Impact of emissions from coal-fired power plants on health in India

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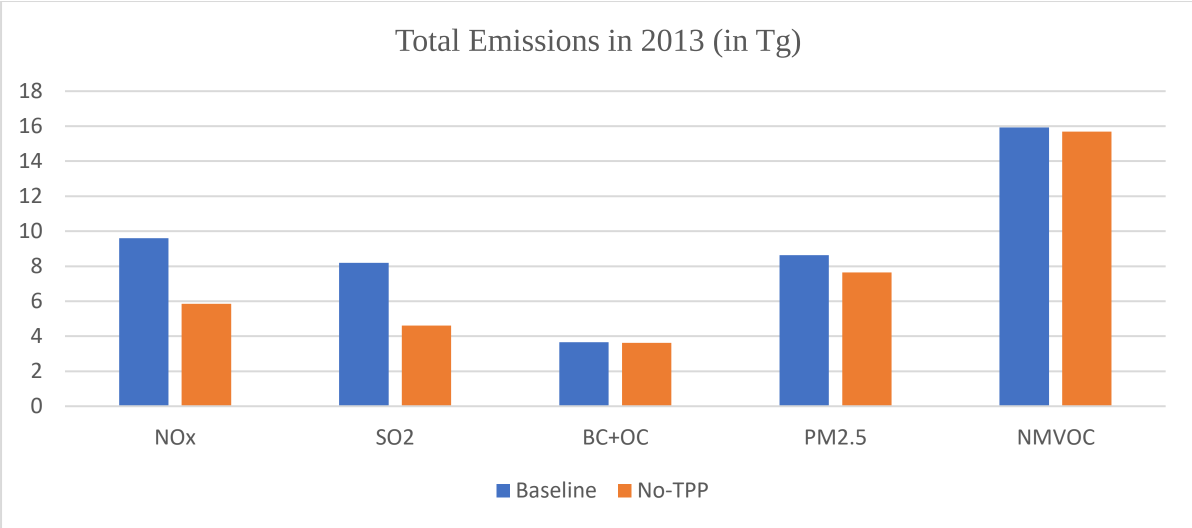
Highlights

- SO_2 and NOx emissions are reduced by 3590 and 3740 kilotons per year respectively by removing thermal power plants
- The average reduction in concentrations of $PM_{2.5}$ and O_3 nationally from removing thermal power plants is about 8.4% and <1% respectively
- The $PM_{2.5}$ concentrations fall below the permissible limit of 60 $\mu g/m^3$ after reducing the impact of coal
- The O_3 concentrations exceed the permissible limit of 100 $\mu g/m^3$ by a small margin even after reducing the impact of coal
- Premature deaths avoided from $PM_{2.5}$ and O_3 when removing coal-fired power plants is about 43,000 and 2300 respectively
- In total, removing coal-fired power plants in favor of renewables avoids 45,300 premature deaths due to ambient air pollution

