III.
China: CDM Opportunities and Benefits

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Summary
China's handling of its coal reserves will be central to its economic and environmental development over the next few decades. Largely dependent on coal for its present energy needs, coal is the main driver of China's severe air quality problems and is also responsible for high levels of acid rain. Consequently, any climate-motivated reduction in coal use will yield substantial noncarbon benefits in terms of air quality improvements and reduced acid rain. In view of the potential scale of improvement, these benefits tend to overwhelm other potential noncarbon benefits. In itself, this ensures a strong correlation between projects that are best from a global carbon perspective and those that are best from China's development perspective.

This paper also reviews a number of coal-displacing abatement options, including fuel switching, efficiency improvements in the power and industrial sectors, and the wider application of renewable energy sources.

Other areas where a mix of global and local benefits can be achieved include the greater use of digester technologies to treat wastewater discharges and simultaneously provide a source of natural gas. Afforestation projects could also offer a significant mix of carbon, soil protection, and flood-prevention opportunities as well as provide employment in low-income areas.

Introduction
In population terms, China makes up fully a quarter of the developing world. Although its share of developing country economic activity is smaller, China's economy has been growing rapidly, at an annual average rate of 10 percent between 1981 and 1997 (CCCCS, 1999). This rapid economic growth has been accompanied by steady, though smaller, increases in energy consumption. China consumes 1,096 million tons of oil equivalent (Mtoe) of primary energy per year, second only to the United States. (IEA, 1998). However, per capita energy consumption is still low—about a fifth of that of the countries in the Organization for Economic Cooperation and Development (OECD).

China's economic and environmental development hinges largely on the treatment of its coal resources. Coal both fuels China's economic growth and fouls its air. China is the world's largest user of coal—1.4 billion tons (t) in 1997—and relies on coal for up to three quarters of primary energy consumption (WRI, 1998). *(See Figure 3-1).* Coal's high carbon content relative to other fuels means that it accounts for an even greater share, 81 percent, of China's energy-related carbon dioxide (CO_2) emissions (Zhang, 1999).

Coal's contribution to poor air quality is most evident in China's cities. Sulfur dioxide (SO_2) and particulate emissions released in coal combustion are found at extremely high levels in urban areas. *(See Figures 3-2a and 3-2b).* In 1997, concentrations of SO_2 exceeded World Health Organization (WHO) guidelines in a number of China's major cities, and often by twice as much. Particulate concentrations were at least double, and often triple, the WHO guidelines (WRI, 1998). Ambient air quality is usually worse in the North where winters are colder and where dry-wind-sand effects exacerbate energy-derived pollution.[1] The strong link between coal

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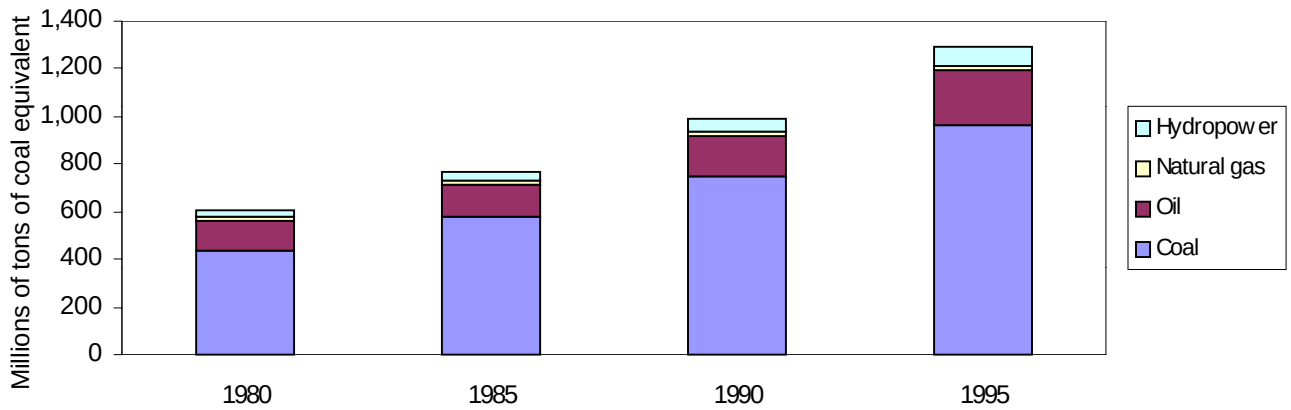
Figure 3-1

Growth of Primary Commercial Energy Consumption in China by Fuel Source



Source: CCCCS (1999).

use and SO_2 and particulate emissions is made clear in a regression analysis conducted for this study. (*See Appendix 3A*). Increasing industrial coal consumption by an extra 1 percent raises SO_2 emissions by 0.88–0.97 percent and particulate emissions by 0.91–0.93 percent.

Poor air quality carries a heavy toll in terms of lost work days, illness and fatalities. The World Bank has estimated that 178,000 premature deaths in urban areas could be avoided each year if China met its Class II air standards—roughly the equivalent of WHO guidelines. Similarly, meeting the standard would prevent 346,000 hospital admissions for respiratory complaints and 6.8 million emergency room visits each year, while restoring 4.5 million person years of employment (World Bank, 1997).

Indoor air pollution is also a major problem. Household stoves used throughout China are either coal- or firewood-based and often used in poorly ventilated areas. Indoor combustion produces nitrogen oxides and carbon monoxide in addition to particulates and SO_2. All contribute to respiratory disease, the leading cause of death in rural areas and the third most important cause in urban areas. Indoor air pollution could be responsible for 111,000 premature deaths a year (World Bank, 1997). Combined, the World Bank study conservatively estimates the total cost of indoor and outdoor pollution at $43 billion per year, equal to 6 percent of China's GDP.[2]

