Harvard Center for Risk Analysis

JANUARY 2007
Volume 15, Issue 1

Risk in Perspective

AIR POLLUTION RISKS IN CHINA

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"Our work suggests that intake fractions can facilitate risk-based priority-setting when resources are limited."

Introduction

As in many rapidly developing countries, energy generation capacity and consumption in China have increased tremendously over the past 25 years and will continue to increase substantially in the foreseeable future. Due to the use of coal for the majority of power generation, many cities are experiencing severe levels of air pollution and decision-makers are faced with the difficult task of mitigating pollution while supporting continued economic growth.

This edition of *Risk in Perspective* reports some results of the Harvard Center for Risk Analysis' work on these issues, undertaken as part of the University's China Project. The China Project is an interdisciplinary academic research program focused on the Chinese atmospheric environment and its national and international implications, bringing together faculty, researchers, and students from across Harvard's schools under the auspices of the University's Center for the Environment and Division of Engineering and Applied Sciences. The research described below was funded by grants from the Energy Foundation, the V. Kann Rasmussen Foundation, the Bedminster Foundation, and the Dunwalke Trust, with additional support from the Harvard Center for Risk Analysis.

As indicated in Figure 1, ascertaining the benefits of air pollution control (i.e., of reducing the human health risks associated with energy generation) involves four main steps: estimating the quantities of pollutants emitted, determining the impact of these emissions on ambient concentrations and hence on population exposure, assessing the incremental damages to human health (e.g., on mortality and morbidity) due to exposure, and determining the value of these damages using monetary or other measures. The analysis discussed in this article focuses on the second of these components, and estimates the impact of emissions on ambient concentrations and population exposure in a form that can be directly translated into human health risks. We also briefly summarize related work on the Chinese monetary values for these risk reductions.

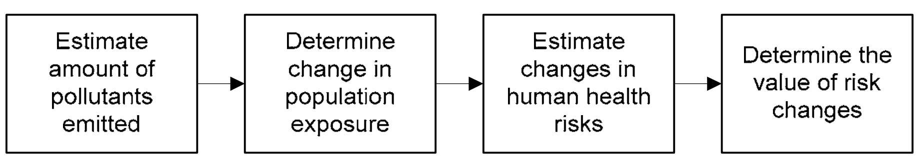

Figure 1: Steps in estimating the benefits of pollution controls

What is an intake fraction?

The link between emissions and exposures is often determined by running complex models that require significant time and resources. However, there are more than 2,000 coal-fired power plants in China with capacity greater than 12 MW. The analytical cost of running detailed fate and transport models for each of them would be prohibitive, and the time needed to apply such models is likely to delay decision-making. Instead, we run a detailed long-range transport model (CALPUFF) for a subset of China's coal-fired power plants and use the outputs to develop simple yet meaningful measures of the emissions-exposure relationship. By building models to determine how this relationship depends on the geographic location of the source, we can estimate the relationship for sites not included in our sample.

For this analysis, we utilize the concept of an "intake fraction," defined as the proportion of material or its precursor released from a source that is eventually inhaled or ingested by a population. For pollutants with linear concentration-response functions, population health risk will be directly proportional to the intake fraction.

The intake fraction (iF) can be calculated as:

$$iF = \frac{\sum_{i=1}^{N} P_i \times C_i \times BR}{Q}$$

Our modeling domain covers all the heavily populated areas in China, and is divided into 14,400 grid cells indexed by i. P_i is the population in cell i, derived using 1999 county-level population data. C_i is the incremental concentration at location i (g/m^3), estimated using CALPUFF. BR is the population-average breathing rate (m^3/s), for which we assume a nominal value of 20 m^3/d. Q is the emission rate of the modeled pollutant or its precursor (g/s).

Pollutants modeled

Primary pollutants are formed directly during the combustion process, while secondary pollutants are formed in the ambient air by the chemical reactions of gaseous precursors during atmospheric transport. We calculate intake fractions for primary pollutants (particulate matter (PM) and sulfur dioxide (SO_2)), and for secondary pollutants (ammonium sulfate inhaled per unit of sulfur dioxide emissions and ammonium nitrate inhaled per unit of nitrogen oxide emissions).