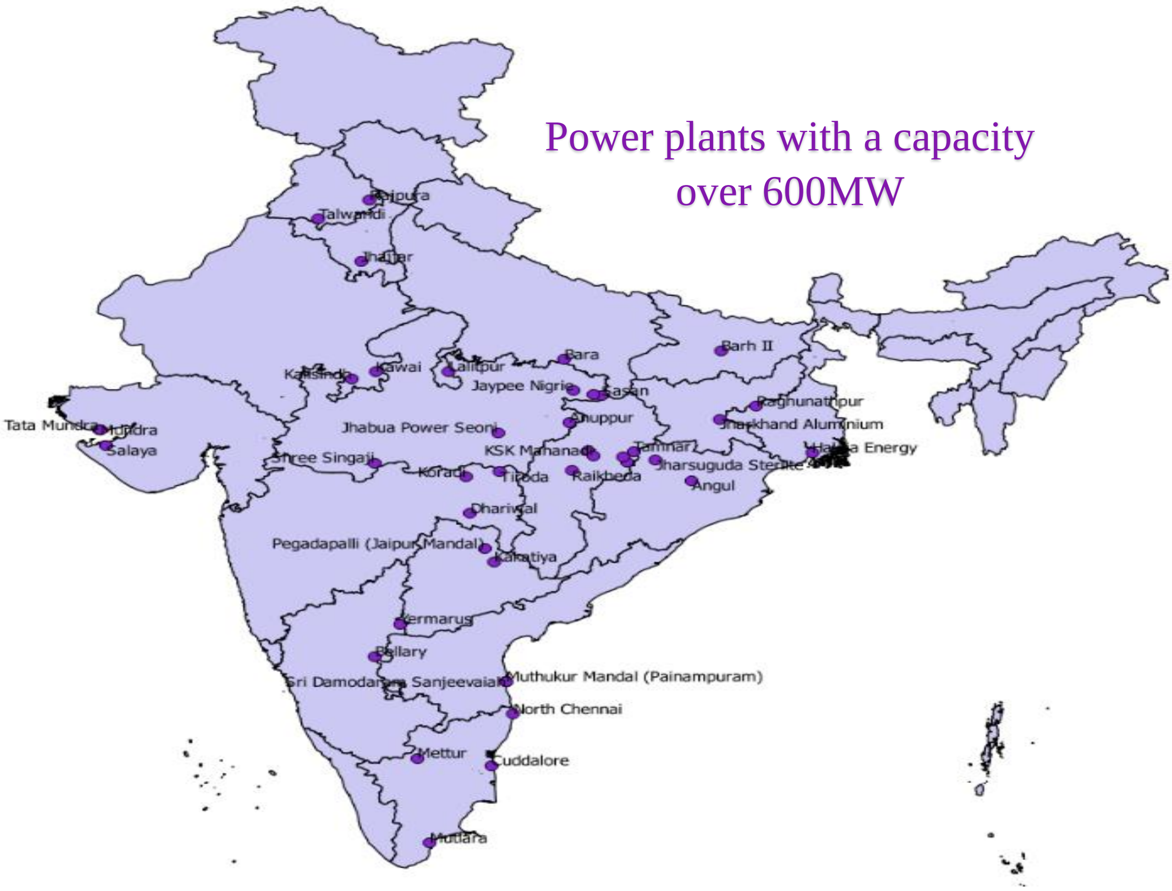
Coal-fired power plants are a significant source of air pollution in India. The emissions occurring from high stacks of coal-fired power plants result in high background concentrations for sulphur oxides, nitrogen oxides and particulates known to be hazardous to human health. In order to analytically determine the health costs of coal, we use the anthropogenic emissions inventory IND 15-2013 developed and maintained for India by Prof. Chandra Venkataraman at IIT Bombay. In addition, we use the GEOS-FP (Forward Processing) meteorology at a resolution of 2x2.5 degrees present in the GEOS-Chem model, which is a well-known air chemistry modeling technique. Our analysis is guided by GEOS-Chem run on Amazon Web Services (AWS) and integrated exposure response functions from the Global Burden of Disease (GBD) Study 2016.

First, we use the emissions from IND-15-2013 and in-built GEOS-FP meteorology to simulate air quality under two scenarios: 'All source categories' (Baseline) and 'All source categories except TPP' (No-TPP). The air quality is determined by estimating the model concentrations of pollutants (or species) such as CO, SOx, NOx, $PM_{2.5}$ and O_3 for 'All sectors' and 'No-coal' sensitivity study. Second, we reduce emissions from thermal power plants and obtain the population weighted species concentrations for the "clean energy" scenario (TPP). Third, we compare the IND-15-2013 emissions inventory for the baseline and no-TPP scenarios. And lastly, we evaluate the impacts of coal pollution on adult health burden (mortality) following the GBD 2016 study.

