ESM267

China: Air Pollution and Acid Rain Control

The Case of Shijiazhuang City and the Changsha Triangle Area

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Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP)

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Abbreviations and Acronyms

ADB	Asian Development Bank
API	Air Pollution Index
BTU	British Thermal Unit
CFBC	Circulating Fluidized Bed Combustion
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CRAES	Chinese Research Academy for Environmental Sciences
CZX	Changsha-Zhuzhou-Xiangtan
ECON	Centre for Economic Analysis, Norway
EIA	Energy Information Administration
EPB	Environmental Protection Bureau
ESMAP	Energy Sector Management Assistance Programme
FBC	Fluidized Bed Combustion
FGD	Flue Gas Desulfurization
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IGCC	Integrated Gasification Combined Cycle Technology
LPG	Liquefied Petroleum Gas
LPS	Large Point Sources
MW	Megawatt
MWe	Megawatt equivalent
NAAQS	National Ambient Air Quality Standards
NORAD	Norwegian Agency for Development Cooperation
NO_x	Nitrogen Oxides
O & M	Operation and Maintenance
PM	Particulate Matter
PM_{10}	Particulate Matter With Diameter < 10?m
$PM_{2.5}$	Particulate Matter With Diameter < 2.5?m
RAINS-Asia	Regional Air Pollution Information and Simulation Model for Asia
RMB	*Renminbi* - Chinese currency
SEPA	State Environmental Protection Administration
SO_2	Sulfur Dioxide

SO_3	Sulfur Trioxide (sulfate)
TCZ	Two Control Zone Plan (Policy for SO_2 and Acid Rain Abatement)
TSP	Total Suspended Particulates
VOC	Volatile Organic Compounds
WB	World Bank
WSA	Wet gas Sulfuric Acid

Executive Summary

Background and objectives of the study and technical assistance

1. In 1998, China adopted national legislation to limit ambient sulfur dioxide (SO_2) pollution and to stem the growing incidence of acid rain. The program became known as the "two control zones (TCZ)" plan, referring to its geographical coverage of: (i) cities with high ambient levels of SO_2 that are subject to ambient concentration compliance requirements, and (ii) regions with serious acidification problems that are required to reduce the incidence of acid rain through the reduction of SO_2 emissions. Targets were put forth in the National 10th Five-Year (2001-2005) Plan for Environmental Protection, which stipulated that by 2005:[1]

- Annual sulfur emissions in the two control zones were to be reduced by 20 percent, compared with their 2000 levels.
- Annual ambient SO_2 concentration levels of 31 noncompliant cities must attain the national standard for residential areas.

2. These are tough targets to meet considering that SO_2 emissions were previously unregulated in China. China is the first among developing countries to regulate sulfur on such a large scale and with such aggressiveness; the only parallels are the sulfur control legislation and control measures that have been adopted in Europe and North America. The cities and provinces in China affected by the legislation were required to submit their detailed implementation plans for SO_2 control to the State Environmental Protection Administration (SEPA) by January 2003.

3. This study, and the associated technical assistance project, has three main objectives. The first is to help localities in China address several questions related to the planning and implementation of SO_2 emissions and acid rain control:

- What are the environmental consequences, especially for the specific localities, of different pollution control strategies in terms of the impacts on human health, agricultural productivity, and other sectors and activities?
- What are the relative costs of different sulfur emission reduction plans?
- Will the proposed strategies enable localities to meet the environmental targets set by the central government?

[1] Plans and Reports, SEPA, China. http://www.zhb.gov.cn/649364983179640832/index.shtml.

4. The second objective is to assist with capacity building and training in China to enable cities and regions to carry out environmental and economic analyses of sulfur emission impacts and control programs.

5. The third objective is to provide a forum for discussion with the central government, primarily SEPA, on the results of the case studies and the implications for national policy with respect to sulfur control.

6. Most localities in China lack tools and assessment capacities for determining the relative benefit of emission reductions within a spatial framework, and instead have typically focused on quantifying the total emission reductions from a set of control measures, without regard to where those emissions originate and where they subsequently end up. Pollution impacts from sulfur are closely correlated with the spatial distribution of ambient concentrations of sulfur and with the incidence of acid rain, as opposed to the total emissions of sulfur. It is therefore important to understand the dynamics of concentrations and geographic locations when planning abatement strategies. Similarly, analysis of the costs of pollution control in China has typically looked narrowly at the upfront capital costs of measures to reduce emissions, without looking at the operating costs or the multiple benefits that some pollution control measures bring (for example, natural gas). A better understanding of the emissions and impact relationship also helps to clarify the benefits and costs of emission control—a focus on the cost of damages reduced instead of emissions reduced—thus allowing cities and regions to allocate better their scarce financial resources for environmental improvement.

7. This study analyzes China's national sulfur pollution control program by looking at local implementation plans and actions for reducing sulfur emissions in two municipalities— Shijiazhuang and Changsha. The city of Shijiazhuang in Hebei Province was chosen for a case study on ambient SO_2 pollution control, representing a northern Chinese city, while the tri-city region of Changsha, Zhuzhou, and Xiangtan in Hunan Province was chosen to represent a southern area experiencing serious levels of acid rain.

8. At the national policy level, the case studies provide specific local lessons that can be used to inform China's national sulfur control policy, including providing guidance on the effectiveness and impact of meeting the national emission control targets. Follow-up meetings with SEPA will be held to discuss both the strengths and weaknesses of the sulfur control policy in terms of reducing ambient air pollution and acid deposition in the areas covered by the policy.

Why did China regulate sulfur emissions?

9. Sulfur dioxide (SO_2) emissions from coal burning have long been a major contributor to ambient air pollution in Chinese cities and are the primary cause of acidic precipitation in ecologically sensitive areas in China and on much of its most fertile land.

By 1996, when China's coal consumption reached historic highs, ambient SO_2 pollution was severe and widespread in major cities. Of the 90 cities with reported data, the median annual SO_2 concentration level was 60 micrograms per cubic meter (? g/m^3), with the highest concentration at 418 ? g/m^3, compared with the WHO guideline value of 50 ? g/m^3. Acid rain, defined as precipitation with a pH value lower than 5.6, had expanded from a few pockets in southwestern China in the mid-1980s, to about 30 percent of the country's land area by the mid-1990s.

10. With the passage of the TCZ legislation, the Chinese government took an unprecedented step to control sulfur emissions. There is no doubt that by the late 1990s ambient SO_2 concentrations in many densely populated urban areas were exceedingly high and harmful, and many incidences of acid rain had been documented in China's principal agricultural areas such as Sichuan Province. Backed with studies and expert opinion from leading Chinese universities and research institutions, SEPA helped win approval of the sulfur control legislation. However, most of the evidence of human health and acid rain damage at the time in China was anecdotal, with no systematic assessment of the level and extent of the impact of ambient SO_2 levels and acid rain. SEPA was very effective in convincing the government of the importance of controlling SO_2 emissions, using evidence that reportedly included future scenarios of human health impacts and damages of acid rain on manmade structures, forests and other ecosystems, water bodies, and especially agricultural production. China was probably also influenced by international attention on acid rain, and China's growing contribution to regional and global SO_2 emissions.

Key challenges to sulfur control in China

11. Controlling sulfur pollution in China is more difficult than in North America or Europe for several reasons:

(1) China's economy is extremely dependent on coal, and the demand for it is expected to grow over the next 20 years. The impact of regulating SO_2 emissions goes far beyond coal-fired power plants in China—the electric power sector consumes less than 50 percent of national coal consumption. About half of China's population relies on coal-fired devices for space heating, and there are more than 400,000 small to medium-size coal-fired boilers in China in use by industry and commerce. Controlling emissions from such a large number of dispersed users, in applications where there are few available and affordable control measures, is a key problem for sulfur control in China.

(2) Capital is scarce in China, especially for environmental control investments, and in light of competing environmental issues. For both national and local governments, policy decisions involve not only balancing GDP growth and environmental protection, but also stretching

environmental resources among air, water, solid waste, and natural resource concerns. Before the mid-1990s, China's industrial sector (including the electric power industry) made little investment in sulfur emissions abatement because of a lack of regulatory and financial incentives.

(3) Institutional capacity for managing air pollution in China is underdeveloped, and most local environment agencies do not have sufficient capacity to monitor and regulate sulfur emissions effectively. China is still at an early phase in developing and implementing a permit system for large emitters of SO_2, while numerous small coal users are collectively important but difficult to regulate.

Case study findings and lessons learned

12. The two case studies that were carried out provide examples of the impacts of SO_2 and the options for and benefits of controlling sulfur emissions in two specific localities in China. The detailed case studies are covered in Chapters 3 and 4 of this report. Some of the key conclusions and recommendations of the case studies are provided in Box E1.

13. Based on the case studies, and information gathered during the course of the project on China's experience in sulfur emission control, the following conclusions can be drawn:

(1) There is a clear divide between northern and southern cities and regions in China in terms of the impacts of sulfur dioxide and potential solutions. Acid rain is mostly a southern phenomenon, while high ambient SO_2 levels are more prevalent in northern cities where winter space heating exacerbates air pollution problems. Emission control efforts in the north will benefit from access to significant quantities of low sulfur coal, the lack of which in the south will significantly increase the cost of sulfur emission control.

(2) Regulating large versus small emission sources requires very different policy instruments, and the costs of control are significantly different as well. While large sources with tall stacks contribute most to long-range transport of sulfur emissions, small-scale emissions contribute a relatively larger amount to local ambient concentrations in densely populated areas so that their contribution to impacts is also relatively greater. Given the economies of scale—both technically and institutionally—in sulfur emissions control, regulatory efforts for large emission sources such as power plants and key specialty industries can greatly reduce total emissions, long-range transport, and impacts, to the extent that large sources are located close to major urban areas, as the case study in

Changsha has shown. For small residential and commercial coal users, restricting or banning coal use in urban areas has proven to be an effective way of addressing ambient SO_2 pollution. Such measures have been most successful when they are part of a cross-sectoral plan that has included the widespread provision of cleaner fuels (for example, natural gas) and the relocation of industry.

(3) Gaining a better scientific understanding of the impacts of sulfur emissions and improving estimates of the relative benefits of different control options are two important pieces of information for leveraging local implementation efforts. The case studies indicate that local governments are usually able to identify sulfur control activities that would achieve the required emission reduction targets of the central government. Weaknesses of the localities include (i) the inability to determine whether control activities would achieve targets for ambient SO_2 concentration levels; (ii) lack of analysis of the impacts of sulfur pollution, including acid rain hot spots; and (iii) inadequate analysis of the cost-effectiveness of control activities.

(4) Promoting policies with multiple benefits is an effective way of cutting sulfur pollution without reliance on regulatory policies or institutions. The marked decline of ambient SO_2 levels in many Chinese cities over the past five years is largely the result of the decrease in coal consumption among small-scale users that has come about through widespread urban natural gas investments and through systematic industrial relocation. While the pressure for air pollution control has been critical, the change in urban fuel mix is part of a larger urban development strategy that many local governments have embraced in the last decade or so

Box E1: Summary of Case Studies

Shijiazhuang City, Hebei Province

?? Sulfur pollution in Shijiazhuang is dominated by central heating boilers and large point sources (both inside and outside the city limits), with the highest annual average SO_2 concentrations reaching 180 µg/m^3, and with health impacts alone equivalent to about 10 percent of local GDP.

?? More than 90 percent of the planned sulfur emission reductions through 2005 would come from fuel substitution? – low-sulfur coal for industrial and power sector boilers, and natural gas for domestic cooking and heating and for small industrial boilers.

?? Proposed sulfur control measures for the 10th Five-Year Plan in Shijiazhuang are likely to fall short of allowing the city to meet ambient pollution standards as required by SEPA.

?? Additional emission reductions from the power sector would be sufficient to ensure compliance with the TCZ requirements, which would reduce health impacts to around 0.2 percent of local GDP (Tables 3.10 and 3.11) and could be gained most cost-effectively by the use of additional low-sulfur coal from neighboring Shanxi Province.

Greater Changsha (including Xiangtan and Zhuzhou), Hunan Province

?? Total sulfur deposition in the greater Changsha region, a hot spot of acid rain in China, is dominated by large industrial smelters and power plants. Besides large quantities of acid deposition, SO_2 pollution is also high around the large power plants and smelters, with annual average ambient concentration levels exceeding 300 µg/m^3.

?? Planned sulfur emission reductions rely on a large increase in natural gas and low-sulfur coal for industrial boilers. A significant amount of the reduction would be achieved through industrial renovation investments and the installation of pollution control equipment at a single smelter in Zhuzhou.

?? The proposed sulfur control measures in the 10th Five-Year Plan is likely to allow the greater Changsha region to meet the sulfur emission reduction target set by SEPA. However, the environmental costs from acid rain in the region would remain high (Figure 4.3).

?? Sulfur control targets are threatened in the short to medium term by social and economic constraints of shutting down local coal mines producing high-sulfur coal, and by the planned construction of new coal-fired electricity-generating capacity near the city.

National policy lessons and recommendations

14. In addition to their value for local decision making, the case studies provide useful information to the central government about the TCZ policy and its implementation. The successes of China's sulfur control policy include: (i) introduction of restrictions on the production of high-sulfur coal, (ii) requirements for coal-fired power plants to switch to low-sulfur coals or to install emission control equipment, and

(iii) the setting of targets for emission reduction. SEPA has also effectively mobilized local environmental agencies to plan and prepare for its implementation; local environment and municipal authorities have: (i) been collecting sulfur emission charges, and (ii) instituted restrictions on coal-burning devices and in some localities an outright ban on coal-burning in densely populated areas.

15. Setting simple and clear goals at the national level and letting local governments and line agencies work out the details of implementation has been an effective strategy for sulfur control that reflects the administrative and bureaucratic structure of China's governmental system. The system works well when both the central and local governments are committed to achieving results, which appears to be the case for sulfur control.

16. Specific implications for national sulfur control activities and policy based on the findings of the case studies are the following:

(1) SEPA needs to take a long-term look at the targets and goals for sulfur pollution control in China, for example, a 20-year horizon, and assess the needs and efforts accordingly. More specifically, the understanding of the dynamics of long-term sulfur emissions should be given greater support, and the implications in terms of specific "hot spots" of sulfur impacts for ecosystems, agriculture, and human settlement areas should be a focus of SEPA's work. Regulatory policy should consequently be directed at key polluters and growth sectors and on avoiding the creation of hot spots.

(2) SEPA should continue to provide scientific evidence of the impacts of sulfur, especially from thermal power plants, to mitigate interregional transport of emissions that would help the power sector comply with national sulfur regulations at the least cost. The power sector is likely to determine the long-term success of China's sulfur pollution control program because of its projected growth and the general softening of or reduction in coal demand in other economic sectors. In terms of other sectors, SEPA should continue to monitor the contribution to sulfur emissions by the transport sector, which has been a rather minor contributor in most Chinese cities.

(3) Regulations on small emission sources should be kept simple and straightforward, and rely on cross-sector policy support to help reduce clusters of small sources in urban areas. This effort will depend on the development of natural gas transmission lines and local investments in distribution facilities. The provision of gas for scattered coal-fired space heating systems in northern cities is an important option. Large reduction in heating coal consumption can also be obtained with a rapid scale-up of the development of energy-efficient buildings in northern China.

(4) There should continue to be a focus on large emission sources and key industries, where moving to a permit system would reduce regulatory

uncertainty and likely lead to lower costs of compliance. This will require a substantial increase in institutional and regulatory capacity at the provincial and municipal levels. A permit system is not simply a way of allocating emission quotas; it carries with it a host of regulatory requirements on emissions and compliance as well as consequences for violation. Such a system would pave the way for the future introduction of a tradable permit system.

(5) The central government should provide assistance to localities to increase their capacity for carrying out the type of analysis done in Shijiazhuang and Changsha. Capacity building should be focused on developing skills and institutions to: (i) assess and quantify the impacts of sulfur emissions, (ii) evaluate the benefits of control options in terms of reducing ambient concentrations of sulfur and associated impacts, and (iii) assess the cost-effectiveness of control options, looking specifically for options with multiple benefits.

1

Introduction And Background

1.1 Emissions of SO_2 from coal combustion are a primary contributor to acid rain and local air quality problems in China. Besides human health impacts, acid deposition has been recognized as an environmental threat to China's agricultural productivity. Acidic substances adversely affect aquatic systems, forests, monuments, and the regional climate, altering the sensitivity of lakes, forests, soils, and ecosystems. Of long-term concern is the leaching by acids of nutrients from soils, resulting in diminishing agricultural yields.

1.2 Acid rain, a form of precipitation that contains high levels of sulfuric or nitric acids, affects about 30 percent of the land area in China (Pu and others, 2000). Both sulfates and nitrates are also known to contribute to the acid deposition problem through their atmospheric conversion into acids that are deposited as rain or snow on the ground many miles downwind of the original source. They also contribute to atmospheric haze, that is, visibility impairment.

1.3 Particularly high acid deposition levels have been recorded in areas of south China, northeast India, Thailand, and the Republic of Korea, which are near or downwind from major urban and industrial centers. The effects are already being felt in the agriculture sector. It was estimated that ~19 percent of the agricultural land in the seven provinces (Jiangsu, Zhejiang, Anhui, Fujian, Hunan, Hubei, and Jiangxi) in southern China was affected by SO_2 and acid rain pollution. The average crop yield reduction due to the combined effects of SO_2 and acid rain was 4.3 percent in the mid-1990s. Vegetable yield was reduced by 7.8 percent, wheat by 5.4 percent, soybean by 5.7 percent, and cotton by 5.0 percent. In these seven provinces, 4.2 percent of the forest was affected by acid deposition (Yang and others, 2002). Other ecosystems are also beginning to suffer. A study of oak and pine trees in acid rain-affected areas of the Republic of Korea, both rural and urban, showed significant declines in growth rates since 1970 (Downing and others, 1997).

1.4 Sulfur dioxide emissions are also known to contribute significantly to fine particulate matter ($PM_{2.5}$) through formation of sulfate particles. Sulfates and nitrates (formed by means of oxidation of SO_x, and NO_x emissions) are essentially fine particulate compounds often transported in the air over long distances. The health effects of particulates are strongly linked to particle size. The constituents in small particulates also tend to be chemically active. In parts of China, the Democratic Republic of Korea (Korea hereafter), and Thailand, sulfates are estimated to contribute significantly to the ambient PM_{10} and $PM_{2.5}$ concentrations (World Bank, 1998). A majority of Chinese cities may have unhealthy levels of fine particulate concentration.[2]

1.5 The health impacts of fine particulates have been shown to be correlated with respiratory disease in China, which presently accounts for 18 percent of all deaths in China. According to a growing number of epidemiological studies (Akbar and Kojima, 2003), fine particulates contribute to the aggravation of asthma, heart and lung disease, and general lung functions by penetrating deep into the human respiratory tract. Although the general situation of ambient air pollution has improved, estimates of the health damages of fine particulate pollution in China in 1995 resulting from violation of relevant ambient standards included 178,000 premature deaths, 346,000 registered hospital admissions, more than 6 million emergency room visits, and more than 75 million asthma attacks, among other things. The costs associated with these negative health effects was equivalent to more than 4 percent of China's GDP (World Bank, 1997).

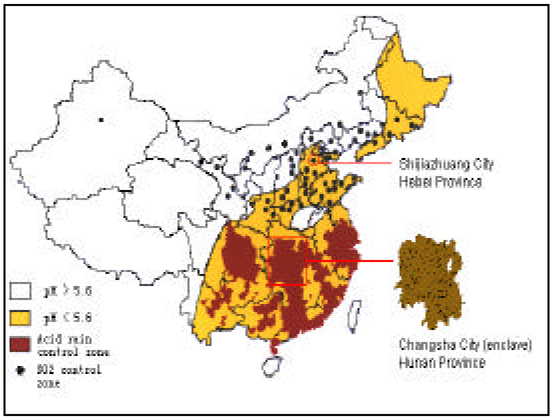
1.6 Coal is the principal source of energy in China and a primary source of air pollution. The cities in China are heavily polluted by SO_2 and PM emissions. The major sources of SO_2 emissions are fossil fuel, including coal-fired power plants and boilers, ore smelters, and oil refineries. Smaller stationary combustion sources, such as space heating, also contribute to the problem, especially in urban areas during the winter. The combustion sources include small domestic stoves as well as large industrial plants. Besides SO_2 and PM emissions, NO_x, CO, CO_2, volatile organic hydrocarbons (VOC) and other greenhouse gases GHGs are also emitted, which are likely to increase from all sectors with growing incomes and industrialization in China, further contributing to both local and global environmental concerns.

1.7 The growing demand for transport and rapid increase in the number of vehicles on the road have led to an increase in air pollution from the transport sector, including sulfur emissions. However, recent emission inventories published by SEPA and other environmental organizations in China and abroad suggest that so far the transport sector has larger influence with respect to NO_x, VOC, CO, and CO_2 emissions than sulfur emissions. Approximately 2 percent of the total annual sulfur emissions in China in 2001 was attributed to the transport sector as compared to about 86 percent from industrial and power sectors combined (Streets and others, 2003). Certainly, sulfur emissions from the transport sector are significant in specific cities transport corridors today, and there is a

[2] China currently does not report monitoring data for fine particulate pollution. Among 341 Chinese cities, nearly two thirds of them have annual total suspended particle (TSP) concentration levels surpassing the Class 2 national ambient air quality standard (200?g/m^3), the maximum level deemed acceptable for residential areas (2001 China Environment Status Report). Anecdotal evidence in China indicate that when TSP levels violate its Class 2 standard, the associated PM10 levels also violate its Class 2 standard (World Bank, 2001).

need to include the sector in future analyses. While transport emissions of sulfur have been used in similar studies in Shanghai,[3] because of lack of data and the belief by the study teams that sulfur emissions were less important in the cities looked at in this study, sulfur emissions from the transport sector were not included in the analysis.

Figure 1.1: Two Control Zones in China and Case Study Locations



Source: *SEPA, China*

1.8 In 1998, China adopted nationwide legislation known as the "two control zones (TCZ)" plan to limit ambient sulfur dioxide pollution and to stem the growing incidence of acid rain. The SO_2 pollution control zone includes 64 major cities where ambient SO_2 concentrations are high; the acid rain control zone encompasses 12 provinces of southern and eastern China currently affected by acid rain (Figure 1.1). Together, the two zones cover 1.09 million km^2 and account for about two-thirds of China's total annual SO_2 emissions. The TCZ plan calls for closing of mines producing high-sulfur coal, limits on the sulfur content of coal and other emission controls by power plants and large industries, implementation of SO_2 emission charges, SO_2 pollution compliance requirements for most major cities in China, and sulfur emissions and acid rain reduction plans for large areas of the south and the east. The SEPA plans to reduce the annual SO_2 emissions in these two zones by 20 percent by 2005 compared with emissions in 2000. In order to meet the targets set by the central government, cities and provinces would have to undertake a variety of emission control measures, including investments in pollution control equipment, alternative fuels such as natural gas, and more efficient and less polluting coal-burning facilities.

1.9 Such legislation is unprecedented among developing countries; the only parallels for such wide-ranging sulfur control legislation are in Europe and North America. What seems to have prompted the TCZ plan was the growing concern among

[3] Li et al., 2003. "Quantifying the Human Health Benefits of Curbing Air Pollution in Shanghai."

the scientific community, policymakers, and the public over severe air pollution in general, and acid rain in particular. Backed by scientific evidence from leading Chinese universities and research institutions, SEPA helped win approval of the legislation. While the incidence of acid rain has been well documented in China, most of the evidence of actual acid rain damage in China up to that time had been anecdotal. It is presumed that the government was concerned with the potential damage of acid rain on manmade structures, forests and other ecosystems, water bodies, and especially agricultural productivity. The areas with the highest incidence of acid rain in China are within China's major agricultural producing areas, and this was undoubtedly a major consideration for the passage of the TCZ legislation.

1.10 The focus of most localities with respect to the TCZ policy is the reduction in sulfur emissions, since hard targets are set and quotas are assigned by the central government. Cities thus look at the total amount of sulfur emission reduction that can be achieved by various interventions. However, environmental impacts are more closely related to the spatial distribution of ambient air pollution concentrations and to the incidence of acid rain rather than to the total emissions of sulfur. In assessing the environmental impact, it is thus important to know the location of emissions (horizontally and vertically) as well as the atmospheric conditions in the area that will determine the formation of acid rain and human exposure.. Most localities in China lack tools and assessment capacities for determining the relative benefit of emission reductions within a spatial framework.

1.11 From a cost perspective, it is typical in China for pollution control investments to be looked at from a cost per ton of pollutant reduced. This is problematic given that a ton of sulfur reduced from a downwind power plant on the outskirts of town will achieve much different results compared to a ton of sulfur reduced from a small boiler located in a densely populated urban area. The cost analysis is further complicated in the Chinese setting since what are typically available are only initial capital investment costs. Without knowing the operation and maintenance costs (as well as debt service and depreciation), the cost-effectiveness of the pollution control intervention cannot be accurately determined. A second complication in estimating the cost-effectiveness of pollution control projects is whether the measure has multiple benefits. For example, natural gas may be a relatively expensive means of reducing sulfur emissions but is also highly desired by consumers for its convenience and cleanliness. By contrast, expenditures on end-of-pipe pollution control would have few additional benefits and would not likely be undertaken without enforcement by environmental authorities.

1.12 The objective of this study, and that of the corresponding technical assistance project, was to help localities in China address two main questions related to sulfur pollution and acid rain control.

