Climate Change, Air Quality and Development: Where are the Win-wins (if any) ?

Milind Kandlikar,
University of British Columbia
This talk

- Climate, AQ, and Development
- India
  - Air Quality
  - Climate Change
- Evidence for Mitigating Air pollution and Climate together
- Science-Policy & the Development challenge.
Why India?

• Critical Climate Actor
  – A key emitter – 4\textsuperscript{th} highest in aggregate terms (though still small in per-capita terms)
  – Fast growing, huge population aspiring for a better life
  – If India goes China’s way…..

• At the cusp of Climate Engagement
  – ”You caused it, you fix it” (1990-2002)
  – ”Co-benefits and Renewables” (2010-Present)
What Co-benefits?

SHIFTING ENVIRONMENTAL BURDENS

Local → Global
Immediate → Delayed

Annu. Rev. Environ. Resour. 30:291–333
<table>
<thead>
<tr>
<th>Emitted Compound</th>
<th>Resulting Atmospheric Drivers</th>
<th>Radiative Forcing by Emissions and Drivers</th>
<th>Level of Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Well-Mixed Greenhouse Gases</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>CO₂</td>
<td>1.68 [1.33 to 2.03]</td>
<td>VH</td>
</tr>
<tr>
<td>CH₄</td>
<td>CO₂, H₂Ostr, O₃, CH₄</td>
<td>0.97 [0.74 to 1.20]</td>
<td>H</td>
</tr>
<tr>
<td>Halocarbons</td>
<td>O₃, CFCs, HCFCs</td>
<td>0.18 [0.01 to 0.35]</td>
<td>H</td>
</tr>
<tr>
<td>N₂O</td>
<td>N₂O</td>
<td>0.17 [0.13 to 0.21]</td>
<td>VH</td>
</tr>
<tr>
<td><strong>Anthropogenic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>CO₂, CH₄, O₃</td>
<td>0.23 [0.16 to 0.30]</td>
<td>M</td>
</tr>
<tr>
<td>NMVOC</td>
<td>CO₂, CH₄, O₃</td>
<td>0.10 [0.05 to 0.15]</td>
<td>M</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Nitrate, CH₄, O₃</td>
<td>-0.15 [-0.34 to 0.03]</td>
<td>M</td>
</tr>
<tr>
<td><strong>Short Lived Gases and Aerosols</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerosols and precursors</td>
<td>Mineral Dust, Sulphate, Nitrate, Organic Carbon, Black Carbon</td>
<td>-0.27 [-0.77 to 0.23]</td>
<td>H</td>
</tr>
<tr>
<td>Cloud Adjustments due to Aerosols</td>
<td></td>
<td>-0.55 [-1.33 to -0.06]</td>
<td>L</td>
</tr>
<tr>
<td>Albedo Change due to Land Use</td>
<td></td>
<td>-0.15 [-0.25 to -0.05]</td>
<td>M</td>
</tr>
<tr>
<td><strong>Natural</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changes in Solar Irradiance</td>
<td></td>
<td>0.05 [0.00 to 0.10]</td>
<td>M</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Anthropogenic RF relative to 1750</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
</tr>
<tr>
<td>1.25 [0.64 to 1.86]</td>
</tr>
<tr>
<td>0.57 [0.29 to 0.85]</td>
</tr>
</tbody>
</table>

**IPCC AR5**

Radiative Forcing relative to 1750 (W m⁻²)
Climate and AQ ‘Co-benefits’ Case Studies

Lots of case studies
Need the big picture
### ‘Criteria’ Pollutants

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>WHO Guidelines</th>
<th>EPA for CO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PM 2.5</strong></td>
<td>25 μg/m³ (Daily) 10 μg/m³ (Annual)</td>
<td>Mortality (Heart disease, Lung Function, Stroke)</td>
</tr>
<tr>
<td><strong>CO</strong></td>
<td>10 μg/m³ (8 hr) 40 μg/m³ (1 hr)</td>
<td>Acute effects Ozone formation</td>
</tr>
<tr>
<td><strong>NOx</strong></td>
<td>200 μg/m³ (1 hr) 40 μg/m³ (Annual)</td>
<td>Respiratory PM precursor</td>
</tr>
<tr>
<td><strong>SOx</strong></td>
<td>5000 μg/m³ (10 min) 200 μg/m³ (Annual)</td>
<td>PM, O3, Toxics Precursor</td>
</tr>
<tr>
<td><strong>Ozone</strong></td>
<td>100 μg/m³ (8 hour)</td>
<td>Lung Damage? Mortality?</td>
</tr>
</tbody>
</table>

