Current and future burden of disease from major air pollution sources in China and India

Michael Brauer
916,000 deaths
5th ranking

Household air pollution
807,000 deaths
6th ranking

Lancet. 2015 Sep 10; doi: 10.1016/S0140-6736(15)00128-2
http://vizhub.healthdata.org/gbd-compare
79 risk factors (top 58 shown)

- High blood pressure
- Household air pollution
- High fasting plasma glucose
- Smoking
- High sodium
- Low fruit
- High total cholesterol
- Ambient particulate matter
- Alcohol use
- High body mass index
- Unsafe water
- Low physical activity
- Low vegetables
- Low whole grains
- Low omega-3
- Low glucerol filtrations
- Unsafe sanitation
- Childhood wasting
- Handwashing
- Low fiber
- Low nuts and seeds
- Unsafe sex
- Low PFAA
- Lead
- High trans fat
- Occupational particulates
- Partial breastfeeding
- Ozone
- High processed meat
- Low bone mineral density
- Intimate partner violence
- Childhood underweight
- Secondhand smoke
- Iron deficiency
- Childhood stunting
- Occupational injury
- Childhood sexual abuse
- Occupational asthmas
- High sweetened beverages
- Vitamin A deficiency
- Drug use
- Zinc deficiency
- Discontinued breastfeeding
- Suboptimal calcium
- Low milk
- Radon
- Occupational diesel
- High red meat
- Occupational SHS
- Occupational silica
- Occupational sulfuric acid
- Occupational nickel
- Occupational asbestos
- Occupational PAH
- Occupational benzene
- Occupational arsenic
- Occupational chromium
- Occupational formaldehyde

India, Both sexes, All ages, 2013

- 587,000 deaths
  8th ranking

- Household air pollution
  924,000 deaths
  2nd ranking

Lancet. 2015 Sep 10; doi: 10.1016/S0140-6736(15)00128-2
http://vizhub.healthdata.org/gbd-compare
<table>
<thead>
<tr>
<th></th>
<th>CHINA OUTDOOR PM</th>
<th>CHINA HOUSEHOLD PM</th>
<th>INDIA OUTDOOR PM</th>
<th>INDIA HOUSEHOLD PM</th>
<th>USA OUTDOOR PM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IHD</strong></td>
<td>236,926 17%</td>
<td>151,722 11%</td>
<td>296,489 19%</td>
<td>315,039 20%</td>
<td>43,160 7.9%</td>
</tr>
<tr>
<td><strong>Stroke</strong></td>
<td>363,494 19%</td>
<td>256,674 13%</td>
<td>139,941 20%</td>
<td>166,871 23%</td>
<td>10,881 6.6%</td>
</tr>
<tr>
<td><strong>COPD</strong></td>
<td>75,761 8%</td>
<td>295,786 32%</td>
<td>56,665 7%</td>
<td>338,491 45%</td>
<td>1,710 1.1%</td>
</tr>
<tr>
<td><strong>Lung Cancer</strong></td>
<td>201,864 37%</td>
<td>75,050 14%</td>
<td>21,432 35%</td>
<td>12,882 21%</td>
<td>17,363 9.8%</td>
</tr>
<tr>
<td><strong>ALRI</strong></td>
<td>38,064 18%</td>
<td>28,041 13%</td>
<td>72,041 18%</td>
<td>90,878 22%</td>
<td>5,718 6.7%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>916,102</td>
<td>807,238</td>
<td>586,788</td>
<td>924,550</td>
<td>78,814</td>
</tr>
</tbody>
</table>

http://vizhub.healthdata.org/gbd-compare
Mortality attributable to ambient PM$_{2.5}$

CHINA
- 59% ↑ in deaths
- 33% ↑ in per capita deaths
- 49% ↑ in proportion of deaths attributable to PM$_{2.5}$

