Programs to Control Air Pollution and Acid Rain

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Sulfur dioxide (SO_2) emissions from coal combustion are a primary contributor to acid rain and poor local air quality in China. Besides having adverse effects on human health, acid deposition has been recognized as an environmental threat to China's agricultural productivity. Acidic substances adversely affect aquatic systems, forests, monuments, and regional climates and alter the sensitivity of lakes, forests, soils, and ecosystems. In the long term, acids leach nutrients from the soil and diminish agricultural yields.

These effects are already being felt in the agricultural sector; an estimated 19 percent of the agricultural land in seven provinces (Jiangsu, Zhejiang, Anhui, Fujian, Hunan, Hubei, and Jiangxi) in southern China has been affected by SO_2 and acid rain. The average decrease in crop yield attributable 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, soybeans by 5.7 percent, and cotton by 5.0 percent. In the same seven provinces, 4.2 percent of forests have been affected by acid deposition (Yang et al., 2002).

Other ecosystems are also beginning to suffer. A study of oak and pine trees affected by acid rain in both rural and urban areas of the Democratic Republic of Korea (North Korea) showed significant declines in growth rates since 1970 (Downing et al., 1997).

SO_2 emissions are also known to contribute significantly to fine particulate matter (PM) through formation of sulfate particles. Fine particulate compounds from sulphates and nitrates (formed by oxidation of emissions of sulfur and nitrogen oxides [NO_x], respectively) are often transported in the air over long distances. The health effects of particulates are strongly linked to particle size.

The constituents in small particulates tend to be chemically active. In parts of China, North Korea, and Thailand, sulfates are estimated to contribute significantly to the ambient particulate concentrations (PM_{10} and $PM_{2.5}$) (Guttikunda et al., 2003). The majority of Chinese cities have unhealthy levels of fine particulate concentration.[1]

The health effects of PM have been shown to be correlated with respiratory disease, which presently accounts for 18 percent of all deaths in China. A growing number of epidemiological studies have shown that fine particulates penetrate deep into the human respiratory tract, aggravating asthma, heart and lung disease, and general lung functions (e.g., Akbar and Kojima, 2003). Although ambient air quality has improved, estimates of the health effects of PM pollution in China in 1995 resulting from violations of ambient air-quality 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. The costs associated with these negative health effects were equivalent to more than 4 percent of China's GDP (Downing et al., 1997).

Coal is the principal source of energy and a primary source of air pollution in China, which is both the largest consumer and the 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 (EIA, 2002). With the rapid economic growth in China in the last two decades, coal use has doubled, driven by fast-growing thermal electricity generation, as well as growing demand in the industrial and domestic sectors.

Cities in China are heavily polluted by SO_2 and PM emissions, primarily from the combustion of fossil fuels by both small domestic stoves and large industrial plants, including coal-fired power plants and boilers, ore smelters, oil refineries, etc. Smaller stationary combustion sources, such as space heaters, also contribute to the problem, especially in urban areas during the winter. Besides SO_2 and PM, emissions include NO_x, carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs), and other greenhouse gases (GHGs). GHG concentrations are likely to increase from all sectors as incomes and industrialization increase, further contributing to both local and global environmental concerns.

The growing demand for transportation and the rapid increase in the number of vehicles on the roads have led to an increase in air pollution, including sulfur emissions. However, recent emission inventories published by the State

[1] China does not currently report monitoring data for fine particulate pollution. Of 341 Chinese cities, nearly two-thirds have annual total suspended particle (TSP) concentration levels above the Class 2 national ambient air quality standard (200 micrograms per cubic meter [$\mu g/m^3$]), the maximum level acceptable for residential areas.

Environmental Protection Administration (SEPA) and other environmental organizations in China and abroad suggest that the transportation sector emits more NO_x, VOCs, CO, and CO_2 emissions than sulfur. Approximately 2 percent of the total sulfur emissions in China in 2001 was attributable to transportation, compared to about 86 percent from the industrial and power sectors combined (Streets et al., 2003). However, sulfur emissions from the transportation sector are not insignificant and should be included in future analyses.

One objective of the present study and the associated technical assistance project is to help localities in China address several questions related to the planning and implementation of regulations to control SO_2 emissions and acid rain:

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

REGULATION OF SULFUR DIOXIDE EMISSIONS IN CHINA

SO_2 emissions from coal combustion 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 and much of China's most fertile land areas. By 1996, when China's coal consumption reached historic highs, ambient SO_2 pollution had become 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 ($\mu g/m^3$); the highest concentration was 418 $\mu g/m^3$, compared with the World Health Organization (WHO) guideline value of 50 $\mu g/m^3$.

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. Figure 1 shows the critical loads calculated in the RAINS-ASIA 7.5 model for China at 10 percentile (i.e., about 90 percent of the ecosystem in each grid will have a low risk of being damaged if the acid deposition does not exceed this 10-percentile critical load). A critical load is an estimate of the maximum allowable input of acid deposition that will not adversely affect growth or otherwise damage ecosystems. This report has been prepared for a 10-percentile critical load, but ecosystems in southern China, which are very susceptible to soil acidity, have lower critical loads.

