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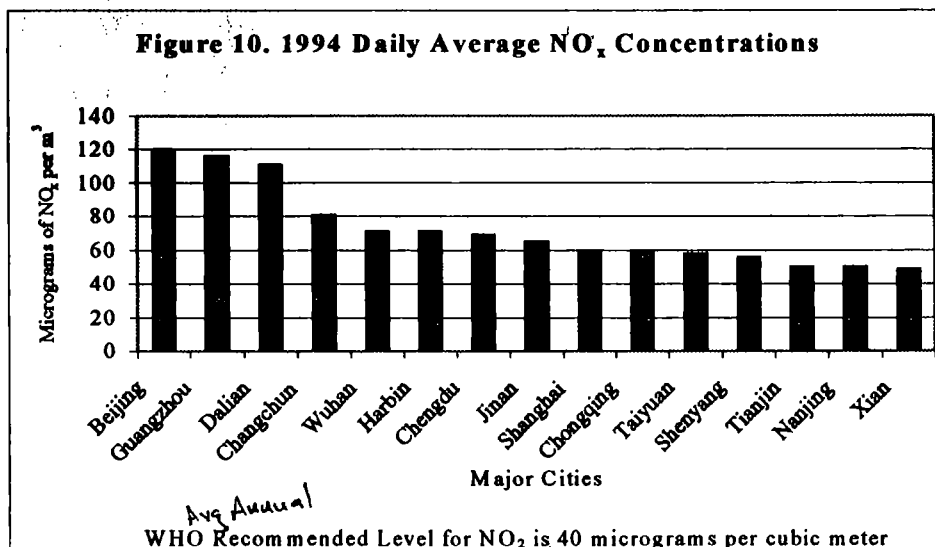
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III. Local Air Quality Benefits from Abating Greenhouse Gas Emissions

The same combustion processes that emit carbon dioxide and other greenhouse gases also generate numerous local air pollutants like sulfur dioxide and particulate matter. In its Report on the State of the Environment in China, the State Environmental Protection Administration noted that "atmospheric pollution results mainly from coal-burning" (SEPA 1998, p. 8). This is true for both global and local pollutants. By reducing carbon dioxide emissions through the use of coal substitutes and the adoption of more efficient coal combustion methods, China can simultaneously abate greenhouse gases and improve local air quality.

A. Local Air Quality

Local air quality is the most immediate environmental threat facing China. As figures 9 and 10 show, a number of China's cities regularly encounter more than 2 times the World Health Organization's recommendations for levels of sulfur dioxide (SO₂) and nitrogen dioxide (NO₂). ^{(A) 2/3}



In recent years, the level of pollutants has stabilized due primarily to two countervailing effects (Florig 1997). First, more efficient power generation technology and the use of pollution control devices have reduced emissions from industrial sites. Second, household pollution, primarily a result of cooking and heating with coal, increased substantially, leaving the total pollution levels constant. Estimates from the World Bank (1997), however, show particulate emissions increasing 39% and household smoke increasing 90% between 1995 and 2020. ^{+ changes in dist of output} ^{5/6}

China's overall industrial production has ↑
substantially, leaving total pollution levels constant.



REPORT ON THE STATE OF THE ENVIRONMENT IN CHINA

1997

State Environmental Protection Administration



ATMOSPHERIC ENVIRONMENT

Atmospheric pollution results mainly from coal-burning. Soot and sulfur dioxide were the major pollutants. In 1997, the total amount of sulfur dioxide emissions was 23.46 million tons, to which, industrial polluters contributed 18.52 million tons, accounting for 78.9% of the total SO_2 emissions and domestic polluters contributed 4.94 million tons. With regard to the industrial emission of SO_2 , industrial enterprises at the county level and above contributed 13.63 million tons, accounting for 73.6% of total industrial emissions (see Figure 4); the amount of SO_2 emission by TVIE's was 4.89 million tons. The total amount of soot emission was 18.73 million tons, in which the industry emitted 15.65 million tons, accounting for 83.6%; while domestic emission was 3.08 million tons. With regard to industrial soot emission, enterprises at and above county level were responsible for 6.85 million tons, accounting for 43.8% of the total; while TVIEs were responsible for 8.88 million tons. The total emission of industrial particles was 15.05 million tons, including 5.48 million tons of emission by enterprises at the county level and above (account for 36.4% of the total emission of fine industrial dust), and TVIE's emitted 9.57 million tons.

Acid rain was very serious in central and southwestern China, with notable increases in the southwest. Some areas in

the north such as Tumen and Qingdao regions also suffered serious acid rain problems.

CURRENT CONDITIONS

Acid Rain In 1997, the annual average pH value of precipitation varied from 3.74 to 7.79 (see Map 1).

There were 44 cities with annual average precipitation pH values lower than 5.6, accounting for 47.6% of the total number of the cities that were monitored. Of the southern cities (those south of the Yangtze River), 75% had average pH values lower than 5.6. Changsha, Zunyi, Hangzhou, and Yibin had the pH value lower than 4.5. Among the cities under monitor-

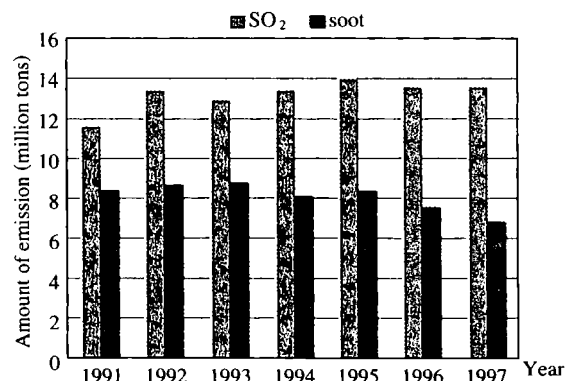


Figure 4: Emission of soot and SO_2 by enterprises at the county level and above



Sustainable Development and Healthy Environments

Protection of the Human Environment

- ▶ WHO Home
- ▶ Protection of the Human Environment Home
- ▶ Site map
- ▶ **Specific topics**
 - ▶ Air quality management
 - ▶ Burden of disease and cost-effectiveness intervention
 - ▶ Chemical safety
 - ▶ Climate and health
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 - ▶ Electro-magnetic fields (EMF)
 - ▶ Food safety
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Air quality management

Air quality guidelines

Air quality guidelines can be provided as guideline values derived from the concepts of lowest-observed- effect-levels, lowest-observed-adverse-effect-levels, no-observed-effect-levels, or no-observed-adverse- effect-levels by application of uncertainty factors (WHO, 1987). If thresholds for the onset of health effects do not appear to exist, air quality guidelines are derived in the form of percent-change-of-effect/concentration relationships (risk-concentration relationships) or, equivalently, unit risks (WHO, 1987, WHO, 1994a, WHO 1995; WHO, 1996a). In both cases often linear relationships are assumed to be valid in a certain concentration range.

Air quality guidelines are health- or environment-based levels but not standards per se. Air quality standards are air quality guidelines promulgated by governments for which additional factors may be considered such as prevailing exposure levels, natural background contamination, environmental conditions such as temperature and humidity extremes, altitude, and socio-economic factors. When proceeding from guidelines to standards policy options include the questions on which proportion of the general population and which susceptible groups should be protected.

The WHO Air Quality Guidelines for Europe (EURO, 1987) are being revised and updated using the principles sketched above. A different procedure, however, had to be adopted for suspended particulate matter (PM₁₀, PM_{2.5}) due to the fact that a threshold for the onset of health effects could not be detected. Here an argumentation related to that of carcinogenic compounds was applied by deriving linear relationships between the PM₁₀ or PM_{2.5} concentrations and various types of health effects. The updated and revised, globally applicable air quality guidelines of WHO for non-carcinogens are shown in tables 1 and 2.

Table 1. WHO air quality guidelines for "classical compounds"

Compound	Annual ambient air concentration [µg/m³]	Health endpoint	Observed effect level [µg/m³]	Uncertainty factor	Guideline value [µg/m³]	Averaging time
					100 000	15 minutes
					60 000	30 minutes



Carbon monoxide	500-7000	Critical level of COHb < 2.5%	n.a.	n.a.	60 000	30 minutes
					30 000	1 hour
					10 000	8 hours
Lead	0.01-2	Critical level of Pb in blood < 25 µg Pb/l	n.a.	n.a.	0.5	1 year
Nitrogen dioxide	10-150	Slight changes in lung function in asthmatics	365-565	0.5	200	1 hour
					40	1 year
Ozone	10-100	Respiratory function responses	n.a.	n.a.	120	8 hours
Sulphur dioxide	5-400	Changes in lung function in asthmatics	1000	2	500	10 minutes
		Exacerbations of respiratory symptoms in sensitive individuals	250	2	125	24 hours
			100	2	50	1 year

Table 2. WHO air quality guidelines for non-carcinogenic compounds

Compound	Average ambient air concentration [µg/m ³]	Health endpoint	Observed effect level [mg/m ³]	Uncertainty factor	Guideline value [µg/m ³]	Averaging time	Source
Acetaldehyde	5	Irritancy in humans	45 (NOEL)	20	2 000	24 hours	EHC 167, 1995
		Carcinogenicity related irritation in rats	275 (NOEL)	1000	300	1 year	
Acrolein	15	Eye irritation in humans	130	2.5	50	30 min	EHC 127, 1992
Acrylic acid	No data	Nasal lesions in mice	15 (LOAEL)	50	54	1 year	EHC 191, 1997
Cadmium	(0.1-20) · 10 ⁻³	Renal effects in the population	n.a.	n.a.	5 x 10 ⁻³	1 year	EURO, 1997
Carbon disulphide	10-1500	Functional CNS changes in workers	10 (LOAEL)	100	100	24 hours	EURO, 1987
Chloroform	0.3-10	Hepatotoxicity in beagles	from TDI	1000	1.3	24 hours	EHC 163, 1994
1,2-Dichloroethane	0.2-6	Inhalation in animals	700 (LOAEL)	1000	700	24 hours	EURO, 1987

China's Air Pollution Risks

Although China is struggling with major urban air quality problems, its most serious health problem is indoors.

H. KEITH FLORIG

Not long ago, environmental health risks in China paled in comparison to threats from malnutrition and infectious diseases. But as China modernized, these ominous risks were brought under control, decreasing the total death rate from 20 per 1000 in 1949 to approximately 6 per 1000 in 1995. Today, diseases linked to air pollution are among the largest threats to public health in China, ranking with smoking as the most frequent cause of death.

Data compiled from a series of Chinese epidemiologic studies and official disease statistics suggest that air pollution is responsible for more than 1 million deaths per year in China, or about one in every eight deaths nationwide. Although Chinese run lower risks than Americans from several other kinds of hazards, their individual risk of death from air pollution is 7-10 times higher (1-6; Table 1). Of the many air pollutants to which the Chinese population is exposed, particulate matter, sulfur dioxide (SO₂), and polycyclic aromatic hydrocarbons from fuel combustion cause the most extensive health damage.

Most of the scientific and regulatory attention that nations have devoted to air pollution has focused on outdoor air quality in urban areas. Although China is struggling with some of the world's worst urban air quality problems, its more serious air pollution problems are found indoors.

Like residents of other developing nations, much of China's population cooks and heats by using unvented stoves fueled by coal or biomass. Air pollution levels in Chinese homes often exceed Chinese and World Health Organization (WHO) standards for ambient outdoor air and typical urban outdoor pollution levels. For most of the population, the health impacts from home exposure to air pollutants are greater than the effects of occupational exposure.

Because exposure patterns and the composition of air pollution in China are quite different from those in Western industrialized countries, the extensive literature in the West on the adverse effects of air pol-

lution is of limited value in estimating the way it affects health in China. Using methods tailored to Chinese patterns of pollution and population, Chinese epidemiologists began more than a decade ago to tackle the task of measuring these health effects.

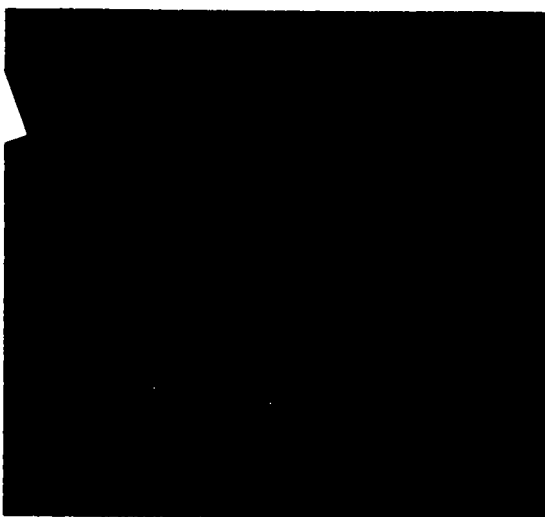
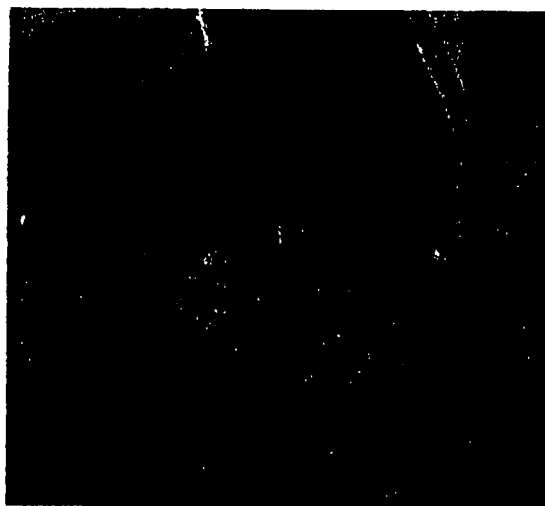
Role of household fuel burning

In urban China, coal burning is the dominant source of indoor and outdoor air pollution. More than 75% of China's primary energy needs are supplied by domestic coal. Studies of the contribution of various sources of air pollution from coal burning suggest that household coal burning is the largest contributor to outdoor particulate and SO₂ concentrations at ground level in all but the most heavily industrial northern cities. Industrial coal burning plays a more significant role in southern cities without major heating needs (7).

Since the publication of China's first particulate control regulations in 1973, most industrial and residential boilers have adopted some basic particulate controls, although average removal efficiencies are only about 70%. But there are no particulate controls on China's hundreds of millions of household stoves. Controls on SO₂ emissions are rare, even on large industrial boilers, kilns, and furnaces.

China began systematic monitoring of outdoor air quality in the early 1980s and today maintains a network of monitors measuring multiple pollutant species in more than 100 cities. Data from this network show intercity variations of almost an order of magnitude in annual average concentrations of particulates and SO₂. These variations reflect intercity differences in heating demand, local coal quality, amount of heavy industry, natural dust, weather, and topography.

Daily patterns of outdoor urban particulate and SO₂ levels show morning and evening peaks that correspond to periods when most cooking is done. Seasonal patterns in particulate and SO₂ levels show pronounced increases in northern cities that correspond to periods of high heating demand.



A typical Chinese coal-burning stove (above). Honeycomb coal briquettes (top) are helping to replace raw coal for home use in China. The briquettes are cleaner and more efficient for cooking and heating. (Courtesy Keith Florig, top; K. R. Smith, above)

Although particulate and SO_2 levels in many cities are high compared with Chinese regulatory standards and WHO guidelines (8; Table 2), concentrations of these pollutants are not worsening over time despite the several-fold increase in China's industrial production since 1980. Changes in industrial and residential energy use are largely responsible for this stability.

The pollution intensity of many major industries has declined in response to new economic conditions that reward efficient production. The Chinese steel industry, for instance, is using 25% less coal per ton of steel produced today than it did in 1980 (5). The closing of inefficient state-owned factories has also eased pollution loadings in many urban areas.

Significant reductions are being made in pollution emissions from household heating and cooking. Single-story houses heated with individual coal-burning stoves are being replaced with centrally heated multistory apartment buildings. Electric cooking appliances, piped and bottled gas, and processed coal briquettes are becoming more readily available and affordable, thus reducing the amount of raw coal used by households.

Although the number of factories in China's rural towns and villages is growing, residential fuel burn-

ing is still the dominant source of outdoor air pollution in most of these areas. Outdoor pollution levels in rural areas depend on housing density, fuel and stove type, heating demand, and weather conditions. The results of monitoring in rural towns and villages show that outdoor particulate and SO_2 concentrations range from 10% to 100% of indoor levels (9).

Indoor air quality in China is partly influenced by infiltration of outdoor pollutants, but the main contributors are sources of combustion within the home. In urban areas, about 56% of the energy for household use is supplied by coal stoves and small coal boilers, and the remainder is supplied by electricity (30%), district heating (8%), and gas (6%). In rural areas, fuels for household uses are crop residues (supplying 38% of rural household energy needs), wood (36%), coal (22%), dung, and other fuels (4%) (9). Because the rural population of China is so large (70% of the population), the average consumption of biomass fuels for household use actually exceeds the average residential consumption of coal. To combat deforestation, the Chinese government recently issued a regulation prohibiting households from burning wood. As a practical matter, however, compliance with this rule is limited to those communities able to find affordable substitute fuels.

The factors that influence the concentration of indoor air pollutants from stoves include the type of fuel, stove design, whether the stove is vented, the frequency and duration of stove use, outside air infiltration, and whether the stove is physically isolated from the main living area. A recent compilation of results from more than 100 studies of air pollution levels in Chinese homes (9) shows large variations across households, fuel types, and season of the year (see Table 3).

Analyzing health effects

The known health problems associated with common air pollutants include a variety of acute and chronic respiratory ailments, heart disease, impaired immune function, fatigue, impaired lung development, neurological deficits, and cancer. Assessing the health effects of any particular air pollutant is problematic. Records of diseases and causes of death, on which epidemiologic studies often depend, may be inconsistent and biased. Studies that look for relationships between risk and outdoor pollutant concentrations do not control for variations in indoor exposure to air pollution, which, in the case of China, can be enormous. Crude exposure measures such as total suspended particulates (TSP) concentration do not capture differences in the size and composition of particles. High correlations between environmental concentrations of different pollutants and possible synergies between pollutants make it hard for epidemiologists to separate the effect of any one species. And in any epidemiologic study involving lung diseases, tobacco smoking and occupational exposures to air pollution can be powerful confounders.

Smoking rates are on the rise in China and in many other developing countries. Tobacco production for domestic consumption in China tripled between 1981 and 1992 (4). Currently, an estimated 75% of adult men and 10% of adult women smoke. Smoking rates in urban and rural districts are similar.

FEAR
FOR
BLUE
SKIES



THE WORLD BANK

Future pollution loads

Particulates. Fine particulate emissions will increase by 39 percent between 1995 and 2010 but will decline slowly thereafter (figure 3.3). By 2020 particulate emissions will be 35 percent higher than in 1995. This outcome represents the sum of two sets of forces. Better particulate controls for large sources—heavy industry and power and heat plants—will reduce emissions as older equipment is replaced, causing their share in total emissions to fall from 60 percent in 1995 to 52 percent in 2020. Emissions in the residential, commercial, and small industrial sectors will increase, however. New technology offers much smaller gains in these sectors—except to the extent that more coal washing, improved energy efficiency, and better boiler and stove designs lower average emissions per ton of coal burned.

Unless policies are changed, there will be substantial growth in fine particulates emitted from small sources. Pollution discharged from low chimneys is the main contributor to poor air quality in urban areas. Under the business as usual scenario the amount of smoke emitted by households will grow by 90 percent between 1995 and 2020. Thus particulate emissions would stabilize at a level that is associated with extremely poor air quality for most urban households, which continue to rely on coal as the primary fuel for heating and cooking.

Sulfur dioxide. Under the business as usual scenario sulfur dioxide emissions will increase 150 percent by

2020 (figure 3.4). As with particulates, growth in the use of coal by households and other small sources drives the initial increase in emissions. Later, an increase in demand for electricity outweighs the initial drop in sulfur dioxide emissions per ton of coal burned in power and heat plants (a drop made possible by improvements in the thermal efficiency of new power plants and by the adoption of low-cost control measures). As a result power and heat plants account for all of the growth in sulfur dioxide emissions after 2005.

Nitrogen oxides. Nitrogen oxide emissions will increase rapidly during 1995–2020 as a result of brisk growth in emissions from small sources (figure 3.5). Much of this growth is the result of increased oil consumption by motor vehicles—motorcycles, cars, trucks, and buses. Nitrogen oxide emissions from power and heat plants follow the same pattern as for sulfur dioxide emissions but with a higher overall growth rate. Although the scenario assumes that burners with lower nitrogen oxide emissions will gradually be incorporated in new boilers, this will only partly offset the effects of rapid growth in electricity demand and production.

Lead. To be consistent with the rest of the scenario, the projections for lead do not take into account the government's recent announcement of plans to phase out lead from gasoline by 2000. As such, the scenario provides a baseline against which to measure implementation of that decision.