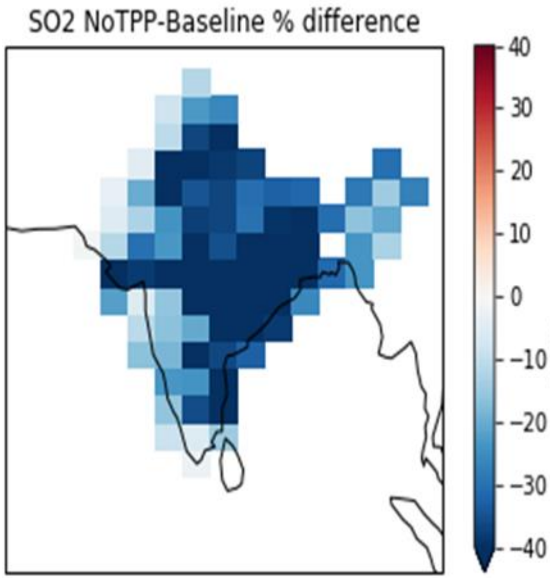


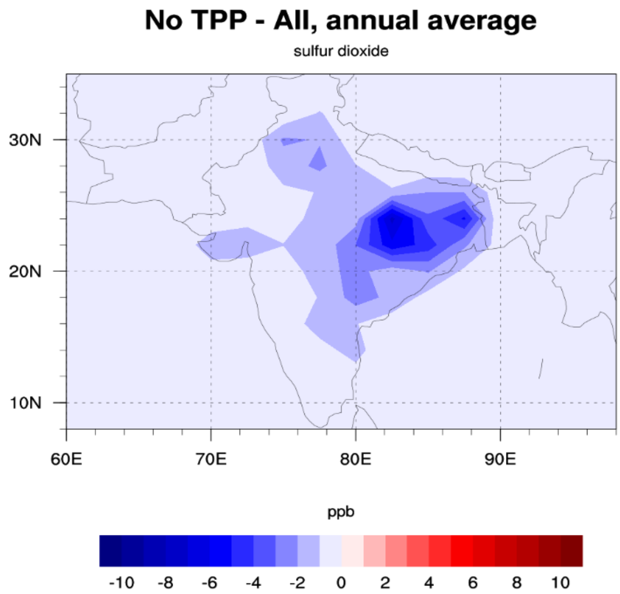
Post the GEOS-Chem simulation run for the two scenarios, species concentrations are generated for 2015. We find that thermal power plants contributed to 40.2% of the baseline SO_2 concentrations, 37% of the baseline NIT (inorganic nitrates) concentrations, 30.8% of the baseline NH_4 concentrations, 29.6% of the baseline NO_2 concentrations and 8.4% of the baseline $PM_{2.5}$ concentrations among other species.

The map below shows locations of power plants in India with a capacity over 600 MW. Majority of the large power plants are in the northern, central, and eastern belt (also known as the coal belt).

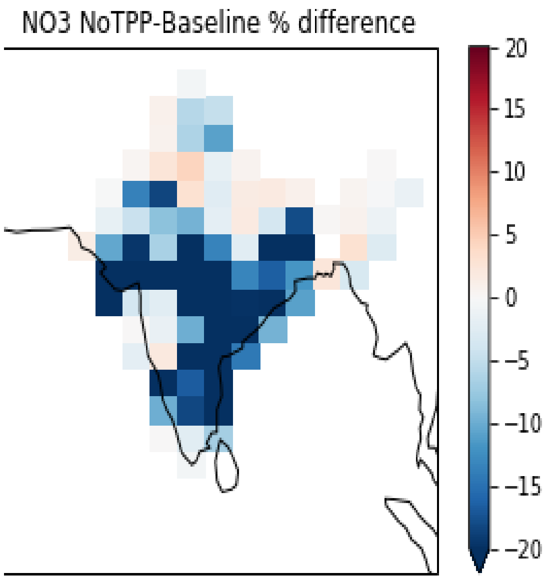


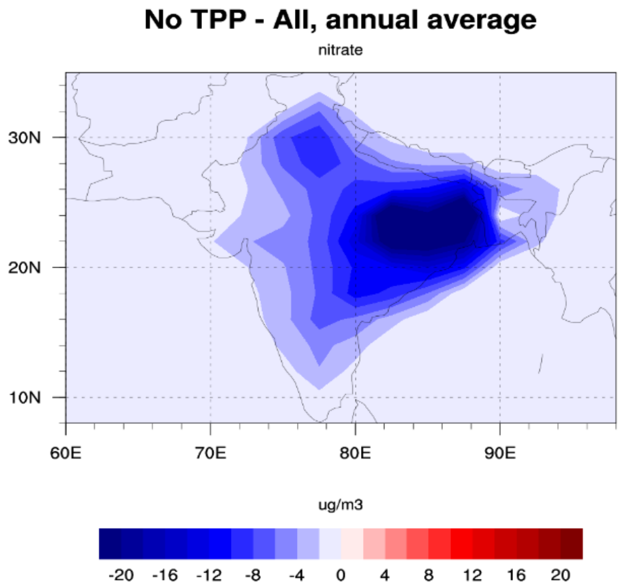
The GEOS-Chem species concentration is plotted for gases such as SO_2, NO_2 and O_3 in parts per billion (ppb) and for particles such as NIT and $PM_{2.5}$ in micrograms per meter cubed ($\mu g/m^3$). The concentrations for SO_2 are in the range 0-10 ppb with high concentrations in the coal belt and the Delhi region attributed to thermal power plants. The SO_2 sensitivity run demonstrates that by removing the effect of thermal power plants, we can drastically reduce the SO_2 emissions (by about 40%) in the coal belt and the Delhi region.



