Air Pollution in Cities
Part 1: Problems and solutions

Global Sustainability Summer School
Santa Fe Institute

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Learning outcomes

• Discuss state of air pollution problems
• Identify solutions for cities, specifically considering the nexus between air pollution and health and benefits
• Make the case for holistic perspectives in decision making
• Propose and evaluate health promoting urban strategies
• Get a sense of the complexity of air quality research and policy
THE PROBLEM
More than 80% of people living in urban areas are exposed to air quality levels that exceed World Health Organization limits (WHO, 2016).

- Populations in low-income cities are the most impacted.
  - 98% of cities* in low and middle-income countries do not meet WHO levels.
  - This percentage decreases to 56% in high-income countries.
What air pollutants?

“Criteria air pollutants”

- **Nitrogen dioxide (NO$_2$)** – NOx, NO and NO$_2$ stem form high temperature combustion
- **Particulate matter** – **PM$_{10}$** and **PM$_{2.5}$**, primary (incomplete combustion; dust) or secondary (reactions between SO$_2$, NH$_3$, and NOx)
- Ozone – formed from NOx and VOCs in the presence of sunlight
- Sulfur dioxide (SO$_2$) – combustion in power generation or industrial processes
- Carbon Monoxide (incomplete combustion)
- Lead (e.g. metal processing, incinerators, battery manufacturers)

+ In EU (limit value): Benzene (petroleum sources)

Secondary PM formation:
- SO$_2$ emitted -> SO$_4$ sulfate
- NH$_3$ emitted -> NH$_4$ Amonium
- NOx emitted -> NO$_3$ nitrate
Air pollutants

Also (not criteria pollutants):

- Ammonia (NH₃)
- VOCs (including benzene)
- Ultrafine particles
- Black carbon component:

Nose, throat:

Trachea, bronchi, bronchioli:

Pulmonary alveoli:

Pulmonary tissue, circulation:

Trace metals, quinones, endotoxins, PAHs, black carbon...

Inorganic secondary aerosols, primary and secondary organic aerosols...

TOXICITY OF PM COMPONENTS?
The air pollution burden: in comparison to other environmental pollutants

Lancet Commission on pollution and Health

Figure 4: Global estimated deaths (millions) by pollution risk factor, 2005-15
Using data from the GBD study and WHO. IHME = Institute for Health Metrics and Evaluation.
Air pollution: Deaths attributable to PM2.5 worldwide in 2015

Cohen et al. The Lancet 2017
Ambient air pollution health effects

- More than 6 million deaths/year (particulate matter and ozone)
  - 40% Ischemic Heart disease
  - 40% stroke
  - 11% COPD
  - 6% Lung cancer
  - 3% Acute lower respiratory infection in children

- But also:
  - low birth weight and preterm birth
  - cognitive development
  - autism
  - diabetes
  - obesity
Sources of Air Pollutants in cities: contributions to PM$_{2.5}$ concentrations

Karagulian et al. 2015 Atmospheric Environment 120

Fig. 2. Population-weighted averages for relative source contributions to total PM$_{2.5}$ in urban sites. *: regions in which *(s) unspecified sources of human origin and *(t) domestic fuel burning sources have not been assessed. ¹Based only on one study including domestic fuel burning, and therefore only provides indicative results. ²Based only on two studies, and therefore only provides indicative results.
Figure 2.11: PM$_{10}$ emissions from all sources$^8$ in central London in 2008

- 80% contribution from traffic sector
- 35% from tyre and brake wear

Emission sources in cities

London’s Mayor Air Quality Strategy 2010
JOURNEY TO A HEALTHIER YOU

Pollution from exhausts...you cannot see, feel, touch or smell it. However, it can damage or even kill you. Only Airbubbl cleans all the deadly gases and particles that enter your vehicle.
Electric vehicles: example China

- 300,000 deaths/year from ambient AP
- Auto ownership: 3 cars/1000 people in 1998, at least 39 cars/1000 people in 2009
- Energy sources: 75% coal
Comparison of emissions and environmental health impacts from the use of conventional vehicles and electric vehicles in 34 major cities in China

- Station-to-wheel emission estimates
  - emission factors from conventional vehicles (CV) and electricity generation units (EGU) varying along 15 regional electricity grids
- Intake fraction and mortality impacts
**PM2.5 mortality risk** per $10^{10}$ passenger-km, for the 34 cities considered. Icon size is proportional to city population. In each plot, “R” is the population-weighted average ratio between x- and y-axes, “P” is the proportion of the population (among the 34 cities) for which the mortality risk is lower for EVs than for CVs. For reference, dashed lines are 1:1 lines. The population-weighted average value is indicated with an asterisk.

