Estimating the Health Impacts of Coal-Fired Power Plants Receiving International Financing

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Summary

In addition to the environmental and human health harm caused by greenhouse gas emissions, coal-fired power plants emit massive amounts of toxic air pollutants that result in significant numbers of deaths and disease. We estimate that between roughly 6000 and 10,700 annual deaths from heart ailments, respiratory disease and lung cancer can be attributed to the 88 coal-fired power plants and companies receiving public international financing.

This range of estimated mortality reflects different assumptions regarding use of air pollution control technologies in plants for which this information was not obtainable. Air pollution from coal-fired power plants is also associated with other health outcomes, including infant deaths, asthma and other lung diseases.

Estimates of the number of people experiencing these additional health outcomes were not made in this study, as the necessary data from the countries where the power plants are located were not available. This suggests that the deaths estimated here represent only a portion of a larger overall health burden related to air pollution from these power plants.

Background

In the course of energy production, coal-fired power plants directly emit particulate matter (PM, sometimes called "soot") as well as gases that undergo chemical reactions to form fine particles in the atmosphere, such as SO_2 and NO_X. These emissions of PM, SO_2 and NO_X increase the ambient concentration of PM less than 2.5 microns in diameter ($PM_{2.5}$) over hundreds to thousands of kilometers downwind of the plants. Exposure to $PM_{2.5}$ has been consistently linked with increased mortality from cardiopulmonary diseases, lung cancer (Cohen et al., 2005; Pope et al., 2002), and numerous other respiratory illnesses and associated morbidity (Pope, 2000).

While most new power plants in both developed and less-developed countries have some modern pollution controls, such as electrostatic precipitators (ESPs), use of flue-gas desulfurization (FGD) is relatively rare in the less-developed countries. When utilized on plants that otherwise do not remove large amounts of sulfur from their emissions (e.g., through coal fluidized bed techniques), FGD can reduce sulfur dioxide emissions by 90%, resulting in substantial human health risk reductions.

The decision whether or not to add FGD is influenced by trade-offs between added costs and country-specific emission requirements. Additional controls are less likely to be added in projects in lower-income countries because of these cost considerations and often less stringent emissions standards. This is exemplified by the following excerpt from an Environmental Impact Assessment for two super thermal plants in India:

> An FGD unit was not included in the final plant design because . . . the CPCB (Central Pollution Control Board) ambient air quality standard for SO_2 will be met by the existing units. Installation

> of an FGD would increase the cost of generation and such costs would not be permitted as a recoverable cost. . . . (NTPC Limited, 2006, p. 8)

Greater awareness of health impacts from coal-fired power plants is needed to assure that energy policy decisions, especially in developing countries, take these external costs into account (Li et al., 2004). More thorough accounting of the external costs of energy generation would be likely to support increased use of pollution control technology and make other alternative sources of energy more cost-effective. This analysis estimates the emissions and subsequent numbers of deaths from heart and lung diseases and lung cancer specifically that can be attributed to 88 public-financed coal-fired power plants.

Methods

The online database Carbon Monitoring for Action (CARMA, 2009), provided the precise location of all of the 88 examined power plants. As emissions from coal-fired power plants are dispersed over a large area, populations living within 50, 100, 200, 500 and 1000 kilometers of each plant were estimated by applying a GIS mapping program to a gridded population dataset (CIESIN, 2009).

Information on air pollution control technologies was obtained by reviewing environmental impact assessments in online project descriptions. Individual plants, or in some cases companies, were placed into one of three categories based on available information on use of FGD: reported or planned use; no use; and unknown or undetermined use.

Annual emissions of primary particulate matter, sulfur dioxide and nitrogen oxides (the latter two forming secondary fine particles) were estimated based on the total megawatt-hours generated by each plant. Estimates of power plant–associated mortality from cardiovascular causes and lung cancer were made for each individual plant based on estimated exposures to primary and secondary fine particles of the populations within 1000 km of the plant.

