The Health Benefits of Air Pollution Control in India

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Five Questions About Air Pollution in India

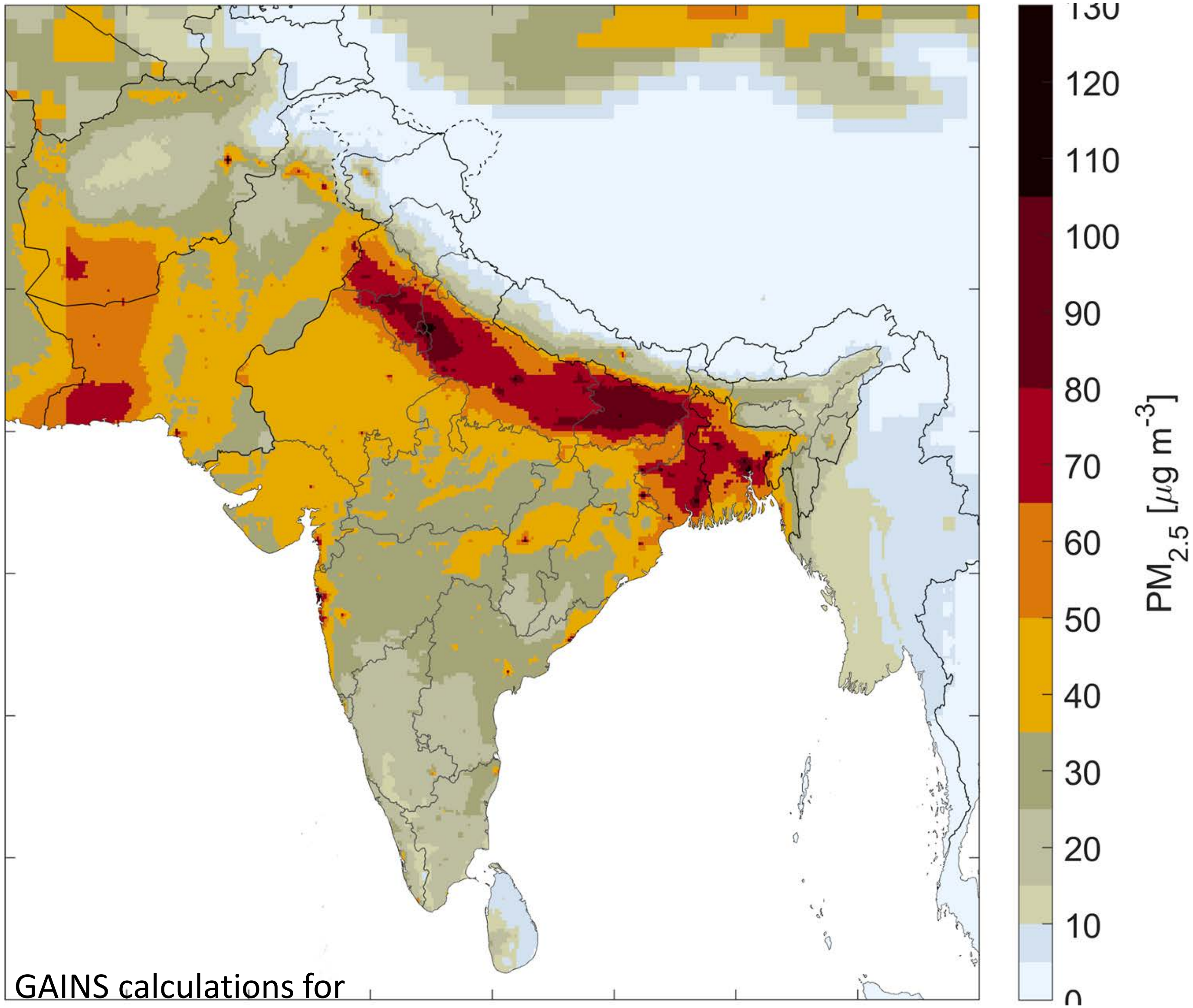
- How high is ambient air pollution in different parts of India?
- What are the morbidity and mortality consequences of ambient air pollution (AAP)? What are the health consequences of exposure to household air pollution (HAP)?
- What are the health costs of pollution-related morbidity and mortality?
- What are the sources of ambient air pollution in different parts of India? What does this imply for policies to control air pollution?
- What are the health benefits and the costs of reducing pollution from coal fired power plants?

Air Pollution Levels in India

Measuring Ambient Air Pollution

- Method 1: Ground-based monitoring stations
- Method 2: Modeled estimates from atmospheric chemistry models (e.g., CAMX, CMAQ)
  - Requires an emission inventory and meteorological data
  - Urban Emissions Info. (Sarath Guttikunda); IIASA GAINS model
- Method 3: Satellite data on Aerosol Optical Depth (AOD) combined with atmospheric chemistry modeling (Global Burden of Disease; Sagnik Dey, IIT Delhi)
- Methods 2. and 3. are validated by comparisons with 1.

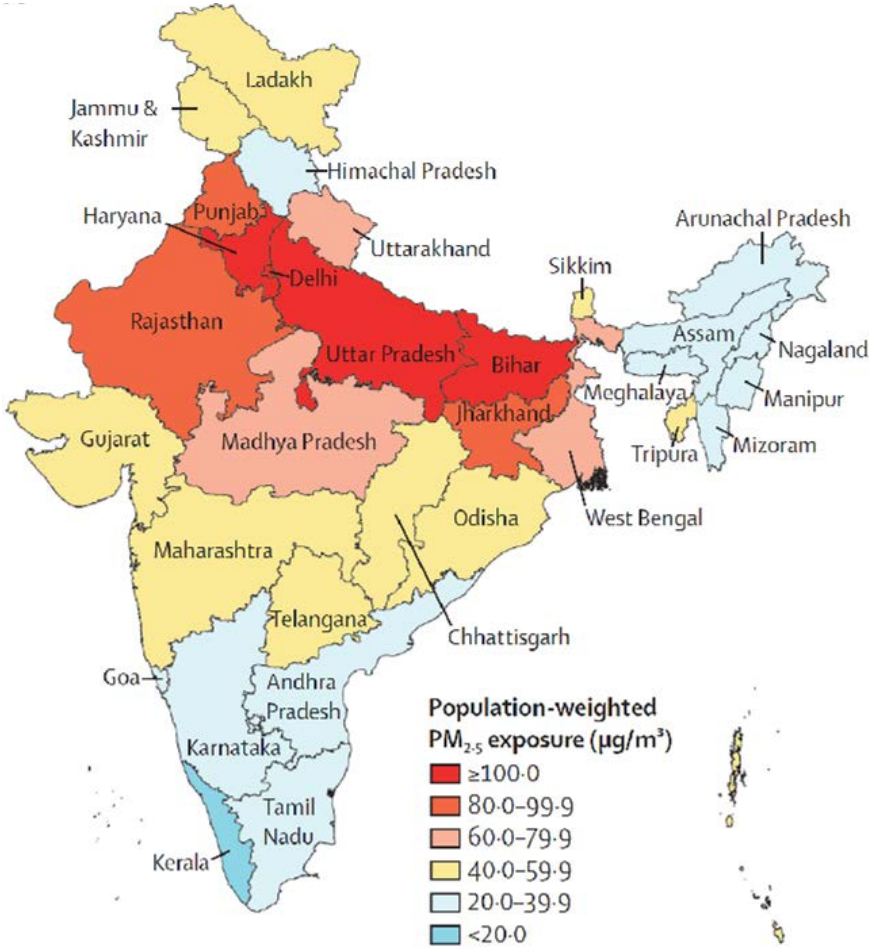
2018 Annual Average PM2.5 Based on GAINS Model



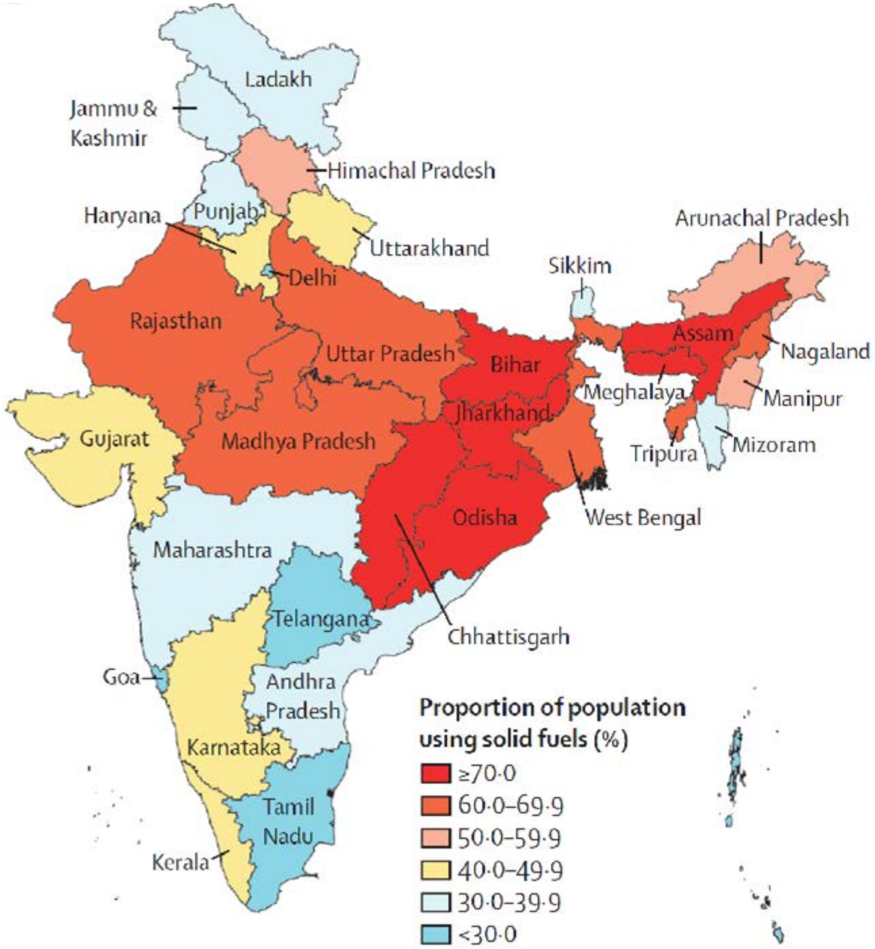
GAINS calculations for 2018

GBD 2019 Estimates

Annual Average Ambient PM2.5



Percent HHs Burning Solid Fuels



Health Impacts of AAP and HAP

What Are the Health Impacts Associated with PM2.5?

- How many deaths were associated with ambient PM2.5 (AAP) in 2018?
- How many deaths were associated with HAP in 2018?
- How do deaths vary by state?
- How does exposure to HAP affect a person’s health risks from exposure to AAP?
- What are the health benefits of reducing AAP and HAP in the IGP?

