Applying Benefit-Cost Analysis to Air Pollution Control in the Indian Power Sector

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Motivation

- Coal-fired power plants in India generate 76% of electricity
  - Generating capacity doubled between 2008 and 2014
  - Grid-connected capacity currently 196 GW
  - Plans for an additional 114 GW by 2030
- Significant health impacts associated with coal plants
  - Global Burden of Disease (2018) estimated over 82,000 deaths attributable to coal-fired power plants in 2015
- Can reduce health impacts by:
  - Installing flue-gas desulfurization units (scrubbers)
  - December 2015 regulations effectively require FGDs but few plants have installed them

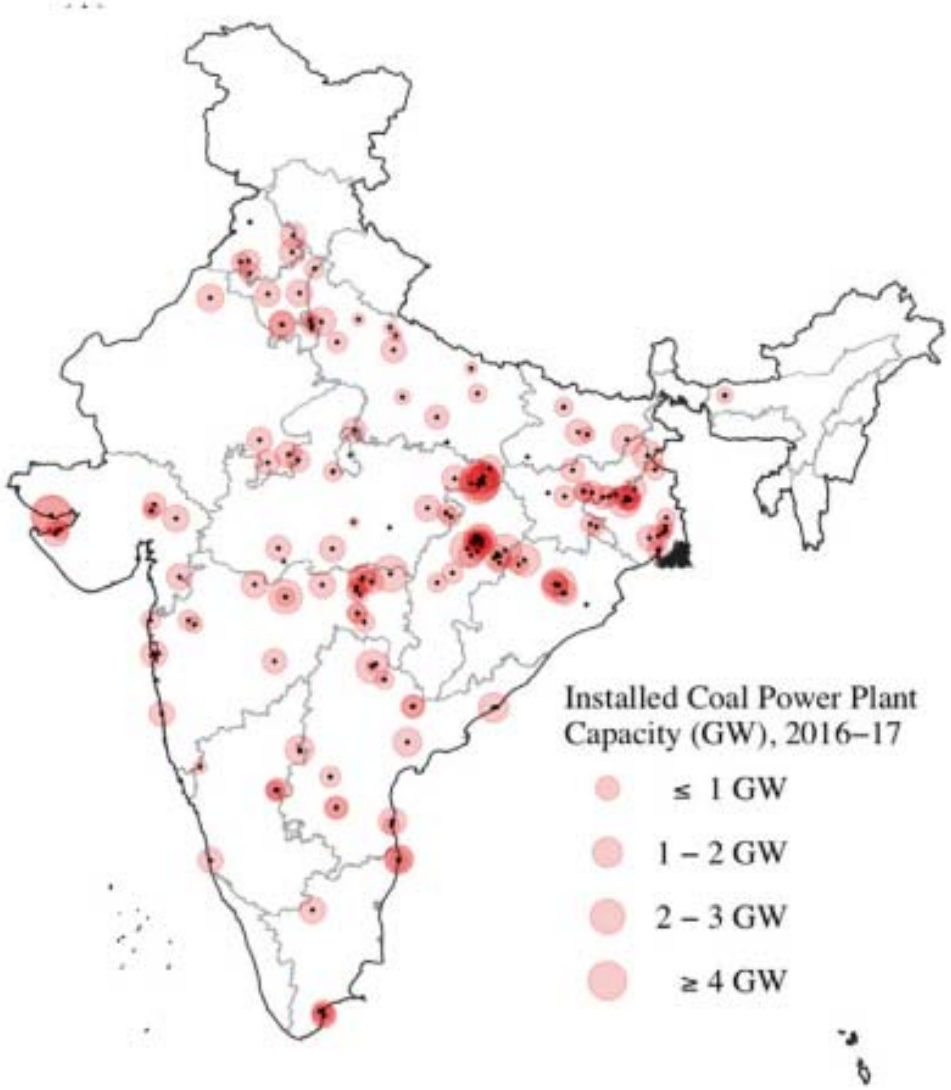
Questions Addressed

- Does retrofitting coal-fired power plants in India with FGDs (scrubbers) pass the benefit-cost test?
  - In the aggregate?
  - At individual plants?
- How should the retrofitting of FDGs be prioritized?
  - One method is to prioritize plants based on net benefits of retrofitting
- How sensitive are net benefits to the VSL and the discount rate?

