which NGOs can truly exercise legal mechanisms for enforcing pollution prevention and control remains to be seen.

7.1.3 Role of Public Participation

Public participation in the regulatory process will need to be enhanced. This dissertation does not describe voluntary measures or public participation in detail, but they are also important. The public has tried to voice its demand for higher environmental quality in China. The Chinese government collects information about the number of letters and visitors that have complained about pollution that are received by the government each year. The number of letters complaining about air pollution increased thirteen-fold between 1995 and 2010, while visits to government offices from individuals with complaints about air pollution increased between 1995 and 2005, but declined thereafter (China Environment Yearbook Editing Committee 1996; China Environment Yearbook Editing Committee 2011). As the government works to make more data publicly available, ordinary citizens will have a greater ability to identify problems and call for government action.

7.1.4 Develop Outcome-oriented Targets

When officials from the Chinese central government think about holding local government officers accountable by setting targets for them, they may wish to emphasize those targets directly related to environmental quality like concentrations of pollutants and health outcomes, rather than total emissions alone. When assessing the attainment of FYP environmental goals, efforts have been focused on reducing total emissions of pollutants. While emissions of SO₂ and NO_x serve as precursors for PM_{2.5} formation, simply focusing on reducing emissions can be misleading. Such an emphasis on one or two pollutants could be the result of gradual improvements in understanding the sources of pollution. In the future, however, to truly emphasize implementation and enforcement of more comprehensive, multi-sector and multi-pollutant strategies, a quality based target maybe more effective in bringing true environmental and health benefits.

7.2 Policy Design

Environmental progress made so far has largely relied on FYP targets and associated command and control policies. Some argue that China's environmental quality improvements are a consequence of these "low hanging fruits. . . amenable to command and control measures and infrastructure upgrading" (OECD 2013). While such tools follow China's traditional approach and have led to partial attainment of environmental goals, they provide little incentive for polluters to seek the most cost-effective ways to reduce emissions.

The Chinese government is expanding its environmental policy instruments to include more market-driven approaches. However, the recently introduced pollution discharge levy system has several issues with implementation. First, the initial levels of the emissions levy have been set too low to truly motivate polluters to reduce pollution. Second, enforcement has been weak. And third, collection of pollution levies requires a high level of compliance to be effective, with a combination of firms' self-reporting and validation by local environmental agencies.

Despite limited success, the Chinese government continues to experiment with pollution discharge permits and the discharge fee system. It plans to introduce pollution trading schemes to ensure that the marginal cost of abatement is equalized among polluters and that the overall efforts of pollution reduction become more cost-effective. In December 2015, the CCP and the State Council (i.e., the highest levels of the party and the executive branch, respectively) announced a reform plan for promoting ecological progress (CPC and The State Council 2015). The plan called for the development of eight systems for promoting ecological progress by 2020, including a system of property rights for natural resources and a market system for environmental governance and ecological conservation.

The bigger question is whether China should and could implement and enforce a cap-and-trade system for air pollutants. The SO₂ emission trading system has been unsuccessful as the trades have been largely driven by the government, and firms do not have excess emission credits to sell (i.e., many buyers but no sellers) (Cunningham 2015). A successful tradable pollution market also requires reliable monitoring, reporting, and verification of emissions data. Otherwise, firms will not have enough confidence to participate. China would also need extensive capacity building to train qualified staff to manage the market and educate enterprises to understand the emissions market.

7.3 Interpretation of the PRD Case Study

The case of PRD indicates that the consequences of noncompliance with existing laws and regulations could be substantial. The health impacts of high levels of air pollution tend to be long term. With many Chinese cities still suffering from high levels of air pollution, focusing on quick reductions of pollution levels in the short term will bring enduring benefits, whereas failing to do so will lead to continued large welfare losses.

The PRD case study also illustrates the importance of structural change in the power sector. To attain goals for improving air quality, without structural changes in fuel use, the efficiency with which some pollutants would have to be removed by 2020 would be as high as 98 percent, a rate that would be almost impossible to achieve reliably. Even with such high end-of-pipe pollution-removal rates, the PRD region would still be unlikely to meet the WHO's recommended healthy level for PM_{2.5}. In the PRD region and Guangdong Province, coal's share in energy consumption is below China's average share. To achieve further reductions of PM_{2.5} and its associated health impacts, China will need to dramatically shift energy consumption away from coal.

Reducing the share of fossil fuels in China's energy system is in harmony with China's goal of having carbon dioxide emissions peak around 2030. Chinese policymakers have made ambitious plans and introduced reforms that indicate their intentions of curbing the nation's greenhouse-gas emissions. For example, in the Reform Plan to Promote Ecological Progress, the Chinese government has mentioned phasing out all fossil-fuel subsidies (CPC and The State Council, 2015). According to the International Monetary Fund's estimates, China's total energy post-tax subsidies reached \$2.3 trillion in 2015,³³ accounting for 20 percent of its annual GDP (IMF 2015). China has significantly increased the installed capacity of renewable energy sources. However, utilizing that capacity is proving to be challenging. In some areas of China, regulations have curtailed wind and solar energy production by at least 30 percent in 2015 (Cao 2016). How to absorb newly added renewable energy capacity into China's grid should be a future focus for the government.

³³ In nominal dollars. Includes subsidies for petroleum, coal, natural gas, and electricity. 94 percent of these subsidies are for coal (IMF 2015).

7.4 Final Thoughts

When the Chinese government thinks about next steps for improving environmental quality, two additional aspects of policy design should be considered. First, the government should consider policies that can influence residents' behavior toward energy consumption. China is still undergoing a vast urbanization process, but its citizens' per capita energy demand is still low compared to that of developed nations. Without proper guidelines to manage energy demand, increases in per capita energy demand are likely and may cancel out the benefits of reductions in pollution achieved through pollution-control and energy-efficiency improvements. The long-term rebound effects illustrated through the PRD case study indicates such a risk is likely.

Second, the government needs to consider how to incorporate mid- to long-term planning into China's traditional five-year planning cycle. Power and industrial infrastructure often have life spans of decades. Environmental damage from new plants may not become visible during a cadres' term. The pilot plan of holding officials accountable for natural resources assets and environmental damage after they leave a post is an encouraging development (CPC and The State Council, 2015). It extends the time frame in which leaders need to consider the environmental consequences of their decisions. The actual environmental impact of such reforms may not appear immediately, but may have an enduring impact on China's future environmental quality.

Over the past few decades, in some instances and locations, China has made progress towards improving its air quality. The reforms are especially significant since the Tenth FYP period beginning in 2000. A wide range of policy tools has been tried. The government is continuously seeking ways to improve implementation and enforcement of environmental regulations. However, as demonstrated in this dissertation, these efforts have not yielded the hoped for improvement in China's environmental quality, and the price of insufficient progress is significant. China has introduced and is undergoing more fundamental structural reforms of its economic and energy systems. The success of these reforms and improved enforcement of environmental regulations will have long-term implications for the health of all Chinese citizens.

References

- “2013 City PM2.5 Pollution Ranking Launched,” Greenpeace, January 10, 2014. In Chinese, as of August 25, 2016:
<http://www.greenpeace.org/china/zh/news/releases/climate-energy/2014/01/PM25-ranking/>
- A Prüss-Ustün, J Wolf, C Corvalán, and R Bos and M Neira. 2016. “*Preventing Disease through Healthy Environments: A Global Assessment of the Burden of Disease from Environmental Risks.*” http://apps.who.int/iris/bitstream/10665/204585/1/9789241565196_eng.pdf?ua=1.
- Alford, William P., and Benjamin L. Liebman, “Clean Air, Clear Processes? The Struggle over Air Pollution Law in the People’s Republic of China,” *Hastings Law Journal*, Vol. 52, No. 3, March 2001.
- Amann, Markus, Imrich Bertok, Jens Borken-Kleefeld, Janusz Cofala, Chris Heyes, Lena Höglund-Isaksson, Zbigniew Klimont, Nguyen Thanh Binh, Maximilian Posch, Peter Rafaj, Robert Sandler, Wolfgang Schöpp, Fabian Wagner, and Wilfried Winiwarter, “Cost-Effective Control of Air Quality and Greenhouse Gases in Europe: Modeling and Policy Applications,” *Environmental Modelling and Software*, Vol. 26, No. 12, December 2011, pp. 1489–1501. doi:10.1016/j.envsoft.2011.07.012
- Amann, Markus, Jiang Kejun, Hao Jiming, Shuxiao Wang, Zhuang Xing, Deng Yi Xiang, L. Hong, X. Jia, Z. Chuying, Imrich Bertok, Jens Borken-Kleefeld, Janusz Cofala, Chris Heyes, Lena Höglund-Isaksson, Zbigniew Klimont, P. Purohit, Peter Rafaj, Wolfgang Schöpp, G. Toth, Fabian Wagner, and Wilfried Winiwarter, *GAINS Asia: Scenarios for Cost-Effective Control of Air Pollution and Greenhouse Gases in China*, Laxenburg, Austria: International Institute for Applied Systems Analysis, 2008. As of September 25, 2016: <http://pure.iiasa.ac.at/8670/>
- Andrews, Steven Q., “China’s Air Pollution Reporting Is Misleading,” *Chinadialogue*, March 27, 2014. As of August 25, 2016:
<https://www.chinadialogue.net/article/show/single/en/6856-China-s-air-pollution-reporting-is-misleading>
- Asian Development Bank, *Toward an Environmentally Sustainable Future: Country Environmental Analysis of the People’s Republic of China*, August 2012.
- Bureau of Environmental Supervision. “Forum for Adjustment of Pollution Discharge Fee Standard,” 2016. As of September 1, 2016: <http://pwsf.envsc.cn/tb/>.
- Becker, Gary S., “Crime and Punishment: An Economic Approach,” in Gary S. Becker and William M. Landes, eds., *Essays in the Economics of Crime and Punishment*, National Bureau of Economic Research, 1974, pp. 1–54. As of August 25, 2016:

<http://www.nber.org/chapters/c3625.pdf>

Beijing Environmental Protection Bureau, Beijing Department of Finance, and Beijing National Development and Reform Commission, “Notification on Various Issues Related to the Pollution Discharge Standards of Four Pollutants,” 2013. In Chinese, as of August 25, 2016: <http://pwsf.envsc.cn/tb/file/bj.pdf>

Beijing Environmental Protection Bureau, Beijing Department of Finance, and Beijing NDRC—*See* Beijing Environmental Protection Bureau, Beijing Department of Finance, and Beijing National Development and Reform Commission.

Bell, Ruth Greenspan, and Clifford Russell, “Environmental Policy for Developing Countries,” *Issues in Science and Technology*, Vol. 18, No. 3, Spring 2002, pp. 63–70.

Blackman, Allen, and Winston Harrington, “The Use of Economic Incentives in Developing Countries: Lessons from International Experience with Industrial Air Pollution,” *Journal of Environment and Development*, Vol. 9, No. 1, March 2000, pp. 5–44.

Cao, Shulin, “Gansu’s Wind Energy Curtailment Reached 39% Last Year,” *People’s Daily*, 2016. In Chinese, as of August 25, 2016: <http://finance.sina.com.cn/chanjing/cyxw/2016-08-05/doc-ixutfp4502728.shtml>

Central Committee of the Communist Party of China and State Council, “China National New-Type Urbanization Plan 2014–2020,” 2014. In Chinese, as of August 25, 2016: http://www.gov.cn/zhengce/2014-03/16/content_2640075.htm

Chang, Yen-Chiang, and Nannan Wang, “Environmental Regulations and Emissions Trading in China,” *Energy Policy*, Vol. 38, No. 7, July 2010, pp. 3356–3364. doi:10.1016/j.enpol.2010.02.006

Chen, Siwei, “NO_x Emissions Noncompliance, Five Entities Under the Guangdong Utility Group Was Fined,” *South Metropolitan*, 2015.

China Electricity Council, “Basic Electricity Statistics Summary,” 2015. In Chinese, as of August 25, 2016: <http://www.cec.org.cn/guihuayutongji/tongjixinxi/niandushuju/2015-11-30/146012.html>

———, “2016 National Electricity Supply and Demand Assessment and Projection Report,” February 3, 2016a. In Chinese, As of August 25, 2016: <http://www.cec.org.cn/yaowenkuaidi/2016-02-03/148763.html>

———, “2015 Thermal Power Plant Environmental Protection Industry Status,” April 25, 2016b. In Chinese, as of August 25, 2016: <http://huanzi.cec.org.cn/tuoliu/2016-04-25/152005.html>

China Environment Yearbook Editing Committee, “China Environment Yearbook 1990,” 1990.

———, “China Environment Yearbook 1996,” 1996.

- , “China Environment Yearbook 1997,” 1997.
- , “China Environment Yearbook 1998,” 1998
- , “China Environment Yearbook 1999,” 1999
- , “China Environment Yearbook 2000,” 2000.
- , “China Environment Yearbook 2001,” 2001.
- , “China Environment Yearbook 2002,” 2002.
- , “China Environment Yearbook 2003,” 2003.
- , “China Environment Yearbook 2004,” 2004.
- , “China Environment Yearbook 2005,” 2005.
- , “China Environment Yearbook 2006,” 2006.
- , “China Environment Yearbook 2007,” 2007.
- , “China Environment Yearbook 2008,” 2008.
- , “China Environment Yearbook 2009,” 2009.
- , “China Environment Yearbook 2010,” 2010.
- , “China Environment Yearbook 2011,” 2011.
- , “China Environment Yearbook 2012,” 2012.
- , “China Environment Yearbook 2013,” 2013
- , “China Environment Yearbook 2014,” 2014.
- , “China Environment Yearbook 2015,” 2015.

Clay, Karen, and Werner Troesken, “Did Frederick Brodie Discover the World’s First Environmental Kuznets Curve? Coal Smoke and the Rise and Fall of the London Fog,” in Gary D. Libecap and Richard H. Steckel, eds., *The Economics of Climate Change: Adaptations Past and Present*, Chicago, Ill: University of Chicago Press, 2011, pp. 281–309.

Clean Air Alliance of China, “*Twelfth Five-Year Plan*” on Air Pollution Prevention and Control in Key Regions: *English Translation*, April 2013.

———, *Performance Assessment Measures for Air Pollution Prevention and Control Action Plan (for Trial Implementation): China Clean Air Updates—English Translation*, June 2014. As of August 25, 2016:
<http://en.cleanairechina.org/product/6429.html>

Coase, Ronald H. “The Problem of Social Cost.” CHAP. In *Classic Papers in Natural Resource Economics*, 87–137. 1960. Springer.

- CPC, and The State Council. *Integrated Reform Plan for Promoting Ecological Progress*. 2015. As of August 25, 2016: http://english.gov.cn/policies/latest_releases/2015/09/22/content_281475195492066.htm.
- Crane, Keith, and Zhimin Mao, *Costs of Selected Policies to Address Air Pollution in China*, Santa Monica, Calif.: RAND Corporation, RR-861-TI, 2015. As of August 25, 2016: http://www.rand.org/pubs/research_reports/RR861.html
- Cropper, Maureen L., and Wallace E. Oates, “Environmental Economics: A Survey,” *Journal of Economic Literature*, Vol. 30, No. 2, June 1992, pp. 675–740.
- Cunningham, Edward A. “China’s New Plans for a Cap and Trade System Just Might Work.” *Foreign Policy*. 2015. As of August 25, 2016: <http://foreignpolicy.com/2015/10/06/china-carbon-emissions-climate-change-cap-trade-us/>.
- Dasgupta, Susmita, Kirk Hamilton, Kiran D. Pandey, and David Wheeler, “Environment During Growth: Accounting for Governance and Vulnerability,” *World Development*, Vol. 34, No. 9, 2006, pp. 1597–1611. doi:10.1016/j.worlddev.2005.12.008
- Department of Environmental Protection of Guangdong Province, “2013 Report on the State of Guangdong Provincial Environment,” 2013.
- Di Falco, Salvatore, “Economic Incentives for Pollution Control in Developing Countries: What Can We Learn from the Empirical Literature?” *Politique Agricola Internazionale*, Vol. 2, 2012, pp. 7–24.
- Doonan, Julie, Paul Lanoie, and Benoit Laplante, “Determinants of Environmental Performance in the Canadian Pulp and Paper Industry: An Assessment from Inside the Industry,” *Ecological Economics*, Vol. 55, No. 1, October 2005, pp. 73–84. doi:10.1016/j.ecolecon.2004.10.017
- Dusik, Jiri, and Jian Xie, *Strategic Environmental Assessment in East and Southeast Asia: A Progress Review and Comparison of Country Systems and Cases*, Washington, D.C.: World Bank, 2009. As of August 25, 2016: <http://documents.worldbank.org/curated/en/385961468247268166/Strategic-environmental-assessment-in-East-and-Southeast-Asia-a-progress-review-and-comparison-of-country-systems-and-cases>
- Economy, Elizabeth C., and Michel Oksenberg, eds., *China Joins the World: Progress and Prospects*, Council on Foreign Relations, January 1999.
- Ellerman, A. Denny, “Designing a Tradable Permit System to Control SO₂ Emissions in China: Principles and Practice,” *Energy Journal*, Vol. 23, No. 2, January 2002, pp. 1–26. doi:10.2307/41322952
- European Parliament and Council of the European Union, *Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for*