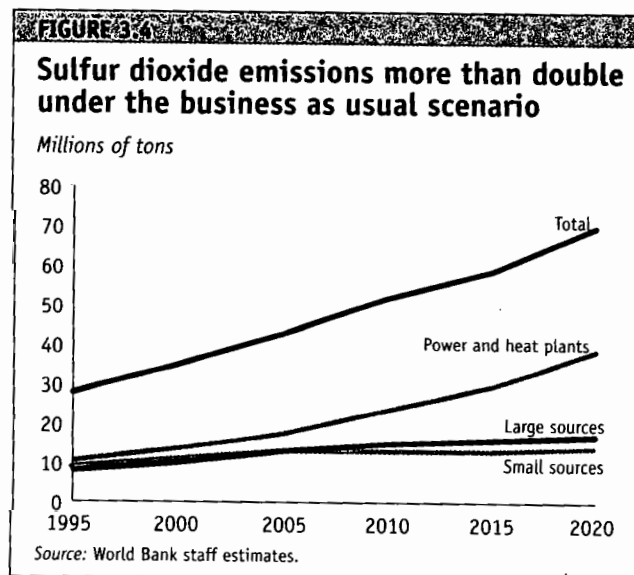
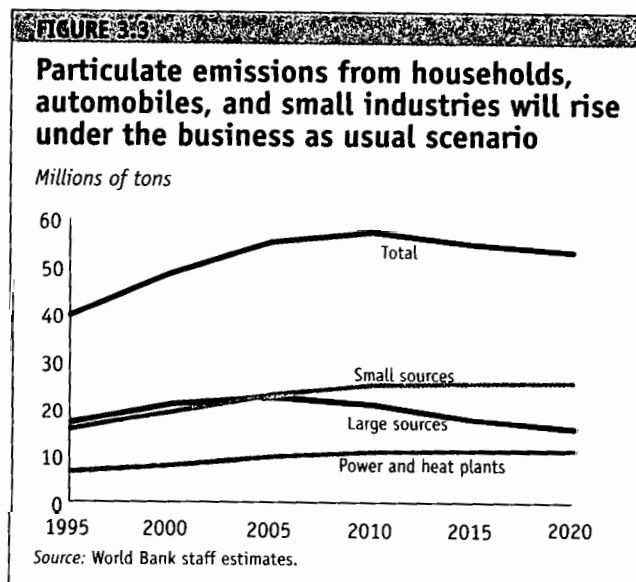
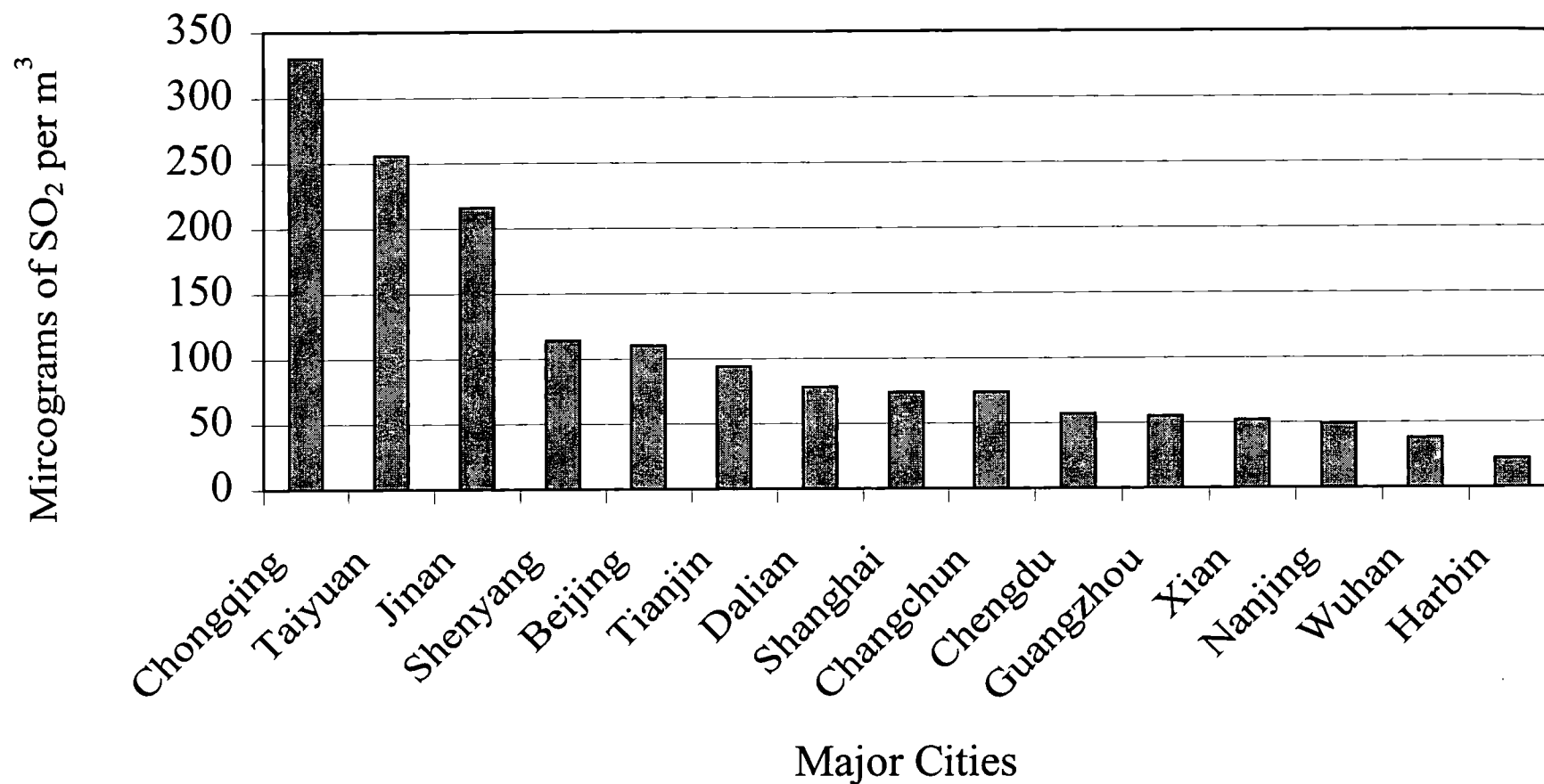


Figure 9. 1994 Daily Average SO₂ Concentrations



WHO Recommended Level is 50 micrograms per cubic meter

1994 Daily Average SO₂ Emissions

	Chongqing	330
2	Taiyuan	256
3	Jinan	216
4	Shenyang	114
5	Beijing	110
6	Tianjin	94
7	Dalian	78
8	Shanghai	74
9	Changchun	74
10	Chengdu	57
11	Guangzhou	55
12	Xian	52
13	Nanjing	49
14	Wuhan	38
15	Harbin	22

Ambient SO₂ Concentrations in Chinese Cities
(ug/m³, annual daily average)

City	north-south north=1;south=0	coast coast=1	Population *	1981	1982	1983
Shanghai	0	1	8249.1	100.0	120.0	38.0
Beijing	1	1	6093.3	110.0	80.0	92.0
Tianjin	1	1	4720.5	160.0	200.0	224.0
Shenyang	1	1	3762.0	160.0	120.0	90.0
Wuhan	0	0	3519.6	50.0	50.0	57.0
Guangzhou	0	1	3113.8	80.0	70.0	44.0
Harbin	1	0	2505.2	30.0	94.0	42.0
Chongqing	0	0	2377.8	280.0	430.0	324.0
Nanjing	0	1	2224.2	60.0	60.0	
Xian	1	0	2114.9	120.0	100.0	75.0
Chengdu	0	0	1932.8	10.0	90.0	81.0
Dalian	1	1	1855.2	60.0	70.0	53.0
Changchun	1	0	1810.4	30.0	40.0	52.0
Jinan	1	1	1659.9	300.0	160.0	
Taiyuan	1	0	1642.3	380.0	240.0	
Qingdao	1	1	1584.1	160.0	240.0	257.0
Zibo	1	1	1346.3			
Zhengzhou	1	0	1323.7	70.0	90.0	84.0
Lanzhou	1	0	1295.6	50.0	40.0	25.0
Anshan	1	0	1251.7	90.0	70.0	145.0
Kunming	0	0	1240.0	100.0	80.0	35.0
Changsha	0	0	1198.1	160.0	150.0	77.0
Hangzhou	0	1	1184.3	70.0	60.0	66.0
Nanchang	0	0	1168.7	80.0	70.0	49.0
Shijiazhuang	1	0	1159.4	150.0	190.0	202.0
Guiyang	0	0	1131.2	450.0	520.0	
Urumqi	1	0	1130.3	260.0	130.0	83.0
Jilin	1	0	1117.8	100.0	120.0	39.0
Tangshan	1	1	1110.2	80.0	110.0	
Baotou	1	0	1032.9	50.0	90.0	72.0
Fuzhou	0	1	952.3		80.0	
Xuzhou	1	1	879.8			
Hefei	1	0	866.8	50.0	20.0	32.0
Luoyang	1	0	863.3	40.0		
Datong	1	0	845.0			
Nanning	0	0	829.4	110.0	110.0	70.0
Yicun	1	0	800.3			
Suzhou	0	1	766.3	100.0	90.0	81.0
Daqing	1	0	752.1			
Shenzhen	0	1	695.6			
Hohhot	1	0	683.2	80.0	70.0	
Ningbo	0	1	612.0			
Xining	1	0	569.8			
Hegang	1	0	569.2			
Jiangyang	0	0	543.1			
Xiaifeng	1	0	535.3			
Baoding	1	0	519.2			
Pingdingshan	1	0	517.6			

Xiangfan	0	0	498.0			
Zanjiang	0	1	491.8			
Jiaozuo	1	0	476.8			
Xiamen	0	1	458.6			
Anyang	1	0	458.4			
Pingxiang	0	0	451.7			
Wenzhou	0	1	449.7	60.0	30.0	28.0
Zigong	0	0	430.5			
Yichang	0	0	428.4			
Nantong	0	1	422.3			
Yinchuan	1	0	412.9		20.0	
Qinghuangdao	1	1	412.5	20.0	20.0	74.0
Liupanshui	0	0	408.0			
Guilin	0	0	398.9	60.0	90.0	96.0
Leshan	0	1	384.3			
Baoji	1	0	379.3			
Haikou	0	1	364.7			
Sipin	0	0	354.6			
Nanchong	0	0	330.0			
Jiujiang	0	0	322.3			
Shizhuishan	1	0	297.9			
Jingdezhen	0	0	294.0			
Qitaihe	1	0	261.8			
Yibin	0	0	261.3			
Wanxian	0	0	258.5			
Ganzhou	0	0	239.4			
Wuzhou	0	0	236.2			
Hejiou	0	0	216.4			
Ganzhong	1	0	197.4			
Sanming	0	1	181.8			
Huaihua	0	0	168.7			
Yuncheng	1	0	135.1			
Yanan	1	0	126.8			
Lasha	0	0	118.0			
Baise	0	0	104.2			
Tumen	1	0	101.6			
Hechi	0	0	97.2			
Jiayuguan	1	0	96.8			
Jian	1	0	73.5			
fushun	1	0	1245.7	80	60	82
benxi	1	0	805.4	210.0	290.0	220.0

* 1994 city-proper non-agricultural population, a conservative lower bound of urban population.

**Data from 1981 to 1990 is from the China National Environmental Monitoring Station

***Data from 1991 to 1995 is from China's National Environmental Protection Agency

1984	1985	1986	1987	1988	1989	1990
94.0	110.0	110.0	120.0	120.0	98.0	83.0
87.0			123.0	115.0	99.0	98.0
202.0	208.0	220.0	172.0		125.0	106.0
119.0	118.0	158.0	134.0	100.0	146.0	111.0
69.0	66.0		51.0	43.0	48.0	39.0
	81.0	65.0	80.0	90.0	100.0	
35.0	33.0	46.0	50.0	48.0	40.0	28.0
307.0	504.0	401.0	430.0	360.0	338.0	422.0
83.0	78.0	73.0	90.0	89.0		78.0
109.0	114.0	121.0	110.0	59.0	51.0	51.0
82.0	79.0	69.0	80.0	70.0	82.0	65.0
69.0	66.0	61.0	60.0	60.0	54.0	38.0
67.0	73.0	70.0	46.0	40.0	54.0	44.0
180.0	167.0	191.0	162.0	175.0	117.0	120.0
170.0	217.0	242.0	240.0	247.0	394.0	
241.0		249.0	248.0		263.0	233.0
14.0				164.0	147.0	127.0
84.0	70.0	67.0	68.0	86.0	65.0	77.0
	121.0	116.0	106.0	74.0	62.0	77.0
133.0	110.0	135.0	119.0	79.0	100.0	
82.0	55.0	76.0	35.0	58.0	55.0	46.0
109.0	151.0	143.0	107.0	131.0	186.0	144.0
82.0	91.0	107.0	104.0	105.0	97.0	122.0
62.0			55.0	64.0	72.0	37.0
198.0	218.0	175.0	274.0	261.0	269.0	247.0
363.0	400.0	434.0	434.0	435.0	372.0	356.0
	137.0	313.0	128.0	152.0	201.0	222.0
43.0		52.0		55.0	67.0	67.0
84.0	113.0	100.0	102.0	143.0	122.0	107.0
93.0			194.0		126.0	117.0
93.0	96.0	80.0	79.0	70.0	86.0	
87.0	70.0	73.0	70.0	72.0	71.0	90.0
28.0	25.0	54.0	39.0		55.0	53.0
45.0		63.0	69.0	74.0	105.0	54.0
142.0	125.0	104.0	68.0		62.0	
77.0	83.0	88.0	98.0		77.0	70.0
7.0	13.0	16.0	8.0		8.0	14.0
	141.0	72.0	76.0	65.0	92.0	39.0
			20.0	47.0	46.0	64.0



63.0	68.0	60.0	73.0	55.0	67.0	
52.0	62.0	75.0	103.0	84.0		52.0
50.0	59.0	52.0	40.0	30.0	19.0	57.0
65.0	69.0	55.0	70.0	73.0	55.0	76.0
	79.0	83.0	96.0	60.0	138.0	
					2.0	3.0



86	93	53
222.0	225.0	



1991	1992	1993	1994	1995	City
83	93	89	74 8	53	Shanghai
135	129	120	110 5	90	Beijing
160	180	180	94 6	82	Tianjin
145	140	122	114 4	99	Shenyang
44	40	40	38 14	40	Wuhan
71	59	47	55 11	57	Guangzhou
	27	29	22 15	23	Harbin
390	390	270	330 1	340	Chongqing
74	50	73	49 13	62	Nanjing
	68	58	52 12	60	Xian
70	66	75	57 10	77	Chengdu
94	75	79	78 7	61	Dalian
56	61	61	74 9	21	Changchun
	135	226	216 3	132	Jinan
265	277	303	256 2	211	Taiyuan
229	204	207	215	190	Qingdao
	121	142	121	198	Zibo
67	86	90	67	63	Zhengzhou
84	102	79	94	102	Lanzhou
80	104	125	115	115	Anshan
52	45	50	72	19	Kunming
	173	180	79	113	Changsha
123	122	107	121	68	Hangzhou
43	41	65	74	69	Nanchang
	162	121	175	129	Shijiazhuang
353	341	463	451	424	Guiyang
222	207	301	210	60	Urumqi
110	75	89	95	92	Jilin
	86	97	157	95	Tangshan
140	142	119	136	110	Baotou
	82	72	67	26	Fuzhou
	81	76	17	19	Xuzhou
48	46	41	40	50	Hefei
		110	155	176	Luoyang
134	179	150	185	192	Datong
56	50	86	74	70	Nanning
				5	Yicun
	65	64	63	71	Suzhou
	15	10	14	11	Daqing
16	16	7	26	15	Shenzhen
40	35		121	93	Hohhot
43				27	Ningbo
66	51	46	54	46	Xining
		11	9	11	Hegang
	62	68	73	125	Hengyang
				45	Kaifeng
		138	182	52	Baoding
	43	34	49	42	Pingdingshan

42	40	38	40	49	Xiangfan
		39	34	32	Zanjiang
				67	Jiaozuo
		7		11	Xiamen
	79	94	95	83	Anyang
		67		75	Pingxiang
50	61	38	39	37	Wenzhou
			129	116	Zigong
246	165	128	165	216	Yichang
		42	50	46	Nantong
53	56	68	43	85	Yinchuan
	45	41	59	64	Qinghuangdao
67	46	55	86	102	Liupanshui
107	85	70	76	26	Guilin
			89	62	Leshan
	54	39	26	48	Baoji
	4	7	8	5	Haikou
35		36	62	74	Sipin
	239	242	244	134	Nanchong
89	82	99	115	86	Jiujiang
106	104	209		123	Shizhuishan
45	50	54	80	60	Jingdezhen
				29	Qitaihe
	305	287	307	205	Yibin
				70	Wanxian
43	44	40	48	32	Ganzhou
130	109	134	142	141	Wuzhou
		31	55	35	Gejiou
	50	61	49	49	Hanzhong
	25	38		42	Sanming
		76	79	72	Huaihua
90	94	132	65	124	Yuncheng
	60	44	48	92	Yanan
		2		2	Lasha
	45	46	32	40	Baise
	28	41	22	28	Tumen
			204	125	Hechi
		35	49	36	Jiayuguan
				31	Jian

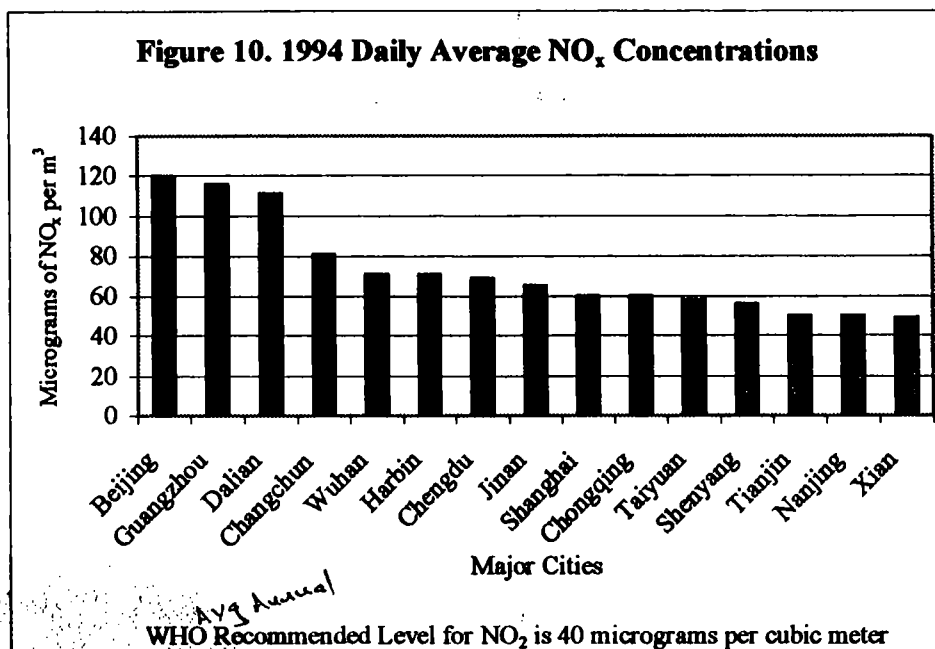
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B. Costs of Local Air Pollution

A number of studies have analyzed the relationship between current high levels of local air pollutants and health problems. Xu Zhaoyi and associates at the Liaoning Public Health and Anti-Epidemic Station estimated that indoor and outdoor pollution cause 60% of urban chronic obstructive pulmonary disease cases (Florig 1997). Research by Xu Xiping at the Harvard School of Public Health and his colleagues found that a one-percent increase in SO₂ and total suspended particulates (TSP) levels increased the number of non-surgical visits by 20% and 17%, respectively (Xu et al 1995a; Xu et al 1995b). Xu Zhaoyi and Xu Xiping have also estimated the effects of pollution on mortality rates in Shenyang and Beijing respectively (Xu 1998). In Beijing, a doubling of SO₂ levels increased the mortality rate by 11% while in Shenyang, mortality increased by 2% for each 100 µg/m³ of SO₂ and by 1% for each 100 µg/m³ for TSP. The World Bank (1997) estimates that the economic costs from lost work hours, hospital and emergency room visits, and chronic bronchitis at more than \$20 billion per year in China.

Researchers have also documented the effects of pollution on children. Liu Yulin of the Institute of Pediatrics in Beijing found that children's chances of contracting pneumonia doubled if they lived in a home with coal stoves or adults who smoked. He Qingci of the Wuhan Environmental Protection Institute showed that children from Wuhan's urban areas had lung capacities 5% smaller than children from the suburbs where outdoor TSP levels are 50% lower (110 µg/m³ vs. 251 µg/m³). Finally, Xu Zhaoyi found "up to four times more rhinitis, pharyngitis, and tonsillitis [inflammation of the nasal mucous membrane, pharynx, and tonsils, respectively] among children living in areas of heavier

China's Air Pollution Risks

Although China is struggling with major urban air quality problems, its most serious health problem is indoors.

H. KEITH FLORIG

Not long ago, environmental health risks in China paled in comparison to threats from malnutrition and infectious diseases. But as China modernized, these ominous risks were brought under control, decreasing the total death rate from 20 per 1000 in 1949 to approximately 6 per 1000 in 1995. Today, diseases linked to air pollution are among the largest threats to public health in China, ranking with smoking as the most frequent cause of death.

Data compiled from a series of Chinese epidemiologic studies and official disease statistics suggest that air pollution is responsible for more than 1 million deaths per year in China, or about one in every eight deaths nationwide. Although Chinese run lower risks than Americans from several other kinds of hazards, their individual risk of death from air pollution is 7–10 times higher (1–6; Table 1). Of the many air pollutants to which the Chinese population is exposed, particulate matter, sulfur dioxide (SO₂), and polycyclic aromatic hydrocarbons from fuel combustion cause the most extensive health damage.

Most of the scientific and regulatory attention that nations have devoted to air pollution has focused on outdoor air quality in urban areas. Although China is struggling with some of the world's worst urban air quality problems, its more serious air pollution problems are found indoors.

Like residents of other developing nations, much of China's population cooks and heats by using unvented stoves fueled by coal or biomass. Air pollution levels in Chinese homes often exceed Chinese and World Health Organization (WHO) standards for ambient outdoor air and typical urban outdoor pollution levels. For most of the population, the health impacts from home exposure to air pollutants are greater than the effects of occupational exposure.

Because exposure patterns and the composition of air pollution in China are quite different from those in Western industrialized countries, the extensive literature in the West on the adverse effects of air pol-

lution is of limited value in estimating the way it affects health in China. Using methods tailored to Chinese patterns of pollution and population, Chinese epidemiologists began more than a decade ago to tackle the task of measuring these health effects.

Role of household fuel burning

In urban China, coal burning is the dominant source of indoor and outdoor air pollution. More than 75% of China's primary energy needs are supplied by domestic coal. Studies of the contribution of various sources of air pollution from coal burning suggest that household coal burning is the largest contributor to outdoor particulate and SO₂ concentrations at ground level in all but the most heavily industrial northern cities. Industrial coal burning plays a more significant role in southern cities without major heating needs (7).

Since the publication of China's first particulate control regulations in 1973, most industrial and residential boilers have adopted some basic particulate controls, although average removal efficiencies are only about 70%. But there are no particulate controls on China's hundreds of millions of household stoves. Controls on SO₂ emissions are rare, even on large industrial boilers, kilns, and furnaces.

China began systematic monitoring of outdoor air quality in the early 1980s and today maintains a network of monitors measuring multiple pollutant species in more than 100 cities. Data from this network show intercity variations of almost an order of magnitude in annual average concentrations of particulates and SO₂. These variations reflect intercity differences in heating demand, local coal quality, amount of heavy industry, natural dust, weather, and topography.

Daily patterns of outdoor urban particulate and SO₂ levels show morning and evening peaks that correspond to periods when most cooking is done. Seasonal patterns in particulate and SO₂ levels show pronounced increases in northern cities that correspond to periods of high heating demand.

Chinese epidemiologic studies have examined the effects of smoking and air pollution on the incidence of many diseases. Of these, the largest impact on public health arises from chronic obstructive pulmonary disease (COPD), lung cancer, coronary heart disease (CHD), and childhood pneumonia.