In 1998, China adopted national legislation to limit ambient SO_2 pollution and halt the increase of acid rain. The program became known as the "two control zones (TCZs) plan," because of its geographical coverage of: (1) cities with high ambient levels of SO_2 that are subject to ambient concentration

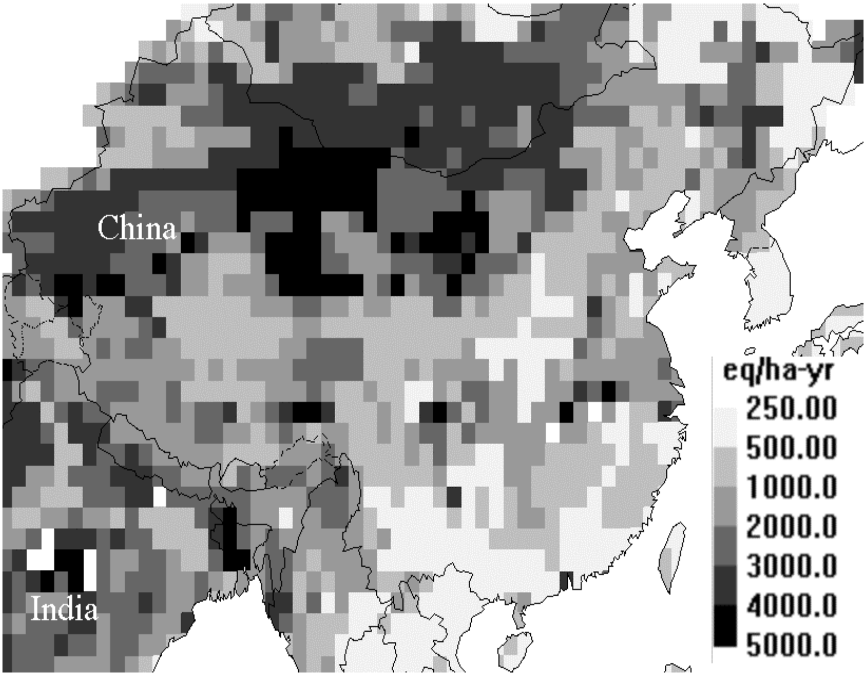

FIGURE 1 Critical loads for acid deposition at 10 percentile, in equivalent hectacres per year (eq/ha-year). Source: Downing et al., 1997.

compliance requirements; and (2) regions with serious acidification problems that are required to reduce the incidence of acid rain through reductions in SO_2 emissions (Figure 2) (Pu et al., 2000; SEPA, 2002).

Targets in the National Tenth Five-Year (2001–2005) Plan for Environmental Protection, included the following stipulations for 2005:

- Annual sulfur emissions in the TCZs must be reduced from their 2000 levels by 20 percent.
- Annual ambient SO_2 concentration levels of 31 noncompliant cities must meet the national standard for residential areas.

With the passage of the TCZ legislation, the Chinese government took an unprecedented step toward controlling sulfur emissions. 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, including Sichuan Province. Backed by studies and expert opinion from leading Chinese universities and research

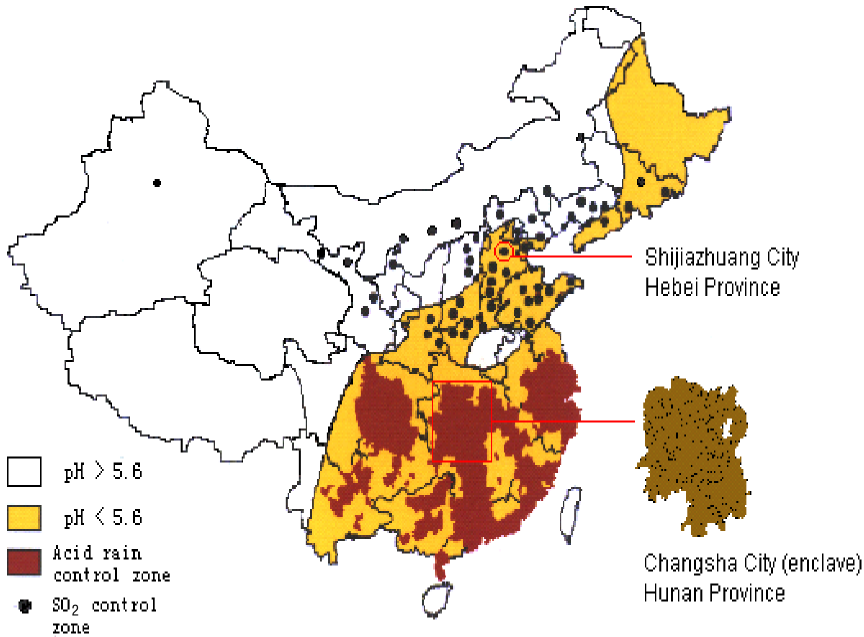

FIGURE 2 Two control zones in China with case study locations. Source: SEPA, 2002.

institutions, SEPA helped win approval of the sulfur-control legislation. At the time, most of the evidence of human health effects and acid rain damage was anecdotal, and there was no systematic assessment of the level or extent of the impact of ambient SO_2 levels and acid rain. Nevertheless, SEPA convinced the government of the importance of controlling SO_2 emissions, using evidence that reportedly included future scenarios of human health impacts and damage from acid rain on manmade structures, forests and other ecosystems, bodies of water, and especially agricultural production. The government was probably also influenced by international concerns about acid rain and China's growing contribution to regional and global SO_2 emissions.