Calculation of Mortality Impacts Due to AAP and HAP

- Use 2019 Global Burden of Disease methodology to calculate mortality impacts of PM2.5 in 2018
- Impacts calculated for each $0.1^{\circ} \times 0.1^{\circ}$ grid square using 2019 mortality rates
- Mortality impacts calculated for Ischemic Heart Disease (IHD), Stroke, Lower Respiratory Infection (LRI), Chronic Obstructive Pulmonary Disease (COPD), Type II Diabetes and Lung Cancer
- Results aggregated to 23 regions of India

2019 GBD Approach to Calculating PM2.5 Mortality Risks

- Risk of death from PM2.5 depends on all sources of PM2.5 exposure: PM2.5 in the ambient air (AAP) and household air pollution (HAP)

- We estimate total PM2.5 exposure and evaluate the fraction of deaths (by cause) attributable to total PM2.5 exposure

- Ambient PM2.5 Deaths =

  (Deaths attributable to total PM2.5)*(Fraction of total PM2.5 due to ambient PM2.5)

- And similarly for HAP deaths

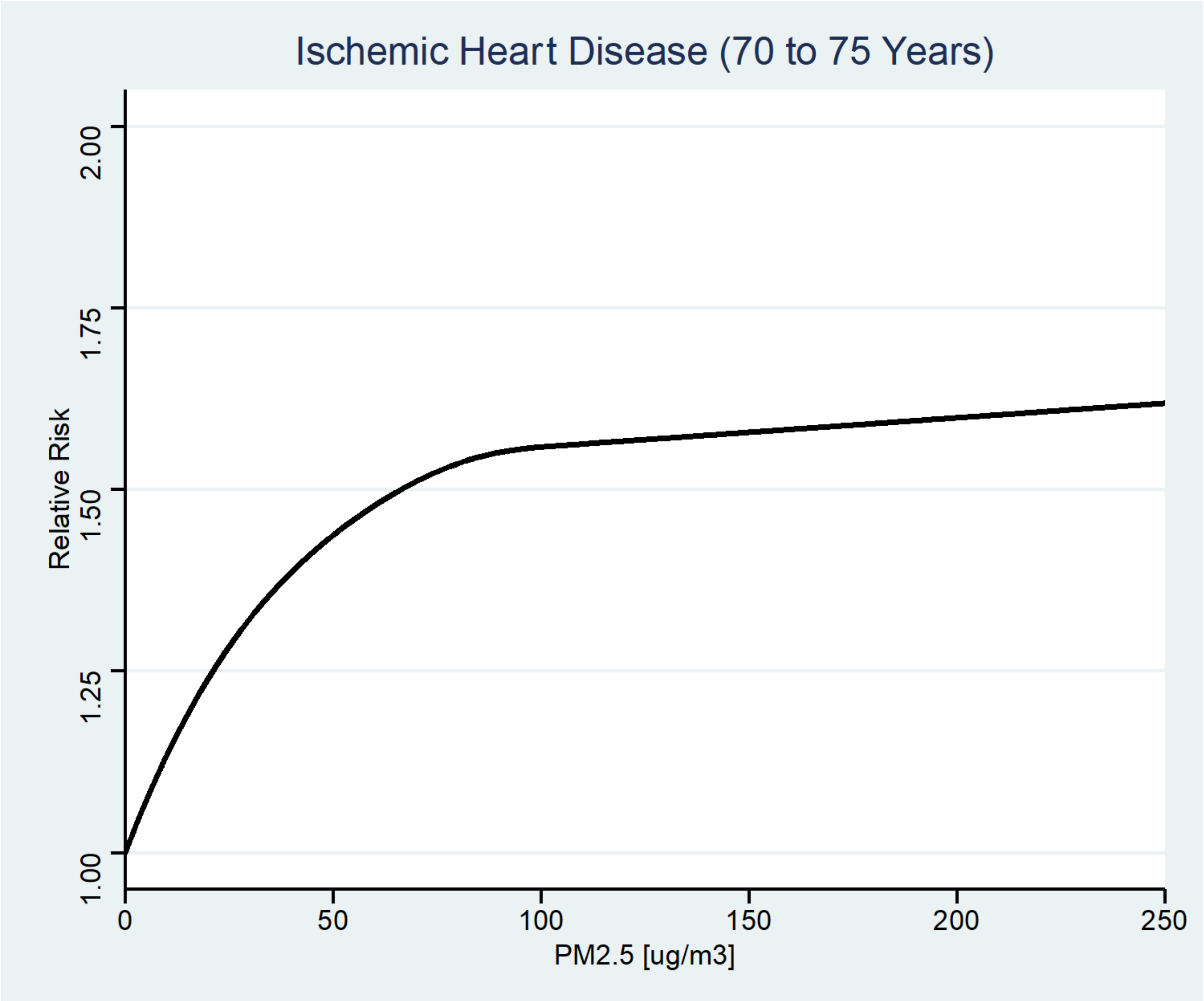
2019 GBD Approach to Calculating PM2.5 Mortality Risks

An important fact:

- The health risks of PM2.5 per microgram inhaled decrease as exposure increases
- So, the impact of ambient exposure per microgram will be lower if people are also exposed to HAP
- If two areas have the same ambient PM2.5 levels, the one with higher HAP exposure will have a lower ambient PM2.5 death rate

Impact of PM2.5 on Relative Risk of Ischemic Heart Disease

- The impact of inhaling an additional microgram of PM2.5 declines the more you inhale.
- When reducing AAP, the marginal benefits are smaller when exposure to HAP is high



Deaths Due to Ambient PM2.5 Exceeded 740,000 in 2018

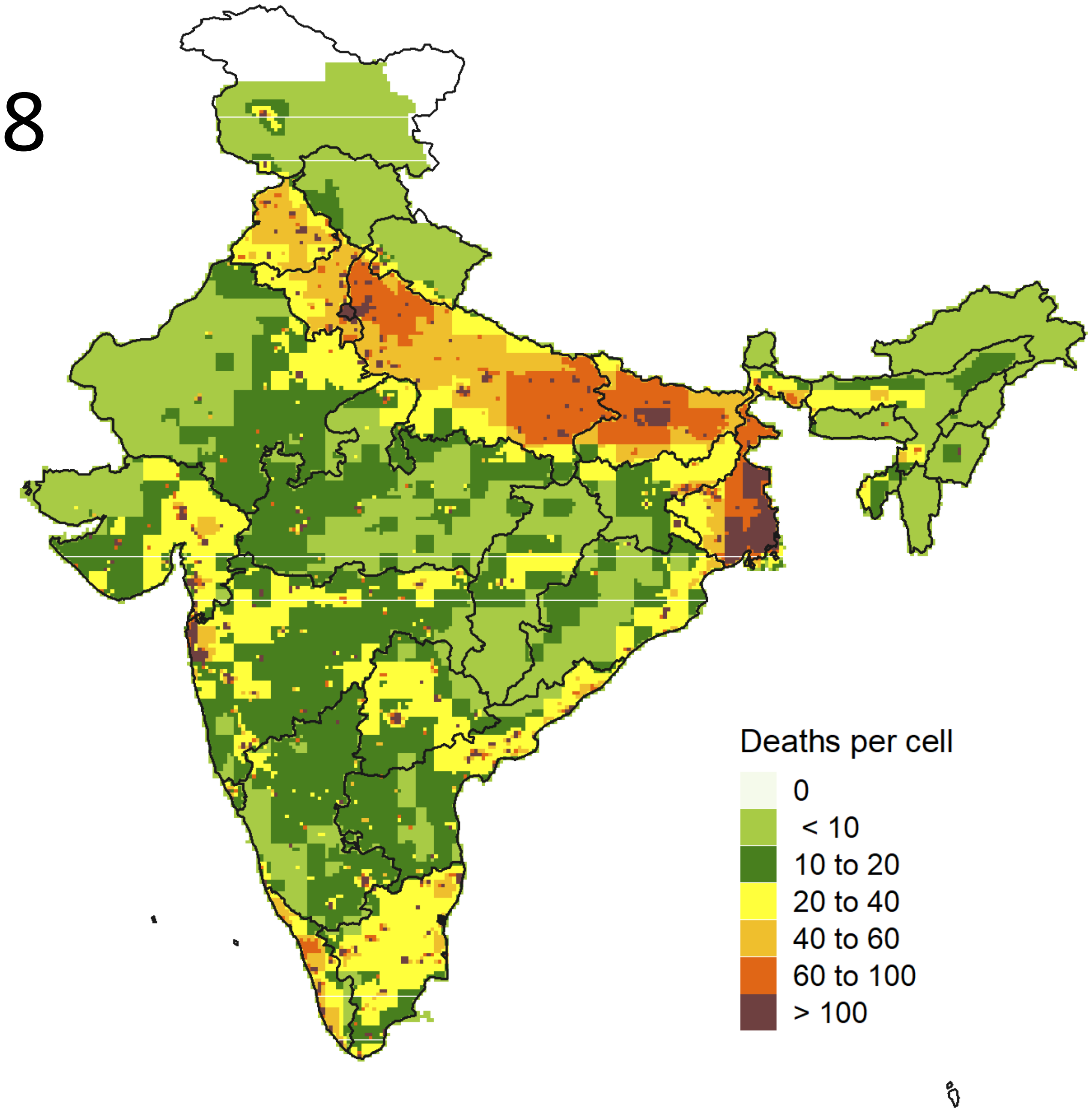
- Estimate of mortality attributable to ambient PM2.5 = 744,000

- 325,000 deaths in the Indo-Gangetic plain
- 124,000 deaths in Gujarat + Maharashtra
- 66,000 deaths in Tamil Nadu + Kerala
- 54,000 deaths in Andhra Pradesh + Telangana

- Deaths per 100,000 are highest in Haryana, Punjab and Delhi

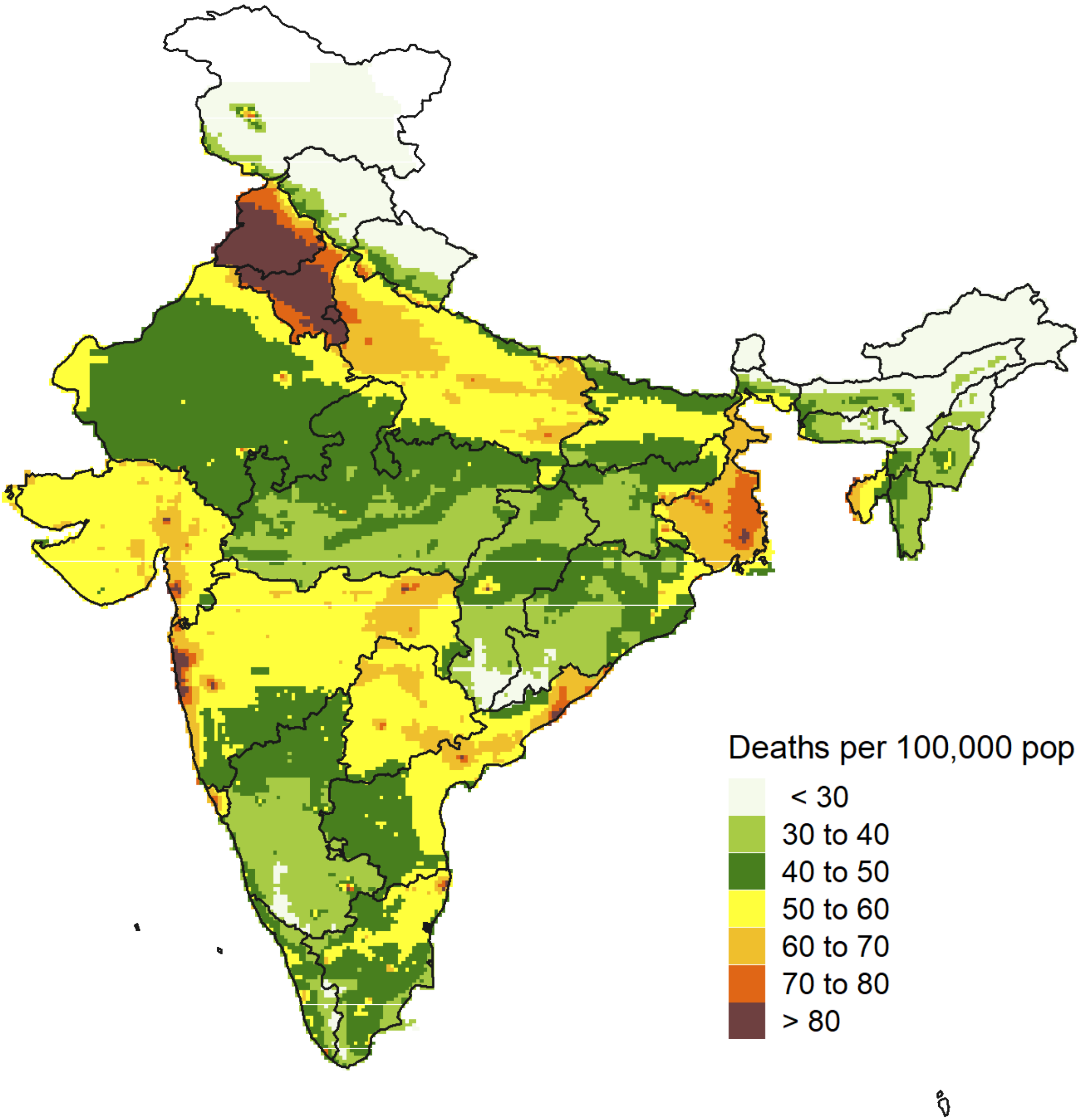
AAP PM2.5 Deaths 2018

- Map shows deaths per 11km x 11km square
- Other things equal, deaths are higher:
- In areas with higher ambient PM2.5
- In more densely populated areas