(1) What are the environmental impacts of different pollution control strategies in terms of human health, productivity losses to agricultural production, and other factors? A subcomponent of this task was to see whether the sulfur control plans proposed by specific localities would

allow them to meet the environmental targets established by the central government.

(2) What are the relative costs of different sulfur emission reduction plans? Recognizing that localities in China will be required to bear the bulk of the investments for sulfur emission control, this question is of particular importance to municipalities as they consider how to allocate scarce resources for pollution control.

1.13 With these questions in mind, the SEPA of China proposed that the project undertake case studies in two Chinese cities, one from each of the two control zones. There would be one northern city in the “sulfur dioxide control” region, and one southern city in the “acid rain control” region. Upon review of candidate cities, Shijiazhuang, the capital city of Hebei Province in the north, and the region of Changsha, Zhuzhou, and Xiangtan (CZX), cities of Hunan Province in the south, were chosen for the case studies.

1.14 Comprehensive plans have been drafted by the Shijiazhuang Municipal Environmental Protection Bureau (EPB)[4] and the Hunan Provincial EPB, which oversees the CZX region acid rain control program,[5] to implement the TCZ policy. These included controlling large point sources, shutting down small emission sources, switching to low-sulfur coal and cleaner fuels, and introducing a SO_2 levy. Both the adopted measures and the action plans will be the basis for developing policy scenarios to control SO_2 and acid rain in the case study areas

[4] Shijiazhuang Municipal EPB—Plans for Controlling SO_2 Pollution in Shijiazhuang, December (1998); Implementation Plans for Environmental Protection in Shijiazhuang, April (1999); An Update on the Shijiazhuang SO_2 Control Zone, July (2000).

[5] Hunan Provincial EPB—Controlling Acid Rain in the Changsha, Zhuzhou, and Xiangtan Region, Changsha, 1998; Hunan 10th Five-Year plan for SO_2 control through 2015 (2000); Changsha Municipal EPB-Air Pollution and Abatement Strategies for Changsha Municipality, Changsha (1998).

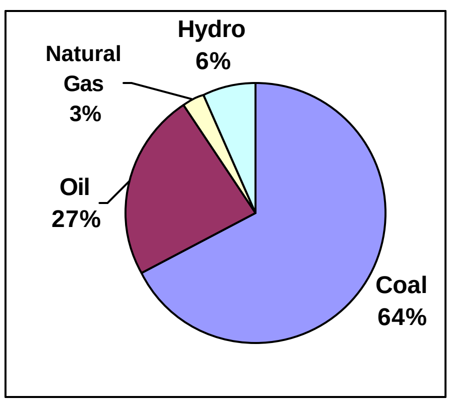
2

Sulfur Emissions And Control Options In China

Sulfur Emission Trends

2.1 China is the currently the largest sulfur-emitting country in the world. The vast majority of the sulfur is emitted through the combustion of coal, which accounted for 64 percent of the country's primary energy consumption in 2000 (Figure 2.1). China is both the largest consumer and largest producer of coal in the world. China's coal consumption in 2000 was 1.17 billion metric tons, or 25 percent of the world total (Energy Information Agency EIA, 2001). Economic growth in China in the last two decades has been accompanied by a doubling of coal use, driving by fast-growing thermal electricity generation, as well as by growing demand in industrial production and in the domestic sector.

Figure 2.1: China: Percent Contribution to Total Energy Consumption, 2000



2.2 Power generation accounts for nearly 40 percent of coal consumption in China; industrial uses, including feedstock for coking plants, account for the bulk of the remainder. In comparison, power plants in the United States account for more than 85 percent of all coal consumption. Coal continues to be the main fuel in nonpower sectors, reflecting China's abundant coal reserves and limited access to other sources of energy. Coal use and production have been reduced in the recent years, owing to economic slow down and restructuring, long-term dependency on coal is likely to continue.

Table 2.1: SO_2 Emissions in Chinese Provinces between 1995 to 2000 (thousand metric tons)

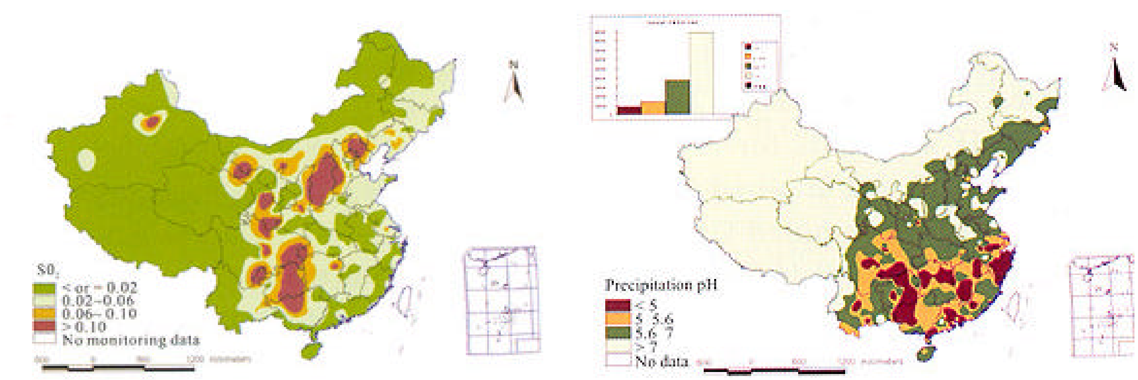
Province	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
Anhui	500.3	458.0	488.6	423.5	409.8	462.7
Beijing	382.9	361.7	348.2	334.8	284.6	360.4
Chongqing	952.2	952.0	898.0	930.7	941.1	947.3
Fujian	234.8	335.0	474.8	165.0	190.4	204.6
Gansu	440.5	434.8	429.3	383.4	312.4	444.9
Guangdong	937.4	770.7	693.0	678.8	694.9	853.9
Guangxi	1024.6	844.5	992.6	700.9	583.5	809.0
Guizhou	1403.0	900.0	1764.8	1927.9	1494.5	1063.0
Hainan	37.8	29.3	20.8	20.4	22.4	35.9
Hebei	1660.0	1581.0	1460.2	1403.0	1326.2	1369.1
Heilongjiang	289.6	321.0	305.6	300.1	294.1	318.1
Henan	1535.8	1210.0	922.6	1002.9	849.7	1230.0
Hubei	650.6	646.2	579.5	568.8	553.3	607.8
Hunan	881.6	990.0	820.9	722.1	758.4	671.0
Inner-Mongolia	729.5	789.0	753.1	728.0	690.9	666.7
Jiangsu	1390.9	1413.1	1369.8	1254.6	979.7	1221.2
Jiangxi	633.9	435.0	406.3	304.6	284.3	518.2
Jilin	255.0	238.7	286.6	283.9	293.7	252.5
Liaoning	1029.0	1102.0	1124.3	991.9	937.4	970.3
Ningxia	204.0	233.1	221.8	215.2	207.9	254.0
Qinghai	39.3	29.5	37.3	31.3	31.0	53.7
Shaanxi	999.2	994.3	758.4	660.1	647.8	893.7
Shangdong	2438.0	2118.0	2473.2	2258.9	1829.8	1996.6
Shanghai	510.6	571.6	508.5	488.9	403.1	518.7
Shanxi	1578.5	1080.0	1820.1	1419.9	1239.5	1482.7
Sichuan	2156.0	1555.2	1032.2	1407.7	812.7	818.1
Tianjin	336.0	360.0	272.0	229.9	242.4	390.4
Tibet	1.0	3.0	1.0	1.4	0.9	
Xinjiang	354.9	351.4	309.1	335.6	337.1	349.2
Yunnan	447.0	513.0	410.4	360.1	336.6	415.4
Zhejiang	613.9	804.0	672.8	645.5	636.4	558.7
Total	24647.8	22425.1	22655.8	21179.8	18626.5	20737.9

Source: *Data collected during the visits to CRAES and SEPA, and communication with Dr. David Streets at Argonne National Labs, Chicago, USA*

2.3 Table 2.1 presents estimated emissions of SO_2 in China by province from 1995 to 2000, using the RAINS-Asia model.[6] In 2000, the estimated emissions of 20.7 million metric tons was in agreement with the official Chinese estimate of 19.95 million metric tons. According to SEPA, sulfur emissions from the TCZ accounts for about 66 percent of the national total. About half of sulfur emissions in the TCZ are from power plants.

2.4 The significant decline of China's coal consumption (by official statistics) in the second half of the 1990s brought some optimism to the national sulfur control program. The reported 20 percent or so reduction of sulfur emissions between 1996 and 2000, mainly the result of absolute reduction in coal consumption, may have influenced SEPA's decision to tighten the requirements for emission reduction in the 10th Five-Year Plan period. The long-term projection for coal demand in China still points to a significant rise in the next two decades, perhaps doubling the 2000 consumption level (EIA, 2002). It may still be too early to say that the net sulfur emissions have peaked in China. Drastic reduction of sulfur emissions will be needed just to maintain the current emission level if this coal demand scenario materializes.

Figure 2.2: (a) Annual average SO_2 Concentration (? g/m^3) and (b) pH levels in China in 2001



Source: *SEPA, China (2000)*

Ambient Sulfur Dioxide Levels and the Status of Acid Rain

2.5 Figure 2.2 presents the SO_2 concentration and pH levels in China in 2001 (SEPA, 2001). Significant improvements in SO_2 pollution control have been achieved in recent years as many cities have limited or banned coal use in downtown areas and made residential and commercial use of gaseous fuels a top priority for urban energy supply.

[6] The latest RAINS-Asia inventory includes emissions from domestic biofuel combustion, biomass burning, and Hong Kong sources, which are excluded from the inventory provided by SEPA.

For example, a 90-city monitoring data set indicates that the medium annual average SO_2 concentration decreased from 60 to 36 ?g/m^2 between 1995 and 2000. The cities that suffer the most serious SO_2 pollution are located in the provinces of Shanxi, Hebei, Guizhou, Chongqing, Gansu, Shaanxi, Sichuan, Hunan, Guangxi, and Inner Mongolia, which are either China's top coal producers or where high-sulfur coal is widely used.

2.6 In 2001, among the 274 monitored cities for acid rain precipitation, 101 experienced pH values of 4.2 to 8.0 in their rainwater, with an annual average pH of under 5.6, and most of them are located in the regions of eastern, southern, central, and southwestern China. The overall acid rain situation has stabilized in recent years because of stabilization of sulfur emissions, largely because of a decline in overall coal consumption.

Box 2.1: Main Policy Measures of the "Two Control Zones" Plan (1998)

There are three main policy measures embodied in the "two control zones" plan.

Controlling the sulfur content of coals supplied. Construction of new collieries based on coal with a sulfur content of 3 percent and above is prohibited. Existing collieries mining similar coals will face production restrictions or be gradually phased out. Coal mines producing coals with sulfur content greater than 1.5 percent should construct washing facilities that match their mining capacity. Local governments can set limits on sulfur contents of urban coal and fuel oil supply.

Controlling emissions from coal-fired power plants. Construction of coal-fired power plants in downtown and nearby suburbs of medium-size and large cities is prohibited, except for co-generation plants whose primary purpose is supplying heat. Newly constructed or renovated coal-fired power plants using coals with sulfur content greater than 1 percent must install sulfur- scrubbing facilities. Existing coal-fired power plants using coals with sulfur content greater than 1 percent must adopt SO_2 emission reduction measures, including flue gas desulfurization (FGD). Other industrial facilities with serious sulfur pollution impact must install control equipment or adopt other mitigation measures.

Collecting SO2 emission fees. Emission fees should be collected from major sulfur emitters, and no less than 90 percent of emission fees should be used for specific SO2 pollution control investments at these polluting sources

2.7 Particulate pollution, which ambient SO_2 concentration is partly responsible, continues to be China's primary ambient air quality concern. Nearly two-thirds of the 341 cities monitored for total suspended particulates (TSP) in 2001 had annual TSP concentration levels above the Class 2 standard (200? g/m^2). This, however, is masked by the high percentage of wind-blown dust in northern China. The more accurate measurement of particulate pollution, ambient concentration of PM_{10} or $PM_{2.5}$, is not widely used in China.

Regulatory Framework for Sulfur Control and the 10th Five-Year Plan

2.8 The legal framework for sulfur control is laid out in the Air Pollution Prevention and Control Law of China, which was amended in 2000. The law includes a chapter specifically written for prevention and control of air pollution caused by coal burning and endorses policies such as control of total (national) emissions, enforcement of emission standards, restrictions on mining of high-sulfur coal, promotion of cleaner fuels, and requirements for emission control equipment at major polluting sources.

2.9 The TCZ plan, a SEPA legislation endorsed by the State Council in 1998, set forth some basic targets and policy and regulatory measures for reducing ambient SO_2 pollution and acid rain impact (Box 2.1).

Box 2.2: Main Policy and Regulatory Measures Set Forth in the 10th Five-Year Plan for the TCZ

1. Local governments should formulate their own five-year plans and annual implementation plans for controlling acid rain and SO_2 pollution, following the national plan, and incorporate prioritized investment projects into local social and economic development five-year plans.

2. SO_2 emission standards should be amended so that they are consistent with the total emission control target of the 10th Five-Year Plan.

3. The national government will allocate the total SO_2 emission quota of the TCZ to individual provincial-level governments, and each provincial government will then confirm permitted SO_2 emissions of key local pollution sources and issue SO_2 emission permits to these sources.

4. Collection of SO_2 emission fees should be strengthened and expanded, gradually increasing the fee levels to encourage pollution control.

5. Trials of SO_2 emission rights trading should be carried out in order gradually to establish the trading system for SO_2 emission rights.

2.10 The targets and regulatory measures were further clarified and tightened in the 10th Five-Year (2001-2005) Plan for Acid Rain and SO_2 Pollution Control in the TCZ proposed by SEPA and approved by the State Council. Encouraged by the recent reduction in total annual SO_2 emissions, SEPA has raised the emission control target from a 10-year stabilization (zero increase in net emissions by 2010), set in the original TCZ plan, to a 5-year reduction of 20 percent of net emissions by 2005, compared to the 2000 baseline level of 13.16 million metric tons. In addition, 31 cities are required to achieve compliance with Class 2 standards by 2005, including Taiyuan, Benxi, Chongqing, and Guiyang, cities with the worst ambient SO_2 pollution in China (SEPA, 2002). These are tall orders, considering that coal consumption was expected to reverse its recent decline and begin to grow after 2001. To ensure the attainment of these goals and pave the way for further emission reduction, main policy and regulatory measures are set forth in the 10^{th} Five-Year Plan (Box 2.2).

2.11 The SO_2 emission control projects proposed in the 10^{th} five-year plans of the provincial governments in the TCZ amount to 550, with an estimated total investment of 96.7 billion Yuan, resulting in an estimated total annual reduction of SO_2 emissions of 3.87 million metric tons. The 279 key projects, for which SEPA has itemized information, would generate 3.04 million tons of emission reduction. Power plant desulfurization, which accounts for 72 percent of the total investments (of 41 billion Yuan) in the key projects, is expected to produce 2.12 million tons of annual emission reduction.

Sulfur Pollution Control Measures in China

2.12 This study is concerned mainly with sulfur pollution generated by burning coal. In that regard, the commonly adopted sulfur pollution control approaches fall into three categories:

?? Switching to low-sulfur fuels

?? Sulfur removal during coal combustion

?? Flue gas desulfurization.

2.13 Many advanced coal utilization technologies, such as the integrated gasification and combined cycle (IGCC) power generation, are highly efficient in sulfur removal but remain experimental and costly at present. Energy efficiency investments reduce demand for coal and the associated sulfur emissions. In general they need to be justified on the economics of energy savings, although sulfur regulations could provide added incentives for such investment.

2.14 Fuel switching usually involves the use of low-sulfur coal or sulfur-fixed briquettes at the lower cost end, and gaseous fuels such as liquefied petroleum gas (LPG) and natural gas at the higher cost end. These options represent a wide spectrum of costs and are subjected to the constraints of local access to various types of low-sulfur fuels. Some Chinese cities also encouraged the use of electricity for cooking, water heating, and even space heating in recent years. However, this could be a case of diluting local pollution if the electricity comes from coal-fired power plants without SO_2 emissions controls.

2.15 Sulfur removal during coal combustion (in situ sulfur removal) is achieved in industrial and utility boilers by applying sorbent injection techniques or fluidized bed combustion (FBC) technology. The former usually involves injection of dry sorbent (either calcium or sodium-based) into the furnace of a boiler,[7] while the latter involves the firing of suspended fine mixture of coal and sorbent (such as lime). The basic furnace sorbent injection technique is easy to set up and operate and is relatively inexpensive. It is rarely used in China in part because of lack of experience with the technology. Nonpressurized FBC boilers are beginning to penetrate the market, especially in the large boiler segment (70 ton-steam per hour or larger sizes) as domestic manufacturers have successfully absorbed the technology.

2.16 Flue gas desulfurization (FGD) is usually applied in coal-fired power plants, where the technology is most cost-effective. The wet scrubbers, using gas/liquid reactions to remove sulfur from flue gas, are the dominant FGD technology. The spray dry scrubbers, a cheaper alternative to wet scrubbers, are usually used for small utility boilers or old plants. Both technologies have been demonstrated in China and appear to be in demand from the large amounts of proposed investments for the 10th Five-Year Plan. So far, there are only a few operating facilities, as a result of cost concerns and rigid utility pricing regulations.

2.17 The suitability of the control measures described above at a given locality depends on the availability and costs of low-sulfur fuels, costs of control technologies, the conditions of existing facilities, and local (or even site-specific) emissions control goals.

2.18 Sulfur pollution control became a major regulatory pursuit in China when the TCZ plan was initiated in 1998. This has prompted many coal-fired power plants to switch to low-sulfur coal. However, adoption of specific sulfur emission control technologies is rare in power plants and among industrial coal users. The broad-based urban residential and commercial fuel-switching programs began more than a decade ago and have had a significant impact on reducing ambient SO_2 pollution, among other benefits. Thus, except for fuel-switching approaches, the sulfur emission mitigation measures discussed are not common applications.

Residential and Commercial Sectors

2.19 In provincial capital cities, such as Shijiazhuang and Changsha, gaseous fuels already dominate residential cooking and water-heating fuel supply, and are widely used by restaurants. LPG is most widely available, and in many urban areas household income appears to be the main constraint for acquiring LPG. In regions needing winter space heating, such as Shijiazhuang, coal remains the dominant fuel for residential and commercial uses. In general, future SO_2 emissions reduction in urban residential and commercial energy activities will come primarily from space heating in northern climate cities and, to a much lesser extent, from commercial cooking and water heating in southern climate cities.

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[7] Downstream sorbent injection into the duct (for flue gas) is more sophisticated. A combination of the two can achieve a higher level of sulfur removal.

Table 2.2: SO_2 Emission Control Options for Urban Residential and Commercial Energy Activities in Chinese Cities

Emission control options	*Targeted activities*	*Sulfur removal*	*Readiness of fuel and/or technology, main constraints, and development potential*
Sulfur-fixed briquettes	Residential cooking and space heating	About 40 percent sulfur fixing	Honeycomb briquettes are widely used but sulfur fixing is not always done. No apparent constraints. Only a short- to mid-term option, especially for cooking.
LPG replacing coal	Residential/commercial cooking and water heating	Emit little SO_2	Widely available in major urban areas. Can be costly to low-income households and high-volume commercial users. Most readily option to replace coal in cooking.
Coal gas replacing coal	Residential/commercial cooking and water heating	Emit little SO_2 at end uses. But sulfur emission at the gasification plants can be significant for some outdated processes.	Relatively limited utilization due to high costs. Increasing competition from natural gas. Declining interest among city governments. Long-term outlook uncertain.
Natural gas replacing coal	Residential/commercial cooking, water heating, and space heating	Emit little SO_2	Limited by availability of natural gas. Lack of distribution facilities. Costly to high-volume applications such as space heating. National development interest. Large potential for growth.
Blended steam coal with sulfur-fixing additives	Space-heating boilers	About 40 percent sulfur fixing	Rarely used. Limited by the lack of facilities. Retail coal distribution in cities is fragmented with inadequate environmental oversight. A low-cost measure worth

			promoting but lacks institutional support.
Low-sulfur raw steam coal	Space-heating boilers	Depend on sulfur contents of coal. Current regulations define sulfur content of 1% or less by weight as low.	Rarely used. Limited by local protectionism, transportation bottlenecks, and competition from power plants. Market remains underdeveloped partly due to poor enforcement of sulfur regulation.
Low sulfur washed steam coal	Space-heating boilers	Depend on sulfur contents of coal	Rarely used. Limited by availability, and relatively high cost. Washed steam coal is-mostly exported. Domestic market remains underdeveloped partly due to poor enforcement of air pollution regulation.
Furnace sorbent injection	Space-heating boilers	30-70 percent sulfur removal achievable, depending on calcium to sulfur ratio.	Anecdotal evidence of applications. Relatively low-cost and easy to implement. Could become a main emission control measure for heating boilers.
CFBC boilers	Replacement of old heating boilers or new district heating facilities	Up to 95 percent sulfur removal achievable depending on calcium to sulfur ratio.	Domestic manufacturers are able to produce up to 100 ton-steam/hour sizes. Current costs are relatively high. Could be good candidate for large district heating facilities. Cogeneration installation would further improve energy efficiency and financial returns.

2.20 For space heating, coal is either burned in coal stoves or in boilers of centralized heating systems, which are the main heating mode in large cities, including Shijiazhuang. Multiple changes are going on in urban space heating and they are in general beneficial to pollution control. At the low end, honeycomb briquettes and improved stoves are now widely available for the stove users, although the use of sulfur-fixing additives in briquettes may not be widely practiced. District heating systems have been promoted to meet new demand and to replace dispersed small systems, which are usually more polluting. This would facilitate sulfur emissions control with fewer and larger emission sources. For example, circulating fluidized bed combustion (CFBC) boilers plus cogeneration units, technologies already commercialized in China, could be an attractive option. In cities with access to a large supply of natural gas, gas heating has become a viable alternative, although only Beijing has made a serious effort to develop gas heating.

2.21 Commercial cooking and water-heating activities have been a target of SO_2 pollution control in recent years. Some cities simply banned the use of coal in restaurants and forced conversion of small coal-fired water heating boilers (usually with sizes below one ton-steam per hour) to gas, oil, or electric boilers. Conditions exist, and affordability is not a significant issue for similar actions in the two case study areas covered by this report.

2.22 There still are a significant number of urban households using coal stoves for cooking, even in large cities such as Shijiazhuang and Changsha. Most of such households are likely to be low-income families located in the fringe areas of cities. Provision of sulfur-fixed briquettes would be a practical solution in the short to medium term.

2.23 Table 2.2 summarizes basic characteristics of residential and commercial SO_2 emission control and relevant options that have been applied, demonstrated, or proposed in Chinese cities. Their suitability to Shijiazhuang City and the Changsha-Zhuzhou-Xiangtan tri-city area will be further assessed in the case studies.

Industrial Sector

2.24 Little progress has been made in SO_2 emissions control for coal-fired industrial facilities in China. The reported reduction of SO_2 emissions from the industrial sector in recent years probably has more to do with the overall structural adjustments, including the reduced operation or closing of many loss-making state-owned factories, than it has to do with implementation of specific emission control measures. Among major coal-burning industrial facilities, boilers are most prevalent and are least complicated for SO_2 emissions control. Coal-fired industrial furnaces and kilns are used mainly in specialized industries such as metals and cement manufacturing, where fugitive emissions of SO_2 are more difficult to deal with. This study focuses on SO_2 emission mitigation measures for industrial boilers, which, technically speaking are identical or similar to space-heating boilers discussed before. But industrial boilers usually operate year-round, compared to the four-six months of seasonal operation of most space heating boilers, and thus are in greater need of emission control.

2.25 Many cities already have regulations that limit the sulfur content of steam coal used in center-city areas. Supplying blended coal to match individual boilers was promoted as an energy efficiency measure in the early 1980s and is now considered an effective way of managing the distribution of low-sulfur coal or coal blended with sulfur-fixing agent among industrial users. But with the disintegration of the state-controlled coal distribution system, coal blending at area depots became impractical and was mostly abandoned. New investments and initiatives to consolidate local coal distribution channels will be needed to make such measure work.

Table 2.3: SO_2 Emission Control Options for Coal-Fired Industrial Boilers

Emission control options	*Sulfur removal*	*Readiness of fuel and/or technology, main constraints, and development potential*
Blended steam coal with sulfur-fixing additives	About 40 percent sulfur fixing	Rarely used. Limited by the lack of facilities. Retail coal distribution in cities is fragmented with inadequate environmental oversight. A low-cost measure worth promoting but lacks institutional support.
Low-sulfur raw steam coal	Depend on sulfur contents of coal	Rarely used in high-sulfur coal-producing regions. Limited by local protectionism, transportation bottlenecks, and competition from power plants. Market remains underdeveloped partly due to poor enforcement of sulfur regulation.
Low-sulfur washed steam coal	Depend on sulfur contents of coal	Rarely used. Limited by availability, and relatively high cost. Washed steam coal is mostly exported. Domestic market remains underdeveloped partly due to poor enforcement of air pollution regulation.
Sulfur-fixed briquettes	About 40 percent sulfur fixing	Demonstration of centralized facilities has failed to show commercial viability. Relatively costly. May be competitive as onsite operations, but lacks demonstration.
Furnace sorbent injection	30–70 percent sulfur removal achievable.	Anecdotal evidence of applications. Relatively low-cost and easy to implement. Could become a main emission control measure for industrial boilers.
FBC boilers	Up to 95 percent sulfur removal achievable.	Domestic manufacturers are able to produce CFBC boilers up to 100 ton-steam/hour sizes, as well as bubbling FBC boilers in 10 to 20 ton-steam/hour sizes. Current costs are relatively high compared to conventional coal-fired boilers. But the technology is maturing and the commercial market, especially for large sizes, is opening up. Higher coal prices and more stringent sulfur regulation will help market uptake.