- Europe*, L 152/1, June 11, 2008. As of August 25, 2016:
<http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32008L0050&from=EN>
- Falk, Robert L., and Jasmine Wee. “China’s New Environmental Protection Law- Implications for Overseas Investors, Joint Ventures and Trading Partners.” 2014. As of August 25, 2016:
<http://www.mondaq.com/china/x/345932/Environmental+Law/Chinas+New+Environmental+Protection+Law>.
- Fisher-Vanden, Karen, Erin T. Mansur, and Qiong (Juliana) Wang, *Costly Blackouts? Measuring Productivity and Environmental Effects of Electricity Shortages*, Cambridge, Mass.: National Bureau of Economic Research, Working Paper 17741, January 2012. As of August 25, 2016:
<http://www.nber.org/papers/w17741>
- “Full Text: Integrated Reform Plan for Promoting Ecological Progress,” State Council, People’s Republic of China, updated September 22, 2015. As of August 25, 2016:
http://english.gov.cn/policies/latest_releases/2015/09/22/content_281475195492066.htm
- General Office of the State Council, “Notice of the General Office of the State Council About Forwarding Guiding Opinions on Pushing Forward the Joint Prevention and Control of Atmospheric Pollution to Improve the Regional Air Quality Developed by the Ministry of Environment Protection and Relevant Departments,” No. 33, May 11, 2010. As of August 25, 2016:
http://www.chinafaqs.org/files/chinainfo/ChinaFAQs_Joint_Prevention_and_Control_of_Atmospheric_Pollution_by_State_Council_translated.pdf
- Ghanem, Dalia, and Junjie Zhang, “‘Effortless Perfection:’ Do Chinese Cities Manipulate Air Pollution Data?” *Journal of Environmental Economics and Management*, Vol. 68, No. 2, July 2013, pp. 203–225. doi:10.1016/j.jeem.2014.05.003
- Global Burden of Disease from Major Air Pollution Sources Working Group, *Burden of Disease Attributable to Coal-Burning and Other Major Sources of Air Pollution in China*, Boston, Mass.: Health Effects Institute, August 2016. As of August 25, 2016:
<https://www.healtheffects.org/system/files/GBDMAPS-ReportEnglishFinal.pdf>
- Global Commission on the Economy and Climate, *China and New Climate Economy*, Institute of Energy, Environment and Economy, Tsinghua University, 2014. In Chinese, as of August 25, 2016:
http://newclimateeconomy.net/sites/default/files/nei_ye_xiao_zhi_liang_20141113_reduced.pdf
- Goulder, Lawrence H., and Ian W. H. Parry, “Instrument Choice in Environmental Policy,” *Review of Environmental Economics and Policy*, Vol. 2, No. 2, 2008, pp. 152–174.
- Gray, Wayne B., and Ronald J. Shadbegian, “When and Why Do Plants Comply? Paper Mills in

- the 1980s,” *Law and Policy*, Vol. 27, No. 2, April 2005, pp. 238–261. doi:10.1111/j.1467-9930.2005.00199.x
- Gray, Wayne B., and Jay P. Shimshack, “The Effectiveness of Environmental Monitoring and Enforcement: A Review of the Empirical Evidence,” *Review of Environmental Economics and Policy*, Vol. 5, No. 1, 2011, pp. 3–24.
- Greenpeace. “The End of China’s Coal Boom,” April, 2014. As of August 25, 2016: <http://www.greenpeace.org/international/Global/international/briefings/climate/2014/The-End-of-Chinas-Coal-Boom.pdf>.
- Greenstone, Michael, and B. Kelsey Jack, “Envirodevonomics: A Research Agenda for an Emerging Field,” *Journal of Economic Literature*, Vol. 53, No. 1, March 2015, pp. 5–42.
- Guangdong Provincial Environmental Protection Department. “Guangdong Provincial Industrial Boiler Pollution Control Implementation Plan (2013-2015).” 2012.
- Guangdong Provincial Statistics Bureau, “Guangdong Provincial Statistics Yearbook 2011,” 2011.
- Guangdong Provincial Statistics Bureau, “Guangdong Provincial Statistics Yearbook 2015,” 2015.
- Hao, Jiming, Lei Duan, Xuelong Zhou, and Lixin Fu, “Application of a LRT Model to Acid Rain Control in China,” *Environmental Science and Technology*, Vol. 35, No. 17, 2001, pp. 3407–3415.
- Hebei Provincial Development Research Center, Hebei Provincial Department of Finance, and Hebei Provincial Department of Environmental Protection, “Notification About Issues Related to the Adjustment of Pollution Discharge Fee Standard,” 2014. In Chinese, as of August 25, 2016: <http://pwsf.envsc.cn/tb/file/hb.pdf>
- Hong Kong Information Service Department. “JWGSDEP Holds 12th Meeting in Guangzhou and Endorses next Phase of PRD Regional Air Pollutant Emission Reduction Plan.” 2012. As of August 25, 2016: http://gia.info.gov.hk/general/201211/23/P201211230440_0440_102939.pdf.
- Huan, Qingzhi, “Regional Supervision Centres for Environmental Protection in China: Functions and Limitations,” *Journal of Current Chinese Affairs*, Vol. 40, No. 3, 2011, pp. 139–162.
- Huang, Yanzhong, “Is China Serious About Pollution Controls?” Council on Foreign Relations, November 20, 2015. As of August 25, 2016: <http://www.cfr.org/china/china-serious-pollution-controls/p37270>
- Huang, Zhiyuan, and Zhen Cui, “MEP: 35 EIA Assessment Entities Disqualified,” *Caixin News*, October 14, 2015. In Chinese, as of August 25, 2016:

- <http://m.china.caixin.com/m/2015-10-14/100862961.html>
- IEA—See International Energy Agency.
- IMF—See International Monetary Fund.
- International Monetary Fund, Fiscal Affairs Department, “How Large Are Global Energy Subsidies? Country-Level Subsidy Estimates,” June 29, 2015. As of August 25, 2016: <http://www.imf.org/external/np/fad/subsidies/data/codata.xlsx>
- International Energy Agency, *Energy Technology Perspectives 2012- Pathways to a Clean Energy System*, Paris, 2012. As of August 25, 2016: http://www.iea.org/publications/freepublications/publication/ETP2012_free.pdf
- , *World Energy Outlook Special Report 2016: Energy and Air Pollution*, 2016. As of August 25, 2016: <https://www.iea.org/publications/freepublications/publication/weo-2016-special-report-energy-and-air-pollution.html>
- Jiang, Jie, “Steep Rise in Pollution Discharge Fees,” *Global Times*, May 7, 2014. As of August 25, 2016: <http://www.globaltimes.cn/content/859067.shtml>
- Jiang, Shanshan, “Too Much, Too Late,” *Chinadialogue*, 2010.
- Johnson, Todd M., Feng Liu, and Richard Newfarmer, *Clear Water, Blue Skies: China’s Environment in the New Century*, World Bank, September 30, 1997. As of August 25, 2016: <http://documents.worldbank.org/curated/en/944011468743999953/Clear-water-blue-skies-Chinas-environment-in-the-new-century>
- Karagulian, Federico, Claudio A. Belis, Carlos Francisco C. Dora, Annette M. Prüss-Ustün, Sophie Bonjour, Heather Adair-Rohani, and Markus Amann, “Contributions to Cities’ Ambient Particulate Matter (PM): A Systematic Review of Local Source Contributions at Global Level,” *Atmospheric Environment*, Vol. 120, November 2015, pp. 475–483. doi:10.1016/j.atmosenv.2015.08.087
- Khanna, Madhu, and Wilma Rose Q. Anton, “What Is Driving Corporate Environmentalism: Opportunity or Threat?” *Corporate Environmental Strategy*, Vol. 9, No. 4, December 2002, pp. 409–417. doi:10.1016/S1066-7938(02)00118-5
- Khanna, Madhu, and Surender Kumar, “Corporate Environmental Management and Environmental Efficiency,” *Environmental and Resource Economics*, Vol. 50, No. 2, October 2011, pp. 227–242. doi:10.1007/s10640-011-9469-7
- Klimont, Z., J. Cofala, I. Bertok, M. Amann, C. Heyes, and F. Gyarfas, *Modeling Particulate Emissions in Europe: A Framework to Estimate Reduction Potential and Control Costs*, Laxenburg, Austria: International Institute for Applied Systems Analysis, IR-02-076, 2002.

As of August 25, 2016:

<http://pure.iiasa.ac.at/6712/>

Kong, Linjue, “Decentralizing EIA Approval Faces Large Challenge,” *Caixin*, January 4, 2016.