The particle size distributions of primary PM can vary substantially for different combustion processes and control equipment and influence the fate and transport of particles in the atmosphere and therefore the intake fractions. For the purpose of this study, we define PM_1 to be particles of 1 μm in aerodynamic diameter, with parallel definitions for PM_3, PM_7 and PM_{13}. We calculate the intake fraction of total primary particles as the weighted average of the intake fractions of particles of different sizes.

Power plant selection and source characteristics

For our analysis, we select power plants that allow us to evaluate geographic factors that influence intake fractions. We randomly choose one site from each of the Chinese administrative units covered by our modeling domain. Figure 2 shows the locations of the 29 selected sites.

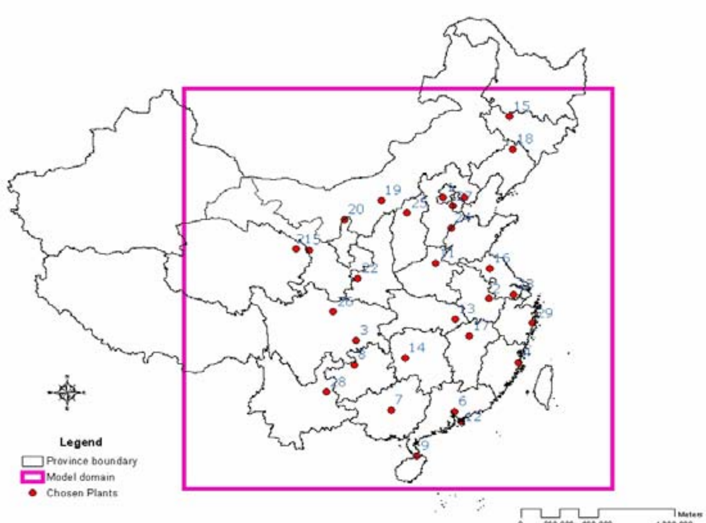

Figure 2: Locations of modeled power plants

Allowing plant characteristics to vary significantly between sites would make it difficult to identify the independent effects of population and meteorology on intake fractions. Moreover, newly constructed or proposed power plants in China follow the same engineering design guidelines and their source characteristics (e.g., stack height, exit temperature, exit velocity) are usually within a narrow range. Consequently, we evaluate the intake fractions associated with locating a typical modern power plant in China at each of the 29 sites.

Results

Table 1 lists the estimated annual average intake fractions for the 29 sites as well as the standard deviation and minimum and maximum values. PM_1 has the highest mean intake fraction, 1 x 10^{-5}. This means that for every metric ton of PM_1 emitted, 10 grams are eventually inhaled by people in the domain. PM_3 has the second highest mean intake fraction, followed by SO_2, secondary ammonium sulfate, PM_7, secondary ammonium nitrate, and PM_{13}. Among the primary particles, larger particles have smaller intake fractions. Averaging the intake fraction estimates for PM yields an overall intake fraction for primary particles of 6 x 10^{-6}.

Table 1. Annual average intake fraction estimates and summary statistics across 29 power plant sites in China.

	Sulfur Dioxide	Sulfate	Nitrate	Primary PM_1	Primary PM_3	Primary PM_7	Primary PM_{13}
Mean	4.8E-06	4.4E-06	3.5E-06	1.0E-05	6.1E-06	3.5E-06	1.8E-06
Standard Deviation	1.9E-06	1.5E-06	1.7E-06	3.7E-06	3.0E-06	1.8E-06	1.0E-06
Minimum	1.8E-06	7.3E-07	8.0E-07	2.8E-06	1.7E-06	1.1E-06	6.7E-07
Maximum	8.9E-06	7.3E-06	7.1E-06	1.9E-05	1.2E-05	8.2E-06	5.2E-06

Note: PMx = particulate matter with aerodynamic diameter equal to “x” µm.

We also estimated how far from the power plant one would need to be to capture at least half of the intake fraction (and therefore half of the population risk). The average distance ranges from less than 200 km (for PM_{13}) to nearly 500 km (for secondary nitrate particles). For primary particles, the distance from the source capturing a certain percentage of the total intake fraction decreases with increasing aerodynamic diameter.