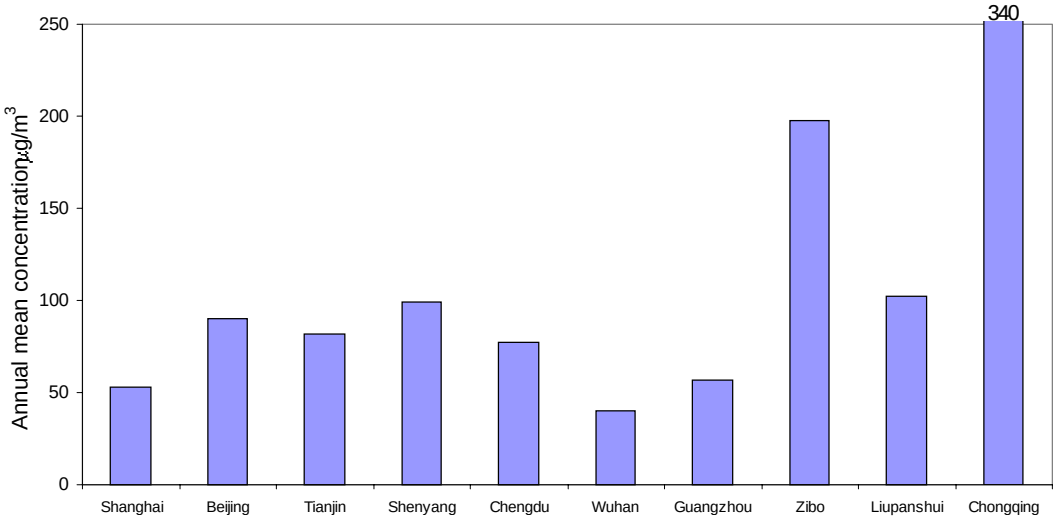
Coal use is also the main driver of acid rain, which damages crops and vegetation and corrodes materials. Though previously concentrated in the South, where high-sulfur coal is burned in large quantities, acid rain now afflicts most parts of Southwestern, Southern, Eastern, and Central China. Several cities in the South such as Changsha, Zunyi, Hangzhou and Yibin have precipitation with annual average pH lower than 4.5 (EBCEY, 1997). More than 23 million tons of SO_2 a year are emitted into the atmosphere, causing acid rain to fall in 40 percent of the nation's territory (*China Daily*, May 4, 1999). More than 11 percent of China, by area, suffers from both acid rain and SO_2 pollution levels deemed problematic by the State Council (*China Environmental News*, Feb 19, 1998).[3]

China's coal-related environmental problems are exacerbated by the low quality of domestic coal, which has 25 percent less heating value, 25 to 50 percent more sulfur, and 50 percent more ash than internationally traded coal.

As poor as conditions are, they would be worse were it not for the beneficial trend in energy inten-

Figure 3-2a

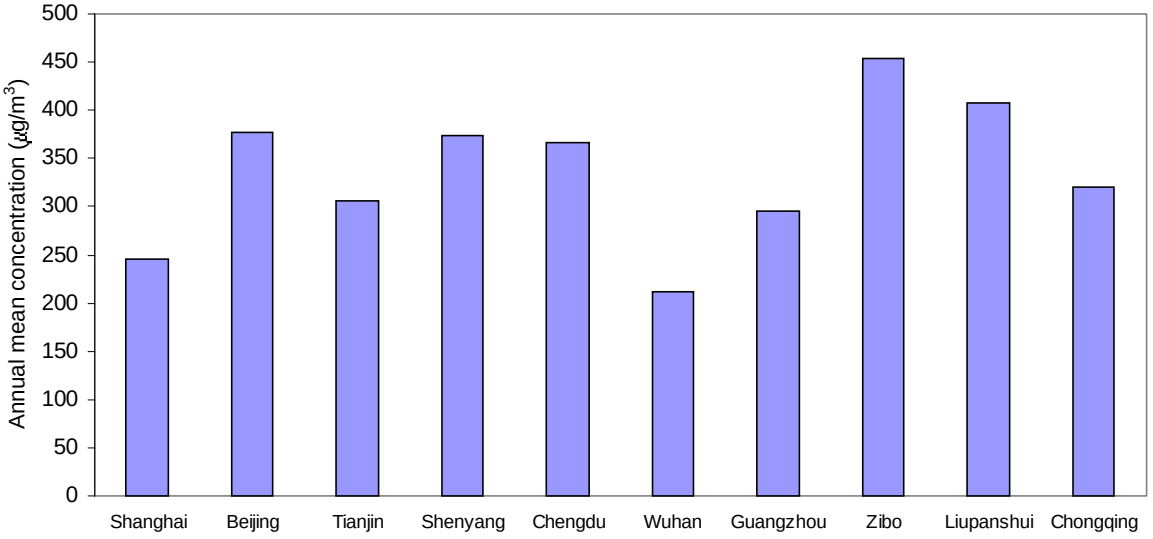
Annual Mean Concentrations of SO_2 in Major Chinese Cities, 1995
WHO Guideline - 50µg/m³



Source: World Resources Institute (1998).

Figure 3-2b

Annual Mean Concentrations of Total Solid Particulates in Major Chinese Cities, 1995, WHO Guideline 90 µg/m³



Source: World Resources Institute (1998).

sity over the last 20 years. Since 1980, China's energy intensity has fallen by nearly a half, a phenomenon unmatched by the other major industrializing economies (Baumert et al., 1999).[4] The reduction in energy intensity is the result of various government initiatives.

General economic reform since the late 1970s has been the foundation for change, allowing greater investment in modern and efficient technologies. The opening of China's economy has provided some of this impetus. One quarter of its GNP now comes from the internationally related economic sectors. Advanced technologies have been transferred through joint ventures and other foreign investments, through bilateral or multilateral cooperation, and through technical assistance programs. For example, technology transfer through the Baoshan Steel and Iron Corporation reduced the energy consumption of steel making in China by 20 percent.

General reform has been supplemented by more specific measures. Since the 1980s, the Chinese government has implemented about 30 laws aimed at energy efficiency, culminating in the Energy Conservation Law that came into force in 1998 (Zhang, 1999). These have created a series of economic and administrative measures to encourage energy conservation. They include special funds for energy conservation as well as favorable lending rates and tax exemptions for appropriate investments (Dadi and Fengqi, 1997).

In addition, energy pricing has been radically altered through the reduction of subsidies. Coal subsidy rates have fallen from 61 percent in 1984 to 29 percent in 1995; petroleum rates from 55 percent in 1990 to 2 percent in 1995 (Reid and Goldemberg, 1997). Energy efficiency has also been improved through project activities such as the development of larger and more efficient coal-fired power plants, which have led to modest improvements in China's average generation efficiency, while shutting down small, low-efficiency, and heavy-polluting power projects.

Without such measures, carbon emissions would have been nearly 50 percent higher today (Zhang, 1999). Urban air pollution and acid rain would also be commensurately worse. Even with these improvements, China's overall energy efficiency remains absolutely low, implying opportunity for further gains. Energy consumption per unit of GNP is more than double those of the European Union and Japan (Baumert et al, 1999).

Looking Forward: Development Objectives

Economic and Energy Growth

In 1996, the National People's Congress (NPC) approved the Ninth Five-Year Plan (1996–2000) and the 2010 Long-Term Goals for National Economic and Social Development, which together frame economic and energy aspirations.[5] The long-term economic goal calls for a doubling of GNP between 2000 and 2010 (NPC, 1996). The plan sets targets for continued growth in energy production to sustain expansion but also sets a goal of reducing energy intensity by a further 20 percent from 1995 to 2000.