2.26 China has tried to develop industrial briquettes for boilers to improve energy efficiency and control air pollution. But the few state-sponsored pilot projects have failed to demonstrate the commercial viability of large-scale briquette production as a result of poor product quality and high production cost. Proponents of industrial briquettes still believe that they could become cost-effective and attractive with proper technologies such as on-site briquetting machines that feed briquettes directly into boilers.

2.27 Sorbent injection could be a rapidly adoptable emission control technology for industrial boilers in China. More demonstration may still be needed because of unfamiliarity with this technique in China. CFBC boilers can achieve up to 95 percent SO_2 removal with a calcium/sulfur ratio of 1.5 to 2, and could be a highly effective technology in regions that burn high-sulfur coal of relatively low heating value. Application of CFBC technology is usually found in relative large-size boilers, say, about or above 30 ton-steam per hour. For smaller boilers, bubbling FBC technology is typical. In China, most 2,500-3,000 small FBCs are bubbling, with typical sizes in the 10 to 20 ton-steam per hour range.

2.28 Natural gas and low-sulfur fuel oil are often too expensive for producing industrial steam and have rarely been used in industrial boilers. This situation is likely to continue.

2.29 In summary, there are a range of options for controlling SO_2 emissions of industrial boilers. However, the low-cost measures usually require some degree of local organizational effort, for example, in securing the supply of low-sulfur coal and in producing and distributing blended coal. Adoption of direct emission control technologies such as sorbent injection and CBFC boilers may still require demonstration and stricter regulations and enforcement. Table 2.3 summarizes the main practical options available to Chinese industrial boiler operators; their suitability and costs in Shijiazhuang and Changsha will be analyzed in the case studies.

Electric Power Sector

2.30 Power plants in the "two controls" regions have reacted to government regulation by shifting to low-sulfur steam coal, usually the cheapest compliance measure. Washed-steam coal is rarely used in Chinese power plants, although it has multiple benefits to power plant operation in addition to reduced particulate and sulfur emissions, and could become a primary fuel for new power plants. Construction of natural gas-fired power plants are being considered in Guangdong Province; these are likely to gain favor elsewhere in the future as major natural gas supply infrastructures are built.

2.31 The government has supported pilots and demonstrations of various sulfur emission control technologies. But the actual commercial applications are few because of their relatively high costs. Wider application of emission control technologies may also require more stringent emission control regulations than currently exist. CFBC technology in power generation has been demonstrated. The government also adopted aggressive measures to phase out highly inefficient coal-fired units, which are characterized as units at or below 50 MW.

2.32 Realistically speaking, switching to low-sulfur coal or washed coal will be the primary means for power plants to meet current sulfur regulations. Sorbent injection techniques are likely to be a practical solution for additional emission requirements, especially for small or old facilities. Sulfur scrubbers are relatively expensive and usually require significant additional space. They are best suited for large new power plants or large existing facilities with stringent emissions control requirements and a long remaining life. Table 2.4 summarizes the basic SO_2 emission control options available for coal-fired power plants in China (Oskarsson and others, 1997).

Table 2.4: SO_2 Emission Control Options for Coal-Fired Power Plants

Emission control options	*Sulfur removal*	*Readiness of fuel and/or technology, main constraints, and development potential*
Low-sulfur raw steam coal	Depend on sulfur contents of coal	Popular with power plants. Limited by local protectionism.
Low-sulfur washed steam coal	Depend on sulfur contents of coal	Rarely used. Limited by availability, and relatively high cost. Washed steam coal is mostly exported. Domestic market remains underdeveloped partly due to crooked power plant economics and lenient air pollution regulation.
Sorbent injection	30–70 percent sulfur removal achievable.	Demonstrated in China. Matured technology in industrialized countries. Not widely adopted due to lenient and poor enforcement of sulfur regulations and a lack of demonstration. Relatively low-cost and easy to implement. Suitable when a moderate sulfur removal is acceptable, and for small utility boilers and old facilities with limited remaining life.
Spray-dry scrubbers	70–95 percent sulfur removal.	Demonstrated in China. Matured technology in industrialized countries. Relatively costly but cheaper (capital costs) to build than wet scrubbers. Relatively high operation costs limit their use mostly to small utility boilers burning low- to medium-sulfur coals, or for peak-load operation of large plants.
Wet scrubbers	95–99 percent sulfur removal achievable.	Demonstrated in China. Matured and most popular scrubbing technology in industrialized countries. Most costly of direct emission control technologies. Can be used for all utility boiler sizes.
CFBC boilers	90 percent or more sulfur removal achievable.	Demonstrated in China for 100 MWe plants. Atmospheric fluidized bed combustion technology is commercialized for plant size up to 200 MWe in industrialized countries.

Analysis of Sulfur Control in China

2.33 Given the enormous financial implications of the proposed sulfur control legislation, China is actively searching for policy and technical options for minimizing the costs of SO_2 control. As part of the TCZ policy, the city legislations under the "SO_2 control zone" and the "acid rain control zone" are authorized to propose sulfur control measures to reach the goals passed under the "total emissions control program," that is, capping the total emissions of SO_2. At present, most of these projects focus on reduction of the emissions, instead of on designing an optimized program that includes analysis of various technical and legislative options and their benefits not only from air pollution, but also in terms of environmental impacts.

2.34 In recent years, a number of sulfur impact studies and sulfur emission reduction techniques have become available and analyzed with special reference to

- ?? Direct implications of acidic deposition levels on vegetation, particularly on food crops (Hao, 2000)
- ?? Aggregated ecosystems impacts, especially whether critical loads for acidification are exceeded given deposition levels and different buffering capacities of soils (IMPACTS, 2002)
- ?? Implications to human health, through formation of particulate matter from SO_2 emissions (Li and others, 2003).

2.35 These studies provided further information on the impacts of high concentrations and deposition of SO_2 emissions, beyond the well-documented impacts on human health, ecosystems productivity, and material damages. These studies are particularly important because they document environmental changes of high-emission scenarios by using detailed representations of the numerous nonlinear dose–response relationships between emissions, atmospheric concentrations, deposition, ecosystems sensitivity thresholds, and impacts. All recent studies agree that unabated high SO_2 emissions would yield high impacts not only for natural ecosystems and forests, but also for economically important food crops and human health, especially in Asia, where emissions growth is projected to be particularly high.

Methodology Employed in the Study

2.36 A wide range of tools are available to address air pollution problems, including expertise in monitoring, emission inventories, integrated assessment modeling, evaluating human health and ecosystem impacts, emission scenario analysis, interventions in the policy process, and capacity building. In addition, advanced Geographic Information Systems (GIS) capability enables spatial analysis and mapping of air pollution and the analysis of results. The Integrated Assessment of Air Pollution used in this study provides a systematic framework for analyzing the interactions between economic drivers (economic activity, emission control measures) and environmental endpoints (health, agriculture, and so forth). The framework can be used to explore the effects of changes in energy end-use patterns and application of pollution control technology on urban air quality, to assess the resulting impacts on human health and to balance the costs of the measures against monetized environmental benefits. This report outlines the development and application of a methodology for quantifying the health and agricultural damages and cost of potential reductions in ambient sulfur pollution levels to the integrated assessment.

2.37 A conceptual model in a decision-making framework has been developed for use in the two case study cities—Shijiazhuang and CZX—to translate emission reductions into local sulfur concentrations and deposition and estimate the expected risk of exposure and agricultural damage.

Emissions and Modeling

2.38 Sulfur emissions under base case and control scenarios were developed with the help of the city-level authorities by sector and region. As part of the program, two workshops were organized for data collection—July-August 2001 in Beijing, China, and November 2001 at the University of Iowa, Iowa City. Emissions under various control options are discussed in detail in the next chapter. The impact of urban emissions on ambient concentrations was then estimated using the ATMOS/UrBAT model, a three-layer Lagrangian puff transport model.[8]

Economics of Control Measures

2.39 In the following chapters, cost and benefit analysis of sulfur pollution control measures are performed for the case study cities. Attempts are made to rank different control measures according to their relative costs and benefits. Overall, the economic analysis involves three aspects of work: (i) estimation of emission abatement cost per measure in different sectors, (ii) estimation of pollution damage caused by emissions of different sources, and (iii) assessment of the overall costs/benefits profile of pollution control measures.

2.40 The costs of SO_2 emission abatement in this study are derived from current average fuel prices and engineering cost estimates of actual projects in the case study cities or other cities in China. Because of lack of data and information, the distortions in prices and project specific conditions are not controlled. For comparison purpose, all abatement costs are standardized by per ton of SO_2 emissions reduction.

2.41 For fuel-switching measures, the costs would normally include differences in fuel costs (reflected in price per equivalent heating value) between the alternative fuel and the baseline coal, plus other net costs involved with fuel switching, including, for

[8] The total sulfur deposition and SO_2 concentrations are calculated using the ATMOS/ UrBAT model utilized as part of the RAINS-Asia atmospheric dispersion module. Details of the model are presented in Calori et al., 1999 and Guttikunda et al., 2003.

example, connection fees (for piped gas) and facility changes or modifications, such as converting to gas boilers or burners. The other two categories of measures, sorbent injection and FGD, involve both capital investments and operation and maintenance (O&M) costs of emission control equipment.

2.42 Joint cost is clearly an issue in some of the abatement measures that generate emission reduction of multiple pollutants, for example, SO_2, PM, and NO_x emissions reduction resulting from switching from coal to natural gas. Since it is often impossible to distribute joint cost to individual emission reduction in such cases, the balance is made by accounting for the benefits of emission reduction of all pollutants when possible.

Health and Environmental Benefit Analysis

2.43 Actual health impacts of air pollution are determined by two factors: concentrations of pollutants in the atmosphere and the presence of people in the region affected by these pollution levels. A large number of studies conducted in Asia and elsewhere document a consistent association between elevated ambient PM_{10} and $PM_{2.5}$ levels and an increase in mortality rates, respiratory infections, number and severity of asthma attacks, and the number of hospital admissions. However, studies from China, where SO_2 levels are high, tend to give SO_2 a more important role, and since SO_2 is measured more regularly in China, it is used an indicator to study health-related benefits in the cities. In this study, health impacts of emission controls are estimated in the following way:

?? The implications of a given control strategy on emissions and concentrations are estimated.

?? The corresponding changes in ambient concentrations (in different grid cells) are subsequently combined with the population at risk of exposure based on dose–response functions. [9]

?? The reductions in exposure levels are then monetized for benefit analysis.

2.44 A similar methodology is used to calculate the impacts of changing sulfur deposition levels with control measures on agricultural output.

[9] A is the dose–response incidence rate of mortality and morbidity, POP is the total population of the grid cell, d(C) is change in concentration levels, and d(POP) is the population exposed.

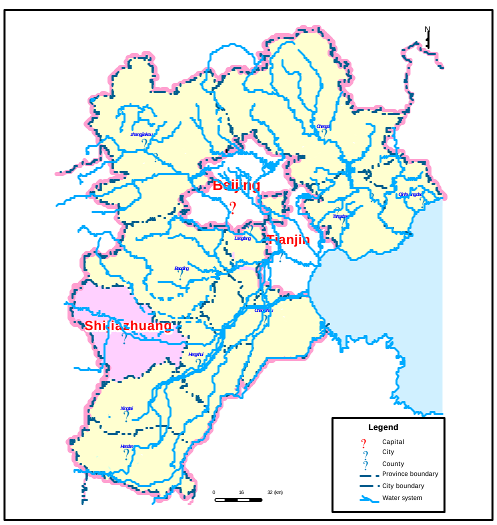
3

Case Study: Shijiazhuang City

Social and Natural Environment

3.1 Shijiazhuang City, the capital of Hebei Province, is 275 km southwest of Beijing. The city has about 1.6 million urban population residing on 254 km of urban district area. Of the 110 square km^2 of established (built-up) areas, residential area accounts for 27 percent, and industrial area for 23 percent. The jurisdiction area of Shijiazhuang Municipality is much larger than the city itself. It includes 6 districts and 17 counties and borders Shanxi Province (Figure 3.1), covering an area of 16,000 km^2, of which 56 percent is mountainous. The municipality as a whole has about 9 million residents, and is largely rural.

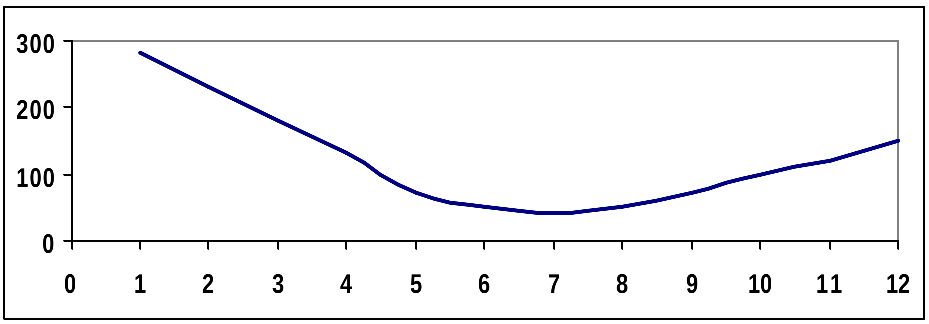
Figure 3.1 Geography of Hebei Province



Source: *Shijiazhuang EPB (2000)*

3.2 In 1998, the gross domestic product (GDP) of Shijiazhuang City (urban district only) was 32.76 billion Yuan, of which services, manufacturing, and agriculture accounted for 50.2, 48.4, and 1.4 percent, respectively. The local economy has experienced significant changes since the early 1990s, when the manufacturing industry accounted for 65 percent of GDP. This change of urban economic structure has had an impact on the quantity and pattern of energy consumption, and consequently on ambient air pollution.

Figure 3.2 Monthly Average SO_2 Concentrations Measured Between 1996 and 2000 in Shijiazhuang



Source: *Shijiazhuang EPB (2000)*

3.3 Among all the environmental challenges, air pollution is the major focus of attention for Shijiazhuang, though water quality and land degradation are serious problems province-wide. The annual average concentration of SO_2 in the urban district rose from 122? g/m^3 in 1995 to 169?? g/m^3 in 2000, compared with 60? g/m^3 of the Class 2 National Ambient Air Quality Standards (NAAQS).[10] During the same period TSP also rose from 312 ? g/m^3 to 431 ? g/m^3, compared with 200 ?? g/m^3 of the Class 2 NAAQS. In 1999, of the 210 days of daily reports, ambient air quality in 176 days was above Class 2 limits. While the high concentration level of TSP is a general characteristic of northern Chinese cities that has much to do with wind-blown dust, the serious ambient SO_2 pollution in the urban district is caused primarily by coal burning of various sorts. The high concentration level of SO_2 also is a good indication of possible high-level fine particulate pollution, which is most harmful to human health.

3.4 Ambient sulfur pollution in Shijiazhuang closely follows the coal-burning cycle that peaks in the heating season of mid-November to mid-March (Figure 3.2). This

[10] China adopts three classes of ambient air quality standards. Class 1 are limits for tourist, historic, and conservation areas. Class 2 are limits for residential urban and rural areas. Class 3 are limits for industrial areas and heavy traffic areas.

variation also corresponds to the strong temperature inversion in the winter, which blocks the dilution and dispersion of pollutants. [11]

Table 3.1 Energy Consumption and SO_2 Emissions by Sector in Shijiazhuang, 1995

	Plant Number	*Coal (1000 tons)*	*Oil (1000 tons)*	*Gas (1000 m^3)*	*SO_2 (ton)*
Medical/pharmaceutical	10	64	9		740
Chemical	12	283	13	336	3598
Machinery	40	247	8	6	3039
Steel making	1	135			1279
Thermal power and heating	12	2609	0.1	56	43512
Food and tobacco	10	20			180
Printing	20	11	2		166
Coking, petroleum refining	2	85		1293	879
Rubber	5	4			53
Plastic	3	4			64
Metallurgic	5	14	2	1	211
Mining	4	48			733
Textile	18	102	0.1		1625
Construction materials	8	301	0.1		4801
Residential		603		186850	7999
Other		249		45150	2102
Total [12]	***146***	***4777***	***36***	***232000***	***70016***

Source: *Shijiazhuang EPB report, 2002*

[11] Shijiazhuang City lies in the variable zone with distinctive seasonal climate. The coldest month is January, with an average temperature below -2ºC; the hottest month is July, with an average temperature above 26ºC. The average precipitation is about 537.2mm, most of which occurs in the period of June to August. Spring and winter are relatively dry. During the summer months, southeastern winds are prevalent, with an average wind speed of 1.5 m/s and during the winter months, northwestern winds prevail with an average speed of 1.8m/s. The rate of temperature inversion is high at about 72 percent on an annual basis, and reaches over 90 percent in the winter.

[12] Coal, oil, and gas consumptions are converted to comparable units of standard coal equivalent at 3411, 56 and 133,000 tons, respectively, with shares in the order of 94.7, 1.6 and 3.7 percent in total fuel consumption.

3.5 Within the roughly 100- km^2 area inside the city's second ring road, there are 1,600 coal-fired boilers with size greater than 1 ton-steam per hour (equivalent of 0.7 MW), more than 100 coal-burning industrial kilns, and more than 5,000 coal-burning commercial stoves (in restaurants and cafeterias). In 1999, they consumed 5 million tons of coal. Dozens of industrial facilities are located in the city area, such as a large coal-fired power plant, a steelworks with an associated coking plant, a chemical fertilizer plant, and a pharmaceutical plant. In addition, there are more than 70 cement and lime factories upwind to the northwest of the city. The geographic conditions also exacerbate the air pollution problem, as the city lies in a low area at the foot of the Taihang Mountain, which reduces air dispersion above the city.

Fuel Consumption and Relevant Sulfur Emissions

3.6 Coal dominates the fuel mix in Shijiazhuang. The share of coal in total fuel consumption was over 95 percent in 1998. Most coal was bought from nearby Shanxi Province, with sulfur content between 1 to 1.8 percent and ash content around 30 percent. Gas consumption (coal gas and LPG) has been increasing in recent years, especially in the residential sector, but accounted for only about 3 percent in total fuel consumption in 1998. Oil was under 2 percent in total fuel use.

3.7 Table 3.1 summarized sectoral patterns of energy consumption and SO_2 emissions in 1995, the most recent year for which such data were available. Thermal power plants and central heating stations accounted for 55 percent of fuel use and 62 percent of sulfur emissions in Shijiazhuang, followed by households, with about 13 percent in coal consumption and 11 percent in SO_2 emissions. Other chief culprits included the building materials (mainly cement), chemical (mainly fertilizer), and manufacturing (including steel making) sectors. Small sources such as household emissions were important contributors, especially when taking into account household heating, which was not extensively centralized.

3.8 Detailed fuel consumption and emission data collected by the Shijiazhuang EPB enable the breakdown of emission sources by sector, by burning facility, by large point source, and by area source. Large point sources (LPS) are identified by stacks higher than 45 meters that burn more than 15,000 tons of coal a year. Smaller sources are classified as area sources, which are estimated by dividing the Shijiazhuang City into grids of 1 km by 1 km size, with 19 east-west grids and 13 north-south grids, which make 247 cells in total.

3.9 Table 3.2 shows coal consumption and SO_2 emissions by burning facility. Between 1995 and 1998, large facilities (industry boilers and kilns) decreased by 100 in number, but smaller facilities (tea and bath boilers and food industry stoves) increased by 812 units. It should be noted that a majority of boilers were outside the power sector. Space-heating boilers account for a large portion of nonpower plant boilers. The increase in tea and bath boilers and their coal consumption, perhaps as a result of the expansion of the service sector (restaurants, bath houses, and so forth), deserves attention since their low stack height means more impact on ground-level ambient concentrations than the high stack boilers used by power plants and industries.

Table 3.2 SO_2 Emissions by Facility in Shijiazhuang, 1995 and 1998

	Facility Numbers		*Coal Consumption (1000 ton)*		*SO_2 (ton)*
	1995	1998	1995	1998	1995
Boilers	2735	2692	4265	3846	53819
Power		30		1826	
Nonpower[13]		2662		2019	
Kilns	146	89	368	27	11601
Tea and bath	1034	1199	20	91	640
Food industry	4231	4878	18	11	589
Other			105		3366
Total	***8146***	***8858***	***4777***	***3975***	***70016***

Source: *Shijiazhuang EPB report, 2002*

3.10 In 2000, of all the coal-burning sources, large point sources with stack height over 45m accounted for 48 percent; heat-only central-heating boilers with an average stack height at 14m accounted for 34 percent; and tea and bath boilers and small industrial boilers, accounted for 18 percent of the total SO_2 emissions in the city area.

3.11 Emissions from outside the Shijiazhuang urban area also negatively affect the air quality in the city, especially the large number of cement and lime factories upwind to the northwest of the city. There are also two large thermal power plants located in the vicinity of Shijiazhuang, each more than double the size of the largest power plant in the city area and emitting more SO_2 than all the city emissions combined. It was estimated that these power plants and cement factories together emitted 186,000 tons SO_2 in 1995, compared to about 70,000 tons from within the city area. The capacities of and emissions by the outside plants are presented in Table 3.3.

[13] Includes coal consumption of 1,730,000 tons used during the winter heating season, and 289,000 tons in the non-heating season.

Table 3.3 SO_2 Emissions from Large Point Sources in Shijiazhuang, 1998

	Stack Height	*Boiler Capacity*		*Coal Use*	*SO_2*	*TSP*
	(m)	Steam (t)	Unit #	(ktons)	(ton)	(ton)
Within city area						
Shijiazhuang Thermal Power Plant	180	1820	13	1459	31303	33458
Shijiazhuang City Thermal Power Plant #1	80	250	6	108	1382	432
Shijiazhuang City Thermal Power Plant #2	120	160	4	101	2074	683
Shijiazhuang City Thermal Power Plant #3	80	180	4	115	1918	604
Shijiazhuang City Thermal Power Plant #4	105	170	4	150	6566	3283
Shijiazhuang Steelworks[14]	65	61	19	160	752	14777
Shijiazhuang Coking Plant[15]	50	82	8	31	381	236
Shijiazhuang Fertilizer Plant	80	110	6	103	1175	268
Shijiazhuang Pharmaceutical Plant #1	50		2	32	614	160
Wanlimiao Heating Plant	120	130	3	27	648	89
Within city LPS subtotal				***2286***	***46813***	***53990***
Outside city area						
Shangan Thermal Power Plant	210	4080	4		68900	
Xibaipo Thermal Power Plant	210	4080	4		78300	
Yongtai Thermal Power Plant	120	150	6	78	610	258
Shijiazhuang Cement Product Factory	45	12.5	5	28	64	84
Outside city LPS subtotal					***147874***	

Source: *Shijiazhuang EPB report, 2002*

[14] Shijiazhuang Steelworks had 3 boilers and 16 kilns, with capacities of 24 tons and 37 tons, respectively.
[15] Shijiazhuang Coking Plant had 4 boilers and 4 kilns, with capacities of 80 tons and 2 tons, respectively.

Box 3.1: Shijiazhuang Atmospheric Pollution Prevention Ordinance

Issued on November 27, 2000

?? Large polluters such as power plants must confirm total emissions of criteria pollutants for licensing and must maintain and use advanced air pollution treatment equipment properly.
?? The government department in charge of environmental protection above the county level must carry out periodical emission monitoring inspections. The large polluters must install an auto-monitoring system and report emission data periodically.
?? Businesses and housing complexes covered by the district heating system network are not allowed to use old or build new coal-fired heating boilers. Businesses and housing complexes outside the network are not allowed to use coal-fired boilers with a capacity of less than 0.7 MW.
?? Newly built and renovated boilers must be approved by the EPB.
?? Boilers with capacity greater than 0.7 MW must use low-sulfur, low-ash coal or other clean energy, or must install desulfurization units to reach the national emission standard.
?? Coals and other products with sulfur content over 1 percent are banned for sale or burning in the Shijiazhuang urban area; the high-tech development district; and the cities of Xinji, Luquan, Xinle, Gaocheng, Jinzhou, Zhengding, Luancheng, Jingjing, and Pingshan, unless their uses are approved by the Shijiazhuang EPB.
?? The environmental impact report of new construction projects must pass the EPB standard test. The air pollution prevention equipment of the project must be checked and accepted by EPB before the project is put into production. If the project doesn't meet the standard, it cannot be put into production or be used.
?? Cement plants, quarries, coal mines, and smelters must treat the pollutants before releasing them into air or water outlets. If standards are not met in time, the factories will be charged a penalty and closed.
?? Factories producing cement and lime are banned from using equipment or techniques declared discontinued by the state.
?? Businesses engaged in food services and construction must use LPG, coal gas, natural gas, electricity, or another clean energy.
?? Barbecues in the open air are banned in the Shijiazhuang urban area.
?? Burning of asphalt, oil residues, rubber, plastics, leather, garbage, or other material that can cause poisonous and harmful smoke is banned in the city.
?? Constructions that do need to burn asphalt in the open air must be approved by the local EPB and must use a heating system with waste gas treatment equipment.
?? Burning crop residues or leaves in the open air is banned in the city.

