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The Health Impacts of Coal-Fired Power Plants in India and the Co-benefits of Greenhouse Gas Reductions†

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Under the Paris Agreement, India has pledged that 40 percent of its electricity generating capacity will come from non-fossil fuel sources by the year 2030; however, this pledge does not limit total coal-fired generating capacity. Indeed, as of 2019, planned increases in coal-fired capacity totaled 95 GW—46 percent of installed capacity in 2018.

In this paper we estimate the CO_2 benefits and the health co-benefits of not building these plants. The co-benefits of reducing reliance on fossil fuels are often used as an argument for imposing carbon taxes, arguing that they will offset the costs associated with a carbon tax. Indeed, recent studies (Markandya et al. 2018) claim that the health co-benefits of reducing reliance on fossil fuels in India exceed the costs of replacing fossil fuels with renewables. The health impacts of coal-fired electricity generation can, however, be used more directly to incentivize the adoption of renewable energy by taxing electricity generation at a rate that reflects health damages. We calculate the value of mortality damages per kWh of electricity generation from coal based on PM2.5 generated by the 2018 stock of coal-fired power plants (CPPs). We find that the mortality damages associated with coal-fired generation, a lower bound to domestic damages, are between ₹74 and ₹90/kWh—more than a carbon tax of $10 per ton of CO_2, at an exchange rate of ₹70 to $1.

To estimate the health impacts of CPPs in India, we assemble a database of power plants operating in 2018 and a database of planned plants. We add these to an emissions inventory for India in 2018 and use an air quality model (CAMx) to calculate the contribution of current and planned power plants to ambient PM2.5. The mortality impacts of ambient PM2.5 attributable to current power plants and avoidable by not building future plants are calculated using exposure-response functions from the 2019 Global Burden of Disease project (GBD; Murray et al. 2020).

I. Coal-Fired Power Generation in India and Its Impact on Ambient PM2.5

In fiscal 2018, 200 GW of coal-fired generating capacity were connected to the grid in India. Operating at an average plant load factor of 60.9 percent, these plants generated approximately 1,000 GWh of electricity (Central Electricity Authority 2019). Although CPPs exist throughout the country, 50 percent of 2018 capacity was located in 5 states: Maharashtra, Chhattisgarh, Uttar Pradesh, Madhya Pradesh, and Gujarat (see Figure 1, panel A). The locations of plants in the planning stages—which total 95 GW—as of November 2019 are shown in Figure 1, panel B. New capacity is concentrated in the east and south of the country, with Tamil Nadu, Andhra Pradesh, Odisha, Chhattisgarh, and Jharkhand accounting for over half of planned expansion. Coal-fired capacity after planned plants are built is concentrated in North and Central India and in Tamil Nadu.

To model the impact of plants on ambient PM2.5, we estimate emissions factors for SO_2, NO_x, and primary PM2.5 for each plant and assume that each plant operates at 60 percent

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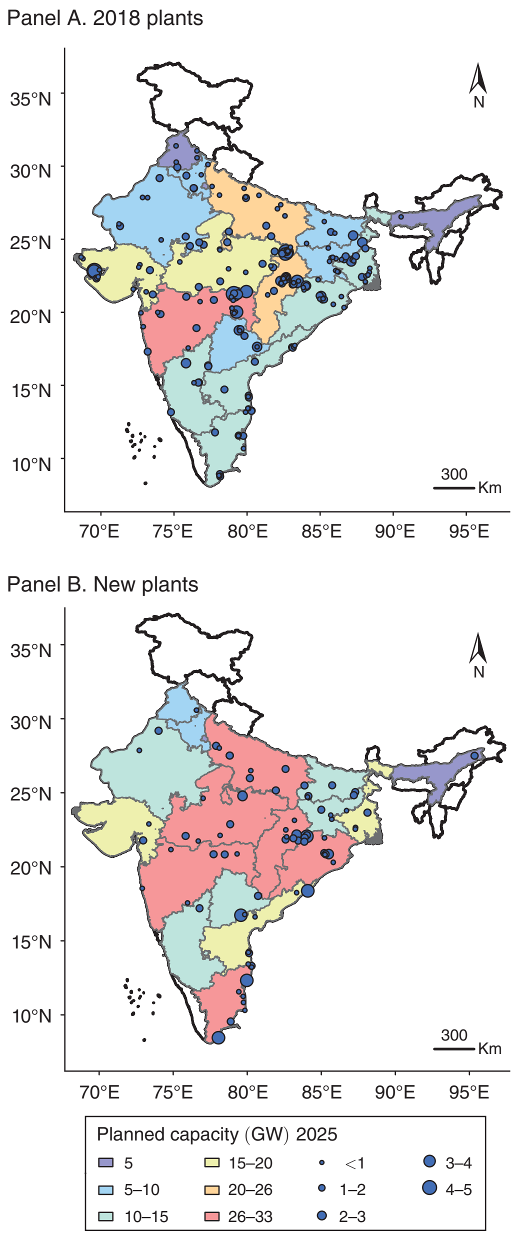