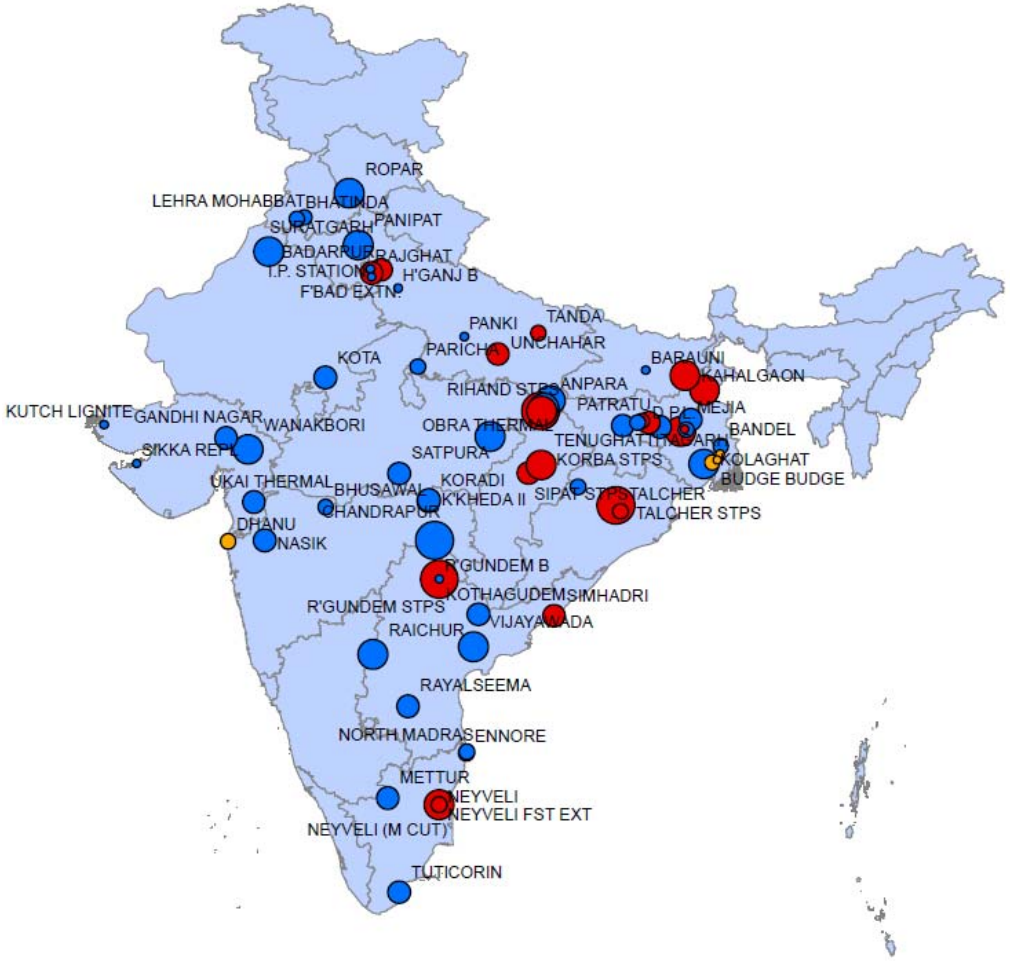
Our Research

- Cropper et al. DCP3, *Injury Prevention and Environmental Health (2017)*
  - Estimate cost per life saved of installing FGDs at 72 power plants in operation in 2008-09
  - Plant-by-plant study
- Cropper et al. *Journal of Benefit-Cost Analysis (2019)*
  - Estimate net benefits of scrubbing at 8 model power plants
  - Emphasizes impact of location on damages, with implications for prioritizing retrofitting
  - Also impact of valuation methods on net benefits