Local Sulfur Control Policies and Measures

3.12 Emissions of major air pollutants in Shijiazhuang have been falling in recent years because of economic structural adjustments and control efforts under the "Total Emission Control Plan,"[16] a national program enforced top-down from the central government that assigns emission quotas to local administrative areas. Emission reduction, however, has not been equally matched by improvement in urban air quality. The Shijiazhuang municipality has cut emissions well below its quota in recent years, and SO_2 emissions declined by almost 30 percent between 1998 and 2000; yet monitored ambient concentrations[17] of SO_2 in Shijiazhuang increased, from 129 to 169 ? g/m^3. The fine particulate matter of sulfate was not monitored, but would be no better, as SO_2 is the precursor to sulfate (note that the monitored TSP level increased from 366 to 431 ? g/m^3).

3.13 In order to tighten control of the growing air pollution in the city, the Shijiazhuang People's Congress issued a new ordinance in 2000 (Box 3.1). Shijiazhuang EPB also adopted specific emission-control measures that are discussed here in more details.

Targeting Small Coal-Fired Boilers

3.14 Small area sources are a main contributor of SO_2 and particulate concentrations in Shijiazhuang. A main measure adopted by Shijiazhuang has been to shut down small boilers and replace them with larger and more efficient facilities that reduce both energy consumption and emissions, mainly in the space-heating sector. In recent years, more than 700 small boilers (0.7 MW or less) used for winter heating have been demolished and replaced by district heating plants. The target for the next five years is to add 10 million m^2 of district heating areas and increase the coverage rate of district heating to more than 70 percent of residential and commercial floor areas.

3.15 Eight district heating projects are planned for completion in the 10th Five-Year-Plan (2001-2005). Most of these projects will be capacity expansions of existing thermal power plants (Table 3.4). The Shijiazhuang Thermal Power Plant project, for

[16] The State Environmental Protection Administration first introduced the "Total Emission Control Plan" in 1996 to control the total national emissions of 12 major air pollutants. Quotas were allocated to each of the 31 provinces and autonomous regions (including municipalities that report directly to the central government) to meet the national targets. The annual SO_2 emission quota for the Shijiazhuang municipal administrative area as a whole was 197,000 tons based on its 1995 emission level, which was set as the ceiling for annual emissions in the 9th Five-Year-Plan (1996-2000). The quota was not met in the first three years, and emissions peaked in 1998 at 218,000 tons, but have since come down to 154,000 tons in 2000. *Source*: Shijiazhuang EPB, 2000.

[17] At present, Shijiazhuang city operates only five monitoring sites measuring PM_{10}, SO_2, CO, NO_x, and dust within the second ring road. During the World Bank mission of June 2000, inspections showed that the monitoring locations are confined between new construction buildings near road traffic, enabling the equipment to measure a relatively higher pollution levels due to entrapments and re-suspensions. One of the recommendations to the city EPBs was to consider relocation of the sites for a better understanding of local pollution patterns.

example, will add two 140 MW thermal power units to supply heat to areas that currently depend on about 600 small coal-fired boilers for heating. This project is expected to replace these 600 small boilers and save close to a half million tons of coal each year, which would reduce annual SO_2 emissions by 6,450 tons, according to the local EPB's estimate.

Table 3.4: Planned Central Heating Projects in Shijiazhuang, 1998

	Completion Year	*New Heating Capacity*		*Cost (millions)*
		Floor area (mil -m^2)	Steam (T/h)	RMB
Shijiazhuang Thermal Power Plant	2003	11.2	1000	1960
Shijiazhuang City East Suburb	2002	9		327
Shijiazhuang City West Suburb	2002	12		600
Shijiazhuang City Thermal Power Plant #1	2001		1x130	130
Shijiazhuang City Thermal Power Plant #2	2004		4x220	899
Shijiazhuang City Thermal Power Plant #3	2001		1x130	120
Shijiazhuang City Thermal Power Plant #4	2001		1x130	181
Shijiazhuang Beijiao Thermal Plant	2001	0.8	3x40	25

Source: *Shijiazhuang EPB report, 2002*

3.16 In general, the measures applied to small emission sources have been limited. Replacing many small boilers with a few large ones is an effective way to increase fuel efficiency and centralize emissions control. This works especially well in Shijiazhuang, where ground-level concentrations of SO_2 emitted from low stack heating boilers is a major concern. An alternative to this consolidation to large coal-fired district heating plants would be distributed gas heating, such as the heating fuel switching program currently being implemented in Beijing.[18] Shijiazhuang has in fact planned to use most of its new natural gas supply for space heating (see below).

[18] Under Beijing Municipal Government's Clean Air Initiative, the city's some 9,000 medium-size (0.7-7MW) coal-fired heating boilers are to be replaced by cleaner heating modes, mostly by natural gas-fired boilers. Half of the coal-fired boilers were replaced between 1998 and 2002. The rest will be replaced by 2006. The gas heating program has received financial and technical assistance from the World Bank and the Global Environmental Facility.

Promoting Natural Gas

3.17 Shijiazhuang currently has no natural gas supply and has planned to tap into the second natural gas pipeline from Shanxi to Beijing. Town gas from coal gasification and LPG currently make up about 3 percent of the city's total fuel use.[19] Over 90 percent of the urban residents in Shijiazhuang have access to these gaseous fuels.

3.18 Under the first stage of the natural gas supply project, Shijiazhuang plans to import 220 million m^3 of natural gas by the year 2003. Priorities for natural gas use are set for five thermal power plants, three central heating stations, and eight heating areas downtown. The city expects to ban coal use inside the second ring road by 2005, except for space heating, power supply, and several special enterprises. Local EPB expects the new access to natural gas to reduce Shijiazhuang's reliance on coal by about 10 percent.

Restricting the Use of Medium Sulfur Coal

3.19 Shijiazhuang buys most of its coal from the neighboring Shanxi Province, where low-sulfur coal is abundant. Coal sample tests done by the Shijiazhuang Municipal EPB in 2000 indicated that about half of the coal used in the city was under the 1 percent sulfur content limit. Anthracite accounts for about 20 percent of total coal use, mainly for small boilers that are not of a suitable size to be fitted with equipment to reduce sulfur emissions and that often lack soot or smoke control. Still, there are many users who consume lower-grade coals with sulfur content as high as 1.8 percent. The mandate to restrict the sulfur content to 1 percent for all coal sold and used in Shijiazhuang became effective in November 1999. As indicated by EPB spot checks, the initiative has so far met with partial success.

Large Point Sources Desulfurization

3.20 Technical options of desulfurization have been actively explored by Shijiazhuang. Some technologies such as furnace sorbent injection and CFBC are, however, relatively costly. A widely adopted and less costly measure is to double the duty of wet (water screen) precipitators on boilers to remove sulfur from flu gas as well. The local EPB claims that by adding lime to the water used in the precipitators, the efficiency in removing sulfur increases from 10 percent to 30 percent for large boilers producing 10~70 tons of steam per hour , and to 50 percent for medium boilers producing 1~10 tons.. This of course raises the issue of proper disposal of the acidic slurry generated by such a process.

3.21 The SO_2 abatement measures applied to the top LPS in Shijiazhuang are listed in Table 3.5. Of all the measures, the water screen desulfurization is the most widely adopted. In 1999, there were 143 boilers with capacities greater than 10 tons per hour, and 135 of them used the water screen desulfurization method. Based on the figures

[19] In 1999, gas consumption was 122.3 million m^3 of coal gas and 31,651 tons of LPG in Shijiazhuang.

in Table 3.5, the average cost of SO_2 emissions reduction is 590 Yuan/ton-SO_2 for low-sulfur coal, compared with 910 Yuan/ ton-SO_2 for CFBC and 770~1000 Yuan/ ton-SO_2 for water screen desulfurization.

Table 3.5: LPS Desulfurization Measures in Shijiazhuang

LPS	*Abatement Method*	*Sulfur removal efficiency (%)*	*Total Cost (1000 RMB)*	*SO_2 reduction (ton)*
Shijiazhuang Thermal Power Plant	Water screen desulfurization	30	5000	6600
City Thermal Power Plant #1	Water screen desulfurization	30	510	648
City Thermal Power Plant #2	CFBC	50	2100	2400
City Thermal Power Plant #3	Water screen desulfurization	30	380	364
City Thermal Power Plant #4	Low sulfur coal	50	1200	2035
Yongtai Thermal Power Plant	CFBC	50	1100	1200
Shijiazhuang Fertilizer Plant	Water screen desulfurization	30	560	690

Source: *Shijiazhuang EPB report, 2002*

3.22 In addition, Shijiazhuang has also introduced pro-environment policy initiatives to enhance air quality management. These include the pollution levy, industrial structural adjustment, and financial incentives for energy efficiency investment. The pollution levy program, for example, charges noncompliance fees on emissions that exceed national emission standards. For SO_2 emissions, there is a separate emission fee of 200 Yuan per ton assessed for all SO_2 emitted. This fee rate, however, appears to be substantially lower than the reported least cost emission abatement measure (low-sulfur coal). It is thus questionable whether it would have any significant effect on emissions reduction even if fully enforced.

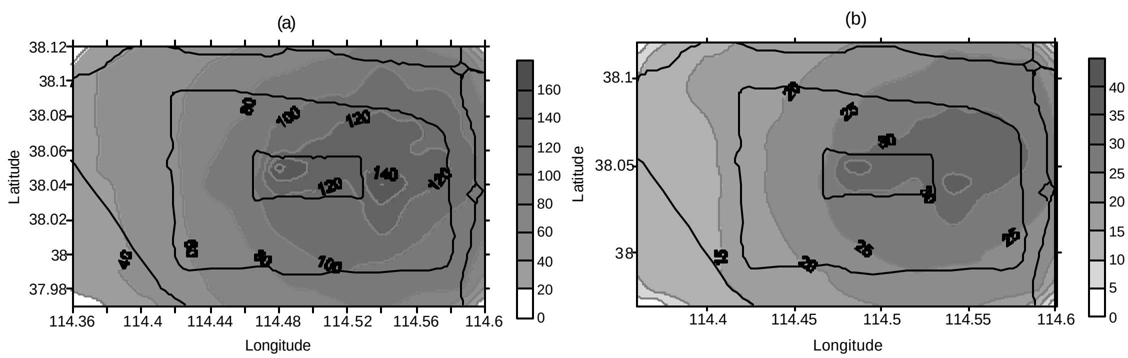
Analysis of Sulfur Control Options

3.23 In order to achieve better understanding of the health and economic implications of planned or proposed sulfur control measures, the ATMOS/UrBAT model and the RAINS-Asia model are used to analyze the physical and health impacts and the costs and benefits of alternative sulfur control strategies for Shijiazhuang. Since SEPA requires Shijiazhuang (urban area) to meet the Class 2 NAAQS for SO_2 by 2005, this national compliance requirement is taken as the policy objective of sulfur emissions control for Shijiazhuang.

3.24 The *baseline* situation is modeled based on year 2000 energy consumption and emissions patterns. Two scenarios are analyzed. Scenario I represents adoption of the planned actions (10th Five-Year Plan) by Shijiazhuang between 2001 and 2005. Scenario II is contingent on whether Scenario I actions meet the policy objective of achieving compliance as required by SEPA. If Scenario I measures fail to achieve compliance, Scenario II would include additional or alternative sulfur control options that would achieve compliance.

3.25 Analysis of scenarios and various control measures is done by modeling the changes in ambient concentrations arising from emission control, estimating the improvements from the baseline situation, and valuing these in economic terms. The Shijiazhuang case study focuses on adverse health effects, using dose–response functions established in other studies and economic values based on the benefit transfer technique, which applies adjusted willingness-to-pay valuation of developed countries to China using an coefficient based on per capita GDP (ECON, 2002 and World Bank, 1997).

Figure 3.3 Calculated (a) SO_2 and (b) SO4 Concentrations in Shijiazhuang in 2000



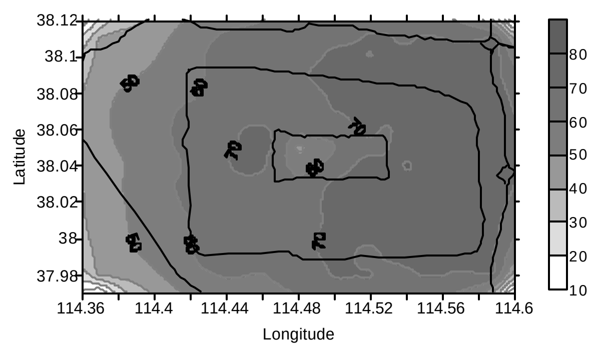
Baseline Analysis

3.26 In the study's modeling analysis, a geographical matrix is developed to analyze emissions. This matrix divides the Shijiazhuang urban district into 1 km by 1 km grid cells, with 19 east-west grids and 13 north-south grids. While large point sources are identified individually with longitude and latitude coordination, emissions from numerous small boilers are measured by area sources. About 55,000 tons of SO_2 were emitted in Shijiazhuang urban district in 2000. One-third of the emissions originated from space-heating boilers scattered in the residential areas, and about 15 percent from small and medium-size industrial boilers and kilns. The rest was attributed to the large power-and-heat plants. In addition, distant emissions from outside the urban district are also included to account for long-range transport effects of sources around the urban district. In 2000, the large thermal power plants and cement factories upwind of the urban district emitted 61,000 tons of SO_2. Figure 3.3 presents the concentrations of SO_2 and SO_4 modeled for the urban district of Shijiazhuang using the ATMOS/UrBAT model. The results include in-city, outside-city, and transboundary sources (calculated using the RAINS-Asia model).

3.27 Large areas of urban Shijiazhuang are found to have SO_2 concentrations far above the compliance target of 60 µg/m^3, with the northeast area of the city, the most populated and industrialized area, having more than twice this value. In general, the concentrations ranged from 74 µg/m^3 to 182 µg/m^3 inside the second ring road of the city. These results are consistent with monitored SO_2 levels: For example, modeled annual average SO_2 concentration was 130 µg/m^3 for 2000, compared with monitored annual average of 169 µg/m^3 calculated from five air sampling stations. The ring roads are shown in Figure 3.3 to delineate the layout of the Shijiazhuang urban area but are not related to the pattern of SO_2 concentrations.

3.28 The sulfate concentrations (of SO_4) are presented in Figure 3.3b. Sulfate particles are known to contribute significantly to the $PM_{2.5}$ (harmful fraction of the TSP). For the baseline scenario, the concentrations of SO_4 ranged from 10-36 ? g/m^3. Most of the high concentrations were observed inside the first ring road with high population density open to higher exposure levels.

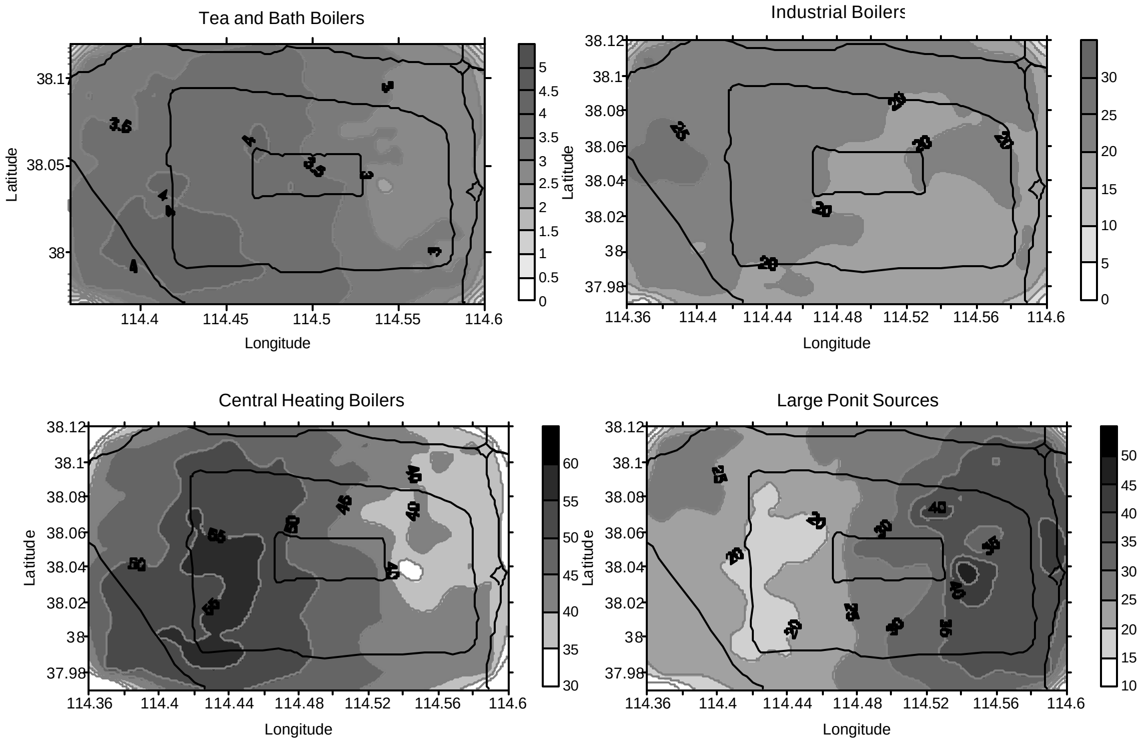
Figure 3.4 Calculated Percent Contribution of In-City Emission Sources to Total SO_2 Concentrations in Shijiazhuang in 2000



3.29 The impact of outside sources upwind to the northwest of the city is reflected in the west suburbs, but inside sources from the northeast area of the city dominate the sulfate concentration pattern. Most of the high concentrations (over 60 percent) observed within the second ring road are estimated to have originated from the city emissions alone, with highs reaching 90 percent.

3.30 Figure 3.4 presents the percentage contribution of the in-city emissions to total annual average SO_2 concentrations in Shijiazhuang for the baseline scenario in 2000. The rest of the pollution is estimated to have originated from large point sources, especially power plants, located to the west of the city. As indicated before, these sources account for more emissions than the in-city emissions and, because of their relatively high emission release point and prevalent northwesterly winds, these emissions find their way into the city limits. Furthermore, a background concentration of 11 ?g/m^3 of SO_2 from outside Hebei Province is assumed for exposure analysis (calculated from the RAINS-Asia model excluding Hebei emissions).

Figure 3.5 Calculated Percent Sectoral Contribution of In-City Emission Sources to SO_2 Concentrations in Shijiazhuang in 2000



3.31 The four major sources that contribute to the local SO_2 emissions? tea and bath boilers, industrial boilers, central heating boilers, and large point sources? are modeled separately to study their relative contributions. Tea and bath boilers, which contribute less than 3 percent of total emissions, ranged from 1 to 3 percent of the SO_2 concentrations. Most of the contribution came from the central heating boilers and the large point sources. Due to the geographical distribution of the emissions from these sectors and the emission release height, their dominance is felt at different locations? central heating sources dominating to the west of the city and LPSs to the east. Each of them is estimated to contribute more than 30 percent to the urban SO_2 pollution. Industrial boilers averaged about 20 percent of the in-city pollution. Figure 3.5 presents the geographic distribution of percent contributions from each of the sources.

Table 3.6: Health Effects of SO_2 Pollution above the NAAQS in Shijiazhuang, 2000

	Dose Response Coefficient	*Health Impacts*	*Economic Evaluation*	
			$ per unit	*$ in total (mil)*
Mortality	24	2,736	60,000	164.17
Hospital admissions	97	11,059	330	3.65
Admissions for respiratory disease	56	6,384	203	1.30
Emergency room visits	55	6,270	7.5	0.05
Hospital outpatient visits	4,670	532,414	3.33	1.77
Workday loss (person-days)	18,400	2,097,735	2.5	5.24
Acute respiratory symptoms (days)				
Children[20]	21,500	735,347	3.2	2.35
Adult	28,320	2,260,082	3.2	7.23
Chronic bronchitis				
Children	403	13,783	8,700	119.92
Adult	34	2,713	5,800	15.74
Chronic cough in children	517	17,683		76.03
Asthma attacks	1770	201,793	1	0.20
Health cost in total (million $)				396.4
Health cost as percent of local GDP[21]				10.1

Note: *Dose–response functions are effects per 1 million people per 1 ?g/m^3 change in the ambient PM_{10} concentration. Per unit $ rate is per effect (ECON, 2002 and World Bank, 1997).*

3.32 The dose–response functions of PM_{10} are used in this study to estimate the health impacts of ambient SO_2 pollution because they are more accurate than the dose–response functions of SO_2. But there are insufficient data to model PM_{10} concentrations. The monitoring data from five stations in Shijiazhuang were analyzed to develop a ratio of TSP/PM_{10} to SO_2 concentrations measured and enabled us to use the PM_{10} dose–response functions to correlate with the changing SO_2 concentrations in the city. For this

[20] Assumes that 30 percent of the population are children

[21] GDP for Shijiazhuang municipality in the year 2000 was RMB 100.1 billion, and urban residents accounted for 18 percent of the municipal population. An exchange rate of 8.34 Yuan/1.0 US$ is applied.

analysis, a ratio of 1.54 is estimated for PM_{10} to SO_2 concentrations measured in Shijiazhuang.[22]

Table 3.7: Main Planned SO_2 Control Activities in Shijiazhuang, 2001-2005

Projects	*Projected SO_2 Reduction (ktons/yr)*	*Estimated Investment (million yuan)*	*Actions*
Supply of low-sulfur coal	19	225	**1.** Mandate the sulfur content of the coal sold in the city to less than 1 percent **2.** Promote projects to import more low-sulfur coal from neighboring Shanxi province
Substitution of coal with natural gas	13	513	**1.** Gasify part of central space heating in downtown area **2.** Increase share of gaseous fuel in fuel mix from the current 3 percent to at least 10 percent
Targeting small coal-fired boilers and kilns	3	100	**1.** Dispose all coal-fired boilers with a capacity of less than 1 ton or use low-sulfur anthracite or gas **2.** Replace 700 small boilers used for winter heating by district heating systems **3.** Convert 50 dispersed coal-fired heating boilers to electric or gas boilers
Desulfurization	1	150	**1.** Apply water screen desulfurization and introduce circulating fluidized bed combustion methodology to the thermal power plants

Source: *Shijiazhuang EPB report, 2002*

3.33 Table 3.6 presents the resulting estimates of health effects of SO_2 concentrations in 2000, counting only those concentrations above the national ambient standard of 60 ? g/m^3 under the baseline scenario. It is estimated that 2,736 premature deaths, about 3.2 million cases of acute and chronic morbidity, and 2.1 million person-days of workday loss would have been avoided if Shijiazhuang had met the national

[22] The estimated numbers need to be taken with a grain of salt, and may be best interpreted as effects in the presence of both PM_{10} and SO_2.

ambient air quality standards in 2000. This implies US$164.2 million for premature deaths and US$231 million for morbidity, using economic valuation figures based on GDP indexed willingness to pay (Liand others, 1998; ECON, 2002; and World Bank, 1997). The total health cost of US$396 million was equivalent to about 10 percent of Shijiazhuang's GDP in 2000 (urban district only).

3.34 These results are much higher than the estimates of health costs by local researchers who adopted the human capital approach of using average local salary for economic valuation (Li, 1998). Using incidence rates and survey data, Li and others estimated the costs of public health associated with air pollution in Shijiazhuang to be 523 million Yuan in 1995, equivalent to US$63 million. The higher value estimated for 2000 in this paper reflects mainly the higher valuation of costs using the Willingness to Pay (WTP) method and a higher pollution level in 2000 as well (25 percent rise in monitored TSP concentrations).

Scenario I: Implementation of Planned Sulfur Control Actions

3.35 Shijiazhuang has proposed actions for SO_2 emissions reduction in its 10^{th} Five-year Plan (2001-2005). These planned actions (Table 3.7), if fully implemented, would result in a total reduction of 36,000 tons of SO_2 emissions by 2005. Most of the expected reduction would come from the expected new natural gas supply and greater use of low-sulfur coal, with each action generating 13,000 and 19,000 tons of emissions reduction, respectively. Most of the LPS sources are assumed to start using low-sulfur coal or convert a fraction of their fuel mix to natural gas as required by the city ordinance. The simple desulfurization technique would be applied to a limited extent only for coal-fired boilers, yielding only a reduction of 1,000 tons/yr.

3.36 Dispersion modeling was conducted in a similar fashion to the baseline analysis. The above options were modeled individually to compare the range of benefits possible and how close does each of the options bring the ambient levels to compliance. Table 3.8 presents the modeling results for each of the control options.

3.37 Estimates of SO_2 emission reductions and the associated costs are obtained from the Shijiazhuang EPB, assuming all options are implemented fully as planned. Of the 247 km^2 region, upon implementation of the four measures, more than 50 percent of the cells (90 out of 177 km^2) experiencing SO_2 pollution levels above compliance levels will fall below 60 ? g/m^3.

3.38 Figure 3.6 presents the calculated SO_2 and SO_4 concentrations upon implementation of actions in Scenario I. The modeling analysis indicates that application of the planned control actions would not be sufficient to reach the compliance level by 2005. A large portion of the emissions still originate from the large power plants, and in spite of their higher release point they are expected to contribute to the local pollution to a large extent. The tea and bath boilers that are operated at the ground level did not have a large effect on final calculations. A large portion of the reduction is the result of the combined application of low-sulfur coal to the small-scale industries and power plants and increasing natural gas usage. From Table 3.8, it is evident that, individually, fuel switching (to either low-sulfur coal or natural gas) has the most significant effect in reducing ambient concentrations.