Figure 1. Location of CPPs in India

of capacity. For 2018 plants, we know where coal was sourced and what pollution-control equipment was in place. For planned plants, we assume that coal will come from the sources used by nearby plants. We assume that pollution-control equipment on new plants will be similar to that used by existing plants. This is an important assumption. Emission limits on thermal power plants issued in 2015 effectively require plants commencing operations in 2017 to install flue gas desulfurization units and use selective catalytic reduction to reduce NO_x emissions (Center for Study of Science, Technology and Policy 2018). The 2015 regulations would also require most pre-2017 units to be retrofitted with flue gas desulfurization units (Cropper et al. 2017). Because these regulations have not yet been implemented, we assume that pollution-control equipment currently in place will be used in the future. Installing pollution-control equipment to achieve mandated emissions limits would reduce emissions of SO_2 and NO_x from CPPs by about 70 percent.

To estimate the impact of CPPs on ambient PM2.5, we first run CAMx, an Eulerian photochemical dispersion model that allows for secondary particle formation, using an emissions inventory for India but omitting CPPs. The model is run for 365 days, using 2018 meteorological data, at an $0.25° \times 0.25°$ resolution. In a second run, we add emissions from 2018 CPPs to the emissions inventory. In a third run, we add emissions from planned plants as well as 2018 plants to the inventory.

Online Appendix Figures A1a and A1b show the impacts of current and current plus planned plants on ambient PM2.5. Current plants raise ambient PM2.5 by an average of 6 to 8 $\mu g/m^3$ in the Indo-Gangetic Plain and by over 10 $\mu g/m^3$ in parts of Chhattisgarh, Odisha, and West Bengal. Adding planned plants intensifies these effects. Ambient PM2.5 attributed to power plants (online Appendix Figure A1b) is between 7 and 10 $\mu g/m^3$ in Chhattisgarh, Uttar Pradesh, Maharashtra, and Odisha—the four states with the highest installed capacity, including planned plants. Some states that are downwind from large expansions in capacity, however, experience even larger impacts: CPPs account for 12.5 $\mu g/m^3$ of PM2.5 in West Bengal and 10.8 $\mu g/m^3$ of PM2.5 in Jharkhand. In Delhi, CPPs account for over 9 $\mu g/m^3$ of PM2.5.

To put these effects in context, we estimate population-weighted ambient PM2.5 in India in 2018 to be 53.5 $\mu g/m^3$. CPPs contribute 9.2 percent of ambient PM2.5, population weighted. When planned power plants are added, ambient PM2.5 increases to 55.9 $\mu g/m^3$, 13 percent of which is attributable to CPPs.

II. Health Impacts of Power Plants

To estimate the health effects of CPPs, we calculate the impact of ambient PM2.5 on premature mortality in each $0.25° \times 0.25°$ grid square. Deaths attributable to CPPs equal the number of deaths associated with ambient PM2.5 multiplied by the fraction of ambient PM2.5 attributable to CPPs.

The health effects of PM2.5 depend on total exposure to PM2.5 from both ambient sources (ambient air pollution, AAP) and household exposure to solid fuels (household air pollution, HAP). We calculate total exposure for each grid cell by adding estimates of HAP to estimates of AAP. HAP is calculated using data on the percent of households using solid fuels for cooking and estimates of exposure to HAP, conditional on using solid fuels (see online data Appendix). Estimates of premature mortality associated with total PM2.5 exposure for ischemic heart disease, stroke, chronic obstructive pulmonary disease, lower respiratory infection, type 2 diabetes, and lung cancer are calculated using exposure-response functions from the 2019 GBD (Murray et al. 2020) and the mortality rates and population estimates described in the online data Appendix. To calculate mortality associated with AAP, we multiply deaths by cause in each grid cell by the fraction of total PM2.5 accounted for by AAP. Mortality associated with CPPs equals the fraction of AAP attributed to power plants times the number of deaths attributed to AAP.