AAP Death Rate 2018

- Map shows death rate per 100,000 in each cell
- Other things equal, death rate is higher:
- The higher is ambient PM2.5
- The lower is household exposure to HAP

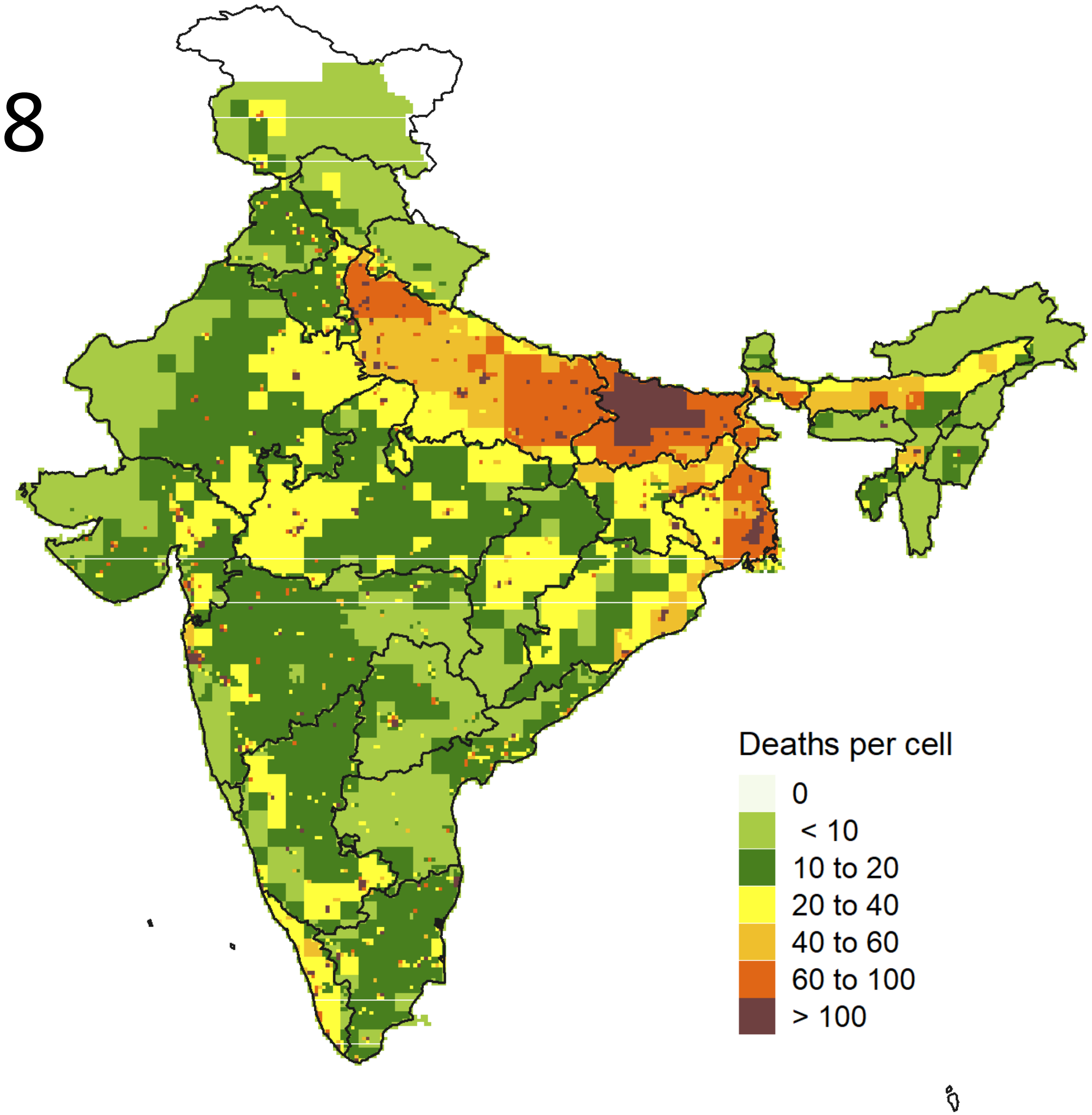


Deaths Due to HAP Exceeded 660,000 in 2018

- Estimate of mortality attributable to HAP = 665,000
- This represents direct exposure within the household to burning of solid fuels for cooking.
- For those exposed, HAP exposure exceeds 90 μg/m3 in eight states in north and central India
- For those exposed, HAP accounts for greater PM2.5 exposure than AAP in 18 states in India

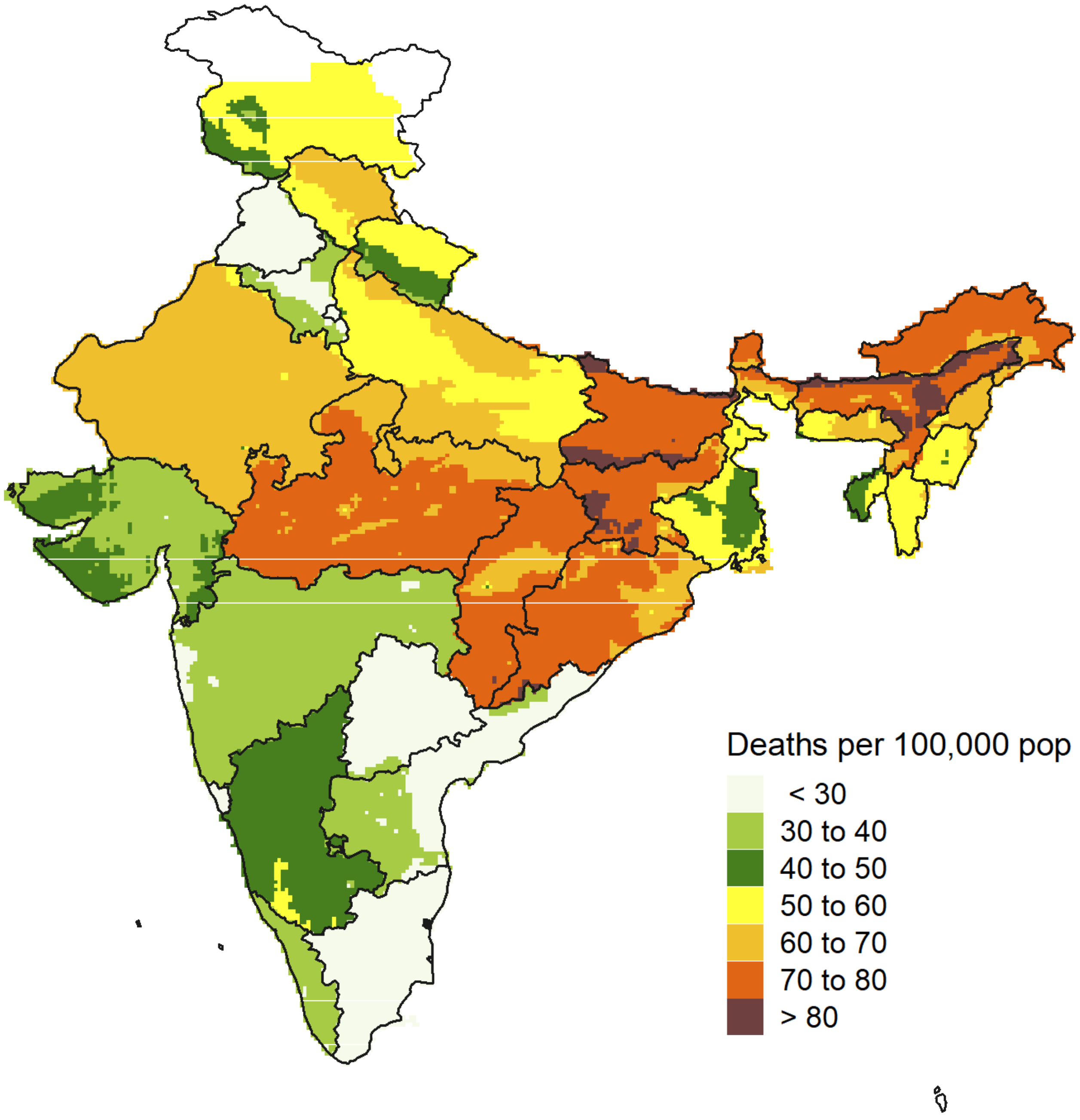
HAP PM2.5 Deaths 2018

- Map shows deaths per 11 km x 11km cell
- Deaths are highest in populous states with a high percent of households burning solid fuels:
- Uttar Pradesh, Bihar, West Bengal, Rajasthan, Madhya Pradesh



HAP Death Rate 2018

- Map shows deaths per 100,000 per cell
- States with highest death rate are those where over half of PM2.5 exposure comes from HAP:
- Bihar, Assam, Jharkhand Chhattisgarh and Odisha



7 IGP States - Punjab, Haryana, Delhi, Uttar Pradesh, Bihar, Jharkhand and West Bengal

- Account for almost half of ambient air pollution (AAP) deaths in India in 2018 and half of HAP deaths in India 2018
- HAP also accounts for a large fraction of AAP: 34% in Bihar, West Bengal, 21% in Delhi, Uttar Pradesh, Jharkhand, 15% in Haryana, Punjab
- Programs to reduce HAP can also reduce AAP—a double benefit
  - Reducing AAP to 35 μg/m3 and cutting HAP by 50% would eliminate 160,000 deaths in the 7 IGP states
  - Reducing AAP to 10 μg/m3 and cutting HAP by 50% would eliminate 290,000 deaths in the 7 IGP states

Health Costs Due to AAP and HAP

What are the health costs of PM2.5?

- Direct health costs = costs of medical treatment; indirect health costs = output lost due to illness or premature death

- India State-Level Disease Burden Initiative Air Pollution Collaborators computed the output losses associated with PM2.5 morbidity and mortality in 2019

- Morbidity measured by Years Lived with Disability (YLDs)
    - A year with (e.g.) chronic bronchitis is a fraction of a YLD
    - YLDs are valued using lost output per worker in 2019

- Premature mortality valued using the PDV of lost output

What are the health costs of PM2.5 in 2019?

- We calculate, by state, the lost output associated with premature deaths and YLDs in 2019
- Lost output in India attributable to air pollution in 2019 is $36.8 billion, 1.36% of GDP
  - $28.8 billion (1.06% of GDP) due to premature deaths
  - $8.0 billion (0.30% of GDP) due to YLDs
- Results as a percent of GSDP vary widely across states:
  - From 2.15% of GSDP in Uttar Pradesh and 1.95% of GSDP in Bihar to 1.06% in Maharashtra and Tamil Nadu and 0.67% in Sikkim
- Losses as a percent of GSDP reflect high levels of exposure to AAP and HAP

Methodology
Adjusted Average output

- In state i, the average output per worker is calculated as

$$W_i = \frac{(Labor's\ share\ of\ output\ in\ India)(GSDP_i)}{\#\ workers\ in\ state\ i}$$

- We adjust for the probability of working and for non-market output for an individual in age j:

$$W_{ij} = \left(WPR_{ij} + \lambda\left(1 - WPR_{ij}\right)\right) W_i$$

WPR_{ij} = worker-population-ratio

λ = 0.3

Methodology
Lost Output from Premature Deaths

- Presented discounted value of lost market and non-market output for a person who dies in 2019 at age j is calculated

$$PV_{ij} = \sum_{t=j}^{84} \pi_{ij,t} \left(\frac{1+g}{1+r}\right)^{t-j} W_{it}$$

- $\pi_{ij,t}$ is the probability of survival to age $t > j$ for a j year-old in state i, which are calculated using GBD India lifetables
- r is the annual discount rate, chosen as 6% to reflect the annual yield on 10-year government bonds.
- g is the annual growth rate of output per worker = 4.83%