Coal-fired Power Plant Capacity 2016-17



Coal-fired Power Plants 2008-2009



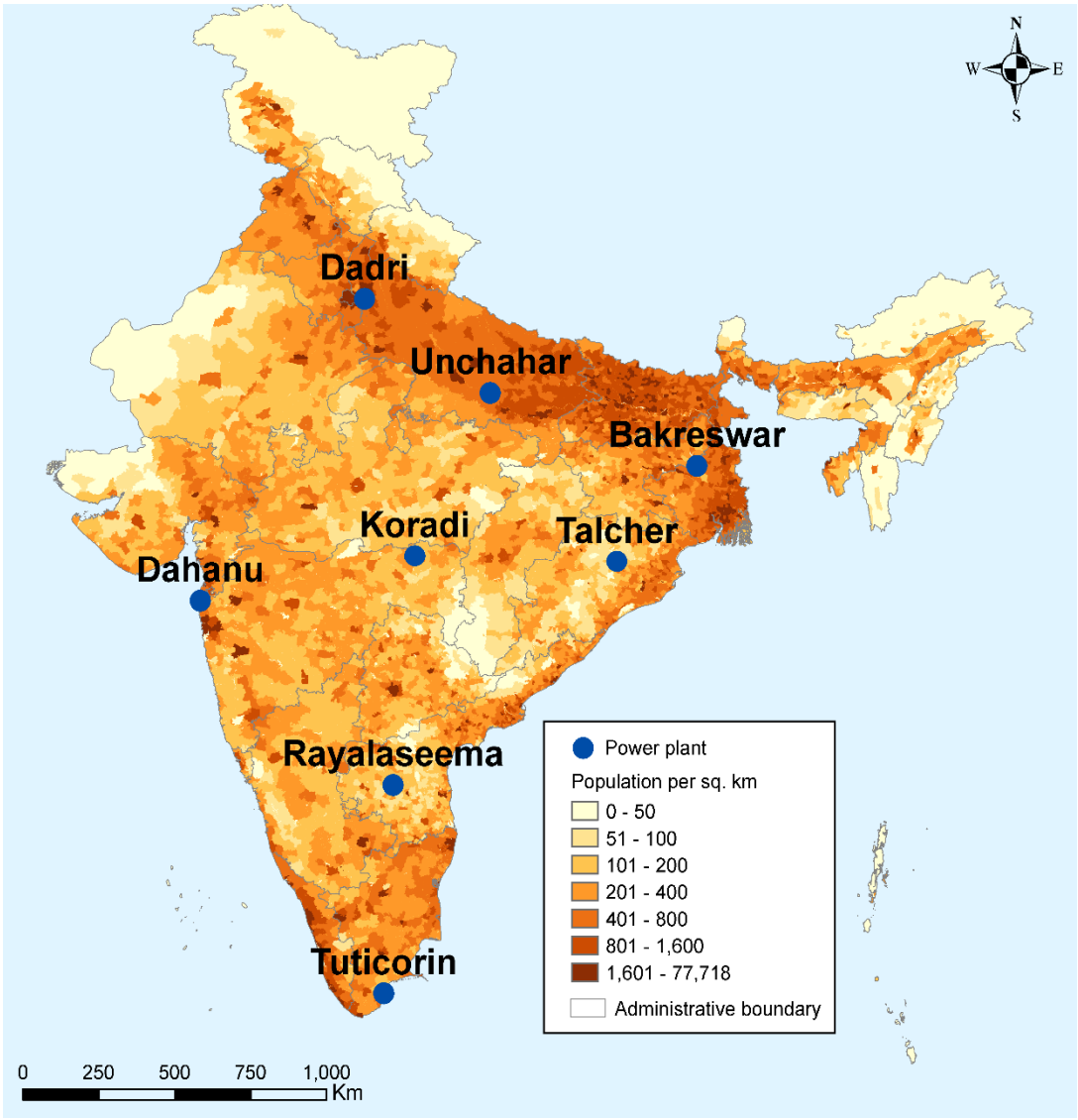
Is Retrofitting FGDs Cost-Effective?