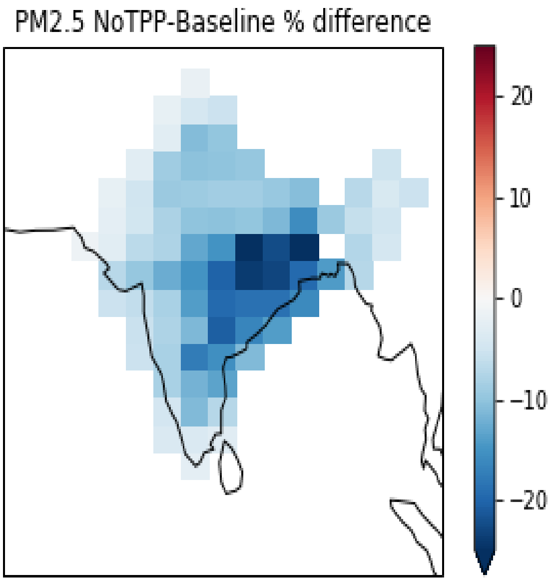


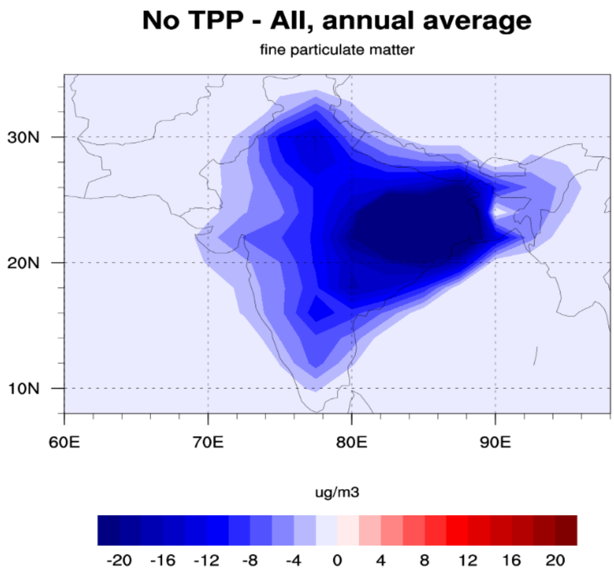
The concentrations plots for NO_3 tells us that by removing thermal power plants, there would be a significant reduction in concentrations by 20% mainly in Madhya Pradesh, Jharkhand, West Bengal and Orissa in the central and east, Gujarat and Maharashtra in the west, Andhra Pradesh, Karnataka and Tamil Nadu in the south.