In Chinese, as of August 25, 2016:

<http://weekly.caixin.com/2016-01-01/100895184.html>

Korsbakken, Jan Ivar, Glen P. Peters, and Robbie M. Andrew. "Uncertainties around reductions in China's coal use and CO₂ emissions." *Nature Climate Change*, 2016.

Li, Bo, “Devolving EIAs to Local Officials Is a Mistake, Warn Chinese NGOs,” *Chinadialogue*, June 18, 2013. As of August 25, 2016:

<https://www.chinadialogue.net/article/show/single/en/6108-Devolving-EIAs-to-local-officials-is-a-mistake-warn-Chinese-NGOs>

Li, Wanxin, “Translating Regulatory Promise into Environmental Progress: Institutional Capacity and Environmental Regulation in China,” undated. As of August 25, 2016:

[http://www.cet.net.cn/new/english/EG-case study-Capacitychina-en.pdf](http://www.cet.net.cn/new/english/EG-case%20study-Capacitychina-en.pdf)

Li, Wanxin, and Paul Higgins, “Controlling Local Environmental Performance: An Analysis of Three National Environmental Management Programs in the Context of Regional Disparities in China,” *Journal of Contemporary China*, Vol. 22, No. 81, 2013, pp. 409–427. doi:10.1080/10670564.2012.748961

Lim, Stephen S., Theo Vos, Abraham D. Flaxman, Goodarz Danaei, Kenji Shibuya, Heather Adair-Rohani, Markus Amann, H. R. Anderson, K. G. Andrews, M. Aryee, C. Atkinson, L. J. Bacchus, A. N. Bahalim, K. Balakrishnan, J. Balmes, S. Barker-Collo, A. Baxter, M. L. Bell, J. D. Blore, F. Blyth, C. Bonner, G. Borges, R. Bourne, M. Boussinesq, M. Brauer, P. Brooks, N. G. Bruce, B. Brunekreef, C. Bryan-Hancock, C. Bucello, R. Buchbinder, F. Bull, R. T. Burnett, T. E. Byers, B. Calabria, J. Carapetis, E. Carnahan, Z. Chafe, F. Charlson, H. Chen, J. S. Chen, A. T. Cheng, J. C. Child, A. Cohen, K. E. Colson, B. C. Cowie, S. Darby, S. Darling, A. Davis, L. Degenhardt, F. Dentener, D. C. Des Jarlais, K. Devries, M. Dherani, E. L. Ding, E. R. Dorsey, T. Driscoll, K. Edmond, S. E. Ali, R. E. Engell, P. J. Erwin, S. Fahimi, G. Falder, F. Farzadfar, A. Ferrari, M. M. Finucane, S. Flaxman, F. G. Fowkes, G. Freedman, M. K. Freeman, E. Gakidou, S. Ghosh, E. Giovannucci, G. Gmel, K. Graham, R. Grainger, B. Grant, D. Gunnell, H. R. Gutierrez, W. Hall, H. W. Hoek, A. Hogan, H. D. Hosgood III, D. Hoy, H. Hu, B. J. Hubbell, S. J. Hutchings, S. E. Ibeanusi, G. L. Jacklyn, R. Jasrasaria, J. B. Jonas, H. Kan, J. A. Kanis, N. Kassebaum, N. Kawakami, Y. H. Khang, S. Khatibzadeh, J. P. Khoo, C. Kok, F. Laden, R. Lalloo, Q. Lan, T. Lathlean, J. L. Leasher, J. Leigh, Y. Li, J. K. Lin, S. E. Lipshultz, S. London, R. Lozano, Y. Lu, J. Mak, R. Malekzadeh, L. Mallinger, W. Marcenes, L. March, R. Marks, R. Martin, P. McGale, J. McGrath, S. Mehta, G. A. Mensah, T. R. Merriman, R. Micha, C. Michaud, V. Mishra, K. Mohd Hanafiah, A. A. Mokdad,

- L. Morawska, D. Mozaffarian, T. Murphy, M. Naghavi, B. Neal, P. K. Nelson, J. M. Nolla, R. Norman, C. Olives, S. B. Omer, J. Orchard, R. Osborne, B. Ostro, A. Page, K. D. Pandey, C. D. Parry, E. Passmore, J. Patra, N. Pearce, P. M. Pelizzari, M. Petzold, M. R. Phillips, D. Pope, C. A. Pope III, J. Powles, M. Rao, H. Razavi, E. A. Rehfuess, J. T. Rehm, B. Ritz, F. P. Rivara, T. Roberts, C. Robinson, J. A. Rodriguez-Portales, I. Romieu, R. Room, L. C. Rosenfeld, A. Roy, L. Rushton, J. A. Salomon, U. Sampson, L. Sanchez-Riera, E. Sanman, A. Sapkota, S. Seedat, P. Shi, K. Shield, R. Shivakoti, G. M. Singh, D. A. Sleet, E. Smith, K. R. Smith, N. J. Stapelberg, K. Steenland, H. Stöckl, L. J. Stovner, K. Straif, L. Straney, G. D. Thurston, J. H. Tran, R. Van Dingenen, A. van Donkelaar, J. L. Veerman, L. Vijayakumar, R. Weintraub, M. M. Weissman, R. A. White, H. Whiteford, S. T. Wiersma, J. D. Wilkinson, H. C. Williams, W. Williams, N. Wilson, A. D. Woolf, P. Yip, J. M. Zielinski, A. D. Lopez, C. J. Murray, M. Ezzati, M. A. AlMazroa, and Z. A. Memish, "A Comparative Risk Assessment of Burden of Disease and Injury Attributable to 67 Risk Factors and Risk Factor Clusters in 21 Regions, 1990–2010: A Systematic Analysis for the Global Burden of Disease Study 2010," *Lancet*, Vol. 380, No. 9859, December 15, 2012, pp. 2224–2260. doi:10.1016/S0140-6736(12)61766-8
- Lin, Xinyan, and Mark Elder, *Major Developments in China's National Air Pollution Policies in the Early 12th Five-Year Plan*, Institute for Global Environmental Strategies, Research Report 2014/03, last modified May 13, 2015. As of August 25, 2016: <http://pub.iges.or.jp/modules/envirolib/view.php?docid=4954>
- Liu, H., X. M. Wang, J. M. Pang, and K. B. He, "Feasibility and Difficulties of China's New Air Quality Standard Compliance: PRD Case of PM_{2.5} and Ozone from 2010 to 2025," *Atmospheric Chemistry and Physics*, Vol. 13, No. 23, 2013, pp. 12013–12027. doi:10.5194/acp-13-12013-2013
- Liu, Jianguo, and Jared Diamond, "China's Environment in a Globalizing World," *Nature*, Vol. 435, June 30, 2005, pp. 1179–1186.
- Lu, Z., D. G. Streets, Q. Zhang, S. Wang, G. R. Carmichael, Y. F. Cheng, C. Wei, M. Chin, T. Diehl, and Q. Tan, "Sulfur Dioxide Emissions in China and Sulfur Trends in East Asia Since 2000," *Atmospheric Chemistry and Physics*, Vol. 10, No. 13, 2010, pp. 6311–6331. doi:10.5194/acp-10-6311-2010
- Ma, Xiaoying, and Leonard Ortolano, *Environmental Regulation in China: Institutions, Enforcement, and Compliance*, Rowman and Littlefield Publishers, 2000.
- Marquis, Christopher, Jianjun Zhang, and Yanhua Zhou, *Regulatory Uncertainty and Corporate Response: How China's Environmental Enforcement Is Catching Up to Regulation and How Business Can Keep Up*, September 21, 2011. As of August 25, 2016: http://www.people.hbs.edu/cmarquis/regulatory_uncertainty_cmr_final.pdf
- Matus, Kira, Kyung-Min Nam, Noelle E. Selin, Lok N. Lamsal, John M. Reilly, and Sergey