Figure 3.6 Calculated (a) SO2 and (b) SO4 Concentrations under Scenario I in Shijiazhuang in 2000

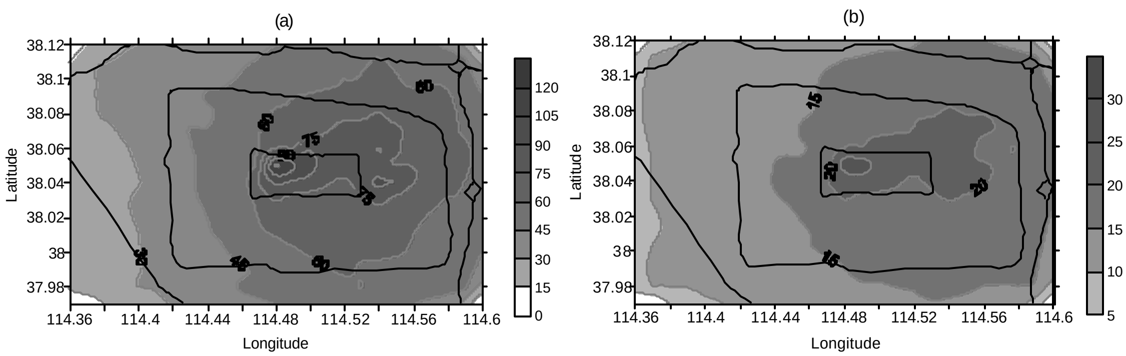


Table 3.8: Modeling Results from Planned Sulfur Control Actions in Shijiazhuang

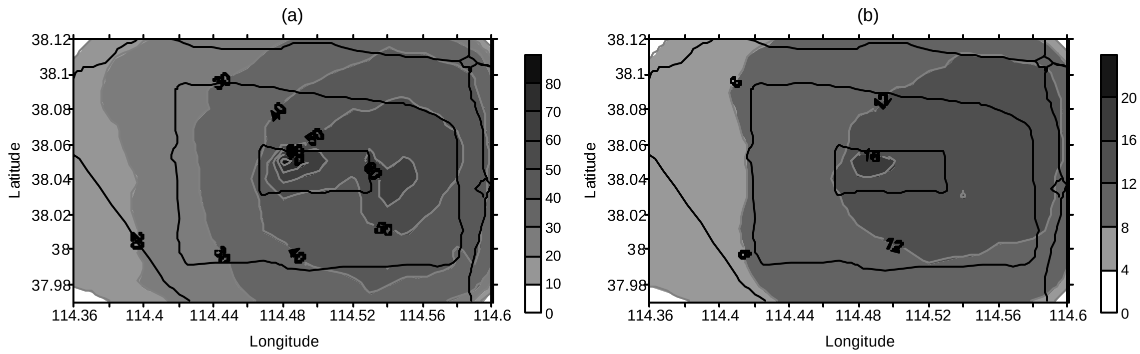
Control Measure ✍	*Baseline Scenario*	*Low-Sulfur Coal*	*Natural Gas*	*District Heating*	*LPS Desulfurization*	*All Control Options Combined*
Emission reduction (ktons)		19	13	3	1	36
No. of grid cells above 60 ?g/m^3	177	149	155	172	175	87
No. of grid cells above 80 ?g/m^3	142	66	85	126	137	15
No. of grid cells above 100 ?g/m^3	80	19	27	59	72	2

3.39 Similar to the baseline scenario calculations, results of human exposure are generated by the UrBAT model, measuring the reductions in population exposure to change in SO_2 concentrations from baseline levels. Table 3.9 presents the number of human health effects reduced upon application of the measures and the human health costs that might be incurred under this scenario, counting only those concentrations above the national ambient standard of 60 ?g/m^3 under Scenario I. It is estimated that 660 premature deaths, about 0.8 million cases of acute and chronic morbidity, and 0.5 million person-days of workday loss would still occur even if the planned actions are completed by 2005. This implies US$39.6 million for premature deaths and US$56.3 million for morbidity, using economic valuation figures based on GDP indexed willingness to pay (Li and others, 1998; ECON, 2002; and World Bank, 1997). A total health cost of US$95.6 million (in 2000 dollars) indicates that the exposure levels would still be exceeding the national ambient standards and further abatement actions may be warranted.

Table 3.9: Health Effects of SO_2 Pollution above the NAAQS in Shijiazhuang under Scenario I

	Dose–Response Coefficient	*Health Impacts*	*Economic Evaluation* $ per unit	*Economic Evaluation* $ in total (millions)
Mortality	24	660	60,000	39.60
Hospital admissions	97	2,667	330	0.88
Admissions for respiratory disease	56	1,540	203	0.31
Emergency room visits	55	1,512	7.5	0.01
Hospital outpatient visits	4,670	128,423	3.33	0.43
Workday loss (person-days)	18,400	505,994	2.5	1.26
Acute respiratory symptoms (days)				
Children	21,500	177,373	3.2	0.57
Adult	28,320	545,153	3.2	1.74
Chronic bronchitis				
Children	403	3,325	8,700	28.92
Adult	34	654	5,800	3.80
Chronic cough in children	517	4,265		18.34
Asthma attacks	1,770	48,674	1	0.05
Health cost in total (million $)				95.61
Health cost as percent of local GDP				2.4

Figure 3.7 Calculated (a) SO_2 and (b) SO_4 Concentrations under Scenario II in Shijiazhuang in 2005



Scenario II: Additional Actions Needed for Compliance

3.40 The modeling analysis of Shijiazhuang's five-year emissions control plan (Scenario I) indicates that it would go a long way toward the policy objective of achieving SEPA's compliance requirement by 2005. About 65 percent of the urban area would become compliant by 2005, compared to less than 30 percent in 2000.

3.41 More important, seriously polluted areas (annual SO_2 concentration greater than 100 ? g/m^3) would shrink from 32 percent in 2000 to less than 1 percent by 2005. Health damages would fall drastically from 10 percent of GDP to 2.4 percent. But the planned actions would still fall short of achieving the compliance goal.

3.42 In order to attain full compliance by 2005, Shijiazhuang would need to do more, especially in targeting high pollution areas of the city. As Figure 3.6 illustrates, most of the region still noncompliant comprises the inner-ring areas with the highest population density and those places where the industrial and large point sources dominate the contribution to local air pollution. There appears to be a particular need for further controls at large point sources within the first ring road. The contribution from these sources exceeds 40 percent in the area. Further analysis of the contributions from various sources also suggests that in the year 2005, the contribution of the power plants and cement factories located northwest of the urban Shijiazhuang area will contribute more to local air pollution compared to its contribution in the baseline case. Since these power plants are also considered to be part of the Shijiazhuang Municipal EPB jurisdiction, one applicable option is to require these plants to use low-sulfur coal or install FGD equipment.

3.43 Under Scenario II, it is assumed that these LPSs would use more low-sulfur coal than in Scenario I. This would lead to a 50 percent reduction of their SO_2 emissions, compared with the 2000 baseline, instead of the 33 percent reduction estimated under Scenario I, and result in an additional 2,530 tons of SO_2/yr reduced from large point sources within the city limits. In addition, it is assumed that the power plants outside - the city limit will receive low-sulfur coal at a similar transition rate as the inner-city plants, amounting to a 33 percent reduction in the emissions. A total reduction of 20,720 tons of SO_2 by 2005 is expected from these power plants, reducing the local pollution contribution by an equivalent of 30 percent in addition to what is expected for the in-city pollution reduction programs. Table 3.10 presents a synopsis of emissions and emission reductions applicable under each of the scenarios discussed in this case study.

Table 3.10: Comparison of Emissions and Reductions Expected under the Control Options and Sectors

(Emissions in tons/yr)	*Tea and Bath + Small-Scale Industrial Boilers*	*Heating Boilers*	*Large Point Sources in the City Limits*	*Large Point Sources Outside the City Limits*
Total Emissions under				
Baseline	10,165	18,700	26,895	60,940
Scenario I	0	9,614	15,976	60,940
Scenario II	0	9,614	13,447	40,220
Reductions from Baseline				
Scenario I	10,165	9,086	10,919	0
Scenario II	10,165	9,086	13,448	20,720

3.44 For the background concentrations originating from sources outside Hebei Province, it is assumed that the rest of China will also undergo similar changes and adopt the best available technology. Under this scenario, the background concentration contribution calculated using the RAINS-Asia model with best available technology reduced from 11.5 to 7.5 ? g/m^3 of SO_2.

3.45 One should keep in mind that all of the modeling calculations were performed using only one set of meteorological data. It is an underlying assumption that the meteorological features will remain the same in 2005 and beyond. Given the uncertainty level in any of the modeling results, from Figure 3.7 it can be said that most of the region will fall under the compliance levels of Scenario II. Higher concentrations of around 70 ? g/m^3 are still observed around the large point sources (10 out of 247 grid cells exceeded the class II levels), which is assumed to be present because of the high density of emissions in the vicinity. Nevertheless, the concentrations are estimated to fall below the compliance level of 60 ? g/m^3 upon implementation of the new measures in Scenario II in the urban district of Shijiazhuang by 2005.

3.46 Table 3.11 presents a number of the human health effects reduced upon application of the measures, and the human health costs that might be incurred under this scenario, counting only those concentrations above the national ambient standard of 60 ?g/m^3 under Scenario II. It is estimated that 45 premature deaths, about 52,900 cases of acute and chronic morbidity, and 34,341 person-days of workday loss will be incurred by Shijiazhuang in 2005. This is a reduction of about 98 percent from the baseline calculations. A total health cost of US$6.5 million (in 2000 dollars) indicates that the exposure levels will still be exceeding the national ambient standards in some areas of the city.

Table 3.11: Health Effects of SO_2 Pollution above the NAAQS in Shijiazhuang under Scenario II

	Dose–Response Coefficient	*Health Impacts*	*Economic Evaluation*	
			$ per unit	*$ in total (millions)*
Mortality	24	45	60,000	2.69
Hospital admissions	97	181	330	0.06
Admissions for respiratory disease	56	105	203	0.02
Emergency room visits	55	103	7.5	0.00
Hospital outpatient visits	4,670	8,716	3.33	0.03
Workday loss (person-days)	18,400	34,341	2.5	0.09
Acute respiratory symptoms (days)				
Children	21,500	12,038	3.2	0.04
Adult	28,320	36,999	3.2	0.12
Chronic bronchitis				
Children	403	226	8,700	1.96
Adult	34	44	5,800	0.26
Chronic cough in children	517	289		1.24
Asthma attacks	1,770	3,303	1	0.00
Health cost in total (million $)				6.49
Health cost as percent of local GDP				0.2

Costs and Benefits of Sulfur Emission Abatement Actions

3.47 Power plants and space-heating boilers, two dominant sulfur emission sources in Shijiazhuang, are critical to the city's abatement strategies and compliance goals. Small emission sources such as tea boilers and restaurant stoves, while still numerous and highly polluting, are likely to become substantially controlled by the planned natural gas supply by 2005. This study thus focuses on the options and costs of sulfur emission control in power plants and space-heating boilers.

Costs of Alternative Emission Abatement Options for Space-Heating Boilers

3.48 The current strategy adopted by Shijiazhuang is to consolidate many dispersed heat-only small boiler houses into a relatively few large district heating facilities that often use combined heat and power technology. Meanwhile, low-sulfur coal is required for all heating boilers. Technically speaking, and other things being equal, this consolidation would save coal because of improved combustion efficiency of larger or cogeneration boilers. Most of the emission reduction, however, would have to come from switching to low-sulfur coal, and to natural gas, as planned.

3.49 According to Shijiazhuang EPB, half of the coal used in boiler houses is already low-sulfur (< 1 percent). Transportation is unlikely to be a constraint for low-sulfur coal supply because Shijiazhuang already buys more than 90 percent of its coal from neighboring Shanxi, where most of China's low-sulfur coal is produced. The main issue for Shijiazhuang is to buy coals selectively, especially with regard to their sulfur content. There is not sufficient evidence indicating that a sulfur premium is systematically figured into the pricing of low-sulfur coals in China. In many cases, low-sulfur coal is relatively expensive because of its higher heating value and lower ash content. In a documented case(Table 3.5) of switching to low-sulfur coal in a local power plant, the revealed average cost of abatement was about 590 Yuan/ton-SO_2. The average abatement cost at heat-only boiler houses could be lower if modification of boilers were not needed.[23]

3.50 Wet precipitators are used for low-level sulfur scrubbing at some boiler houses in Shijiazhuang. However, cost information is scarce and incomplete. Local documentation of power plant application of wet precipitators in Shijiazhuang indicates average abatement costs of 760~1050 Yuan/ton-SO_2, with about 30 percent removal efficiency. The average abatement cost at heating boiler houses could be higher because of inferior economies of scale. At least in power plant application, CFBC technology appears to be competitive for sulfur abatement compared with the wet precipitator technique, registering an average cost of about 900 Yuan/ton-SO_2 (50 percent removal).

[23] Even though industrial boilers are usually designed to burn coal of specific characteristics, boiler house operators in China normally burn whatever coal they can buy from the market. For a conventional pulverized coal power plant, modification of boilers is often necessary if switching to a different type of coal.

3.51 The planned switch to natural gas for part of the central space heating systems is a drastic measure to combat air pollution. Using information from the Beijing coal to gas conversion project, it is calculated that the average abatement cost is about 15,000 Yuan per ton of SO_2.[24] This of course is a joint cost for a measure that essentially eliminates particulate emissions, greatly improves occupational health benefits, and has other non-environmental benefits.

3.52 In summary, switching to low-sulfur coal is most likely to be the least costly way to achieve sulfur abatement in space-heating boilers in Shijiazhuang because of the city's easy access to Shanxi's low-sulfur coals. The wet precipitator technique may be applied in addition to low-sulfur coal if a particular boiler house still exceeds its emission quota. Because of its superior sulfur control potential, CFBC technology could be an attractive option for new district-heating boiler plants. Replacing coal with natural gas in space heating has multiple benefits and is especially attractive in densely populated urban areas where air quality is highly valued.

Costs of Alternative Emission Abatement Options for Power Plants

3.53 From cost information discussed above, switching to low-sulfur coal is significantly cheaper than the other two emission control technologies used in Shijiazhuang's power plants, most of them cogeneration plants that also supply steam for space heating. Currently, most power plants in Shijiazhuang use coal with an average sulfur content of about 1.5 percent. The wet precipitator technique (with 30 percent removal efficiency) would only be marginally sufficient to achieve emission reduction equivalent to using 1 percent sulfur coal, the maximum level allowed for power plants in the "two-control regions." Other emission control technologies, such as furnace sorbent injection and dry or wet scrubbers, are likely to be more expensive, but would be more effective in sulfur removal as well. Their application may be needed for large power plants where higher sulfur removal rates are necessary to keep Shijiazhuang's future emissions in check.

Comparing the Costs and Benefits of Sulfur Emission Reduction

3.54 The modeling analysis of Scenario I indicates that by successfully implementing its 10th Five-Year Plan, Shijiazhuang would cut health damages caused by ambient SO_2 pollution by about 2.49 billion Yuan, yielding an average benefit of about 69,000 Yuan per ton SO_2 abated. This far outweighs the average abatement cost of any

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[24] Operation cost data of coal-fired and gas-fired systems in Beijing were used. Main assumptions (based on actual case information) include: coal price 220 Yuan/ton, coal sulfur content 1.45 percent, natural gas price 1.8 Yuan/m^3, coal boiler efficiency 65 percent, and natural gas boiler efficiency 85 percent. End users usually have to pay for the gas connection, which can be expensive if the boiler house is not very close to the distribution network. This cost is not included in the calculation.

of the planned actions, except perhaps natural gas, which still is far cheaper but at the same order of magnitude.

3.55 The incremental benefits of further emissions reduction would be significantly lower, at about 32,000 Yuan per ton SO_2 abated, assuming the additional actions in Scenario II are implemented. Since Scenario II assumes that more low-sulfur coal is used in large point sources in or outside of the city limit, the additional cost of abatement would still be low, compared to the additional health benefits.

Findings and Conclusions

3.56 Shijiazhuang presents an interesting case for the potential as well as the constraints of using fuel switching as a main strategy for ambient SO_2 pollution control. The low-sulfur coal and the natural gas options account for 53 and 36 percent of the planned emissions reduction between 2001 and 2005, respectively. Even though the 10^{th} Five-Year Plan actions (Scenario I) are not sufficient to achieve full compliance with the Class 2 ambient SO_2 standard, additional measures that rely solely on switching to low-sulfur coal at large point sources (Scenario II) would essentially bring Shijiazhuang into full compliance. In both scenarios the implicit assumption is that coal consumption would not grow, at least between 2001 and 2005. This may be optimistic, unless natural gas can continue to take up a bigger share of Shijiazhuang's fuel supply.

3.57 Central to continuous compliance in Shijiazhuang is the capping of sulfur emissions from the space-heating boiler houses and power plants in and near the city proper. This could mean that further emission reduction at these sources is needed, should rising space-heating demand drive up coal consumption. The current strategy of consolidating small coal-fired central heating systems into large district heating systems would facilitate emission control and compliance monitoring. It is also worth noting that most of this consolidation and expansion of space-heating capacity will be using combined heat and power facilities, which improve the economics of investing in large district heating systems in a relatively mild climate.[25] Alternatively, expansion of distributed natural gas-fired space heating can be pursued if the gas supply becomes more abundant and is priced more competitively. The economic and financial implications of large district heating systems vs. distributed gas heating need to be studied to provide better guidance to the local government's infrastructure investment decisions. Construction of more energy-efficient buildings and the introduction of consumption-based heat pricing and billing would significantly reduce future demand for heating fuels. This is a cross-sector policy that would clearly benefit Shijiazhuang's air pollution control efforts.

3.58 Capping sulfur emissions also implies that Shijiazhuang should avoid adding new coal-fired power plants in its vicinity. Strict environmental review would be

[25] The official heating season last four months, from November 15 to March 15. The average outdoor temperature in the coldest month, January, is between –4.6 and –2.7?C.

needed for the expansion of power projects as a result of the consolidation of dispersed heating boiler houses.

3.59 Finally, the emission abatement strategy adopted by Shijiazhuang would not succeed without strong policy and regulatory support, especially in the 10^{th} Five-Year Plan period. Extensive compliance enforcement efforts will be needed to ensure that low-sulfur coal is used by the numerous heating or industrial boiler houses, because the local coal market is completely decentralized and coal transactions are difficult to track. This and other common regulatory issues will be discussed in more details in the final chapter.

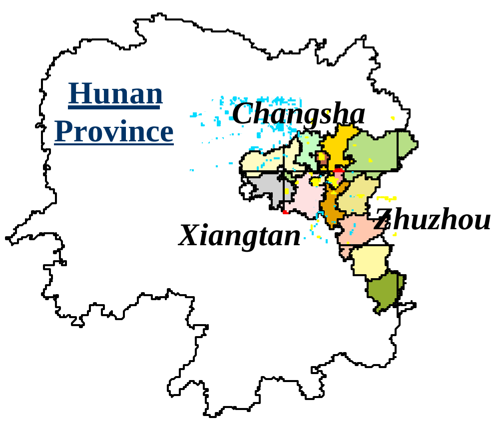
4

Case Study: Changsha Triangle Area

Social and Natural Environment

4.1 Changsha, Zhuzhou, and Xiangtan are a cluster of cities located in the downstream plains of the Xiang River between two mountain ranges in Hunan Province (Figure 4.1). The tri-city region is blessed with fertile soil and a favorable subtropical monsoon climate for crops. As one of China's grain basins, the region has been increasingly threatened by acid rain over the last two decades. Large areas of rice paddy, fields planted with vegetables, and forests suffer damage following acid rain. Cases of crop losses claimed by peasants have been settled in the amount of millions of Yuan[26].

Figure 4.1 Changsha Tri-City Area and Hunan Province



Source: *Hunan EPB (2000)*

[26] According to local EPB officials, cases of farmers suing industries for crop losses have taken place frequently in recent years. Local EPBs often act as mediators to resolve the cases by estimating crop losses based on historical harvests (*Source*: Discussion notes during the World Bank Mission, July, 2001).

4.2 The tri-city region is anchored by Changsha, the capital of Hunan, with Xiangtan and Zhuzhou, two medium-size industrial cities, at the lower tips of a triangle. This region covers an area of about 4,500 km^2 and has the highest density of population in Hunan province. In 1999, the region's population reached 12.3 million, about 19 percent of Hunan's population. The GDP of the area reached 108.3 billion Yuan and an industrial output value of 58.6 billion Yuan, accounting for 32 percent and 41 percent of the provincial total, respectively.

4.3 The entire triangle area is negatively affected by acid rain, with an average pH value of 4.2 in annual precipitation. Some rainfall is reported to have a pH level lower than 3, far below the threshold value of 5.6. The local soil type is red, which is not assimilative to acid compounds. This has led to a significant reduction in food production in the region (Yang and others, 2002).

4.4 As with the cause of air pollution in other areas of China, the chief culprit for acid rain in the Changsha triangle is coal, which accounts for over 80 percent of primary energy consumption in the region. Most coal is produced locally, with a sulfur content of up to 3 percent or more. The resulting emissions from coal consumption are high in sulfur, helped by the geographic and climatic conditions in the region: The mountain ranges act to reduce air flows and trap acid compounds in the atmosphere, and (the high humidity in the region provides water and oxygen for chemical reactions among airborne pollutants, thus resulting in acid rain in the region.[27] In the tri-city area, SO_2 concentration levels are reported to vary seasonally, usually with the highest value in winter and lowest in summer. In winter, there are more stagnant weather patterns and strong inversion conditions, further enhancing the acid rain problem.

4.5 In addition to acid rain, the three cities also face air pollution problems specific to their own urban residents, mainly in the form of high ambient concentrations of air pollutants, with levels in Changsha being the most severe. The leading pollutant is SO_2, which contributes 40-53 percent of the published weekly air pollution index (API)[28]; TSP is the second leading pollutant, contributing 28-40 percent of the API. In recent years, Changsha had the highest SO_2 concentration, with the annual average hovering around 116 ?g/m^3, compared with 60 ?g/m^3 of the Class 2 standard. Zhuzhou's ambient SO_2 pollution worsened significantly, with the annual average concentration rising from 55 ?g/m^3 in 1996 to 106 ?g/m^3 in 2000. Xiangtan achieved Class 2 ambient SO_2 compliance in 2000.

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[27] More commonly, acid deposition is to the result of secondary pollutants that form from the oxidation of SO_2 and NO_x gases that are released into the atmosphere. The process of altering these gases into their acid counterparts can take several days. Acid precipitation formation can also take place at the surface level when SO_2 and NO_x settle on the landscape and interact with dew or frost. The conversion process is represented in a simplified manner in the following set of reactions: (1) $SO_2 + H_2O \rightarrow H_2SO_3$ and $SO_2 + 1/2O_2 \rightarrow SO_3 + H_2SO_4$ (2) $NO + 1/2O_2 \rightarrow NO_2$, $2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$ and $NO_2 + OH \rightarrow HNO_3$.

[28] API is a weighted index that SEPA uses to measure urban ambient air quality.

4.6 Measurements from the three cities over the last decade indicate that acid rain deteriorated toward the mid-1990s in the Changsha city area as pH indexes fell and the acid rain frequency rose. In 1998, the situation eased somewhat in Changsha, but intensified in Xiangtan and Zhuzhou. The moving around of the pH and frequency indexes between cities indicates changes in regional emission patterns. Local environmental agencies have realized that combating acid deposition in the entire region needs to be a joint effort of the three cities. A regional plan on SO_2 emissions reduction has been proposed (see below).

4.7 Overall, Changsha ranks top among the three cities in both acid rain and urban air pollution. Evidence from the collected data shows that the values of pH vary considerably between the Changsha city center and surrounding areas.[29] Typically, the city pH value is 0.5 lower than that outside the city. One interpretation of this phenomenon by the Changsha EPB is that the primary source of acidity is localized; otherwise, the pH values would be more uniform over the Changsha area if there were an outside source for acid deposition in Changsha. One possible theory to support this interpretation is that some airborne acid compounds become attached to rain drops and are carried to the ground. This is consistent with observations in Changsha that the first rains are more acidic than the later, and the finer the droplets, the more acidic the rain[30].

4.8 In Changsha, detailed chemical analysis of the rain samples has also been performed since 1991. Chemical analysis shows that the sulfate to nitrate ratio ranged from 5.4 to 11.8 in favor of sulfate concentrations as the key factor in the formation of acid rain in the region. However, the ratio of sulfate to nitrates has been falling in recent years, which coincides with an increase in nitrate concentrations, suggesting NO_x from the growing vehicle population is an increasingly important pollutant in Changsha.