INDIA
- 60% ↑ in deaths
- 11% ↑ in per capita deaths
- 50% ↑ in proportion of deaths attributable to PM$_{2.5}$

http://vizhub.healthdata.org/gbd-compare
GBD-MAPS general methodology

- Estimate major source contribution to ambient PM$_{2.5}$
- Calculate fraction ambient PM$_{2.5}$ attributable to each source

\[ f_{\text{source}} \times \text{PM}_{2.5} \] source \rightarrow \text{ambient PM}_{2.5} \text{ attributable to each source}

- Use integrated exposure response functions and cause-specific mortality estimates in combination with \( \text{PM}_{2.5} \) source \( i \) \rightarrow source contribution to disease burden
Population-weighted proportions of ambient PM$_{2.5}$ by source, China

<table>
<thead>
<tr>
<th>Source</th>
<th>Total Coal</th>
<th>Industrial</th>
<th>Power Plant</th>
<th>Domestic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Industrial Plant</td>
<td>40.3%</td>
<td>17.4%</td>
<td>9.5%</td>
<td>4.3%</td>
</tr>
<tr>
<td>Domestic Biomass</td>
<td>10.3%</td>
<td>15.1%</td>
<td>14.8%</td>
<td>7.6%</td>
</tr>
</tbody>
</table>

GBD MAPS China Report, 2016
Estimated disease burden in 2013, China

<table>
<thead>
<tr>
<th>Subsector</th>
<th>Mean PM$_{2.5}$</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Ambient PM2.5</td>
<td>54.3</td>
<td>916,000</td>
</tr>
<tr>
<td>Total Coal</td>
<td>21.9</td>
<td>366,000</td>
</tr>
<tr>
<td>Powerplant Coal</td>
<td>5.2</td>
<td>86,500</td>
</tr>
<tr>
<td>Industrial Coal</td>
<td>9.4</td>
<td>155,500</td>
</tr>
<tr>
<td>Non Coal Industrial</td>
<td>5.6</td>
<td>95,000</td>
</tr>
<tr>
<td>Domestic Coal</td>
<td>2.4</td>
<td>41,000</td>
</tr>
<tr>
<td>Domestic Biomass</td>
<td>8.0</td>
<td>136,500</td>
</tr>
<tr>
<td>Traffic</td>
<td>8.2</td>
<td>137,500</td>
</tr>
<tr>
<td>Open Burning</td>
<td>4.1</td>
<td>70,000</td>
</tr>
</tbody>
</table>

Source sector contributions to mean population-weighted ambient PM$_{2.5}$ and PM$_{2.5}$ - attributable deaths in China, 2013.

GBD MAPS China Report, 2016
Total PM2.5 by Province & Breakdown of Major Sources – 2013

GBD MAPS China Report, 2016
Future scenarios

<table>
<thead>
<tr>
<th>Energy policy</th>
<th>End of Pipe Emission Control Policy</th>
</tr>
</thead>
</table>
Population-weighted mean exposure

GBD MAPS China Report, 2016
Total coal contribution: Population-weighted mean exposure

GBD MAPS China Report, 2016
Deaths attributable to ambient PM2.5

China (both sexes, all ages)

Year


Deaths attributable to ambient PM2.5

GBD MAPS China Report, 2016

LC  IHD  Stroke  COPD  ALRI
Provincial level results: Jing-Jin-Ji region

- Deaths attributable to PM$_{2.5}$ in 2013: Beijing 4900 due to coal (total 13,000), Hebei 3200 (8800), Tianjin 24,600 (63,700)
- Deaths in Beijing & Tianjin for most future scenarios decrease; patterns in Hebei follow national projections
- Decreases projected in Beijing and Tianjin mainly due to decreases in non-coal source sectors such as transportation, domestic (coal and biomass) and open biomass burning.