Although total energy consumption will undoubtedly grow significantly, projections differ regarding the overall increase that may occur and what this will imply for CO_2 and SO_2 emissions. *(See Table 3-1)*. The high and low projections for total energy consumption in 2020 differ by 25 percent; those for CO_2 emissions, by 35 percent. Differences are attributable to different assumptions about the economic growth rate, changes in industrial structure, elasticity of energy consumption, and population growth—all of which are difficult to forecast.

To address poor environmental quality, China has established environmental goals for 2000 and 2010 under both the Ninth Five-Year Plan and the 2010 Long-Term Goals for Environmental Protection. These include National Ambient Air Quality Standards for cities, setting differential targets for urban areas depending on baseline air quality. Standards are higher for southern cities (which must meet Class II Standard) than for northern ones (Class III).[6] The plan also sets nationwide emissions targets for SO_2, particulate matter, and industrial dust.

The Chinese government has explicitly targeted the control of SO_2 emissions and acid rain pollution for the coming decade. "Double Controlled Zones" (DCZs), that have a high level of both acid rain and SO_2 pollution have been made target areas for

Table 3-1

China's Commercial Energy Consumption and CO_2 and SO_2 Emissions, Business as Usual Projections

	Study project	1990	2000	2010	2020
Energy consumption (Mtce)	UNEP	987	1,498	2,053	2,576
	GEF	987	1,560	2,380	3,300
	ADB[a]	987	1,490	1,962	2,434
	CCCCS	987	1,562	2,235	—
CO_2 emissions (MtC)	UNEP	647	987	1,369	1,635
	GEF	650	1,026	1,512	2,045
	ADB[a]	617	907	1,190	1,354
	CCCCS	560	915	1,320	—
SO_2 emissions (Mt)	UNEP	16	24	31	36
	GEF	16	23	29	33
	ADB[a]	16	27	41	55
	CCCCS	—	—	—	—

Mtce million tons of coal equivalent; UNEP United Nations Environment Programme; GEF Global Environment Facility; ADB Asia Development Bank; CCCCS China Climate Change Country Study
Source: NEPA-ERI-UNEP (1995); CCCCS (1999).
a. The ADB study did not make a forecast for 2010. The 2010 data for the ADB study are estimated by the team for the UNEP project.

policy. *(China Environmental News,* Feb 19, 1998). According to goals approved by the State Council for the DCZs, systems for SO_2 control should be in place, and all industrial SO_2 sources within DCZs should comply with the National Emission Standard for SO_2, by 2000. Moreover, SO_2 emissions will be further controlled to under 2000 levels by 2010 and the national ambient air quality standard is to be met in all cities within the DCZs.

To meet these goals, the State Council requires that the production of high-sulfur coal (more than 3 percent sulfur content) be first limited and then prohibited within a few years. Coal mines producing coal with a higher sulfur content than 1.5 percent must install coal-washing processes; while coal-burning power plants, as well as chemical, metallurgical, cement, and nonferrous metallurgical sectors must implement relatively costly desulfurization processes before 2010 *(China Environmental News,* Feb 19, 1998).

To realize China's environmental goals for 2000, the Trans-Century Green Investment Plan, totaling 450 billion yuan (US$55 billion) for 1996–2000, has been launched by SEPA and approved by the State Council. Nearly half of the planned investment is targeted toward 328 key projects for air pollution control. These projects include installation of flue-gas desulfurization and coal-washing capacity, increase in natural gas supply, implementation of district heating, and enhanced capacity of smoke and dust abatement. All told, this should result in 1.8 million metric tons (Mt) of SO_2 abatement and 1.5 Mt of particulate matter reduction. (NEPA, SPC, and SETC, 1996). These are ambitious goals especially in view of likely capital shortages.

Other Development Issues

Although the impacts of coal dominate China's economic and environmental development concerns, several other issues overlap with potential carbon-abatement efforts.

Water quality is a growing problem in China particularly for the water-scarce northern regions. Fifty percent of urban area river stretches do not meet minimum water quality standards—a disproportionate share of them in the North (SEPA, 1999). Although wastewater from regulated industrial sites has leveled off in recent years, continuing increases from municipal sources and from town and village enterprises (TVEs) have ensured that overall waste

levels have increased, to 47 billion cubic meters (m^3) in 1995, up from 41 billion m^3 in 1989 (EBCEY, 1996). More than 80 percent of waste discharge is not treated at all (CCCCS, 1999).

Governments at both national and local levels are implementing stricter protection measures for industrial waste, including organic waste. An example of this is the creation of the Huai River Basin water pollution control program, prompted by severe conditions in the Huai River. The program sets out stringent standards that have forced some industrial plants to close and others to cut production (CRED, 1996d). In creating a stringent basinwide program, the initiative is considered a model for future efforts in this area.

Forestry is another focal area for environmental protection, especially since the serious floods of 1998, which claimed more than 3,000 lives and caused $20 billion in damage (UNDAC, 1998). A main reason for this disaster was the long-term deforestation in the western upstream areas from which several main river basins, including the Yangtze and Yellow Rivers, emerge. The State Council has promulgated an order to prohibit deforestation and has set a goal of net afforestation. The present Five-Year Plan is aiming for a net afforestation of nearly 10 million ha between 1996 and 2000, which would increase total forest coverage to 15.5 percent of China's land area by 2000. A more ambitious longer term goal envisages forest coverage of up to 30 percent by 2050. In addition, "tree webs"—trees planted among crops to improve soil quality by reducing erosion—are planned for all farms located on the plains.

There are some significant links between rural development and forestry and energy issues. Some targeted programs, intended to accelerate rural development, are priorities under the rural development goals. These programs include plantation of fast-growing firewood forests, diffusion of biomass gas use, tree web plantation on plain farms, and the recently initiated extension of rural electricity grids.

China has also put forward specific goals for poverty alleviation. The Five-Year Plan tackles key poverty issues such as hunger and lack of winter clothing. Because poverty is greater in western and rural regions, development priorities have a regional slant.[7] More resources should end up being channeled into these regions, speeding up their social and economic development and narrowing the income gap between eastern and western regions as well as between urban and rural areas.

Summary

China's plans for the future indicate a desire to couple economic growth with improvements in environmental quality, and especially air. On the energy front, past conservation measures, undertaken for the sake of domestic development, provide evidence of the strong overlap between China's development goals and the global objective of reducing carbon emissions. Coal's central role in energy provision and local and global environmental quality creates a common objective for sustainable development and carbon-abatement programs. Any reduction in coal use will generate commensurate benefits in air quality and acid rain reduction. Away from energy, the Five-Year Plan targets several other issues from rural development to afforestation that offer potential overlap with carbon-abatement projects.