Energy Consumption and Emissions

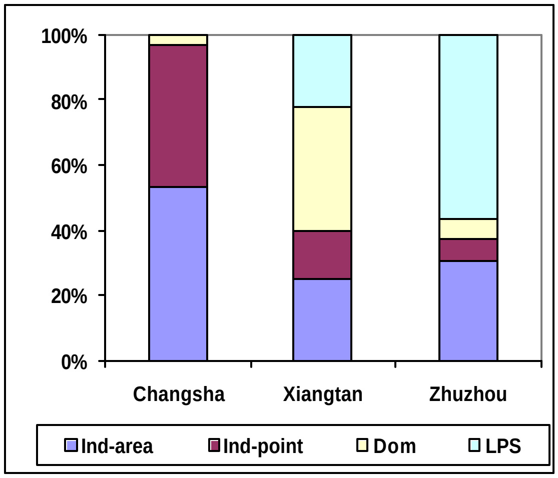
4.9 While the industrial sector dominates energy consumption in the CZX region, the three cities have different industrial profiles. Changsha is oriented toward downstream manufacturing, such as electronics, mechanical equipment, textiles, and chemicals, and the manufacturing industry accounts for about 80 percent of total final energy consumption of the city. Zhuzhou is clustered with large energy users, including a

[29] Changsha started monitoring acid rain in 1982. Three monitoring stations are manned to cover an area of 120 km^2 centered around Changsha, using the open-bucket method (manually putting out plastic buckets to collect water samples when it rains. Automatic devices for rain sampling were tried but abandoned as they quickly became corroded because of high acidity and high humidity). These three stations also collect air samples. Two more unmanned stations were also set up, using automatic equipment to monitor air quality only.

[30] Observations by the Xiangtan EPB are the opposite but may support the same theory. The first rains in the Xiangtan area tend to be less acidic than follow-up rains. The explanation is that most of the airborne compounds attached to raindrops before they fall to the ground are actually alkaline because of emissions from the many cement factories and refractory plants in Xiangtan.

big smelter and a power plant. Xiangtan, on the other hand, boasts a large iron and steel company and is the region's new thermal electric power center.

Figure 4.2: Composition of SO2 Emissions in Changsha Triangle Region, 2000



Source: *Changsha, Xiangtan and Zhuzhou EPB's (2000)*

4.10 In 2000, the CZX region emitted 200,100 tons of SO_2, about 35 percent of the total emissions in Hunan Province. As revealed in Figure 4.2, the emission patterns differ significantly among the three cities. Changsha's total emissions of about 72,200 tons came primarily from uncontrolled burning of high-sulfur coal in many small facilities (area and small-point industrial sources dominate emissions). Zhuzhou emitted about 76,700 tons, with a large proportion from large point sources, notably the lead smelter. Xiangtan's total emissions were significantly lower, at about 51,200 tons, and had a rather large share of small residential and commercial sources.

4.11 The quantity and pattern of emissions in the region are expected to change significantly in the next 5 to 10 years as a result of planned emission control activities as well as the continued economic development of the region. While overall emissions are expected to fall, new emissions will originate mainly from the power sector. A 2x300 Mega Watt equivalent (MWe) coal-fired power plant is near completion in Zhuzhou, and a 2x600 MWe coal-fired power plant is planned for Xiangtan.

CZX Regional Sulfur Control Policies and Measures

4.12 The CZX region, one of the hot-spot areas identified in SEPA's "two-control regions," was selected as a national pilot area for comprehensive prevention and control of acid rain. Such a distinction has made acid rain control in the CZX region a top priority for the Hunan Provincial Environmental Protection Bureau, which leads the formulation and implementation of CZX regional sulfur emissions abatement strategies. A comprehensive acid rain control plan for the region was proposed in 2001, and includes the following priority areas:

?? Reduce the sulfur content of coal by closing high-sulfur coal (greater than 3 percent) mines, and by increasing the capacity of coal cleaning, screening, washing, and blending.

?? Control emissions from thermal power plants by strict enforcement of emission standards and closing highly polluting small units.

?? Control emissions of coal-fired boilers and kilns through the use of cleaner fuels (including low-sulfur coal) and flue gas desulfurization.

?? Ban the use of raw coal in residential and commercial applications.

?? Increase the supply of gaseous fuels, especially the introduction of natural gas from Sichuan Province.

?? Control fugitive emissions by phasing out highly polluting production equipment and processes, introducing clean production technologies, and promoting energy and resource conservation.

4.13 These strategies are backed up by a series of planned investment projects, some of them already being implemented. The basic regulatory approach follows the national policy of "total emission quantity control," with quotas distributed to each city and then to sectors and major polluters. Major ongoing sulfur control activities or initiatives in the CZX region are discussed in more detail here and will be analyzed later using models.

Restricting the Use of High-Sulfur Coal

4.14 The characteristics of the coals consumed in Changsha are representative of the general situation in the region, which depends heavily on locally produced high-sulfur coals (Table 4.1). The average sulfur content of coals consumed in Changsha is in the range of 2.5–3 percent. The Changsha Municipal Government now limits sulfur content to 1 percent for non-industrial users and 2.5 percent for industrial users who have installed desulfurization equipment. Plans are proposed to establish a coal allocation center to centralize the buying and selling of low-sulfur coal to ensure that coal users do not go out on their own to purchase coal that does not meet the standards.

4.15 Efforts to restrict the use of high-sulfur coal have met with limited success because of the high dependence on cheap, locally produced coals. In spite of the restrictions, high-sulfur local coal continues to be traded in the market, and coal users try to elude the authorities. Prices appear to be the main determinant for small users. On average, low-sulfur coal (less than 1 percent) imported from Shanxi or Henan costs 100~150 Yuan more than local or Hunan coals, which averaged about 190~250 Yuan per ton in 1999. Taking into account differences in heating values, the main cost differential is due to transportation cost.

4.16 Phasing out the use of locally produced high sulfur coal is also a socioeconomic issue that will take time to resolve. Hunan is an important coal producer in China, with an annual production of about 50 million tons of coal, with an average sulfur content above 2 percent. The CZX region is a main consumer of that coal. The current policy is not to discontinue the use of local coal but to process it so as to reduce sulfur emissions. Major initiatives include investing in steam coal-blending facilities (mixing low- and high-sulfur coal with sulfur-fixing additives), increasing screening and washing capacity for steam coal, and manufacturing coal briquettes for small and medium-size boilers. The merits of these measures are discussed later.

Table 4.1: Quality of Coal Used in Changsha

	Sulfur Content	*Ash Content*	*Heat Value*	*Share*	*Sources*
	(%)	(%)	(Cal/kg)	(%)	
Bituminous	3~5	14~26	4400~6500	56	Local
Bituminous	1~2	16~21	5400~6000	15	Hunan
Anthracite	1.2	18~25	4500~5500	22	Hunan
Bituminous	0.8	12~16	6000~6500	4	Shanxi
Bituminous	0.6	16~25	4800~6000	4	Henan

Source: *Changsha EPB, 1998.*[31]

Promoting Natural Gas

4.17 The three cities are also investing in cleaner alternative fuels, especially in bringing piped natural gas to the region. Currently, only coal gas and LPG are available, mostly to residential and commercial users. Further expansion of gas utilization will come mainly from natural gas. Up to 700 million m^3 of natural gas supply to the region is expected by 2005, displacing more than 1 million tons of steam coal, and making a major contribution to the reduction of sulfur emissions in the region. Changsha also plans to increase LPG use by building a distribution network for LPG.

4.18 Measures to increase gas supply alone may not automatically increase gas consumption. Natural gas usage is likely to be sensitive to the price of the delivered gas relative to that of coal, especially for high-volume industrial users. It is possible that the CZX region may have to resort to regulatory measures, as is being done in Beijing, to make full use of natural gas supplies when they arrive in a few years. For example, a

[31] Comprehensive Plan for Sulfur Dioxide Pollution Control in Changsha (in Chinese).

considerable number of households and restaurants in Changsha that have access to LPG choose not to use the fuel because the cost is about four times that of coal.[32] Many coal stoves used by restaurants in the city area were destroyed in 1999 but some have since re-emerged.

Targeting Small and Medium-Size Coal-Fired Boilers and Kilns

4.19 The basic strategy adopted by the CZX region is similar to practices in other Chinese cities. Small boilers and kilns are either dismantled or converted to burn gas or oil. Larger facilities (for boilers with capacity above 0.7 MW) are either required to burn low-sulfur coal or adopt certain emission control measures, usually the use of domestically produced wet precipitators.

4.20 Both Changsha and Xiangtan have plans to use central heating plants to supply steam for industrial and commercial users, replacing small and medium-size boilers. Liling City, in the Zhuzhou jurisdiction, successfully converted many of its coal-fired ceramics kilns to gas, reducing pollution while improving product quality.

4.21 Besides promoting the use of low-sulfur coal and gas, city authorities are also promoting implementation of desulfurization technology for coal-fired boilers. The typical method in Changsha uses lime and soda-based water to absorb SO_2 at an efficiency rate of about 50 percent. The method was initially applied to boilers larger than 2.8 MW, but has been extended to smaller boilers. By the end of 1997, a total of 537 boilers with a total capacity of 1,359 MW were using this method. These boilers burn about 750,000 tons of coal each year. It was estimated that the resulting annual reduction of SO_2 was 18,000 tons at a total cost of 18 million Yuan, averaging 1000 Yuan per ton of SO_2 reduction, similar to cost of the water screen method adopted in Shijiazhuang. In 2000, in the tri-city area, of the 2,364 coal-fired boilers, 1,000 boilers were using wet precipitators for FGD.

Large Point Source Desulfurization

4.22 Large point sources contribute about 33 percent of the sulfur emissions in the area, and they have a large impact on the region's acid deposition as a result of their location and high stack height. Zhuzhou smelting plant, the biggest SO_2 emission source in the region, invested 140 million Yuan to introduce Wet gas Sulfuric Acid (WSA) technology from TOPSPE (Denmark) to convert the flue gas SO_2 emissions into a useful byproduct of sulfuric acid. The plant authorities forecast that the sulfuric acid output will be 68,000 tons/yr, which amounts to a reduction of 15,000 tons/yr of SO_2 emissions (an

[32] In Changsha, the average price of gas was about 55 RMB per one standard container of compressed gas, while the price of coal was about 4~5 RMB per 100 *Jing* in August 2000. A typical household uses 3 standard containers of compressed gas for a period of 2 months, or 400 *Jing* of coal at maximum of for one month. This gives an average monthly cost of more than 80 RMB for using gas compared to 16~20 RMB for using coal.

estimated 7 percent reduction in the local emissions from one plant alone). Application of WSA technology for this smelter plant not only reduces the acid deposition in Zhuzhou area by up to 20 percent, but also reduces large amounts of deposition in the neighboring counties, which collect agricultural damages of up to 2 million Yuan each year from the plant (Communication with Zhuzhou EPB). Similarly, the existing Zhuzhou power plant (not considering its expansion) and Xiangtan fertilizer plant are expected to reduce 6,000 and 1,000 tons/yr of deposition, respectively, through application of desulfurization units.

4.23 In the late 1990s, the power plants in the region cut their SO_2 emissions by more than 17,000 tons by retiring highly polluting small generation units. New generation units under construction are required to burn low-sulfur coal or to install FGD equipment. Since the power sector has been designated by the local government as a main growth sector over the next 10 years, it is critical that sulfur emission control regulations be enforced or even strengthened, in order to ensure the net reduction of sulfur emissions in the region.

Analysis of Sulfur Control Options

4.24 Because the primary concern of the region is acid deposition, this study has used the ATMOS/UrBAT model and RAINS-Asia model to analyze the effects of current emissions and emission control options on agricultural yield using dose–response functions established in other studies.[33] The national 10th Five-Year Plan (2001-2005) has explicit sulfur emission reduction goals and ambient quality compliance requirements for the provinces and cities that fall into the "two-control zones." A target of 21 percent SO_2 emissions reduction by 2005 (compared with the 2000 emission level) is set for Hunan Province and would apply to the CZX region. In addition, Changsha is also required to achieve compliance with Class 2 ambient standard for SO_2 by 2005. These are considered in the modeling analysis as the policy objectives of sulfur emissions control for the CZX region by 2005.

4.25 While air quality is of great importance to the region, the analysis here is restricted to acid deposition and its impact on agricultural productivity in the tri-city area. A large part of the region has exceeded the critical load[34] by a factor of at least 2, hampering the production of wheat, soybeans, cotton, and vegetables.

[33] Hao, J., et al. "*Dispersion Modeling and Damage Cost Valuation in China: A Case Study in Hunan Province.*" Tsinghua University, Beijing, China, 2000.

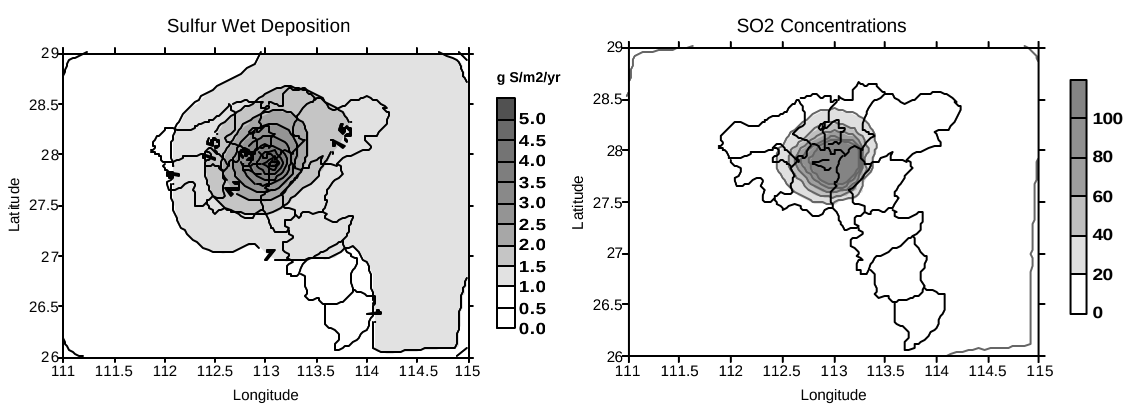
[34] A critical load of an ecosystem is essentially a "no-effect" level for a pollutant, that is, the level of a substance (acid deposition, as an example) that does not cause long-term damage to an ecosystem. Areas that have a limited natural capacity to absorb or neutralize acid rain have a low critical load. Ecosystems that are more able to buffer acidity (through different soil chemistry, biological tolerances, or other factors) have a correspondingly higher critical load. Assessing the natural capacity of ecosystems to withstand current and projected levels of pollution is a method of measuring ecosystem health, and can serve as a way to assess the environmental benefits of emissions reductions.

4.26 The baseline situation is modeled based on year 2000 emission patterns. Two scenarios are analyzed. Scenario I represents the adoption of planned actions by the three cities between 2001 and 2005. Scenario II is contingent on whether Scenario I actions meet the policy objectives. If Scenario I measures fail to achieve the policy objectives, Scenario II would include additional or alternative sulfur control options that would accomplish the policy objectives.

Baseline Analysis

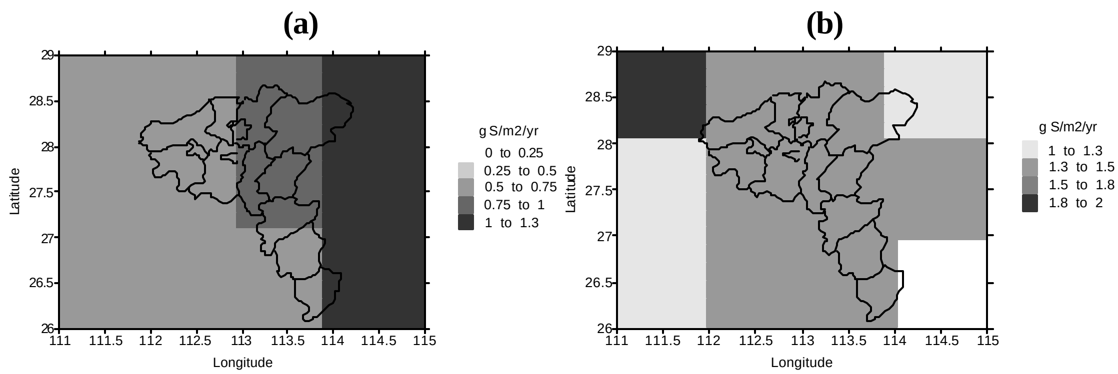
4.27 A matrix that divides the Changsha tri-city area into 15 km by 15 km grid cells (approximately 0.2º by 0.2º), with 40 east-west grids and 30 north-south grids, was used to map out emissions. Approximately 200,100 tons of SO_2 was emitted in the CZX area in 2000, with 36, 38, and 25 percent of the emissions originating from the Changsha, Zhuzhou, and Xiangtan jurisdictions, respectively. For the region as a whole, one-half of the emissions originated from ground-level residential and small-scale industrial sources, and 22 percent from medium-size industrial boilers and kilns. The rest was attributed to the large point sources. A major part of the large point source emissions came from only one plant? Zhuzhou smelter, with annual SO_2 emissions of 43,500 tons. Figure 4.3 shows calculated total wet sulfur deposition and SO_2 concentration levels from all the regional sources.

Figure 4.3: Total Wet Sulfur Deposition and SO2 Concentration Levels in the Changsha Tri-City Area (including trans-boundary sources) in 2000



4.28 Because acid deposition is a regional phenomenon, background and transboundary sources play a vital role in calculating excess levels and damages. Results presented in Figure 4.3 also include sulfur deposition caused by sources outside the Hunan province, calculated using the RAINS-Asia model. The transboundary contribution and the critical load for acid deposition for the study region are presented in Figure 4.3. Total wet deposition in the region ranged from 0.5 g-S/m^2/yr for emission sources (mostly background deposition levels) to 5.0 g-S/m^2/yr near the Zhuzhou smelter plant. Similarly, calculated SO_2 concentrations were high around the LPS locations, especially around the Zhuzhou smelter area, with highs of 324 ?g/m^3 (annual average). The figure shows that because of the high emission release point and large amount of emissions, the smelter is also influencing the air quality in the parts of Xiangtan and Changsha counties. Though the levels are not as high as those measured near the smelter, parts of the counties show calculated SO_2 concentration levels well above the ambient standard of 60 ? g/m^3, if not controlled.

Figure 4.4: (a) Total Wet Sulfur Deposition Resulting from Emission Sources outside Hunan Province in 2000; (b) Critical Loads in the Changsha Tri-City Area in 2000



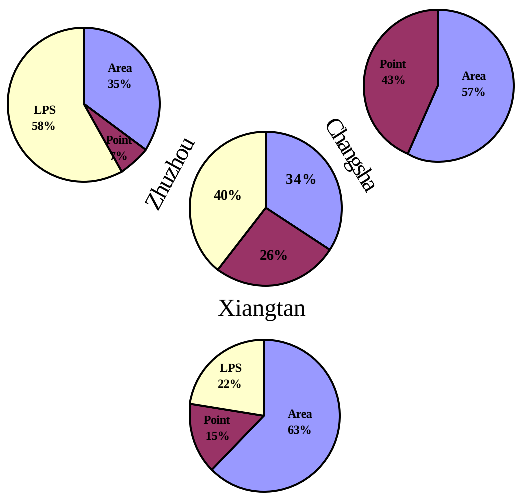
Source: *RAINS Asia, version 8.0*

4.29 Also presented in Figure 4.4 is the average critical load over the Changsha tri-city area, with values of over 1.0 g-S/m^2/yr. It is clear that most of the local area exceeds these values significantly enough to alter the soil characteristics and agricultural production and cause extensive material and structure damage. Not included in this study is analysis of acidification and the eutrification resulting from nitrogen and ammonia emissions.

4.30 Figure 4.5 presents the relative percentage contributions of each of the jurisdictions to total wet sulfur deposition in the region (not including transboundary deposition). Also presented are the contributions from the three main sectors (area, point, and LPS) from each of the cities. A similar distribution for emissions is presented in Figure 4.2.

4.31 The relative contributions are to the total regional deposition and should not be interpreted as city-to-city contributions. Most of the time, the deposition profile follows the emission pattern with the largest contribution in the local area. Of the local emission sources, the single largest contribution comes from the Zhuzhou smelter, and its impact also reaches far south. For convenience, gridded plots of percentage contributions to the region from each city are not presented in this paper. It is clear that the focus of controls needs to be different for each of the city authorities. Zhuzhou, with most of its deposition coming from the smelter, will benefit more from LPS controls. Xiangtan and Changsha, more dominated by the low-level emissions, will benefit the most from the controls of small and medium-size boilers.

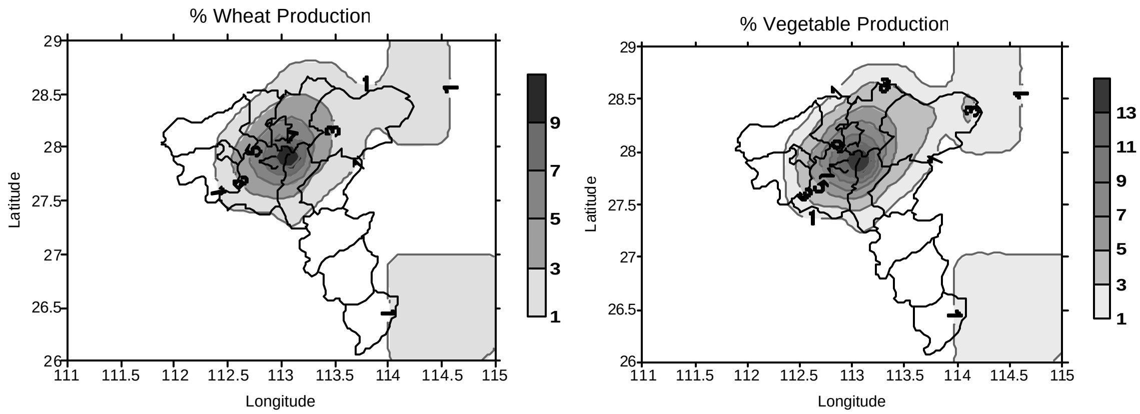
Figure 4.5: The Net Contribution of Emissions from Changsha, Xiangtan, and Zhuzhou and Relative Contributions from Sectors in Each City to Total Regional Wet Sulfur Deposition in 2000



4.32 Gridded agricultural productivity in the Hunan province for the year 2000 is obtained from Hao, 2000, a study that focused on linking decreasing productivity of wheat, soybean, cotton, and vegetables with total sulfur deposition in Hunan province.[35] The agricultural damage analysis is conducted only for the counties under the EPB jurisdictions of Changsha, Xiangtan, and Zhuzhou. Figure 4.6 presents percentage reductions in wheat and vegetable production experienced in 2000; total production of wheat, soybeans, cotton, and vegetables is presented in Table 4.2. Because of similar patterns in cotton and soybeans yield reductions, those figures are not included here for convenience.

[35] There are several possibilities for using a dose response function to calculate agricultural yield reductions vs. deposition levels in excess of critical loads. In this analysis, a simple linear method is utilized for sulfur deposition levels exceeding the critical load in order to avoid the non-linear behavior of the model due to variation in fertilizer use, climatic conditions, and other variables. It is known that the thresholds occur when an ecosystem or an organism has natural repair mechanism that can prevent or counteract damage up to a certain limit. Since, the threshold is not easy to identify, in this project we assume that any gS/m^2 deposited in excess of soil critical loads causes damage to agricultural yield in the region. Acid deposition resulting from the NO_x emissions is not taken into consideration.

Figure 4.6: Percentage Reduction in Wheat and Vegetable Crop Production Resulting from Sulfur Deposition in Excess of Critical Loads in the Tri-City Area in 2000



4.33 Table 4.2 presents the estimated agricultural damage that the cities are experiencing in excess of the critical loads. It is estimated that excess sulfur deposition damages about 2,850 tons of commercial agricultural products (wheat, cotton, and soybean) and about 110,000 tons of vegetable production in the three cities, equivalent to about US$68 million in agricultural damages. The damage assessment presented here is only for the agricultural sector. While difficult to quantify, material and structural damage is prevalent in acid rain areas. Municipal and state jurisdictions bear substantial costs in restoring public areas, including historical sites, parks, schools, public buildings, bridges, and dams.

Table 4.2: Agricultural Effects of Sulfur Deposition above the Critical Levels in CZX Region, 2000

	Total Production (million kilos)	*Reduction in yields (tons)*	*Economic Evaluation*	
			RMB per ton	*$ in total (millions)*
Agricultural yield (tons)				
Wheat	37.0	609	1,500	0.11
Cotton	74.1	1,146	5,100	0.70
Soybeans	55.1	1,107	15,000	1.83
Vegetables	4681.6	109,065	2,500	65.39

Scenario I: Implementation of the 10th Five-Year Plan

4.34 Current economic and social development trends in the tri-city region indicate that there will be an average increase of 13 percent in SO_2 emissions over 2000 levels during the 10th Five-Year Plan. Most of the increase is expected from the power plant expansion in Zhuzhou (2x300MW plant expected to be operational by 2005). A baseline emissions inventory was developed for the year 2005, with total emissions of 226,100 tons of SO_2 in the region. Estimates of SO_2 emission reductions and the associated costs have been obtained from the Changsha, Xiangtan, and Zhuzhou EPBs. The scenario assumes that all projects are implemented fully as planned. Upon implementation of Scenario I actions, a total reduction of 77,600 tons of SO_2 emissions would be achieved by 2005. The net reduction, correcting for new emissions, would be about 51,600 tons, or about a 26 percent reduction from the 2000 baseline. If this materializes, it will be more than what SEPA has required (21 percent reduction).