Considering that SO_2 emissions have not been regulated in the past, the TCZ targets will be difficult to meet. China is the first developing country to regulate SO_2 emissions aggressively and on a large scale; the only parallels are sulfur-control legislation and control measures that have been adopted in Europe and North America. The cities and provinces in China affected by the TCZ legislation were required to submit detailed implementation plans to SEPA for controlling SO_2 by January 2003.

NATIONAL GOALS

National long-term goals are concerned mainly with SO_2 pollution generated by burning coal. The widely adopted pollution-control approaches fall into three categories: fuel switching; sulfur removal; and flue gas desulfurization.

Fuel Switching

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 subject to the constraints of local access to low-sulfur fuels. Some Chinese cities have also encouraged the use of electricity for cooking, water heating, and even space heating in recent years. However, if the electricity comes from coal-fired power plants with no controls on SO_2 emissions, this could simply dilute local pollution.

Sulfur Removal during Coal Combustion

Sulfur can be removed during coal combustion (in situ sulfur removal) in industrial and utility boilers by using sorbent-injection techniques or fluidized bed combustion (FBC) technology. The former usually involves injecting dry sorbent (either calcium-based or sodium-based) into the furnace of a boiler. The latter involves firing a suspended fine mixture of coal and sorbent (such as lime). Even though the basic sorbent-injection technique is easy to set up and operate and relatively inexpensive, it is rarely used in China, in part because of a lack of experience with the technology. Non-pressurized FBC boilers are beginning to penetrate the market, especially in the large boiler segment (i.e., 70-ton steam per hour or larger), as domestic manufacturers master the technology.

Flue Gas Desulfurization

Flue gas desulfurization (FGD) is most cost effective in coal-fired power plants. The most widely used FGD technology, wet scrubbers, uses gas/liquid reactions to remove sulfur from flue gas. A cheaper alternative, spray dry scrubbers, is usually used for small utility boilers or older plants. Both technologies have been demonstrated in China and, based on the large proposed investments in the Tenth Five-Year Plan, both appear to be in demand. So far, because of high costs and rigid utility pricing regulations, only a few facilities are operating with FGD technology.

Progress to Date

Many advanced coal utilization technologies, such as integrated gasification and combined cycle (IGCC) power generation, are highly efficient for sulfur removal but are still experimental and costly. Investments in energy efficiency can reduce the demand for coal and associated sulfur emissions, but they must be justified by the economics of energy savings; regulations on sulfur emissions could provide added incentives for such investment. The suitability of control measures at any given locality depends on the availability and cost of low-sulfur fuels, the cost of control technologies, the condition of existing facilities, and local (or even site-specific) emission-control targets.

Control of sulfur pollution became a major regulatory pursuit in China with the TCZ plan, which has prompted many coal-fired power plants to switch to low-sulfur coal. However, few power plants or industrial coal users have adopted specific sulfur-emission control technologies. Broad-based urban residential and commercial fuel-switching programs, which began more than a decade ago, have significantly reduced ambient SO_2 pollution, among other benefits. Thus, fuel switching is the only common measure for mitigating sulfur emissions.

CHALLENGES

Controlling sulfur pollution in China is more difficult than in North America or Europe for several reasons. First, China's economy is largely dependent on coal, and the demand is expected to increase over the next 20 years. Regulating SO_2 emissions will affect far more than coal-fired power plants in China (the electric power sector accounts for less than 50 percent of national coal consumption). About half of the population relies on coal-fired devices for space heating, and more than 400,000 small to medium-sized coal-fired boilers are used in industry and commerce. Controlling emissions from such a large number of dispersed users, especially where there are few available and affordable control measures, will be extremely difficult.

Second, capital for investing in environmental control is scarce in China. For both national and local governments, policy decisions involve not only balancing GDP growth and environmental protection, but also stretching resources to address concerns about air, water, solid waste, and natural resources. Until the mid-1990s, there were few regulatory or financial incentives for industry (including the electric power industry) to invest in sulfur-emissions abatement.

Finally, 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. The development and implementation of a permit system for large emitters of SO_2 are still at an early phase, and the regulation of numerous small coal users, although important, is very difficult. The lack of institutional capacity also limits urban-scale micro-analysis of sulfur-control measures and regulations.

CHINA'S NATIONAL SULFUR-CONTROL PROGRAM

Most localities in China lack the tools and assessment capabilities for determining the relative benefits of emission reductions and, therefore, have typically focused on quantifying reductions in total emissions, without regard to where those emissions originated or where they ended up. Unlike total emissions, however, pollution impacts from SO_2 are closely correlated with the spatial distribution of ambient concentrations and the incidence of acid rain. Thus, it is important to understand the dynamics of concentrations and geographic locations when planning abatement strategies.