- Paltsev, "Health Damages from Air Pollution in China," *Global Environmental Change*, Vol. 22, No. 1, February 2012, pp. 55–66.
- Mechler, Reinhard, Markus Amann, and Wolfgang Schöpp. "A Methodology to Estimate Changes in Statistical Life Expectancy due to the Control of Particulate Matter Air Pollution." Laxenburg, Austria, International Institute for Applied System Analysis (IIASA) (2002).2002.
- Meng, Xianglu, "Rethinking Coal Fired Power Plants 'Closing Small Units, Replace with Large Ones,'" *China Energy News*, 2010. In Chinese, as of August 25, 2016:
<http://energy.people.com.cn/GB/13424147.html>
- MEP—See Ministry of Environmental Protection of the People's Republic of China.
- MEP and NDRC—See Ministry of Environmental Protection of the People's Republic of China and National Development and Reform Commission.
- MEP, NDRC, and Ministry of Finance of China—See Ministry of Environmental Protection of China, National Development and Reform Commission, and Ministry of Finance of China.
- MEP, and Standardization Administration of China. 2013. "Limits and Measurement Methods for Emissions from Light-Duty Vehicles (China 5)."
<http://kjs.mep.gov.cn/hjbhzb/bzwb/dqjhjbh/dqydywrwpfbz/201309/W020131105534056881723.pdf>.
- Ministry of Environmental Protection of the People's Republic of China, "Notification About the Total Emission Control Plan Development During the 12th FYP," 2010. In Chinese, as of August 25, 2016:
[http://222.143.24.250:86/Portals/0/fujian/%E5%8D%81%E4%BA%8C%E4%BA%94%E5%87%8F%E6%8E%92%E8%A7%84%E5%88%92%E6%8C%87%E5%8D%97%EF%BC%881a%EF%BC%89%EF%BC%8D%E7%8E%AF%E5%8A%9E\[2010\]97%E5%8F%B7\(0\).pdf](http://222.143.24.250:86/Portals/0/fujian/%E5%8D%81%E4%BA%8C%E4%BA%94%E5%87%8F%E6%8E%92%E8%A7%84%E5%88%92%E6%8C%87%E5%8D%97%EF%BC%881a%EF%BC%89%EF%BC%8D%E7%8E%AF%E5%8A%9E[2010]97%E5%8F%B7(0).pdf)
- , "Notification Regarding the National Environmental Protection Exemplary City Development and Management Measure," 2011. In Chinese, as of August 25, 2016:
http://www.mep.gov.cn/gkml/hbb/bgt/201102/t20110212_200595.htm
- , "Work Plan for Decoupling EIA Assessment Entities from Environmental Protection Agencies," 2015. In Chinese, as of August 25, 2016:
<http://politics.people.com.cn/n/2015/0325/c1001-26747173.html>
- , "2015 Report on the State of the Environment in China," 2016a. In Chinese, as of August 25, 2016:
http://www.mep.gov.cn/home/jrtt_1/201606/W020160602419515164060.pdf
- , "National Key Monitored Enterprises Pollution Discharge Fee Default of Payment Status Report 2015," April 18, 2016b. In Chinese, as of August 25, 2016:
http://www.mep.gov.cn/home/rdq/jdzf/wryjg/pwsf/201605/t20160522_341454.shtml

- , “Notification of Special Inspection of Pollution Discharge Fee Collection Among Steel and Coal Industries,” May 19, 2016c. In Chinese, as of August 25, 2016:
http://www.mep.gov.cn/gkml/hbb/bgth/201605/t20160526_346937.htm
- Ministry of Environmental Protection of the People’s Republic of China and National Development and Reform Commission, “Regarding the Development of Enterprise Environmental Credit System,” 2015. In Chinese, as of August 25, 2016:
http://www.mep.gov.cn/gkml/hbb/bwj/201512/t20151215_319169.htm
- Ministry of Environmental Protection of China, National Development and Reform Commission, and Ministry of Finance of China, “Key Regions Air Pollution Prevention and Abatement ‘Twelfth Five-Year’ Plan,” 2013. In Chinese, as of August 25, 2016:
<http://www.mep.gov.cn/gkml/hbb/bwj/201212/W020121205566730379412.pdf>
- Ministry of Finance and SEPA—*See* Ministry of Finance and State Environmental Protection Administration.
- Ministry of Finance and State Environmental Protection Administration, *Administrative Rule for the Collection and Usage of the Pollution Discharge Fee*, March 20, 2003. In Chinese, as of August 25, 2016:
http://www.mep.gov.cn/gzfw_13107/zcfg/gz/bmgz/gwybmyggz/201605/t20160531_352590.shtml
- Muller, Nicholas Z., Robert Mendelsohn, and William Nordhaus, “Environmental Accounting for Pollution in the United States Economy,” *American Economic Review*, Vol. 101, No. 5, August 2011, pp. 1649–1675.
- National Bureau of Statistics of China, “Table 9-9: Consumption of Energy by Sector (2012),” 2015a. As of August 25, 2016:
<http://www.stats.gov.cn/tjsj/ndsj/2014/indexeh.htm>
- , *China Statistical Yearbook 2015*, 2015b. As of August 25, 2016:
<http://www.stats.gov.cn/tjsj/ndsj/2015/indexeh.htm>
- , “Statistical Communiqué of the People’s Republic of China on the 2015 National Economic and Social Development,” February 29, 2016. In Chinese, as of August 25, 2016:
http://www.stats.gov.cn/tjsj/zxfb/201602/t20160229_1323991.html
- National Bureau of Statistics of China and MEP—*See* National Bureau of Statistics of China and Ministry of Environmental Protection of China.
- National Bureau of Statistics of China and Ministry of Environmental Protection of China, “China Environment Statistics Yearbook 2015,” 2015.
- National Development and Reform Committee, “Coal-Fired Power Plant Units Desulfurization Electricity Premium and Desulfurization Equipment Operation Management Measure,”

- May 29, 2007. In Chinese, as of August 25, 2016:
http://www.mep.gov.cn/gzfw_13107/zcfg/hjjzc/gjfbdjzcx/lsjgzc/201606/t20160623_355431.shtml
- , “Notification About Issues Related to the Adjustment of Pollution Discharge Fee Collection Standard,” 2014. In Chinese, as of August 25, 2016:
http://www.sdpc.gov.cn/zwfwzx/zfdj/jggg/201409/t20140905_624992.html
- National People’s Congress, *Environmental Protection Law of the People’s Republic of China*, December 26, 1989. As of August 25, 2016:
http://www.npc.gov.cn/englishnpc/Law/2007-12/12/content_1383917.htm
- , *Organic Law of the Local People’s Congresses and Local People’s Governments of the People’s Republic of China*, February 12, 2011. As of August 25, 2016:
http://www.china.org.cn/china/LegislationsForm2001-2010/2011-02/12/content_21906985.htm
- , “13th Five Year Plan for Economic and Social Development,” March 17, 2016. In Chinese, as of August 25, 2016:
http://www.gov.cn/xinwen/2016-03/17/content_5054992.htm
- NDRC—See National Development and Reform Committee.
- NEPA, *Water Pollutant Emissions Permit Management Temporary Guideline*, 1988.
- NPC—See National People’s Congress.
- Oates, Wallace E., and Paul Portney, “The Political Economy of Environmental Policy,” in Karl-Göran Mäler and Jeffrey R. Vincent, eds., *Handbook of Environmental Economics*, Vol. 1: *Environmental Degradation and Institutional Responses—Perspectives on Environmental Economics*, North-Holland, 2003, pp. 325–354. doi:10.1016/S1574-0099(03)01013-1
- OECD—See Organisation for Economic Co-operation and Development.
- Organisation for Economic Co-operation and Development, *Regulatory Policies in OECD Countries: From Interventionism to Regulatory Governance*, OECD Reviews of Regulatory Reform, October 14, 2002. As of August 25, 2016:
http://www.oecd-ilibrary.org/governance/regulatory-policies-in-oecd-countries_9789264177437-en
- , *Environmental Compliance and Enforcement in China: An Assessment of Current Practices and Ways Forward*, 2006. As of August 25, 2016:
<https://www.oecd.org/env/outreach/37867511.pdf>
- , *OECD Economic Surveys: China 2013*, March 22, 2013. As of August 25, 2016:
http://www.oecd-ilibrary.org/economics/oecd-economic-surveys-china-2013_eco_surveys-chn-2013-en

