The mortality impacts of current and planned coal-fired power plants in India

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We examine the health implications of electricity generation from the 2018 stock of coal-fired power plants in India, as well as the health impacts of the expansion in coal-fired generation capacity expected to occur by 2030. We estimate emissions of SO_2, NO_X, and particulate matter 2.5 μm ($PM_{2.5}$) for each plant and use a chemical transport model to estimate the impact of power plant emissions on ambient $PM_{2.5}$. Concentration-response functions from the 2019 Global Burden of Disease (GBD) are used to project the impacts of changes in $PM_{2.5}$ on mortality. Current plus planned plants will contribute, on average, 13% of ambient $PM_{2.5}$ in India. This reflects large absolute contributions to $PM_{2.5}$ in central India and parts of the Indo-Gangetic plain (up to 20 μg/m³). In the south of India, coal-fired power plants account for 20–25% of ambient $PM_{2.5}$. We estimate 112,000 deaths are attributable annually to current plus planned coal-fired power plants. Not building planned plants would avoid at least 844,000 premature deaths over the life of these plants. Imposing a tax on electricity that reflects these local health benefits would incentivize the adoption of renewable energy.

India | air pollution | electricity from coal | cobenefits of renewables

Coal-fired power generation capacity has expanded rapidly in India—doubling from 2008 to 2014—and currently provides over 75% of the electricity supplied to the grid. At the same time, electricity consumption per capita in India is less than one-10th of US per capita consumption (1). The important question, from the perspective of global climate change, as well as India's own development priorities, is to what extent the country will continue to rely on coal to supply its electricity needs. According to the pipeline of projects under development, India's coal-based power generation capacity may increase from ∼200 GW in 2018 to 300 GW by 2030 (2). However, these near-term infrastructure investments, although allowed under India's Nationally Determined Contribution (NDC) pledges, are inconsistent with long-term climate goals of limiting global temperature change below 1.5 °C or 2 °C. A rapid shift away from coal-centered electricity generation to other, nonemitting sources (such as renewables) is not only essential to stabilize the global climate but could accord with India's own development agenda.

One argument for transitioning from coal to renewable energy is that it will provide local health benefits. Existing literature has demonstrated the air quality and health cobenefits that accompany climate mitigation in various regions (3–8). Several studies have analyzed the air pollution or human health impacts specifically contributed from coal-fired power generation (9–12).

Studies of the health impacts of Indian electricity sector are, however, for earlier years and do not reflect the state of the art for calculating mortality impacts of particulate matter 2.5 μm ($PM_{2.5}$) (12, 13).

In this paper, we examine the mortality implications of electricity generation from the 2018 stock of coal-fired power plants in India, as well as from new plants (or extensions of current plants), at various stages of the planning process as of 2019. The health benefits from new plants' cancellation and existing plants' retirements can potentially provide additional motivation for India to decarbonize its energy system. Specifically, we estimate emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_X), and directly emitted particles ($PM_{2.5}$) for each plant and use the chemical transport model CAMx to estimate the impact of power plant emissions on ambient $PM_{2.5}$. Concentration–response functions from the 2019 Global Burden of Disease (GBD) are used to project the impacts of changes in $PM_{2.5}$ on mortality.

The location of coal-fired power plants in India in 2018 and the location of the planned plants whose impacts we model appear in *SI Appendix*, Fig. S1. *SI Appendix*, Table S1 summarizes plant capacity and emissions by state. In 2018, five states in North and Central India—Chhattisgarh, Uttar Pradesh, Maharashtra, Madhya Pradesh, and Gujarat—accounted for 50% of installed coal capacity. The majority of planned capacity is, in contrast, concentrated in the eastern half of the country, with the states of Tamil Nadu, Andhra Pradesh, Odisha, Chhattisgarh, and Jharkhand accounting for 53% of planned capacity expansion.

To estimate the impact of 2018 plants and planned plants on ambient $PM_{2.5}$, we first run CAMx using the baseline emissions inventory for all nonpower-plant sources of $PM_{2.5}$, SO_2, and NO_X in India for 2018 (run 1). We run the model for 365 d and compute annual average $PM_{2.5}$ at a spatial resolution of $0.25^\circ \times 0.25^\circ$. In a second run (run 2), we add estimates of 2018 power plant emissions to the baseline emissions inventory, assuming that

Significance

Under current operating conditions, coal-fired power plants in India generate significant amounts of particulate air pollution. We quantify the impact of plants operating in 2018 and plants in the planning stage as of 2019 on ambient $PM_{2.5}$ and on premature mortality. The health damages from coal-fired power plants can be avoided by replacing coal-fired power plants with renewable energy sources, which will also reduce GHG emissions. Taxing electricity generated from coal at a rate that reflects the value of health damages would incentivize the adoption of renewable energy. We calculate the magnitude of this tax. We also discuss the health benefits of reducing power plant emissions by implementing India's emission control laws enacted in 2015 but not yet in force.