Similarly, analyses of the costs of pollution control have typically focused narrowly on up-front capital costs of implementing measures to reduce emissions, without taking into account operating costs or the multiple benefits of some pollution-control measures (e.g., the use of natural gas). A better understanding of the relationship between emissions and impacts—the decrease in the cost of damage rather than the amount of emissions reduced—can also clarify the benefits and costs of emission controls and enable cities and regions to make better decisions about allocating scarce funds for environmental improvement.

This study, funded the by the World Bank Energy Sector Management Assistance Program (ESMAP), analyzes China's national sulfur-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, a northern Chinese city, was chosen for a case study on ambient SO_2 pollution control; the urban region of Changsha, Xiangtan, and Zhuzhou (CXZ) in Hunan Province was chosen to represent a southern area that has high levels of acid rain.

The case studies provide specific local lessons that can inform China's national sulfur-control policy and provide guidance on the effectiveness and consequences of measures for meeting national targets. Follow-up meetings with SEPA will be held to discuss the strengths and weaknesses of the sulfur-control policy in terms of reducing ambient air pollution and reducing acid deposition in areas covered by the TCZ policy.

Shijiazhuang City, Hebei Province

Shijiazhuang city, the capital of Hebei Province, is 275 km southwest of Beijing. The city has a population of about 1.6 million in an area of 254 km^2. Of the 110 km^2 of established (built-up) areas, 27 percent is residential, and 23 percent is industrial. The jurisdictional area of Shijiazhuang Municipality, which is much larger than the city, includes six districts and 17 counties; the municipality borders Shanxi Province and covers an area of 16,000 km^2, 56 percent of which is mountainous. The municipality as a whole has about nine million residents and is largely rural.

The sources of sulfur pollution in Shijiazhuang are largely central heating boilers and large point sources, both inside and outside the city limits. The highest annual average SO_2 concentrations reach 180 μg/m^3, and the health effects alone are equivalent to about 10 percent of local GDP. More than 90 percent of planned reductions in sulfur emissions 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 small industrial boilers (Table 1).

Even if Shijiazhung meets the proposed sulfur-control targets for the Tenth Five-Year Plan, it is likely to fall short of the ambient pollution standards

TABLE 1 Planned SO_2 Control Measures in Shijiazhuang, 2001–2005

Projects	Projected SO_2 Reduction (ktons/yr)	Estimated Investment (million yuan)	Measures
Supply of low-sulfur coal	19	225	1. Limit the sulfur content of coal sold in the city to less than 1 percent. 2. Promote the importation of low-sulfur coal from neighboring Shanxi Province.
Substitution of natural gas for coal	13	513	1. "Gasify" some central heating in the downtown area. 2. Increase the share of gaseous fuel in the fuel mix from the current 3 percent to at least 10 percent.
Small coal-fired boilers and kilns	3	100	1. Dispose of all coal-fired boilers with a capacity of less than 1 ton or require that they use low-sulfur anthracite or gas. 2. Replace 700 small boilers used for winter heating with 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 for thermal power plants.

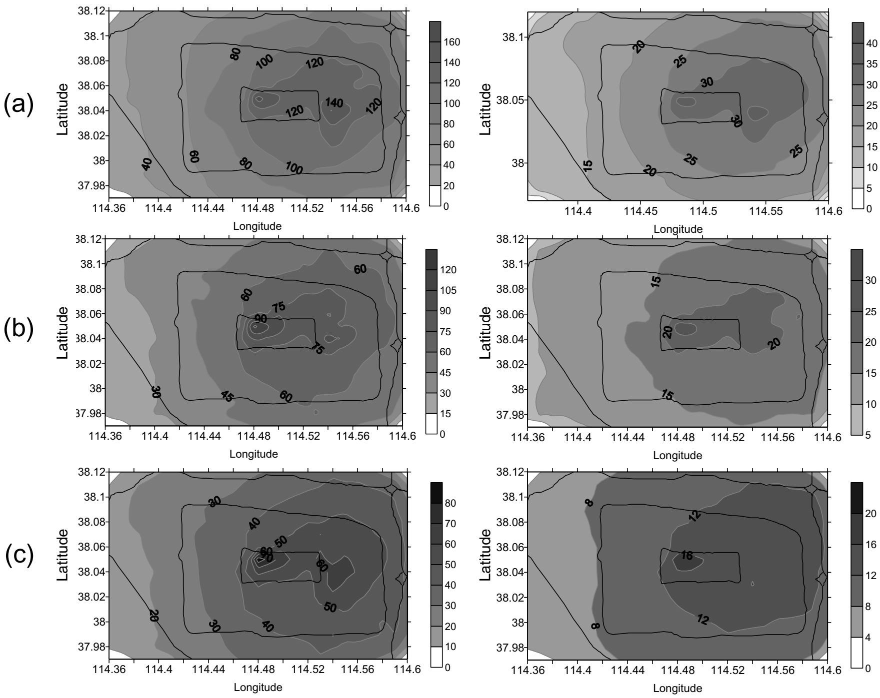

FIGURE 3 SO_2 and SO_4 concentrations (in μg/m^3) in Shijiazhuang in 2000. 2a. Estimated SO_2 and SO_4 concentrations in Shijiazhuang. 2b. The base-case scenario (Scenario I) for 2005. 2c. Scenario II for 2005. Source: Downing et al., 1997.

required by SEPA. Shijiazhuang is an interesting example of both the potential and the constraints of using fuel switching as the main strategy for controlling ambient SO_2 pollution. The low-sulfur coal and natural gas options account for 53 and 36 percent, respectively, of planned reductions between 2001 and 2005. Even though the Tenth Five-Year Plan actions (Scenario I) are not sufficient for Shijiazhuang to achieve full compliance with the Class 2 ambient SO_2 standard, switching to low-sulfur coal at large point sources (Scenario II) would essentially bring Shijiazhuang into full compliance.