COPD, a condition involving permanent structural changes to the lung that interfere with breathing, is responsible for about 1.4 million deaths in China each year (1). Most COPD deaths are preceded by 10–15 years of disability, so the quality-of-life effects of this disease are great.

Standardized death rates from COPD are five to six times greater in China than in the United States (10). Smoking and air pollution are the primary causes of COPD. The high relative rates of COPD in China cannot be explained by smoking, however, because cumulative per capita consumption of cigarettes and leaf tobacco in China is much lower than in the United States (11, 12). In addition, COPD mortality among Chinese women is only slightly less than among Chinese men, despite the low percentage of women who smoke. Occupational exposures to dust and fumes contribute to COPD, but Chinese epidemiologic studies that consider these factors suggest that the high rates of COPD in China are caused primarily by air pollution from residential fuel combustion. In a meta-analysis of epidemiologic studies of COPD in different Chinese cities, Xu Zhaoyi and co-workers at the Liaoning Public Health and Anti-epidemic Station in Shenyang concluded that indoor and outdoor pollution combined are responsible for about 60% of the urban COPD cases nationwide. Smoking was estimated to contribute another 20% of all urban cases.

Mortality rates for COPD in rural areas are 66% higher than in the cities (1). This might result from either higher indoor air pollution levels in rural households or more limited access to health care of rural residents. Since China's rural population is about 2.3 times as large as the urban population, the number of COPD deaths in rural areas in a given year (1.1 million) is almost four times the number of COPD deaths in urban areas (0.3 million).

Indoor air pollution versus smoking

Lung cancer claims 250,000 lives per year in China, two-thirds of which are men (1). In a meta-analysis of eight Chinese epidemiological studies of lung cancer, Liu Zhiyuan, of the Chinese Academy of Preventive Medicine, concludes that about 60% of male lung cancers and 25% of female lung cancers in urban China are attributable to smoking (13). Most lung cancers not caused by smoking result from exposure to indoor air pollutants. Tao Xuguang and colleagues at Shanghai Medical University, for instance, estimated that 30% of the lung cancers among Shanghai men who burn coal indoors are attributable to indoor air pollution.

The large difference between men and women in the amount of lung cancer attributable to smoking arises from the greater prevalence of smoking among Chinese men than among women and from the greater exposures of women to both mutagenic fumes from cooking oils and smoke from indoor stoves (14–16). In a study in the northern city of Harbin, Dai

TABLE 1

Estimated annual deaths from COPD in China

City	Estimated annual deaths from COPD
Beijing	100,000
Shanghai	100,000
Guangzhou	100,000
Harbin	100,000
Chengdu	100,000
Wuhan	100,000
Shenzhen	100,000
Yantai	100,000
Qingdao	100,000
Shijiazhuang	100,000
Xi'an	100,000
Chongqing	100,000
Nanjing	100,000
Hangzhou	100,000
Wenzhou	100,000
Shaoxing	100,000
Wuxi	100,000
Suzhou	100,000
Yangzhou	100,000
Zhenjiang	100,000
Nantong	100,000
Wafangdian	100,000
Benxi	100,000
Yichang	100,000
Changsha	100,000
Chengdu	100,000
Wuhan	100,000
Shenzhen	100,000
Yantai	100,000
Qingdao	100,000
Shijiazhuang	100,000
Xi'an	100,000
Chongqing	100,000
Nanjing	100,000
Hangzhou	100,000
Wenzhou	100,000
Shaoxing	100,000
Wuxi	100,000
Suzhou	100,000
Yangzhou	100,000
Zhenjiang	100,000
Nantong	100,000
Wafangdian	100,000
Benxi	100,000
Yichang	100,000
Changsha	100,000

TABLE 2

Estimated annual deaths from COPD in China

City	Estimated annual deaths from COPD
Beijing	100,000
Shanghai	100,000
Guangzhou	100,000
Harbin	100,000
Chengdu	100,000
Wuhan	100,000
Shenzhen	100,000
Yantai	100,000
Qingdao	100,000
Shijiazhuang	100,000
Xi'an	100,000
Chongqing	100,000
Nanjing	100,000
Hangzhou	100,000
Wenzhou	100,000
Shaoxing	100,000
Wuxi	100,000
Suzhou	100,000
Yangzhou	100,000
Zhenjiang	100,000
Nantong	100,000
Wafangdian	100,000
Benxi	100,000
Yichang	100,000
Changsha	100,000

Chinese Academy of Preventive Medicine, 1997. Average annual TSP and SO₂ concentrations in 50% of Chinese cities in 1997: a factor of 2.5 of the median value for Europe. China Environment Yearbook 1997.

Xudong and co-workers at Harbin Medical University found that nonsmoking women who had used a coal stove to heat their bedrooms for 30 years or more were 18 times more likely to get lung cancer than nonsmoking women who had never used a coal stove in the bedroom. Women who cooked by frying their food were nine times more likely to get lung cancer than women who did not. Because smoking is so prevalent among Chinese men, many women are chronically exposed to secondhand tobacco smoke. However, the influence of passive smoking on female lung cancer is thought to contribute much

Association of Air Pollution with Hospital Outpatient Visits in Beijing

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ABSTRACT. Data collected at a community-based hospital in Beijing, China, were analyzed in an assessment of the association of air pollution with daily outpatient visits. Total suspended particle (TSP) measurements were available for 210 d (mean, $388 \mu\text{g}/\text{m}^3$; maximum, $1\,255 \mu\text{g}/\text{m}^3$), and sulfur dioxide (SO_2) measurements were available for 2 d (mean, $119 \mu\text{g}/\text{m}^3$; maximum, $478 \mu\text{g}/\text{m}^3$). The average number of daily hospital outpatient visits was 1 386; approximately 8.5% of these visits were to the surgery department, 7.9% were to the pediatrics department, and 20.6% were to the internal medicine department. A large increase in nonsurgery outpatient visits was observed in association with increases in both SO_2 and TSP in linear regression models, after adjusting for temperature, humidity, season, and day of the week. The estimated effects (in which the most polluted days were compared with the least polluted days) on nonsurgery outpatient visits were increases of 20% ($SE = 5\%$) and 17% ($SE = 4\%$) in association with increases in SO_2 and TSP, respectively. In a department-specific analysis, the association was found to be 1.5- to 2.0-fold stronger for pediatrics and internal medicine visits than for other types of visits. The separate associations of SO_2 and TSP with internal medicine visits remained statistically significant when both SO_2 and TSP were considered simultaneously and when adjustment was made for surgery visits. SO_2 and TSP were found to be significant, independent predictors of internal medicine visits in both winter and summer. The association between outpatient visits and air pollution appeared to be stronger in summer than in winter, although the summer daily mean SO_2 concentration was only $17 \mu\text{g}/\text{m}^3$ (maximum, $51 \mu\text{g}/\text{m}^3$). These data, together with data obtained in previous studies, provide coherent evidence that current air-pollution levels in Beijing are associated with adverse health outcomes, and they also suggest that air pollution in Beijing needs to be controlled more effectively.

ACUTE HEALTH EFFECTS of air pollution have been evaluated by mortality, hospital admissions, emergency room visits, and hospital outpatient visits. Episodes of high particulate and sulfur dioxide (SO_2) concentrations

have been associated with excess daily mortality, even when concentrations are below the cutoff established by air quality standards of the World Health Organization (WHO).¹⁻⁴ Studies based on hospital records have

correlated increased air pollution with increase hospital admissions⁵ and with increased emergency room visits.⁶⁻⁸ Few studies, however, have examined the association of air pollution with daily hospital outpatient visits, mainly because of the difficulty in obtaining complete information for such visits in a given community.

Each year in the United States, there are about 2 million deaths,⁹ approximately 31 million hospital admissions,¹⁰ and about 693 million visits to physicians' offices.¹¹ Therefore, data on mortality, hospital admissions, and emergency room visits can reflect only a small proportion of the population potentially affected by air pollution. In contrast, information on hospital outpatient visits offers greater coverage because it encompasses less severe cases; thus, this information may confer a greater power to detect health effects of air pollution. A nonlinear association between daily mortality and air pollution has been documented on the basis of data from London¹² and China.⁴ One explanation is that the deaths of individuals who are susceptible to the effects of air pollution reduce the pool of subjects at risk for early death from subsequent episodes of air pollution.¹² If this hypothesis is true, then visits to physicians' offices that return the affected individuals back to the pool at risk may not show such nonlinearity.⁴ In this study, daily outpatient visits at Fuxing Hospital, a community-based hospital in Beijing, were used to investigate the acute effects of air pollution. Exposure-response relationships were also examined in low- and high-pollution seasons (i.e., summer and winter). Fuxing Hospital is located in a residential district (Xichen) of central Beijing (north and west of Tiananmen Square) that is free of major manufacturing industries. Bicycles are the primary form of transportation. The major source of air pollution consists of coal stoves used for heating and cooking. Few homes are air conditioned, and windows are kept open during the summer.

Method

Daily numbers of outpatient visits in 1990 were obtained from the Fuxing Hospital Reception Department, where all patients must register and pay a registration fee prior to seeing a physician. Patients are seen in specific departments, including surgery, pediatrics, internal medicine, obstetrics and gynecology, orthopedics, dermatology, neurology, ophthalmology, ear-nose-throat, stomatology, and Chinese traditional medicine. Outpatient visits occur all day on Monday, Tuesday, Thursday, Friday, and on Wednesday and Saturday mornings. Patients can see doctors on Sunday, Wednesday afternoon, and Saturday afternoon if they agree to pay a higher registration fee. There were 10 legal holidays in 1990: January 1 (New Year); January 27, 28, 30 and 31 (Chinese New Year); May 1 and 2 (International Labor Day); May 13 (recess); and October 1 and 2 (National Day). On these days, only emergency rooms were open; these days were therefore excluded from the analyses.

Total suspended particulate (TSP) and SO₂ concentrations were measured at WHO's Global Air Monitoring

station in the center of the Xichen and Jichang districts. TSP was measured gravimetrically, and SO₂ was measured by colorimetric pararosaniline methods.¹³ Daily air samples were collected and analyzed for 2 to 3 wk each mo, starting with the 2nd wk of the month. In 1990, the highest daily TSP concentration was 2 235 µg/m³ (January 17, 1990); this level, which is more than 6 standard deviations (200 µg/m³) above the annual mean level (388 µg/m³), was approximately 1 000 µg/m³ higher than the second highest level (1 255 µg/m³) found on December 8, 1990. The high level found on January 17, 1990, was excluded from the analysis because it was attributed to strong winds and wind-blown dust. The mean concentrations of TSP and SO₂ measured at the Dongchen and Xichen sites were used for analysis. Temperature and humidity data were obtained from the Beijing Weather Bureau.

Daily hospital outpatient visits were distributed approximately normally. Daily outpatient visits were regressed by means of a linear regression with a Markov correction for auto-correlation in time-series data.¹⁴ In an effort to make the regression coefficients comparable among the different departments, the daily visits to each department were expressed as percentages, by dividing by annual mean number of visits and multiplying the result by 100. The basic model can be expressed as

$$E(Y_t) = \alpha f_1(X_t) + \beta f_2(Z_t) + \sum_j \gamma_j Y_{t-j}$$

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page for
coefficients

where $t = 1, 2, \dots, 365$ (day of year); $j = 1, 2, 3$ (lag day for outpatient visits); y_t is the percentage of visits on day t ; x_t is the vector of covariates on day t (i.e., temperature, humidity, season, and day of the week); and z_t is the vector of air pollution variables on day t . Smoothing plots, obtained by a generalized additive modeling technique, were first produced to determine the functional dependence between daily hospital visits and covariates, without imposing a rigid parametric assumption about that dependence.^{15,16} The regression coefficients were then estimated by a quasi-likelihood approach¹⁴ with robust estimates of variances.¹⁷ Given that the model included previous days' outpatient visits, the estimated coefficients for air pollution represented the effects, based on the previous days' visits.

Results

The mean number of hospital outpatient visits in Fuxing Hospital in 1990 was 1 386/d; 8.5% of those visits were to the surgery department; 7.9% to the pediatrics department; 20.6% to the internal medicine department; and the remaining 63.1% to other departments, including obstetrics and gynecology, orthopedics, dermatology, neurology, ophthalmology, ear-nose-throat, stomatology, and Chinese traditional medicine. TSP measurements were available for 210 d (mean, 388 µg/m³; maximum, 1 255 µg/m³), and SO₂ measurements were available for 206 d (mean, 119 µg/m³; maximum, 478 µg/m³). TSP and SO₂ concentrations were much lower in summer than in winter (Table 1).

Table 2.—Linear Regression Analysis of Estimated Effects* (Percentage Increase) of SO₂ and TSP on Hospital Outpatient Visits: Comparison between Most Polluted and Least Polluted Days

Type of visit	SO ₂ (μg/m ³)			TSP ^b (μg/m ³)		
	β	SE ^c	t	β	SE ^c	t
<i>Pollutants analyzed separately</i>						
Surgery	-5.2	13.2	-0.4	3.7	8.1	.5
Nonsurgery	22.2	5.7	4.1	17.3	4.1	4.2
Pediatrics	38.2	13.7	2.7	28.9	9.5	3.0
Internal medicine	30.7	8.5	3.7	25.6	5.7	4.5
Other ^d	15.1	5.7	2.7	11.8	4.2	2.8
Total	20.3	5.2	4.1	16.5	4.0	4.1
<i>Pollutants analyzed simultaneously</i>						
Surgery	-14.6	14.8	-1.0	8.2	8.4	1.0
Nonsurgery	12.7	6.0	2.1	12.4	4.2	2.9
Pediatrics	24.4	18.3	1.3	19.1	11.5	1.7
Internal medicine	17.5	9.0	1.9	19.2	6.0	3.2
Other ^d	7.6	6.4	1.2	8.6	4.5	1.9
Total	10.7	5.6	1.9	12.3	4.3	2.9

Note: Values for SO₂ and TSP were 478 μg/m³ and 1 255 μg/m³ on the most polluted day and 6 μg/m³ and 106 μg/m³ on the least polluted day.

*The model was adjusted for quintiles of temperature, quintiles of humidity, indicator variables for the day of the week, and season.

^cStandard errors were estimated by robust method.

^dObstetrics and gynecology, orthopedics, dermatology, neurology, ophthalmology, ear-nose-throat, stomatology, and Chinese traditional medicine.

monary disease and levels of SO₂ and black smoke in Barcelona, Spain.

Few reports on air pollution and outpatient visits are available. Lutz found a strong positive correlation between average weekly pollutant levels and the percentage of diagnoses made by respiratory tract and cardiac physicians during visits to a small family practice clinic in Salt Lake City, Utah.²⁰ The study was limited by use of weekly, rather than daily outpatient visits. Two major factors restrict the potential for epidemiologic studies of the short-term association of air pollution with outpatient visits in the United States: (1) outpatient visits are usually scheduled by appointment, and (2) many patients do not visit doctors in local clinics or hospitals. Therefore, outpatient records from a hospital do not reliably reflect the true morbidity in a given community.

In China, patients seek medical care in their designated local hospitals. Outpatient visits are scheduled on a first-come, first-serve basis. Visits to doctors in higher level hospitals often require referral from local community hospitals. Thus, records from a community-based hospital provide reliable information on morbidity for a geographically defined population and offer an opportunity to evaluate the association between daily hospital outpatient visits and air pollution.

A statistically significant relationship was found between increased levels of TSP and SO₂ and an increased number of daily hospital outpatient visits. The estimated associations with air pollution were 1.5- to 2.0-fold stronger for pediatrics and internal medicine visits than for other visits. Increased levels of TSP and SO₂

were associated independently with increased numbers of outpatient visits. The association remained significant for internal medicine visits, even after adjustment for surgery visits. In season-specific analyses, SO₂ and TSP were each associated significantly with internal medicine visits in both winter and summer. The mean daily SO₂ concentration was only 17 μg/m³ (maximum, 51 μg/m³) during summer, a value that is far below the cut-off level designated in the WHO-recommended air-quality standard. This study and several previous investigations^{4,18,19} provide coherent evidence that current air-pollution levels in Beijing are associated with adverse health outcomes, including decreased pulmonary function, respiratory symptoms, increased numbers of hospital visits, and increased mortality. These data indicate that attention needs to be given to reduce air pollution in Beijing.

In the present study, the range of SO₂ levels (maximum to minimum) was 45 μg/m³ in summer and 466 μg/m³ in winter, for a 10-fold seasonal difference. However, the adjusted between-season difference in the percentage of internal-medicine visits was less than 2-fold (16% in summer and 28% in winter). A similar pattern of seasonal differences was observed for TSP. These results were consistent with those of a previous study on mortality,⁴ suggesting a steeper association between morbidity and air pollution at low concentrations of pollutants than at high concentrations. Such a nonlinear association is contrary to the model in which effects are minimal or undetectable at low concentrations, but such effects rapidly become stronger with increasing exposure above some

ENERGIZING CHINA

*Reconciling Environmental Protection
and Economic Growth*

EDITED BY

Michael B. McElroy, Chris P. Nielsen, and Peter Lydon

AIR POLLUTION AND ITS HEALTH EFFECTS IN URBAN CHINA

Xu Xiping
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BACKGROUND

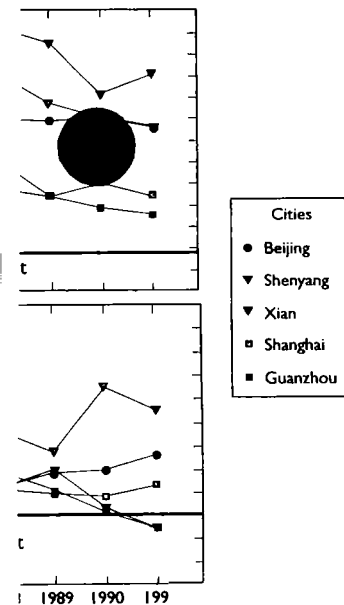
CHINA IS IN THE MIDST of rapid industrialization and economic growth. The environmental and health consequences of economic activity have become an increasing public concern. A national survey of mortality has shown that respiratory diseases are the second leading cause of death among the overall population in China (Five major 1987). Several studies from Beijing have demonstrated an exposure-response relationship between air pollution level and several health endpoints, including loss of pulmonary function, self-report of respiratory symptoms and doctor-diagnosed bronchitis, daily hospital admissions, and daily mortality (X. Xu et al. 1991; X. Xu and Wang 1993; X. Xu et al. 1994; Pope and X. Xu 1993; X. Xu et al. in press; Gao, Xu, Li, et al. 1993; Gao, Xu, Chen, et al. 1993; X. Xu, Li, and Huang 1995; Z.Y. Xu, et al. 1993).

Coal has long been the dominant energy source in China, now accounting for more than 70% of total energy production (Zhao and Sun 1986). Sulfur dioxide (SO_2) emissions result primarily from coal combustion, and are estimated at about 18 million tons each year. Nearly half of the coal consumed is burned in the cities, much in small boilers and household stoves for heating and cooking. It is burned with low

her compared data nor ap-
control procedures to cross-
s been a great difference in
or e... the average TSP
ve winter (January) days in
ang EPB was 1,550 micro-
to 610 $\mu\text{g}/\text{m}^3$ by the Anti-
IS program. It is not clear
by monitoring at different
urting in 1994, the EPB took
five cities. The ambient data
m because it is believed that

P measured in the five cities
81–1991) mean concentra-
 $\mu\text{g}/\text{m}^3$) and lowest in Shang-
and Xian in between (97, 89,

for Five Cities



and 88 $\mu\text{g}/\text{m}^3$ respectively). In contrast to SO_2 , the average annual particulate concentration was highest in Xian (502 $\mu\text{g}/\text{m}^3$) and lowest in Guangzhou (228 $\mu\text{g}/\text{m}^3$), with Shenyang, Beijing, and Shanghai in between (461, 421, and 248 $\mu\text{g}/\text{m}^3$ respectively). There is a distinct seasonal variation in SO_2 and TSP, with the lowest concentration of both between July and September and the highest concentration of both between December and March (Figures 2 and 3), suggesting that coal combustion for household heating is an important source of air pollution.