In many respects, ongoing economic reform will continue to bring benefits—most overtly in the improvement of energy efficiency. The opportunity for the CDM is to identify and finance investment opportunities consistent with these trends, thereby helping China accelerate its economic and environmental development.

Options for Carbon Abatement in China

In this section, we review abatement options in the power generation, industrial, and renewable sectors, in addition to looking at afforestation prospects. Much of the quantitative information on abatement options is drawn from a series of recent reviews and reports, often involving collaboration between Chinese experts and international partners. Here, we focus particularly on the potential noncarbon benefits.

Conventional Power Generation

Appropriate development of the power sector will be central to meeting China's economic and environmental aims.[8] The power sector has grown rapidly since the late 1970s with around $115 billion invested between 1979 and 1995 (Zha, 1996). In 1997, installed capacity stood at 230 GW with an annual generation of 1,100 terawatt-hours (TWh). During the Ninth Five-Year Plan, China aims to install 16 GW of further capacity every year to support annual generation growth of 7 percent.

Coal fuels 72 percent of electricity generation, amounting to 430 Mt of raw coal annually, expected to rise to 580 Mt by 2000 (Zha, 1996). Currently, oil and natural gas make only a limited contribution.

China's thermal power plants operate at low efficiency levels—around 30 percent which compares poorly with the efficiency rate of developed countries.[9] Equipment is often of low quality and inefficiently used. In 1995, only 2 percent of turbogenerator units in the power sector were deemed "high quality" by international standards; 50 percent and 40 percent were categorized, respectively, as "ordinary" and "poor". Similarly, only 4 percent of water turbogenerator units met international standards, with 78 percent and 10 percent categorized, respectively, as "ordinary" and "poor" (OTNIC, 1997).

Average efficiency levels are also low because of the preponderance of small-scale units. In 1995, China had only two 900 MW generating units, and seven 600 MW units (Electric Power in the World, 1997). All told, generating units larger than 300 MW account for only 17 percent of total installed capacity, while units of 100 MW or smaller account for 32 percent of capacity (Xing, 1997). Smaller units tend to be less energy-efficient and more environmentally damaging. Average coal use in 200 MW units is 70 to 80 grams/kWh more than that for 300 MW units, while SO_2 emissions from small units are generally 60 to100 percent higher than from larger facilities (Xing, 1997). Even the more efficient, larger units manufactured domestically are less efficient than developed-country units.

Coal dependence and poor efficiency combine to make the power sector a major contributor to airborne pollutant emissions. In 1995, the power sector accounted for 25 percent of particulate and dust releases and 30 percent of SO_2 emissions from the industrial sector. Using less coal more efficiently will yield important dividends in terms of air quality improvements and acid rain reduction.

With large investment in the power sector inevitable in coming years, it is crucial that additional capacity embody new technologies and be efficiently installed and operated. In addition, there are important opportunities to modernize and improve existing capacity. However, capital availability will be important. An estimated 690 billion yuan ($83 billion) will be invested in the power sector during the Ninth Plan (Shi, 1996). The central government is expected to furnish 40 percent of the total; local governments and enterprises, another 40 percent. The government hopes that foreign investors will provide the remaining 20 percent ($17 billion).

Improving Coal Use

China's natural resource structure, and its inability to finance large imports of petroleum and natural gas, means that dependence on coal will continue into the foreseeable future. Coal-fired power plants will account for 60 to 70 percent of the overall installed capacity even as total capacity triples by 2020 (Li Junfeng et al., 1997a). Hence, improving coal use will be key to reducing global and local emissions.

Efficiency can be improved in a number of ways: increasing average unit size, moving toward cogeneration, realizing efficiency improvements in situ, modernizing and updating installed technology, encouraging fuel switching, and enhancing the power dispatch system to make better use of large generators. The dissemination of advanced generation technologies will be important. For China, priority technologies include: supercritical and ultra-supercritical steam parameter units with capacity of 1,000 MW or greater; large fluidized bed combustion (FBC) generating units; large pressurized fluidized bed combustion (PFBC) generating units;

and integrated gasification combined cycle (IGCC) generating technology (CCCCS, 1999).

New investment will center largely on coal-fired generation units with per-set capacity of 300 MW and 600 MW, a reasonable baseline for the abatement assessment. The CO_2 abatement potentials of the main options for thermal power generation are estimated in Table 3-2.[10]

Traditional clean coal technologies such as coal washing, screens, and the use of briquettes, though already commercialized, make only a limited contribution to carbon abatement. In contrast, such high-tech clean coal technologies as IGCC or ICGCC, and fuel cell, have greater potential, offering energy efficiency of 45 to 55 percent— 10 to 20 percentage points higher than traditional coal-fired power systems.

After extensive R&D in developed countries, IGCC is close to being commercially competitive with conventional coal-fired generation. However, weak international demand has inhibited gains from learning by doing. Indeed, in the short and medium term, China may be the only user of this technology. Hence, the real obstacle to the spread of IGCC is the high transition cost for adopting the technology. The estimated capital cost isUS$1,250/kW (Deshun and Wei, 1997). The abatement cost is estimated at $67/tC.

Fuel Switching

Although coal makes up 90 percent of China's proven energy reserves, there is some scope for fuel switching. Full utilization of available natural gas and petroleum resources could increase energy efficiency. In addition, both natural gas and petroleum are cleaner than coal in terms of sulfur and dust/ash intensity. Thus, fuel switching may dramatically reduce local SO_2 and particulate pollution. However, an important obstacle is the lack of a pipeline structure for transfer of gaseous and liquid fuels. This implies that these options are relatively more expensive than in developed countries, where necessary infrastructure is already in place.

China also has an abundance of potential hydropower sites, with an estimated 380 GW of exploitable resources—nearly twice current total generating capacity. Unfortunately, most of them are in the mountainous and remote southwestern region, making transmission to populous northern and eastern areas awkward and expensive. In addition, developing large hydroelectricity sites often engenders widespread ecological damage and population displacement. Thus, in deciding whether to build such dams, the Chinese government and people will have to weigh carefully a complex mix of

Table 3-2

Potential CO_2 Mitigation for Major Options in Thermal Power Generation

Mitigation options	Projection time frame	Estimated capital cost of options (US$)	Estimated CO_2 emissions mitigation (Mt CO_2/yr)
• Replacement and renovation of low- and medium-pressure generator	1994–2010	720 $/kW	8
• Renovation of existing large-scale generator	1994–2010	830 $/kW	6
• New installation of large-scale generator (10 GW/yr)	1994–2010	1,000 $/kW	11
• Increase of cogeneration	1994–2010	850 $/kW	1
• CFBC	2000–2020	–	1
• IGCC	2010–2020	1,250 $/kW	3

Source: Liu Deshun and Z. Wei, 1997.

benefits and damages resulting from their decisions.

