Air pollution: its impact on health and possible solutions.

Christopher Whitty
Gresham College 2018
Pollutants get into us by several routes.

But only three have substantial public health importance.

• The lung.

• The gut (food and water).

• The skin. A fairly impervious barrier.

Professor Michael Faraday gives his card to Father Thames. "And we hope the Dirty Fellow will consult the learned Professor" (Punch, 1885).
Air pollution predates Gresham College, and remains common. Much is indoor.

Bruce Kirenga, Lancet. Uganda.

Hampton Court kitchen (circa 1529). Pinterest.
London’s pre-eminence as a global city came at a cost in air pollution (but was a boon for art).

The yellow fog that rubs its back upon the window-panes,
The yellow smoke that rubs its muzzle on the window-panes,
Licked its tongue into the corners of the evening,
Lingered upon the pools that stand in drains,
Let fall upon its back the soot that falls from chimneys....
Curled once about the house, and fell asleep.

*The love song of J. Alfred Prufrock.*
*TS Eliot 1920.*

*Trouée de soleil dans le brouillard.*
*C. Monet 1904.*
Attempts to address air pollution are not new.

• King Edward I banned the use of sea-coal in London 1272.

• John Evelyn’s *Fumifugium, or, The inconveniencie of the aer and smoak of London dissipated* 1661.

• Recommended removing polluting industries like lime-burning from London.

*The Ballad of Gresham College* (1663, anon).

....He shewes that 't is the seacoale smoake
That allways London doth Inviron,
Which doth our Lungs and Spiritts choake,
Our hanging spoyle, and rust our Iron.
The biggest spur to UK action in recent times was the Great Smog of 1952.

- A combination of cold and atmospheric conditions.
- At least 4000 people died (maybe up to 12,000) and 100,000 made unwell over 3 days of severe smog.
- Led to the Clean Air Act of 1956.

Not all air pollution is human-created.

• In some parts of the world it is a minority.
• Volcanoes, dust storms, forest fires, lightning examples of highly polluting events.
• The last major eruption of Laki (1783) killed around 23,000 people in the UK.
• In most industrialised countries most air pollution is from human activity.
Air pollution has effects on the lung, but many pollutants have wider effects.

• Several types with different causes and effects.
• This lecture will concentrate on:
  • Lead.
  • Particulate matter (PM10 and PM2.5).
  • Sulphur dioxide (SO$_2$).
  • Nitrogen oxides (NOx: NO and NO$_2$).
• Ammonia.

A “Pyramid of Effects” from Air Pollution

US Environmental Protection Agency.
World Health Organization global estimates (2016).

- 1 in every 9 deaths due to air pollution.
- Around 3 million deaths attributable solely to ambient (outside) air pollution.
- Heart disease (36%), stroke (36%), lung cancer (14%) and lung disease dominate.
Air pollution is subject to strong advocacy positions, in both directions.

- There are trade-offs between optimising economic and health outcomes.
- The least wealthy countries, and the least wealthy in a society can bear the brunt of both.
- But especially the health effects.

*Source: Bjorn Lomborg, Economist 2001*
This talk will concentrate on outdoor (ambient) air pollution in high-income countries but it is a major global problem. WHO infographic on global situation.

THE INVISIBLE KILLER
Air pollution may not always be visible, but it can be deadly.

- 36% of deaths from lung cancer
- 34% of deaths from stroke
- 27% of deaths from heart disease
There is broad support for the role of the state in reducing air pollution across the political spectrum.
Global data are best in wealthier countries. The burden of pollution is heaviest in poorer and industrialising countries. WHO data, 2008-15.
Age-standardised deaths/100,000 due to ambient air pollution. WHO estimates 2016.
Risk depends on exposure. High pollution with few people may be much less dangerous than lower pollution and many people.

Yallourn W brown-coal power station Victoria, Australia. Marcus Wong.

VE Day, London 1945
Degree of certainty about health effects varies by pollutant and disease.

**Strong evidence:**
- Lead
- Particulate matter PM2.5 and PM10
- Sulphur dioxide

**Less certain current evidence on size of effect:**
- Nitrogen oxides (NOx)
- Ozone
- Ammonia

**Easiest for sudden medical events, short intense exposure**
- Asthma
- Stroke
- Heart attack

**Less easy for gradual-onset events, chronic low-grade exposure**
- Dementia
- Cancer
Myocardial infarction (heart attack) and particulate matter systematic review.