- We assume, conservatively, that scrubbers reduce deaths by 72% annually
- Using benchmark operating conditions, scrubbing at all plants would:
  - Save 13,000 lives per year (329,000 life years)
  - Average CPLS = $131,000 (2013$)
  - Average cost per life-year saved = $5,000
  - But CPLS varies from $25,000 to $1,200,000
- More efficient approaches suggested on next slide

Cost-Effectiveness of FGD Installation, 2013$

	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

Location of Model Plants



Benefit-Cost Analysis Framework

- Benefit Estimation:
  - Estimate plant's SO_2 emissions
  - Translate emissions into impact on ambient $PM_{2.5}$
  - Estimate health impacts of ambient $PM_{2.5}$
- Do this with and without the FGD
- Benefits = Monetized value of reduction in health impacts (PDV of health benefits over life of FGD)
- Subtract PDV of costs of operating the FGD over its lifetime from benefits to calculate net benefits

Costs of Scrubbing

- Assume that a scrubber is retrofitted at each 500 MW model plant
  - Seawater FGD for plants on the coast
  - Wet limestone FGD for all other plants
- Capital costs based on values for FGDs installed or in planning stages in India
- Model plant will be retrofitted with an FGD (raises capital costs by 30%) which has life of 20 years
- PDV of cost of wet limestone FGD are:
  - $165 million (2015$) at 3%; $127 million (2015$) at 8%

Benefits of Scrubbing

- Calculate emissions of $PM_{2.5}$, NO_x, SO_2 for each plant
- For each plant: estimate population-weighted ambient concentrations of $PM_{2.5}$ associated with SO_2 emissions
  - Use CAMx applied plant by plant; 2011 population data
- Use concentration-response functions from the Global Burden of Disease to estimate impact of SO_2 emissions on stroke, IHD, COPD, lung cancer and ALRI deaths
- Estimate mortality impacts only (not morbidity); assume scrubber will reduce deaths by ~ 72% annually
- Value reduced mortality by transferring VSL from HICs

Mortality Impact of a Plant

- Deaths associated with a plant:

  Plant deaths = (Baseline deaths) x (Δ pop-wtd PM2.5) x
  (Δ Mortality per µg/m3 PM2.5)

- <u>Can measure Δ Mortality per µg/m3 two ways:</u>
- Treat plant as marginal emitter—use slope of IER at current annual average PM2.5
- Treat plant as average emitter—use slope of a ray from the origin to the IER at current annual average PM2.5
- We treat the plant as the marginal emitter