Methodology

Total Output Loss

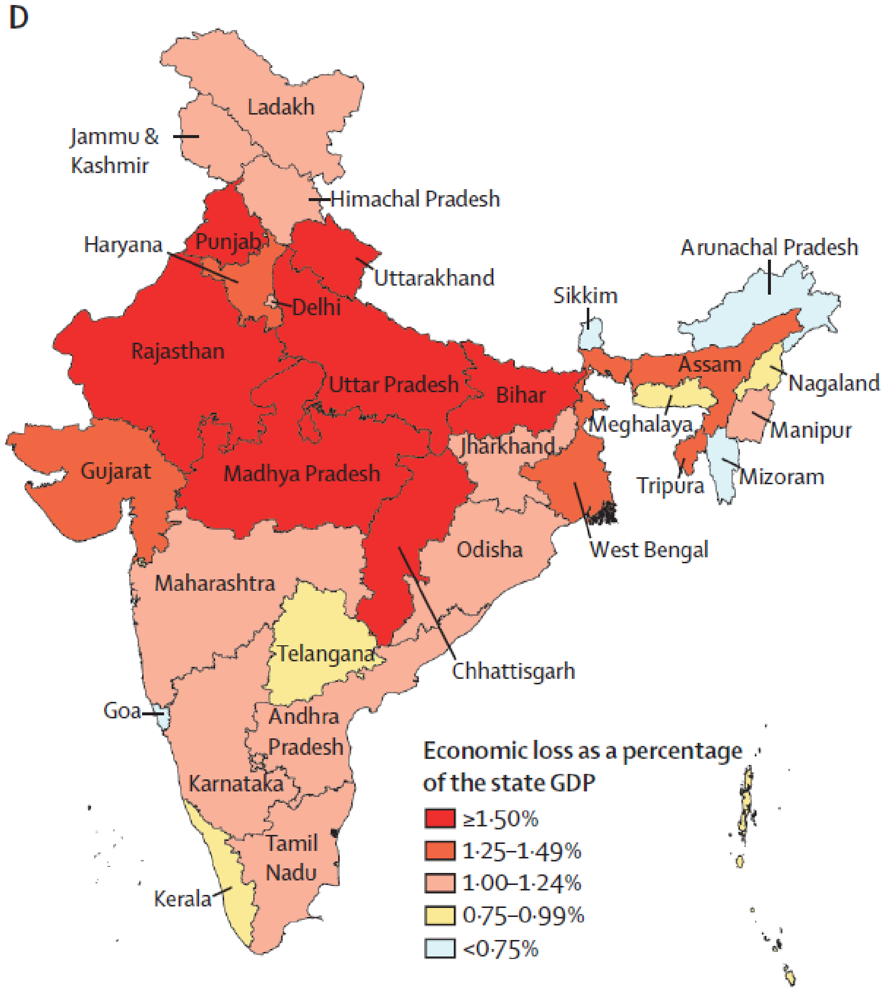
- Output loss associated with YLDs in 2019 for persons of age j in state i is given by

$$M_{ij} = W_{ij} YLD_{ij}$$

- Total output loss in state i in 2019 is obtained by summing over output loss due to premature deaths and YLDs at each age

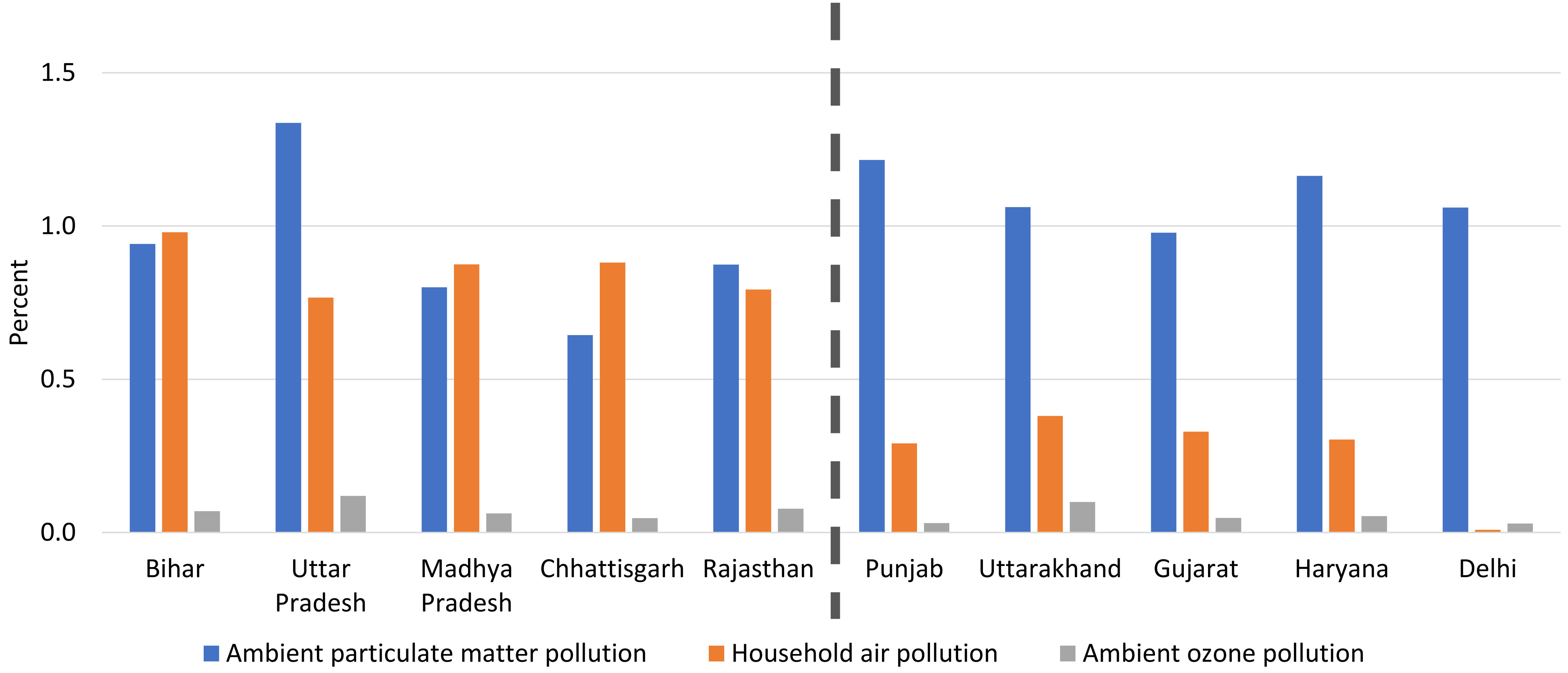
$$\sum_{j} \left(Deaths_{ij} PV_{ij} + M_{ij} \right)$$

Output Loss as a % of GSDP by State/UT



- Largest losses as a percentage of GSDP
  - Uttar Pradesh, 2.15%
  - Bihar, 1.95%
  - Rajasthan, 1.70%
  - Madhya Pradesh, 1.70%
  - Chhattisgarh, 1.55%
- Smallest losses as a percentage of GSDP
  - Sikkim, 0.67%.
  - Mizoram, 0.70%
  - Goa, 0.72%
  - Arunachal Pradesh, 0.74%
  - Meghalaya, 0.80%

Output Loss as a % of GSDP attributed to Different Types of Air Pollution – Selected States/UTs

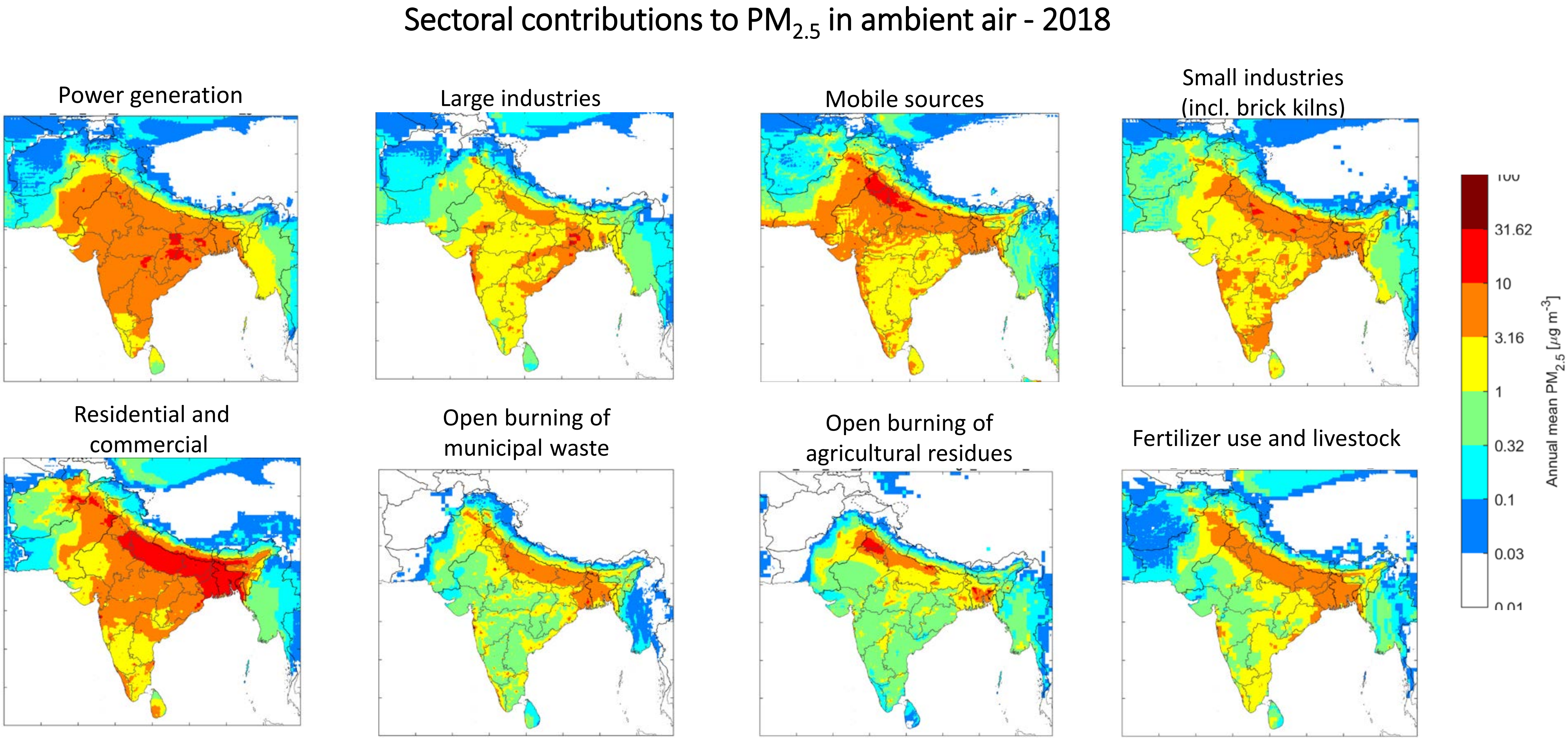


Health Cost: Conclusions

- Output losses from YLDs and premature mortality associated with air pollution in India in 2019 are substantial:
- Morbidity losses are, in the aggregate, about 0.30% of India's GDP; mortality losses about 1.06% of GDP
- In 8 states these losses are between 1.5% and 2% of GSDP
- Household air pollution directly accounts for 36% of economic losses for the country as a whole and is also an important source of ambient air pollution
- Economic losses from air pollution far exceed what we have quantified