- Organisation for Economic Co-operation and Development Working Party on Environmental Performance, *Environmental Performance Review of China: Conclusions and Recommendations (Final)*, Beijing, November 8–9, 2006. As of August 25, 2016: <http://www.oecd.org/env/country-reviews/37657409.pdf>
- Parker, Christine, *Reducing the Risk of Policy Failure: Challenges for Regulatory Compliance*, Organisation for Economic Co-operation and Development, April 6–7, 2000. As of August 25, 2016: <https://www.oecd.org/gov/regulatory-policy/1910833.pdf>
- People’s Government of Guangdong Province, “Guangdong Province Pearl River Delta Region Clean Air Action Plan,” 2013.
- , “Guangdong Issues Action Plan on Air Pollution Control (2014–2017),” 2014a.
- , “Guangdong Province Air Pollution Prevention and Management Action Plan 2014–2017,” 2014b.
- Perera, Frederica P., Virginia Rauh, Robin M. Whyatt, Wei-Yann Tsai, Deliang Tang, Diurka Diaz, Lori Hoepner, Dana Barr, Yi-Hsuan Tu, David Camann, and Patrick Kinney, “Effect of Prenatal Exposure to Airborne Polycyclic Aromatic Hydrocarbons on Neurodevelopment in the First 3 Years of Life Among Inner-City Children,” *Environmental Health Perspectives*, Vol. 114, No. 8, August 2006, pp. 1287–1292. doi:10.1289/ehp.9084
- Phillips, Tom, “Airlpocalypse Now: China Pollution Reaching Record Levels,” *Guardian*, November 8, 2015. As of August 25, 2016: <https://www.theguardian.com/world/2015/nov/09/airpocalypse-now-china-pollution-reaching-record-levels>
- Pizer, William, “Choosing Price or Quantity Controls for Greenhouse Gases,” in Wallace Oates, ed., *The RFF Reader in Environmental and Resource Policy*, 2nd ed., Taylor and Francis, January 2006, pp. 225–234. doi:10.4324/9781936331642
- Prüss-Ustün, A., J. Wolf, C. Corvalán, R. Bos, and M. Neira, *Preventing Disease Through Healthy Environments: A Global Assessment of the Burden of Disease from Environmental Risks*, Geneva: World Health Organization, 2016. As of August 25, 2016: http://apps.who.int/iris/bitstream/10665/204585/1/9789241565196_eng.pdf?ua=1
- Qi, Yao, and Xin Zhou, *Water Pollution Control in China: Review of Laws, Regulations and Policies and Their Implementation*, Institute for Global Environmental Strategies, Research Report 2009/04, last modified June 11, 2013. As of August 25, 2016: <http://pub.iges.or.jp/modules/envirolib/view.php?docid=2775>
- Rock, Michael T., *Pollution Control in East Asia: Lessons from Newly Industrializing Economies*, Routledge, September 30, 2010.

- Schreifels, Jeremy J., Yale Fu, and Elizabeth J. Wilson, “Sulfur Dioxide Control in China: Policy Evolution During the 10th and 11th Five-Year Plans and Lessons for the Future,” *Energy Policy*, Vol. 48, September 2012, pp. 779–789. doi:10.1016/j.enpol.2012.06.015
- Schwabe, Julian, and Markus Hassler, “The Impact of Periodic Air Pollution Peaks in Beijing on Air Quality Governance in China,” *Journal of the Geographical Society of Berlin*, Vol. 147, No. 1, 2016. As of August 25, 2016:
<http://www.die-erde.org/index.php/die-erde/article/view/255>
- Shao, Zhenying, D Wagner, and Zifei Yang. “Costs and Benefits of China 5/V and 6/VI Standards in Guangdong Province.” The International Council on Clean Transportation. 2014. As of August 25, 2016:
http://www.theicct.org/sites/default/files/publications/ICCT_GuangdongCBA_20140616_revDec2014.pdf.
- Standing Committee of the National People’s Congress, *Law of the People’s Republic of China on Appraising of Environment Impacts*, Order 77 of the President of the People’s Republic of China, issued October 28, 2002. As of August 25, 2016:
<http://www.lawinfochina.com/display.aspx?lib=law&id=2496&CGid=>
- Standing Committee of the NPC—See Standing Committee of the National People’s Congress.
- State Council, “Decision of the State Council on Several Issues Concerning Environmental Protection,” August 3, 1996. As of August 25, 2016:
<http://en.pkulaw.cn/display.aspx?cgid=15018&lib=law>
- , “Administrative Regulations on Pollution Discharge Levy,” January 7, 2003. In Chinese, as of August 25, 2016:
<http://www.people.com.cn/GB/shizheng/16/20030117/909481.html>
- , “Notification of Various Opinions About Accelerated Phase-Out of Small Coal-Fired Power Units,” 2007. In Chinese, as of August 25, 2016:
http://www.sdpc.gov.cn/zcfb/zcfbqt/200701/t20070131_115037.html
- , “Notice of the State Council on the Air Pollution Prevention and Control Action Plan,” 2013. In Chinese, as of August 25, 2016: http://www.gov.cn/zwggk/2013-09/12/content_2486773.htm.
- , *China Environmental Protection 12th Five-Year Plan*, December 20, 2011. In Chinese, as of August 25, 2016:
http://www.gov.cn/zwggk/2011-12/20/content_2024895.htm
- Statistics Bureau of Guangdong Province, “Guangdong Statistical Yearbook 2014,” 2014.
- Stavins, Robert N., “Experience with Market-Based Environmental Policy Instruments,” in Karl-Göran Mäler and Jeffrey R. Vincent, eds., *Handbook of Environmental Economics*, Vol. 1: *Environmental Degradation and Institutional Responses*, North-Holland, 2003, pp. 355–

435. doi:10.1016/S1574-0099(03)01014-3

Sterner, Thomas, and Jessica Coria, *Policy Instruments for Environmental and Natural Resource Management*, Routledge, October 30, 2013.

Stewart, Richard B., “Regulation, Innovation, and Administrative Law: A Conceptual Framework,” *California Law Review*, Vol. 69, No. 5, September 1981, pp. 1256–1377.

Sun, Jian, Jeremy Schreifels, Jun Wang, Joshua S. Fu, and Shuxiao Wang, “Cost Estimate of Multi-Pollutant Abatement from the Power Sector in the Yangtze River Delta Region of China,” *Energy Policy*, Vol. 69, June 2014, pp. 478–488. doi:10.1016/j.enpol.2014.02.007

Suwanteep, Kultip, Takehiko Murayama, and Shigeo Nishikizawa, “Environmental Impact Assessment System in Thailand and Its Comparison with Those in China and Japan,” *Environmental Impact Assessment Review*, Vol. 58, April 2016, pp. 12–24. doi:10.1016/j.eiar.2016.02.001

Tianjin Development Research Center, “Notification About the Adjustment of Pollution Discharge Fee Standards for Four Pollutants Including SO₂,” 2014. In Chinese, as of August 25, 2016:
<http://pwsf.envsc.cn/tb/file/tj2.pdf>

Tietenberg, Thomas, “Economic Instruments for Environmental Regulation,” *Oxford Review of Economic Policy*, Vol. 6, No. 1, February 1990, pp. 17–33. doi:10.1093/oxrep/6.1.17

U.S. Bureau of Economic Analysis. “Table 1.1.9 Implicit Price Deflators for Gross Domestic Product.” 2016. As of August 25, 2016:
<http://www.bea.gov/iTable/iTable.cfm?reqid=9&step=3&isuri=1&903=13#reqid=9&step=3&isuri=1&904=2005&903=13&906=a&905=2010&910=x&911=0>.

U.S. Energy Information Administration, “China,” undated. As of August 25, 2016:
<http://www.eia.gov/beta/international/country.cfm?iso=CHN>

U.S. Environmental Protection Agency, “Table of Historical Particulate Matter (PM) National Ambient Air Quality Standards (NAAQS),” last updated September 7, 2016. As of September 8th, 2016:
<https://www.epa.gov/pm-pollution/table-historical-particulate-matter-pm-national-ambient-air-quality-standards-naaqs>

Van Aken, Tucker, “Making the Grade: Performance Targets and Industrial Energy Policy,” *China Environment Series*, Vol. 12, 2012–2013a.

———, “China’s Secrets? Performance Targets,” *Diplomat*, June 27, 2013b. As of August 25, 2016:
<http://thediplomat.com/2013/06/chinas-secret-performance-targets/>

Van Aken, Tucker, and Orion A. Lewis, “The Political Economy of Noncompliance in China: The Case of Industrial Energy Policy,” *Journal of Contemporary China*, Vol. 24, No. 95,