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plants operate at 60% of capacity, and use the pollution control equipment in place in 2018. The difference between ambient $PM_{2.5}$ levels between run 2 and run 1 represents the impacts of coal-fired power plants operating in 2018. In run 3, we add to the emissions inventory in run 2 estimated emissions from planned plants, assuming that they operate at 60% of capacity and use pollution control equipment similar to that used in 2018. This enables us to compute the impact of all plants—current and planned—on ambient air quality (comparing runs 1 and 3), as well as the impact of the planned plants (i.e., the difference in concentrations between runs 2 and 3) on ambient $PM_{2.5}$ compared to the situation in 2018.

We estimate the impact of ambient $PM_{2.5}$ on premature mortality using 2017–18 population and mortality rates and exposure–response functions from the 2019 GBD (14). Mortality is computed for stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD), lower respiratory infections, diabetes mellitus, and lung cancer. We compute total deaths attributable to ambient $PM_{2.5}$ in 2018 and the share of those deaths attributable to 2018 power plant emissions; i.e., total deaths multiplied by the fraction of ambient $PM_{2.5}$ accounted for by power plants. We also compute total deaths attributable to ambient $PM_{2.5}$ in run 3 (i.e., assuming the planned plants are implemented) and 1) the fraction of these deaths attributable to all coal-fired power plants (2018 operating plants plus planned plants); and 2) the fraction of ambient $PM_{2.5}$ deaths attributable only to planned plants.

To calculate the deaths avoided by not building planned plants, we calculate the reductions in mortality risk, measured from ambient $PM_{2.5}$ levels in run 3, that would occur if planned plants were not built. This is the marginal reduction in mortality risk. Due to the concavity of exposure response functions for ambient $PM_{2.5}$, deaths avoidable by not building planned plants are less than deaths attributable to planned plants, which reflect the average, rather than the marginal, impact of a change in $PM_{2.5}$.

Our calculations of the health impacts of coal-fired power plants are based on total household exposure to $PM_{2.5}$ from ambient and household sources. Deaths associated with total exposure to $PM_{2.5}$ are then apportioned to ambient $PM_{2.5}$ based on the ratio of ambient to total exposure. For households who burn solid fuels for cooking, the marginal impact of reductions in ambient $PM_{2.5}$ is evaluated based on total exposure to $PM_{2.5}$ due to both household air pollution (HAP) and ambient pollution. Because of the concavity of exposure–response functions, the reduction in risk of death associated with a marginal reduction in ambient $PM_{2.5}$ is greater for households who do not burn solid fuels than for household who do.

Results

Impacts of Coal Plants on Ambient $PM_{2.5}$. Annual average ambient $PM_{2.5}$, population-weighted, based on all sources of air pollution in 2018 (run 2), is 53.5 μg/m^3 but varies greatly across the country (Fig. 1). Ambient $PM_{2.5}$ is much higher in the Indo-Gangetic plain and in areas with high coal-fired generating capacity than in the south of India. Ambient $PM_{2.5}$ would increase to 55.9 μg/m^3 if planned plants were also operating (run 3).

In 2018, coal-fired power plants contributed ∼9% of population-weighted ambient $PM_{2.5}$ in India (Fig. 2, Left). The impact of coal-fired power plants was greatest in states with high installed capacity (Chhattisgarh and Maharashtra) or in states that are downwind of states with high installed capacity (Jharkhand and Odisha) (*SI Appendix*, Table S2). The proportion of ambient $PM_{2.5}$ contributed by power plants in our analysis is slightly higher than the 8% reported in refs. 12 and 15 for 2015.

If planned plants were also operating, coal-fired power plants would contribute almost 13% of population-weighted ambient $PM_{2.5}$ in India (Fig. 2, Right). Ambient $PM_{2.5}$ attributed to power plants is between 7 and 10 μg/m^3 in Chhattisgarh, Uttar Pradesh, Maharashtra, and Odisha—the four states with the highest installed capacity, including planned plants. Some states which are downwind from large expansions in capacity, however, experience even larger impacts: coal plants account for 12.5 μg/m^3 of $PM_{2.5}$ in West Bengal and 10.8 μg/m^3 of $PM_{2.5}$ in Jharkhand. In Delhi, coal-fired power plants account for over 9 μg/m^3 of $PM_{2.5}$.

Attributable Versus Avoidable Deaths. In studies of the contribution of different sources of air pollution to premature mortality, deaths attributable to a particular source are calculated by multiplying the total deaths attributable to air pollution by the fraction of air pollution attributable to that source (15). The rationale for this is that it is impossible to say whether a source contributes the first microgram of $PM_{2.5}$ inhaled or the last. Because concentration–response functions for mortality are concave (14, 15), the first microgram inhaled has a larger impact on mortality than the last microgram inhaled; however, if we do not know which microgram can be attributed to a source, it makes sense to use the average of these marginal impacts—i.e., to treat each source as the average emitter.