HEALTH EFFECTS OF AIR POLLUTION

Acute Effects on Mortality

Beijing study (X. Xu *et al.* 1994). Beijing was listed previously as one of the five large cities which participated in GEMS. The association of air pollution with daily mortality in 1989 was examined in two residential areas in Beijing in collaboration with China's Ministry of Public Health. Annual mean concentrations of SO_2 were 102 $\mu\text{g}/\text{m}^3$ (maximum daily

FIGURE 2

Average Monthly SO_2 Concentration for Three Areas in Beijing

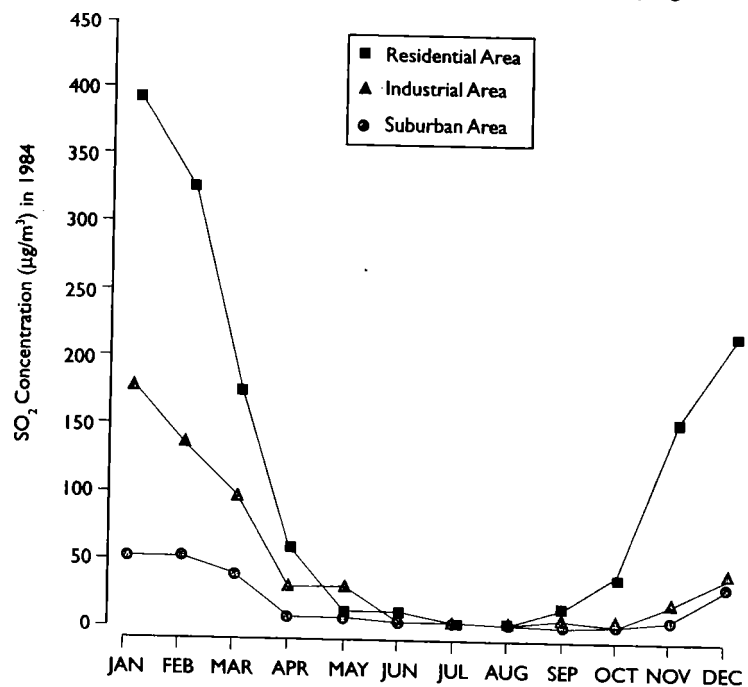
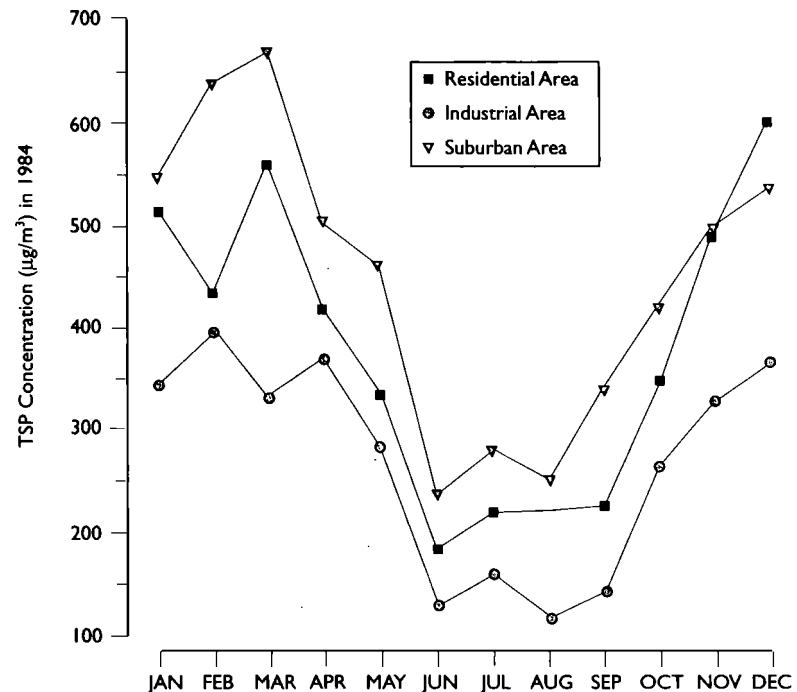


FIGURE 3

Average Monthly TSP Concentrations for Three Areas in Beijing



concentration: $630 \mu\text{g}/\text{m}^3$) and mean total suspended particulates was $375 \mu\text{g}/\text{m}^3$ (maximum daily concentration: $1003 \mu\text{g}/\text{m}^3$). Daily counts of deaths were regressed using Poisson regression on the logarithms of sulfur dioxide (SO_2) and TSP concentrations, controlling for temperature, humidity, and day of week effects. A highly significant association was found between $\ln(\text{SO}_2)$ and daily mortality (Figure 4). The risk of total mortality was estimated to increase by 11% (95% Confidence Interval [CI]: 5% to 16%) with each doubling in SO_2 concentration. The association of $\ln(\text{TSP})$ with total daily mortality was positive but not significant (4% increase in mortality with each doubling in TSP; 95% CI: -2% to 11%). When mortality was analyzed separately by each of the underlying causes, the association with a doubling in SO_2 was significant for chronic obstructive pulmonary disease (29%), pulmonary heart disease (19%), and cardiovascular disease (11%). It was marginally significant for the other nonmalignant causes (8%), but not statistically significant at the 95% CI for cancer (2%). A similar association was seen for a doubling in TSP (4%, 38%, and 8% for total, chronic ob-

Areas in Beijing

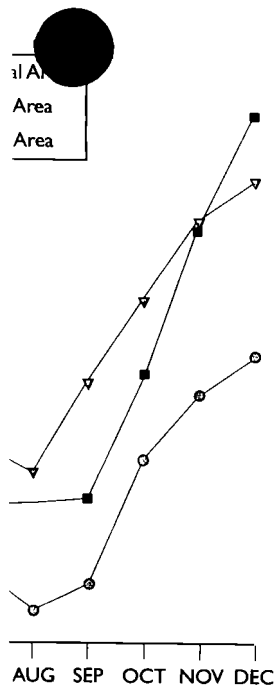
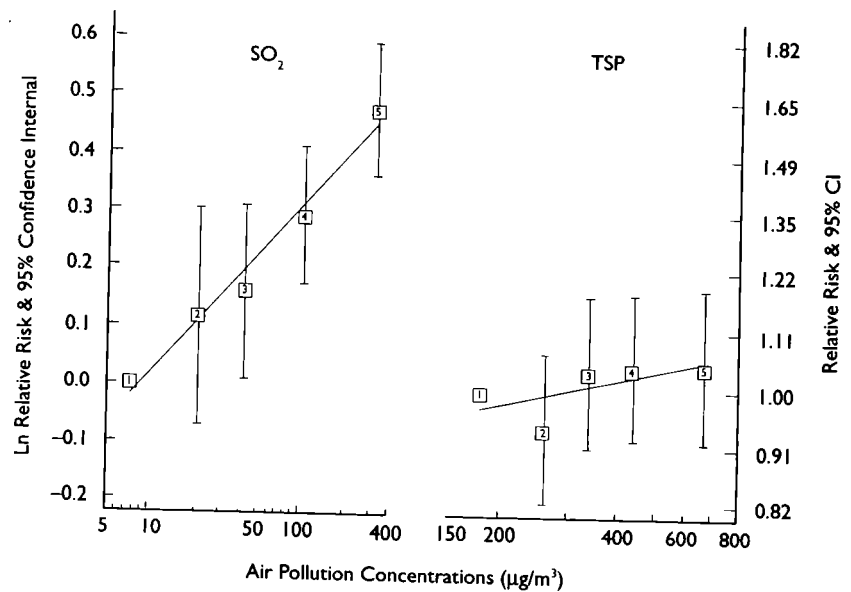


FIGURE 4

Relative Risk of Mortality Associated with SO₂ and TSP Concentrations in Beijing



structive pulmonary disease, and pulmonary heart disease mortality respectively), but the result was only statistically significant for chronic obstructive pulmonary disease. In season-specific analysis, both SO₂ and TSP were found to be significant predictors of total daily mortality in summer. In winter, SO₂ was again significantly associated with increased mortality, but no positive association was found between TSP and mortality. In both seasons, the strongest effects of SO₂ and TSP were consistently seen for mortality from respiratory diseases.

Shenyang study (Z. Y. Xu *et al.* forthcoming). The relation between air pollution and daily mortality in 1992 was examined in Shenyang. Very high concentrations of SO₂ (mean 197 μg/m³, maximum 659 μg/m³) and TSP (mean 430 μg/m³, maximum 1140 μg/m³) were observed in the residential and commercial areas. As with the Beijing study, daily counts of deaths were regressed using Poisson linear regression on the SO₂ and/or TSP, this time controlling for temperature, humidity, and seasons. Previous three day running averages of TSP and SO₂ were used as air pollution measurements. A significant association of total mortality was found for SO₂ and a marginally significant one was found for TSP. Total mortality was estimated to increase by 2% with each 100 μg/m³ increase in SO₂ concentration, and by 1% with each 100 μg/m³ in-

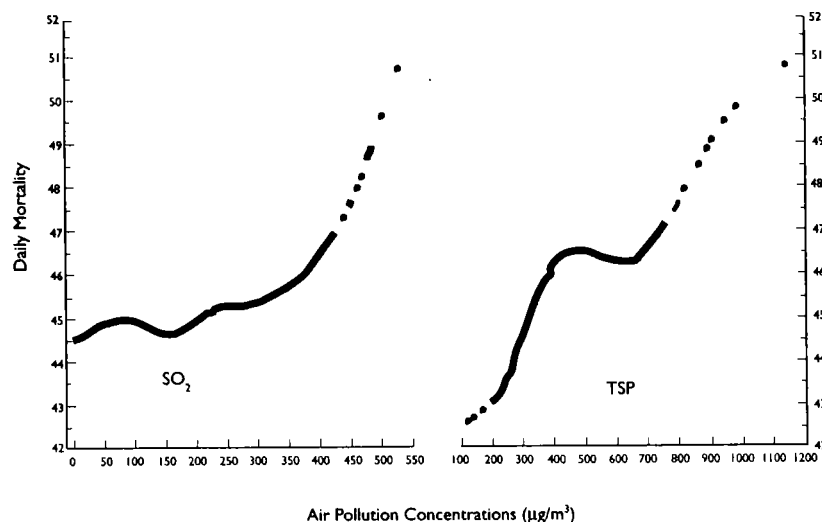
crease in TSP (Figure 5). When mortality was analyzed separately by cause, SO_2 was found to be a significant predictor of death from chronic obstructive pulmonary disease (COPD) (6% increase), cardiovascular disease (CVD) (3% increase), and other-cause diseases (4% increase), but not for cancer (0% increase). TSP was only significantly associated with cardiovascular disease (2% increase). Since TSP and SO_2 were highly correlated in the dataset, both TSP and SO_2 were simultaneously included in the model to estimate the independent effect of each pollutant. TSP and SO_2 each remained significant predictors for CVD and COPD. The results from this primary analysis suggest that increased daily mortality in Shenyang is associated with high air pollution levels.

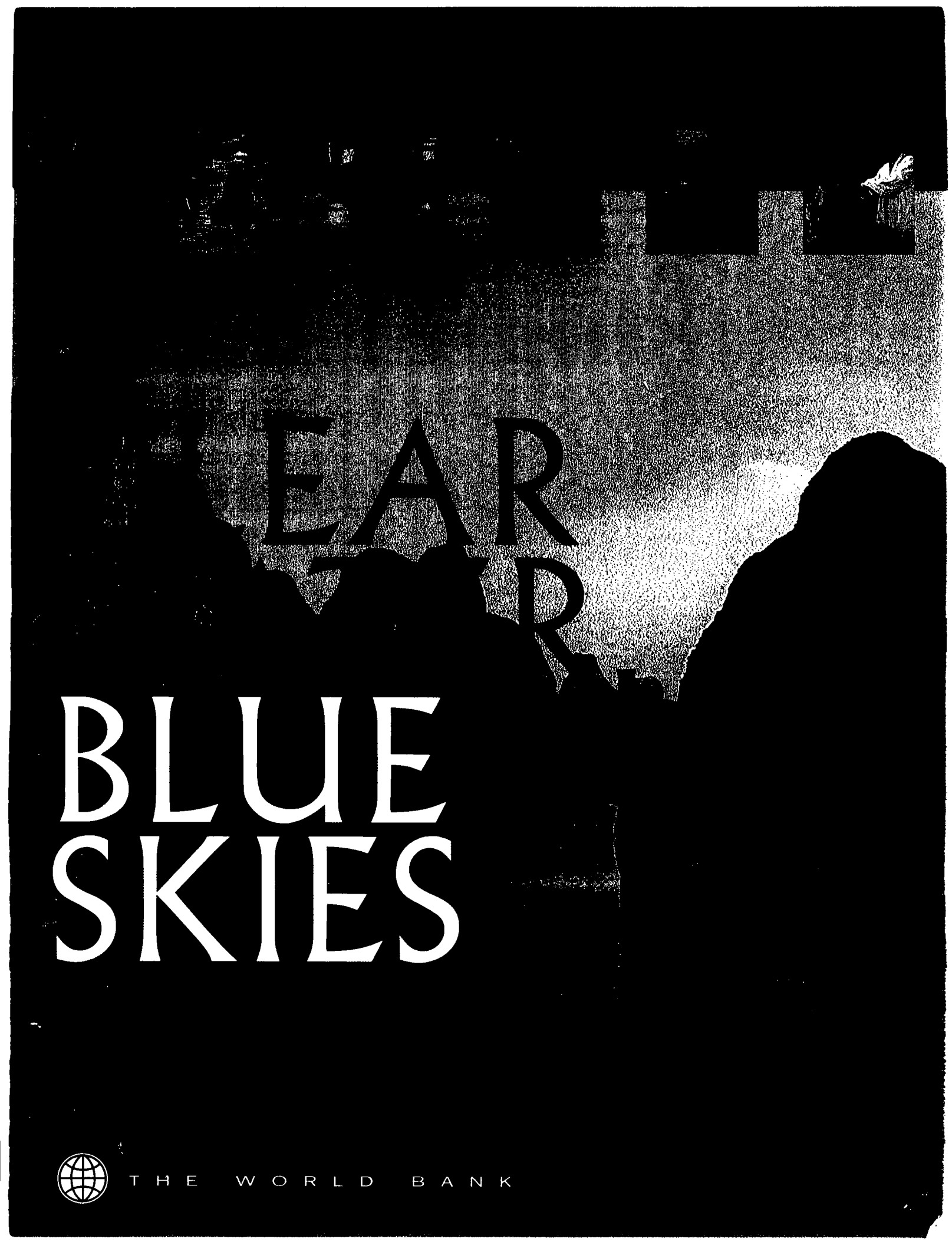
Chronic Effects on Mortality

Shenyang study (Z.Y. Xu 1993). Shenyang monitoring data was grouped into three areas according to outdoor air pollution levels (low, middle, or high). SO_2 mean concentrations were 256, 116, and $75 \mu\text{g}/\text{m}^3$ respectively in high, middle, and low polluted areas; TSP mean concentrations were 560, 497, and $353 \mu\text{g}/\text{m}^3$ respectively. The total age-adjusted mortality rate was highest in the most polluted area, and lowest in the middle polluted area. Because many residents living in the low polluted area may work in the high polluted area, or may have recently moved from the high polluted area, the outdoor air pollution data for their

FIGURE 5

Daily Mortality and SO_2 and TSP Concentrations in Shenyang





FEAR NOT BLUE SKIES



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are expected to occur beyond the time frame of this study (that is, after 2020). Local and regional pollution is expected to cause more damage in the short term.

Economic valuation of impacts

Valuation of the physical damages of air and water pollution can provide a useful guide to environmental policy. For individual pollutants it is possible to find the least-cost means of abatement without assigning monetary values. One way is to rank the costs of various options for meeting environmental standards or other targets. But when policymakers have to compare the costs of different pollutants—to human health or productivity—cost-effectiveness analysis based on physical damages is not feasible. How should a municipality decide how much of its budget to devote to controlling air pollution relative to water pollution, for example? Or, within the water pollution budget, how much should be devoted to controlling biological oxygen demand pollution and how much for heavy metals?

The most common way to create a comparative framework is to convert physical damages to economic values. The economic valuation of a human life poses the greatest difficulty because it raises social, political, and ethical questions. To value the excess mortality attributable to pollution, this report uses measures of willingness to pay, the standard methodology for valuing environmental impacts in industrial countries. A mid-range estimate of the willingness to pay to avoid a premature death in the United States is about \$3 million per statistical life. This estimate can be conservatively scaled for use in China by multiplying by the ratio of average per capita incomes in the two countries (\$500/\$25,000), which results in an estimate of \$60,000 per statistical life in urban areas and \$31,800 in rural areas. Much lower values are obtained by using the “human capital” approach, which includes only the lost wages due to a premature death. Lost wages total about \$9,000 in urban areas and \$4,800 in rural areas.⁶ Premature deaths caused by air pollution cost about \$14 billion a year under the willingness-to-pay valuation and \$2 billion a year under the human capital valuation (table 2.4). However, disease and illness account far more damages under both the willingness-to-pay and human capital approaches.

TABLE 2.4

Air and water pollution cost China about 8 percent of GDP

(millions of U.S. dollars)

Problem	Willingness-to-pay valuation	Human capital valuation
Urban air pollution	32,343	11,271
Premature deaths	10,684	1,597
Morbidity	21,659	9,674
Restricted activity days	3,842	3,842
Chronic bronchitis	14,092	2,107
Other health effects	3,725	3,725
Indoor air pollution	10,648	3,711
Premature deaths	3,517	526
Morbidity	7,131	3,185
Lead exposure (children)	1,622	270
Water pollution	3,930	3,930
Health care costs	1,988	1,988
Agricultural and fishery losses	1,159	1,159
Water shortages	783	783
Acid rain	5,046	5,046
Crop and forest damage	4,364	4,364
Materials damage	271	271
Ecosystem damage	411	411
Total	53,589	24,228
Percentage of GDP	7.7	3.5

Source: Annexes 2.1 and 2.2.

The valuation of other impacts, such as the medical costs of illness or damage to agricultural crops, is not as contentious. The health and productivity losses associated with urban air pollution, including hospital and emergency room visits, lost work days, and the debilitating effects of chronic bronchitis, are estimated at more than \$20 billion a year, making them the single largest environmental cost in China today. Although comprehensive data on lead poisoning in China are not available, it is possible to estimate the lead exposure of children based on numerous studies of lead poisoning (annex 2.1).

Total air and water pollution costs are conservatively estimated at \$54 billion a year, or roughly 8 percent of GDP (see table 2.4). The largest losses to health, productivity, and agriculture are:

- Health losses associated with urban air pollution—particularly debilitating chronic bronchitis.
- Health losses associated with indoor air pollution.
- Chronic disease from water pollution—especially heavy metals and toxics.
- Crop and forestry damage from acid rain.
- Nervous system damage and reduced intelligence among children exposed to high levels of lead.

China's Air Pollution Risks

Although China is struggling with major urban air quality problems, its most serious health problem is indoors.

H. KEITH FLORIG

Not long ago, environmental health risks in China paled in comparison to threats from malnutrition and infectious diseases. But as China modernized, these ominous risks were brought under control, decreasing the total death rate from 20 per 1000 in 1949 to approximately 6 per 1000 in 1995. Today, diseases linked to air pollution are among the largest threats to public health in China, ranking with smoking as the most frequent cause of death.

Data compiled from a series of Chinese epidemiologic studies and official disease statistics suggest that air pollution is responsible for more than 1 million deaths per year in China, or about one in every eight deaths nationwide. Although Chinese run lower risks than Americans from several other kinds of hazards, their individual risk of death from air pollution is 7-10 times higher (1-6; Table 1). Of the many air pollutants to which the Chinese population is exposed, particulate matter, sulfur dioxide (SO₂), and polycyclic aromatic hydrocarbons from fuel combustion cause the most extensive health damage.

Most of the scientific and regulatory attention that nations have devoted to air pollution has focused on outdoor air quality in urban areas. Although China is struggling with some of the world's worst urban air quality problems, its more serious air pollution problems are found indoors.

Like residents of other developing nations, much of China's population cooks and heats by using unvented stoves fueled by coal or biomass. Air pollution levels in Chinese homes often exceed Chinese and World Health Organization (WHO) standards for ambient outdoor air and typical urban outdoor pollution levels. For most of the population, the health impacts from home exposure to air pollutants are greater than the effects of occupational exposure.

Because exposure patterns and the composition of air pollution in China are quite different from those in Western industrialized countries, the extensive literature in the West on the adverse effects of air pol-

lution is of limited value in estimating the way it affects health in China. Using methods tailored to Chinese patterns of pollution and population, Chinese epidemiologists began more than a decade ago to tackle the task of measuring these health effects.

Role of household fuel burning

In urban China, coal burning is the dominant source of indoor and outdoor air pollution. More than 75% of China's primary energy needs are supplied by domestic coal. Studies of the contribution of various sources of air pollution from coal burning suggest that household coal burning is the largest contributor to outdoor particulate and SO₂ concentrations at ground level in all but the most heavily industrial northern cities. Industrial coal burning plays a more significant role in southern cities without major heating needs (7).

Since the publication of China's first particulate control regulations in 1973, most industrial and residential boilers have adopted some basic particulate controls, although average removal efficiencies are only about 70%. But there are no particulate controls on China's hundreds of millions of household stoves. Controls on SO₂ emissions are rare, even on large industrial boilers, kilns, and furnaces.

China began systematic monitoring of outdoor air quality in the early 1980s and today maintains a network of monitors measuring multiple pollutant species in more than 100 cities. Data from this network show intercity variations of almost an order of magnitude in annual average concentrations of particulates and SO₂. These variations reflect intercity differences in heating demand, local coal quality, amount of heavy industry, natural dust, weather, and topography.

Daily patterns of outdoor urban particulate and SO₂ levels show morning and evening peaks that correspond to periods when most cooking is done. Seasonal patterns in particulate and SO₂ levels show pronounced increases in northern cities that correspond to periods of high heating demand.

less to total population risk than does air pollution from cooking and heating (16).

Historically, the Chinese diet has been low in animal fat. As a result, the death rate from heart disease in China is only half that in industrialized countries like the United States. CHD, characterized by a narrowing of the coronary arteries, is the most common form of heart disease. Smoking and air pollution are the most important risk factors for CHD in China. In a review of Chinese epidemiologic studies on the health effects of smoking, Gao Yutang and colleagues at the Shanghai Cancer Institute concluded that mortality rates from CHD in urban areas are about three times higher among smokers than among nonsmokers. This implies that about 60% of the 85,000 urban deaths per year from CHD are smoking related.

Xu Xiping and colleagues at Harvard University, Cambridge, Mass., studied the relationship between daily mortality and ambient air pollution levels in Beijing. Adjusting for temperature and humidity effects, they found that rates of death from heart disease are about doubled during the few months of the year with the highest outdoor levels of particulates and SO_2 . This study implies that outdoor and indoor pollution from coal burning (the dominant source of air pollution in Beijing) is likely to contribute much of the remaining population risk for CHD in urban China.

Mortality rates for both lung cancer and CHD in rural areas are only half those in urban areas, despite comparable rates of smoking and higher levels of indoor air pollution in the countryside. Possible explanations for this paradox include a higher ratio of pipe to cigarette smoking in rural areas; more misclassification of rural lung cancer and CHD deaths; and, in the case of CHD, differences in diet and exercise among urban and rural residents.

Pneumonia is the leading cause of death among Chinese children, killing approximately 300,000 annually (6). In a review of the causes of death from childhood pneumonia in China, Jiang Zaifang and colleagues at Beijing Medical University found that high pneumonia mortality is associated with par-

ents' chronic respiratory infections, crowded living conditions, passive smoking, high levels of indoor air pollution from fuel combustion, and parents' delay in seeking medical attention for sick children. These last two factors are thought to be responsible for the fact that the mortality rate from childhood pneumonia in rural areas in China is four times that in the cities.

The morbidity risks associated with exposure to air pollution in childhood have been studied by several Chinese investigators. Liu Yulin from the Institute of Pediatrics in Beijing found that children living with adults who smoke or in homes with coal stoves had almost double the chance of contracting pneumonia as did children in homes without coal and smokers. Xu Zhaoyi in Shenyang found up to four times more rhinitis, pharyngitis, and tonsillitis among children living in areas of heavier versus lighter outdoor air pollution. Finally, He Qingci of the Wuhan Environmental Protection Institute found that children who lived in Wuhan's urban core, where outdoor TSP levels averaged 251 micrograms per cubic meter ($\mu g/m^3$), had lung capacities that were 5% smaller than children living in the suburbs where outdoor TSP levels averaged 110 $\mu g/m^3$.

Epidemiologic studies in China, as elsewhere, have shown increased risks for lung cancer, leukemia, chronic respiratory illness, and heart disease resulting from exposure to various air pollutants in the workplace. For some industries, including asbestos, textiles, and metals smelting, air pollution risks on the job often exceed average population risks from indoor residential fuel burning. Such high-risk occupations, however, comprise only a small fraction of all jobs and thus contribute less than residential exposures to total population health damage. In a study of lung cancer among workers in the industrial city of Tianjin, Wang Qingsheng and co-workers of the Tianjin Cancer Institute found that only 2% of the lung cancers in Tianjin could be attributed to differences in the type of industry in which workers were employed.