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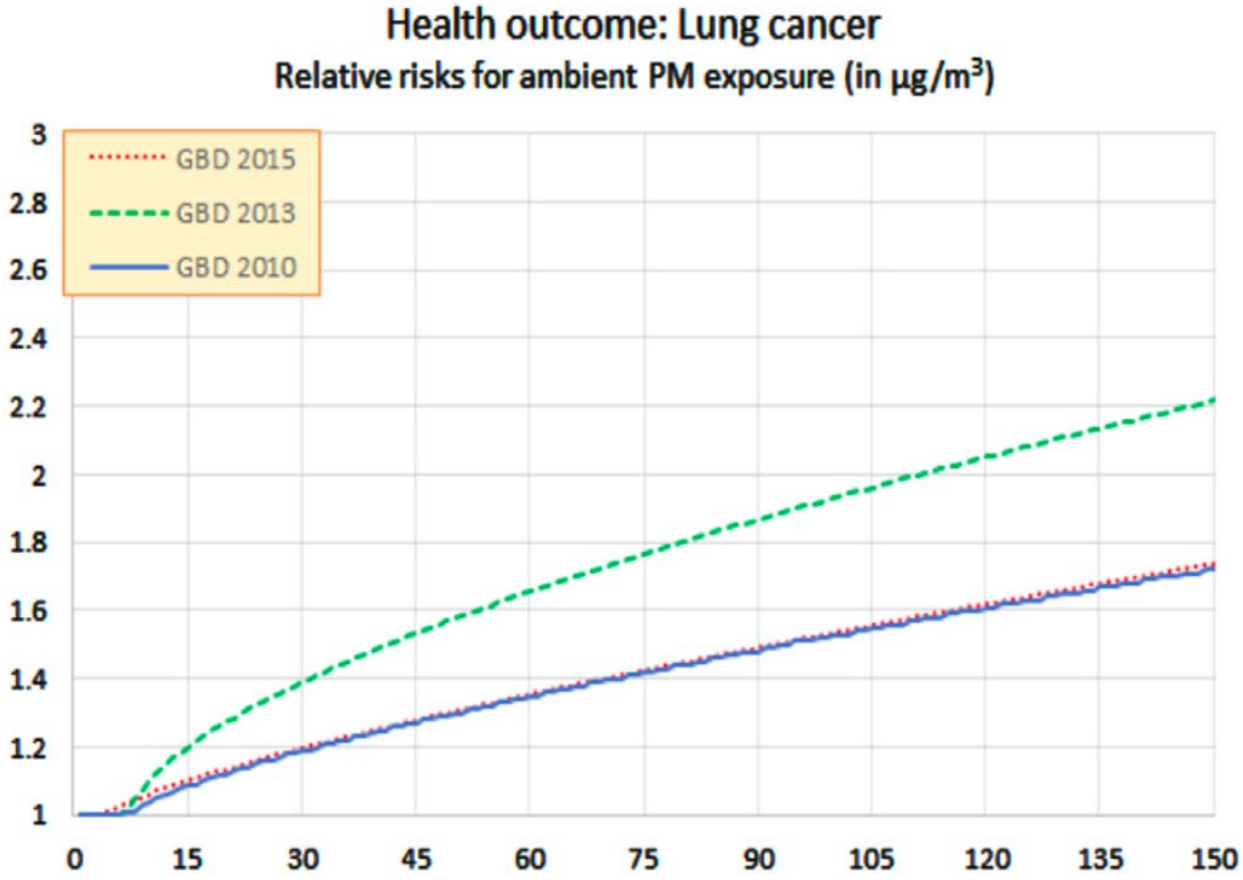