If, however, a source is to be removed by a policy, and other sources are to remain constant, the impact of the source on mortality is computed using its marginal impact (16). The concavity of concentration–response functions implies that the impact of the first microgram of $PM_{2.5}$ reduced is smaller than the impact of the second microgram reduced, and that the deaths avoided by closing down a power plant will be smaller than deaths attributable to the plant.

Deaths Attributable to Coal Plants. Deaths associated with ambient $PM_{2.5}$ are calculated for each $0.25^{\circ} \times 0.25^{\circ}$ grid square, by cause of death, and then summed across all causes. (Results, aggregated to the state level, with uncertainty bounds, are reported in *SI Appendix*, Table S3.) Deaths attributed to all sources of ambient $PM_{2.5}$ total 846,000 in 2018. Deaths range from 162,000 in Uttar Pradesh to 878 in Goa. Most of the variation in deaths across states is due to variation in state population; however, deaths per 100,000 persons due to ambient air pollution are highest in the Indo-Gangetic plain.

Deaths associated with coal-fired power plants in 2018 equal total deaths associated with ambient $PM_{2.5}$ in each grid square multiplied by the fraction of ambient $PM_{2.5}$ contributed by coal plants. Deaths by grid square are plotted in Fig. 3, *Left* and aggregated by state in *SI Appendix*, Table S3. For all of India, coal plants are responsible for over 78,000 deaths in 2018, or ∼9.2% of deaths associated with ambient $PM_{2.5}$. Attributable deaths vary greatly across states (Fig. 3, *Left* and *SI Appendix*, Table S4). Deaths are highest in Uttar Pradesh and Maharashtra but range from 4,000 to 6,000 deaths annually in seven states.

Our estimates indicate that if planned plants were operating in addition to 2018 plants, deaths associated with coal-fired power plants would rise to over 112,000, ∼13% of deaths attributable to ambient $PM_{2.5}$ (Fig. 3, *Right* and *SI Appendix*, Table S4). Fig. 3, *Right* is based on the same assumptions regarding population, death rates, and exposure to HAP as in Fig. 3, *Left*; hence, any differences in deaths can be attributed to emissions from planned plants. Comparing Fig. 3, *Left* and *Right*, in Odisha and Jharkhand, where planned plants double installed coal capacity, deaths increase by 50%. However, states with smaller proportionate increases in planned capacity—Bihar, West Bengal, and Uttar Pradesh—experience the largest percentage gains in deaths. Bihar and West Bengal are downwind of large expansions of capacity in Jharkhand and Odisha and, under the assumption that current pollution control practices continue, will experience significant health impacts from cross-border pollution.

It should be emphasized that the deaths attributable to power plants would be much greater if households were to switch to

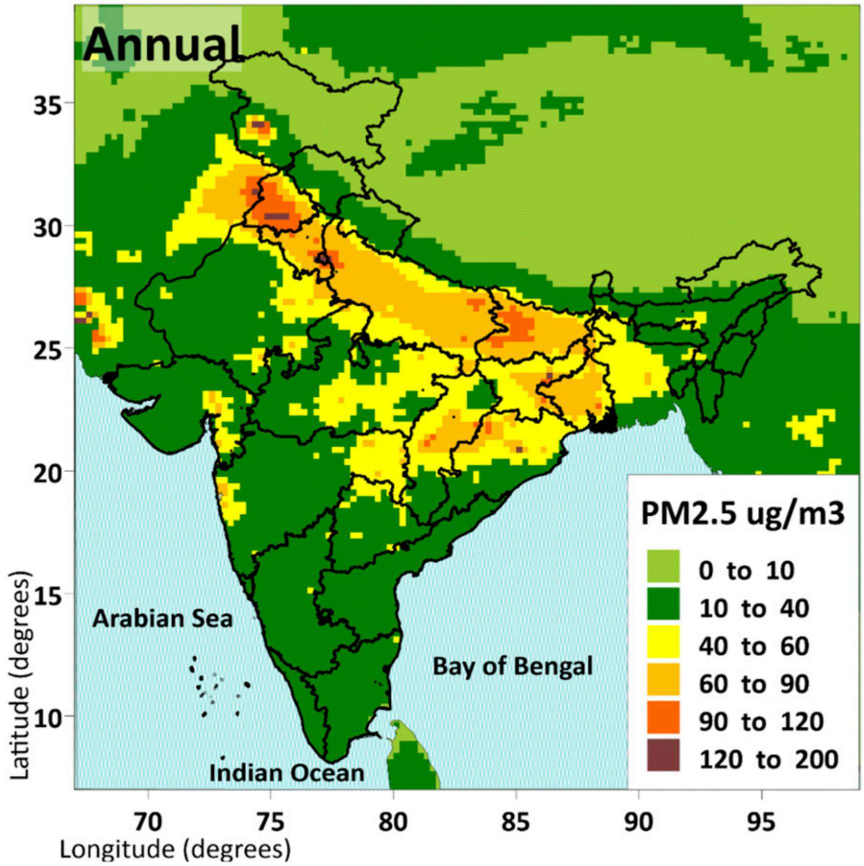

Fig. 1. Modeled ambient $PM_{2.5}$ concentrations, 2018.