Smaller risks associated with widespread workplace exposures to coal dust and coal smoke may have a larger population-wide impact on health than exposures in these high-risk occupations. In a random sample of working-age adults in Beijing, Xu Xiping and colleagues at Harvard University found that almost 50% of workers reported being exposed to dust, gas, or fumes in the workplace. Symptoms of chronic lung disease were more common among the work-exposed cohort, but the strength of this effect was smaller than that commonly associated with either smoking or the use of indoor coal stoves.

Information from the available Chinese epidemiologic literature on attributable risks and background rates of disease in urban and rural populations was used to make upper and lower bound estimates of the nationwide health impacts of air pollution in China (see Table 4). The results, which contain considerable uncertainty, suggest that COPD is by far the largest contributor to pollution-related mortality among the four major diseases considered here.

The results further indicate that deaths from all pollution-related diseases are much greater in the countryside than in the cities—a consequence of China's large rural population and, for COPD and child-

TABLE 3

Air pollution in Chinese homes

Average pollutant levels in 95% of the homes in each category are within a factor of 3 of these typical values.

Pollutant	Area	Fuel	Typical indoor concentration ($\mu g/m^3$)	
			Winter	Summer
TSP	Urban	Coal	700	270
TSP	Urban	Gas	350	170
TSP	Rural	Coal	900	250
TSP	Rural	Biomass	3500	950
SO_2	Urban	Coal	270	190
SO_2	Urban	Gas	85	60
SO_2	Rural	Coal	750	250
SO_2	Rural	Biomass	—	—

Note. Insufficient information is available to adequately characterize SO_2 levels in rural homes burning biomass fuels.
Source: Indoor Air Pollution Database for China (9).

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Retinopathy- any disease or disorder of the retina; usually refers to damage to the retina caused by high blood pressure or diabetes mellitus

Retinoscopy- a method of determining focusing errors of the eye in which light is shined through the pupil and the reflected beam is measured

Retroviruses- a group of viruses that are made up of RNA instead of DNA, including HIV and the virus that causes T-cell leukemia

Reye's syndrome- a rare disorder mainly affecting those under the age of 15 that is characterized by brain and liver damage following a viral infection such as chickenpox or the flu; may be linked to taking aspirin to treat a viral infection

Rh blood group- a blood group classifying whether the substances called Rhesus (Rh) factors are present on the surface of red blood cells; the "positive" or "negative" designation in blood classification (for example, "O negative")

Rheumatic fever- a disorder that follows a throat infection by the streptococcus bacteria and causes inflammation in body tissues

Rheumatoid arthritis- a condition in which joints in the body become inflamed, stiff, painful, and sometimes deformed because of the body's own immune system attacking the tissues

Rheumatoid factors- antibodies that are present in about 80 % of people with rheumatoid arthritis; their detection through blood testing can help to diagnose the disorder

Rh immunoglobulin- a substance used to prevent a woman who is Rh incompatible with her fetus from becoming Rh sensitized

Rh incompatibility- a condition in which a pregnant woman's Rh factor does not match that of the fetus; can lead to the production of antibodies by the mother that destroy the fetus' red blood cells

Rhinitis- inflammation of the mucous membrane lining the nose, which can cause sneezing, runny nose, congestion, and pain; when caused by substances in the air, it is called allergic rhinitis or hay fever

Rhinoplasty- surgery that changes the structure of the nose, either to improve appearance or to correct a deformity or injury

Rhinophyma- a bulb-shaped deformity and redness of the nose as a result of severe rosacea

Rh sensitized- a condition in which a woman who is Rh-negative develops permanent antibodies against Rh-positive blood as a result of exposure to the blood of her fetus; can cause fetal hemolysis in subsequent pregnancies

Rhythm method- a method of preventing pregnancy in which a couple does not have sexual intercourse during the days of the menstrual cycle during which fertilization can occur

Riboflavin- a vitamin belonging to the vitamin B complex that is important in many processes in the body and helps to maintain healthy skin

Periostitis- inflammation of the periosteum

Peripheral nervous system- the nerves that branch out from the brain and spinal cord to the rest of the body

Peripheral vascular disease- the narrowing of blood vessels in the legs or arms, causing pain and possibly tissue death (gangrene) as a result of a reduced flow of blood to areas supplied by the narrowed vessels

Peristalsis- wavelike movement of smooth muscle-containing tubes, such as the digestive tract

Peritoneum- the membrane that lines the abdominal cavity and covers the abdominal organs

Peritonitis- inflammation of the peritoneum

Pernicious anemia- an anemia caused by a failure to absorb vitamin B₁₂; which is essential in the production of normal red blood cells

Perthes' disease- inflammation of the growing head of a femur; a type of osteochondritis juvenilis

Pertussis- a bacterial infection of the respiratory tract characterized by short, convulsive coughs that end in a whoop sound when breath is inhaled (commonly called whooping cough); mainly affects children

Petit mal- a seizure characterized by loss of awareness for brief periods

PET scanning- see Positron emission tomography scanning

Peutz-Jeghers syndrome- a genetic disorder in which there are polyps in the small intestine and brown melanin spots on the lips, mouth, fingers, and toes

pH- a measure of the acidic or basic character of a substance

Phagocyte- an immune system cell that can surround and digest foreign bodies, unwanted cellular material, and microorganisms

Phantom limb- the sensation of a limb after it has been amputated

Pharyngitis- inflammation of the throat (the pharynx), causing sore throat, fever, earache, and swollen glands 12

Pharynx- the throat; the tube connecting the back of the mouth and nose to the esophagus and windpipe

Phenothiazines- a group of drugs used as antipsychotics, antihistamines, and antiemetics

Phenylketonuria- a hereditary disorder in which the enzyme that converts the amino acid phenylalanine into another amino acid is defective, meaning phenylalanine must be kept out of the diet

Pheochromocytoma- a noncancerous tumor of cells that produce epinephrine and norepinephrine, causing higher levels of these hormones in the blood and an increase in blood pressure

TIA- see Transient ischemic attack

Tibia- the thicker of the two long bones in the lower leg; commonly called the shin

Tic- an involuntary, repetitive movement such as a twitch

Tic douloureux- see Trigeminal neuralgia

Ticks- small, eight-legged animals that can attach to humans and animals and feed on blood; sometimes spread infectious organisms via their bites

Tietze's syndrome- inflammation of the cartilage that joins ribs to the breastbone, causing chest pain

Tinea- a group of common infections occurring on the skin, hair, and nails that are caused by a fungus; commonly referred to as ringworm

Tinnitus- a persistent ringing or buzzing sound in the ear

Tipped uterus- an abnormal condition in which the uterus is tilted backward instead of slightly forward

Tissue plasminogen activator- a substance produced by the body and as a genetically engineered drug to prevent abnormal blood clotting

Tissue typing- tests used to determine the compatibility of tissues used in grafts and transplants

T-lymphocyte- a type of white blood cell that fights infections and destroys abnormal cells directly; as compared with releasing antibodies to fight infection

T-lymphocyte killer cell- a type of T-lymphocyte white blood cell that attaches to abnormal cells and releases chemicals that destroy them

TMJ syndrome- see Temporomandibular joint syndrome

Tolerance- decreased sensitivity of the body to a certain drug, usually either because the liver becomes more efficient at breaking down the drug or the body's tissues become less sensitive to it; increased tolerance creates a need for a higher dose of the drug in order to have the same effects

Tonometry- the procedure used to measure the pressure within the eye; is useful in detecting glaucoma

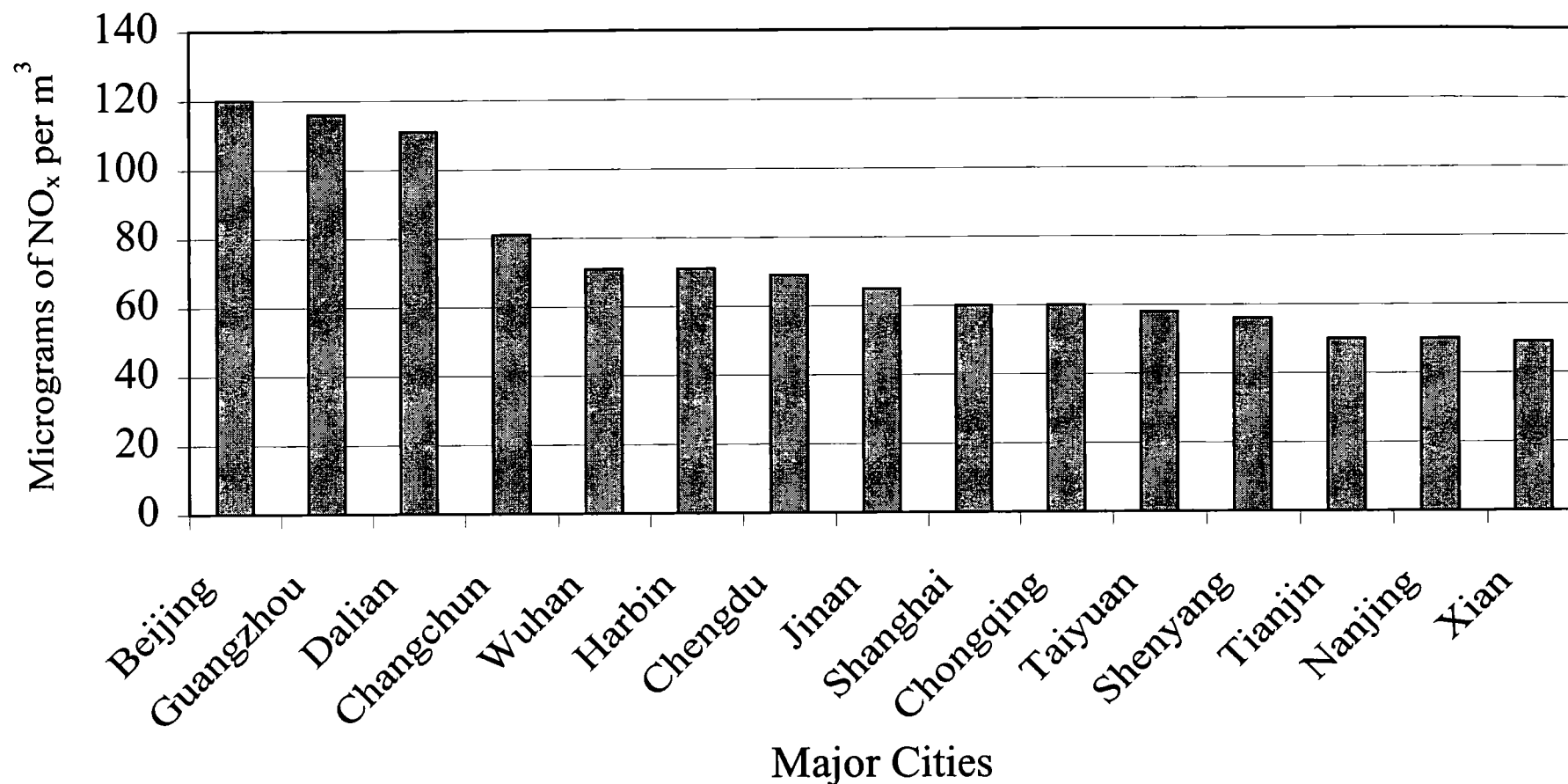
Tonsils- masses of lymphoid tissue located at either side of the back of the throat

Tonsillectomy- surgical removal of the tonsils, usually to treat tonsillitis

Tonsillitis- infection and inflammation of the tonsils 13

Tourette's syndrome- a movement disorder characterized by involuntary tics and noises, and in some cases uncontrollable shouting of obscenities

Figure 10. 1994 Daily Average NO_x Concentrations



WHO Recommended Level for NO₂ is 40 micrograms per cubic meter

1994 Levels of 15 most populated cities
1994 Daily Average NO_x Emissions

1	Beijing	120
2	Guangzhou	116
3	Dalian	111
4	Changchun	81
5	Wuhan	71
6	Harbin	71
7	Chengdu	69
8	Jinan	65
9	Shanghai	60
10	Chongqing	60
11	Taiyuan	58
12	Shenyang	56
13	Tianjin	50
14	Nanjing	50
15	Xian	49

Ambient NOx Concentrations in Chinese Cities
(ug/m3, annual daily average)

City	north-south north=1;south=0	coast coast=1	Population *	1981	1982	1983
Shanghai	0	1	8249.1	80.0	60.0	38.0
Beijing	1	1	6093.3	60.0	60.0	42.0
Tianjin	1	1	4720.5	80.0	70.0	70.0
Shenyang	1	1	3762.0	90.0	70.0	56.0
Wuhan	0	0	3519.6	50.0	50.0	77.0
Guangzhou	0	1	3113.8	50.0	50.0	79.0
Harbin	1	0	2505.2	40.0	80.0	94.0
Chongqing	0	0	2377.8	40.0	70.0	49.0
Nanjing	0	1	2224.2	60.0	80.0	
Xian	1	0	2114.9	60.0	50.0	43.0
Chengdu	0	0	1932.8	20.0	40.0	44.0
Dalian	1	1	1855.2	70.0	110.0	66.0
Changchun	1	0	1810.4	50.0	40.0	44.0
Jinan	1	1	1659.9	90.0	60.0	
Taiyuan	1	0	1642.3	60.0	50.0	
Qingdao	1	1	1584.1	30.0	60.0	73.0
Zibo	1	1	1346.3			
Zhengzhou	1	0	1323.7	50.0	60.0	61.0
Lanzhou	1	0	1295.6	70.0	50.0	38.0
Anshan	1	0	1251.7	90.0	50.0	91.0
Kunming	0	0	1240.0	50.0	60.0	47.0
Hangsha	0	0	1198.1	40.0	30.0	30.0
Hangzhou	0	1	1184.3	50.0	40.0	35.0
Nanchang	0	0	1168.7	60.0	60.0	23.0
Shijiazhuang	1	0	1159.4	60.0	60.0	58.0
Guiyang	0	0	1131.2	30.0	90.0	
Urumqi	1	0	1130.3	30.0	40.0	41.0
Jilin	1	0	1117.8			62.0
Tangshan	1	1	1110.2	90.0	70.0	
Baotou	1	0	1032.9	80.0	80.0	70.0
Fuzhou	0	1	952.3		30.0	
Xuzhou	1	1	879.8			
Hefei	1	0	866.8	40.0	50.0	44.0
Luoyang	1	0	863.3	20.0		
Datong	1	0	845.0			
Nanning	0	0	829.4	20.0	20.0	9.0
Yicun	1	0	800.3			
Suzhou	0	1	766.3	50.0	40.0	39.0
Daqing	1	0	752.1			
Shenzhen	0	1	695.6			
Hohhot	1	0	683.2	30.0	30.0	
Ningbo	0	1	612.0			
Xining	1	0	569.8			
Hegang	1	0	569.2			
Jiayengyang	0	0	543.1			
Kaifeng	1	0	535.3			
Baoding	1	0	519.2			
Pingdingshan	1	0	517.6			

Xiangfan	0	0	498.0			
Zanjiang	0	1	491.8			
Jiaozuo	1	0	476.8			
Fuzhou	0	1	458.6			
Anyang	1	0	458.4			
Pingxiang	0	0	451.7			
Wenzhou	0	1	449.7	30.0	30.0	28.0
Zigong	0	0	430.5			
Yichang	0	0	428.4			
Nantong	0	1	422.3			
Yinchuan	1	0	412.9		40.0	
Qinghuangdao	1	1	412.5	20.0	30.0	40.0
Liupanshui	0	0	408.0			
Guilin	0	0	398.9	20.0	20.0	10.0
Leshan	0	1	384.3			
Baoji	1	0	379.3			
Haikou	0	1	364.7			
Sipin	0	0	354.6			
Nanchong	0	0	330.0			
Jiujiang	0	0	322.3			
Shizhuishan	1	0	297.9			
Jingdezhen	0	0	294.0			
Qitaihe	1	0	261.8			
Yibin	0	0	261.3			
Wanxian	0	0	258.5			
Ganzhou	0	0	239.4			
Wuzhou	0	0	236.2			
Bejiou	0	0	216.4			
Hanzhong	1	0	197.4			
Sanming	0	1	181.8			
Huaihua	0	0	168.7			
Yuncheng	1	0	135.1			
Yanan	1	0	126.8			
Lasha	0	0	118.0			
Baise	0	0	104.2			
Tumen	1	0	101.6			
Hechi	0	0	97.2			
Jiayuguan	1	0	96.8			
Jian	1	0	73.5			
fushun	1	0	1245.7	40.0	40.0	33.0
benxi	1	0	805.4	40.0	30.0	28.0

* 1994 city-proper non-agricultural population, a conservative lower bound of urban population.

**Data from 1981 to 1990 is from the China National Environmental Monitoring Station

***Data from 1991 to 1995 is from China's National Environmental Protection Agency

1984	1985	1986	1987	1988	1989	1990
55.0	50.0	57.0	60.0	70.0	59.0	59.0
65.0			80.0	92.0	83.0	86.0
64.0	63.0	66.0	50.0		52.0	42.0
65.0	72.0	63.0	58.0	61.0	60.0	78.0
43.0	43.0		57.0	58.0	59.0	39.0
	75.0	98.0	105.0	110.0	133.0	
79.0	77.0	95.0	70.0	42.0	56.0	39.0
75.0	84.0	89.0	80.0	70.0	58.0	71.0
60.0	45.0	59.0	59.0	54.0		51.0
51.0	58.0	81.0	66.0	35.0	48.0	51.0
40.0	53.0	48.0	60.0	50.0	58.0	47.0
77.0	58.0	58.0	58.0	60.0	65.0	71.0
54.0	60.0	50.0	62.0	54.0	56.0	43.0
90.0	45.0	78.0	61.0	62.0	41.0	42.0
43.0	43.0	53.0	54.0	59.0	65.0	
58.0		58.0	61.0		50.0	49.0
17.0				28.0	28.0	31.0
59.0	44.0	44.0	67.0	120.0	140.0	91.0
	94.0	81.0	74.0	79.0	88.0	106.0
76.0	70.0	78.0	77.0	50.0	58.0	74.0
41.0	69.0	79.0	55.0	60.0	52.0	38.0
46.0	30.0	32.0	38.0	42.0	50.0	37.0
40.0	53.0	63.0	60.0	60.0	49.0	62.0
41.0			25.0	23.0	34.0	26.0
65.0	38.0	39.0	65.0	53.0	61.0	52.0
49.0	51.0	42.0	40.0	39.0	33.0	40.0
	53.0	108.0	74.0	98.0	136.0	130.0
54.0		71.0		46.0	57.0	54.0
73.0	73.0	77.0	80.0	55.0	57.0	56.0
73.0			85.0		52.0	49.0
48.0	48.0	30.0	27.0	40.0	36.0	
42.0	46.0	60.0	70.0	58.0	62.0	70.0
51.0	50.0	62.0	43.0		58.0	44.0
28.0		33.0	44.0	45.0	58.0	7.0
18.0	13.0	15.0	17.0		14.0	
46.0	47.0	54.0	46.0		50.0	45.0
19.0	22.0	18.0	19.0		23.0	28.0
	51.0	88.0	39.0	28.0	22.0	25.0
			50.0	62.0	61.0	29.0



37.0	24.0	22.0	13.0	9.0	10.0	
32.0	28.0	34.0	40.0	37.0		29.0
33.0	42.0	41.0	30.0	10.0	27.0	22.0
41.0	33.0	28.0	38.0	42.0	38.0	35.0
	23.0	18.0	21.0	18.0	24.0	
					19.0	12.0



36.0	54.0	82.0	64.0
24.0	42.0		



1991	1992	1993	1994	1995	City
67	84	76	60 9	73	Shanghai
109	119	109	120 1	122	Beijing
50	50	70	50 13	50	Tianjin
96	79	81	56 12	73	Shenyang
56	49	56	71 5	43	Wuhan
112	107	116	116 2	136	Guangzhou
	40	55	71 6	30	Harbin
60	70	50	60 10	70	Chongqing
57	50	50	50 14	49	Nanjing
	51	51	49 15	56	Xian
50	56	65	69 7	74	Chengdu
71	101	102	111 3	100	Dalian
32	35	71	81 4	64	Changchun
	52	74	65 8	45	Jinan
69	80	92	58 11	55	Taiyuan
49	41	51	55	64	Qingdao
	25	35	37	43	Zibo
90	114	129	91	95	Zhengzhou
		72	99	104	Lanzhou
70	80	84	70	88	Anshan
44	38	32	50	33	Kunming
	37	36	33	41	Changsha
62	54	66	71	54	Hangzhou
28	25	22	27	29	Nanchang
	43	48	64	61	Shijiazhuang
	34	52	40	53	Guiyang
139	164	152	147	70	Urumqi
	59	57	70	69	Jilin
	43	53	75	66	Tangshan
52	71	80	73	69	Baotou
	32	28	33	41	Fuzhou
	67	59	45	65	Xuzhou
	36	36	34	53	Hefei
		66		46	Luoyang
45	49	36	37	43	Datong
12	11	11	10	13	Nanning
				35	Yicun
	48	46	48	49	Suzhou
	27	28	26	30	Daqing
71	85	108	118		Shenzhen
22	32		40	32	Hohhot
23				33	Ningbo
	42	42	54	48	Xining
			33	25	Hegang
	25	28	24	28	Hengyang
				51	Kaifeng
39	44	39	48	18	Baoding
	36	32	36	42	Pingdingshan

Xiangfan
Zanjiang
Jiaozuo
Xiamen
Anyang
Pingxiang
Wenzhou
Zigong
Yichang
Nantong
Yinchuan
Qinghuangdao
Liupanshui
Guilin
Leshan
Baoji
Haikou
Sipin
Nanchong
Jiujiang
Shizhuishan
Jingdezhen
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While these estimates demand consideration, they should be used with caution. This area of epidemiology has a relatively short history compared with other disciplines. As a result, many of the studies ignore the effects of pollution levels over time and may not adequately control for the presence of covariates that could magnify or diminish the estimated effects of pollution levels on public health. This criticism notwithstanding, the Working Group on Public Health and Fossil-Fuel Combustion (1997) estimates the number of potential lives that could be saved from particulate matter (PM) alone through a 10% reduction from business as usual over the 2000 to 2020 period. The authors project that 1.5 million premature deaths could be avoided in Centrally Planned Asia.⁶ Since the study assumes an immediate reduction in the mortality rate after a reduction in PM concentrations, the actual number of premature deaths avoided may extend beyond 2020. Additionally, the study does not account for other causes of death, which brings into question the actual number of life-years these statistical lives represent. By assuming PM distributions similar to the United States, however, the authors underestimate the number of deaths because of China's higher use of coal and residential reliance on coal and biomass stoves.