Electric vehicles: example China

Portion of primary PM2.5 health impacts from EGUs experienced by rural versus urban populations. Icon area is proportional to PM2.5 emission factor (g km\(^{-1}\)) for an EV in that power grid. Numbers identify nonurban mortality impact proportions, i.e., of the total mortality impacts attributable to primary PM2.5 from electricity generation – here, owing to urban use of EVs. Urban use of EVs rather than CVs typically moves the emissions (and, exposures and health impacts) to more rural locations. In general, a substantial proportion – on average, about half – of the emissions from urban use of EVs are inhaled by nonurban populations.

Air quality vs greenhouse gases: Trade-offs

% effect of emissions and air quality

Switch to Diesel

Smaller Cars

Areas where the most polluting vehicles are regulated.

- At least 250 cities in Europe operate LEZ
- UK, Germany, Sweden, Netherlands, Denmark, Italy, Hong Kong, Japan, Singapore

Typically targets commercial vehicles, but London’s latest proposal includes private vehicles.
Light commercial vehicles (LCVs - 60% of freight in London LEZ) became subject to LEZ requirements for the first time in 2012.

Mean PM10 concentration decreased by 13% in LEZ vs 7% decrease outside the LEZ.

Ellison et al./Transportation Research Part D (2013) 25-33
Health impact modelling of traffic reductions: Barcelona, Spain

Modelling health benefits of 40% car traffic reduction
Assume mode shifts from cars to active travel

Avoided premature deaths

Health benefits:
Behavioural vs Technological approaches in London

Policy scenarios to reach same level of greenhouse gas emissions reductions

Woodcock et al. 2009 The Lancet, v3674, 9705: 1930-1943
Behavioural vs Technological approaches in London

Avoided premature deaths / million

Data from Woodcock et al. 2009 The Lancet, v367, 4, 9705: 1930-1943
Policy scenarios in London: comparing avoided deaths

Premature Deaths Prevented

- Low Emiss Zone
- Diesel to Petrol
- Electric Car
- Electric Vehicle Fleet
- Cycle Path-10
- Cycle Path-20
- 10pct Car Reduc
- 50pct Car Reduc
- Technological change scenario
- Behavioural change scenario

Source: Andrea Calderon, PhD work in progress
Active travel promotion: Urban planning solutions

5 “D”s

- Density – dense land uses, dense and efficient transportation network
- Diversity – mix of land use types

- Design – “human scale”, building orientation, block length, parking location, landscaping, pedestrian and cycling amenities, etc
- Destination Accessibility
- Distance to Transit

(Ewing and Cervero 2010)
Urban form and health

• Sprawl:
  • increased obesity, overweight, BMI, hypertension, chronic diseases, traffic fatalities (Ewing et al. 2003, Lopez 2004, Sturm and Cohen 2004)

• Neighborhood land use density, land use mix, “walkability”:
  – Positive effects on overweight, obesity, BMI, physical activity and mental health (Giles-Corti et al. 2003, Saelens 2003, Frank et al. 2004, Frank et al. 2007, Berke et al. 2007)

• “Greenness”
  – Positive effects on stress recovery, emotions, physical activity, overweight, all-cause and CVD-related mortality, mental health and wellbeing (van den Bosch and Nieuwenhuijsen 2016)
Fig. 1. Pollutant dispersion in a regular street canyon (Dabberdt et al., 1973).
Density (x axis) vs Population exposed defined as living within 300m of highways and 50m of major roads (y axis)
Beware of trade-offs
Accounting for potential negative consequences

Impacts of mode shift from cars to active travel (Barcelona, Spain)

- Air pollution - general population
- Physical activity
- Traffic mortality
- Air pollution - traveller

Avoided premature deaths

Can air pollution negate the health benefits of cycling and walking?

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For a given level of air pollution, is there a tipping beyond which additional physical activity does not bring additional benefits, and a “break-even” point beyond which additional physical activity brings greater risks?
Delhi, 153 µg/m³ of PM2.5

Cycling a risk after 45 min of cycling per day

(Tipping point reached at 7 hours per day)
Air pollution and physical activity: Epidemiological evidence

London air pollution cancels positive health effects of exercise in over 60s

Experimental study comparing health effects of a walk in Hyde park vs Oxford St
Synharay et al. The Lancet 2017
Medium-long term effects

Black carbon reduces de PA effect on Lung Function

Laeremans et al, 2018
Quantifying potential co-benefits of planning strategies...

Estimated preventable deaths under compliance with exposure recommendations by exposure domain in Barcelona, Spain.

Air pollution strategies: conclusion

- Urban design strategies provide additional benefits compared to air pollution technological solution

Co-benefits?
- Climate change
- Greenspace
- Biodiversity
- Noise
- Physical activity
- Traffic injuries
- Diet
- Etc.

Trade-offs?
- Cooling agents
- Air pollution inhalation
- Traffic injuries
- Pollen
- Etc.
Challenge questions

• Are less car-dependent cities healthier than more car-dependent cities globally?
• Are walking and cycling-friendly cities healthier than less walking-cycling-friendly cities?
• As cities become cycling friendly, do they become healthier?
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