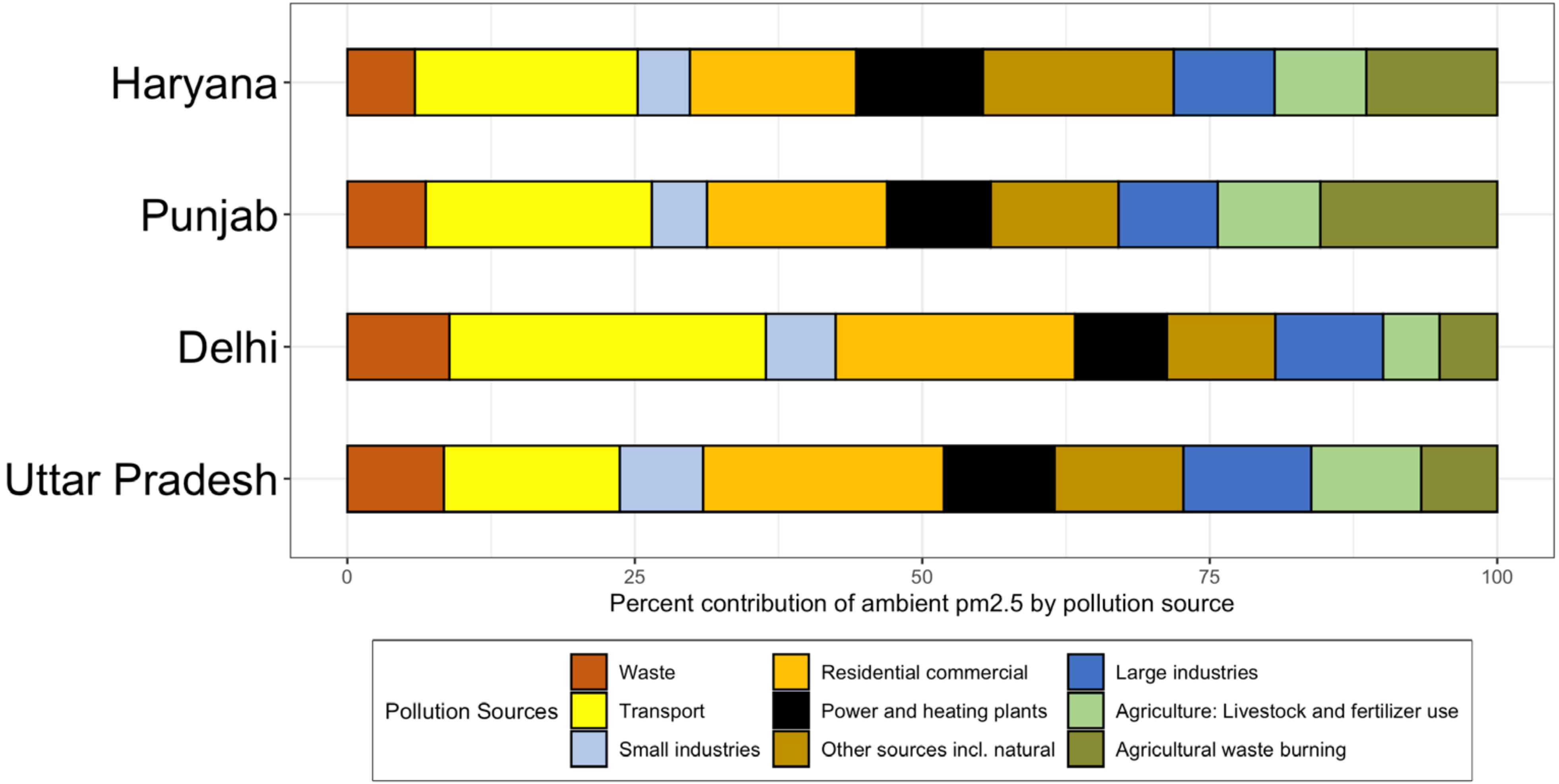
What Are the Sources of Ambient Air Pollution?