Figure 3 shows estimated SO_2 and SO_4 concentrations under baseline and control scenarios.[2] Both scenarios are based on the implicit assumption that coal

[2]More detailed analyses of the scenario emissions and modeling results can be found elsewhere (World Bank, 2003); the scenario analyses are based on other work (Li, 1998a; ECON, 2002).

consumption will not increase, at least between 2001 and 2005. This may be optimistic, unless more of the fuel supply comes from natural gas.

Capping sulfur emissions from space-heating boilers in houses and from power plants in and near the city proper will be essential for continuous compliance in Shijiazhuang. If growing demand for space-heating leads to an increase in coal consumption, further emission reductions at these sources will be necessary. The current strategy of consolidating small coal-fired central-heating systems into large district heating systems would facilitate emission control and compliance monitoring. In addition, most of the consolidation and expansion of space-heating capacity will use combined heat and power facilities, which will make it more economical to invest in large district heating systems in a relatively mild climate (the official heating season lasts four months, from November 15 to March 15, with an average outdoor temperature in the coldest month, January, of –4.6°C to –2.7°C).

Alternatively, if the natural gas supply increases and the price of natural gas becomes more competitive, distributed gas-fired space heating could become a practical option. The economic and financial implications of large district heating systems and distributed gas heating should be compared to provide guidance to the local government in making investments in infrastructure. In addition, the construction of more energy-efficient buildings and the introduction of consumption-based pricing and billing would significantly reduce future demand for heating fuels. This cross-sector policy would clearly help Shijiazhuang control air pollution.

Shijiazhuang should not add new coal-fired power plants in its vicinity. Strict environmental reviews of power projects will be necessary to ensure the consolidation of heating-boiler houses.

Finally, the emission abatement strategy adopted by Shijiazhuang will succeed only with strong policy and regulatory support, especially in the Tenth Five-Year Plan period. Extensive monitoring and enforcement of compliance will be necessary to ensure that low-sulfur coal is used by the many heating and industrial boiler houses, because the local coal market is completely decentralized and coal transactions are difficult to track. This and other regulatory issues are discussed in more detail in the final section of this paper.

Greater Changsha Including Xiangtan and Zhuzhou (CXZ), Hunan Province

This tri-city region is anchored by Changsha, the capital of Hunan Province; Xiangtan and Zhuzhou, two medium-sized industrial cities, are located at the lower points of the triangle. The CXZ region covers an area of about 4,500 km^2 and has the highest density of population in Hunan Province. In 1999, the population reached 12.3 million, about 19 percent of the population of Hunan. In the same year, the GDP of the area reached 108.3 billion yuan with an industrial output value of 58.6 billion yuan, accounting for 32 percent and 41 percent, respectively, of the provincial total.

Sulfur deposition in the greater Changsha region, a hot spot of acid rain in China, is dominated by emissions from large industrial smelters and power plants. SO_2 pollution is also high around the large power plants and smelters, with annual average ambient concentration levels exceeding 300 μg/m^3. Large areas, including rice paddies, fields planted with vegetables, and forests, have been damaged by acid rain. Claims of crop losses by peasants have been settled for millions of yuan.[3]

Planned reductions in sulfur emissions are predicated on a large increase in the use of natural gas and low-sulfur coal for industrial boilers. A significant amount of the reduction would be achieved through industrial renovations and the installation of pollution-control equipment at a single smelter in Zhuzhou (Table 2). Figure 4 shows a comparison of various options for reducing sulfur emissions in the tri-city area.

Figure 5 shows the sulfur wet-deposition option under two scenarios (for 2000 and 2005). Because acid deposition is a regional phenomenon, the results include sulfur deposition caused by sources outside Hunan Province, calculated using the RAINS-ASIA model. 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. SO_2 concentrations were also high around the LPS locations, especially around the Zhuzhou smelter, with highs of 324 μg/m^3 (annual average). More detailed analyses of the scenario emissions and modeling results can be found elsewhere (World Bank, 2003).

The sulfur-control measures proposed in the Tenth Five-Year Plan are in line with emission-reduction targets set by SEPA for the CXZ region. However, even if they are met, the environmental costs of acid rain in the region would remain high. Sulfur-control targets are threatened in the short to medium term by the social and economic constraints of shutting down local coal mines that produce high-sulfur coal and by the planned construction of new coal-fired electricity-generating capacity near the city.

Although acid rain is the major air pollution problem in the CXZ region, ambient SO_2 pollution and fine particulate pollution are also critical issues. Because the primary cause of all of these problems is the burning of high-sulfur coal, abatement measures for acid rain will also address ambient air quality concerns. The proposed strategies for controlling sulfur emissions in the Tenth Five-Year Plan address the major emission sources, but are also formulated not to cause drastic cutbacks in the consumption of locally produced high-sulfur coal, at least in the near term.