Mustafic et al, JAMA 2012

A. PM$_{10}$ analysis

<table>
<thead>
<tr>
<th>Source</th>
<th>Study Design</th>
<th>Relative Study Weight, %</th>
<th>Relative Risk (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balkadir et al,2010</td>
<td>Case-crossover</td>
<td>8.60</td>
<td>1.007 (0.990-1.015)</td>
<td>.99</td>
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<tr>
<td>Bergold et al,10,2010</td>
<td>Case-crossover</td>
<td>0.06</td>
<td>0.990 (0.851-1.152)</td>
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<td>Bhaaskaran et al,28,2011</td>
<td>Case-crossover</td>
<td>6.95</td>
<td>0.992 (0.982-1.002)</td>
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<tr>
<td>Hsieh et al,24,2010</td>
<td>Case-crossover</td>
<td>4.78</td>
<td>1.031 (1.017-1.045)</td>
<td>&lt;.001</td>
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<td>Nakatake et al,5,2011</td>
<td>Case-crossover</td>
<td>5.10</td>
<td>1.004 (0.991-1.017)</td>
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<tr>
<td>Peters et al,26,2001</td>
<td>Case-crossover</td>
<td>0.08</td>
<td>1.169 (1.034-1.322)</td>
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<td>Zanobetti and Schwartz,45,2006</td>
<td>Case-crossover</td>
<td>14.10</td>
<td>1.006 (1.003-1.009)</td>
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<td>Braga et al,1,2001</td>
<td>Time-series</td>
<td>13.10</td>
<td>1.007 (1.003-1.011)</td>
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<tr>
<td>Centonze et al,11,2006</td>
<td>Time-series</td>
<td>0.45</td>
<td>1.032 (0.979-1.087)</td>
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<tr>
<td>Cheng et al,23,2009</td>
<td>Time-series</td>
<td>2.62</td>
<td>1.015 (0.986-1.045)</td>
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<tr>
<td>Hoek et al,32,2000</td>
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<td>11.97</td>
<td>1.001 (0.996-1.006)</td>
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<td>Lentini et al,24,2005</td>
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<td>8.77</td>
<td>1.003 (0.995-1.011)</td>
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<tr>
<td>Lin et al,12,2000</td>
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<td>12.02</td>
<td>1.010 (1.005-1.015)</td>
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<tr>
<td>Mann et al,36,2002</td>
<td>Time-series</td>
<td>5.63</td>
<td>0.987 (0.977-1.011)</td>
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<td>Medina et al,27,1997</td>
<td>Time-series</td>
<td>0.41</td>
<td>0.979 (0.927-1.034)</td>
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<tr>
<td>Sharovsley et al,43,2004</td>
<td>Time-series</td>
<td>0.13</td>
<td>1.010 (0.914-1.116)</td>
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<tr>
<td>Steb et al,39,2009</td>
<td>Time-series</td>
<td>4.84</td>
<td>1.002 (0.986-1.016)</td>
<td>.77</td>
</tr>
</tbody>
</table>

Combined

(P^2 = 57%, Egger regression test, P = .61)

B. PM$_{2.5}$ analysis

<table>
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<tr>
<th>Source</th>
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<th>Relative Risk (95% CI)</th>
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<tr>
<td>Barnett et al,3,2006</td>
<td>Case-crossover</td>
<td>3.93</td>
<td>1.031 (0.985-1.082)</td>
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<td>Balkadir et al,24,2010</td>
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<td>Peters et al,29,2001</td>
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<td>1.272 (1.081-1.525)</td>
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<td>Peters et al,43,2005</td>
<td>Case-crossover</td>
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<td>1.105 (0.991-1.232)</td>
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<tr>
<td>Pope et al,26,2006</td>
<td>Case-crossover</td>
<td>5.58</td>
<td>1.042 (1.003-1.083)</td>
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<tr>
<td>Rich et al,21,2010</td>
<td>Case-crossover</td>
<td>4.43</td>
<td>1.010 (0.986-1.036)</td>
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<tr>
<td>Sullivan et al,22,2005</td>
<td>Case-crossover</td>
<td>4.50</td>
<td>1.020 (0.976-1.066)</td>
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<tr>
<td>Zanobetti and Schwartz,45,2006</td>
<td>Case-crossover</td>
<td>5.25</td>
<td>1.051 (1.010-1.094)</td>
<td>.02</td>
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<tr>
<td>Mata et al,25,2010</td>
<td>Time-series</td>
<td>7.26</td>
<td>1.086 (1.033-1.111)</td>
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<tr>
<td>Steb et al,39,2002</td>
<td>Time-series</td>
<td>6.14</td>
<td>1.024 (0.983-1.066)</td>
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<td>Ueda et al,38,2009</td>
<td>Time-series</td>
<td>11.31</td>
<td>1.013 (0.991-1.035)</td>
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<tr>
<td>Zanobetti et al,30,2009</td>
<td>Time-series</td>
<td>17.53</td>
<td>1.022 (1.011-1.034)</td>
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<tr>
<td>Zanobetti and Schwartz,31,2009</td>
<td>Time-series</td>
<td>20.03</td>
<td>1.011 (1.004-1.018)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Combined

(P^2 = 51%, Egger regression test, P = .004)
Mortality not the only outcome- pregnancy.