In addition to public health effects, local air pollution adversely impacts agricultural and silvicultural production activities. The World Bank (1997) estimates that the share of farming and forestry output damaged by sulfur deposition is more than 5% of total economic output in these industries in several provinces. This damage affects commodities representing a value of perhaps more than \$4 billion annually in the Chinese economy.

C. Options for Carbon Dioxide Abatement and Local Air Quality Improvement

The future increases in pollution levels reflect the growth of numerous pollution sources, including new power plants, household heating sources, and automobiles. China has set a goal of 95% electrification by the year 2000, and to that end, electricity capacity has increased by 200% between 1980 and 1994. Because Chinese generators tend to be small, to run for long life spans, and to have low efficiency levels, significant potential exists both to improve ambient air quality and to generate credits for carbon abatement under an emissions target. Even relatively simple policies such as washing and screening coal could both improve air quality and generate more efficient power, reducing levels of carbon dioxide emissions (Murray and Rogers 1998).

To reduce congestion on public transportation and to improve commercial service, China has begun encouraging the use of automobiles. Between 1983 and 1990, the ~~automobile stock~~^{# of private vehicles} increased from 1.8 million to 8.2 million and road transportation volume increased at an average annual rate of 13.5% for both passengers and freight while rail volume only increased 7.7% and 5.6% for passengers and freight, respectively (Lin and Polenske 1998). China's emissions standards and automotive technology are similar to those of the west in the 1970's; compared to foreign vehicles, Chinese

⁶ Centrally Planned Asia includes China, Laos, North Korea, and Vietnam.

Articles

Short-term improvements in public health from global-climate policies on fossil-fuel combustion: an interim report

*Working Group on Public Health and Fossil-Fuel Combustion**

Summary

Background Most public-health assessments of climate-control policies have focused on long-term impacts of global change. Our interdisciplinary working group assesses likely short-term impacts on public health.

Methods We combined models of energy consumption, carbon emissions, and associated atmospheric particulate-matter (PM) concentration under two different forecasts: business-as-usual (BAU); and a hypothetical climate-policy scenario, where developed and developing countries undertake significant reductions in carbon emissions.

Findings We predict that by 2020, 700 000 avoidable deaths (90% CI 385 000–1 034 000) will occur annually as a result of additional PM exposure under the BAU forecasts when compared with the climate-policy scenario. From 2000 to 2020, the cumulative impact on public health related to the difference in PM exposure could total 8 million deaths globally (90% CI 4.4–11.9 million). In the USA alone, the avoidable number of annual deaths from PM exposure in 2020 (without climate-change-control policy) would equal in magnitude deaths associated with human immunodeficiency diseases or all liver diseases in 1995.

Interpretation The mortality estimates are indicative of the magnitude of the likely health benefits of the climate-policy scenario examined and are not precise predictions of avoidable deaths. While characterised by considerable uncertainty, the short-term public-health impacts of reduced PM exposures associated with greenhouse-gas reductions are likely to be substantial even under the most conservative set of assumptions.

Lancet 1997; 350: 1341–49

-Log Structure
-Statistical Life years

7

Introduction

Since the industrial revolution, the contribution of anthropogenic sources of greenhouse gases to the global environment has increased significantly.¹ Atmospheric concentrations of greenhouse gases, including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), are of greater importance today than at any other time in human history. These trends can be largely attributed to human activities, primarily fossil-fuel combustion, and change in land use and agricultural practices. In the absence of efforts to reduce greenhouse gases, the concentrations of these gases are expected to grow significantly throughout the next century. The mid-range estimate from the Intergovernmental Panel on Climate Change (IPCC) is that human-induced climate-change will increase surface temperatures by about 2°C by the year 2100;² many uncertainties exist about this projection.

In an effort to protect the global-climate system for future generations, over 150 nations signed the UN Framework Convention on Climate Change (UNFCCC) in June, 1992.³ The UNFCCC established the objective of stabilising atmospheric greenhouse-gas concentrations at levels that would avoid dangerous anthropogenic interference with the global-climate system. Signatory countries will be considering options to control greenhouse gases at the third conference of parties in Kyoto, Japan, in December, 1997.

Short-term public-health impacts have generally not been considered in assessments of global-climate change. Two studies,^{4,5} for example, have projected that well into the next century, weather patterns resulting from climate change are expected to affect the health of future generations. Heat-related mortalities and illnesses, physical and psychological traumas, and changes in vector-borne and infectious diseases, food supplies, and coastal sea-levels are expected to become evident. With various models, we estimate likely public-health benefits of current and future global-climate-change mitigation policies in the first two decades of the 21st century in developed and developing countries.

Many of the fossil-fuel combustion processes that produce CO₂ and other greenhouse gases also produce a host of air pollutants such as particulate matter (PM), sulphate, ozone, and other pollutants, all of which have short-term adverse effects on public health. We use PM as a sentinel air pollutant because it is commonly associated with fossil-fuel combustion. Extensive public-health literature in several countries has shown that both mortality and morbidity are significantly associated with exposure to PM.^{6,7} Most air pollutants from fossil fuels have local impacts but some airborne pollutants (eg, fine particulates) can be transported thousands of miles and have global impacts.⁸

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Figure 1: Models used in estimating the global impact of fossil-fuel consumption on public health

We combined analyses from several independent models of energy consumption (to provide a first approximation of likely CO₂ emissions), associated concentrations of PM, and probable increases in mortality associated solely with PM by the year 2020 (figure 1). This analysis presents a scenario-based order-of-magnitude estimate of the possible size of the air-pollution impacts on populations in developed and developing countries.

Methods

Scenario development

Estimation of the consequences for public health of projected global events requires the development of scenario-based impact assessment that relies on complex models of environmental change.⁹ Our study develops two possible CO₂ emission scenarios: a business-as-usual (BAU) scenario which updates IPCC's 1992 analysis of expected trends in energy consumption and associated CO₂ emissions;¹⁰ and a hypothetical climate-policy scenario, which considers the stated intentions of the European Union regarding proposed reductions in CO₂ emissions for developed countries,¹¹ coupled with additional measures by developing countries. Under our hypothetical climate-policy scenario, developed countries would undertake concerted and binding efforts to reduce energy-related CO₂ emissions 15% below 1990 levels by the year 2010. Under this same climate-policy scenario, developing countries are assumed to reduce their emissions 10% below their levels of greenhouse-gas emissions forecast for 2010—that is, 10% below what would otherwise be their BAU trends by 2010. This is consistent with agreements made by developing countries under the Berlin Mandate to advance implementation of existing commitments to promote technologies, practices, and processes that reduce greenhouse-gas emissions.

Both these scenarios assume that total energy use and efficiencies in the developing countries continue to increase to meet the needs of economic growth. The differences between them lie in the rates of growth in energy use, the fuel mixes, and their combustion and end-use efficiencies. Under each of these scenarios, emissions of PM are taken as representative of general ambient air pollution associated with fossil-fuel combustion and CO₂ emissions. Based on projected concentrations of PM, we estimate annual and cumulative numbers of avoidable deaths in the years 2010 and 2020 among adults aged over 30 years and infants of up to 1 year in developed (annex 1) and developing (non-annex 1) countries (UNFCCC

nomenclature). Avoidable deaths refers to the estimated annual premature mortality associated with PM from modelled fossil-fuel combustion (ie, attributable risk) that could be avoided by adopting the hypothesised climate-policy scenario. Because the aerodynamic size of the particles produced is of great importance, our model estimates the emissions and concentrations of particles that are less than 10 µm (PM₁₀) and fine particles of less than 2.5 µm (PM_{2.5}). A host of other adverse acute and chronic health effects are also associated with PM and other air pollutants, but are not analysed here.^{12,13}

Fossil-fuel consumption and carbon emissions

Future fossil-fuel consumption and resulting emissions of greenhouse gases and other air pollutants reflect complex interactions of several key variables, including economic activity, transportation modes, demographic trends, the rate and nature of technological innovations, and energy prices. The IPCC devised six well-documented projections of greenhouse-gas emissions in 1992.¹⁴ The IPCC used the Atmospheric Stabilisation Framework (ASF) model to relate socioeconomic scenarios to carbon emission trajectories. The ASF model contains detailed representations of fossil-fuel consumption for four sectors (electric utility, residential/commercial, industrial, and transportation) for nine global regions.

All CO₂ emission estimates in this paper refer to emissions attributable to the combustion of fossil fuels, which represent about 75% of current global anthropogenic emissions of CO₂.¹⁵ The CO₂ emission projections presented in this paper fall within the range of other emission projections documented in the literature. The 8.3 billion metric tonnes of carbon (BMTc) from fossil-fuel combustion presented in this paper for 2010 is slightly lower than the estimate of 8.8 BMTc as predicted by Energy Information Administration.¹⁶ Our 2020 projection of 10.7 BMTc is higher than the IASA/WEC projection of 8.4 BMTc¹⁷ and similar to the Shell Oil sustained-growth scenario estimate of 10.5 BMTc.¹⁸

The input in this study has been updated to reflect more recent population projections, the breakup of former Soviet Union, and lower anticipated fossil-fuel prices. The model assesses CO₂ emission-reduction goals, by choosing the most efficient and least cost emission-reduction opportunities available in each region, and recognises efficiency improvements in many developing countries.¹⁹ The global-population data used for these scenarios are consistent with the World Bank's medium-growth assumptions.²⁰ The gross national product (GNP) growth assumed for the BAU scenario is slightly higher than the one used in the IS92a scenario, which reflects several economic, energy, and climate-change-related studies.^{21,22}

Table 1 and figure 2 indicate several trends and associations of fossil-fuel consumption patterns modelled under both the BAU and climate-policy scenarios. In 1990, despite having only 24% of the world's population, annex 1 countries accounted for 70% of global fossil-energy consumption and 68% of carbon emissions from fossil fuels. Under BAU, overall growth in CO₂ emissions from annex 1 countries is relatively moderate through the projection period, 1990–2020, rising by only 17.5% through 2020. This moderate growth may be explained by current trends of fossil-fuel consumption patterns in Russia and the former Soviet Union. These regions

Centrally Planned Asia¹ Energy Consumption (aJ) and Carbon Emissions (MMTC)

BAU

		1990	1995	2000	2005	2010	2015	2020
Electric Utility	Coal	8.1	10.6	13.1	14.5	16.4	18.1	20.1
	Oil	0.3	0.5	0.8	1.5	2.5	3.6	4.9
	nat. gas	1.8	2.9	4.2	5	5.6	6.2	6.6
Industry	Coal	8.5	10.8	12.9	15.3	18	20.4	22.7
	Oil	0.2	0.3	0.5	0.8	1.3	1.9	2.8
	nat. gas	0.6	1	1.5	2.1	2.8	3.6	4.4
Residential/Comm.	Coal	9.1	10.9	12.1	13.4	14.5	14.8	14.1
	Oil	0.3	0.6	1.1	1.6	2.4	3.5	5.1
	nat. gas	0.9	1.3	1.9	2.6	3.3	4.3	5.6
Transportation	Oil	1.9	2.8	4.1	5.1	6.9	9.2	12.2
	Total	31.7	41.7	52.2	61.9	73.7	85.6	98.5
	Carbon	812	1054	1298	1523	1796	2061	2342

Climate Policy

		1990	1995	2000	2005	2010	2015	2020
Electric Utility	Coal	8.1	10.6	13.1	13.2	13.8	14.6	16.1
	Oil	0.3	0.5	0.8	1.4	2.5	3.6	5
	nat. gas	1.8	2.9	4.2	5.2	5.9	6.5	6.9
Industry	Coal	8.5	10.8	12.9	14.6	16.5	18.4	20.3
	Oil	0.2	0.3	0.5	0.8	1.4	2.1	3
	nat. gas	0.6	1	1.5	2.2	3.1	4	4.9
Residential/Comm.	Coal	9.1	10.9	12.1	12.4	12.7	12.5	11.8
	Oil	0.3	0.6	1.1	1.6	2.4	3.5	5
	nat. gas	0.9	1.3	1.9	2.6	3.4	4.4	5.6
Transportation	oil	1.9	2.8	4.1	5.1	6.9	9.2	12.3
	total	31.7	41.7	52.2	59.1	68.6	78.8	90.9
	carbon	812	1054	1298	1443	1647	1864	2122

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Centrally Planned Asia Region Mortality Estimates from Lancet Article

Year	Lower bound	Central Bound	Upper Bound
2005	21,399	39,024	57,610
2010	39,717	72,342	106,602
2015	68,528	124,635	183,257
2020	71,570	130,155	191,307
Total (2000-2020)	862,932	1,570,469	2,311,268

Pope et al. (1995) reported three coefficients: a central value, and lower (5% confidence level estimate) and upper (95% confidence level estimate) bounds. The upper and lower bounds therefore yield the 90% confidence interval estimate.

¹ Includes China, Hong Kong, Laos, North Korea and Vietnam

prospective cohort studies have attempted to account for all important confounders, some potential confounders may not have been considered. However, sensitivity analyses done in the study by Pope and colleagues found that the association between PM and mortality was relatively insensitive to several important potential confounders, including occupational exposure and smoking. This analysis also assumes there is a consistently increasing association between long-term exposure to PM and increased mortality risks, which is the same in the rest of the world as it is in the USA. In most developing countries, exposure to PM is an order of magnitude or more higher than that in the USA. Additional increases in mortality risks could diminish as exposures approach a saturation level. If the exposure response is not the same at these higher doses, then extrapolation of the USA estimates to developing countries may overestimate the avoided deaths in non-annex 1 countries. The results from the Pope study, of adult mortality, probably reflect both the effects of long-term and short-term exposure to PM, and there is possibly some overestimation of the annual avoided mortality associated with estimated annual decrements in PM. Another factor that could lead to overestimation is that PM levels in the USA have generally improved over the past few decades, especially for coarse particulate levels. If the premature mortality effects are related to cumulative exposure over a long period, then the observed effects in the Pope study could be associated with a larger PM change than observed (leading to a smaller risk per unit change).

Our analysis accounts for the age-distribution of the populations affected. If the RR is higher for older people, then the analysis could overestimate mortality effects in non-annex 1 countries. However, the younger populations of developing countries must often confront other health threatening conditions (eg, malnutrition), which may increase their vulnerability to pollutants. Estimates of the percentage of cardiorespiratory deaths in non-annex 1 countries (except for subSaharan Africa) is similar to that in annex 1 countries, indicating that it is reasonable to apply PM associations found in the USA to other countries. While we are not aware of any attempt to replicate the study by Woodruff and colleagues, similar results of infant mortality associated with PM have been found in the Czech Republic.⁴⁰

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The quantification of mortality benefits derived from our analysis only considers outdoor sources of PM from fossil-fuel combustion. For many countries around the world, burning biomass indoors can also be an important source of PM. For example, in China, households burn about 500 million tons of biomass fuels for cooking and heating each year.⁴¹ The suspended PM in Chinese households often exceeds recommended air-quality guidelines by WHO by more than tenfold.⁴² For most of the Chinese population, the health impacts from indoor exposure to air pollutants greatly exceed that of workplace or outdoor exposure. Data from a series of studies and official disease statistics suggest that air pollution from both indoors and outdoors is responsible for more than 1 million deaths per year in China, or about one in every eight deaths nationwide.⁴³

In 1990, lower-respiratory-infections were the leading components of disability adjusted life years.⁴⁴ By 2020, respiratory-related diseases are projected to rank among the top ten causes of poor health in the world. The total

number of annual deaths that could be avoided under the climate-policy scenario in 2020 in much of the developed world almost equals the projected number of fatal injuries caused by automobile accidents.⁴⁵ In the USA, by the year 2020, at least 33 000 deaths a year could be avoided from implementation of the climate-policy scenario. This projected number of avoidable deaths in the USA is of the same order of magnitude as currently occurs as a result of several major causes of death from illnesses, each of which is subject to major public-policy interventions, including human immunodeficiency and chronic liver diseases.

Newspaper reports this year from Sumatra, Borneo, and other regions⁴⁶ indicate that measured levels of air pollution associated both with burning forests and air pollution from energy production sometimes exceed the levels measured in London during the killer fog of 1952. This episode of elevated pollution in London was associated with nearly 3000 excess deaths in 1 week.⁴⁷

Health patterns in any region reflect an intricate combination of factors: poverty, nutrition, population density, housing and sanitation, smoking, and workplace and environmental factors. While environmental factors cannot account for all these patterns, they are important because they can be changed by public policy. Patterns of rapid growth and development in emerging mega-cities of the developing world can impose significant involuntary risks from air pollution on large proportions of their population.^{48,49} Control or prevention of this exposure needs to be recognised as critical to the development of environmental and public-health policy. Even if environmental factors pose relatively small risks of common ailments, but the exposure is widespread and vulnerable groups exist in the exposed population, the public-health impact of air pollution can be significant. Where exposure is universal and where the population is vulnerable the marginal contribution of air pollution can be significant.⁵⁰

Conclusion

Regardless of how or when greenhouse gases alter climate,⁵¹ reducing them now will save lives worldwide by lessening particulate air pollution. The beneficial effects of reduced particulate pollution appear to be far greater in rapidly developing countries than in developed countries, although they are substantial in both regions. The overall scientific challenge is to discern enough from present and past trends to reduce uncertainties, so that an integrated impact assessment can yield useful results. Our analysis should not be misconstrued as precise predictions, but as relative indicators of the magnitude of the effects that are likely to arise under conditions that we have specified in these climate-related scenarios.

The transdisciplinary activity pursued in this assessment provides a systematic framework for the estimation of potentially far-ranging and substantial health impacts in an uncertain future world. This estimate looks beyond the restricted view of environmental health as a local problem,⁵² recognising the truly global reach of climate policies. There is a dynamic between being able to predict future impacts and being able to affect policies to avoid those potential impacts. In the 18th century, the philosopher Saint-Simon noted "savoir pour prévoir" and "prévoir pour pouvoir". With knowledge comes the ability to predict. With the ability to predict, comes the power to change those predictions.

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point sources. The model also estimates the carrying capacity for acid deposition of 31 types of ecosystems. Values for sulfur depositions are based on a yearly average and are calculated at a 1 x 1 degree resolution. Aggregate results of source and receptor information on acid deposition patterns for each region or country can be obtained. Local impacts of acid deposition can be estimated as well. The temporal range of the model is 1990–2020. A detailed description of the model and its uses can be found in Downing, Ramankutty, and Shah (1997).

Acid deposition can have a range of impacts, including:

- Acidification of soils and damage to trees and other vegetation, including agricultural crops and forests.
- Acidification of lakes and rivers, leading to fish loss.
- Eutrophication of surface waters due to excess nitrogen inputs.
- Direct impacts on vegetation due to exposure to sulfur dioxide and nitrogen oxides in the vicinity of major emitting sources.
- Corrosion of metals and building materials.
- Health effects caused by increased levels of sulfate and other aerosols.

In Asia a limited amount of work has been conducted on acid rain impacts and their costs. Studies of acid rain impacts have been carried out in parts of southwestern China. Some of the impacts seen in the vicinity of Chongqing, Sichuan, and Guiyang, Guizhou, include 50 percent dieback of forests on Nanshan mountain, more than 50 percent reduction in biomass production in commercial spruce forests experiencing acid rain with a pH of less than 4.5, yellowing of rice in large areas near Chongqing after rainfall with a pH of less than 4.5, and wheat fields that are seriously affected by rainfall with a pH of less than 3.5 during the middle and late growing periods.

Simulations with the model show that exceedences—that is, deposition of sulfur exceeding the critical loads of the ecosystem—are most severe in and around urban areas such as Shanghai and large regions around Chongqing (see map 1). It is estimated that nearly 10 percent of the total land area is exposed to more than 1,000 milligrams per square meter (mg/m^2) a year of sulfur deposition in excess of critical loads. About 1 percent of the total land area (concentrated in and around Chongqing) has exceedences of

ANNEX 2.2 TABLE 1
Estimates of sulfur dioxide damage to farming and forestry, 1995

Province	Gross output (billions of yuan)			Annual sulfur dioxide deposition (mg/m^2)	Ambient sulfur dioxide concentrations	Share of output damaged (percent)	Total damage (10^8 yuan)
	Farming	Forestry	Total				
Liaoning	392	13	405	1,500	50	1.9	7.70
Beijing	87	3	90	1,700	56	2.2	1.98
Tianjin	85	1	86	3,100	104	5.2	9.15
Hebei	754	24	778	1,500	50	2.0	15.56
Shanxi	203	13	216	1,000	33	0.8	1.73
Shanghai	78	0	78	4,600	154	8.5	6.63
Jiangsu	986	21	1,007	4,200	141	7.6	76.53
Zhejiang	482	50	532	2,500	84	4.0	21.28
Anhui	638	40	678	2,100	71	3.2	21.70
Fujian	340	59	399	1,300	44	1.5	5.99
Jiangxi	332	41	373	1,800	60	2.5	9.33
Shandong	932	42	974	2,300	77	3.8	37.01
Henan	866	38	904	2,000	66	3.0	27.12
Hubei	612	28	640	1,800	60	2.5	16.00
Hunan	580	42	622	1,500	50	1.9	11.82
Guangdong	778	46	824	1,900	62	2.6	21.42
Guangxi	384	33	417	1,600	53	2.0	8.34
Sichuan	887	45	932	2,900	97	5.0	46.60
Guizhou	224	15	239	3,000	101	5.1	12.19
Yunnan	299	41	340	400	12	0.0	0.00
Shaanxi	258	17	275	1,300	43	1.5	4.13
Total	10,197	612	10,809	44,000		4	362.19
							(\$4.36 billion) 5

Source: World Bank staff estimates.

4

LIVING WITH COAL: COAL-BASED TECHNOLOGY OPTIONS FOR CHINA'S ELECTRIC POWER GENERATING SECTOR

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INTRODUCTION

THIS CHAPTER EXPLORES THE ECONOMIC COSTS and environmental impacts of China's proposed investments in electric power generating capacity over the next twenty-five years. It highlights the economic and environmental aspects of different technology choices within such an investment strategy. As the title suggests, this paper is focused exclusively on the coal-based production of electricity, and does not explore alternative energy sources such as hydropower, nuclear power, or renewable energy sources (see the chapters in this volume by Fang et al. and by Ni and Sze for details).