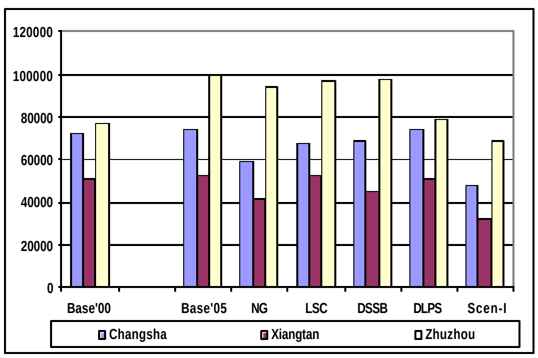
Table 4.3: Main Planned SO_2 Control Activities in CZX Region, 2001-2005

Projects	*Projected SO_2 Reduction (tons/yr)*	*Estimated Investment (million Yuan)*	*Actions*
Supply of low-sulfur coal	8,400	330	1. Construction of coal-processing centers in Changsha and Zhuzhou
Increasing the use of gaseous fuels	31,600	1,635	1. Natural gas supply to Changsha, Xiangtan, and Zhuzhou 2. Distribution of piped mixture of LPG and air in Changsha 3. Fugitive coal gas recovery in Xiangtan
Emission control of coal-fired boilers and kilns	15,000	325	1. Disposing of small coal-fired boilers in Changsha 2. Wet precipitators for medium-size boilers in Changsha 3. Fugitive emissions control in Zhuzhou 4. Boiler smoke control in Xiangtan 5. Centralized steam supply in Changsha and Xiangtan
LPS Desulfurization	22,600	250	1. Apply desulfurization techniques at Zhuzhou power plant and Xiangtan fertilizer plants 2. Introduce TOPSPE method to convert SO_2 to commercial sulfuric acid at Zhuzhou smelter? expected to be operational in 2003

Source: *Hunan Environmental Protection Bureau, 2001*

4.35 Table 4.3 outlines the major sulfur control measures proposed (some already under implementation) by the local authorities for the region's 10th Five-Year Plan. This package of actions is highlighted by the large investment in natural gas supply, which is expected to bring the largest sulfur emission reductions for the region by 2005. Controlling LPS emissions is also high on the agenda. It is clear that the phasing out of locally produced high-sulfur coal will be a gradual process, given the socioeconomic implications of a quick and drastic program. The initial plan is to blend high-sulfur coal with low-sulfur coal, increase the screening and washing of steam coal, and invest in industrial coal briquette facilities. Investment in sulfur emission control for medium-size boilers assumes that high-sulfur coal will be used in those boilers. The trade-off between importing low-sulfur coal and making briquettes or investing emissions control, as well as other options related to the current plan, will be discussed in more detail below.

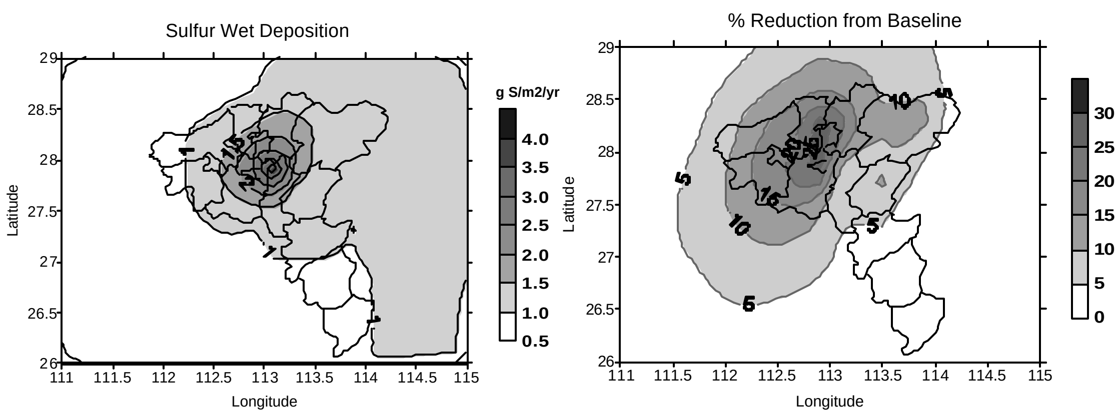
Figure 4.7: Baseline and Scenario I Emission Estimates for Years 2000 and 2005 in the Tri-City Area



4.36 Figure 4.7 presents relative reductions expected for each city by the projects. Compared to the baseline emissions of 2000, Changsha and Xiangtan emissions decrease 34 and 37 percent respectively. Zhuzhou reaches only 10 percent of reduction due to the new power plant expansion due to be operational by 2005.

4.37 The use of natural gas and LPG accounted for a reduction of 14 percent (31.6 ktons) of the 2005 emissions, most of which is concentrated in the populated counties of Xiangtan and Changsha. Of the total area sources, about 28 and 20 percent of reduction in sulfur emissions is expected from the industrial area sources of Changsha and Xiangtan. Figure 4.8 presents the total wet deposition estimated under this scenario and percent reduction in total sulfur deposition upon implementation of scenario I. Given the planned expansions and expected increase in 2005 SO_2 emission levels, no one project will be sufficient to counteract the additional deposition. The new power plant expansion is expected to increase the deposition levels in the region on average by 15 percent over 2000 baseline levels. Note that in Figure 4.8(b) below the plots are different from the 2000 baseline emission calculations, which do not include the new Zhuzhou power plant expansion. Percent reduction without the expansion plant ranged as high as 40 percent instead of the 25 percent shown in the plot. For LPS measures, the maximum reductions of acid deposition were centered around the point sources, with reductions of up to 10 percent of total sulfur deposition from the baseline (figures not presented here).

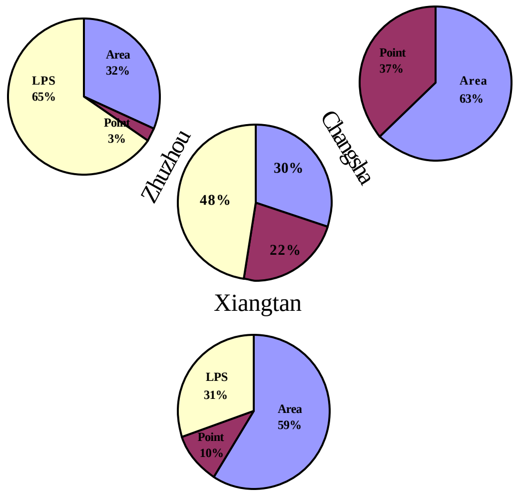
Figure 4.8: (a) : Total Wet Sulfur Deposition (including transboundary sources); (b) Percentage Reduction in Total Sulfur Deposition through Various Projects in the Changsha Tri-city Area under Scenario I



4.38 Similar to the baseline study, the contribution from each of the sectors is simulated to understand the change in relative contributions from each of the sectors and counties to the regional pollution. Stricter controls for low-level sources and the availability of cleaner fuels results in a decrease in the overall contribution from low-level area sources. Because of the power expansion unit in Zhuzhou, their share of deposition levels increased from about 40 percent in the baseline to about 48 percent under Scenario I (Figure 4.9). It is clear that the large point sources? the power sector and smelters and small and medium-size coal-fired boilers and kilns? should remain the focus of sulfur emissions abatement in the future.

4.39 Assuming that agricultural production levels remain the same as in 2000, upon full implementation of all the actions listed under Scenario I, it is estimated that some local regions would exceed the critical load even though total emission reductions would surpass the national “two-control zones” quota. Unlike the baseline, maximum deposition levels are around 2.0 $gS/m^2/yr$, half the levels observed before. Table 4.4 presents the impact assessment of sulfur deposition under this scenario. Agricultural production damage under this scenario decreases from $US68 million to less than $US40 million by 2005.

Figure 4.9: Contribution of Emissions from Changsha, Xiangtan, and Zhuzhou and Relative Contributions from Sectors in Each City to Total Regional Wet Sulfur Deposition in 2005



4.40 A similar analysis is conducted for ambient SO_2 concentrations in the Changsha area. The relative impact of the reductions in SO_2 pollution from implementation of Scenario I is nullified because of the proximity of Changsha to the new power plant expansions in Zhuzhou; there was an increase of 21,000 tons of SO_2 emissions from the new power plant compared to a reduction of 15,000 tons of SO_2 emissions from the Zhuzhou smelter. By 2005, SO_2 ambient concentrations of more than 300 ?g/m^3 are estimated to prevail in the vicinity of the power plant and in the nearby industrial and domestic areas of Changsha and Zhuzhou.

Table 4.4: Agricultural Effects of Sulfur Deposition above the Critical Levels in CZX Region, 2000

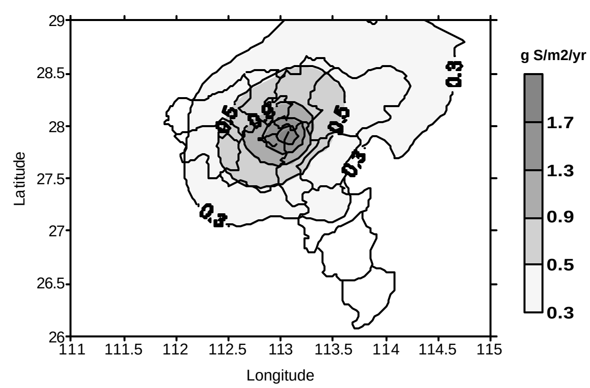
	*Total Production (*1000 tons)*	*Reduction in yields (tons)*	*Economic Evaluation*	
			RMB per ton	*$ in total (millions)*
Agricultural yield (tons)				
Wheat	37.0	316	1,500	0.06
Cotton	74.1	662	5,100	0.40
Soybeans	55.1	551	15,000	1.00
Vegetables	4,681.6	64,333	2,500	38.6

Scenario II: Assessing the Impact of Phasing Out High Sulfur Coal on Critical Load

4.41 Since the current planned action in the CZX region would meet SEPA's SO_2 reduction goals by 2005, the models are used to look specifically at the impact of phasing out high-sulfur coal on regional acid deposition. Under Scenario II, it is assumed that all of the high-sulfur coal still in use after implementation of Scenario I is replaced with low sulfur coal of at most 1 percent sulfur (directly imported, washed, or briquetted local coal). This leads to an additional reduction of 53,000 tons of SO_2 emissions, originating mainly from small-scale industrial boilers.

4.42 The transboundary sulfur deposition originating from outside Hunan Province is assumed (similar to Shijiazhuang) to follow a similar set of programs implemented for curtailing sulfur emissions and pollution inside Hunan Province. A new set of transboundary contribution calculations were performed using the RAINS-Asia model for this scenario. The transboundary contribution is reduced by at least 30 percent over the region for the Scenario II analysis. Figure 4.10 presents total wet sulfur deposition under scenario II with a maximum of 2.3 gS/m^2/year around the smelter. What this shows is that in the year 2005, the transboundary pollution will play a significant role when it comes to local authorities deciding the best policy for controlling pollution. There is therefore a need for a more coordinated effort by the authorities at various regional levels.

Figure 4.10: Total Sulfur Deposition under Scenario II in the Tri-City Area in 2005



4.43 Table 4.5 presents the relative emissions and reductions under each of the options discussed so far and their impacts on ambient sulfur concentrations and depositions in the tri-city area. Under Scenario II, the sulfur deposition levels are expected to fall below the critical loads for most of the tri-city area. This will also reduce the number of grid cells exceeding the critical loads from 77 (0.2º x 0.2º grids, approximately 15 x 15 km^2 grids) to two. These two cells are located close to the smelter and the power plant in Zhuzhou where the emission density is higher.

Table 4.5: Comparison of Agricultural Effects of Sulfur Deposition above the Critical Levels in the Tri-City Area in 2005 under Two Scenarios

	Changsha	*Xiangtan*	*Zhuzhou*	*Total*
Total Emissions (tons)				
Baseline (2000)	72,202	51,170	76,757	200,130
Scenario I (2005)	47,365	32,084	68,825	148,543
Scenario II (2005)	17,890	25,247	40,707	95,622
Emissions Reductions from Baseline (tons)				
Scenario I	24,837	19,086	7,932	51,587 **(26%)**
Scenario II	54,312	25,923	36,050	104,508 **(52%)**
Reduction in Agricultural yield (tons)				
Baseline				111,837
Scenario I				65,862
Scenario II				4,906
Reduction in Productivity (millions $US)				
Baseline				81.20
Scenario I				40.02
Scenario II				2.94
Maximum Sulfur Deposition (gS/m^2) & No. of cells exceeding critical loads				
Baseline				4.4 (77)
Scenario I				3.9 (57)
Scenario II				2.3 (02)
Maximum Ambient Concentration (? g/m^3) & No. of cells exceeding 60 ? g/m^3				
Baseline				500 (11)
Scenario I				336 (07)
Scenario II				268 (06)

4.44 Ambient SO_2 concentrations would be reduced significantly, from highs in the range of 500 ?g/m^3 in the vicinity of the Zhuzhou smelter and power plant to 200 ?g/m^3. Overall, the average SO_2 concentration in the Changsha tri-city area under the Scenario II would be well below the Class 2 standards in 2005. From the baseline scenario, the number of grid cells exceeding the Class 2 standards also reduced from 11 to 6 under Scenario II.

Costs and Benefits of Sulfur Emission Abatement Actions

4.45 The sulfur emission sources in the CZX region can be categorized into four types: (i) residential and commercial sources (coal stoves and small boilers), (ii) industrial boilers and kilns, (iii) power plants, and (iv) industrial fugitive emission sources. The issue for the first three centers around high-sulfur coal and cleaner alternatives or sulfur-fixing or -scrubbing measures, while cleaner production technologies or processes are most relevant to the last one.

4.46 A formal treatment of cost and benefit analysis for sulfur emissions control in the CZX region is hampered by the lack of necessary data and information. This study has tried to assess the cost of alternative abatement options for coal-fired industrial boilers and power plants, two primary sulfur emission sources in the region. Abatement measures for fugitive emissions, which are also a large emission source in the region, are usually specific to the particular production processes and are not analyzed. Since much of the residential and commercial fuel use in CXZ is already from gas, and most of the remaining coal use in the domestic sector is expected to be converted to gas in the next few years, the outlook for sulfur emissions control in the residential and commercial sectors is optimistic. The analysis therefore focuses on coal use in the industrial and power sectors.

Costs of Alternative Emission Abatement Options for Industrial Boilers

4.47 The options that are currently available or proposed for coal-fired boilers include:

- ?? Low-sulfur coal from Shanxi or Henan Provinces
- ?? Blended coal (imported low-sulfur coal plus local coal and sulfur-fixing agents)
- ?? Washed local coal
- ?? Industrial briquettes made from local coal
- ?? Wet precipitators (for boilers using local coal).

4.48 While furnace sorbent injection is often considered a low-cost measure internationally, it is not a familiar technology with local boiler operators or EPBs and there is little information about its application in China. Fluidized bed combustion (FBC) technologies may represent a realistic solution to the local dilemma of using high-sulfur coal, and are reported to have been successfully commercialized for industrial boilers in China. Again, little information is available about its application and economics in relatively small boilers (2 to10 ton-steam/hour) which are popular with local industries.

4.49 About a quarter of the coal supply in Hunan is low-sulfur (less than1 percent), is a mix of imported Shanxi and Henan coal and Hunan coal produced by large state mines,[36] and is consumed primarily by medium-size and large power plants. The rest of the coal supply comes from Hunan provincial mines and township mines, has an average sulfur content in the range of 2–3 percent, and is consumed by small power plants and industrial, residential, and commercial users. This description roughly applies to the CZX region, the center of Hunan's economy. It is obvious that introducing low-sulfur coal needs to start with the nonpower sectors, which use almost exclusively high-sulfur coal.

4.50 For power plants, the average price of low-sulfur coal is about 340 Yuan/ton, compared with about 240 Yuan/ton for high-sulfur coal. The 100 Yuan difference reflects transportation costs as well as a quality premium (mostly higher heating value). The reported prices of high-sulfur coal for nonpower users range from 190~250 Yuan per ton. It would be reasonable to assume that industrial boiler operators would have to pay the additional 100~150 Yuan per ton for low-sulfur coal, compared with local high-sulfur coal. This translates into a cost of about 800 Yuan per ton of SO_2 abated, an estimate obtained using the more reliable power plant data (Table 4.6). The actual abatement cost could vary significantly depending on actual prices, heating value, and sulfur contents of low- and high-sulfur coals involved.

Table 4.6: Cost of SO_2 Emission Reduction Using Imported Low-Sulfur Coal, Hunan

	Local Steam Coal	*Imported Low-Sulfur Coal*
Average price (Yuan/ton)	240	339
Average sulfur content (by weight)	2.0%	0.9%
Average ash content (by weight)	43.7%	27.3%
Average lower heating value (GJ/ton)	21	27
SO2 emissions per ton of coal (kg)	40	18
Abatement cost (Yuan/ton-SO2)		783

Source: *World Bank, 2000*

[36] The Chinese coal mining industry includes three categories of mines:, large key state mines that used to be under the former Ministry of Coal, medium-size state mines that used to be managed by the provincial government, and small mines operated by townships or private entrepreneurs.

4.51 Simply blending low-sulfur coal and high-sulfur coal is not likely to reduce the cost of abatement and might increase it. Price savings for the supplier (from volume buying) and energy savings for the user (because of more consistent coal) may well be offset by the cost of blending and distribution. Whether or not blended coal could become a less costly option than simply switching to low-sulfur coal would depend on the availability of cheap and effective sulfur-fixing materials, such as lime. This, however, is not clear for the CZX region without further investigation. Coal blending, however, does serve the purpose of making use of some locally produced high-sulfur coal while reducing sulfur emissions.

4.52 Washed coal in general is far superior to raw coal in terms of sulfur and ash contents, heating value, and consistency. Washed coal is typically 50 percent more expansive than unwashed coal of similar origin. If much of the local coal is washable using the conventional physical washing method, meaning that much of the sulfur in raw coal is inorganic, coal washing could be a viable alternative to imported high-sulfur coal, at an abatement cost perhaps somewhat higher than that of using imported low-sulfur coal. But using washed coal also reduces particulate emissions and bottom ash disposal, extra benefits that may offset the additional costs. Zhuzhou has a large coking coal-washing facility that was built decades ago and is underused. There is a plan to upgrade the facility and to make it a regional center of cleaner coal products, such as washed steam coal and industrial briquettes.

4.53 Making briquettes onsite could prove to be practical and effective with a central plant, such as a coal-blending facility, supplying premixed coal of consistent quality to nearby boiler houses with onsite briquetting facilities. Current estimates of the production cost of good-quality industrial briquettes is around 1.5 times or more the price of raw coal,[37] making briquettes at least as costly as using imported low-sulfur coal for sulfur emission abatement. Again, promoting briquettes serve the purpose of using local coal.

4.54 Using a wet dust precipitator for sulfur scrubbing is relatively low in cost. Based on Changsha data, the average abatement cost is about 1,000 Yuan/ton-SO_2, comparable to using imported low-sulfur coal in the CZX region. The removal rate of up to 50 percent claimed by local operators is not independently verified and may require a high calcium to sulfur ratio, which could drive up the cost. In addition, proper disposal of the acidic ash slurry needs to be addressed and would increase the cost of abatement. In general, because of its relatively low-sulfur removal rate the wet precipitator scrubbing may be best used as an additional, instead of stand-alone, measure to achieve higher sulfur emission reduction for medium and large boilers that use medium sulfur fuel, say 1.5~2 percent, such as blended coal, washed local coal, or briquettes made from high-sulfur coal.

4.55 In summary, there appear to be no apparent low-cost solutions to sulfur emission control for coal-fired industrial boilers in the CZX region because of the large

[37] Communications with Masaki Takahashi, World Bank staff.

price gap between imported low-sulfur coal and locally produced high-sulfur coal (if the price differential indeed reflects transportation cost and difference in heating value). Interestingly, this also makes options that involve local high-sulfur coal more attractive, such as blending, washing, and briquetting, easing the short-term impact of drastically cutting consumption of local coal. Even though the cleaner fuel options that use local coal could be competitive in terms of abatement costs, compared with imported low-sulfur coal, they may not generate as much net sulfur emission reduction as the latter because of their moderate (30–50 percent) sulfur removal potential. The promise of FBC technology (up to 95 percent sulfur removal) needs further investigation and would be ideal for sulfur emission control for industrial boilers burning low-cost, high-sulfur coal.

Costs of Alternative Emission Abatement Options for Power Plants

4.56 Large power plants in the CZX region already use low-sulfur coal. Older small power plants were designed to, and still do, use medium- to high-sulfur coal produced in Hunan, and could be phased out in the next 5–10 years as new plants come online. For new power plants, the choice of coal determines whether FGD facilities are needed. Current regulation does not require power plants that use low-sulfur coal (1 percent or less) to install FGD equipment. The limit could be tightened in the future as initial emission reductions level off. Recent reductions in the average sulfur content of coal used by Chinese power plants indicate that the power plants themselves have begun to use low-sulfur coal to satisfy national and local sulfur control requirements.

4.57 Besides the usual choice of switching to low-sulfur coal, the handful of other sulfur emission control options for power plants that burn medium- or high-sulfur coal include sorbent injection and various FGD technologies, none of which is currently applied in the CZX region. Demonstration projects elsewhere in China show that effective emission reduction can be achieved at reasonable cost (Table 4.7). Although the abatement cost figures are specific to power plants and the sulfur content of coal, and may not be comparable or applicable to the CZX region, the numbers indicate that sulfur emission control cost in Chinese power plants is not prohibitively high. Depending on the long-term outlook for Hunan's coal market, the local power sector may find it economic to acquire new power plants that burn local coal using either conventional combustion technology with high-efficiency FGD equipment, or CFBC technology, among other clean coal technologies. For the aging small power plants, using low-sulfur coal or furnace sorbent injection technology would be suitable because of their low capital investment requirements.

Table 4.7: Basic Cost Information of Sulfur Emission Abatement in Power Plants (1995 RMB)[38]

	Sorbent Injection[39]	*Spray Dry Scrubber*[40]	*Wet Scrubber*[41]	*CFBC technology*
Capital				
Present value (Yuan/kWe)	212	476	669	
O & M (annual)				
Fixed (Yuan/kWe)	7.4	15.7	17.9	Generally cheaper than previous three as indicated by international experience.
Variable (fen/kWh)	1.2	1.0	0.9	
Average abatement cost (Yuan/ton-SO_2)	702	770	857	

Source: *Wang et al, 2000*

Comparing the Costs and Benefits of Sulfur Emission Reduction

4.58 Based on the model analysis, the planned actions in the 10th Five-Year Plan period would reduce agricultural damage by about 240 million Yuan per year by 2005, if the projected 77,600 tons of annual SO_2 emission reduction are realized. That would imply an average benefit of about 3,000 Yuan per ton SO_2 removed just for the agriculture sector. It is not possible to derive an average abatement cost figure for the planned actions based on available information. However, except for the high cost of the natural gas supply option, most other measures are likely to result in an average abatement cost in the neighborhood of 1,000 Yuan/ton-SO_2, making them attractive strategies based on reduced agricultural damages alone.

4.59 Since this study covers only a short time period, discounting is not applied. In a recent and more elaborative analysis of sulfur abatement costs for Hunan's nonpower sectors, it is concluded that the discounted abatement costs over the span of 1999-2020 for both industrial steam coal washing and industrial briquetting are under 1,000 Yuan/ ton-SO_2.[42]

4.60 Both Changsha and Zhuzhou violate the Class 2 NAAQS for SO_2 by a large margin. The human health benefits, not evaluated in the CZX tri-city case study, of the planned sulfur abatement activities are likely to be much greater than improved

[38] China has been experiencing a general deflation since 1996. The cost figures could be lower in 2000 than in 1995.

[39] Hybrid calcium spray and humidification process at unidentified power plant, 100 MWe plant capacity, 80 percent sulfur removal

[40] Unidentified power plant, 200 MWe plant capacity, 80 percent sulfur removal

[41] c Lime/limestone wet process, Luohuang Power Plant, 2x360 MWe, 95 percent sulfur removal, Chongqing Municipality

[42] Environmental Compliance in the Energy Sector: Methodological Approach and Least Cost Strategies, Shanghai Municipalities and Henan and Hunan Provinces, China, ESMAP, 2001.

agricultural yields assessed here,[43] further enhancing the justification for implementation of the planned activities.

Findings and Conclusions

4.61 While acid rain headlines the air pollution problems in the CZX region, ambient SO_2 pollution and fine particulate pollution are critical issues as well. Because burning high-sulfur coal is the primary cause of these problems, abatement measures would address acid rain and ambient air quality concerns simultaneously. The proposed regional sulfur control strategies for the 10th Five-Year Plan are substantial and address the main emission sources. The strategies also indicate the intention of adopting emission control options that would not drastically cut back consumption of locally produced high-sulfur coal, at least in the near term. The plan, if implemented successfully, would meet SEPA's requirements for the region's sulfur emissions reduction, and would significantly reduce damages caused by acid rain.

4.62 Further reduction of sulfur emissions after the 10th Five-Year Plan would need to focus on area sources, mostly small and medium-size boilers that continue to burn high-sulfur coal, coal-fired power plants, and on the dirty smelters in the region.

4.63 Successful implementation of the plan will require strong policy support for enforcing current regulations, and substantive government support in arranging and or assisting the financing for the key projects, such as natural gas supply, LPS desulfurization, and cleaner coal supply. This combination of push and pull is needed to create demand for emission control and to augment the supply of emissions reduction actions. Since there are many similarities in policy support between the CZX region and Shijiazhuang, the discussions are deferred to the concluding chapter of the study. Here, only two issues of particular interest to the CZX region are highlighted.

