Co-benefits from Air Pollution Control for Health and Climate in China

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Why Worry about Co-benefits?

- Helps share the cost of greenhouse pollutant mitigation with achievement of other societal goals, such as providing acceptable levels of health protection
- Potentially reduces political gap between developed and developing countries in international climate negotiations – early achievement of more certain benefits that directly relate to development needs ("no regrets investments")
Roadmap

- Many types of co-benefits (e.g., changing built environment)
- Energy related air pollution probably has strongest links
- Two categories discussed here
  - Methane: under-appreciated greenhouse and health-related pollutant
  - Household Fuels in China
Air Pollution from Energy Use

- Household solid fuels
  - Large source of ill-health worldwide in poorest populations – 1.6 million premature deaths
  - Non-renewable biomass and coal carbon emissions
  - Poor combustion leads to non-CO2 GH-related emissions

- Outdoor emissions from energy systems
  - 0.8 million premature deaths
  - Most well documented benefits, climate and health

- Special advantage to eliminating black carbon, but difficult to ascertain relative climate impacts of different aerosols.

- China has the largest global impacts for both these categories of air pollution
Estimated PM10 Concentration in World Cities (pop=100,000+)

PM10 (quintiles)
- I (low)
- II
- III
- IV
- V (high)

WHO, 2004
DALYs Attributable Globally to Urban Outdoor Air Pollution

(\textit{world total 6,404,000})

WHO, 2004

\begin{itemize}
  \item LCA
  \item Cardiopulmonary
  \item ARI < 5yrs
\end{itemize}
Chinese Burden of Disease from Top 10 Risk Factors
Plus Selected Other Risk Factors

- Alcohol
- Blood pressure
- Tobacco
- Underweight
- Occupational hazards (5 kinds)
- Indoor smoke from solid fuels
- Overweight
- Road traffic accidents
- Low fruit & vegetables
- Cholesterol

~300,000
~420,000

Annual premature deaths

Indoor air pollution
Outdoor air pollution

Percent of All DALYs in 2000

0% 1% 2% 3% 4% 5% 6% 7%

Urban outdoor air pollution
Climate change

Unsafe sex
Unsafe water/sanitation
Underweight
Overweight
Blood pressure
Indoor smoke from solid fuels
Low fruit & vegetables
Road traffic accidents
Cholesterol
Leads
Phosphorus


420,000 deaths/year

Smith et al. 2005 (based on WHO data)
Warming in 2005 from emissions since 1750

Note importance of methane and black carbon

IPCC, 2007
The Methane Story: $\text{CH}_4$
Atmospheric Greenhouse gas concentrations

Anthropogenic Sources

$\text{CO}_2$
- Fossil fuels
- Land use change
- Cement manufacturing

Methane
- Landfills
- Rice
- Livestock
- Waste management
- Fossil recovery

$\text{N}_2\text{O}$
- Fertilizer
- Planted N-fixers
- Combustion

Figure SPM.1
IPCC 2007
Methane and Global Warming

- A much more powerful greenhouse gas (GHG) than CO$_2$
- Partly due to its direct effect, but also because it creates ozone (O$_3$), another powerful GHG
- Nearly 100 times more per ton than CO$_2$ at any one time (73x from direct effects)
- Eventually turns to 2.75 times as much CO$_2$ by mass
- Methane has thus contributed a significant amount to global warming, more than half that of CO$_2$
- But has a much shorter atmospheric lifetime compared to CO$_2$
Math of GHG Decay (AR4)

- CO$_2$ goes into four compartments:
  - 19% of total with a lifetime* of 1.2 years
  - 34% at 18.5 y
  - 26% at 173 y
  - 21% with a lifetime of “many thousand years”

- Methane has a 12 y lifetime,
  - but contributes to ozone, a GHG
  - and eventually oxidizes to CO$_2$

*Lifetime refers to the time to reach 1/e (37%) of the original amount
Natural CO2 and CH4 Depletion - first 10 years

Fraction remaining of 2008 emissions

- Carbon Dioxide
- Methane
Global Anthropogenic Methane Emissions ~2005
Total ~ 305 million tons

- Livestock 30%
- Oi/gas 18%
- Coal mining 6%
- Fossil fuel burn 1%
- Biomass burn 3%
- Rice 10%
- Landfills 12%
- Manure 4%
- Waste water 9%
- Other ag 7%

Expected to grow at ~1.5% per year

~47 kg/cap

USEPA, 2006
Warming Contribution of Total ~2008 Emissions of Methane Compared to Total CO2 Emissions