To account for the uncertainty in FGD utilization in some plants, we provide two separate estimates, one assuming all unknown plants used FGD, the other assuming all unknown plants did not use FGD. Additional details on the methods used for the health impact assessment can be found at the end of this report.

Results

We estimate that between roughly 6000 and 10,700 annual deaths (see Table 1) can be attributed to air pollution from 88 publicly financed coal-fired power plants and companies. This includes roughly 5700 to 10,000 deaths from cardiopulmonary causes and 300 to 700 deaths from lung cancer. Table 1 provides further detail on these health outcomes by air pollutant type emitted.

Table 1. Estimated mortality in exposed population attributable to coal-plant emissions supported by public international financing

Particulate Type	Exposure Variable	Attributable Health Outcomes		
	Emission Amount (millions of lb)	Cardiopulmonary Mortality (# cases)	Lung Cancer Mortality (# cases)	**Total Deaths**
PM (direct)	190	1200	80	1300
SO_2 * (assumed + known FGD vs. only known FGD)	4100 to 7100	4400 to 8700	200 to 600	4600 to 9300
NO_2	560	90	10	100
Total Deaths		5700 to 10,000	300 to 700	6000 to 10,700

*SO_2 and TOTALS are presented with lower and upper mortality bounds to reflect Flue-Gas Desulfurization (FGD) utilization assumptions. The lower bound assumes all plants of unknown FGD status in fact do utilize FGD, while the upper bound assumes that only those reported to have FGD in fact do.

Of the 88 coal plants and companies considered in this report, 57% of those in High and Upper-middle income countries[1] used FGD,, compared to only 30% of those in Lower-middle and Low-income countries. As is shown in the mortality results table above, simple assumptions concerning whether plants and companies with unknown air pollution control technologies do or do not use FGD leads to a mortality differential of around 4600 deaths annually. Such a magnitude illustrates the effectiveness of FGD for reductions in disease burdens.

Theoretically, if all of the 88 plants and companies used FGD technology, the overall annual mortality total would drop to 2710 deaths. As an example of the importance of FGD for a single plant, if the Tata Mundra Ultra Mega coal plant installed and activated FGD technology (as it does not currently utilize FGD), its attributable mortality burden would drop from 250 annual deaths to 100 annual deaths.

As plant size and output vary widely, so too does attributable mortality. While some smaller plants are associated with less than one statistical death per year, 20–27 plants are associated

[1] The World Bank (World Bank, 2007) relies on 2007 Gross National Income (GNI) per capita data, and defines income groups as low-income ($935 or less), lower-middle income ($936-3 705), upper-middle income ($3 706 – 11 455), and high income ($11 456 or more). Prices are in USD$.

with more than 50 deaths per year, depending on assumptions of FGD use. Thus, the minority of the 88 coal plants and companies account for a large portion of attributable mortality.

The three coal plants with the largest contributions to annual mortality under lower-bound emissions estimates are presented in Table 2. All of these plants operate without FGD technologies.

Table 2. Coal plants with three largest contributions to mortality in exposed populations

Plant Name, Location	Annual Mortality Attributable to Plant's Emissions of Direct PM, SO_2 *, NO_2		
	Cardiopulmonary Mortality (# cases)	Lung Cancer Mortality (# cases)	**Total Mortality**
Barh, India	870	30	900
Yangzhou – 2, China	730	70	800
Kahalgaon, India	480	10	490
Plant Totals	2080	110	2190

* Non-FGD status reported for these plants.

As is illustrated by the tables, public international financing is currently being used to support three coal plants that together contribute to over 2000 deaths a year. The three plants causing the greatest number of estimated deaths change under an assumption of no FGD use where FGD status is uncertain. In this case, the Henan (Qinbei), China plant would have attributed annual mortality of 1200 deaths and the Ligang, China plant would contribute 900 annual deaths. Beyond the consideration of health impacts that should be undertaken as part of the due diligence of financing all 88 plants and companies in this report, these largest pollution emitters deserve special attention for their mortality impacts on exposed populations.