cleaner fuels for cooking and heating. The biggest impacts of power plants on ambient $PM_{2.5}$ occur in the Indo-Gangetic plain and in northeast and central India (Fig. 2). These are also areas where many households are exposed to HAP. In Bihar, Jharkhand, Odisha, and Chhattisgarh, over 75% households burn solid fuels for cooking; in Uttar Pradesh, West Bengal, Madhya Pradesh, and Rajasthan, approximately two-thirds of households do. The additional exposure to $PM_{2.5}$ that these households receive from HAP averages 112 $\mu g/m^3$. Due to the nonlinearity of exposure–response functions, the fraction of deaths associated with an ambient $PM_{2.5}$ level of (e.g.) 70 $\mu g/m^3$ is higher if this is the only source of PM exposure than if a household receives an additional dose of $PM_{2.5}$ of (e.g.) 100 $\mu g/m^3$ from burning solid fuels.* *SI Appendix*, Table S4 presents estimates of deaths associated with ambient $PM_{2.5}$ if households were no longer exposed to HAP. This increases ambient $PM_{2.5}$ deaths and deaths attributable to current power plants by 44% and deaths attributable to current plus planned plants by 46%.

Deaths Avoided by Not Building Planned Plants. To estimate the health benefits of not building planned plants, we assume that all other sources of emissions remain the same and remove planned plants from the baseline $PM_{2.5}$ levels in run 3. This entails calculating the marginal reductions in deaths from the $PM_{2.5}$ levels in run 3 (*Materials and Methods*). As explained above, the reduction in deaths (i.e., deaths avoided) when new plants are not built is smaller than the deaths attributed to new plants. Due to the concavity of exposure–response functions, marginal reductions in deaths (i.e., deaths avoided) by not building new plants are about half of the size of deaths attributed to these plants in a given year.

Because not building plants yields reductions in ambient $PM_{2.5}$ over the life of the plant, we calculate premature deaths avoided over a 40-y horizon, using the average lifetime of coal plants in India (2). (*SI Appendix*, Table S5 presents deaths avoided by state for 40- and 30-y horizons.) These benefits, pictured in Fig. 4, assume that population grows at an annual rate of 0.48% per year (17) and that death rates, by disease, remain constant. We also assume that the percent of households burning solid fuels and their exposure to HAP remains constant over the life of planned plants, as do ambient $PM_{2.5}$ levels from sources other than planned coal-fired power plants. These assumptions very likely overstate total exposure to $PM_{2.5}$. Since exposure–response functions for PM are concave, our estimates of the marginal reductions in mortality risks are understated. In *SI Appendix*, Table S5, we estimate lives saved were HAP exposures to be reduced immediately to zero.

Not building planned plants avoids ~844,000 premature deaths, assuming a 40-y plant life. Coal plant deaths are reduced by over 170,000 in Uttar Pradesh and in West Bengal, the two states that experience the largest increases in deaths associated with coal plant expansion; however, reductions of between 50,000 and 60,000 deaths occur in Bihar, Maharashtra, Andhra Pradesh, and Tamil Nadu. The magnitude of reductions reflects differences in population and total exposure to $PM_{2.5}$ across states, and the magnitude of the increase in $PM_{2.5}$ associated with planned plants.

We acknowledge that our results are sensitive to assumptions about plant load factors and emissions factors. The plant load

*At a $PM_{2.5}$ level of 70 $\mu g/m^3$, 32% of lower respiratory infection (LRI) deaths are attributable to $PM_{2.5}$. At a level of 170 $\mu g/m^3$ of $PM_{2.5}$, 49% of LRI deaths are attributable to $PM_{2.5}$; however, only 41% of $PM_{2.5}$ is due to ambient $PM_{2.5}$, implying that 20% of LRI deaths are attributable to ambient $PM_{2.5}$.

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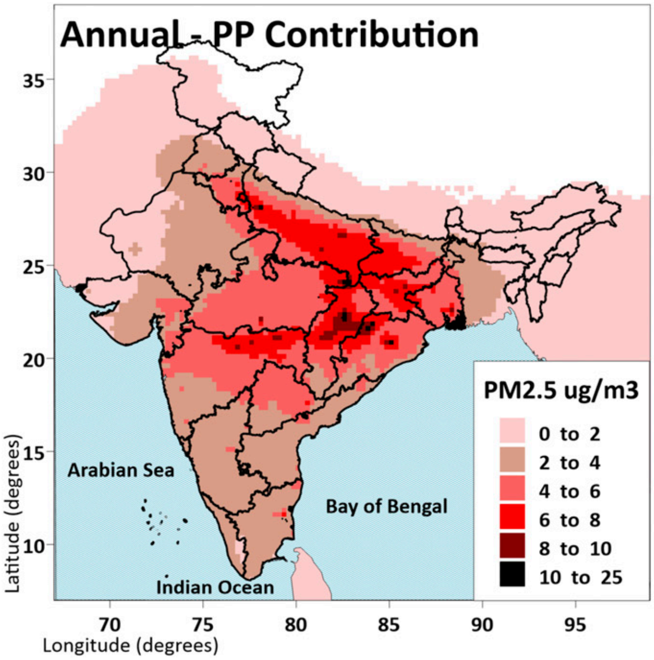