We construct regression models to study whether variability in intake fractions can be explained using easily obtainable parameters that represent the effects of important variables, including meteorological conditions, source characteristics, and population distribution. We include general meteorology variables (such as climate zone and precipitation) and characterize population based on fixed distances from each plant (within 100 km, between 100 and 500 km, between 500 and 1,000 km, and beyond 1,000 km).

We find that population is a strong predictor of intake fractions, as expected. Generally speaking, the near-source population is more important for large primary particles while population at medium and long distances is more important for primary fine particles and secondary particles. We also find that intake fractions are generally lower for power plants in areas with more precipitation.

Sensitivity analyses indicate that stack height has a greater effect on primary than secondary particles, because secondary particles have long residence times, can travel further distances in the atmosphere, and are not as strongly influenced by the local population density as primary particles. The size distribution of primary particles has a large impact on their resulting intake fractions while the background ammonia concentration is an important factor influencing the intake fraction for ammonium nitrate. The background ozone concentration has a moderate impact on the intake fraction for ammonium sulfate and nitrate.

Discussion and conclusions

The intake fraction estimates for China are about an order of magnitude higher than those in similar U.S. analyses. Much of the difference appears to be explained by the higher population density in China. The findings from our regression analyses generally agree with similar analyses of intake fractions for U.S. power plants. For example, population variables alone can explain the majority of the variability in the intake fractions. In addition, population at medium distance (e.g., between 100 and 500 km) significantly influences the intake fraction of primary fine particles while population at longer distances (e.g., beyond 500 km) significantly influences the secondary ammonium sulfate intake fraction.

Valuing reductions in air pollution-related health risks

Determining the appropriate level of pollution control requires careful balancing of the benefits against the costs. Estimating the value of these benefits is a difficult and controversial task, since it involves ascertaining the monetary worth of effects on human health and the environment.

HCRA Director James K. Hammitt and Dr. Ying Zhou have been researching the value of air pollution-related risk reductions in China. Using a contingent valuation survey administered in three diverse locations, they estimate values for three health endpoints: colds, chronic bronchitis, and premature mortality. Averaged across the locations, they find that (in 1999 U.S. dollars using the official exchange rate) median willingness to pay to prevent a cold episode ranges between $3 and $6; to prevent a statistical case of chronic bronchitis ranges between $500 and $1,000; and to prevent a statistical case of premature mortality ranges between $4,000 and $17,000. The mean values are between two and thirteen times larger because some respondents reported values significantly above the median.

The Chinese values are substantially smaller than those for more developed countries; e.g., between about 10 and 1,000 times smaller than similar estimates from the U.S. and Taiwan. These differences are more than proportional to the differences in income: Chinese per capita income is about 50 times smaller than in the U.S. and about 20 times smaller than in Taiwan.

Because an individual power plant contributes a relatively small fraction to ambient concentrations, it is difficult to use monitoring data to "validate" the model outputs, an approach that is further impaired by the relative lack of monitoring data across China. However, we find that the relationship between emissions and modeled concentrations is consistent with aggregate measured PM emissions and concentrations. The correspondence between our results and previous intake fraction estimates, when accounting for population patterns (at least for primary PM), provides some assurance that our estimates are reasonable. The fact that we have not varied power plant characteristics masks some of the true heterogeneity in intake fractions across China, although it allows us to better quantify the influence of geographic location.

The robustness of our atmospheric modeling coupled with the strength of the regression equations and the use of stack characteristics typical of new power plants suggest that our model could reasonably predict the total population exposure to pollution from power plants in China. By combining our findings on population exposure with estimates of emissions, human health damages, and the value of these damages, we can estimate the benefits of increasing pollution controls using different strategies. Our estimates have been incorporated into national-level models in China to determine priorities for pollution control as well as the relative merits of different control strategies (such as environmental taxes), as documented in a forthcoming book from MIT Press, *Clearing the Air: The Health and Economic Damages of Air Pollution in China.*

For further reading, see:

Zhou, Ying, Jonathan I. Levy, John S. Evans, James K. Hammitt. 2003. "Estimating Population Exposure to Power Plant Emissions Using CALPUFF: A Case Study In Beijing, China." *Atmospheric Environment*. Vol. 37, pp. 815-826.

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