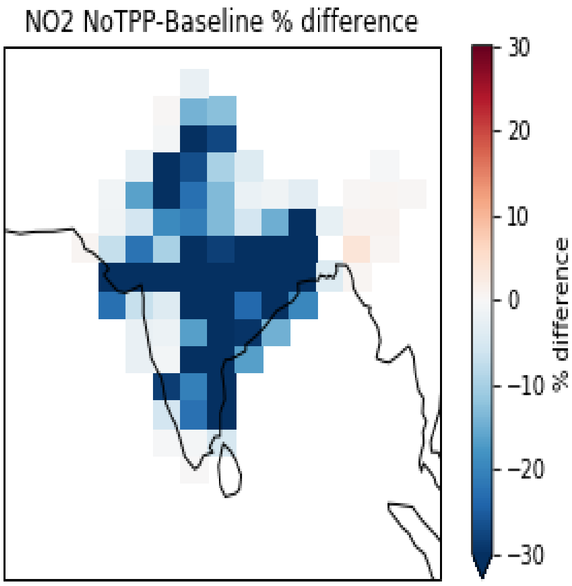


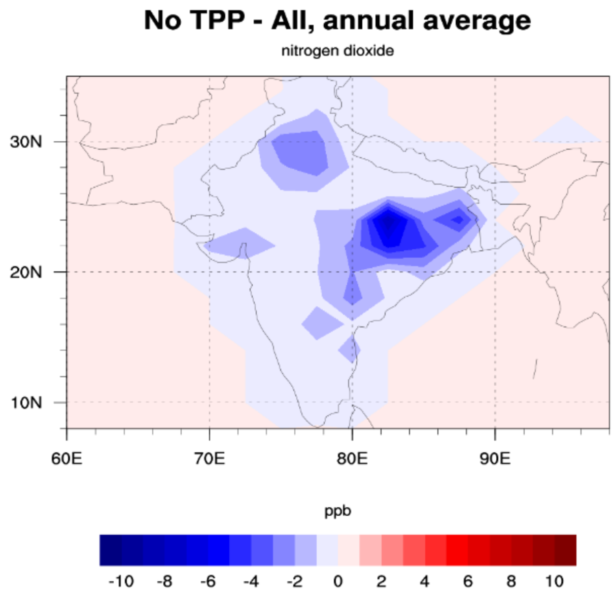
Particulate matter is created by secondary form precursor organic and inorganic aerosols in the gaseous state. These precursors include SO_2, NO_3, VOCs & NH_3. PM_{10} particles (the fraction of particulates in air of very small size (<10 µm)) and $PM_{2.5}$ particles (<2.5 µm) are of major current concern, as they are small enough to penetrate deep into the lungs and so potentially pose significant health risks. By reducing emissions from thermal power, we can significantly decrease the concentration of $PM_{2.5}$ up to 20-30% in the coal belt and central and south of India.



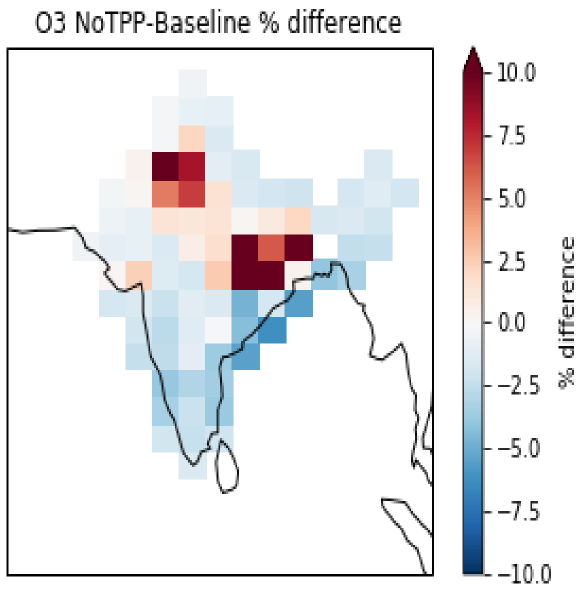


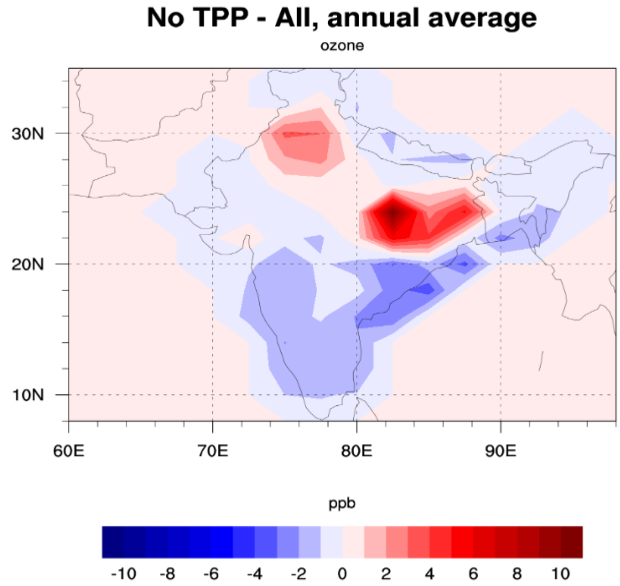
The concentration plots for NO_2 tells us that by removing thermal power plants, there would be a significant reduction in NO_2 concentrations by 30% mainly in the coal belt, Delhi region, Gujarat, Maharashtra, Madhya Pradesh and the south Indian states.