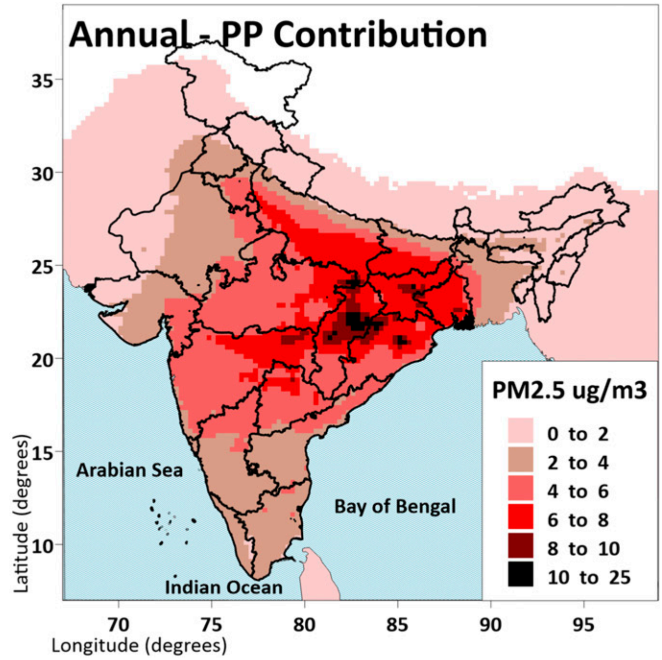
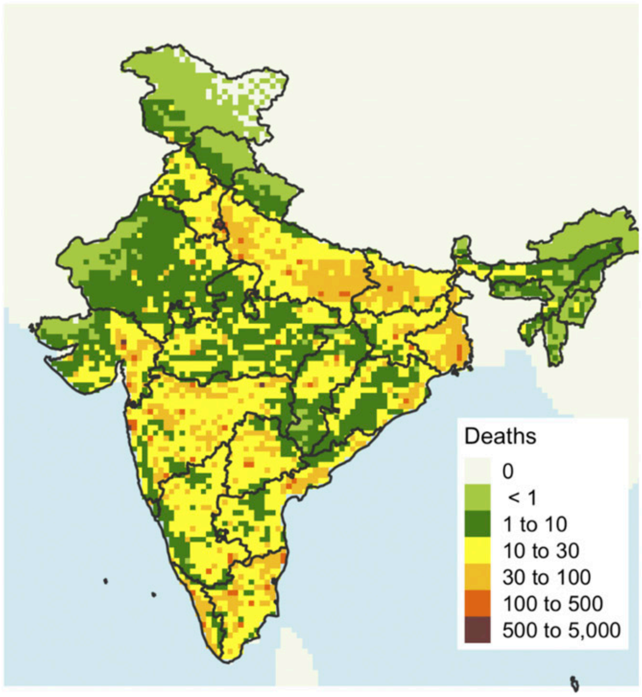


Fig. 2. (*Left*) Impact of 2018 plants on ambient $PM_{2.5}$. (*Right*) Impact of 2018 plants and new plants on ambient $PM_{2.5}$.

factor used for all power plants in our analysis (60%) is based on the average load factor of 60.9% in 2018. Previous analyses (18) have used load factors as high as 85%, the Central Electricity Authority's benchmark operating guideline. We believe 60% to be a more realistic assumption. Our emissions factors reflect the type of coal used by each plant and assume that electrostatic precipitators with 99% removal efficiency are used on each plant. We assume that all plants use low-NO_X burners but do not use flue-gas desulfurization units to remove SO_2. Our estimates of directly emitted $PM_{2.5}$ from 2018 plants are smaller than those used in ref. 15 based on the stock of plants in 2015; however, our estimates of SO_2 and NO_X emissions are higher. Because 80% of $PM_{2.5}$ associated with power plants comes from secondary particles, estimates of SO_2 and NO_2 are key.

