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
  – 70% of electricity could be generated from coal in 2030 even if India fulfills its INDC under the Paris agreement
  – Global Burden of Disease (2018) estimated over 82,000 deaths attributable to coal-fired power plants in 2015

• Electrostatic precipitators required on all plants

• Flue-gas desulfurization units (FGDs) could reduce SO$_2$ emissions and formation of PM$_{2.5}$
  – Only 3 plants currently have FGDs in operation
  – December 2015 regulations effectively require FGDs
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

  - Estimate cost per life saved of installing FGDs at 72 power plants in operation in 2008-09
  - Plant-by-plant study

  - 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
## Cost-Effectiveness of FGD Installation, 2013$

<table>
<thead>
<tr>
<th>Plant Classification</th>
<th>Annual Lives Saved</th>
<th>Annual Cost (Mil.)</th>
<th>Average Cost per Life Saved</th>
</tr>
</thead>
<tbody>
<tr>
<td>72 Plants</td>
<td>12,890</td>
<td>$1,691</td>
<td>$131,000</td>
</tr>
<tr>
<td>30 plants with lowest CPLS</td>
<td>9,196</td>
<td>$ 615</td>
<td>$ 67,000</td>
</tr>
<tr>
<td>30 plants with most deaths</td>
<td>10,061</td>
<td>$ 965</td>
<td>$ 96,000</td>
</tr>
<tr>
<td>30 largest plants (MW)</td>
<td>7,910</td>
<td>$1,164</td>
<td>$147,000</td>
</tr>
</tbody>
</table>
Location of Model Plants
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

• Estimate mortality impacts only (not morbidity); assume scrubber will reduce deaths by ~ 72% annually

• Value reduced mortality by transferring VSL from HICs
Deaths per 1000 tons of SO$_2$ 2015

Dadri 24.8
Unchahar 16.3
Bakreswar 7.4
Dahanu 4.1
Koradi 2.2
Talcher 3.2
Rayalaseema 1.2
Tuticorin 0.9
Net Benefits of Scrubbing

• VSL transfer and discounting 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

• Discount rates used: 3%, 8%, 12%
## Benefit/Cost Ratios for FGD Retrofits

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