WHO Guidelines; EPA for CO
Particulate matter (PM$_{2.5}$)

References:
• Pope and Dockery 2006
• HEI 2010

Metrics

Increasing Intake Fraction

Industry & power
~1/1,000,000

Transport
~1/100,000

Indoor fuel use
~1/1,000

Smoking
2nd hand primary → ~1
Global Burden of Air Pollution

Deaths from air pollution in 2013

Air pollution was responsible for 5.5 million deaths in 2013

- Household air pollution
  - Caused by burning solid fuels for heating and cooking, including:
    - Coal
    - Wood
    - Dung

- Ambient air pollution
  - Caused by emissions from things like:
    - Power generation
    - Transportation
    - Agriculture
    - Open burning

2.9 million deaths from ambient air pollution in 2013

- China
- India
- Other Asia

64% of Asia

36% Elsewhere

High-income countries
- Central/Eastern Europe and Central Asia
- Sub-Saharan Africa
- Middle East and North Africa
- Latin America and the Caribbean

10% of all deaths were from air pollution in 2013

- Ischemic heart disease
- Stroke
- Chronic obstructive pulmonary disease
- Lower respiratory infections
- Lung cancer

Source:
Delhi on a Winter’s Day

One day in November 2016
Moderate Resolution Imaging Spectroradiometer (MODIS)

http://earthobservatory.nasa.gov/IOTD/view.php?id=84731
WINTER

http://earthobservatory.nasa.gov/IOTD/view.php?id=84731
Pic: Greenspon et al.
Smoke from 2-stroke engine

Compressed natural gas (CNG) fuel

Photo courtesy Josh Apte
Image courtesy: Japan Times.
Quantifying Sources of PM 2.5 and GHGs

• Emissions Inventories – bottom up assessment
  – Activity levels * Emissions/Activity (e.g. km*g/km)
  – “Technology” based

• We use a recent comprehensive and spatially resolved inventory of Indian emissions to:
  – Evaluate the inclusion air pollutants from different sectors in the Greenhouse Mitigation basket
  – Evaluate the exposure to outdoor air pollution
  – Examine the overlap!
Spatial Inventory

- A 0.25° x 0.25° spatial resolution
- 18 activities
- 10 species
  - GHGs and Air Pollutants
- Survey data, Engineering models, and ‘best guesses’


Climate Forcing
Converting to CO$_2$-eq

<table>
<thead>
<tr>
<th>GHG</th>
<th>GWP (100)</th>
<th>GWP (20)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Kyoto</strong></td>
<td></td>
</tr>
<tr>
<td>CH$_4$</td>
<td>34</td>
<td>74.7</td>
</tr>
<tr>
<td>N$_2$O</td>
<td>298</td>
<td>298</td>
</tr>
<tr>
<td></td>
<td><strong>Non Kyoto</strong></td>
<td></td>
</tr>
<tr>
<td>BC</td>
<td>533</td>
<td>1915</td>
</tr>
<tr>
<td>OC</td>
<td>-83</td>
<td>-298</td>
</tr>
<tr>
<td>SO$_x$</td>
<td>-64</td>
<td>-236</td>
</tr>
<tr>
<td>CO</td>
<td>2.7</td>
<td>8.89</td>
</tr>
<tr>
<td>VOC</td>
<td>7.3</td>
<td>25.3</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>-30</td>
<td>-68.7</td>
</tr>
</tbody>
</table>

Kyoto Gases alone
Non Kyoto CO$_2$-eq
Kyoto + Non-Kyoto

Carbon Equivalents in MT CO₂

CO₂ EQUIVALENTS
- Transport: 39%
- Thermal Power: 30%
- Industry: 18%
- Unregulated: 13%

Graph showing carbon equivalents in MT CO₂ for different sectors with Kyoto and Non-Kyoto data.
Air Quality - Health Impacts

Exposure Model

• Use simple parameterized box model at each location to calculate intake fraction

• Simple Meteorology
  – Wind speed, Mixing height, ‘back and forth’ factor

• Proximity of individuals to sources
  – Height based Source-location Matrix

• Rural vs. Urban differences
  – Spatially resolved source inventory
  – Population density

• Caveats!