- Low birth weight in children born to mothers exposed to air pollution lower.
- Data on the right from London- low birth weight by pollutant.
- Various confounding factors.

*R Smith et al, BMJ 2017*
Children are more vulnerable to many environmental issues, including air pollution.

- Developing brains and bodies.
- Good evidence for association between lead and brain development in foetuses and children.
- Good evidence of association between lung development and air pollutants.

*Children 11-15 years in 5 sites in USA Gauderman et al, NEJM 2015.*
As pollution reduces child lung function improves.
Data from 5 areas of California.
Gauderman et al. NEJM 2015
We can obsess too much about the exact number of deaths and illnesses. The numbers are large. We have sufficient information to act.

- Waiting for more data is often the right thing to do.
- For lead, particulates, SO$_2$, NOx in particular the evidence of harm is easily good enough to be confident reducing them is beneficial to health for many people.
- There is an important technical question on to what extent harm is a peak/threshold risk, or cumulative lifetime risk.
Effects of a 2 hour walk in Hyde Park or Oxford Street on lung function (top) and arterial stiffness.  
Sinharay et al Lancet 2018. Time in hours, participants over 60.
Lead in petrol. An instructive if extreme example.

- Known to be toxic at high levels for 2 millennia.
- Tetraethyllead (TEL) developed by General Motors added to petrol from the 1920s.
- One of several potential engineering solutions to increased compression (ethyl alcohol another).
- Clear warnings of toxicity from the off.
- For 3 decades research dominated (monopolised) by the industry.
Lead.

*(UK data: National Atmospheric Emissions Inventory (NAEI) 2018)*

- Biggest effect on brains of foetuses and children. Reduces IQ. Possible links to crime.
- Reasonable evidence from the 1960s.
- Restrictions begun in 1970s (US).
- Average American child's blood lead level 13.7 μg/dl 1976, in 2000 it was 2.0.
- UK ban on 4-star in 1998, although being phased down before.
- Officially petrol lead-free worldwide from 2013.
The UK is doing fairly well in tackling emissions of many of the main air pollutants.

DEFRA Emissions of air pollutants in the UK, 1970 to 2016. ONS.
Sulphur dioxide (SO$_2$) has several health effects.

- Triggers asthma attacks. Causality clear. Dose dependent.
- Respiratory effects more widely.
- Associated with preterm birth.
- Associated with excess mortality.
- Contributes to particulate matter (PM).

Proportion of air quality management areas from various sources for SO$_2$.

DEFRA 2017
Methods to reduce $SO_2$ and SOx.

- Coal a major source of $SO_2$.
- In **power**: burn less coal.
- If you burn coal, use low-sulphur coal. Lowest sulphur coal up to 85% less $SO_2$ but more expensive.
- Various methods to reduce $SO_2$ from waste gas (**‘scrubbers’**).
- Low sulphur fuels in **transport**. Relatively small amounts, but near many people.
- **Industrial processes**. Petrol refineries, ore processing etc. Remove $SO_2$ on site.
Sulphur dioxide (SO$_2$). UK 96% reduction since 1970, mainly reduced coal, and in towns fuel mix. 

*NAEI 2018.*
Sulphur dioxide, one day in 2017.

Global Modeling and Assimilation Office (GMAO) at NASA, 2017
Ammonia health effects.

- At high doses very irritant, can trigger asthma.
- Other than those occupationally exposed, no *current* evidence of substantial effects of prolonged low-level exposure.
- Contributes to particulate matter (PM) formation. This may be important in some settings.

*Sutton M et al*  
*Phil Trans R Soc*  
*2013*
Ammonia. Almost all agricultural, especially fertiliser, cattle and poultry.  *NAEI 2018*
DEFRA air quality management areas (AQMA).
UK and Greater London area.
Nitrogen oxides (NOx). *NAEI 2018*
Modelled NO$_2$, London.