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[3]According to local EPB officials, many farmers have sued industries for crop loss in recent years. Local EPBs often act as mediators to resolve these cases by estimating crop losses based on historical harvests (discussion notes during the World Bank Mission, July 2001).

TABLE 2 Major SO_2 Control Measures Planned for the CXZ Region, 2001–2005

Projects	Projected SO_2 Reduction (tons/yr)	Estimated Investment (million yuan)	Measures
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. Increase in natural gas supply to Changsha, Xiangtan, and Zhuzhou. 2. Distribution of piped mixture of LPG and air in Changsha. 3. Recovery of fugitive coal-gas in Xiangtan.
Emission control of coal-fired boilers and kilns	15,000	325	1. Disposal of small coal-fired boilers in Changsha. 2. Introduction of wet precipitators for medium-sized boilers in Changsha. 3. Control of fugitive emissions in Zhuzhou. 4. Control of boiler smoke in Xiangtan. 5. Provision of centralized steam supply in Changsha and Xiangtan.
LPS Desulfurization	22,600	250	1. Application of desulfurization techniques at Zhuzhou power plant and Xiangtan fertilizer plants. 2. Introduction of TOPSOE method to convert SO_2 to commercial sulfuric acid at Zhuzhou smelter—expected to be operational in 2003.[a]

[a] HALDOR TOPSOE, "The Catalyst and Technology Company," specializes in wet gas sulfuric acid (WSA) processes. Source: Downing et al., 1997.

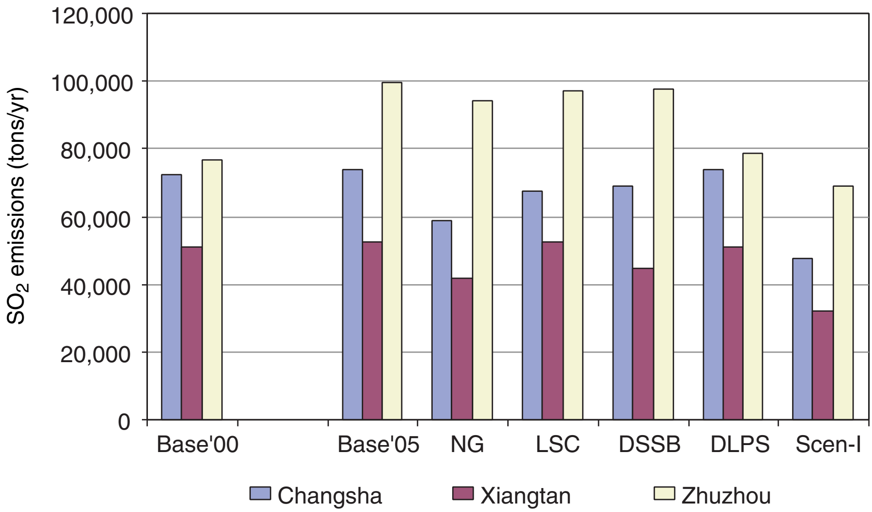

FIGURE 4 Comparison of estimated emissions under the baseline scenario in 2000 (Base '00) and Scenario I in 2005 (Scen-I). Base '05 is the no-controls scenario for 2005. Emissions under scenarios for natural gas (NG), low-sulfur coal (LSC), desulfurization for small-scale boilers (DSSB), and desulfurization for large point sources (DLPS) are also presented.

If implemented successfully, the plan would meet SEPA's requirements for reducing regional sulfur emissions and would significantly reduce damage caused by acid rain. Further reductions of sulfur emissions after the Tenth Five-Year Plan would have to be focused on area sources, mostly small and medium-sized boilers that continue to burn high-sulfur coal, coal-fired power plants, and dirty smelters in the region. Success will depend on strong policy support for enforcing current regulations and substantive government support in arranging for, or assisting in, the financing of key projects, such as increasing the natural gas supply, introducing LPS desulfurization, and ensuring a supply of cleaner coal.

Two issues of particular interest to the CXZ region are highlighted below: (1) the abatement strategy for the industrial sector; and (2) the abatement strategy for the power sector. (Issues that apply to both the CXZ region and Shijiazhuang are discussed in the concluding section of the paper.)

Abatement Strategy for the Industrial Sector

There appear to be two distinct strategies that would lead to different investment decisions and have different socioeconomic implications. The strategy implied in the current Five-Year Plan is focused on phasing out high-sulfur coal