As the Chinese economy continues to grow, the demand for electricity, which is already far greater than its current generating capacity, will continue to increase. There is strong government support for a massive program of capacity expansion; not only to meet new industrial demands, but also to reduce direct burning of coal for domestic heating and cooking. However, power generation in China is a major contributor to air pollution, specifically through emissions of particulate matter, sulfur and nitrogen oxides, and carbon dioxide. The replacement of

icity, or with steam from co-
des oil- and coal-derived syn-
ind air pollution and ur-
at electric power expansion
ortation demands) will more
ents gained from partial dis-
ubustion. Therefore, it can be
ns of nitrogen and sulfur ox-
ere from China will certainly

s China's likely future choice
determine the impact of these
missions. China's future tech-
tion can be grouped into three
ng power plants, traditional
tion control devices,¹ and in-
technologies.² An assessment
odel which captures not only
ces between different choices,
onmental impacts. Future in-
any factors: future electricity
d environmental regulations,
nvironmental protection.

veloped to address these ques-
d it was decided that a math-
more suited to the task and
of the investment process. The
optimization model determines
ricity production goals given
, coal prices, technology effi-
e many existing models of in-
tems, the optimization model
he local, regional, and global
on. In the model we also con-
logy diffusion and uncertain-
rmance.

he characteristics of the opti-
demands. We show that while
oosing inefficient, traditional
e investment in electric power

is nonetheless likely to follow past investment patterns and use tradi-
tional rather than innovative power generating technologies. We specu-
late what it would take to change to a more environmentally benign
investment strategy and illustrate that as a greater emphasis is placed on
environmental goals, the technology investments will change. We high-
light how these changes can be driven not only by traditional environ-
mental regulations but also by economic changes such as increases in
fuel pricing. We show that as a greater emphasis is placed on reducing
local environmental impacts, the use of end-of-pipe pollution controls
will in fact exacerbate carbon dioxide emissions. Furthermore, we show
that while clean coal technologies have the potential to mitigate both
local and global environmental impacts, they are unlikely to enter into
China's investment program due to their high costs and high risks. None-
theless, we show how the U.S. and other developed nations, as a source
of capital, technical expertise, and innovation, can reduce some of the
inhibiting risks and uncertainties surrounding the adoption of these
cleaner technologies in the actual setting of China. We further suggest
that the U.S., Japan, or other nations, through both private and public
intervention, can facilitate the transfer of technologies to China to re-
duce pollution and specifically to decrease CO₂. By so doing, they can
simultaneously meet China's economic and environmental needs, de-
rive global environmental benefits, and expand trading opportunities.

REVIEW OF THE CURRENT STATE OF POWER GENERATING IN CHINA

6.5 An expansion in electric power generating capacity of almost 200% has
been accomplished in China during the fifteen-year period 1980–1994,
as the result of an intensive investment and construction schedule. Ca-
pacity additions reached over 10 gigawatts (GW) per year after 1988
(an annual increase in capacity of between 8–10%), while electricity
generation has grown by between 6% and 12% per year during the same
period (Shi 1993; Goldman Sachs 1994). The size of the investments
made in the power sector are described in more detail in the chapter of
this volume by Murray, Reinhardt, and Vietor.

By 1994, China's electric power generating sector produced approxi-
mately 900 terawatt-hours (TWh) of electricity from an installed ca-
pacity of 195 GW. The overall distribution of this capacity between ther-
mal power and hydropower is approximately 80% to 20%. However,
this ratio varies widely by region. Much of China's thermal power gen-

long. As plants are used beyond their twentieth year of operation, their efficiency, reliability, and capacity drops (Tavroulareas and Charpentier 1995). While substantial documentation is unavailable, anecdotal evidence suggests that Chinese plants are used well beyond their average design life of 20–30 years. For example, the manager of the Zhejiang Province Power Plant is quoted as saying that the plant

...was set up in 1929, and since then, only little gradual improvements have been made to the facilities. We are still using equipment bought in 1929; the newest equipment was bought in 1958. But in a way we are proud of the fact that this old equipment is still running. It shows the Chinese resourcefulness. But the efficiency is low at about 10%. (Murray, Loo, and Vietor 1994)

Therefore, the continued use of very old plants has a profound impact on the overall system efficiency, and therefore emissions, in China. The long lifetime of China's power plants, together with the small size of many new units, and the low efficiency of larger new units has resulted in only a limited overall improvement in the efficiency of China's power system. Current system efficiency is estimated at between 28% and 30% (ADB 1994; World Bank 1990) which is still well below the system average in the U.S. or Japan.⁴

FUTURE TECHNOLOGY OPTIONS AVAILABLE TO CHINA

The most critical characteristics of China's future technology investment options are linked to their financial and environmental performance. Power plants are defined in terms of their costs, thermal efficiency (a function of unit size and technology), and emissions control. The costs can be divided into capital costs which are based on installed capacity, usually measured in megawatts (MW), and the operations and maintenance (O&M) costs which are associated with power generated, measured in kilowatt-hours (kWh). A large component of the O&M costs is the cost of coal used. Coal utilization is related to both plant efficiency and the capacity utilization, i.e., the number of hours a year for which the plant is used to generate electricity. The emissions performance of a plant is based on the level of pollution control but is also closely related to coal use and coal quality, since emissions are the by-products of coal combustion. The key relationships among plant efficiency, capacity utilization, and coal quality are highlighted in the four equations below:

have efficiencies in the range of 33–37% but must be bought at a cost premium, and using foreign exchange reserves.

Traditional Air Pollution Control Options

When traditional coal combustion plants are installed there is a further choice as to whether or not to invest in pollution control systems. Options for traditional pollution control can be divided into precombustion and postcombustion (end-of-pipe) controls. Examples of a range of the most commonly used controls are described briefly in this section. However only the use of two post-combustion controls—scrubbers and electrostatic precipitators—are considered in the detailed assessment presented later in this paper.

Precombustion controls. The most common precombustion technology used to decrease fuel use, improve fuel quality, and plant efficiency, and reduce emissions is coal-washing. In China only about 20% of the coal is washed, and only about 50% of this washed coal finds its way to power generation (World Bank 1990; Sinton et al. 1993). However, further investments in coal-washing remain an important choice available to China. Depending on the sophistication of the process, coal-washing can be used to remove both ash and sulfur from coals. Emissions reduction is most effective when coal-washing is used in conjunction with postcombustion control techniques. A further benefit of coal washing is that by improving the quality of the coal, the efficiency of coal combustion is improved and therefore less coal is needed to produce the same quantity of electricity. In terms of emissions, this contributes to a reduction in CO₂ emissions.

The least sophisticated form of coal-washing is actually coal screening during which coal is separated by size and blended to improve quality and consistency. Screening costs are low, but an economic analysis performed by the World Bank (1990) illustrated that it is only when coal prices are sufficiently high (above state controlled prices) that the costs of coal screening are offset by the value of reduction in the quantity of coal needed to meet electricity demand. More sophisticated coal-washing, involves not only screening, but also the physical and/or chemical cleaning of coal. Physical methods are most effective in reducing the ash content (often by up to 60%), and removing some of the mineral sulfur in the coal. There are significant benefits associated with coal-washing—transportation advantages in removing unwanted elements of the coal, and also additional benefits in minimizing ash disposal, in reducing boiler maintenance due to better coal quality, and in increas-

ENERGIZING CHINA

*Reconciling Environmental Protection
and Economic Growth*

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5

ENERGY USE AND AIR- POLLUTION IMPACTS OF CHINA'S TRANSPORTATION GROWTH

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Standard & Poor's DRI

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TRANSPORTATION ACTIVITY IN CHINA has grown dramatically since the beginning of the economic reform in the late 1970s.¹ Between 1978 and 1993, the total volume of passenger movements more than quadrupled, while that of freight transportation tripled (SSB 1994). Transportation capacity provides accessibility, which is essential to economic development. It supplies materials to factories, distributes products to markets, reduces the time and cost required to move people and goods, thus in effect "bringing places closer" to each other. This enhances specialization, notably spatial specialization. As part of the basic infrastructure in modern societies, the passenger transportation system carries people to and from work and leisure, expands personal freedom, enlarges horizons of awareness, and improves the quality of life. China's demand for transportation is expected to continue to grow for the foreseeable future as the economy rapidly expands.

The benefits of transportation, however, may come at a high cost. Transportation requires a large quantity of gasoline and diesel, both of which are in short supply in China (SSB 1994). The growth in transportation fuel consumption was a primary reason why China, the world's sixth largest oil producer, became a net oil importer by the end of 1993

TABLE 1 (CONTINUED)

Growth in Transportation Volume in China, 1980-1993

Notes (continued):

2. ton = metric ton
3. Freight (Passenger) Traffic Turnover Volume refers to the total physical volume of transported cargo (passengers) divided by the transport distance, usually using ton/km and person/km as calculating units. Normally, the shortest distance between the departure point and the destination is the basis for calculating the freight traffic volume, i.e., the payable distance.
4. Freight (Passenger) Traffic refers to the physical volume of freight (passenger) transported. Freight traffic is measured by tons and passenger traffic by number of persons. Despite the type of freight and travelling distance, the freight traffic is calculated by the actual weight; and despite the travelling distance and ticket price, the passenger traffic is calculated by one person per trip. The half-price and child tickets are also calculated on a one-person per ticket basis.
5. Average distance per trip = Turnover Volume of Passenger (Freight) Traffic / Passenger (Freight) Traffic

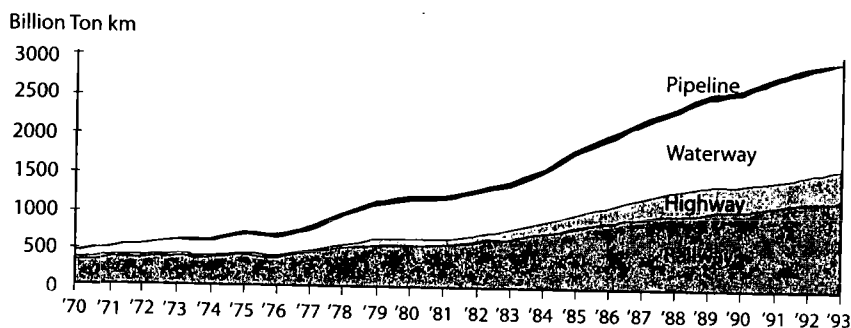
Sources: SSB (1993, Tables 12-5 through 12-8; 1994, Tables 14-5 through 14-8).

on rail transportation than other countries, especially for passengers. In the United States, for example, railways account for 0.6% of passenger-km and 36.8% of the freight ton-km; and, in Japan, the share of railway transportation is 31.3% for passenger-km and only 4.6% for freight ton-km (Sinton 1992, VIII-43).

The modal emphasis of China's transportation is shifting from railways to highways. Between 1980 and 1993, the average annual growth-rate of the road transportation volume was 13.5% for both passenger-kms and freight ton-kms, compared with 7.7% for the railway 13 14

FIGURE 2

Modal Structure of Freight Transport, 1970-1993



Notes:

1. ton = metric ton
2. km = kilometer

Sources: SSB (1993, Table 12-9; 1994, Table 14-9).

1986/	541	237	7,464	218	72	109	2,223	185	9,482	173	234	107
1988	621	272	8,096		77	115	2,383	198	9,822	180	241	110
1989	608	266	7,914		77	115	2,559	213	9,884	181	259	118
1990	563	247	7,727	226	73	109	2,621	218	9,706	178	270	123
1991	618	271	8,060	236	77	115	2,799	233	9,858	180	284	129
1992	695	305	8,609	252	81	121	2,922	243	10,459	191	279	127
1993	786	344	9,966	292	79	118	3,051	254	11,158	204	273	124

Notes:
1. km = kilometer

TABLE 2 (CONTINUED)

Transport Modal Structure in China, 1980, 1985, 1990

Notes (continued):

3. Freight (Passenger) Traffic Turnover Volume refers to the total physical volume of transported cargo (passengers) divided by the transport distance, usually using ton/km and person/km as calculating units. Normally, the shortest distance between the departure point and the destination is the basis for calculating the freight traffic volume, i.e., the payable distance.
4. Freight (Passenger) Traffic refers to the physical volume of freight (passengers) transported. Freight traffic is measured by tons and passenger traffic by number of persons. Despite the type of freight and travelling distance, the freight traffic is calculated by the actual weight; and despite the travelling distance and ticket price, the passenger traffic is calculated by one person per trip. The half-price and child tickets are also calculated on a one-person-per-ticket basis.

Sources: SSB (1993, Tables 12-5 through 12-8; 1994, Tables 14-5 through 14-8).

Freight	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
Railway	571.7	47.5	813	44.2	39.2	1,195	5.6	39.2	1,195	44.2	39.2	1,195	5.6	39.2	1,195
Highway	76.1	6.4	190	10.4	13.3	407	8.4	13.3	407	10.4	13.3	407	8.4	13.3	407
Waterway	505.3	42.0	773	42.1	45.4	1,386	20.9	45.4	1,386	42.1	45.4	1,386	20.9	45.4	1,386
Civil Air	0.1	0.0	0	0.0	0.1	2	1.7	0.1	2	0.0	0.1	2	1.7	0.1	2
Pipeline	49.1	4.1	60	3.3	2.0	61	7.4	2.0	61	3.3	2.0	61	7.4	2.0	61
Total	1202.6	100.0	1,837	100.0	100.0	3,051		100.0	3,051	100.0	100.0	3,051		100.0	3,051

Notes:

1. km = kilometer
2. ton = metric ton

passenger-kms and 5.6% for the railway freight ton-kms (Table 2). The share of railway transportation, on the one hand, declined from 60.6% in 1980 to 44.3% in 1993 for passenger-kms and from 47.5% to 39.2% for freight ton-kms. The road share for passenger transportation volume, on the other hand, increased from 32.0% to 47.1% and for freight from 6.4% to 13.3% (Table 2 and Figures 1 and 2). This was partially caused by the large expansion of highways compared with rail lines and inland waterways (Table 3).

The development of most types of transportation capacity and infrastructure, however, has lagged behind the growth in transportation demand (Table 3). The route lengths for railways, highways, and inland waterways, for example, are increasing very slowly, averaging less than 2% per year. For rail transport between 1980 and 1993, the number of passenger coaches, freight cars, and total locomotives increased by 4.4, 3.0, and 2.7%, respectively. Exceptions to the slow growth of capacity, of course, are air transport, which is increasing rapidly, especially in terms of the length of the routes (13.7% annual rate of growth), and passenger motor vehicles, whose growth rate has been a very large 17.8% annual rate since 1980. The differential growth rates between the transport volumes, which are growing very rapidly, and the amount of rolling stock and infrastructure built, which, for the most part are growing relatively slowly, are creating a large gap between transport demand and supply. This gap is exacerbated by poor transportation management, suboptimal modal coordination, and inappropriate pricing policies.

Transportation has become a major bottleneck in the Chinese economy. Both passenger and freight transportation systems are over-

Average Annual
Growth Rate
(1980-1993) (%)

1985	1993	
12.1	53.8	0.6
12.4	1,083.5	1.6
19.1	110.2	0.1
17.2	960.8	13.7
1.7	16.4	5.1
372	29,395	4.4
386	390,097	3.0
758	419,492	3.4
74	5,109	-3.2
11	7,092	9.5
87	2,196	17.1
72	14,397	2.7
5	2,859.8	17.8
0	5,010.0	11.0
8	905.9	38.5
2	8,175.8	12.5
8	1,481	12.1
5	1,167,915	8.0
3	43,573	7.3
1	646	4.3

we calculated the average annual

we calculated the average annual

sum of passenger vehicles, trucks,

1990; average annual growth rate

TABLE 3 (CONTINUED)

Growth in Transport Capacity, 1980, 1985, 1993

Notes (continued):

1. n/a = data not available
2. ton = metric ton
3. km = kilometer

Sources: SSB (1993, Table 12-2; 1994, Tables 14-3, 14-15, 14-26, 14-27, 14-33; 1991b, 346-348).

loaded throughout most of the country. Congestion occurs, especially in urban areas, causing an alarming reduction, for example, in the mean speed of motor vehicles. Many roads are deteriorating rapidly because of overuse and because thinly paved surfaces cannot stand the weight of heavy modern trucks (World Bank 1993, 25). Millions of people have to stand each day in trains, with many standing while aboard the train for several days at a time (Polenske 1991, 235). Thousands of tons of freight remain in railway yards or intermediate storage for days, even weeks, before it can be transported to its final destination. From time to time, major electric power plants, especially along the eastern coast, cannot provide sufficient electricity to consumers and industries because of coal shortages resulting from inadequate coal transport facilities. The shortages can be so severe that utilities and firms actually must close for several days at a time (Polenske 1991, 235; World Bank 1995, 1).

One main strategy the Chinese government is adopting to break the transportation bottleneck is motorization—a transformation into a motor vehicle-dominant transport system. Until the mid-1980s, the government favored measures to increase rail transport for handling freight movements and long-distance passenger travel; however, the rail system's capacity could not be increased without large investments (Chen 1989).⁴ In addition, the production of goods is shifting from the heavy industry sector to the light industry and service sectors. The growth of these sectors creates a higher demand than before for transporting light loads over short distances, for which road transportation is usually more suitable than the railways. In urban areas, the public-transit system cannot provide sufficient transportation services to meet the growing demand of passenger traffic, and its expansion is constrained by the existing road network and land-use patterns (Li and Dong 1994, 2-3). The bicycle, which currently accounts for over 40% of personal trips in many cities, has reached the saturation level in terms of number of bicycles per rider almost everywhere, according to Li and Dong (1994, 1). Thus, for many Chinese policymakers, motorization seems to be the solution. More importantly, cars and highways are seen as barometers of modern

of planners perceive motor use mobility and modernize urban centers, it reversed its long-term trend and relaxed the restrictions on (Gakenheimer 1995).

Other sectors have large multi-year plans. The Chinese government has identified the key sectors for development and modernization. The dilemmas this may cause—traffic accidents, reduction in urbanization, and so on—are only beginning to be addressed. The country's motor vehicle stock is projected to increase by 2.5 million by the end of the century (China 1994). Current production, of which 80% are private, is outstripped by imports and by a growing number of Chinese auto producers are producing a family car for this unmet demand in the black market (Autos 1994; China 1994). The automobile industry is on target. In only two years, production doubled. The 1992 production, accomplishing the 1995 target (He et al. 1994, 3).

Highway construction has grown by more than 10% annually. Road quality is improving with access expressways in China, most were single-lane, grade-separated. Highway mileage reached 1,145,000 km as under construction. The country's super highways—expressways—by the year 2000 will connect more roads with a total length of 10,000 km. New roads will connect more roads and increase the highway density in

construction. In the last five years, roads have increased 2.9 times

(Li and Dong 1994, 2). Almost all large cities—those with a population of more than 1 million—have undertaken major highway construction and expansion projects since the mid-1980s. To reduce traffic in the urban center, Beijing, for example, built its Second Circular Expressway in 1992, which totals 33 kilometers in length and is the first limited-access urban highway in China. The city also constructed the Third Circular Expressway, which is 5–8 kilometers from the urban center and 48 kilometers in length. This new limited-access highway allows long-distance freight vehicles to bypass the city and helps more local vehicles collect and distribute freight and passengers from the Beijing West Railway Station (Zhang et al. 1994, 47). Many other large cities, such as Shanghai, Tianjin, and Guangzhou, have recently had road construction projects on a similar scale.

The motor-vehicle stock in China has grown dramatically in recent years. Between 1980 and 1993, total civilian motor vehicles increased from 1.8 million to 8.2 million—almost a fivefold increase (Table 3). This growth was mainly caused by the increase in private motor-vehicle ownership. In 1993, private motor vehicles totaled 1.6 million, ten times that in 1984, the first year for which we have private vehicle stock data. The share of private vehicles in the total civilian motor-vehicle stock only increased from 6.7% in 1984 to 19.1% in 1993 (SSB 1994), because nonprivate civilian vehicles were also increasing very rapidly. Of private motor vehicles, 38.4% are passenger vehicles, such as cars, taxis, and buses, and the remaining 61.6% are trucks and other vehicles. Most motor-vehicle growth occurs in urban areas, especially in the rapidly developing coastal regions. Urban vehicles have grown at an annual rate of 15–20% since the mid-1980s (Li and Dong 1994, 3), and motorcycle ownership has grown even faster. In 1980 the number of motorcycles was less than 500,000 (He et al. 1994, 5), while by 1994, the number was estimated to be over 10 million (Li and Dong 1994, 3). With more vehicles on more roads, passenger and freight transportation activity in China is likely to continue to grow rapidly for the foreseeable future.

TRANSPORTATION ENERGY USE AND AIR-POLLUTANT EMISSIONS

Rapid transportation growth may have high energy and environmental costs. Transportation requires a large quantity of energy, especially petroleum, which is in short supply in China. In addition, transportation fuel use generates many air pollutants, such as nitrogen oxide (NO_x),



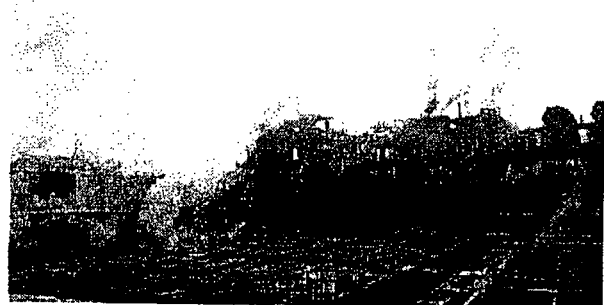
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China's Health and Environment: Air Pollution and Health Effects

WORLD RESOURCES 1998-99

- Poor Ambient Air Quality Prevails
- China's Air Pollution Levels Are Among the World's Highest
- China's Growing Consumption of Coal
- Outdated Vehicles Degrade Urban Air Quality
- Health Effects from Ambient and Indoor Air Pollution
- Air Pollution's Toll
- Air Quality May Be Worse Indoors



Curt Camermark / World Bank

Poor Ambient Air Quality Prevails

"The residents of many of China's largest cities are living under long-term, harmful air quality conditions," Zhao Weijun, deputy director of the air pollution department of NEPA, reported in 1997 in *China Environment News* [16]. China has long recognized air pollution as a critical problem. Ambient concentrations of total suspended particulates (TSP) and sulfur dioxide (SO₂) are among the world's highest. (*See China's Air Pollution Levels Are Among the World's Highest.*) In 1995, more than one half of the 88 cities monitored for SO₂ were above the World Health Organization (WHO) guideline. All but two of the 87 cities monitored for TSP far exceeded WHO's guideline. Some cities such as Taiyuan and Lanzhou had SO₂ levels almost 10 times the WHO guideline [17].

Smoke Pollution in China

Largely because of controls at power plants and within households, particulate emissions have not risen as much as might have been expected with the doubling of coal consumption. Overall, particulate emissions in China have remained relatively level since the early 1980s [18]. In fact, in some large cities, ambient particulate concentrations have decreased markedly since the 1980s [19]. In contrast, SO₂ emissions have roughly paralleled the increase in coal consumption, reflecting heavy coal burning and inadequate sulfur control measures.