London Atmospheric Emissions Inventory, London Air/GLA/TFL.
Transport mix for NOx, London 2010. GLA data, IPPR.
Particulate matter. PM10. *NAEI 2018*
PM2.5. Fall due in large part to reduction in coal. Recent increase due to domestic wood burning.

- Emissions from power stations have fallen by 91% since 1990.
- 85% of domestic combustion emissions in 2015 wood, 13% in 1990.
- In 2015, residential combustion accounted for 37% of PM1.0 emissions, of which 77% of emissions wood burning.

*NAEI. Data in Kt.*
Wood burning stoves are great aesthetically, less great for PM2.5

- Wood burning between 23 and 31% of the urban derived PM2.5 in London and Birmingham.
- Daily variation in North Kensington in winter.

Kings College / NPL for DEFRA 2017
PM10 by source, London 2010. GLA, 2010 data summary IPPR.
PM from transport not just about exhaust fumes. Includes tyres, brakes, tube and resuspension.
The transport mix for emissions, London PM10.

(GLA 2010 data)
Tightening regulation spurs engineering innovation. (This only works if manufacturers do not cheat). Some innovations less effective as vehicles age.

### Vehicle emissions control in Europe

<table>
<thead>
<tr>
<th>Effective date</th>
<th>Upper limit (mg/km)</th>
<th>Gasoline</th>
<th>Diesel</th>
<th>NOx</th>
<th>NOx</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>New model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 0</td>
<td>October 1991</td>
<td>1,000</td>
<td>1,600</td>
<td>Not regulated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 1</td>
<td>July 1992</td>
<td>490</td>
<td>780</td>
<td>140</td>
<td></td>
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</tr>
<tr>
<td>Euro 2</td>
<td>January 1996</td>
<td>250</td>
<td>730</td>
<td>100</td>
<td></td>
<td></td>
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<tr>
<td>Euro 3</td>
<td>January 2000</td>
<td>150</td>
<td>500</td>
<td>50</td>
<td></td>
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<tr>
<td>Euro 4</td>
<td>January 2005</td>
<td>80</td>
<td>250</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 5</td>
<td>September 2009</td>
<td>60</td>
<td>180</td>
<td>5</td>
<td></td>
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<tr>
<td>Euro 6</td>
<td>September 2014</td>
<td>60</td>
<td>80</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reference: European Automobile Manufacturers Association
Need for strong emphasis on the sectors and areas with high density of pollution.

- Taxis.
- Public transport.
- Delivery vans.
- HGVs- 18 tonne, Euro V compared to Euro VI at R (TFL data).
- Diesel cars.
- Ultra-low emission zones.
Electric vehicles. There is no doubt the market is growing. OPEC forecast change 2015 to 2040. Battery technology, charging infrastructure, grid capacity, regulation, consumer demand are factors. 

*Bloomberg New Energy Finance. Roughly 500% change.*
Hydrogen fuel cells - currently a niche product but renewed interest. Projected global hydrogen fuel cell electric vehicle production. Hydrogen central heating being explored in UK. (IHS)
Cycling and active transport. Back to the future?

UK pedal cycle miles 1949-16.  
*Department of Transport, 2018*

Change in travel, City of London 1999-2017. 292% increase cycles.  
*Dept Built Environment 2018.*
Pollution capture by vegetation, especially trees.
(ONS/CEH 2017)

• In 2015 natural pollution removal by plants in UK, ONS estimated:
  • 5,800 fewer respiratory hospital admissions,
  • 1,300 fewer cardiovascular hospital admissions,
  • 27,000 fewer life years lost,
  • 1,900 fewer premature deaths.
Ladder of state intervention.

• Ban.
• Tax heavily.
• Regulate.
• ‘Nudge’ tax or intervention.
• Mass voluntary programme.
• Engage with industry.
• Inform.
• Leave up to individuals.
Reducing air pollutants is possible without crashing the economy. It requires transnational action. UK 1990-2016 -71% NOx, -95% SO₂, -54% PM2.5

DEFRA/ONS 2018.
Substantial variation between cities. Beijing roughly 5x more particulates and Delhi around 10x those of London on average. (WHO data/ATLAS)
In all cities the amount of pollution varies over time as well as distance. In Beijing AQ has probably been improving, but still a challenge for much of the year.

*Wikimedia, data UK Department of States 2017.*
Reducing air pollution substantially is technically possible and essential for health. But not cost-free.

• For many pollutants substantial progress already.
• For NOx there are engineering solutions to much of the risk.
• Particulates are harder, but the health impacts are substantial.
• An international problem.
• Real trade-offs between rapid industrialisation and pollution. But the poorest still suffer most from health effects.