Table 3-3 shows a cost comparison for power generation with different fuels. Interestingly, hydropower and natural gas will also offer SO_2 reductions that might otherwise be achieved through desulfurized coal at comparable expense yet without any carbon benefit.

Coal-Bed Methane Recovery

The environmental burden of coal places a premium on tapping other fuel sources. Coal-bed methane—a natural gas with high calorific value—is one such source.[11] An estimated 6 trillion to 13 trillion m^3 of coal-bed methane is available from proven coal reserves (CCCCS, 1999). Moreover, total reserves—including those from unproven sources—may be up to 35 trillion m^3. Careful collection of this energy resource reduces direct greenhouse gas (GHG) emissions, displaces other fossil fuel use, and improves mining safety.

In 1992, China extracted 543 million m^3 of methane from underground mines, of which 400 million m^3 was utilized. At present, use is limited mainly to households in coal mining areas, where users are connected by short-distance pipelines. Some other uses include fuel for: industrial boilers, preheating mine ventilation air, drying thermal coal, producting carbon black and formaldehyde, and pilot gas turbine power stations.

To extend coal-bed methane use, quality will have to be improved and controlled. This can be achieved by reducing air entrapment in the gas stream during production. Other measures include increasing premining drainage and enriching drained gas. Enrichment will allow for extended coverage over long distances through high-pressure natural gas pipelines, requiring a methane concentration over 95 percent. Higher quality methane would also be suitable for use as a raw material in chemical production and as a fuel for vehicles and gas turbines.

Although methane drainage from coal mines has been undertaken as a safety measure for more than 40 years, much remains to do to build up an industrial system capable of exploiting and utilizing methane on a large scale. Both technology transfer and investment are needed. Coal-bed methane could yield carbon reductions for a slight economic gain, equal to 29 yuan/tC, or $3.50/tC, in 1990 prices (JST, 1994).

Extending Biomass Use

Biomass, used by 70 percent of the Chinese people for cooking and heating, is a major fuel for rural households. The annual consumption of biomass comprises 250 Mt of crop stems, and 80 Mt of firewood (CRED, 1996c). Substituting coal for present biomass would release an additional 200 MtC in China.[12]

Table 3-3

Energy Costs Using Different Energy Sources (1990 Yuan)

	Unit	Normal coal	Desulfurized coal	Hydropower	Natural gas
Capacity	MW	600	600	600	600
Investment	Yuan/kW	6,500	8,450	10,000	4,800
Fuel price	Yuan/t	250	250	0	1.3
Fuel consumption	gce/kWh	320	330	0	246
Fuel cost	Yuan/kWh	0.09	0.10	0	0.24
Operating cost	Yuan/kWh	0.07	0.12	0.05	0.05
Levelized cost[a]	Yuan/kWh	0.27	0.37	0.32	0.38
Cost of carbon reduction	$/tC	BASE	—	25	102

a. Levelized cost is calculated on the basis of an annualized cost under specific assumption of discount rate and life-span for a project.

Source: Li Junfeng et al. (1997b).

Unfortunately, biomass is gradually being replaced by coal and other commercial energy resources. Current use of stalks, straw, and fuelwood is inefficient, and as awareness of the efficiency, cleanliness, and reliability of modern fossil fuel-based stoves and appliances spreads, biomass is being passed up. To promote energy-supply diversity and environmental protection, the Chinese government is trying to encourage more biomass use, particularly in the form of gasification projects that maintain the convenience and lower pollution of modern stoves. The present Five-Year Plan contains several provisions in this vein. They include demonstration projects for village-level gasification systems that provide gas for up to 300 households and applications to provide heat and drying energy for Town and Village Enterprises (TVEs). In addition, international technical assistance has been given with biomass gasification and power generation.

Encouraging biomass use also seems sensible, considering the scale and availability of the overall resource. Every year, 220 Mt of straw and stalks are discarded or burned in fields. Moreover, gasifying the biomass would double the energy output of a given stock compared to burning it directly, while also lowering indoor pollution. The large share of quick-growing crop stems relative to firewood means that the negative effects from utilizing biomass fuels on biodiversity, habitats, and soil protection are slight. The balance of the carbon cycle is easy to maintain, as carbon is quickly absorbed in the crop-growing process.

Gasification could be used in domestic and smaller commercial applications such as providing fuel for TVEs, workshops, and handicraft production and in drying and storing agricultural harvests, timber, and wood products. For example, drying grains and other agricultural produce currently depends on sunlight.

A study by China Renewable Energy Development (CRED) evaluated the installation of a gasification timber-drying system at a furniture manufacturer (CRED, 1996c). The system offers advantages over alternative electric and steam-drying processes. By using wood residues from manufacturing, cost savings accrue from the avoidance of fuel costs and disposal costs of waste wood. The abatement cost for this effort is estimated at $30/tC.

Abatement Options in the Industrial Sector

Industry is a major consumer of energy and a significant source of air and water pollution. A combination of measures promises to reduce carbon and other wastes while improving production efficiency.

Efficiency Improvements in Industrial Equipment

A priority area of China's energy conservation initiatives is industrial machinery and equipment, whose energy efficiency is sensitive to standards of design, manufacturing, and application. Despite progress over the last two decades, further improvements are possible. The average efficiency of industrial boilers is about 10 percent lower in China than in more developed countries while electric motors and fans compare even more poorly (JTCIE, 1994). Industrial equipment—boilers, motors, fans and blowers, pumps, and industrial furnaces—consumes more than 80 percent of all industrial energy. Industrial boilers alone consume about one third of national coal output (350 Mt), while industrial motors account for more than 60 percent of total electricity.

Industrial boilers are the main thermal power source in China. They are scattered in both industrial and residential districts, and normally installed without tall chimneys. Their emissions cause serious local air pollution and account for a disproportionately large quantity of fine and ultrafine particles that are particularly damaging to human health (World Bank, 1997). If the efficiency of China's industrial boilers could be raised to developed-country levels, 25 Mt of coal would be saved, mitigating 13 MtC (CCCCS, 1999). We estimate that this would also eliminate more than 400,000 t of SO_2 and 250,000 t of fume emissions.

Electric motors, used in all sectors, consumed about 600 TWh of electricity in 1994. Of that total, motors used for driving fans, blowers, pumps, and

compressors accounted for about half. Seventy percent of these motors work with varying loads and require some form of output regulation. Traditional flow control relies on dampers or valves to alter the flow, resulting in considerable energy waste. Adjusting the motor speed to load variation is more efficient. Adopting adjustable speed motors can save 10 to 25 percent of electricity.