Fraction of CO2 Warming from Methane

Livestock, 30%

Rice, 26%

Manure, 3%

Landfills, 5%

Waste water, 13%

Oil/gas, 1%

Coal mining, 16%

Solid fuel combustion, 6%

Chinese Methane Emissions in 2005
41 MT = 13% of world

31 kg/capita

USEPA, 2006
Future Warming from 2008 Chinese Methane and CO$_2$ Emissions

Chinese methane released in 2008 creates 67% of the warming over the next 20 years as the CO2 released in 2008.
Methane as a Global Ozone Precursor

Urban

\[ \text{hv} \]

\[ \text{O}_3 \]

\[ \text{NO} \rightarrow \text{NO}_2 \rightarrow \text{O}_3 \]

\[ \text{HO}_2 \rightarrow \text{OH} \]

NMVOCs, CO

Global

\[ \text{hv} \]

\[ \text{O}_3 \]

\[ \text{NO} \rightarrow \text{NO}_2 \rightarrow \text{O}_3 \]

\[ \text{HO}_2 \rightarrow \text{OH} \]

NMVOCs, CO, CH$_4$

- **Urban**
  - NO, NO$_2$
  - OH, HO$_2$
  - NMVOCs, CO

- **Global**
  - NO, NO$_2$
  - OH, HO$_2$
  - NMVOCs, CO, CH$_4$

**Chart:**
- Waste water 9%
- Other ag 18%
- Livestock 30%
- Coal mining 1%
- Natural gas burn 1%
- Biomass burn 3%

**Percentages:**
- Water
- Landfill
- Rice
- Manure
- Methane
- Other ag
- Livestock
- Coal mining
- Natural gas burn
- Biomass burn

**Total:**
- 100%
Background Ozone is Growing ...

Historic and future increases in background ozone are due mainly to increased methane and NO\textsubscript{X} emissions (Wang \textit{et al.}, 1998; Prather \textit{et al.}, 2003).

Ozone trend at European mountain sites, 1870-1990 (Marenco \textit{et al.}, 1994).

Mauzerall 2007
Effect of a reduction of 20% (~61 MT) in global methane emissions on tropospheric ozone

West et al., PNAS, 2006
Reduction in ozone mortality from 20% reduction in methane emissions

West et al, PNAS, 2006
Rural Energy in China: 2004

Total

- Crop wastes: 33%
- Wood: 21%
- Biogas: 1%
- Coal: 35%
- LPG: 1%
- Electricity: 7%
- Kerosene: 2%

Households

- Crop wastes: 44.3%
- Coal: 12.9%
- Biogas: 1.2%
- Wood: 36.6%
- LPG: 1.2%
- Electricity: 3.7%
- Kerosene: 0.1%

70% of total

Ministry of Agriculture

National Bureau of Statistics
Household Energy in China

- >65% of China’s population is rural.
- ~80% of energy use is simple solid biomass (wood, agricultural wastes)
- ~13% as coal
- Thus, it is still true to say that in China most people rely on biomass fuels for most of their energy
- A situation that has not changed since the mastery of fire by the human race
Rural energy situation is typically complex:
Greenhouse warming commitment per meal for typical wood-fired cookstove in China

- **Wood:** 1.0 kg
  - 454 g Carbon

- **CO₂ Carbon:** 403 g

- **Methane Carbon:** 3.8 g

- **Other GHG Carbon**
  - Carbon Monoxide: 38 g
  - Hydrocarbons: 6.3 g
  - Nitrous Oxide: 0.018 g
  - 131 g
  - 69 g
  - 4.7 g

Global warming commitments of each of the gases as CO₂ equivalents

Plus PM2.5 and Black Carbon

Zhang, et al., 2000
Role of Technology: Co-benefits

Improved Biomass Cookstoves

- Reduction in air pollution and GHGs
- Improvement in health outcomes
- Increase in fuel efficiency
- Solution to rural biomass fuel shortage
- Reallocation of time for women and kids
- Decrease in forest degradation
## China National Stove Contest - 2007

<table>
<thead>
<tr>
<th></th>
<th>CO/CO2</th>
<th>Efficiency</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal#</td>
<td>0.12</td>
<td>17.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Traditional Biomass#</td>
<td>0.13</td>
<td>19.1</td>
<td>4.0</td>
</tr>
</tbody>
</table>

### Biomass Stove Contest Winners

<table>
<thead>
<tr>
<th>City</th>
<th>CO/CO2</th>
<th>Efficiency</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daxu</td>
<td>0.020</td>
<td>41.9</td>
<td>0.28</td>
</tr>
<tr>
<td>Luoyang</td>
<td>0.019</td>
<td>35.2*</td>
<td>0.24</td>
</tr>
<tr>
<td>Xintai</td>
<td>0.025</td>
<td>32.6*</td>
<td>0.36</td>
</tr>
<tr>
<td>Zhenghong</td>
<td>0.019</td>
<td>35.9</td>
<td>0.24</td>
</tr>
</tbody>
</table>