Discussion

Our estimates suggest that current plus planned coal-fired power plants will contribute almost 13% of population-weighted ambient



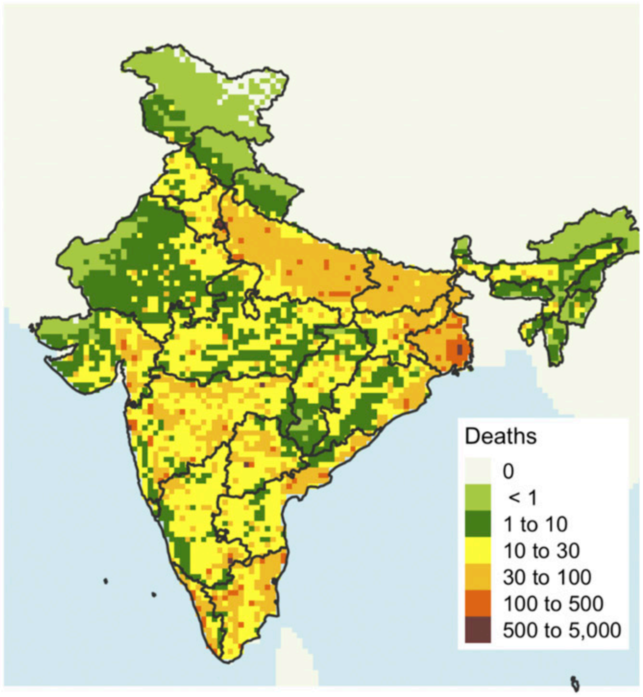


Fig. 3. (*Left*) Deaths attributable to 2018 power plants. (*Right*) Deaths attributed to 2018 plants and new plants.

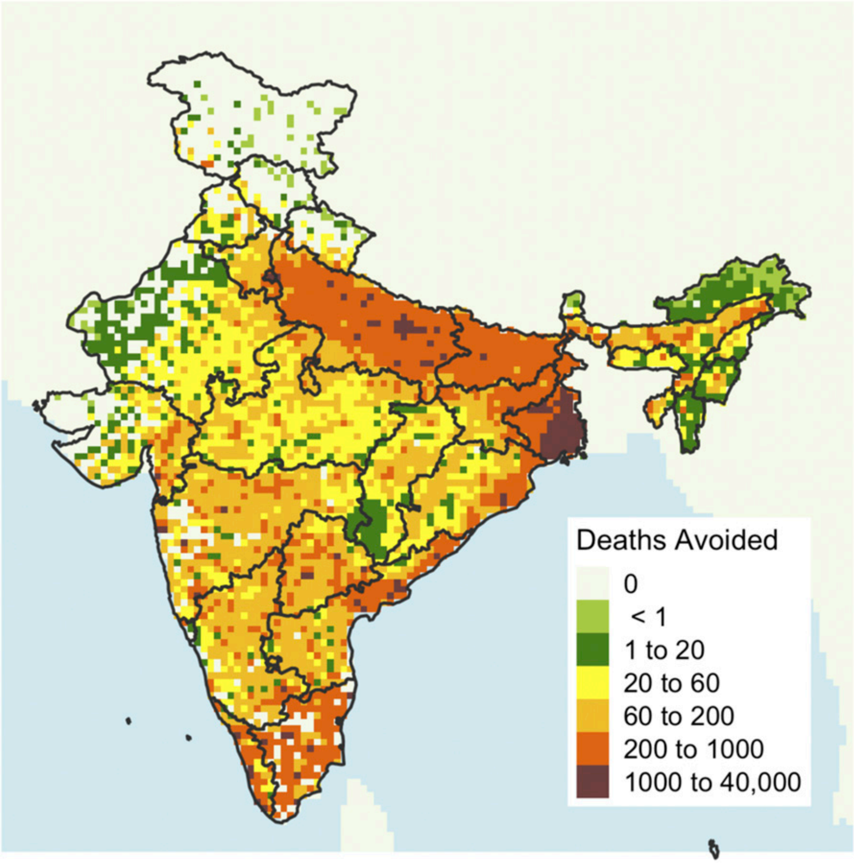


Fig. 4. Deaths avoidable by not building new plants, 40-y plant life.

$PM_{2.5}$ in India. This reflects large absolute contributions to ambient $PM_{2.5}$ from coal plants in central India and in the Indo-Gangetic plain (Fig. 2, *Right*)—increases of over 20 $\mu g/m^3$ in parts of Chhattisgarh and West Bengal. What is less obvious is the proportion of ambient $PM_{2.5}$ contributed by coal plants in the south and east of India. Coal-fired power plants contribute between 15 and 20% of ambient $PM_{2.5}$ even in Kerala and Karnataka, and up to a quarter of ambient $PM_{2.5}$ in parts of Tamil Nadu, Andhra Pradesh, and Odisha (*SI Appendix*, Fig. S2). Although absolute levels of $PM_{2.5}$ are lower in the south of India (Fig. 1), coal-fired power plants make a significant percentage of contribution to air pollution in these states.

The large number of deaths attributable annually to current plus planned coal-fired power plants (over 112,000) and the large number of deaths avoided by not building planned plants—at least 844,000 over the life of the plants—attest to the health effects of coal-fired power plants. We emphasize that these are underestimates of the health effects—they do not include morbidity impacts associated with $PM_{2.5}$, which include childhood asthma (19), as well as respiratory infections, COPD, and heart disease in adults (20). They also ignore the health impacts of emissions from plants in India in adjacent countries.