The costs of carbon abatement for general industrial equipment vary case by case. Table 3-4 shows the carbon-abatement potential for industrial boilers, as well as the simultaneous abatement potential of SO_2 and fume emissions. Carbon-abatement costs are modest for prefuel process, operational improvement, and optimizing combustion for industrial boilers. The abatement cost for high-efficiency boilers is higher.

Anaerobic Technology for Wastewater Treatment and Energy Recovery

The industrial application of anaerobic technologies offers a double benefit by simultaneously cleaning water effluents and displacing coal use—a perfect example of possible synergies between different environmental goals.

China has been a leader in the development of anaerobic technologies. In 1994, 5.4 million household digesters produced 1.3 billion m^3 of biogas (CRED, 1996d). Rural areas in particular have benefited from treating animal and human wastes and using the processed water as an irrigation and fertilization source. Applying these technologies to industrial wastewater streams allows for the conversion of up to 90 percent of the organic waste into biogas—a mixture of methane and CO_2. Without the anaerobic treatment, these gases would simply be released into the atmosphere. Using it as a fuel results in a net zero contribution to GHG stocks in the atmosphere because it is derived from renewable resources such as corn, sugar, and animal wastes.

The application of this technology has been

Table 3-4

Abatement Potential of Industrial Boilers

Technologies	Effective date	Prefuel process	Operational improvement	Optimizing combustion	High-efficiency boilers
Market share (percent)	Current	0.03	0.05	0.01	0.00
	2000	0.15	0.15[a]	0.15[a]	0.10[b]
	2010	0.50	0.50[a]	0.50[a]	0.50[b]
Efficiency	Current	0.65	0.65	0.65	0.75
	Expected	0.70	0.75	0.75	0.78
Coal saving (Mt)	2000	4	7	13	2
	2010	21	40	45	12
CO_2 abatement (MtC)	2000	2	3	7	1
	2010	11	21	23	6
SO_2 abatement[c] (1,000 t)	2000	66	109	210	29
	2010	350	667	739	194
Fume abatement[c] (1,000 t)	2000	40	67	129	18
	2010	214	408	452	119
Cost of carbon abatement ($/t)		< 1	<1	<1	10 to 25

a. Percentage share of boilers to which technology could be applied.
b. Percentage share of new boilers only.
c. The reduction potentials of SO_2 and fume emissions are calculated on the basis of corresponding coefficients derived from a regression analysis on the linkage between coal use and emissions of airborne pollutants. *(See Appendix 3A.)*

formally assessed for the distillery wastewater at the Jixian Alcohol Plant. The alcohol distillery business is just one of several affected industries. Less than 10 percent of processing plants have wastewater treatment facilities in place, while 20 percent of distillers face being forced out of business unless they comply with regulatory deadlines (CRED, 1996d). In this case, the technology would treat 150,000 t/yr of organic wastewater, avoiding RMB220,000 of fines. The digester would generate 3 Mm^3 of biogas, replace 3,600 t of coal, and reduce local air and water emissions.

The technology could be widely extended. Installing anaerobic digesters in the 90 percent of alcohol plants without treatment processes could generate over 900 Mm^3 of biogas a year, reducing total CO_2 emissions by 1.5 million tC. The technology could also be extended to pulp and paper, sugar processing, pharmaceuticals, and food industries, which all produce wastewater and have substantial energy needs that biogas could help meet.

Renewable Technologies

Several renewable options are available, including wind, solar, and geothermal power. Although some of these options are not yet commercially competitive, the current rate of technological improvement and the recognition of their potential benefits for rural or remote-area electrification and for climate issues may soon make their widespread use viable. China is already experimenting with these technologies.

Wind-Powered Electricity Generation

By 1997, China had about 170 MW of wind power capacity (Junfeng and Zhu, 1998).[13] However, this constitutes less than one tenth of 1 percent of total installed power capacity.

China's exploitable wind power potential is estimated at 250 GW. If even 40 percent of this potential could be harnessed, annual wind generation would reach about 300 TWh, a third of China's current total power generation. If this new wind power displaced coal use, the total CO_2 reduction would be about 100 MtC; the SO_2 reduction around 2 Mt.

Currently, wind power costs twice as much to install as normal coal-fired power, based on imported equipment purchased at international market prices. If wind equipment could be manufactured domestically, however, the installation cost of turbines might be reduced by 30 percent or more, lowering the total cost of generation and making wind competitive with alternatives (Junfeng et al., 1997a; NREL et al., 1997). If these manufacturing technologies can be transferred to China, wind-powered generation could be adopted more widely. According to a joint study, the net cost of carbon abatement with wind-powered generation is around 114 yuan/tC ($15/tC at 1990 prices) (JST, 1994). In view of the limitations of constructing conventional capacity in remote areas or transmitting electricity over long distances, wind energy may be important for electrifying remote rural areas where minority and poorer groups live.

Solar Energy

Two thirds of China's land area is suitable for solar energy applications, either solar thermal applications or solar photovoltaic (PV) generation.

Main solar thermal technologies include solar water heaters, passive solar houses, solar dryers, and solar cookers, all mass produced. By the end of 1997, there were about 5 Mm^2 of solar water heaters in China Now China has 500 domestic manufacturers, with a combined annual production of 1.5 Mm^2. Manufacturers and users alike are concentrated in northern and northeastern China. The Ninth Five-Year Plan and the 2010 Solar Water Heater Development Strategy envisage a total of 43 Mm^2 of water heaters in use by 2010. A typical solar water heater reduces household energy consumption by 100–150 kilograms of coal equivalent (kgce) of energy per year.

Solar water heaters can be put to both household use and smaller commercial or institutional uses such as hotels and colleges. Estimates for the latter show that solar water heaters can abate carbon for about $6/t (CRED, 1996a). Although most currently installed heaters are in urban areas, the long-term market potential is in rural areas where 80 percent of the population live and where commercial energy use, without grid access, is not viable.

The use of solar PV for generation is at a more nascent stage. Efficiency of Chinese cells is significantly below developed country levels and costs remain high. Application of solar PV technologies has been limited to some rural electrification in remote areas. By the end of 1997, about 6 MW of solar PV systems were installed in China. Recently, the Global Environment Facility (GEF) approved a market-based 10 MW solar PV installation project involving 200,000 households. The net cost of reducing GHG emissions with solar PV may reach 486 yuan/tC ($60/tC) (JST, 1994).