Figure 2, panel A, shows annual deaths attributed to 2018 CPPs, which total 78,400 (confidence interval = [62,100, 94,000]). The impact of CPPs on premature mortality is greatest in the Indo-Gangetic Plain and Central India; however, it is also significant in south India. This reflects the high population density in these regions and the large contributions of CPPs to ambient PM2.5 (see online Appendix Figure A1a). The impact of CPPs also depends on levels of HAP. Due to the concavity of exposure-response functions for all six causes of death, the higher the HAP exposure, the lower the impact of AAP is. To illustrate, at an AAP level of 70 $\mu g/m^3$, with no HAP exposure, 32 percent of deaths due to lower respiratory infection are attributable to AAP. If HAP exposure of 100 $\mu g/m^3$ occurs in addition to AAP, only 20 percent of lower respiratory infection deaths are attributable to AAP. The impact of a microgram of PM2.5 from CPPs is therefore greater, ceteris paribus, in states where a smaller percent of households burn solid fuels for cooking (e.g., in the states of Maharashtra and Tamil Nadu) than in states such as Bihar, Uttar Pradesh, and West Bengal, where population-weighted average exposure to HAP exceeds AAP exposure.

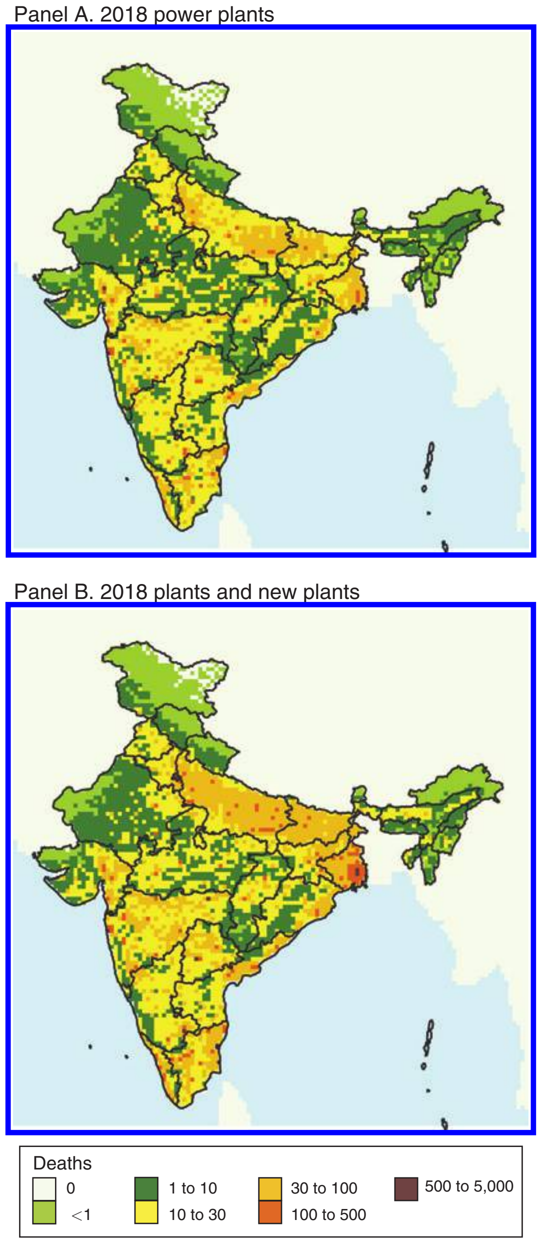

Figure 2. Deaths Attributable to Power Plants

When planned CPPs are operating, deaths attributable to current and planned plants equal 112,700 annually (confidence interval = [90,100, 134,200]), 13 percent of all AAP deaths (see Figure 2, panel B). Compared to Figure 2, panel A, deaths attributable to CPPs are greater in states where large increases in installed capacity occur and in areas downwind of these states. Attributable deaths are 50 percent larger in Odisha, Andhra Pradesh, and Tamil Nadu—states where CPP capacity doubles. Deaths increase by an even greater percent in Bihar and West Bengal, which are downwind of large increases in capacity.

III. CO_2 Emissions and Health Impacts Avoided by Not Building Future Plants

In 2018, CPPs in India generated over one billion tons of CO_2. If planned CPPs were not built, we estimate that emissions of an additional 455 million tons of CO_2 would be avoided annually. CO_2 emissions are calculated based on the carbon content of coal and the amount of coal burned. In 2018, on average, CPPs in India burned 0.615 tons of coal per MWh. Weighting the carbon content of coal from different sources by the fraction of coal burned implies an average carbon content of 46.7 percent. Each MWh of coal-fired electricity generated, on average, 1,030 kg of CO_2. In our simulations, planned CPPs generate 455 million MWh per year, assuming they operate at 60 percent of capacity.