Ambient PM2.5 pollution originates from many different sectors

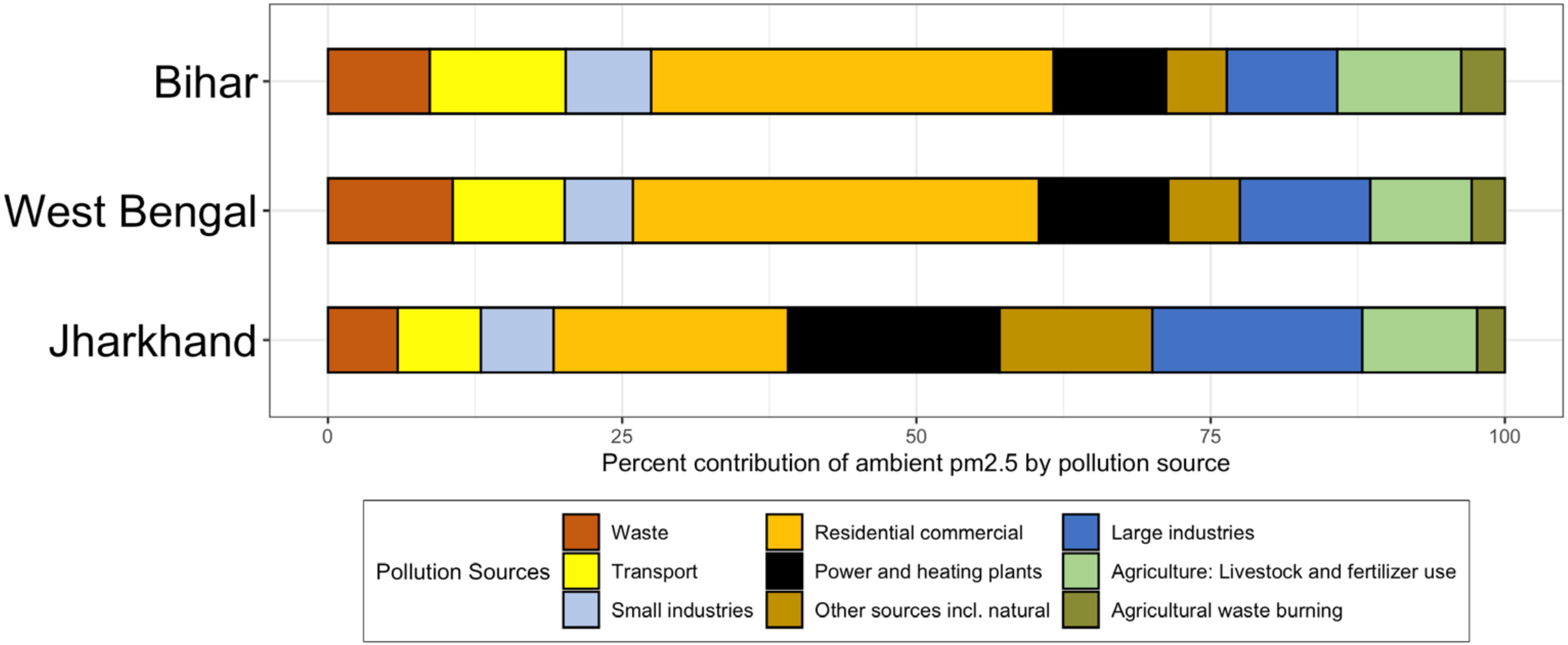


Source: IIASA

Proportion of AAP Deaths by Source

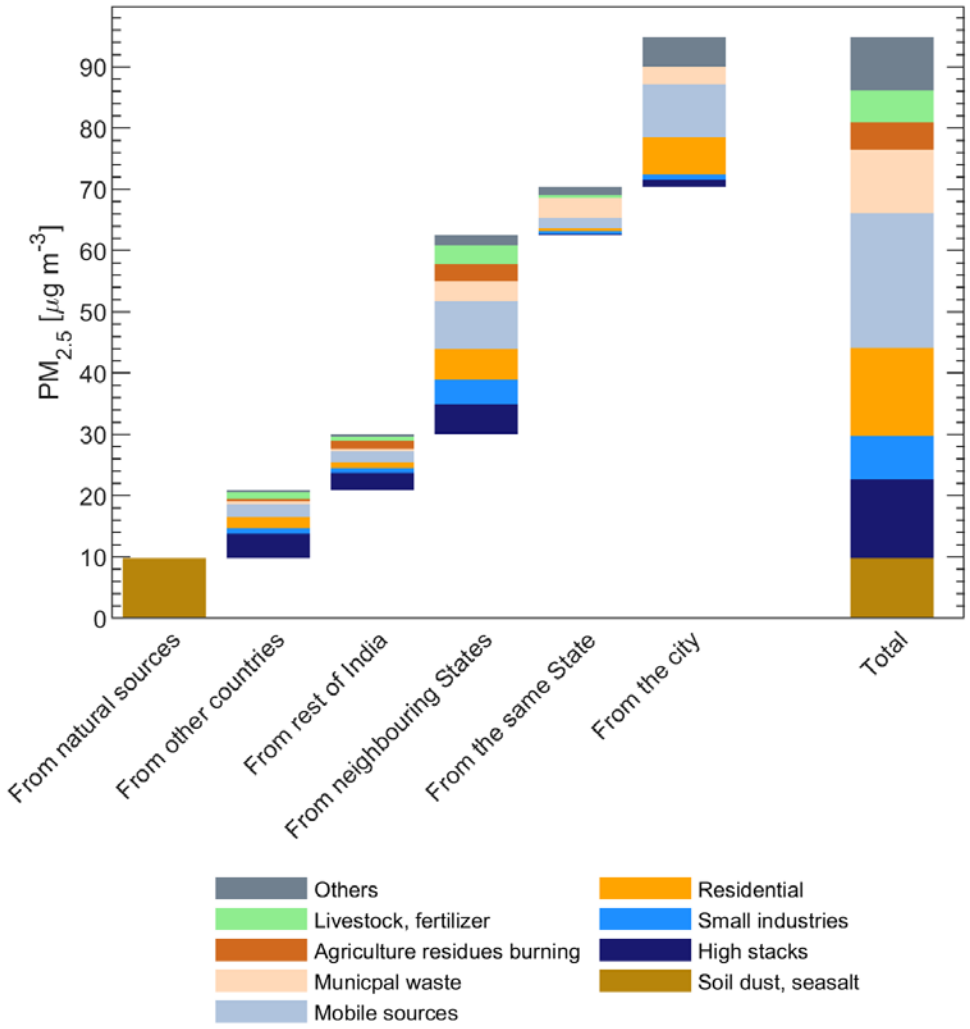


Proportion of AAP Deaths by Source

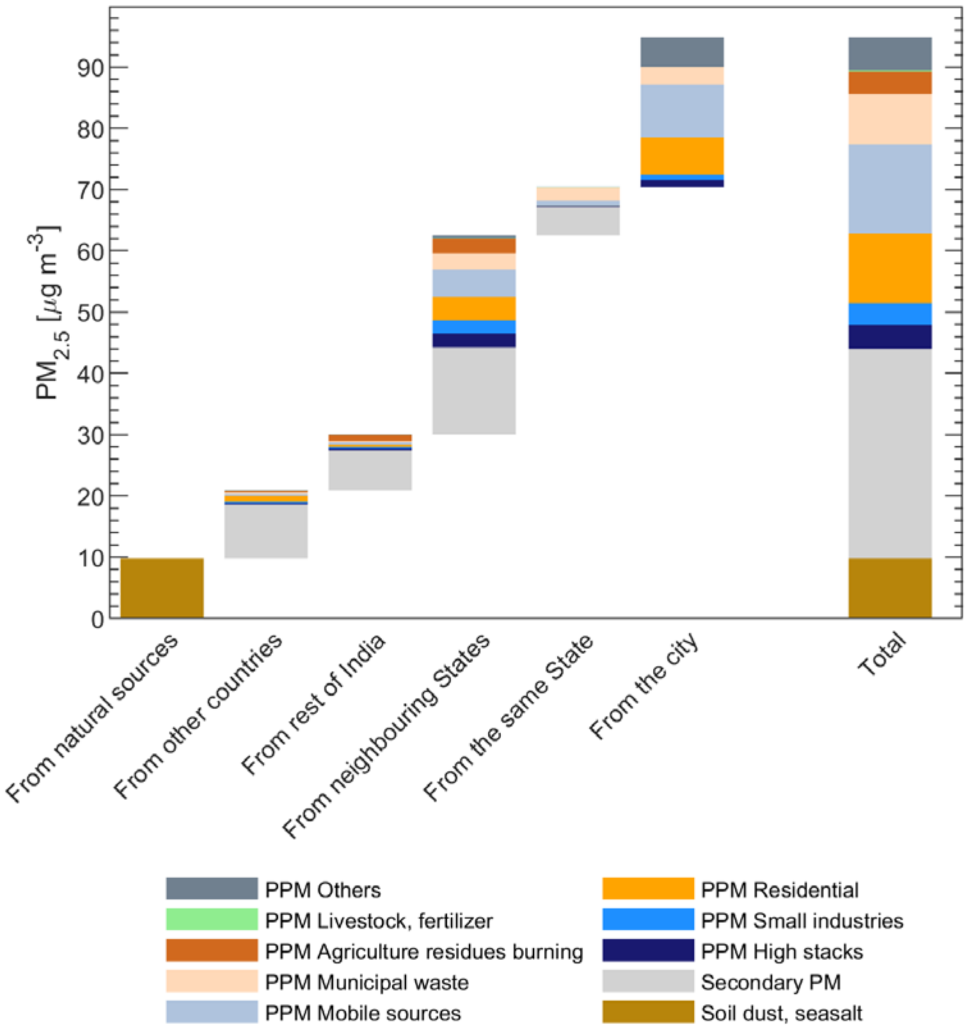


Source apportionment for Delhi NCT - 2018

Total contributions from sectors



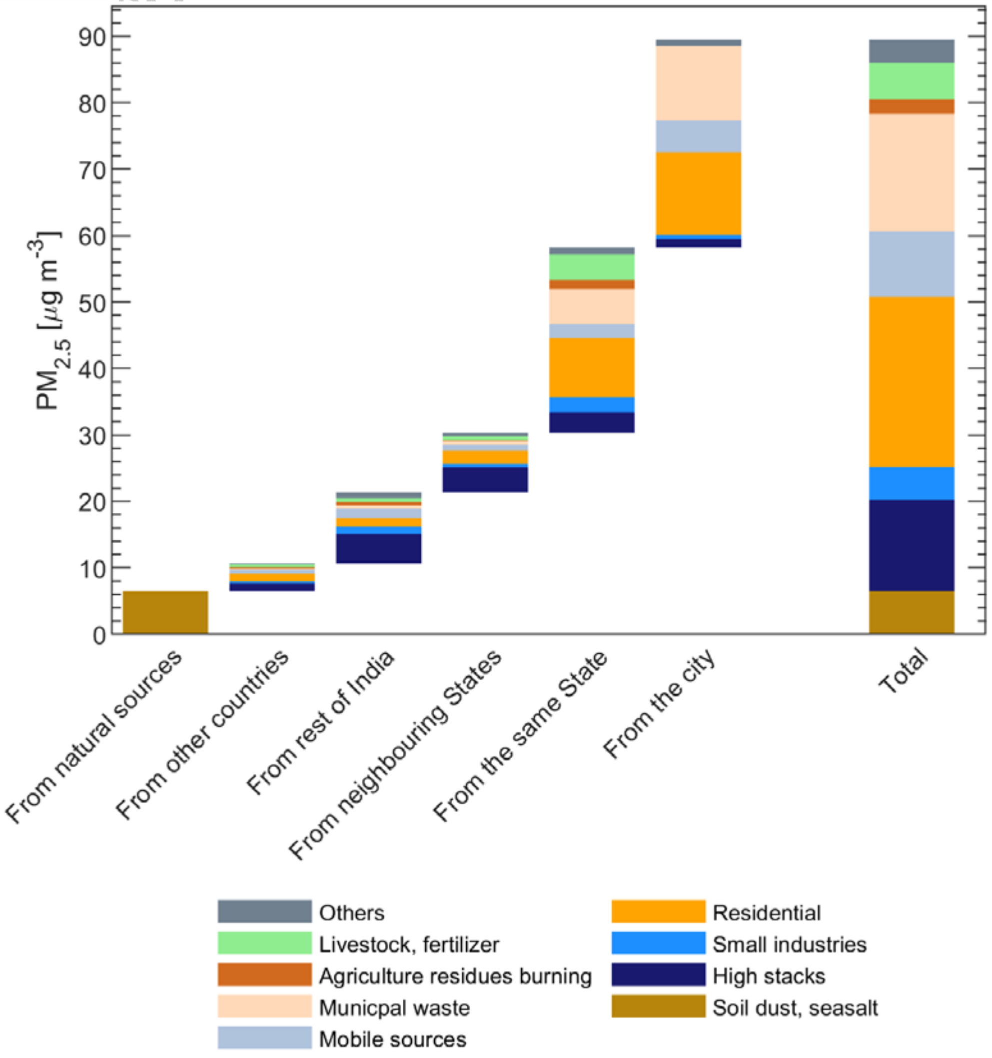
Origin of primary vs secondary



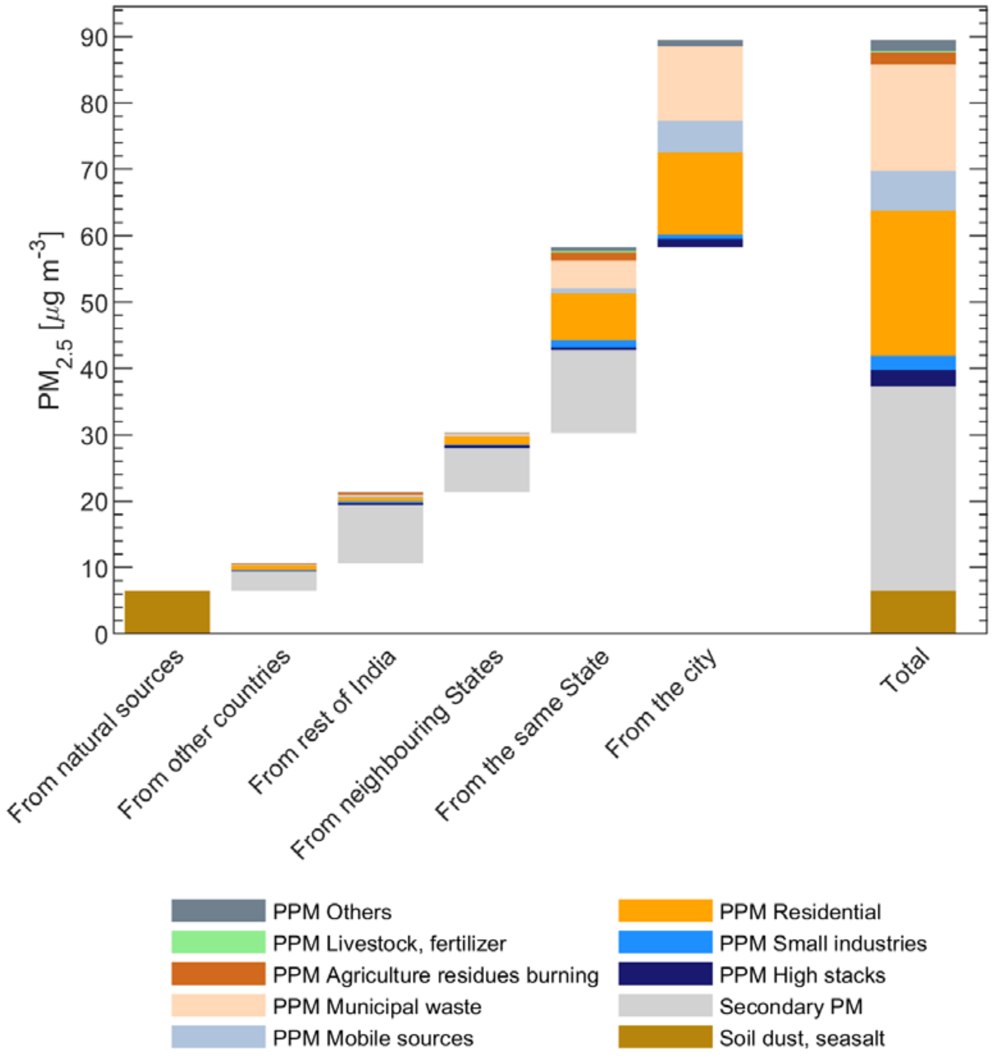
Source: IIASA GAINS

Source apportionment for Kolkata - 2018

Total contributions from sectors



Origin of primary vs secondary



Source: IIASA GAINS

Implications of Previous Slides for Pollution Control

- Need to know most important sources of air pollution affecting a city, district or state

- Need to know where geographically they are coming from
  - Control at appropriate level of government to minimize spillovers

- Need to look for cost-effective methods of control

- This leads to question about controlling pollution from the power sector

Pollution Control in the Electricity Sector

Motivation

- Coal-fired power plants in India are a major source of GHG emissions and local air pollution
  - In 2015, one-third of India's GHG emissions were due to coal-fired electricity generation
  - Coal-fired power plants are a major source of PM2.5 in North and Central India
- Coal-fired power plants are expanding
  - 208 GW of installed capacity in 2018, 95 GW in planning stages as of 2019
- **What would be the benefits in terms of avoided CO2 emissions and reduced PM2.5 mortality from not building planned plants?**
- **Should pollution controls be installed on coal-fired power plants to reduce local air pollution? Do they pass the benefit-cost test?**

Our Approach (PNAS 2021)

- Model impacts of current and planned coal-fired power plants on ambient PM2.5 and CO2
  - Construct emissions factors for each plant operating in 2018 and in the planning stages in 2019
  - Add to 2018 baseline emissions inventory for India
  - Model ambient PM2.5 at a $0.25^{\circ} \times 0.25^{\circ}$ resolution; calculate plant CO2 emissions
- Use exposure-response functions from 2019 GBD to estimate mortality impacts of PM2.5
- Calculate premature mortality and CO2 emissions avoided by not building planned plants

Preview of Results

- 78,000 deaths associated each year with plants operating in 2018
- Not building planned plants would save 450-500 million tons of CO2 annually and (initially) 19,000 lives per year
  - Over the lifetime of the plants between 840,000 and 1.5 million lives would be saved
- 70% of deaths associated with power plants could be avoided by installing pollution controls
- Our research suggest these controls pass the benefit-cost test

Electricity Sector Overview

- Coal-fired power plants (CPPs) generated 75% of electricity in India in 2018 although they constituted only 56% of installed capacity
- Coal-fired generation capacity has expanded rapidly, doubling between 2008 and 2014
- Currently about 200 GW, with 95 GW in planning stages as of November 2019
- In 2018, 5 states in North and Central India accounted for 50% of installed coal-fired capacity
- Planned expansions are concentrated on the Eastern coast of India