Ozone (O_3) in the troposphere is a pollutant. The tropospheric ozone formation primarily occurs when nitrogen oxides (NOx), carbon monoxide (CO) and volatile organic compounds (VOCs) react in the atmosphere in the presence of sunlight, specifically the UV spectrum. NOx, CO and VOCs are considered ozone precursors. We find that when NO_2 increases and reacts with O_3, it leads to what is known as the NOx titration effect in the Delhi region and the coal belt. Ozone concentrations can be lowered by about 10 ppb in these regions by removing NOx emissions from thermal power plants.

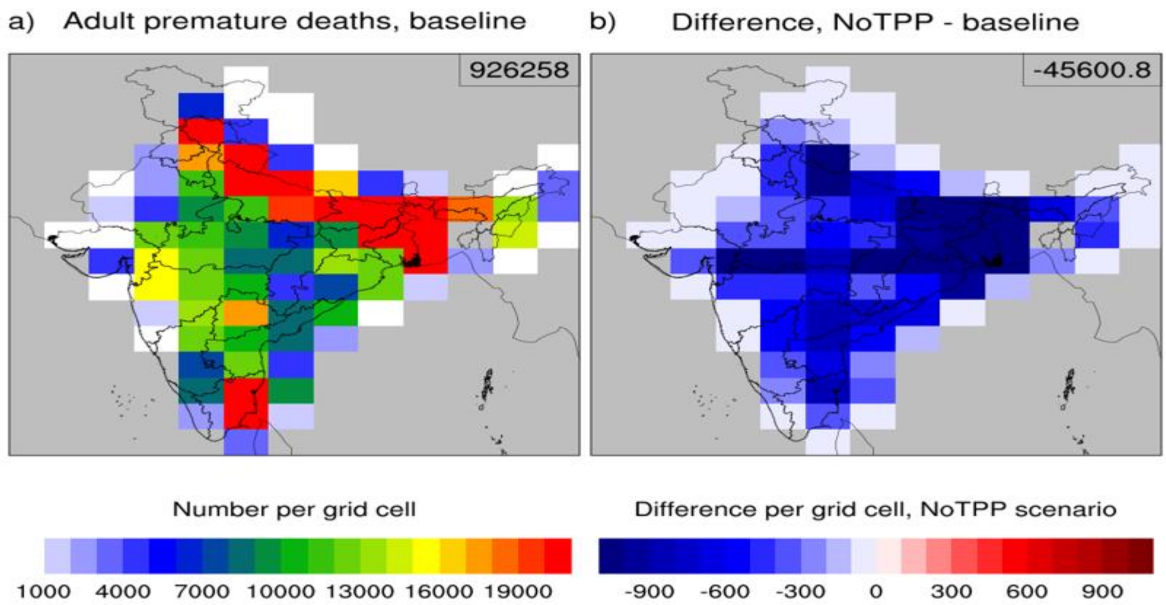




At 25℃, the baseline SO_2 concentrations in ambient air in the coal belt is about 26.163 $\mu g/m^3$ making it ecologically sensitive (exceeds the 20 $\mu g/m^3$ threshold). In addition, the baseline O_3 and $PM_{2.5}$ concentrations at 117.73 $\mu g/m^3$ and 66.65 $\mu g/m^3$ in the coal belt exceed the permissible level of 100 $\mu g/m^3$ and 60 $\mu g/m^3$ respectively set by National Ambient Air Quality Standards.

Below is an image of the combined $PM_{2.5}$ and O_3 health burden implications from baseline emissions and the change from removing the coal power plant emissions and a table identifying the health burden total quantities. You'll note that the premature deaths decrease significantly overall. Using a model at a higher spatial resolution (i.e. 50 km by 50 km or less whereas ours is 2.5 degrees by 2.5 degrees or approximately 250 km by 250 km) would better represent the highly localized reductions in emissions from the coal power plants. In total, about 45,300 deaths are avoided by eliminating emissions from power plants based on this analysis, and nearly all those avoided deaths are due to a reduction in $PM_{2.5}$. Again, from the image we see that the greatest changes in health burden occur along the Indo-Gangetic belt and in the Tamil Nadu region.