To calculate deaths avoided by not building planned plants, we treat the associated reduction in emissions as a marginal reduction in PM2.5 from the baseline at which current plus planned CPPs are operating. Due to the concavity of exposure-response functions, the marginal reduction in exposure yields a smaller reduction in deaths than the 34,000 additional deaths attributable to planned plants in Section II. Specifically, we estimate that, initially, 19,000 deaths would be avoided annually if planned CPPs were not built. These plants, however, could continue to operate for 40 years. The deaths avoided by not building the plants, assuming that population grows at an annual rate of 0.48 percent and that mortality rates by disease and other sources of AAP and HAP remain constant, would amount to over 840,000 deaths.

Figure 3 shows the location of deaths avoided by not building planned plants. The pattern is similar to the pattern in Figure 1, panel B, and reflects the size of the exposed population as well as the impact of planned plants on ambient PM2.5. Because half of the deaths occur in Uttar Pradesh, Bihar, and West Bengal, where exposure to HAP, population weighted, currently exceeds exposure to AAP, the number of deaths in Figure 3 is conservative. As HAP exposures decline over time, the impacts of CPP emissions, ceteris paribus, will increase. Indeed, we estimate that were HAP exposure to disappear, not building planned CPPs would save 1.5 million lives over a 40-year period.

IV. Taxing Electricity Generation from Coal-Fired Electricity

To incentivize greater reliance on renewable energy sources, India could enact a carbon tax. It is also possible to tax electricity generated from coal at a rate that reflects the local damages associated with CPP emissions. Premature mortality is only one externality associated with CPP emissions: others include impacts on morbidity and agricultural output as well as damages to ecosystems. A tax that reflects the value of premature mortality is therefore a lower bound to the value of local damages associated with CPPs.

Although the health impacts of CPPs vary spatially, a uniform tax on electricity from CPPs would be more feasible to implement. We calculate this tax based on 78,400 premature deaths associated with 2018 CPPs. Quantifying the mortality impacts of CPPs requires establishing a value of a statistical life (VSL) for India. There are several estimates of the VSL for India based on revealed and stated preference studies (see Cropper et al. 2018 for a summary). Somanathan and Chakravarty (2018) recommend a VSL of ₹10,300,000 (= $147,000 at 2018 exchange rates), based on their updates to a stated preference study conducted in India by Bhattacharya, Alberini, and Cropper (2007). Robinson et al. (2019) suggest estimating the VSL in low- and middle-income countries using a ratio of the VSL to per capita income of 100:1. This would yield a VSL of ₹12,600,000 in 2018.

These numbers imply that a tax per MWh of ₹738 to ₹903 would internalize the mortality impacts of CPPs. For comparison, a carbon tax of $10 per ton of CO_2 would equal ₹722 per MWh.

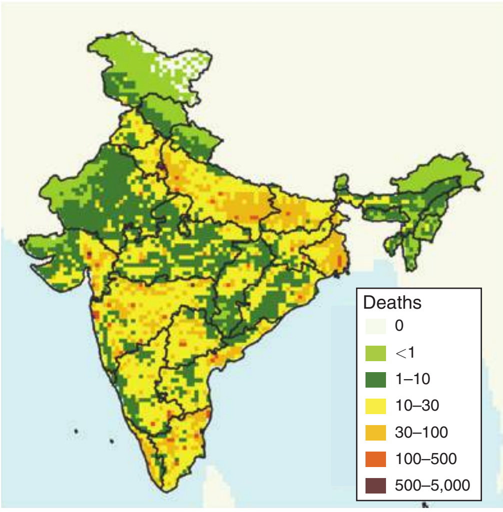

Figure 3. Deaths Avoidable by Not Building New Plants, Assuming 40-Year Plant Life

V. Conclusions

In 2018, CPPs in India emitted over one billion tons of CO_2. CPPs in the planning stages in 2019 would increase these emissions by almost 500 million tons annually if they operated, as do current plants, at 60 percent of capacity. The health damages associated with these plants are substantial: our analysis indicates that over 78,000 deaths in India in 2018 were attributable to PM2.5 created by CPPs. This figure would rise to over 112,000 deaths if CPPs in the planning stages were also operating. A tax of between ₹0.74 and ₹0.90 per kWh hour—about 20 percent of the cost of generating electricity at CPPs—would internalize the premature mortality associated with emissions generated by CPPs in 2018. This would be comparable in magnitude to a tax of \$10 per ton of CO_2.

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