Geothermal Power

The demand for space heating and hot water will increase as the economy grows and the standard of living rises. Low- and medium-temperature geothermal resources can be used to provide heat and hot water for either household or commercial uses. Geothermal energy is also used in various industrial applications including heating, drying, and boiler feed-water preheating. Higher temperature geothermal resources can be harnessed for electricity generation.

In certain areas, geothermal energy has already made inroads into the provision of space heat and hot water. In 1995, Tianjin city had 2.3 Mm^2 of geothermal heated space, displacing 80,000 t of coal. Across China, the total use of geothermal power in 1995 displaced 5 Mt of coal. By 2010, this could be as much as 13Mt. Increasing the availability of this energy source is consistent with the Chinese government's aim of providing renewable alternatives and reducing urban air pollution.

Economic feasibility estimates were derived from a prospective site in the Tianjin Technological and Scientific Park, which would draw heat and hot water from Wanglanzhuang geothermal field (CRED, 1996b). The estimated abatement cost is $14/tC. If Tianjin expands its geothermal capacity to 5.7 Mm^2 as planned, 200,000 t of coal would be displaced, saving 147,000 tC, 6,000 t SO_2, and 6,300 t of particulates.

Afforestation

China has approximately 130 Mha of forest, covering 14 percent of its total land area, mainly in the northeast, southwest, and south.[14] Currently, China exhibits slight net afforestation, sequestering 86 MtC per year (about 15 percent of energy emissions) (CCCCS, 1999).

Past afforestation efforts have been relatively unsuccessful owing to poor land quality, poor forest management, and technical problems associated with land siting, species selection, and seed supply. However, since 1998, the Chinese government has aimed to reverse current deforestation trends and achieve net afforestation. The Chinese government has set an ambitious long-term target of reaching 28 to 30 percent forest coverage by 2050. This, more than doubling current forest cover, would enable sequestration of a total of 560 MtC/yr—more than half of China's current emissions. These efforts have been lent urgency by the serious flooding in the Yangtze and Songhua river basins in 1998, which was partly the consequence of long-term deforestation in these watersheds. As a result, afforestation efforts will focus on this region.

Afforestation promises not only to increase greenhouse gas sinks but could also lead to water and soil conservation, biodiversity protection, and poverty alleviation—by creating more afforestation employment opportunities in underdeveloped western regions.

Afforestation efforts in China could abate potentially vast quantities of carbon for little or no net cost. One study assesses the sequestration potential of alternative afforestation projects including plantations, managed forests, and agroforestry efforts (Xu, 1995). Crucially, large-scale afforestation efforts could be undertaken on government lands for which no purchase price would be required. The Chinese State Forestry Administration is estimated to have more land available for future afforestation efforts than is now under forest cover, and additional land under the control of the Ministry of Agriculture could be used for agroforestry projects.

According to the study, afforestation of 120 Mha—roughly equal to the long-term goal—could be attained by a mix of afforestation and agroforestry projects that would yield overall net savings through the sustainable use of timber. However, such an effort would require up-front investment of nearly $12 billion (Xu, 1995). The study also shows that using all the land available for afforestation—some 200 Mha—for perpetual rotations would lead to a *cumulative* carbon sequestration of 9.7 billion t—15 times more than the carbon released from energy in 1990. The total cost for establishing the necessary projects is estimated at US$19.3 billion. Even on a much reduced scale, carbon sequestration in China offers substantial opportunity.

Conclusions

A great many projects that could be undertaken in China are consistent with both global and local development concerns. Energy-based projects have been the main focus here, in light of coal's role in meeting China's economic aspirations and its contribution to key environmental problems.

Even without the CDM, China's overall energy efficiency is expected to improve from ongoing reforms and restructuring, to the benefit of China's economic development and the global climate alike. Structural adjustment will not only bring high value-added products and introduce new technologies of high-efficiency and low-energy-consumption processes but also facilitate economies of scale, production organization, and management, all resulting in direct and indirect energy conservation. Bilateral and multilateral international assistance will remain important and could be made more effective through related policy reform in China. Central to progress will be technology transfer to facilitate efficiency improvements and to enable implementation of renewable energy and clean coal technologies. Removing present barriers to technology transfer is of obvious importance.

The CDM could extend these gains. The marginal costs of the mitigation options reviewed here vary. *(See Table 3-5.)* Many options entail mutual benefits for both the global and local environment as well as the local economy. Most significantly, any option that reduces coal use from the baseline will yield important benefits in terms of SO_2 and particulate reductions and so improve air quality and reduce acid rain. Most assessments flag these two issues as the major environmental problems confronting China today, ensuring that coal reduction reaps a double environmental dividend. Although the location of reductions is not important from a carbon perspective, the local and regional benefits of reduced coal use could be maximized by tailoring reductions so as to achieve the greatest benefit for densely populated or badly afflicted areas. From this perspective, enhancement of local environmental quality will have be weighted heavily in project evaluation within China.

In addition to their immediate energy benefits, projects offer benefits ranging from improved industrial competitiveness, rural electrification, wastewater treatment, mining safety, soil retention, and flood prevention. The digester technology that could be applied to wastewater discharges is a perfect example of a technology capable of meeting diverse environmental goals. Similarly, afforestation provides another important overlap area—increasing GHG sink, enhancing local water and soil conservation, facilitating biodiversity protection, and creating more jobs for rural employment and poverty alleviation.

Three of the areas reviewed include options that have negative incremental costs, implying economic as well as environmental gains (See Table 3-5). These options have been evaluated in financial and technical terms case by case. In practice, several key barriers may impede realization of projects, even if they are profitable. Barriers include a lack of capital for initial investments in R&D and transfer of technologies; a lack of training for qualified and adequate human resources; weak institutional capacity for technology transfer and diffusion; and environmentally insensitive institutional procedures that reward low capital costs over low life-cycle costs. Capital constraints are the most problematic. Even for options with negative and small costs, a shortage of initial capital may inhibit investment. It is in addressing this failure that the CDM could be invaluable for transforming China's development.

Table 3-5

Summary of Potential Abatement Options in China

Projects	Carbon-abatement costs ($/tC)	Environmental and development benefits[a]
Conventional Power Generation		
Fuel switching	25 to 100	Will provide lower cost alternatives to desulfurization of coal use.
Clean coal technologies	67	Will increase energy efficiency in generation.
Coal-bed methane	–4	Is consistent with ensuring mine safety and represents collection of a free untapped resource.
Biomass gasification	30	Reduces indoor air pollution where it displaces direct burning of stalks and stems. Gasification doubles energy efficiency of a given stock of biomass.
Industrial Sector		
Anaerobic wastewater treatment and gasification	11	Reduces industrial wastewater discharge, improving water quality and eliminating penalty payments.
Equipment efficiency	<1 to 25	Will raise competitiveness of industrial production.
Renewables		
Wind power	15	Will facilitate electrification of off-grid rural and remote areas and may lead to development of a domestic wind power industry.
Solar power Solar thermal applications Solar PV	 6 60	Will facilitate electrification of off-grid rural and remote areas and development of a domestic industry.
Geothermal	14	Harnesses a free untapped resource.
Afforestation		
Afforestation	–13 to 2	Will improve flood control and reduce soil run-off; may create employment opportunities in poorer Western regions.