We do not quantify other damages associated with $PM_{2.5}$. These include the impacts of $PM_{2.5}$ on children's neurological development (21–23) and on worker productivity (24, 25). Ecological damages include impacts on crop yields (26) and on visibility.

Reducing Air Pollutant Emissions from the Electricity Sector. One way to reduce coal plants' air pollutant emissions and associated damages is to install pollution control equipment. Our results assume that pollution control equipment in place in 2018 will continue to be used in the future. The significant health effects attributable to coal-fired power plants suggest substantial benefits from installing additional pollution control equipment to reduce power plant emissions.

In December 2015, India issued regulations governing SO_2 and NO_X emissions from thermal power plants and strengthened regulations governing directly emitted PM. If implemented, these regulations would effectively require control equipment on planned plants (flue-gas desulfurization units for SO_2 and selective catalytic reduction for NO_X) that would reduce SO_2 emissions by 90–98% and NO_X emissions by 95% (27). Studies (18) have estimated that meeting the 2015 regulations would also require the retrofitting of most 2018 electricity generating units with flue-gas desulfurization units, which would reduce their SO_2 emissions by 90–98%. Comparisons of the benefits versus the costs of these regulations (27) suggest that, in the aggregate, these regulations pass the benefit-cost test; however, the enforcement of these regulations continues to be postponed, although a recent National Clean Air Program targeting 2021–2022 may improve enforcement (28).

Were these regulations to be implemented, the impact of coal-fired power plants on ambient $PM_{2.5}$ could be reduced significantly. This reflects the fact that 80% of the $PM_{2.5}$ attributable to coal power plants is secondary sulfates, nitrates, and organic aerosols. A rough calculation suggests that a full application of the new regulations would reduce ambient $PM_{2.5}$ attributed to coal power plants by up to 70% per year.

However, continuous improvement of air quality over the long run may not be achieved through end-of-pipe controls, but rather require energy system transitions (29). Foregoing the building of

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new coal-fired power plants and increasing reliance on renewable energy will both improve air quality and make significant contributions toward climate goals. The health damages avoided by replacing coal-fired power plants with renewable energy are the cobenefits of producing electricity from wind and solar power. These cobenefits have been used to justify diverse policies to support reduced coal power reliance, including subsidies to renewable energy, regulatory actions to shift capacity or generation toward cleaner energy, and carbon taxes or other externality pricing policies. India has implemented a number of policies to encourage the adoption of renewables, notably in the areas of increasing solar power and power sector reform. Actions have driven significant cost reductions, and India now has an estimated 84 GW of grid-connected renewable energy capacity against a goal of 175 GW by 2022 (28).

Estimates of health benefits can also be used to incentivize the adoption of renewable energy by taxing electricity generated by fossil fuels (30). To calculate a tax on electricity that reflects the health impacts we have quantified requires monetizing the premature mortality associated with power plant emissions. The value of mortality risk reductions is summarized using the value per statistical life (VSL). This is what individuals would pay for small risk reductions that together sum to one statistical life. A recent study of the Indian electricity market (30) suggests using a VSL for India equal to Rs. 10.3 million for 2018, based on updates of a study of the VSL in India (31). This is similar to the value recommended by the recent References Case Guidelines for Benefit-Cost Analysis (32) based on benefit-transfer principles. Applying this value to the deaths associated with the 2018 stock of power plants suggests a value of mortality damages of Rs. 0.73/kWh—about 20% of the average cost of electricity production from coal (27). As noted above, this is a lower bound to the value of health damages associated with power plant emissions and to all damages associated with these emissions.

Coal-fired power and its potential expansion presents a challenge in India. We have shown the significant damages that current and planned coal plants create through premature mortality, which constitutes a lower bound to the health and other damages associated with coal-fired electricity generation. Although shifting away from coal presents significant political and justice challenges, the multiple benefits of this shift, not only for health but also climate, can be valuable considerations as India seeks to deliver a cleaner and vibrant economy. Moreover, these findings are not unique to India. Other countries with expanding coal fleets should also consider the significant health benefits of replacing coal with cleaner sources of energy as they work toward achieving sustainable development goals.

Materials and Methods

Modeling the Impact of Power Plants on Ambient $PM_{2.5}$. We assembled data on all coal-fired generating units in India operating in 2018 (*SI Appendix*, Fig. S1*A*) and assigned emissions factors to each unit based on coal source and vintage of boilers. The dataset was expanded to include planned plants and planned expansions of 2018 plants (*SI Appendix*, Fig. S1*B*). *SI Appendix*, Table S1 summarizes, by state, coal-fired generating capacity and aggregate emissions of SO_2, NO_X, and primary $PM_{2.5}$ from 2018 coal-fired power plants and 2018 plants plus planned plants.