GBD MAPS China Report, 2016
India
GBD2015 improvements to better capture regional differences & incorporate ground measurements

\[ \log(PM_{2.5}) = \beta_0 + \beta_1 \log(SAT_i) + \beta_{3.n} + \varepsilon_i \]

Variables:
- Population
- \(\Sigma(SO_4^{2-}, NO_3^-, NH_4^+ OC)\) (relative species contribution)
- Mineral dust (relative contribution)
- Inverse distance to nearest urban land surface
- Binary variables related to measurements (N \(\sim 6000\)):
  - Exact location
  - Site monitor
  - PM\(_{2.5}\) direct measure or from PM\(_{2.5}\):PM\(_{10}\) ratio.
- Interactions between binary variables satellite estimates.
- Grid cell random effects on the intercept (multiple ground monitors in a grid cell).
- Country-region-super-region hierarchical random effects for intercepts, satellite and population terms.
- Country level random effects for population using a neighbourhood structure allowing specific borrowing of information from neighbouring countries.

G. Shaddick, M. Thomas, 2016

Deaths

366,000

587,000

Cohen/Brauer et al., Submitted 2016
Proportion of deaths due to exposure
Projected growth in PM-2.5 emissions from 7.4 Tgy$^{-1}$ (2015):

S1: Current legislation in Elec, IND, TRN. Current rates (past 20y) of cleaner technology diffusion in RES, BRK, no control on field burning.

- **10.4 Tg (2030) and 16.9 Tg (2050)**

S2: Aspirational policies in Elec, IND, TRN. Higher (10% > current) rates of cleaner technology diffusion, in RES, BRK, no control on field burning.

- **7.9 Tg (2030) and 9.9 Tg (2050)**

S3: Low-carbon scenario assumptions for Elec, IND; BS-VI (2020) TRN; complete phase out of traditional technologies in residential, bricks and informal industry, field burning controlled by 2030.

- **2.2 Tg (2030) and 1.3 Tg (2050)**
Conclusions

CHINA

• Coal combustion PM$_{2.5}$ in China (2013):
  • 40% of exposure to ambient PM$_{2.5}$
  • 366,000 deaths
  • 12th leading mortality risk factor > high cholesterol, drug use or secondhand smoking.

• Industrial coal, domestic (biomass and coal) combustion: largest contributors to ambient PM$_{2.5}$ attributable mortality in 2013.
  • Domestic combustion (177,000 deaths) > industrial coal (155,000) > transportation (137,000) > power plant coal combustion (86,500)

• Despite decreased ambient PM$_{2.5}$, increases in future attributable deaths for all (2030) scenarios
  • 0.99 - 1.3 million deaths
  • aging population, increased prevalence of diseases impacted by PM$_{2.5}$.

• Urgent need for even more aggressive strategies to reduce emissions from coal combustion (and other sectors)

INDIA

• Past trends indicate increasing burden of disease attributable to ambient PM$_{2.5}$

• Scenarios based on current and aspirational policies indicate increase in emissions without stabilizing through 2050
  • Emissions from industrial sources and power generation to dominate in future
Thank you!

Questions?

Photo: Ecobrick.in
EXTRA SLIDES
## GBD MAPS Working Group

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<tbody>
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<td>Health Effects Institute</td>
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<td>Zhang Qiang</td>
<td>Tsinghua University</td>
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</tr>
<tr>
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<td>IHME</td>
</tr>
</tbody>
</table>
Disease burden in 2013 and 2030: Coal and other major sources

- Predicted mortality increases in all future scenarios, mainly due to population aging and increase of disease in Chinese population;
- Disease burden decrease from BAU1 to PC2 as energy policies and emission control strategies is applied;
- Coal remains as the single largest contributor.
GBD-MAPS

1. Estimate coal combustion/major source sector contribution to ambient $PM_{2.5}$ →
   e.g fraction ambient $PM_{2.5}$ attributable to coal combustion ($f_{\text{coal}}$)

2. $f_{\text{coal}} \times \text{ambient } PM_{2.5} \rightarrow \text{ambient } PM_{2.5}$ attributable to coal combustion ($PM_{2.5, \text{coal}}$)

3. Use integrated exposure response functions and cause-specific mortality estimates in combination with $PM_{2.5, \text{coal}} \rightarrow$ coal combustion contribution to disease burden

• China
• India
• Eastern Europe
Estimating PM$_{2.5}$

Environmental Science & Technology

Ambient Air Pollution Exposure Estimation for the Global Burden of Disease 2013


ABSTRACT: Exposure to ambient air pollution is a major risk factor for global disease. Assessment of the impacts of air pollution on population health and evaluation of trends relative to other major risk factors requires regularly updated, accurate, spatially resolved exposure estimates. We combined satellite-based estimates, chemical transport model simulations, and ground measurements from 79 different countries to produce global estimates of annual average fine particle (PM$_{2.5}$) and ozone concentrations at 0.1° × 0.1° spatial resolution for

continued...