- 2015, pp. 798–822. doi:10.1080/10670564.2015.1013374
- Van Donkelaar, Aaron, Randall V. Martin, Michael Brauer, and Brian L. Boys, “Global Annual PM2.5 Grids from MODIS, MISR and SeaWiFS Aerosol Optical Depth (AOD), v1 (1998–2012),” Palisades, N.Y.: National Aeronautics and Space Administration Socioeconomic Data and Applications Center, 2015a. As of August 25, 2016:
<http://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-avg-pm2-5-modis-misr-seawifs-aod-1998-2012>
- , “Use of Satellite Observations for Long-Term Exposure Assessment of Global Concentrations of Fine Particulate Matter,” *Environmental Health Perspectives*, Vol. 123, No. 2, February 2015b, pp. 135–143. As of August 25, 2016:
<http://ehp.niehs.nih.gov/1408646/>
- Wang, Alex L., “The Search for Sustainable Legitimacy: Environmental Law and Bureaucracy in China,” *Harvard Environmental Law Review*, Vol. 37, 2013, pp. 367–440. As of August 25, 2016:
<http://harvardelr.com/wp-content/uploads/2013/09/Wang-9-2.pdf>
- Wang, Hua, Nlandu Mamingi, Benoit Laplante, and Susmita Dasgupta, “Incomplete Enforcement of Pollution Regulation: Bargaining Power of Chinese Factories,” *Environmental and Resource Economics*, Vol. 24, No. 3, March 2003, pp. 245–262. doi:10.1023/A:1022936506398
- Wang, Yichen, “NEB and NDRC: Multiple Efforts Targeting Phase-Out of Inefficeint Coal-Fired Power Plant Units,” *Economic Daily*, April 22, 2016. In Chinese, as of August 25, 2016:
<http://energy.people.com.cn/n1/2016/0422/c71661-28296112.html>
- Wang, Yungang, Qi Ying, Jianlin Hu, and Hongliang Zhang, “Spatial and Temporal Variations of Six Criteria Air Pollutants in 31 Provincial Capital Cities in China During 2013–2014,” *Environment International*, Vol. 73, December 2014, pp. 413–422. doi:10.1016/j.envint.2014.08.016
- Weitzman, Martin L, “Prices Versus Quantities,” *Review of Economic Studies*, Vol. 41, No. 4, 1974, pp. 477–491.
- “What Kind of Signal Does Central Environmental Protection Supervision Group’s Iron Fist Send?” Xinhua, August 29, 2016. In Chinese, as of August 25, 2016:
http://news.xinhuanet.com/legal/2016-08/29/c_1119474603.htm
- WHO—See World Health Organization.
- Wong, Edward, “Fines Total \$26 Million for Polluters in China,” *New York Times*, December 31, 2014. As of August 25, 2016:
<http://www.nytimes.com/2015/01/01/world/asia/chinese-court-orders-6-companies-to-pay->

26-million-for-polluting.html

World Bank, *Greening Industry: New Roles for Communities, Markets, and Governments*, Report 19851, October 31, 1999. As of August 25, 2016:

<http://documents.worldbank.org/curated/en/421701468772781985/Greening-industry-new-roles-for-communities-markets-and-governments>

———, *Cost of Pollution in China: Economic Estimates of Physical Damages*, Report 39236, February 1, 2007. As of August 25, 2016:

<http://documents.worldbank.org/curated/en/782171468027560055/Cost-of-pollution-in-China-economic-estimates-of-physical-damages>

World Health Organization, *WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide: Global Update 2005—Summary of Risk Assessment*, Geneva, WHO/SDE/PHE/OEH/06.02, 2006. As of August 25, 2016:

http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf?ua=1

———, *Review of Evidence on Health Aspects of Air Pollution: REVIHAAP Project—Technical Report*, 2013. As of August 25, 2016:

http://www.euro.who.int/__data/assets/pdf_file/0004/193108/REVIHAAP-Final-technical-report-final-version.pdf?ua=1

———, *Burden of Disease from Household Air Pollution for 2012*, 2014a. As of August 25, 2016:

http://www.who.int/phe/health_topics/outdoorair/databases/FINAL_HAP_AAP_BoD_24March2014.pdf?ua=1

———, “WHO’s Ambient Air Pollution Database: Update 2014,” 2014b. As of August 25, 2016:

http://www.who.int/phe/health_topics/outdoorair/databases/AAP_database_results_2014.pdf?ua=1

———, “WHO’s Urban Ambient Air Pollution Database: Update 2015,” 2016. As of August 25, 2016:

http://www.who.int/phe/health_topics/outdoorair/databases/AAP_database_summary_results_2016_v02.pdf?ua=1

Xie, Qinyu, “PRD Coal Fired Power Plan Completed Denitrification Equipment Installation, NO_x Emissions Reduced by 43.3%,” *South Daily*, 2014.

Xu, Yuan, “Improvements in the Operation of SO₂ Scrubbers in China’s Coal Power Plants,” *Environmental Science and Technology*, Vol. 45, No. 2, 2011, pp. 380–385.
doi:10.1021/es1025678

Xu, Yuan, Robert H. Williams, and Robert H. Socolow, “China’s Rapid Deployment of SO₂ Scrubbers,” *Energy and Environmental Science*, Vol. 2, No. 5, 2009, pp. 459–465.

doi:10.1039/b901357c

- Yang, Jintian, and Jeremy Schreifels, "Implementing SO₂ Emissions in China," in *OECD Global Forum on Sustainable Development : Emissions Trading—Concerted Action on Tradeable Emissions Permits Country Forum*, Paris: Organisation for Economic Co-operation and Development, 2003. As of August 25, 2016:
<http://www.oecd.org/dataoecd/11/23/2957744.pdf>
- Yee, Wai-Hang, Shui-Yan Tang, and Carlos Wing-Hung Lo, "Regulatory Compliance When the Rule of Law Is Weak: Evidence from China's Environmental Reform," *Journal of Public Administration Research and Theory*, Vol. 26, No. 1, 2016, pp. 95–112.
doi:10.1093/jopart/muu025
- Young, Oran R., Dan Guttman, Ye Qi, Kris Bachus, David Belis, Hong Guang Cheng, Alvin Lin, Jeremy Schreifels, Sarah Van Eynde, Yahua Wang, Liang Wu, Yilong Yan, An Yu, Durwood Zaelke, Bing Zhang, Shiqiu Zhang, Xiaofan Zhao, Xufeng Zhu, "Institutionalized Governance Processes," *Global Environmental Change*, Vol. 31, March 2015, pp. 163–173.
doi:10.1016/j.gloenvcha.2015.01.010
- Yue, Jiashen, and Qiyue Shao, "'Underground Sales Network' of Environmental Impact Assessment Qualifications, Possibly 23% Involves Buying or Selling of Qualifications," *Southern Weekly*, 2015. In Chinese, as of August 25, 2016:
<http://www.infzm.com/content/111260>
- Zhang, Shi-qiu, "Environmental Regulatory and Policy Framework in China: An Overview," *Journal of Environmental Sciences*, Vol. 13, No. 1, 2001, pp. 122–128.
- Zhang, Xuehua, and Jeremy Schreifels, "Continuous Emission Monitoring Systems at Power Plants in China: Improving SO₂ Emission Measurement," *Energy Policy*, Vol. 39, No. 11, November 2011, pp. 7432–7438. doi:10.1016/j.enpol.2011.09.011
- Zhang, Yan-Lin, and Fang Cao, "Fine Particulate Matter (PM_{2.5}) in China at a City Level," *Scientific Reports*, Vol. 5, October, 2015, article 14884. doi:10.1038/srep14884
- Zhen, Cunsun, "Nation's First 'Haze Public Interest Litigation' Summary," *Prosecutorial View*, August 25, 2016. In Chinese, as of August 25, 2016:
<http://www.jcfyzz.com/aj/xaqd/2016/08/25/7211.html>
- Zheng, Siqu, Rui Wang, Edward L. Glaeser, and Matthew E. Kahn. "The greenness of China: household carbon dioxide emissions and urban development." *Journal of Economic Geography*, Vol.11, No. 5, 2011.
- Zusman, Eric Gregory, *The Limits to Access: An Institutional Explanation for Why Air Pollution Regulations Vary in East Asia's Rapidly Industrializing States*, Los Angeles, Calif.: University of California, Los Angeles, thesis, 2007.