The number of deaths estimated here from fine particle–associated cardiopulmonary causes and lung cancer represent only a fraction of the total mortality and morbidity likely to be associated with these power plants. This estimate does not include infant mortality, cases of chronic bronchitis or asthma, adverse reproductive outcomes or other health outcomes that have been associated with coal-fired power plant pollution. It also does not include the health effects of other air pollutants, including ozone smog, mercury and other metals.

In addition, these estimates do not include health effects occurring outside of a 1000 kilometer radius, which are likely to be lower than within that radius but are still nonnegligible (Greco et al., 2007). Thus, these results can be considered conservative estimates of these 88 coal plant's *total* impact on health.

Conclusions

Coal-fired power plants supported by public international finance contribute significantly to the burden of death and disease in the countries in which they are located.

This study estimates that the cardiopulmonary and lung cancer deaths associated with 88 identified plants number conservatively in the thousands and possibly more than ten thousand, if FGD technologies are in fact absent from plants lacking this information. Unfortunately, FGD technologies are not universally used, and they are less frequently employed in power plants in less-developed countries, despite higher rates of illness and exposures in many of those countries.

While the methods of this study are relatively crude, they are based on detailed, plant-specific data and incorporate a number of conservative assumptions. In decisions to finance electricity generation, particularly in less-developed countries, local health impacts of proposed facilities *must* be considered. By supporting the construction of coal-fired power plants rather than cleaner alternative sources of electricity, international finance organizations are consigning the populations of those countries to deaths and illnesses attributable to air pollution emissions. Only by assessing the true costs to local and global societies from contributions to local and global air pollution can a rational and just decision be made.

Detailed Health Impact Assessment Methodology

Air Pollution Estimates

Estimates of each plant's PM, SO_2 and NO_X emissions (in lb) were estimated by applying a table of electricity generating unit emission factors (Milford et al, 2005) to reported plant-specific megawatt-hours generated per annum (CARMA, 2009) as projected into the future. The related Emissions Factors (EF) were provided for both primary and secondary PM precursors (SO_2 and NO_X), for bituminous and subbituminous coals and a variety of power plant types. As EF were not found specific to lignite and anthracite types, lignite was assumed to share the same EF as subbituminous coals and anthracite was assumed to share the same EF as bituminous coal. Where the coal type used by a specific plant was unknown, International Energy Agency statistics (OECD/IEA, 2009) were consulted to identify the most common coal type combusted in that country.

Coal-fired power plants in this study utilize a range of combustion technologies, including subcritical pulverized coal boilers, supercritical pulverized coal boilers, circulating fluidized bed boilers, and a single usage of integrated gasification combined cycle (IGCC). Estimates for plants with unknown technologies assumed use of subcritical pulverized coal boiler technology, as this is technology very likely to be used to satisfy the rapidly increasing global electricity demand, especially in less-developed countries (Li et al., 2004).

A lower bound of total plant emissions was estimated by assuming that all plants for which there was no available information on pollution control technologies did utilize flue-gas desulfurization (FGD). Conversely, in estimating the upper bound of total plant emissions, it was assumed that these unknown plants did not use FGD technologies. As FGD captures at least

90% of SO_2 emissions, upper bound SO_2 emission factors are tenfold higher than the lower bound.

Estimation of Particulate Exposure

Populations exposed to each plant's emissions were estimated after siting the plants on global high-resolution maps. Most plant coordinates were identified through the comprehensive CARMA database (CARMA, 2009), which locates plants on a high-resolution global map. A few plants' coordinates were also acquired through their direct visual identification on high-resolution satellite maps using the Google Earth website.

For twelve remaining plants, whose exact locations could not be identified using these methods, the coordinates were estimated based on the town where they were constructed. There were two development energy companies included in this report (Green Energy & Guangzhou Development) that have power plants pending construction, and therefore lacking specific coordinates. For these two companies, the estimated exposed population was the average of the other Chinese plants in this study.