* # Zhang, et al., 2000
  * Not including water heating function
Health and Greenhouse Gas Benefits of Biomass Stove Options

Daxu Semi-gasifier stove compared to coal stove
17% to 41% fuel efficiency
0.12 to 0.02 CO/CO₂
1.6 to 0.26 g PM/kg fuel
Plus a chimney

Smith & Haigler, 2008

Global Warming Commitment per Meal
## Exposure-Response Relationships in China: Global Comparative Risk Assessment

Table 2  Risks from outdoor and indoor air pollution with example from China. Disability-adjusted life years (DALYs)/exposure will be different in other countries because of different background disease risks. Sources: References 12 and 64

<table>
<thead>
<tr>
<th></th>
<th>Population</th>
<th>Exposure metric</th>
<th>Relative risk per unit</th>
<th>DALYs/exposure$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outdoor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>Adults &gt;30</td>
<td>10 $\mu$g/m$^3$ PM2.5</td>
<td>1.059</td>
<td>1.56E-01</td>
</tr>
<tr>
<td>Lung cancer</td>
<td>Adults &gt;30</td>
<td>10 $\mu$g/m$^3$ PM2.5</td>
<td>1.082</td>
<td>2.26E-02</td>
</tr>
<tr>
<td>Acute lower respiratory infections (ALRI)</td>
<td>Children &lt;5</td>
<td>10 $\mu$g/m$^3$ PM10</td>
<td>1.01</td>
<td>1.64E-02</td>
</tr>
<tr>
<td><strong>Indoor</strong></td>
<td></td>
<td>Household (HH)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease (COPD)</td>
<td>Adults &gt;30</td>
<td>Solid fuel use</td>
<td>3.2</td>
<td>2.72E-02</td>
</tr>
<tr>
<td>Lung cancer</td>
<td>Adults &gt;30</td>
<td>Solid fuel use</td>
<td>1.9</td>
<td>1.00E-03</td>
</tr>
<tr>
<td>ALRI</td>
<td>Children &lt;5</td>
<td>Solid fuel use</td>
<td>2.3</td>
<td>1.48E-02</td>
</tr>
</tbody>
</table>

$^a$These values would be different in other parts of the world. See References 17 and 55.
Economic Development

Once global and national markets pick up their portions, local market can pay remainder

DR ~40%

Rural Energy is Linked to Three Major Sectors

Paying for Rural Energy Development

Global Climate Market

$ per ton-carbon (world carbon market) – DR <1%

National MDG Health “Market”

1-3x $GDP/capita per DALY saved (WHO/IBRD, etc. recommendation) DR ~3%

High-efficiency low-emissions rural energy technology is too expensive for local markets

Once global and national markets pick up their portions, local market can pay remainder DR ~40%

Economic Development
Co-benefits projects
Coal to biomass stoves
Monitoring Requirements

- Fuel Use and Savings
- GHG Emissions
- Air Pollution Exposures

- You don’t get what you expect, but what you inspect.
Monitoring: Indoor Air Pollution

- PM$_{2.5}$: Pump/filter is standard method, but cumbersome, slow, and poor resolution
- Need new method: Small, smart, fast, and cheap
- UCB Monitor using smoke detector technology is an example

With low cost and ease of use, many UCBs can be used at once. 10% of cost of commercial devices. And much smarter!
Measuring Personal Exposure to PM2.5 from Woodsmoke with the UCB-Particle Monitor and the UCB-Personal Locator

Locator – tells who is in kitchen

Cumulative Exposures

Mother’s presence in the kitchen

Detailed Exposure Profiles

UCB Kitchen PM2.5
UCL Mother's presence
Continuous Mother PM2.5
20-month average ground-level PM2.5 from satellite data

Large areas of rural China have high ambient air pollution – much from household fuel
Conclusion

- Methane emissions are more important than current official weighting factors indicate because of its large effect over the next generation.
- Contributes directly to global tropospheric ozone levels.
- Methane is emitted as part of the poor combustion process of solid fuels: Chinese stoves produce ~2 MT of the 300 MT global human methane emissions.
- This incomplete combustion also produces much directly health-damaging pollution and wastes fuel.
- Improving this combustion offers substantial GHG as well as health and other benefits in a cost-effective manner – using carbon offsets provides a mechanism.
- Focuses on the poorest communities in the country.
Publications and presentations available at
http://ehs.sph.berkeley.edu/krsmit/