- Amann, Markus, Imrich Bertok, Jens Borken-Kleefeld, Janusz Cofala, Chris Heyes, Lena Höglund-Isaksson, Zbigniew Klimont, et al. 2011. "Cost-Effective Control of Air Quality and Greenhouse Gases in Europe: Modeling and Policy Applications." *Environmental Modelling & Software* 26 (12): 1489–1501. doi:10.1016/j.envsoft.2011.07.012.
- Amann, Markus, Kejun Jiang, Jiming Hao, Wang Shuxiao, Xing Zhuang, Wei Wei, Yi Xiang Deng, et al. 2008. "GAINS Aisa Scenarios For Cost-Effective Control of Air Pollution and Greenhouse Gases in China." *International Institute for Applied Systems Analysis*, no. November: 1–53.
- Bureau of Environmental Supervision. 2016. "Forum for Adjustment of Pollution Discharge Fee Standard." Accessed January 1. <http://pwsf.envsc.cn/tb/>.
- Cao, Shulin. 2016. "Gansu's Wind Energy Curtailment Reached 39% Last Year." *People's Daily*. <http://finance.sina.com.cn/chanjing/cyxw/2016-08-05/doc-ixxutfpc4502728.shtml>.
- Chen, Siwei. 2015. "NO_x Emissions Noncompliance, Five Entities under the Guangdong Utility Group Was Fined." *South Metropolitan*.
- China Electricity Council. 2015. "Basic Electricity Statistics Summary." <http://www.cec.org.cn/guihuayutongji/tongjixinxi/niandushuju/2015-11-30/146012.html>.
- China Environment Yearbook Editing Committee. 1996. "China Environment Yearbook 1996." ———. 2011. "China Environment Yearbook 2011."
- Coase, Ronald H. 1960. "The Problem of Social Cost." CHAP. In *Classic Papers in Natural Resource Economics*, 87–137. Springer.
- CPC, and The State Council. 2015. *Integrated Reform Plan for Promoting Ecological Progress*. http://english.gov.cn/policies/latest_releases/2015/09/22/content_281475195492066.htm.
- Cunningham, Edward A. 2015. "China's New Plans for a Cap and Trade System Just Might Work." *Foreign Policy*. <http://foreignpolicy.com/2015/10/06/china-carbon-emissions-climate-change-cap-trade-us/>.
- Department of Environmental Protection of Guangdong Province. 2013. "2013 Report on the State of Guangdong Provincial Environment."
- Falk, Robert L., and Jasmine Wee. 2014. "China's New Environmental Protection Law-Implications for Overseas Investors, Joint Ventures and Trading Partners." <http://www.mondaq.com/china/x/345932/Environmental+Law/Chinas+New+Environmenta+Protection+Law>.
- Fisher-Vanden, Karen, Erin T Mansur, and Qiong Juliana Wang. 2012. "Costly Blackouts? Measuring Productivity and Environmental Effects of Electricity Shortages." RPRT. National Bureau of Economic Research.
- Guangdong Provincial Environmental Protection Department. 2012. *Guangdong Provincial Industrial Boiler Pollution Control Implementation Plan (2013-2015)*.
- Guangdong Provincial Statistics Bureau. 2015. "Guangdong Provincial Statistics Yearbook 2015."

- Hong Kong Information Service Department. 2012. “JWGSDEP Holds 12th Meeting in Guangzhou and Endorses next Phase of PRD Regional Air Pollutant Emission Reduction Plan.” http://gia.info.gov.hk/general/201211/23/P201211230440_0440_102939.pdf.
- IEA. 2012. “World Energy Outlook 2012.” http://www.iea.org/publications/freepublications/publication/WEO2012_free.pdf.
- IMF. 2015. “How Large Are Global Energy Subsidies? Country-Level Subsidy Estimates.” <http://www.imf.org/external/np/fad/subsidies/data/codata.xlsx>.
- Jiang, Shanshan. 2010. “Too Much, Too Late.” *China Dialogue*. <http://www.chinadialogue.net/blog/3810-Too-much-too-late/en>.
- Karagulian, Federico, Claudio A. Belis, Carlos Francisco C. Dora, Annette M. Prüss-Ustün, Sophie Bonjour, Heather Adair-Rohani, and Markus Amann. 2015. “Contributions to Cities’ Ambient Particulate Matter (PM): A Systematic Review of Local Source Contributions at Global Level.” *Atmospheric Environment* 120: 475–83. doi:10.1016/j.atmosenv.2015.08.087.
- Klimont, Z., J. Cofala, I. Bertok, M. Amann, C. Heyes, and F. Gyarfas. 2002. “Modelling Particulate Emissions in Europe.” *ILASA, Interim Report* IR-02-076.
- Korsbakken, Jan Ivar, Glen P Peters, and Robbie M Andrew. 2016. “Uncertainties around Reductions in China’s Coal Use and CO₂ Emissions.” *JOUR. Nature Clim. Change* 6 (7). Nature Publishing Group: 687–90. <http://dx.doi.org/10.1038/nclimate2963>.
- Liu, H., X. M. Wang, J. M. Pang, and K. B. He. 2013. “Feasibility and Difficulties of China’s New Air Quality Standard Compliance: PRD Case of PM_{2.5} and Ozone from 2010 to 2025.” *Atmospheric Chemistry and Physics* 13 (23): 12013–27. doi:10.5194/acp-13-12013-2013.
- Mechler, Reinhard, Markus Amann, and Wolfgang Schöpp. 2002. “A Methodology to Estimate Changes in Statistical Life Expectancy due to the Control of Particulate Matter Air Pollution.” *JOUR.*
- MEP, and Standardization Administration of China. 2013. “Limits and Measurement Methods for Emissions from Light-Duty Vehicles (China 5).” <http://kjs.mep.gov.cn/hjbhzb/bzwb/dqhjbh/dqydywrwpfbz/201309/W020131105534056881723.pdf>.
- OECD. 2013. “OECD Economic Surveys: China 2013.” Book. OECD Economic Surveys: China. OECD Publishing. doi:10.1787/eco_surveys-chn-2013-en.
- People’s Government of Guangdong Province. 2013. “Guangdong Province Pearl River Delta Region Clean Air Action Plan.”
- . 2014a. “Guangdong Issues Action Plan on Air Pollution Control (2014-2017).”
- . 2014b. “Guangdong Province Air Pollution Prevention and Management Action Plan 2014-2017.”
- Shao, Zhenying, D Wagner, and Zifei Yang. 2014. “Costs and Benefits of China 5/V and 6/VI Standards in Guangdong Province.” *JOUR.* http://www.theicct.org/sites/default/files/publications/ICCT_GuangdongCBA_20140616_re

vDec2014.pdf.

- Statistics Bureau of Guangdong Province. 2014. “Guangdong Statistical Yearbook 2014.”
- Sun, Jian, Jeremy Schreifels, Jun Wang, Joshua S. Fu, and Shuxiao Wang. 2014. “Cost Estimate of Multi-Pollutant Abatement from the Power Sector in the Yangtze River Delta Region of China.” *Energy Policy* 69 (June): 478–88. doi:10.1016/j.enpol.2014.02.007.
- The Global Commission on the Economy and Climate. 2014. “China and New Climate Economy.”
http://newclimateeconomy.net/sites/default/files/nei_ye_xiao_zhi_liang_20141113_reduced.pdf.
- The State Council. 2013. *Notice of the State Council on the Air Pollution Prevention and Control Action Plan*. http://www.gov.cn/zwgk/2013-09/12/content_2486773.htm.
- U.S. Bureau of Economic Analysis. 2016. “Table 1.1.9 Implicit Price Deflators for Gross Domestic Product.”
<http://www.bea.gov/iTable/iTable.cfm?reqid=9&step=3&isuri=1&903=13#reqid=9&step=3&isuri=1&904=2005&903=13&906=a&905=2010&910=x&911=0>.
- van Donkelaar, A, R V Martin, M Brauer, and B L Boys. 2015. “Global Annual PM2.5 Grids from MODIS, MISR and SeaWiFS Aerosol Optical Depth (AOD), 1998-2012.” DATA. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC).
<http://dx.doi.org/10.7927/H4028PFS>.
- WHO. 2006. “WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide: Global Update 2005: Summary of Risk Assessment.” *Geneva: World Health Organization*, 1–22.
http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf?ua=1.
- Wong, Edward. 2015. “Fines Total \$26 Million for Polluters in China.” *The New York Times*.
http://www.nytimes.com/2015/01/01/world/asia/chinese-court-orders-6-companies-to-pay-26-million-for-polluting.html?_r=0.
- Xie, Qinyu. 2014. “PRD Coal Fired Power Plan Completed Denitrification Equipment Installation, NOx Emissions Reduced by 43.3%.” *South Daily*.
- Xu, Yuan. 2011. “Improvements in the Operation of SO2 Scrubbers in Chinas Coal Power Plants.” *Environmental Science and Technology* 45 (2): 380–85. doi:10.1021/es1025678.
- Xu, Yuan, Robert H. Williams, and Robert H. Socolow. 2009. “China’s Rapid Deployment of SO2 Scrubbers.” *Energy & Environmental Science* 2 (5): 459. doi:10.1039/b901357c.
- Zhang, Qiang, Kebin He, and Hong Huo. 2012. “Policy: Cleaning China’s Air.” *JOUR. Nature* 484 (7393). Nature Publishing Group, a division of Macmillan Publishers Limited. All Rights Reserved.: 161–62. <http://dx.doi.org/10.1038/484161a>.
- Zhang, Shiqiu. 2001. “Environmental Regulatory and Policy Framework in China: An Overview.” *JOUR. Journal of Environmental Sciences* 13 (1).
- Zhang, Xuehua, and Jeremy Schreifels. 2011. “Continuous Emission Monitoring Systems at Power Plants in China: Improving SO2 Emission Measurement.” *JOUR. Energy Policy* 39 (11): 7432–38. doi:http://dx.doi.org/10.1016/j.enpol.2011.09.011.