To determine the relationship between human exposure to $PM_{2.5}$ and annual emissions of particulates and particulate precursors, an intake fraction methodology developed for global use (Joliet & Humbert, 2009) was employed. Intake fraction refers to the ratio between the amount of source pollutant (or its precursor) emitted and the amount actually inhaled by a population (Greco et al., 2007). Meteorological patterns, population distribution, source characteristics and ambient pollutant concentrations are key factors that influence intake fraction values (Levy et al., 2002). Although intake fractions are typically derived using atmospheric dispersion models, it has been demonstrated that regression models provide "reasonable" substitutes for predicting intake fractions in relation to power plant emissions (Levy et al., 2002).

Intake fractions for inhaled $PM_{2.5}$ were estimated for emitted PM_{10}, NO_x and SO_2. For primary particulate matter, the total PM emissions were multiplied by a continent-specific estimated intake fraction (Joliet and Humbert, 2009). A family of regression equations (Joliet & Humbert, 2009) provided intake fractions for secondary PM from NO_x and SO_2 for the estimated population living within the following specific distances from each individual power plant: less than 50 km, 50 to 100 km, 100 to 200 km, 200 to 500 km and 500 to 1,000 km.

Multiplying these intake fractions by the total NO_x and SO_2 emitted provided estimates of total secondary $PM_{2.5}$ inhaled by populations within 1000 km. of each plant. From this, daily per capita intake rates were calculated and then converted into average exposure concentration by dividing by the average volume of air inhaled daily. (USEPA, 1997). This provided a population-weighted estimate of each individual power plant's contribution to ambient $PM_{2.5}$ exposures within a 1,000 km radius.

Estimation of Mortality Impacts

Concentration-response functions (Pope et al., 2002) were used to estimate $PM_{2.5}$ associated mortality. Pope et al. (2002) had found that a 10 $\mu g/m^3$ increase in ambient $PM_{2.5}$ concentration was associated with approximately a 4% increased risk of all-cause mortality, a 6% increased risk of cardiopulmonary mortality and a 8% increased risk of lung cancer mortality for individuals 30 and older. As differences in country-specific socioeconomic development contribute to vastly different all-cause mortality rates among countries, we did not apply the coefficient for "all-cause mortality" derived in the United States to estimates of mortality in the mostly non-OECD countries involved in this study. Instead, we estimated only cardiopulmonary and lung cancer mortality. These contributions to cardiopulmonary and lung cancer mortality were estimated by the following equations:

The change in number of outcomes (E) of health endpoint J when ambient concentrations (C) of PM2.5 change can be given by:

$$\Delta E^J = [\exp(\beta^J \times \Delta C) - 1] \times E_0^J \times Pop^J, \quad (1)$$

where β^J is the CR coefficient of health endpoint J and E_0^J is the baseline incidence rate of health endpoint J in the affected population, Pop^J. Because β^J is small, Eq. 1 can be linearized and expressed as the following:

$$\Delta E^J = \beta^J \times E_0^J \times \Delta C \times Pop^J \quad (2)$$

The resulting output of emission-attributable mortality rate changes for cardiopulmonary disease and lung cancer was then multiplied with existing baseline mortality rates for these diseases in the exposed populations. We approximated baseline cardiopulmonary mortality rates by summing WHO country-specific mortality rates (WHO, 2009) for cardiovascular diseases, respiratory diseases and respiratory infections. We approximated country-specific baseline lung cancer mortality rates from the same database by summing mortality from malignant neoplasms of the trachea, bronchus and lungs. As these baseline mortality rates were not available specifically for the population over 30 for each country, total population mortality rates were used. These values likely underestimate the true over-30 mortality rates, as these considered health endpoints are more prevalent in individuals 30 and over than in individuals under 30.

Changes in numbers of deaths were estimated by multiplying the increases in cause-specific mortality rates by the population over 30 years of age within a 1000 km radius of each power plant, which itself was estimated by multiplying the proportion of the population under 30 years of age in each country (U.S. Census Bureau, 2008) by the total population living within the 1000 km radius.

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