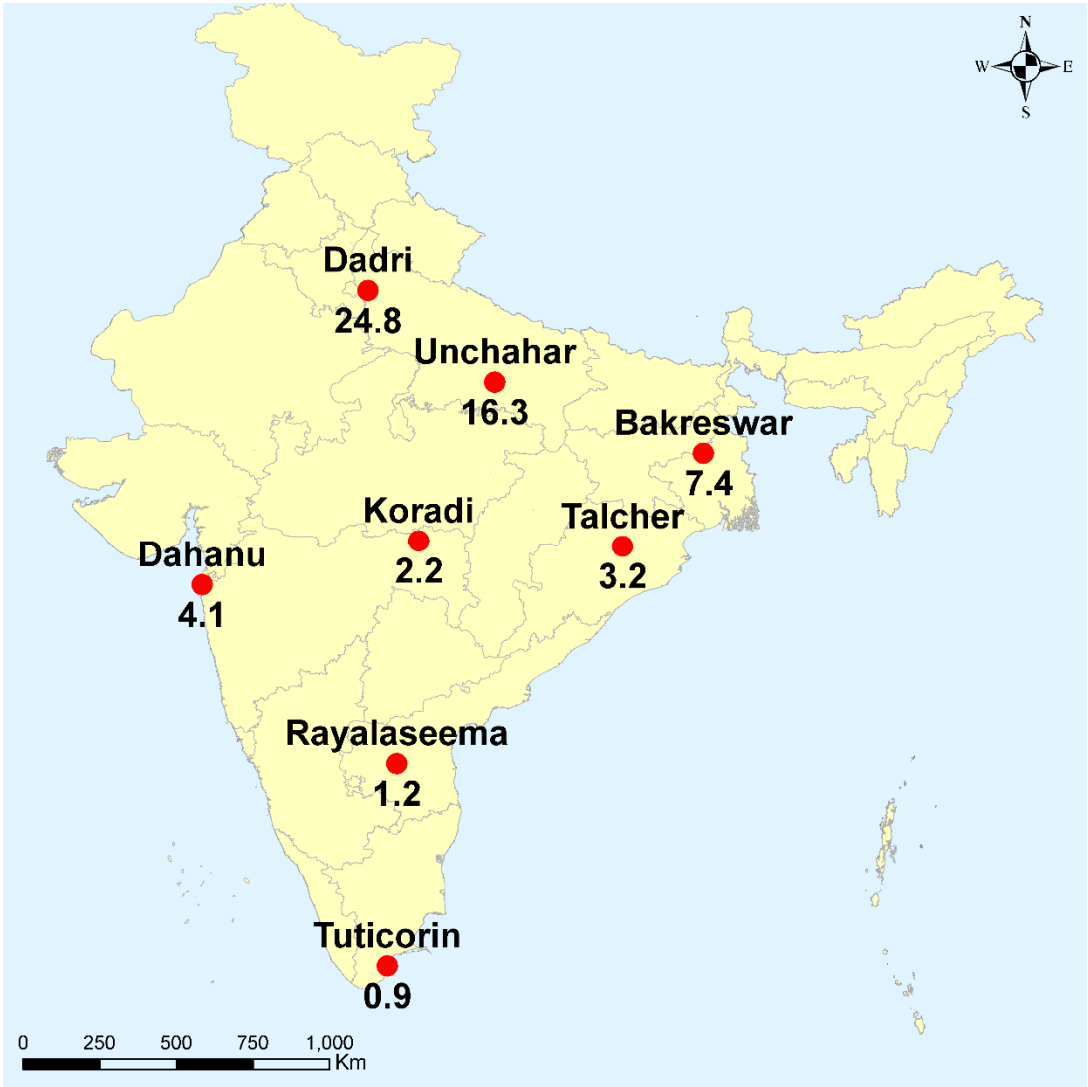
Concentration-Response Function for Lung Cancer