Brauer et al., 2015. doi: 10.1021/acs.est.5b03709
Air pollution is a major contributor to disease burden in China

Deaths from air pollution 1990-2013
1. 59% ↑ in total deaths
2. 33% ↑ in per capita deaths
3. 49% ↑ in proportion of deaths attributable to PM$_{2.5}$
China (both sexes, all ages)

Deaths attributable to ambient PM2.5

Year


China (both sexes, all ages)

Deaths attributable to ambient PM2.5

Year

2013 2030 BAU1 2030 BAU2 2030 PC1 2030 PC2

Legend:

LC  IHD  Stroke  COPD  ALRI
800,000

Deaths attributable to ambient PM2.5

Year

China (both sexes, all ages)

[Diagram showing deaths attributable to ambient PM2.5 in China from 1990 to 2013. The colors represent different causes of death: LC, IHD, Stroke, COPD, ALRI.]
2. Estimating ambient PM$_{2.5}$ attributable to coal combustion

- Final estimates based on average of (1.4 million) grid cell values (SAT, TM5) and calibrated (regression model) with measurements
  - 0.1° x 0.1° resolution
  - extrapolated to 2013 using 2010-2011 trend in SAT
- Incorporate variance between two estimates and measurements in uncertainty assessment
- Unique contributions from each approach

Brauer et al., 2015
Ground measurements – China (2013 annual average)

- 90 Locations PM$_{2.5}$ measurements
- 304 Locations PM$_{2.5}$ estimated from PM$_{10}$ measurements

Brauer et al., 2015
Forouzanfar et al. 2015; Burnett et al. 2014; Cohen/Brauer et al. 2016 Submitted
## Future scenarios

<table>
<thead>
<tr>
<th>Energy scenario</th>
<th>Description</th>
<th>Emission scenario</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Business as usual (BAU)** | Current legislation & implementation status (to end of 2013) | **BAU[1]**          | BAU energy policy  
End-of-pipe control strategy:  
Based on “12th Five-Year Plan for Environmental Protection”; New emission standards released during 2011-2013; progressively strengthened control policies afterwards. |
| **BAU[2]**           |                                                                                |                   | BAU energy policy  
End-of-pipe control strategy:  
full implementation of technically feasible control technologies by 2030, regardless of cost |
| **Alternative policy (PC)** | New stringently enforced energy-policies including life style changes, structural adjustment & efficiency improvements. | **PC[1]**          | PC energy policy  
Same end-of-pipe control strategy as BAU[1] |
| **PC[2]**            |                                                                                |                   | PC energy policy  
Same end-of-pipe control strategy as BAU[2]  
Maximum feasible reductions of emissions |
Population-weighted mean exposure

Deaths attributable to PM2.5

Age-standardized DALY rate attributable to PM2.5
• Final estimates based on average of (1.4 million) grid cell values (SAT, TM5) and calibrated (regression model) with measurements
  - 0.1° x 0.1° resolution
  - extrapolated to 2013 using 2010-2011 trend in SAT
• Incorporate variance between two estimates and measurements in uncertainty assessment
• Unique contributions from each approach

Brauer et al., 2015. doi: 10.1021/acs.est.5b03709
2013 Annual Average PM$_{2.5}$

- Global coverage
- ~11 x 11 km resolution
- 1990 – 2013 trends – annually updated

1990 – 2013 Change in Annual Average PM$_{2.5}$

2013 Annual Average PM$_{2.5}$
GBD2013 Asia, South

GBD2013 Asia, East

BHM Asia, South

BHM Asia, East

PRELIMINARY – DO NOT QUOTE OR CITE