Location of Current and Planned Plants

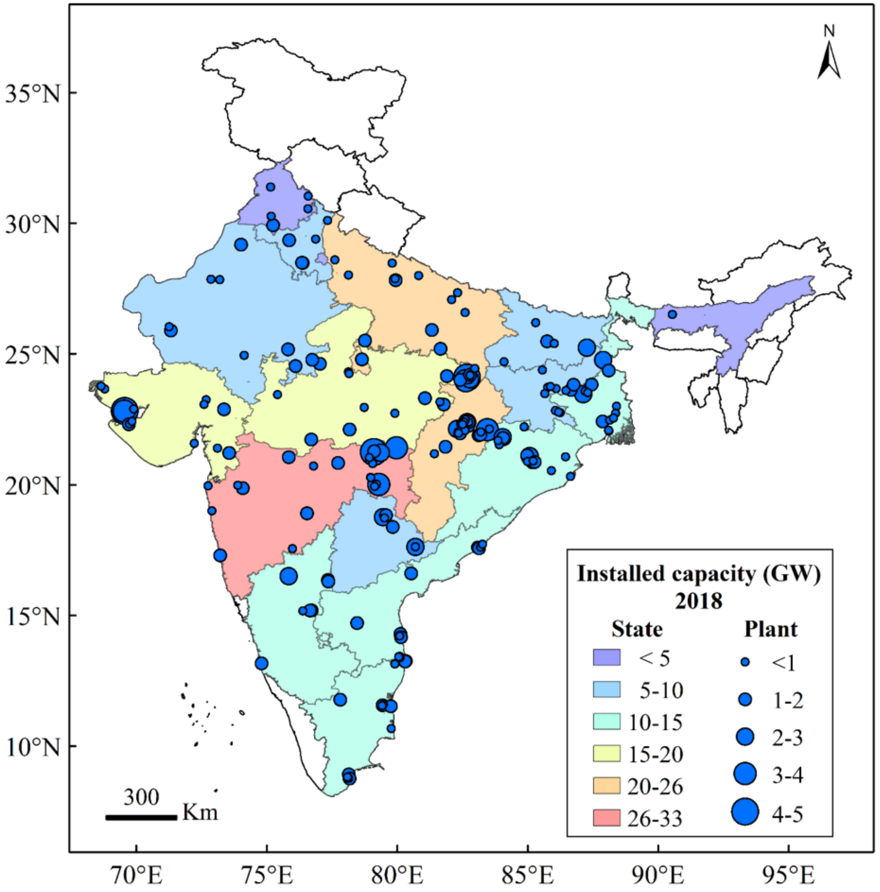


Fig. 1A. 2018 Plants

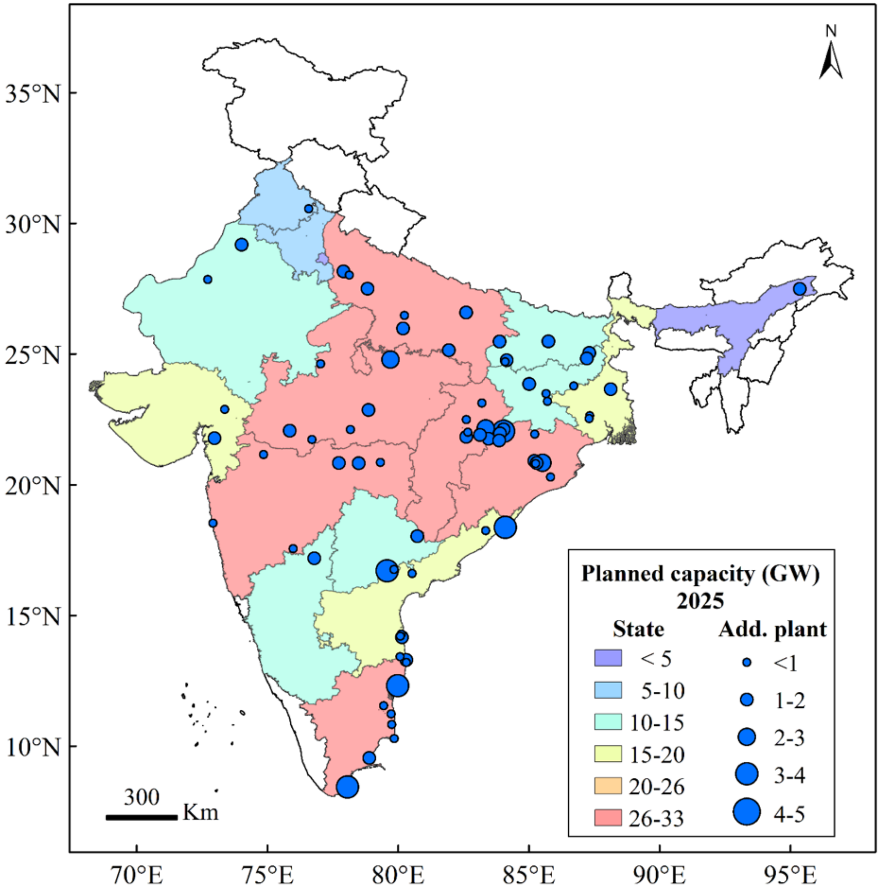


Fig. 1B. New Plants

Impact of Plants on Ambient PM2.5

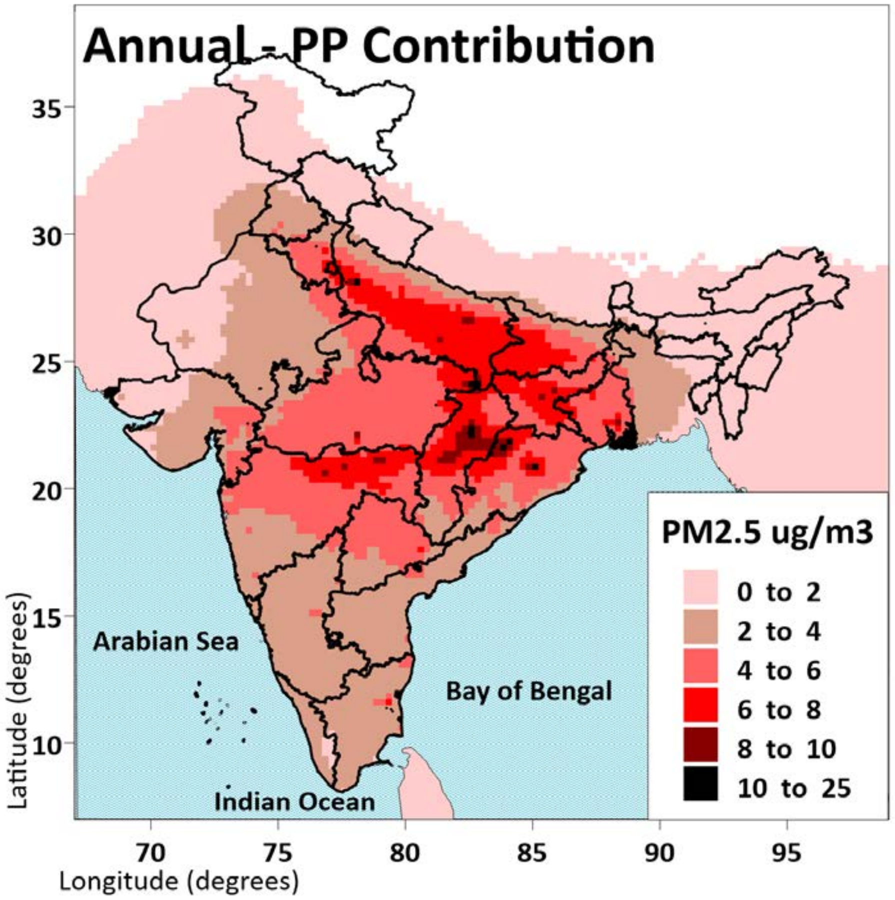


Figure 2A. Impact of 2018 Plants

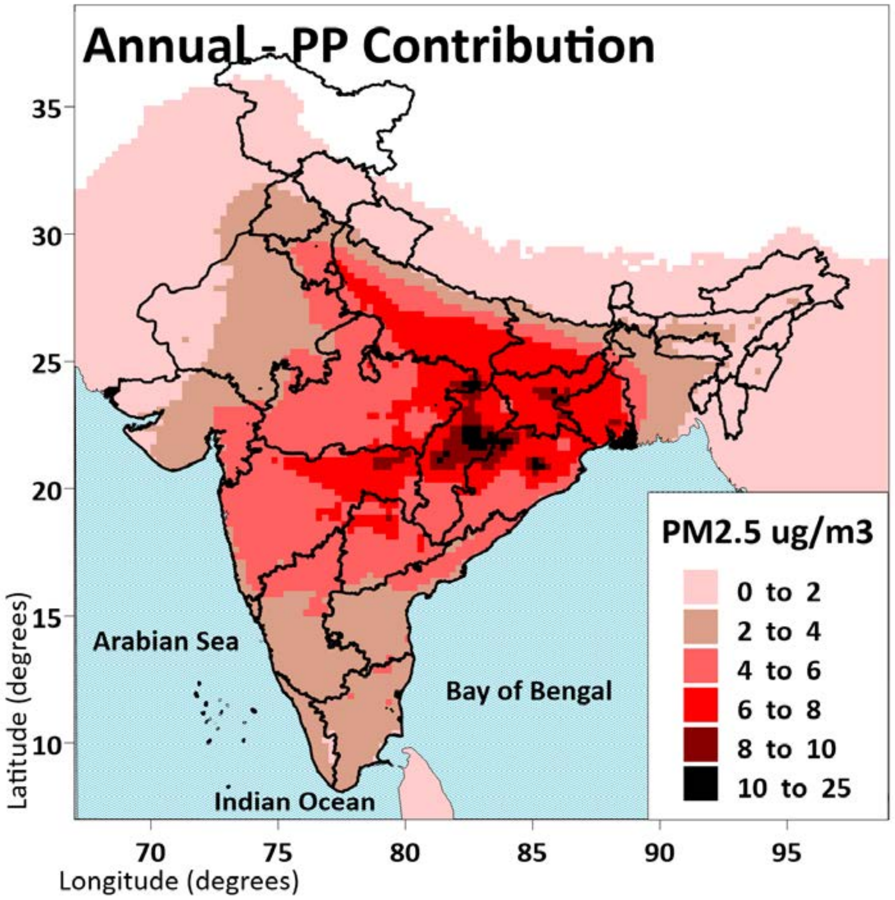


Figure 2B. Impact of 2018 Plants and New Plants

Calculation of Health Impacts

- Calculation of health impacts based on total exposure to PM2.5 = Ambient PM2.5 Exposure (AAP) + Household Exposure to Solid Fuels (HAP)
- We use the MR-BRTs from the 2019 GBD applied to each grid cell
- Deaths attributable to AAP = Total PM2.5 Deaths * [AAP/(AAP + HAP)]
- Deaths attributable to CPPs = AAP Deaths * Fraction of AAP due to CPPs
  - Treats CPPs as the average source of emissions
- **<u>Deaths attributable to 2018 CPPs</u> = 78,000**
- **<u>Deaths attributable to 2018 CPPs plus planned plants</u> = 112,000**