1. The long-term sulfur abatement strategy for the industrial sector, especially for industrial boilers

4.64 There appear to be two distinctive strategies that would lead to rather different investment choices (by government or enterprises) with different socioeconomic implications. The implied strategy by the current Five-Year Plan focuses on the phasing out of high-sulfur coal consumption, either by increasing the use of low-sulfur coal from northern China or by substantially reducing the sulfur content of local or Hunan coal by blending, washing, and briquetting, perhaps in combination with additional emission control measures. The policy objective here appears to be developing a market for cleaner coal among industrial coal users and large commercial operators. The obvious advantage of this strategy is that it requires minimum technical adjustments and low up-

[43] Evaluation of the U.S. acid rain control program indicates that expected reductions in mortality and morbidity are the dominant benefits of sulfur emissions reduction from power plants (Burtraw and others, 1997).

front capital investments on the end user side. However, implementation of this strategy may require serious organizing efforts from the government and possibly large public financing, as it would focus on centralizing and streamlining the local coal supply and distribution system.

4.65 An alternative strategy could be the introduction of FBC boilers that burn high-sulfur coal directly but also achieve high-sulfur removal. The policy objective here is to deploy a cleaner coal-burning technology among industrial coal users and large commercial operators. The most appealing aspect of this strategy is that it helps to sustain the local coal industry while keeping sulfur emissions in check. Particulate emission control is highly efficient for FBC boilers with bag filters. FBC boilers also burn coal more efficiently than conventional fixed-bed or chain-grate boilers. However, FBC technology is unfamiliar to local boiler operators and is relatively expensive and sophisticated. Thus, FBC boilers are more likely to be deployed over a long period of time as aging boilers are replaced. Most of the current stock of industrial boilers is likely to turn over in 10 to 15 years, giving a window of opportunity for FBC boilers.[44]

4.66 It is not difficult to see the dichotomy of the two strategies. Large-scale deployment of FBC boilers would make investments in cleaner coal supply unattractive, or vice versa. The socioeconomic and technical merits of either strategy would need further investigation to justify a clear agenda that lends government support for one or the other.

2. The long-term sulfur abatement strategy for the power sector

4.67 The CZX region and Hunan as a whole are projecting large increases in electricity demand, and major power projects are already under construction or preparation. These new power plants, according to the Hunan Province EPB, will be the primary new sulfur emission sources. Hunan is part of the Central China Power Grid that also covers Hubei, Henan, and Jianxi provinces. The Central China Grid will share the future power from the Three Georges Dam (18.2 GW and 84.7 TWh) with two other grids, and perhaps part of the compensation capacity for the dam’s high seasonal variation of power generation. Thus, power planning in the CZX region is closely linked to Hunan Province and the Central China Grid as a whole.[45]

4.68 The CZX region could approach sulfur emission abatement in the power sector from two very different strategies. The current policy implies that the region is inclined toward a build and control strategy, meaning erecting power plants in the region and investing in FGD or importing low-sulfur coal, whichever is sufficient to comply with environmental regulations. The alternative would be to adopt buy and avoid strategy, meaning importing electricity and avoiding construction of new power plants in

[44] The GEF China high-efficiency industrial boiler project has FBC technology components. This project is now completing, and the technologies it help developed are entering the commercialization phase.
[45] The Central China Power Grid is currently interconnected with the East China Power Grid, and additional interconnections with neighboring regional or independent grids are planned.

the region altogether. Unlike the situation in the industrial sector, the CZX area itself perhaps has little influence on power sector development decisions, which tend to be more centralized. It may also be politically appealing to local governments to support construction of new power plants. However, a previous plan for a large coal-fired power plant in Changsha area was canceled in part because of pollution concerns.

4.69 From an environmental point of view, the CZX area may be better served without new additions of coal-fired power plants, since it is already a national hot spot for acid rain damage. Economically speaking, electricity from a new coal-fired power plant in the CXZ area may not be cheaper than buying hydropower from Hubei or thermal power from Henan in the same regional power grid. There are additional human health and agricultural damages, too. A large coal-fired power plant could easily eat into new supplies (or transport capacity) of low -sulfur coal to the region, affecting allocations to the nonpower sector. A careful review of the electric power development plan in the CZX area, and perhaps in Hunan as a whole may be needed, to make it more amenable to the area's overall long-term economic development and sulfur control goals.

5

Conclusions and Recommendations

Main Findings

5.1 The current costs of sulfur pollution in Shijiazhuang and the Changsha-Zhuzhou-Xiangtan tri-city area are high and would largely justify the sulfur abatement actions proposed by local governments. Air quality modeling indicates that the planned sulfur abatement activities in Shijiazhuang would fall short of achieving the ambient pollution compliance required by SEPA, but additional emission reduction that relies on the least-cost option of low-sulfur coal would ensure compliance. The planned activities in the CZX area would be sufficient to meet the 21 percent reduction (from 2000 level) goal set by SEPA. The CZX area would still have large potential for further reduction if low-sulfur coal or processed coal were widely used. But the CZX area needs to keep its power plant emissions in check in the wake of planned expansions.

5.2 Shijiazhuang City and the CZX area represent two typical cases of sulfur pollution control in China. In the relatively arid northern region where Shijiazhuang is located, acid rain is not a significant environmental issue, although sulfur emissions from this region may affect the southern region through atmospheric transportation. Serious ambient SO_2 pollution often occurs in the winter heating season, when sulfur emissions peak and dispersion slows. In the relatively damp south where the CZX tri-cities are located, acid rain is prevalent and in many cities ambient SO_2 pollution is a major concern as well. While coal is the primary fuel source in both regions, the north does have the advantage of producing most of China's best-quality coal. There are large coal-producing provinces in the south, including Hunan, Sichuan, and Guizhou. But they are endowed with mostly medium- to high-sulfur coals. As indicated by the two case studies, these distinctions clearly affect the formulation of sulfur abatement strategies.

5.3 Fuel switching figured prominently in both Shijiazhuang and the CZX area's five-year sulfur abatement plan, accounting for about 89 and 52 percent, respectively, of each location's planned emission reduction between 2001 and 2005. But Shijiazhuang is counting much of that reduction from switching to low-sulfur coal, while the CZX area will rely on switching to natural gas (Table 5.1). The CZX area's abundant supply of high-sulfur coal and remoteness from low-sulfur coal supplies (thus the high cost of using low-sulfur coal) make its fuel-switching efforts more costly compared with the Shijiazhuang case, although the resulting sulfur reductions would be more substantial.

5.4 It is revealing that Shijiazhuang, a second-tier large city in terms of urban population, would be able to achieve compliance with the Class 2 national SO_2 ambient standard by relying largely on switching to low-sulfur coal if its coal consumption can be capped at the 2000 level. This implies that emissions from additional coal consumption in the future will have to be offset by additional emission reduction at sources that already use low-sulfur coal, making a case for wider application of natural gas or emission reduction technologies such as FGD or FBC.

Table 5.1: Fuel Switching Is a Main Strategy for Sulfur Emission Reduction in the Case Cities

	Shijiazhuang City	*CZX Tri-City Area*
Total Planned Sulfur Emission Reduction, 2001-2005	36,000 tons	77,600 tons
Switching to low-sulfur coal or processed coal	19,000	8,400
Switching to natural gas or LPG	13,000	31,600
Other measures	4,000	37,600

Note: *Other measures includes mostly fugitive emission control from one smelter*

5.5 In the CZX area, the technical and financial challenges are more profound because of the lack of a relatively cheap and ready alternative to the native high-sulfur coal and the added social risk of closing local mines if a large amount of low-sulfur coal is imported. The current local government strategy appears to favor limited and slow introduction of low-sulfur coal from northern China and places a high priority on developing coal-processing (blending, washing, and briquetting) capacity so that locally produced high-sulfur coal can still maintain a presence in the wake of sulfur emission control. The challenge, though, is considerable because such a scheme has never been tried on such a scale in China. The cautiousness of the local governments is reflected in its limited planned experiment in the 10th Five-Year Plan period (Table 5.1).

5.6 FBC technologies may be of particular interest to the CZX area if there is a long-term interest in using local medium- to high-sulfur coal. The latest CFBC boilers manufactured in China are believed to be reliable and would be suitable for the CZX area's plan to develop centralized steam plants for industrial clusters. The bubbling FBC boilers, which have had a large number of applications in China, would be suitable for the more popular medium-size industrial steam plants in the CZX region.

5.7 The CZX area is also in the midst of a power development boom, with major coal-fired expansion projects already under construction or on the drawing board.

Using low-sulfur coal or installing FGD equipment will still result in significant new emissions, and easily offset much of the hard-gained reductions from small nonpower emission sources. Since the CZX area is part of the Central China Power Grid that has vast hydropower capacity, including the Three Gorges Dam, as well as mine-mouth power plants in the northern Henan Province, it may have the option of importing electricity instead of generating it in an area that is particularly vulnerable to acid deposition.

5.8 There are few sulfur emission control technologies available for medium-size and large industrial boilers. Both Shijiazhuang and the CZX area consider the wet precipitators (for particulate emission control) their main SO_2 emission control technology for coal-fired boilers. This piggyback technique is popular because it requires little capital investment for boiler houses that already have wet precipitators, which are popular for medium-size boilers. The effectiveness of this extra function for wet precipitators has not been well documented nor rigorously verified, and the variation in operation could be large. Furnace sorbent injection is a relatively simple technology but has rarely been applied.

5.9 While the quality of coals differs greatly between Shijiazhuang and the CZX area, the characteristics of the local retail coal market (mainly for nonpower sector users) are similar in the two localities. Raw coal is supplied by many vendors and nearby small mines to hundreds or thousands of industrial boiler and kiln operators as well as commercial customers such as restaurants, hotels, and heating facilities. Small coal users usually buy whatever they can find cheap. The quality of their coal is often inconsistent. This presents a major challenge to compliance enforcement for the local EPBs, whether it is monitoring and tracking the sulfur content of coal, or sulfur emissions.

5.10 Unlike the retail market, power plants, especially the large ones, usually have long-term supply contracts with large state mines and have specific procedures to assure the quality of coal supply. Compliance monitoring is relatively easy and less time-consuming. It is actually this positive feature of power sector sulfur emission control that has a negative effect on the nonpower sector emission abatement, at least in the near term. The power plants consume the bulk of good-quality steam coal, leaving the collectively larger nonpower sector coal users with inferior coals. The divergence is rather striking in Hunan Province, where the CZX area is located. Medium-size and large power plants use almost exclusively imported or locally produced low-sulfur coal with less than 1 percent average sulfur content, while the nonpower sector uses almost exclusively medium- and high-sulfur coal with a more than 2.5 percent average sulfur content. Power plants should not be blamed for this problem. There is nothing wrong with them using the best-quality coal they consider economic. However, there appears to be a need for policies or regulations to address the retail coal markets for the vast number of nonpower sector coal users.

5.11 Except for mandatory emission standards or quotas, there is rather limited incentive for polluters to abate under the current sulfur regulations. For example, the 200 Yuan/ton-SO_2 fee levied on sulfur emissions implies that for a coal user to consider switching from 3 percent sulfur coal to 1 percent sulfur coal, the price difference of the two cannot exceed 8 Yuan/ton-coal. But in the CZX area, the price of imported low-sulfur coal usually exceeds the price of local high-sulfur coal by 100 Yuan per ton, rendering the emission fee negligible in the compliance cost calculation. And low-sulfur coal is considered one of the least-cost emission abatement measures in the CZX area.

Recommendations

5.12 The basic findings of the case studies indicate that for Shijiazhuang and the CZX area to achieve their compliance goals by 2005 and to bring sulfur pollution fully under control in the longer term, local policies and regulations need to focus on the areas described below.

Promote fuel switching

5.13 The local governments are already strong supporters of fuel switching, especially in bringing natural gas into the local fuel mix. The main weakness in this area is the continuing market failure to recognize the social benefits of trading and using low-sulfur coal in the nonpower sector. This is in large part the result of weak sulfur regulations and lack of enforcement of them. Because of the complex nature of local coal markets, especially in coal-producing regions such as Shijiazhuang and the CZX area, there is no simple solution to this long-standing problem. Since low-sulfur coal is usually among the least costly sulfur abatement options, any effort to strengthen enforcement and regulation should boost its market uptake.

5.14 The outright ban on raw coal use in small facilities, such as tea boilers and small industrial boilers and kilns, is probably the only effective way of dealing with area emission sources, a policy that has been embraced by many large urban centers such as Beijing and Shanghai. With the national interest in promoting natural gas use, local environmental agencies should maximize their influence in advocating major investments in developing urban natural gas infrastructure.

5.15 The CZX region's attempt to centralize the distribution of nonpower sector coal supply is an intuitively appealing solution to dealing with medium-size to large industrial or commercial coal users. It has two main advantages over the current situation of intractable retail coal movements. First, it aggregates demand, augmenting the economy of scale of coal processing, increasing purchasing power for low-sulfur coal, and making long-term contract possible with coal mines. Second, it enables streamlined quality control of delivered coal and thus ensures effective emission control of dispersed coal users. But a proper business model needs to be developed so that such facilities can operate efficiently and profitably.

Support adoption of cost-effective emission control technologies

5.16 Standardizing the instrumentation and operational procedures of wet precipitator technology could help improve the effectiveness of sulfur scrubbing. The government could also support more demonstrations of furnace sorbent injection technology for medium to large industrial boilers as an alternative to the wet precipitator approach. For aging large industrial boilers needing replacement and large steam and heat supply consolidation projects, the use of CFBC boilers should be encouraged or required.

Promote energy efficiency

5.17 Improving energy efficiency could have a significant impact on sulfur emissions control at a very low net cost. Industrial boiler operations and residential and commercial space heating are two major sulfur emission sources in Shijiazhuang and the CZX area. For industrial boilers, a scheme that has been successfully tried in a few other Chinese cities involves energy service companies, which provide energy efficiency improvement services to industrial boiler operators and in return get a share of cost savings resulting from reduced coal consumption.[46] Achieving energy efficiency improvements in space heating is more complicated and would involve simultaneously implementing heat metering and consumption-based billing on the one hand and enforcement of energy-efficient building standards on the other, a process that is just beginning.

Strengthen sulfur pollution regulation and enforcement

5.18 There are currently several regulatory requirements for sulfur control, each not necessarily complementing the other. For example, a large emission source may have an emission quota allocated by the Changsha EPB it may also need to comply with an existing emission standard that has no relationship with the quota, and it may also have to pay for the 200 Yuan/ton-SO_2 emission fee. It is not clear whether the polluter has a choice of which to comply with, or is assigned one. The purpose of sulfur regulations is to give polluters a clear signal regarding what to do in the wake of compliance enforcement. In this regard, the current state of compliance regulation is confusing. Frankly speaking, the current SO_2 emission fee in Shijiazhuang and the CZX area is too low to justify it as an effective compliance enforcement instrument; it should be abandoned if a viable permit system is introduced and strictly enforced. Alternatively, if there is strong political support to raise the emission fee to a level that would induce comparable emission reduction of the permit system, then the permit system would serve little purpose and become redundant.

5.19 Deployment of multiple policy instruments that are not mutually consistent, such as sulfur content limits, equipment specific emission standards, emission

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[46] World Bank and Global Environmental Facility, China Energy Conservation Promotion Project.

fees, and regional emission quotas may be justifiable in the beginning, when little is known about which instruments will work and anything that works even minimally constitutes progress. The long-term regulatory strategy for sulfur control needs to evolve toward using a single transparent policy instrument that can most effectively serve the goal of "total (emission) quantity control," such as an emission permit system that allocates emission rights under a cap and puts the onus on the polluter to figure out what to do to maintain its permit status.

National policy implications

5.20 In addition to their value for local decision-making, the case studies provide useful information to the central government about the TCZ policy and its implementation. The successes of China's sulfur control policy include: (i) introduction of restrictions on the production of high-sulfur coal, (ii) requirements for coal-fired power plants to switch to low-sulfur coals or to install emission control equipment, and (iii) setting of targets for emission reduction. SEPA has also effectively mobilized local environment agencies to plan and prepare for its implementation, where local environment and municipal authorities have been collecting sulfur emission charges and have instituted restrictions on coal-burning devices and in some localities an outright ban on coal burning in densely populated areas.

5.21 Setting simple and clear goals at the national level and letting local governments and line agencies work out the details of implementation has been an effective strategy for sulfur control that reflects the administrative and bureaucratic structure of China's governmental system. The system works well when both the central and local governments are committed to achieving results, which appears to be the case for sulfur control.

5.22 Specific implications for national sulfur control activities and policy based on the findings of the case studies are as described below.

1. SEPA needs to take a long-term look at the targets and goals for sulfur pollution control in China, for example, a 20-year horizon, and assess the needs and efforts accordingly. More specifically, the understanding of the dynamics of long-term sulfur emissions should be given greater support, and the implications in terms of specific hot spots of sulfur impacts for ecosystems, agriculture, and human settlement areas should be a focus of SEPA's work. Regulatory policy should consequently be directed at key polluters and growth sectors and on avoiding the creation of hot spots.
2. SEPA should continue to provide scientific evidence of the impacts of sulfur, specifically from thermal power plants, to mitigate inter-regional transport of emissions that would help the power sector comply with national sulfur regulations at least cost. The power sector is likely to

determine the long-term success of China's sulfur pollution control program because of its projected growth and the general softening in, or reduction of, coal demand in other economic sectors. In terms of other sectors, SEPA should continue to monitor the contribution to sulfur emissions by the transport sector, which has been a rather minor contributor in most Chinese cities.

3. Regulations on small emission sources should be kept simple and straightforward and rely on cross-sector policy support to help reduce clusters of small sources in urban areas. This effort will depend on the development of natural gas transmission lines and local investments in distribution facilities. The provision of gas for scattered coal-fired space heating systems in northern cities is an important option. Large reduction in heating coal consumption can also be obtained with a rapid scale-up of the development of energy-efficient buildings in northern China.

4. There should continue to be a focus on large emission sources and key industries, where moving to a permit system would reduce regulatory uncertainty and likely lead to lower costs of compliance. This will require a substantial increase in institutional and regulatory capacity at the provincial and municipal levels. A permit system is not simply a way of allocating emission quotas, but carries with it a host of regulatory requirements on emissions and compliance as well as consequences for violation. Such a system would pave the way for the future introduction of a tradable permit system.

5. The central government should provide assistance to localities to increase their capacity for carrying out the type of analysis done in Shijiazhuang and Changsha. Capacity building should be focused on developing skills and institutions to: (i) assess and quantify the impacts of sulfur emissions, (ii) evaluate the benefits of control options in terms of reducing ambient concentrations of sulfur and associated impacts, and (iii) assess the cost-effectiveness of control options and look specifically for control options with multiple benefits.

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Annex 1

Training Program - I, June 2000

A1.1 A series of training sessions were conducted at the EPBs of three cities (Beijing, Shijiazhuang, and Changsha) to prepare for the China sulfur control project, followed by a final workshop at the World Bank country office in Beijing. The meetings were successful in raising understanding of the local SO_2 emission problems and the proposed policy responses for the 10^{th} Five-Year Plan (2000-2005), collecting emission data, and the institutional capacity in conducting modeling and analysis of local pollution by the EPB staff in preparing data and interpreting the results

(1) An agreement was reached on a proposal for a visit by group of local experts consisting of at least one person from each of the Chinese partner organizations (SEPA/CRAES, Shijiazhuang EPB, and Changsha EPB) to spend a week or less at the University of Iowa to discuss detailed abatement policy measures and translate them into control strategies in the model. The World Bank and International Institute of Applied Systems Analysis (IIASA) will join the discussion and facilitate model implementation. The meeting can be critical for the success of the project in terms of policy relevance and policy impact.

(2) A one-day workshop was conducted at the World Bank country office, Beijing, attended by the associates of SEPA, CRAES, State Power Economic Research Center (formally known as BERI), Energy Research Institute (ERI) of the State Planning Commission, Chinese Academy of Sciences (CAS), and Qinghua University. At the workshop, discussions involved China's "two control zones" policy and projects in the area of sulfur control, the World Bank's air quality work in Asia, and China's energy consumption and trends. Also, the tools to be used for the case studies in the China sulfur control project were discussed and illustrated with regard to applying cost-benefit analysis to SO_2 control policy assessment.

(3) Growing out of these meetings, it was proposed at the workshop that a network of air quality research institutions in China be established. CRAES will take the lead in setting up the network. A website will be created that will allow readers to download research work and a host of policy tools.

Table A1.1: Training Program I - Workshop Participants

Institution	*Participants*
CAS, Beijing	Yifen Pu
CRAES, Beijing	Xu Jun, Meng Fan, Zhang De-fa, Cao Dong, Chai Fahe, Xue Zhigang, Li Junfeng
ERI, Beijing	Liu Xueyi, Yang Jintian, Hu Runqing
PERC, Beijing	Hu Ming and Peng Ximing
SEPA, Beijing	Zhou Goumei and Li Lei
World Bank	Sarath Guttikunda, Jitendra Shah, Chaoyang Peng

Table A1.2: Training Program I - Participants at Local EPB Meetings

Institution	*Participants*
City EPB, Shijiazhuang	Zheng Xiaoning, Li Yuebin, and Bai Jinjie
Hebei Provincial EPB, Shijiazhuang	Sun Yanmin, Wang Dechun,
EMC, Shijiazhuang	He Jiajian, Zheng Xiaoning, Li Fenglin, and Li Dong
Hunan EPB, Changsha	Ren Ming, and Zeng Shan

Training Program - II, July 2001

A1.2 Training sessions were conducted in the three cities (Beijing, Shijiazhuang, and Changsha) to discuss the progress of the China sulfur control project with the Chinese partners, the environmental agenda under the 10th Five-Year Plan, the data collection process of sulfur emissions for the two case study cities, and the organization of training workshops on integrated air quality modeling.

(1) Three-day workshops were conducted at each of the city EPB's (Shijiazhuang and Changsha) in collecting and analyzing the data on sulfur pollution in the cities. Under the acid rain control zone, the analysis for Changsha City is extended to the greater Changsha area, including the cities of Xiangtan and Zhuzhou.

(2) A one-day workshop was conducted at the World Bank country office in Beijing on "Integrated Assessment of Air Quality – Special Focus on Sulfur Pollution in China." The workshop was attended by members of SEPA; CRAES; State Power Economic Research Center (formally known as BERI; Energy Research Institute (ERI) of the State Planning Commission; Chinese Academy of Sciences (CAS); local authorities from the EPBs of Hebei, Shijiazhuang, Hunan, Changsha, Zhuzhou, and Xiangtan; and faculty and students from Qinghua University, Beijing

University, and the International Institute of Applied Systems Analysis (IIASA), Austria.

(3) At the workshop, the Regional Air Pollution Information and Simulation Model for Asia (version 8.0) was released to the audience by IIASA. The participants were given hands-on training in the application of the model for integrated assessment of air pollution, information on the latest control technology for sulfur and GHG pollution, and regression of cost-effectiveness of various pollution control measures for integrated assessment. Further details on the model can be obtained at http://www.iiasa.ac.at/~rains/asia2.

(4) The workshop also provided an opportunity to the local EPB authorities to present their framework of sulfur pollution control options and preliminary results from the two-city case study.

Table A1.3: Training Program II - Workshop Participants

Institution	*Participants*
IIASA, Austria	Markus Amann, and Janusz Cofala
CAS, Beijing	Yifen Pu
CRAES, Beijing	Xu Jun, Meng Fan, Zhang De-fa, Chai Fahe, Xue Zhigang, and Duan Ning
ERI, Beijing	Liu Xueyi, Yang Jintian, and Hu Runqing
PERC, Beijing	Peng Ximing
SEPA, Beijing	Ms. Zhou Goumei and Ms. Li Lei
World Bank, Washington DC	Sarath Guttikunda, Jitendra Shah, Todd M. Johnson, and Chaoyang Peng
City EPB, Shijiazhuang	Li Yuebin and Li Dong
Hebei Provincial EPB, Shijiazhuang	Wang Dechun,
Hunan EPB, Changsha	Ren Ming, and Zeng Shan

Training Program - III, November 2001

A1.3 A final training workshop was organized at the Centre for Global and Regional Environmental Research (CGRER), University of Iowa, Iowa City. The workshop was attended by the officials from SEPA; CRAES; the local EPBs of Shijiazhuang, Hunan, Changsha, Xiangtan, and Zhuzhou; and representatives of the World Bank. The overall agenda and findings from the workshop are highlighted below.

(1) The city-level environmental programs, and action plans under the 10th Five-Year Plan for Shijiazhuang and Greater Changsha region were

introduced Presentations included detailed discussion of the case studies: baseline and control scenarios and evaluation of modeling results.

(2) Development and evaluation of costs and benefits (health and environmental) of proposed sulfur control projects were discussed, followed by the implications of the case studies on local and national control programs.

(3) Hands-on training was provided on various air pollution dispersion models:ATMOS/UrBAT, Lagrangian puff transport model for sulfur and particulates dispersion modeling on Unix/Linux environments and IAMS, Integrated Assessment Modeling System, to improve understanding of analysis of the various sulfur control scenarios for the two case studies at the respective local EPBs.

(4) An overview of other air quality modeling activities and applications at CGRER was offered for interested parties.

Chinese Delegation to the University of Iowa:

Zhou Goumei (SEPA)
Meng Fan (CRAES)
Xue Zhigang (CRAES)
Duan Ning (CRAES)
He Yi (CRAES)
Li Yuebin (Shijiazhuang EPB)
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Zhang Zaifeng (Hunan EPB)
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Ou Gulin (Zhuzhou EPB)
Peng Junrong (Changsha EPB)