Air Quality - Health Impacts

- Use simple 'reduced form' model to calculate intake fraction
- Proximity of individuals to sources
- Rural vs. Urban differences


Average Exposure to Outdoor PM 2.5 (Urban + Rural)

- Thermal: 74%
- Industry: 11%
- Transport: 11%
- Informal: 4%
- Residential: 55%
- Agriculture: 15%
Average Exposure to Outdoor PM 2.5 (Rural)

- Thermal: 77%
- Industry: 10%
- Transport: 10%
- Residential: 3%
- Agricultural: 5%
- Informal: 56%

Legend:
- Thermal
- Industry
- Transport
- Residential
- Agricultural
- Informal
Average Exposure to Outdoor PM 2.5 (Urban)

- Thermal: 57%
- Industry: 10%
- Transport: 45%
- Informal: 13%
- Residential: 20%
- Agriculture: 2%

Urban sector contributions to PM 2.5 exposure.
Per-capita Mean Annual PM2.5 Intake (in mg)

Agriculture
- Non-IGP: 2
- IGP: 7

Residential
- Non-IGP: 30
- IGP: 70

Informal
- Non-IGP: 1
- IGP: 4

Transport
- Non-IGP: 2
- IGP: 6

Industry
- Non-IGP: 12
- IGP: 4

Thermal
- Non-IGP: 10
- IGP: 7

<table>
<thead>
<tr>
<th></th>
<th>Thermal</th>
<th>Industry</th>
<th>Transport</th>
<th>Informal</th>
<th>Residential</th>
<th>Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-IGP</td>
<td>10</td>
<td>12</td>
<td>5</td>
<td>2</td>
<td>28</td>
<td>6</td>
</tr>
<tr>
<td>IGP</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>76</td>
<td>20</td>
</tr>
</tbody>
</table>
AQ Co-benefits of Climate Policy

• Kyoto basket of ‘official GHGs’
  – Formal sectors - Power, Transport and Industry 80% of GHG, 40% of outdoor PM 2.5 exposure.
  – Unregulated/Informal sector accounts for 20% of GHG, 60% of outdoor PM 2.5 exposure
  – Reducing Kyoto gases will have little or no effect on indoor exposures

• Using Kyoto gas reductions to reduce PM 2.5 exposure is only a (very) small win-win.
Climate Impacts of AQ Policy—Win-win

• Non-Kyoto gases - Sectors with *net positive* CO$_2$-eqs
  – Emit 950 MT of additional CO$_2$-eqs, or 45% Kyoto Gas emissions (2100 MT)

• These informal sectors account for 70% of outdoor exposure and all of the indoor exposures

• Reducing these emissions is a definite Win-Win
  – But don’t count in global mitigation calculus!
<table>
<thead>
<tr>
<th>Source Type</th>
<th>Formal Sector ‘Modern’</th>
<th>Informal Sector ‘Traditional’</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Point Source</strong></td>
<td>Power Plants Industry</td>
<td>Small-scale industry Bricks; Crematoria,…</td>
</tr>
<tr>
<td></td>
<td>PM 2.5 Exp. = 22%</td>
<td>PM 2.5 Exp. = 4%</td>
</tr>
<tr>
<td></td>
<td>C (Kyoto)= 60%</td>
<td>C (Kyoto)= 7%</td>
</tr>
<tr>
<td></td>
<td>C (Non-Kyoto)= 30%</td>
<td>C (Non-Kyoto)= 17%</td>
</tr>
<tr>
<td><strong>Non-Point Source</strong></td>
<td>Road, Rail and Air Transport</td>
<td>“Garbage Burning” Households Agricultural Waste</td>
</tr>
<tr>
<td></td>
<td>PM 2.5 Exp. = 4%</td>
<td>PM 2.5 Exp. = 70%</td>
</tr>
<tr>
<td></td>
<td>C (Kyoto)= 19%</td>
<td>C (Kyoto)= 12%</td>
</tr>
<tr>
<td></td>
<td>C (Non-Kyoto)= 16%</td>
<td>C (Non-Kyoto)= 29%</td>
</tr>
</tbody>
</table>
Climate Science-Policy and Development

• The UNFCCC process (by definition) does not recognize non-Kyoto gases
• The IPCC won’t provide ‘official’ GWP numbers
  – Worry about Sulfates?
  – Too much uncertainty in Aerosol effects?
  – GWP Time horizon choice?
• Governments like India’s have balked
  – Anxious about ‘increasing’ their own carbon equivalent contributions?
• **Pitch:** A great project for a student to fully examine the reasons for the pariah status of non-Kyoto gases
Final Thoughts

• Are we ‘lamp-posting’ when we use radiative forcing/GWP as the climate metric?

• Emerging literature on regional climate effects of short-lived pollutants as distinct from long-term global ones implicit in GWP
  – Precipitation Effects
  – Insolation and Physiological effects on Agriculture

• Perhaps the co-benefits framing needs a rethink?
Thanks numerous students and post-docs who worked with me over the years - Conor Reynolds, Andy Grieshop, Brian Just, Arvind Saraswat, Simon Harding, Poushali Maji.

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