CAMx, an Eulerian photochemical dispersion model which allows for secondary particle formation, was used to model the effects of power plant emissions on ambient $PM_{2.5}$. Three runs were conducted: run 1 included a baseline emissions inventory of all sources except power plants; run 2 added emissions from power plants operating in 2018 to run 1; run 3 added emissions from planned plants to run 2. The model was applied using a $0.25^\circ \times 0.25^\circ$ resolution for 365 d and meteorological conditions for 2018. (See *SI Appendix* for more details.) The impact of changes in ambient $PM_{2.5}$ due to both primary and secondary particle formation is weighted by 2018 population.

Calculation of Deaths Attributable to Power Plants. To compute the deaths attributable to power plants, we calculated deaths associated with ambient $PM_{2.5}$ for each $0.25^\circ \times 0.25^\circ$ grid square, by cause of death, and then summed across all causes of death. This was multiplied by the fraction of ambient $PM_{2.5}$ attributable to power plants to calculate deaths attributable to power plants for the grid square.

Ambient $PM_{2.5}$ (PM_A) affects both households who use solid fuels for cooking and those who do not. Let p_H represent the fraction of the population in a grid square who are exposed to solid fuels from cooking and PM_H represent their additional $PM_{2.5}$ exposure over and above PM_A. The fraction of the population exposed only to PM_A is $1 - p_H$. The total deaths due to $PM_{2.5}$ in the grid square (computed for each cause of death) is given by

$$\text{PM Deaths} = \text{PAF}(PM_A + PM_H) \times \text{Baseline deaths}_{AP+HP} + \text{PAF}(PM_A) \times \text{Baseline deaths}_{AP}, \quad [1]$$

where Baseline deaths_{AP+HP} represents the total deaths among persons exposed to both ambient (AP) and household (HP) air pollution, and Baseline deaths_{AP} represents total deaths among persons exposed only to ambient pollution. (See *SI Appendix* for calculation of Baseline deaths_{AP} and Baseline deaths_{AP+HP}.) Let RR(z) represent the relative risk of death at PM = z. The population attributable fraction (PAF) is the proportion of deaths attributable to PM and is given by

$$\text{PAF}(z) = [\text{RR}(z) - 1]/\text{RR}(z). \quad [2]$$

The PAF, population attributable fraction, is evaluated at $z = PM_A + PM_H$ for persons exposed to both AP and HP and evaluated at $z = PM_A$ for persons exposed to only to AP. Baseline deaths for each subgroup in the population can be calculated from total deaths (M), p_H, and the relative risk function, as described in *SI Appendix*.

The total deaths attributable to AP is calculated as

$$\text{AP Deaths} = [PM_A/(PM_A + PM_H)]\,[\text{PAF}(PM_A + PM_H) \times \text{Baseline deaths}_{AAP+HAP}] + \text{PAF}(PM_A) \times \text{Baseline deaths}_{AAP}, \quad [3]$$

which assumes that AP deaths among persons exposed to both sources of PM are proportional to the share of PM_A in total PM exposure.

Deaths attributable to power plants are calculated by multiplying AP deaths by the fraction of PM_A attributable to power plants. This effectively treats power plants as the average source of emissions in each grid square.

$$\text{Deaths Attributable to Power Plants} = \text{AP Deaths} \times \text{Fraction of } PM_A \text{due to Power Plants}. \quad [4]$$

Eq. **4** is calculated for each cause of death in each grid square, based on 1) the PM_A contribution of power plants in 2018; and 2) the PM_A contribution of 2018 power plants plus planned plants.

Calculating Deaths Avoided by Not Building Power Plants. If planned power plants are not built and all other sources of PM remain the same, the improvement in PM constitutes a marginal reduction in PM. The deaths avoidable by reducing PM_A from $PM_A{}^0$ to $PM_A{}^1$ are measured by the reduction in risk of death from moving from $PM_A{}^0$ to $PM_A{}^1$ multiplied by baseline deaths

$$\Delta M = (\text{Baseline deaths}_{AP+HP})\left[\text{RR}(PM_A{}^1 + PM_H)/\text{RR}(PM_A{}^0 + PM_H) - 1\right] + (\text{Baseline deaths}_{AP})\left[\text{RR}(PM_A{}^1)/\text{RR}(PM_A{}^0) - 1\right]. \quad [5]$$

We calculate ΔM by setting $PM_A{}^0$ equal to the projected PM_A level once all sources, including planned power plants, are operating, and $PM_A{}^1$ equal to the projected PM_A level without planned plants.

Data on total deaths (M) for each cause of death for the year 2017 were obtained from the Global Health Data Exchange (http://ghdx.healthdata.org/). PM_H and p_H for each state appear in *SI Appendix*, Table S6. The exposure response functions (MR-BRTs) are available in ref. 33.

Data Availability. GBD 2019 Risk Factors Collaborators data have been deposited in the Global Health Data Exchange (https://doi.org/10.6069/KHWH-2703, ref. 33). All study data are included in the article, in openICPSR (https://doi.org/10.3886/E130404V1, ref. 34), and/or *SI Appendix*.

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