Deaths Attributable to Power Plants

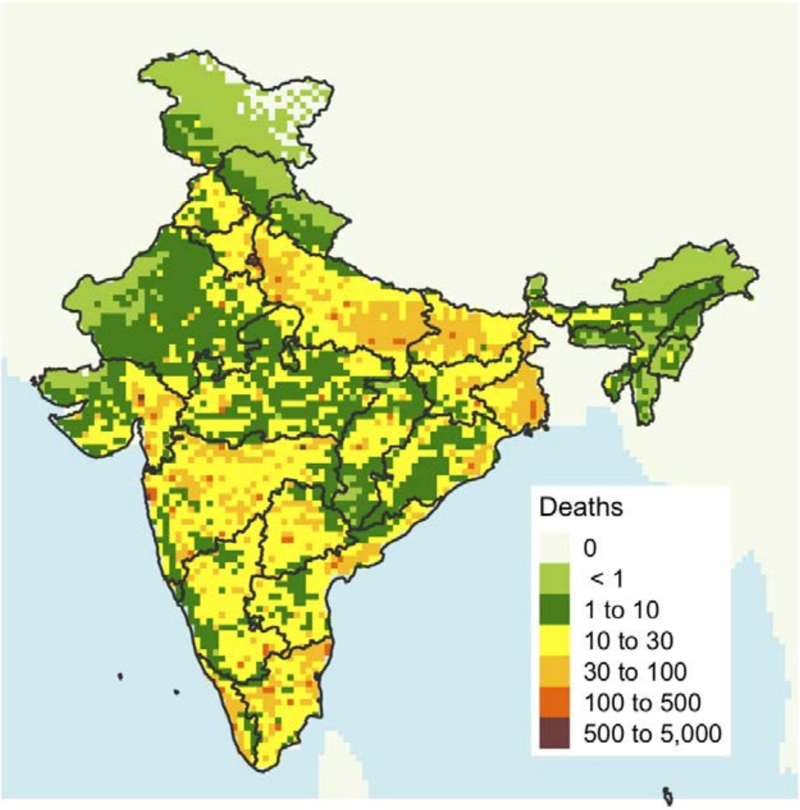


Figure 3A. Deaths Attributed to 2018 Power Plants

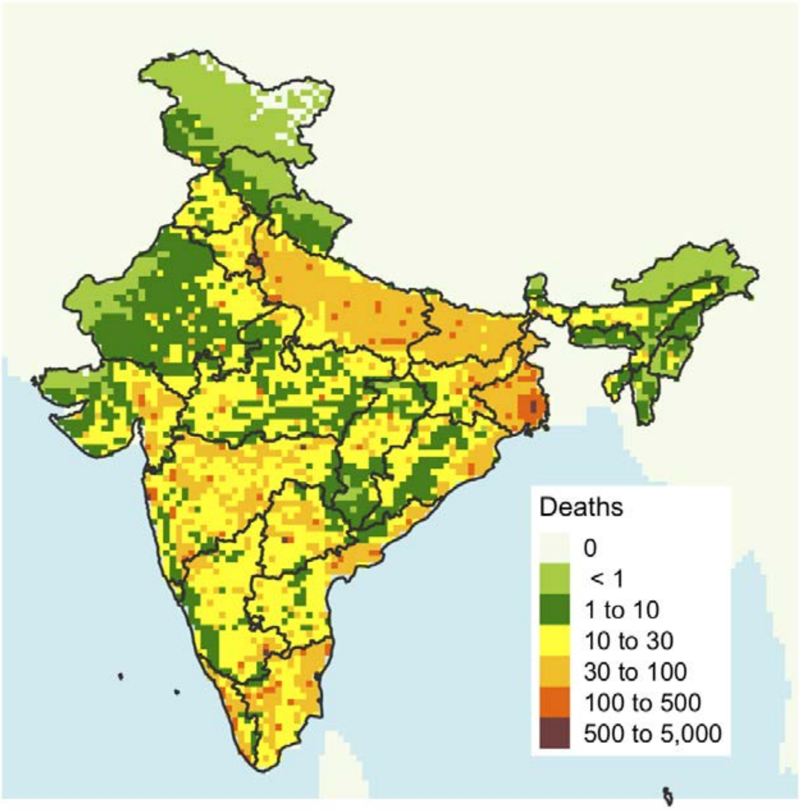


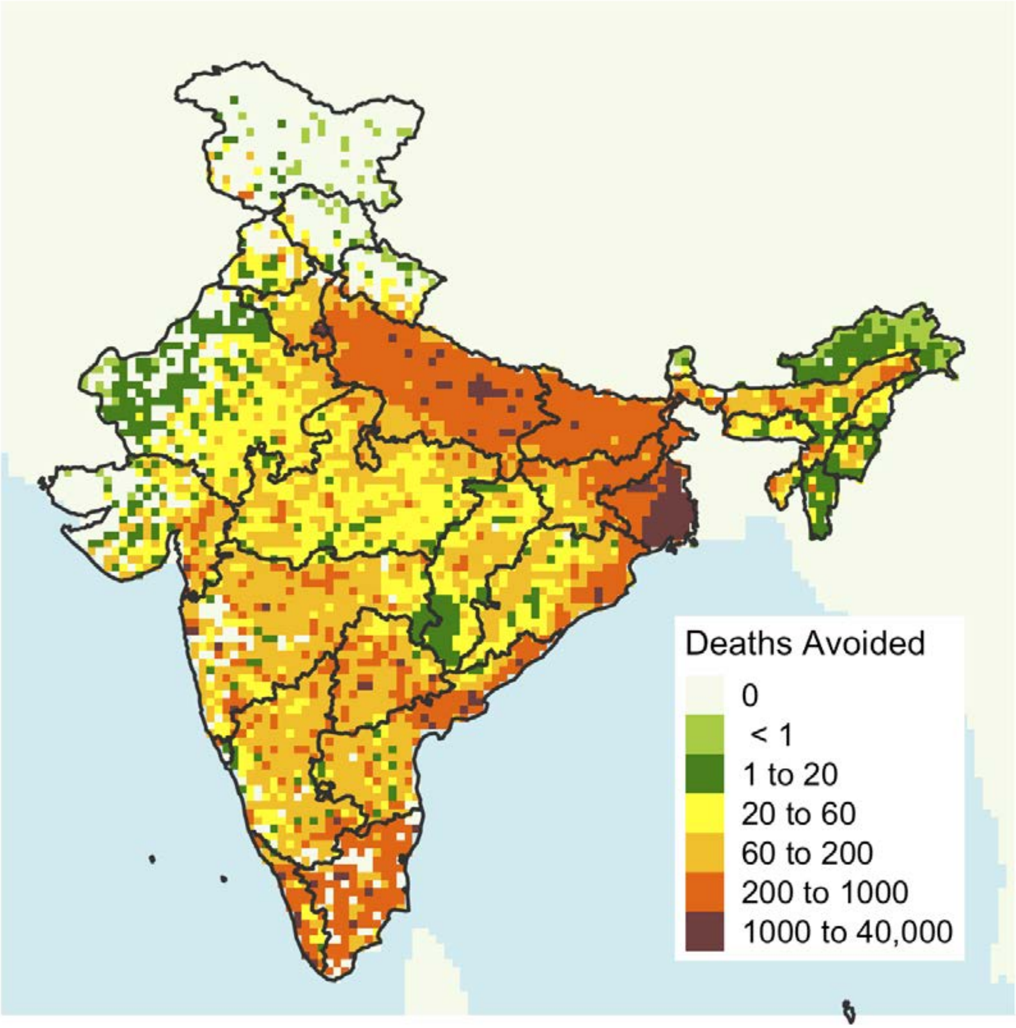
Figure 3B. Deaths Attributed to 2018 Plants and New Plants

Deaths Avoidable by Not Building Planned Plants

- Treat not building planned plants as a marginal decision—reducing concentrations of PM2.5 from a world in which current and future plants exist
- Due to concavity of exposure-response functions, deaths avoidable are much smaller than deaths attributable to planned plants:
- 34,000 deaths are attributable to planned plants
- 19,000 deaths are avoidable by not building planned plants
- Over 40-year plant lifetimes, deaths avoided will grow for two reasons:
  - Population growth
  - Reductions in HAP exposure (moves impacts of power plants toward the steeper part of the ER function)

Deaths Avoided by Not Building Planned Plants

- Deaths reflect population density and impact of planned CPPs on PM2.5
- 49% of deaths avoided are in Uttar Pradesh, Bihar and West Bengal
- Bihar and West Bengal have only 10 GW of planned capacity but are downwind from states with large increases in capacity
- States with 50% of planned CPPs account for 20% of deaths



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

Conclusions

- We find significant health impacts of current power plants on premature mortality associated with PM2.5 – 78,000 deaths annually.
- Not building planned plants would save 450-500 million tons of $CO2$ and, initially, about 19,000 lives per year
  - This could amount to 840,000 – 1.5 million lives over a 40-year plant life
- But existing plants will continue to operate (and new ones may be built): <u>How to reduce local pollution impacts of power plants?</u>

Could Power Plant Pollution Deaths Be Reduced?

- Our estimates of PM2.5 associated with coal-fired power plants are based on actual usage of pollution control equipment in 2018
- Retrofitting existing plants with FGDs to reduce SO2 emissions and using SCR to reduce NOx could reduce 70% of emissions
- Two recent papers have examined the costs and benefits of retrofitting plants with FGDs to reduce SO2 emissions
- The first paper examines the costs and benefits of retrofitting all coal-fired power plants in operation in 2008-09 with FGDs
- The second calculates benefit-cost ratios for installing an FGD at a model power plant in different locations in India

Benefit-Cost Analyses of Pollution Retrofits

- Both studies are bottom-up analyses: examine air pollution emissions from each plant with and without an FGD
- Calculate effect of the FGD on ambient PM2.5 concentrations and the impact of the change in PM2.5 on mortality, over the life of the FGD
- Estimate costs of installing and operating the FGD over its lifetime
- Compare the PDV of costs and benefits
- Mortality benefits valued using the Value per Statistical Life (VSL)—the sum of what people would pay for small reductions in the probability of death that equal one (statistical) life saved

Cost-Effectiveness of FGD Installation, 2008-09

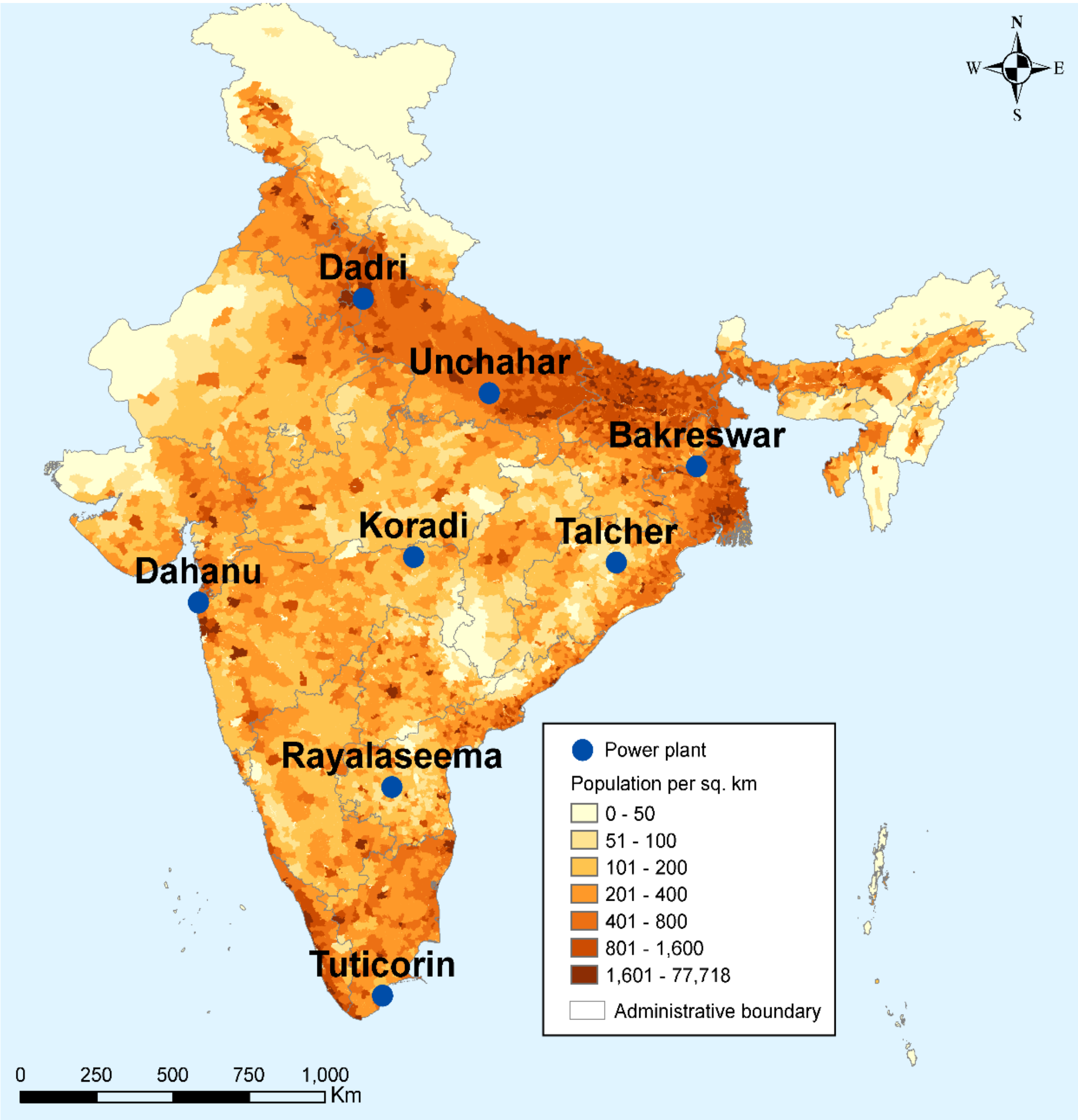
	Annual Lives Saved	Annual Cost (Mil.)	Average Cost per Life Saved
72 Plants	12,890	$1,691	$131,000
30 plants with lowest CPLS	9,196	$ 615	$ 67,000
30 plants with most deaths	10,061	$ 965	$ 96,000
30 largest plants (MW)	7,910	$1,164	$147,000

Cost unit: 2013 USD

When Does a Retrofit Pass the Benefit-Cost Test?

- If the VSL exceeds $131,000 (2013 USD), retrofitting on average would pass the benefit cost test?
- What VSL should be used in India?
- Somanathan and Chakravarty recommend a VSL of 82 times per capita income ($125,000); Gates Commission Report on BCA recommends a VSL of 100 times per capita income ($152,000)
- So, on average, retrofitting the 72 plants passes the B-C test
- But, result varies a lot by plant

Location of Model Plants



Benefit/Cost Ratios for FGD Retrofits

Plant Name	VSL	$160,000	$256,000	$256,000
	Discount rate	3%	3%	8%
Dadri		11	18	14
Unchahar		7.5	12	9.5
Bakreswar		3.4	5.5	4.3
Dahanu		2.4	3.8	3.0
Talcher		1.5	2.4	1.9
Koradi		1.0	1.6	1.3
Rayalaseema		0.56	0.89	0.70
Tuticorin		0.51	0.82	0.65

Benefit-Cost Analyses of Pollution Retrofits

- Especially in North and Central India, retrofitting power plants with pollution controls (FGDs) passes the benefit-cost test
- Installing an FGD on a new plant would be 30% cheaper so would raise the benefit-cost ratio
- None of the previous analysis takes account of the morbidity benefits of reduced PM2.5 concentration—nor of the effects on crop yields or ecosystems.
- So the B/C ratios on the previous slide are underestimates.

Five Questions About Air Pollution in India

- How high is ambient air pollution in different parts of India?
- What are the morbidity and mortality consequences of ambient air pollution (AAP)? What are the health consequences exposure to household air pollution (HAP)?
- What are the health costs of pollution-related morbidity and mortality?
- What are the sources of ambient air pollution in different parts of India? What does this imply for policies to control air pollution?
- What are the health benefits and the costs of reducing pollution from coal fired power plants?

What Questions Have We Not Answered?

- What are the costs of various methods of controlling air pollution?
- What are the most cost-effective methods of controlling different sources of air pollution?
- What are the most politically acceptable methods of controlling different sources of air pollution?
- Joining these answers to estimates of the benefits of pollution control are needed to advance pollution control in India.