Coal burning, the primary source of China's high SO₂ emissions, accounts for more than three quarters of the country's commercial energy needs, compared with 17 percent in Japan and a world average of 27 percent [20]. China's consumption of raw coal increased annually by 2 percent between 1989 and 1993 [21]. (*See China's Growing Consumption of Coal.*) Meanwhile, SO₂ emissions increased by more than 20 percent and TSP increased by approximately 10 percent [22]. The country is expected to burn 1.5 billion metric tons of coal annually by the year 2000, up from 0.99 billion metric tons in 1990 [23].

Without even more dramatic measures to control emissions than are currently in place, the deterioration of air quality seems inevitable.

vehicles in Tokyo or Los Angel
of the two other cities [30].

Beijing motor vehicles equals that in each

Outdated Vehicles Degrade Urban Air Quality

Percentage of Emissions in Selected Chinese Cities Attributable to Motor Vehicles

PERCENTAGE ATTRIBUTABLE TO MOTOR VEHICLES

	CARBON MONOXIDE	HYDROCARBONS	NITROUS OXIDES	CATEGORIES
Beijing	48-64	60-74	10-22	District
Shanghai	69	37		District
Shenyang	27-38		45-53	District
Jinan	28		4-6	District
Hangzhou	24-70			Road
Urumqi	12-50			Road
Guangzhou	70		43	

Source: He *et al.*, "Status and Development of Vehicular Pollution in China," *Environmental Science*, Vol. 7, No. 4 (August 1996).

The problem stems not just from the growing size of the vehicle fleet but also from low emissions standards, poor road infrastructure, and outdated technology, which combine to make Chinese vehicles among the most polluting in the world [31]. Vehicle emissions standards in China are equivalent to the standards of the developed world during the 1970s, and some domestic companies are manufacturing vehicles modeled after vehicles from 20 years ago. Actual emissions often exceed these standards: Chinese vehicles emit 2.5 to 7.5 times more hydrocarbons, 2 to 7 times more nitrous oxides (N₂O), and 6 to 12 times more carbon monoxide (CO) than foreign vehicles [32]. In Beijing, Shanghai, Hangzhou, and Guangzhou, up to 70

percent of CO emissions have been attributed to motor vehicles. Cars also contribute a large share of hydrocarbons and N₂O in the cities where data are available [33]. (See *Outdated Vehicles Degrade Urban Air Quality*.) As a result, although China's vehicle fleet is small compared with the developed countries, its large cities are already blanketed with smog.

A recent study in Beijing revealed that at all monitoring points within the Third Ring Road -- a rough boundary separating downtown Beijing and its outskirts -- the CO levels exceeded the national standard (4 micrograms per cubic meter per day). During the summer, ozone concentrations repeatedly exceeded the national standard, which is set on an hourly basis -- often several times per day. In addition, concentrations of N₂O have almost doubled over the past decade [34].

Compounding these pollution problems is the fact that the burgeoning Chinese motor vehicle fleet is largely fueled by leaded gasoline. Although lead exposure is known to be a significant health hazard in China, no routine monitoring of environmental concentrations or blood-lead levels is performed. A few studies have been conducted and are described below. These scanty data suggest that ambient lead levels in the urban area of major cities such as Beijing are usually 1 to 1.5 micrograms per cubic meter -- the national standard is 1 microgram per cubic meter. In some areas, ambient lead levels can reach as high as 14 to 25 micrograms per cubic meter [35]. The health effects, described below, are significant, although recent and dramatic government actions to phase out leaded gasoline will likely have a major impact on this problem. Beijing and Shanghai as well as other cities have already begun to act, and the countrywide phaseout is expected to be complete by the year 2000.

Health Effects from Ambient and Indoor Air Pollution

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vehicles emit "2.5 to 7.5 times more hydrocarbons, 2 to 7 time more nitrous oxides, and 6 to 12 times more carbon monoxide" (World Resources Institute 1998). These trends are challenging in themselves, but also offer substantial opportunities for simultaneous reductions in local air pollutants and carbon dioxide emissions through improved highway infrastructure and the use of more recent automotive technology.

Finally, most Chinese residents rely on coal and biomass stoves for cooking and heating. These also constitute the main sources of indoor air pollution. If other energy options develop such as natural gas or electricity, then the adoption of gas furnaces or electric appliances would provide an obvious route to reducing pollution levels, perhaps by substantial amounts. Such steps would tend to reduce greenhouse gas emissions, as well. Absent these developments, however, options still exist. China's cities, for example, are very dense. This may allow a more centralized control of pollution emissions through large scale heating systems that service multiple housing units (Fang et al 1998).

IV. Summary

The Kyoto Protocol has the potential to create the incentives necessary for a global greenhouse gas emissions market to evolve. This market would serve as a critical vehicle for countries and private firms to participate in the transfer of capital and technology to the countries where emissions can be abated at least cost. A review of the existing economic literature illustrates that China has significant potential to abate greenhouse gas emissions at low cost, thereby providing an opportunity for it to act as a major supplier of emissions abatement in this global market. While the Clean Development Mechanism can attract some investment in climate-friendly technologies, most economists believe that more substantial economic gains can accrue from an appropriately designed emissions growth target and active participation through international emissions trading. The global emissions market would provide the incentive to China to abate emissions of greenhouse gases, providing the opportunity to sell emissions allowances potentially valued in the billions of dollars annually. In addition, the abatement of carbon dioxide would deliver the substantial benefit of reducing emissions of local air pollutants and improving air quality in many urban areas in China.



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China's Health and Environment: Air Pollution and Health Effects

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- ◆ Air Quality May Be Worse Indoors



Curt Carnemark / World Bank

Poor Ambient Air Quality Prevails

"The residents of many of China's largest cities are living under long-term, harmful air quality conditions," Zhao Weijun, deputy director of the air pollution department of NEPA, reported in 1997 in *China Environment News* [16]. China has long recognized air pollution as a critical problem. Ambient concentrations of total suspended particulates (TSP) and sulfur dioxide (SO₂) are among the world's highest. (*See China's Air Pollution Levels Are Among the World's Highest.*) In 1995, more than one half of the 88 cities monitored for SO₂ were above the World Health Organization (WHO) guideline. All but two of the 87 cities monitored for TSP far exceeded WHO's guideline. Some cities such as Taiyuan and Lanzhou had SO₂ levels almost 10 times the WHO guideline [17].

Smoke Pollution in China

Largely because of controls at power plants and within households, particulate emissions have not risen as much as might have been expected with the doubling of coal consumption. Overall, particulate emissions in China have remained relatively level since the early 1980s [18]. In fact, in some large cities, ambient particulate concentrations have decreased markedly since the 1980s [19]. In contrast, SO₂ emissions have roughly paralleled the increase in coal consumption, reflecting heavy coal burning and inadequate sulfur control measures.

Coal burning, the primary source of China's high SO₂ emissions, accounts for more than three quarters of the country's commercial energy needs, compared with 17 percent in Japan and a world average of 27 percent [20]. China's consumption of raw coal increased annually by 2 percent between 1989 and 1993 [21]. (*See China's Growing Consumption of Coal.*) Meanwhile, SO₂ emissions increased by more than 20 percent and TSP increased by approximately 10 percent [22]. The country is expected to burn 1.5 billion metric tons of coal annually by the year 2000, up from 0.99 billion metric tons in 1990 [23].

Without even more dramatic measures to control emissions than are currently in place, the deterioration of air quality seems inevitable.

vehicles in Tokyo or Los Angel of the two other cities [30].

Beijing motor vehicles equals that in each

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Outdated Vehicles Degrade Urban Air Quality

Percentage of Emissions in Selected Chinese Cities Attributable to Motor Vehicles

	PERCENTAGE ATTRIBUTABLE TO MOTOR VEHICLES			
	CARBON MONOXIDE	HYDROCARBONS	NITROUS OXIDES	CATEGORIES
Beijing	48-64	60-74	10-22	District
Shanghai	69	37		District
Shenyang	27-38		45-53	District
Jinan	28		4-6	District
Hangzhou	24-70			Road
Urumqi	12-50			Road
Guangzhou	70		43	

Source: He *et al.*, "Status and Development of Vehicular Pollution in China," *Environmental Science*, Vol. 7, No. 4 (August 1996).

Health Effects from Ambient and Indoor Air Pollution

ENERGIZING CHINA

*Reconciling Environmental Protection
and Economic Growth*

EDITED BY
Michael B. McElroy, Chris P. Nielsen, and Peter Lydon

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STRATEGIC OPTIONS FOR REDUCING CO₂ IN CHINA: IMPROVING ENERGY EFFICIENCY AND USING ALTERNATIVES TO FOSSIL FUELS

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Richard Wilson
Harvard University

INTRODUCTION

CHINA'S ECONOMIC GROWTH OVER the past fifteen years has been dramatic, with average annual increases in gross national product (GNP) of over 7%. In the next ten years, average annual growth is expected to remain at least at this level (Ho, Jorgenson, and Perkins, this volume). Associated with this economic expansion will be increased energy use. Table 1 lists the overall energy consumption in China by resource in 1993. We would expect that electricity use would rise faster than total energy use in China, as it has in other countries in comparable phases of their development (Bodansky 1991; Starr 1990; Wilson 1989), and in fact, Chinese leaders have decided to expand electricity production as fast as they can (11% per year in recent years).

In a perspective of concern about CO₂ emissions, it is equally or more important that it has been decided that the expansion of electricity production will be predominantly based on coal. The rapid increase in de-

urvey has not yet been under-
n building survey (SSB 1989),
one-story row houses and only
us (two- or three-stories).
low fuel economy, because
ss for a given volume of living

olid bricks (in Beijing a typical
n addition of 30 cm thick aer-
can reduce the heat transfer
•°C) to 0.6 watts/(m² • °C)—
er still, the original construc-
ks. Single-glazed windows are
indows can be cut in half by
ose responsible for construct-
e to keep the cost down and
ions requiring insulation and
to be an inadequate incentive

consumption is to reduce so-
ildings. In the United States,
verheated by European stan-
rn all year long, although this
elsewhere, it is likely that in-

Table 1: Heat Losses in China and

Window	Roof
6.40	1.26
6.40	0.91
3.26	0.77
3.26	0.64
2.86	0.23–0.40
2.22	0.17–0.31

creasing prosperity will increase the demand for heat and air condi-
tioning, but perhaps not to American levels.

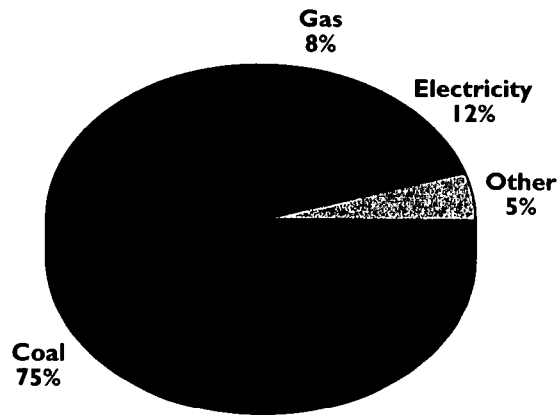
A final option is to use fuel cells to generate electricity, with the pos-
sibility of cogenerating space heat and hot water. Fuel cells convert the
fuel in an electrolytic cell efficiently and directly to electricity, instead of
burning the fuel and using the heat to drive a turbine which in turn
generates electricity. In principle they can be used efficiently on small
scales as well as large scales. But although there are several pilot power
plants and vehicles elsewhere in the world that currently run on fuel
cells, there has been no large-scale adoption. Use of fuel cell technology
in China would require several steps: development of a fuel source (typi-
cal sources are hydrogen or natural gas), decreased capital costs, and
attention to unresolved technological problems, such as contamination
and water requirements. China should closely follow fuel cell develop-
ment in the industrialized world (Penner et al. 1995), so that if and
when these problems are solved, China will be in a position to exploit
the new technology rapidly.

Urban Domestic Energy Consumption: Fuel Switching from Coal to Oil or Gas

In 1993, 75% of urban household fuel consumption was from the di-
rect combustion of coal, 12% from electricity, and 8% from gaseous
fuel (Figure 1). Direct domestic coal combustion in urban areas accounts
for 9% of China's coal consumption. About three quarters of urban
households use coal for cooking.

FIGURE 1

Urban Residential Energy Consumption in China (1993)



There are three principal modes of space-heating in China: individual coal stoves, central heating (using small boilers, for 400 households or fewer, with capacities of 1–4 tons of steam per hour [t/hr]), and district heating systems (capacities of 10 t/hr or more). (In district heating systems, several apartment blocks share a common boiler, or sometimes use waste heat from an industrial complex or electricity generating plant.) The heat efficiencies of these three modes are 15%–40%, 55%, and 75% respectively. A 1989 survey reported in a 1991 article in the *People's Daily* indicated that 75%, 20%, and 5% of the floor area of urban residential buildings were heated by stoves, small boilers, and district heating, respectively. Large scale heating systems are more attractive in China than in many Western countries because most Chinese cities are densely populated and apartment buildings are often clustered together, facilitating district heating. It is worth noting, however, that centralized heating systems may not reduce total coal use as compared to individual coal-burning heaters because of control problems. There are inevitably heat losses in the distribution network and there may be only a partial load or improper operation. But indoor air quality will be greatly improved through centralization at the building or district level, and the emission of pollutants can be more easily controlled with larger facilities. Along with centralizing heating facilities, it is very important to pay attention to the issue of local heat control to maintain efficiency.

see
p 132

² With about 75% of urban residential households heated by individual coal stoves, China is like Great Britain in 1945; but within twenty-five years (by 1970) moderately priced oil and natural gas replaced most of these systems in Britain. China has now become a net importer of oil, and its natural gas is in very short supply. Even if and when China joins a global market economy, transportation costs for imported fuels suggest that China will want to continue using coal in households and therefore much attention has been given to increasing the efficiency of such use. Study has shown that briquettes and energy-efficient stoves (for space-heating and cooking) can increase efficiency from 15% to about 40% (defined as heat output divided by internal energy of fuel consumed).

In 1990, the briquettes sold to urban households had an energy content of 28 Mtce, of which honeycomb briquettes amounted to 27 Mtce. thirty-eight Mtce of raw coal were also consumed. The efficiency of burning honeycomb briquettes is greater than that of burning raw coal by 15% or more. Therefore if all of the raw coal were replaced by honeycomb briquettes, the total fuel consumption would be less by 5 Mtce (0.7% of China's total).

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space-heating in China: individual small boilers, for 400 households of 100 m² per hour [t/hr]), 10% (or more). (In district systems share a common boiler, or a small complex or electricity generated in three modes are 15%–40%, reported in a 1991 article in *Energy*, and 5% of the floor area of stoves, small boilers, and district heating systems are more attractive alternatives because most Chinese buildings are often clustered in cities. Worth noting, however, that the total coal use as compared with the use of control problems. There is no gas network and there may be a problem. But indoor air quality will be improved at the building or district level, and is easily controlled with larger district facilities; it is very important to maintain efficiency. In district households heated by individual stoves in 1945; but within twenty years natural gas replaced most of the coal. China is a net importer of oil, and even when China joins the world market for imported fuels suggests that coal in households and therefore increasing the efficiency of such stoves (for space heating) from 15% to about 40% (degree of fuel consumed). In district households had an energy consumption amounted to 27 Mtce. consumed. The efficiency of district heating is higher than that of burning raw coal. If coal were replaced by honeycombed stoves, the consumption would be less by 5 Mtce.

For household energy use, most countries of the world have switched to electricity or to other fossil fuels, such as oil and gas, where these have been available. These fuels burn more cleanly and efficiently, and with fewer CO₂ emissions per unit of energy.¹ Therefore, from a CO₂ emissions perspective, it is important to understand to what extent the Chinese can switch their cooking from coal to oil or gas (with or without electricity as an intermediate vector) and to encourage such conversion whenever possible.

The proven and estimated reserve of natural gas in China is around 1.4 trillion cubic meters (m³), or 1,900 Mtce. This is a small amount for a country the size of China, but exploration and development have only just begun. In 1993 natural gas provided only 2% of the primary energy in China (17 billion m³ or 22.6 Mtce), compared to 21% worldwide (Sinton 1993). About 50% of the natural gas production in China is used to produce fertilizer and only about 10% is for residential use. In 1990, only 29% of the urban population were able to use gaseous fuels for cooking.

Since one of China's most urgent challenges is to feed its vast and growing population, fertilizer will probably remain the principal use of natural gas in the future. A major switch to oil and gas for residential heating is therefore unlikely, although it is occurring in some of the largest cities. To the extent that this transition is attainable, individual control of the heating system will become easier (as noted above), and by replacement of coal both indoor and outdoor air quality in the cities will be automatically improved.

Production and burning of coal gas is another option for urban domestic use. Although the losses of energy involved in conversion to coal gas and then to heat may be greater than losses in direct coal combustion, this may be made up by the greater control and ease of use that gas affords, and its consequent improved efficiency. By 1988, China's coal gas consumption reached about 19 billion m³, of which 9% is used in residences. In China the gasification technology produces a low-quality gas (carbon monoxide [CO] and hydrogen) as used in Western countries 150 years ago, and often lacking pollution control.²

Large-scale gasification facilities for producing methane are being considered for several places. Indeed their use is an inherent part of the integrated gas combined cycle (IGCC) coal plants. At the present time these facilities must be imported. Also being considered are pipelines for carrying natural gas from Central Asia, or Eastern Siberia, where gas is plentiful, to China. The pipeline cost is about US\$1.5 million per km. If foreign exchange is available, this will be an attractive option.

Rural Domestic Energy Consumption

Over three quarters of the Chinese population is rural, but at the present time this sector consumes less than a quarter of the total national fossil fuel energy supply.³ Rural heating and cooking is often by simple biomass stoves. Pressing for energy efficiency in this sector does not seem, at first sight, to be a major way to prevent CO₂ emissions since little coal would be saved. But such a view would be shortsighted. In Western countries a transition occurred as rural populations developed a standard of living, and with it energy usage, to a level approaching that of the urban population. It is a major aim of the Chinese government and people to likewise upgrade the rural standard of living. At this point, China has the opportunity to make a broad policy decision as to how to guide this transition. In the United States massive, subsidized rural electrification was carried out, exemplified by the Tennessee Valley Authority, and the rural domestic energy system is now effectively the same as in the urban areas. China could follow this "traditional" Western path. Alternatively the government could emphasize local management of distributed energy resources which may be the natural path for a nation with both a large rural population and an extensive network of rural industry with large and rising energy demands. We therefore find the rural energy sector to be of particular importance.

As a transition to higher standards of living occurs, the rural population will use more commercial fuels—primarily coal—and more electricity. To the extent that the rural population uses coal, more CO₂ will be generated; to the extent that they use electricity from nonfossil sources, CO₂ emissions will be avoided. Whichever way China proceeds in this transition, it is easier and more cost-effective to install efficient equipment initially rather than to modify existing systems.

If the transition could take place as fast as it did in the United States there would be little need for specific *rural* energy policies, distinct from urban policies, to manage CO₂ emissions reduction. However, many observers including most Chinese feel that the dependence of rural China on local or regional energy and biomass resources is so deeply rooted that the transition to the standard of living of the urban economy cannot be fast, and if a less CO₂-intensive production pattern is to be achieved, taking specific policy steps will be necessary to avoid not only a "forgotten majority", but to avoid a pollution problem as well. Therefore, attention to rural domestic energy use can be extremely rewarding.

Biomass (fuel wood and agricultural wastes), which supplies over half of rural household energy, is in short supply. Even a casual observer notes

INDOOR AIR POLLUTION FROM RESIDENTIAL ENERGY USE IN CHINA

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INTRODUCTION

IN CHINA, HIGH SPEED economic development is causing rapid growth of energy use, thus creating various forms of environmental pressure, especially air pollution problems. Residential energy consumption, energy used by households, is an important component of China's energy consumption, accounting for around 15% of total commercial energy consumed in 1991 (SSB 1993). With higher per capita income, households seek amenities that consume energy. In addition, rural people are rapidly moving into cities and towns and augmenting their demand for commercial energy as their lifestyle changes. As a result of rapid industrialization and urbanization, China's residential energy demand is expected to grow.

According to the studies by Ma et al. (1994) and Qiu et al. (1993), space heating and cooking are the major energy uses in the household. They accounted for 75–95% of residential energy consumption in China, with space heating dominating all other types of energy use in the home. Coal provides more than 80% of the total commercial energy consumed by households in China. At present, heating by means of small coal stoves,

of which the average thermal combustion efficiency is only about 15%, is the major form of space heating, supplying three-quarters of the total residential space heating in China (see chapters by Fang et al. and Ni and Sze in this volume).

Residential energy consumption in China, fueled predominantly by coal and biomass, is thus inefficient, and contributes significantly to environmental pollution, especially indoor air pollution. Therefore, indoor air pollution from residential energy use, especially from coal burning, is an important and underappreciated component of the air pollution problem in China. 3

CHARACTERISTICS OF RESIDENTIAL ENERGY-RELATED INDOOR AIR POLLUTION

Residential coal consumption causes both indoor and outdoor air pollution. Past research indicates that most of the Chinese population spends a large percentage of its time indoors, and that indoor air pollution has a major effect on people's health (Wang Lihua et al. 1988; Xu Xiping et al. 1991, 1993). Recently, a series of studies done in China has shown that indoor air pollution is very serious in urban China (Xu Fengliang et al. 1991; Ou et al. 1989; Ri et al. 1992). The research results in Shanghai and three other cities confirm the expected result that concentrations of inhalable particulate (IP), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO) in the homes using coal are much higher than in the homes consuming gaseous fuel (Qin et al. 1991). The difference between the IP concentrations caused by the two types of fuel used can reach more than a multiple of ten times during the winter (Wang Lihua et al. 1988). The concentrations of pollutants in kitchens are much higher than those in bedrooms (Tables 1 and 2).

Most of the concentrations are above the national standard (Class II) regardless of season. The national Class II standards for IP is 0.15 milligrams per cubic meter (mg/m^3), for SO_2 is 0.15 mg/m^3 , for NO_2 is 0.10 mg/m^3 , and for CO is 4.00 mg/m^3 , all on the basis of daily average readings. With regard to different kinds of heating systems, separate ones (with small coal stoves) in individual residence units have higher indoor pollution than central heating systems in winter (Table 3).

Table 4 presents the indoor pollution caused by residential energy use in rural China. The indoor pollution contributed by dung, wood, and straw combustion are similar to or even higher than the pollution contributed by burning coal.