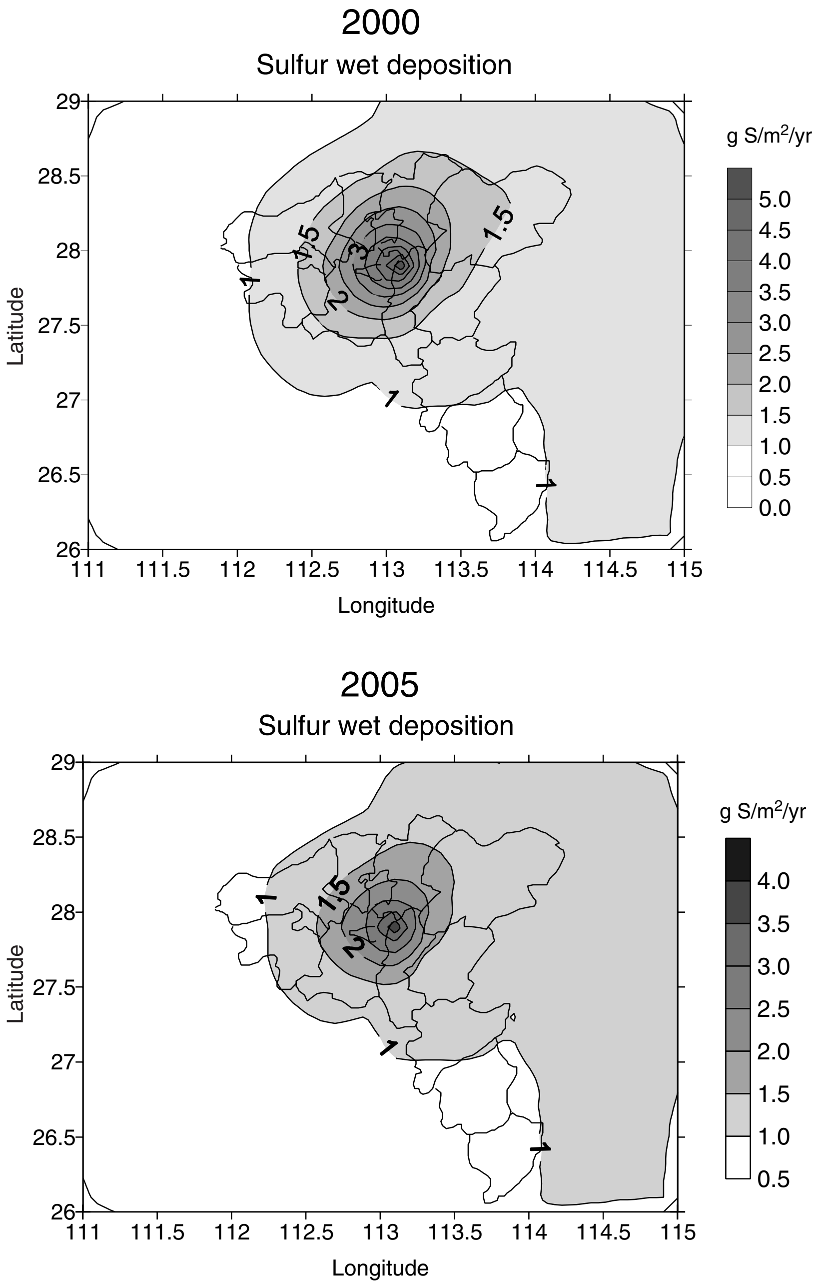

FIGURE 5 Estimates of sulfur wet deposition. 5a. Baseline scenario 2000. 5b. Scenario I 2005. Source: Downing et al., 1997.

consumption, either by increasing the use of low-sulfur coal from northern China or by substantially reducing the sulfur content of local (Hunan) coal by blending, washing, and briquetting, perhaps in combination with additional emission-control measures. The policy objective appears to be the development of a market for cleaner coal among industrial coal users and large commercial operators. The obvious advantage of this strategy is that it requires minimal technical adjustments and low up-front capital investments by end users. However, because this strategy focuses on centralizing and streamlining the local coal supply and distribution system, implementation may require substantial reorganizing by the government and possibly large public financing.

An alternative strategy could be the introduction of FBC boilers that burn high-sulfur coal directly but can also reduce sulfur emissions. FBC boilers burn coal more efficiently than conventional fixed-bed or chain-grate boilers. The policy objective of this strategy 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 would help sustain the local coal industry while keeping sulfur emissions in check. However, FBC technology is unfamiliar to local boiler operators and is relatively expensive and sophisticated. Thus, FBC boilers are 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, providing a window of opportunity for FBC boilers.[4]

The differences between the two strategies are apparent. Large-scale deployment of FBC boilers would make investments in the supply of cleaner coal unattractive, and vice versa. The socioeconomic and technical merits of both strategies require further investigation to justify government support for one or the other.

Abatement Strategy for the Power Sector

In response to large increases in the demand for electricity in the CXZ region and Hunan Province as a whole, major power projects are already under construction or in preparation. According to the Hunan Province Environmental Protection Bureau (EPB), new power plants will be the new sources of sulfur emissions. Hunan is part of the Central China Power Grid that also covers Hubei, Henan, and Jianxi provinces. The Central China Grid will share the 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

[4]The World Bank Global Environment Facility (GEF) China High-Efficiency Industrial Boiler Project has FBC technology components. This project is nearing completion, and the technologies developed are just entering the commercialization phase.

variation of power generation. Thus, planning for the CXZ region is closely linked to planning for Hunan Province and the Central China Grid as a whole.[5]

The current policy implies that the region is inclined to adopt a build-and-control strategy, meaning erecting power plants in the region and investing in FGD or importing low-sulfur coal, whichever is sufficient for the CXZ area to comply with environmental regulations. The alternative would be to adopt a buy-and-avoid strategy, meaning importing electricity and avoiding the construction of new power plants in the region altogether. Unlike the industrial sector, the CXZ area itself may have little influence on decisions related to the power sector, which tend to be centralized. It may also be politically appealing to local governments to support the construction of new power plants. However, a previous plan for a large coal-fired power plant in the Changsha area was canceled in part because of concerns about pollution.