[a] Excluding the displacement of coal and the consequent reduction of air pollutants and acid rain.

Notes

1. "Dry-wind-sand" refers to soil particulates in the air that stem from the desertification and soil erosion in Northern China. In winter and spring, when conditions are dry and windy, sand and soil are transported by winds toward northern cities, directly increasing particulate levels.

2. These estimates are based on willingness to pay valuations. See World Bank (1997) for details.

3. These "Double Controlled Zones" are defined by the former National Environmental Protection Agency (NEPA, now State Environmental Protection Agency, SEPA) on the basis of high levels of both acid rain and SO_2.

4. The income elasticity of energy consumption was only 0.4 from 1986 to 1994, compared to an average of 1.66 for all other low-income countries (Zhang, 1999).

5. Starting in 1953 (and excluding 1963–65), the Chinese government has designed and implemented nine Five-Year Plans. Previously, under a centrally planned economy, the Five-Year Plan played a central role in macroeconomic management, directly controlling financial and material resource allocation. As economic reform has occurred, the role of the Five-Year Plan has changed, now influencing economic progress less directly. The new Five-Year Plan outlines the nation's goals of economic and social development and elaborates the guidelines and instruments of economic and social policies. Development priorities for sectors and regions are also identified.

6. According to the National Ambient Air Quality Standards, the maximum daily average of TSP concentration is specified as 0.3 mg/m^3 for Class II and 0.5 mg/m^3 for Class III; for the maximum daily average of PM10 concentration, 0.15 mg/m3 for class II, and 0.25 mg/m3 for Class III; for the annual average of SO_2 concentration, 0.06 mg/m^3 for Class II, and 0.1 mg/m^3 for Class III. Although standards represent an improvement relative to current conditions, they still fall short of WHO recommendations.

7. The past two decades have seen a growing income disparity between relatively developed eastern coastal regions and relatively underdeveloped western remote mountainous regions.

8. This section draws on Zou Ji (1997).

9. China's plants consume fuel at a rate 60 gce/kWh greater than that of developed countries—approximately a 20 percent difference (CCCCS, 1999; World Bank, 1997).

10. At this stage, having information on capital costs only, the abatement costs/tC avoided cannot be calculated.

11. This section draws on CCCCS (1999).

12. This excludes some possible emissions of CH_4 produced in the process of anaerobic decay. Given that CH_4's climate-warming coefficient is around 21 times higher than CO_2's, the GHG emissions resulting from substitution of coal to biomass will be even higher than 200 MtC mentioned above. This is accepted by scientists, although there has been no accurate estimate of the amount of CH_4 released as part of the anaerobic decay of biomass.

13. This excludes small wind turbines (140,000 sets with 50 W to 300 W each).

14. This section draws on World Bank (1994).

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Appendix 3a Investigating the correlation between coal use and air pollution

A simple statistical analysis was conducted to quantify the relationship between coal use and air pollution (Zou Ji, 1998). Ideally, one would want some measure of how coal use in one area affects ambient air quality in surrounding and downwind areas. To be done properly would require knowledge of coal use and levels of SO_2 and particulates by location together with modeling of airsheds and wind directions that bring the two together.

In this considerably simpler exercise, we investigated how changes in coal use over a number of years, both by province and by sector, were related to releases of SO_2 and particulate emissions. Not surprisingly, the correlation was found to be strong. Results show that increasing coal consumption by an extra 1 percent raises SO_2 emissions by 0.88–0.97 percent and particulate emissions by 0.91–0.93 percent.

For interested readers, results from the regression analyses are attached below. The relevant coal-SO_2 and coal-particulates elasticities are shown in bold type. The better "fit" for the two data sets is for the sector-based data, which provides lower estimates of the elasticities, 0.88 for coal-SO_2 and 0.91 for particulates. Consequently, using the lower end of the ranges shown above may be more appropriate.

Table 3A-1

Definition of Terms and Units

Variables	Definitions	Units of measurement
C	Constant (intercept for linear models)	—
Coal	Industrial coal use	10,000 t/yr
Abate rate	Abatement rates of SO_2 or fume emissions (particulates)	percent
Ln (coal)	Natural logarithm of industrial coal use	—
Ln (abate rate)	Natural logarithm of abatement rates	—
SO_2	Industrial SO_2 emissions	t
Ln (SO_2)	Natural logarithm of industrial SO_2 emissions	—
Fume	Industrial fume (or particulate) emissions	t
Ln (fume)	Natural logarithm of industrial fume (or particulate) emissions	—

Table 3A-2

Results of a Regression for Province-Based Data

Province Panel Data Set, N=112 (28 provinces, 4 years, 1993–96)

Independent variables\ dependent variables	**SO_2**	**Ln (SO_2)**	**Fume**	**Ln (fume)**
C	63,316.1	5.30	796,733.4	4.86
	(1.63)	(11.12)	(5.07)	(12.81)
Coal	142.87	—	89.92	—
	(12.56)		(14.62)	
Abate rate	—	—	–847,277.0	—
			(–4.76)	
Ln (coal)	—	**0.97**	—	**0.93**
		(15.85)		(20.22)
Ln (abate rate)	—	—	—	–2.57
				(–5.93)
Adjusted R^2	*0.59*	*0.69*	*0.66*	*0.78*
F-statistic	*157.87*	*251.26*	*106.97*	*206.57*

Table 3A-3

Results of a Regression for Sector-Based Data

Sector Panel Data Sets N=83 (21 sectors for 1993–95, 20 sectors for 1996)

Independent variables \ dependent variables.	**SO_2**	**SO_2**	**Ln (SO_2)**	**Fume**	**Ln (fume)**
C	–54,298.1	—	6.04	—	5.24
	(–1.66)		(25.74)		(23.31)
Coal	165.89	165.10	—	101.00	—
	(64.35)	(69.98)		(51.35)	
Abate rate	323,759.2	—	—	—	—
	(2.25)				
Ln (coal)	—	—	**0.88**	—	**0.91**
			(27.37)		(29.60)
Ln (abate rate)	—	—		—	—
Adjusted R^2	*0.98*	*0.98*	*0.90*	*0.96*	*0.91*
F-statistic	*2077.19*	—	*749.29*	—	*876.09*