Adult premature deaths, Baseline and TPP



Adult health burden attributable to $PM_{2.5}$ and O_3

	Total Health Burden	% Change in Health Burden, No-TPP
$PM_{2.5}$	916,000 (540,000—1,400,000)	-5% (-43,000 deaths)
O_3	10,700 (400—24,000)	-26% (-2300 deaths)

Adult health burden attributable to $PM_{2.5}$ and O_3 for annual average $PM_{2.5}$ and O_3 concentrations and for the scenario where coal power plants were removed. 95% confidence interval values shown within parentheses. The fraction of total health burden change is very small for $PM_{2.5}$, but one quarter of the premature deaths attributable to O_3 can be avoided by removing coal power plants. In total, removing coal fire power plants avoids 45,300 premature deaths due to ambient air pollution.

Total health burden refers to the following disease-causes for $PM_{2.5}$: chronic obstructive pulmonary disease, ischemic heart disease, lung cancer, and stroke; and the following disease-cause for O_3: chronic obstructive pulmonary disease. Methods follow Karambelas et al., (2018, Environmental Research Letters) but include updated integrated exposure response function parameters following the Global Burden of Disease for 2016. Note that different methods may produce different results.

References:

Venkataraman, C., Brauer, M., Sadavarte, P., Ma, Q., Cohen, A., Chaliyakunnel, S., et al. (2018). Source influence on emission pathways and ambient PM2.5 pollution over India (2015–2050). Atmospheric Chemistry and Physics, 18(11), 8017–8039.

Zhuang, J., D.J. Jacob, J. Flo-Gaya, R.M. Yantosca, E.W. Lundgren, M.P. Sulprizio, and S.D. Eastham, Enabling immediate access to Earth science models through cloud computing: application to the GEOS-Chem model, submitted to Bull. Amer. Met. Soc., 2019.

Sadavarte, P., & Venkataraman, C. (2014). Trends in multi-pollutant emissions from a technology-linked inventory for India: I. Industry and transport sectors. Atmospheric environment, 99, 353-364.

Pandey, A., Sadavarte, P., Rao, A. B., & Venkataraman, C. (2014). Trends in multi-pollutant emissions from a technology-linked inventory for India: II. Residential, agricultural and informal industry sectors. Atmospheric environment, 99, 341-352.

Babatola, S. S. (2018). Global burden of diseases attributable to air pollution. Journal of public health in Africa, 9(3).

Ghude, S. D., Chate, D. M., Jena, C., Beig, G., Kumar, R., Barth, M. C., ... & Pithani, P. (2016). Premature mortality in India due to PM2. 5 and ozone exposure. Geophysical Research Letters, 43(9), 4650-4658.

Malley, C. S., Henze, D. K., Kuylenstierna, J. C., Vallack, H. W., Davila, Y., Anenberg, S. C., ... & Ashmore, M. R. (2017). Updated global estimates of respiratory mortality in adults≥ 30 years of age attributable to long-term ozone exposure. Environmental health perspectives, 125(8), 087021.

Guttikunda, S. K., & Jawahar, P. (2018). Evaluation of particulate pollution and health impacts from planned expansion of coal-fired thermal power plants in India using WRF-CAMx modeling system. Aerosol and Air Quality Research, 18(12), 3187-3202.

Burnett, R. T., Pope III, C. A., Ezzati, M., Olives, C., Lim, S. S., Mehta, S., ... & Anderson, H. R. (2014). An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. Environmental health perspectives, 122(4), 397-403.

Karambelas, Alexandra, Tracey Holloway, Patrick L Kinney, Arlene M Fiore, Ruth DeFries, Gregor Kiesewetter, and Chris Heyes. "Urban versus Rural Health Impacts Attributable to PM $_{2.5}$ and O $_3$ in Northern India." *Environmental Research Letters* 13, no. 6 (June 1, 2018): 064010. https://doi.org/10.1088/1748-9326/aac24d.

Jones, B., and B. C. O'Neill. 2017. Global Population Projection Grids Based on Shared Socioeconomic Pathways (SSPs), 2010-2100. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4RF5S0P.

Jones, B., and B. C. O'Neill. 2016. Spatially Explicit Global Population Scenarios Consistent with the Shared Socioeconomic Pathways. Environmental Research Letters, 11 (2016): 084003.https://doi.org/10.1088/1748-9326/11/8/084003.

Philip, S., Martin, R. V., Snider, G., Weagle, C. L., van Donkelaar, A., Brauer, M., ... & Zhang, Q. (2017). Anthropogenic fugitive, combustion and industrial dust is a significant, underrepresented fine particulate matter source in global atmospheric models. Environmental Research Letters, 12(4), 044018.