Deaths per 1000 tons of SO_2 2015



Mortality Benefits of Scrubbing

- Assume deaths caused by the plant grow at the rate of population growth for India
- FGD reduces deaths by 72% each year
- Number of deaths reduced each year is multiplied by the VSL for that year (see next slide)
- Monetary value of benefits are discounted to the present using three discount rates: 3%, 8%, 12%
  - 3% is same discount rate used in cost effectiveness reference case
  - 8% and 12% reflect rate of growth of the Indian economy

Transferring the VSL to India

- VSL transfer assumptions follow reference case guidance
- Transfer VSL from USA using an income elasticity of 1.5 and also using ratios of VSL/Y of 100:1 and 160:1
- Implies 2015 VSL in India at market exchange rates:
  - $84,000
  - $160,000
  - $256,000
- VSL grows with per capita income using income elasticity underlying benefits transfer

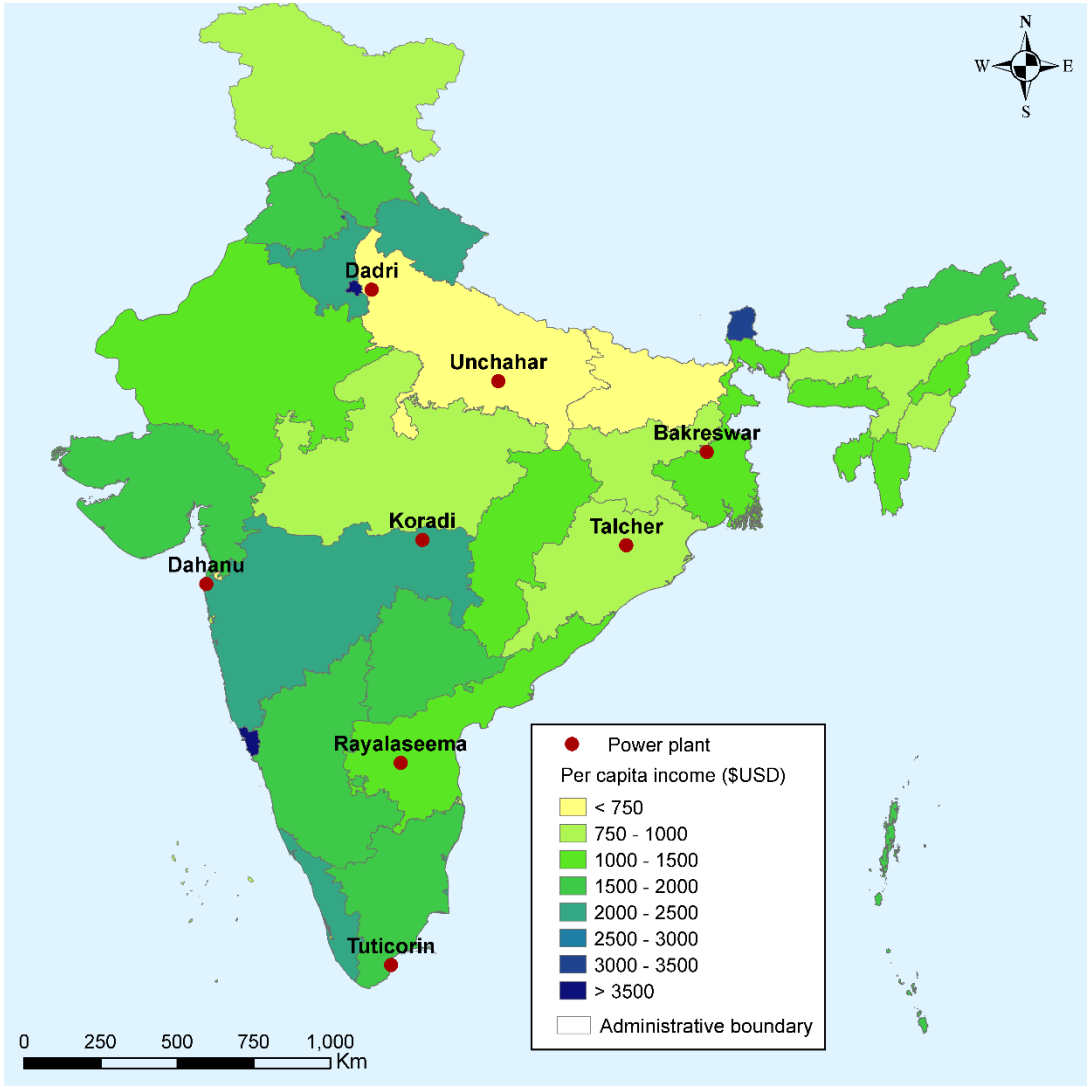
Benefit/Cost Ratios for FGD Retrofits

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

Issues in Calculating Net Benefits

- Only mortality benefits have been calculated
  - Cannot interpret B/C ratio < 1 as indicating FGD fails the benefit-cost test
  - Morbidity benefits will be proportional to the size of the exposed population and possibly to mortality
  - The ranking of locations by net mortality benefits should provide useful information
- Should the VSL vary with state per capita income?
  - Calculations suggest prioritizing retrofits in the North and East of India: Uttar Pradesh and Bihar are poor states
- We follow the US practice of valuing all lives the same within a country

Per Capita Income by State (2017$)



Conclusions

- Retrofitting coal-fired power plants with scrubbers will likely yield positive net benefits in the aggregate
  - This suggested by DCP3 results and VSL transfer
  - But wide variation in health benefits from scrubbing across plants, due to differences in meteorology and size of the exposed population
- Information on net health benefits can aid in prioritizing retrofits
  - Calculations suggest prioritizing retrofits in the North and East of India: Uttar Pradesh, Bihar, West Bengal
- Caution that benefits reflect only avoided mortality