From an environmental point of view, the CXZ area, which is already a national hot spot for acid rain damage, may not be an ideal place for new coal-fired power plants, which would add to human health and agricultural 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, both of which are in the same regional power grid. In addition, 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 non-power sector. A careful review of the electric power development plan in the CXZ area, and perhaps in Hunan as a whole, may be necessary to ensure that it meets the overall long-term economic and sulfur-control goals.

FINDINGS AND LESSONS LEARNED

These case studies and information gathered from other experience with sulfur-emission control in China support the following findings.

Finding 1. There is a clear divide between the northern and southern cities and regions in China in terms of the impact of SO_2 emissions and in terms of potential solutions.

Acid rain is a mostly southern phenomenon; high ambient SO_2 levels are more prevalent in northern cities where winter space heating exacerbates air pollution. The north has access to significant quantities of low-sulfur coal. The south does not, which will significantly increase the cost of controlling sulfur emissions.

[5]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.

Finding 2. Regulating large emission sources requires very different policy instruments and has very different costs from regulating small emission sources.

Large sources with tall stacks contribute most to the long-range transport of sulfur emissions; small sources have even greater sulfur emissions, but they contribute mostly to local ambient concentrations in densely populated areas. Given the economies of scale—both technically and institutionally—regulatory regimes for large emission sources, such as power plants and key specialty industries, can greatly reduce total emissions, long-range transport, and impacts, depending on how close they are 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 includes the widespread provision of cleaner fuels (e.g., natural gas) and the relocation of industry.

Finding 3. A better scientific understanding of the impacts of sulfur emissions and better estimates of the relative benefits of different control options will be very important for planning and implementing local control regimes.

The case studies indicate that local governments are usually able to identify sulfur-control measures to meet the emission-reduction targets of the central government. However, local governments need help in several areas: (1) determining whether control measures would achieve targets for ambient SO_2 concentration levels; (2) analysis of the impacts of sulfur pollution, including acid-rain hot spots; and (3) analysis of the cost effectiveness of control measures.

Finding 4. Promoting policies that have multiple benefits is an effective way of cutting sulfur pollution without relying 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 reduced coal consumption among small-scale users made possible by widespread investments in natural gas and systematic relocations of industries. Thus, changing the fuel mix is part of a larger urban-development strategy that many local governments have embraced in the last decade or so.

LESSONS FOR NATIONAL POLICY

These case studies provide valuable information not only for local decision making, but also for the central government's decisions for the TCZ policy. The successes of China's sulfur-control policy include: (1) the introduction of restrictions on the production of high-sulfur coal; (2) requirements that coal-fired power plants switch to low-sulfur coals or install emission-control equipment; and (3) the setting of targets for reducing emissions. In anticipation of the implementation of pollution controls, SEPA has effectively mobilized local environmental agencies to begin planning and preparations. Local environment and municipal authorities have not only begun collecting sulfur-emission information, but they have also instituted restrictions on coal-burning devices and, in some localities, banned coal burning outright in densely populated areas.

Setting simple, 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.

RECOMMENDATIONS

Recommendation 1. SEPA should undertake a study of the long-term (20-year horizon) targets and goals for controlling sulfur pollution in China and assess the country's needs and efforts accordingly. SEPA should focus on understanding the dynamics of long-term sulfur emissions and the impacts of specific hot spots of sulfur emissions on ecosystems, agriculture, and human settlement areas. Regulatory policy should then be directed toward controlling emissions from key polluters and economic sectors and on avoiding the creation of hot spots.

Recommendation 2. SEPA should continue to provide scientific evidence of the impacts of sulfur, especially from thermal power plants, to reduce the interregional transport of emissions and thereby help the power sector comply with national sulfur regulations in the most economical way. 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 even reduction in, the demand for coal in other economic sectors. SEPA should also continue to monitor sulfur emissions in the transportation sector, a minor contributor in most Chinese cities.

Recommendation 3. Regulations for small emission sources should be kept simple and straightforward and should rely on cross-sector policy support to help eliminate clusters of small sources in urban areas. This will require 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 reductions in coal consumption for heating can also be made through a rapid scale-up in the development of energy-efficient buildings in northern China.

Recommendation 4. The focus on large emission sources and key industries should be continued. A permit system would reduce regulatory uncertainties and would probably reduce the 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 also includes a host of regulatory requirements on emissions and compliance, as well as consequences for violation. Such a system would pave the way for the introduction of a tradable permit system in the future.

Recommendation 5. The central government should provide assistance to localities to enable them to carry out the type of analysis done in Shijiazhuang and Changsha. Capacity building should be focused on the development of skills and institutions to: (1) assess and quantify the impacts of sulfur emissions; (2) evaluate the benefits of control options, including reductions in ambient concentrations of sulfur and associated impacts; and (3) assess the cost effectiveness of control options to determine which options will have multiple benefits.

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