Air Pollution and Health Impact Assessment (HIA) - Background

Presented by
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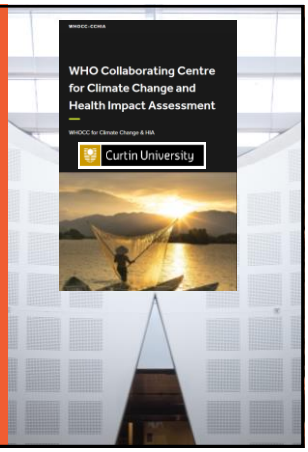

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What we will cover

1. What is an air pollution Health Impact Assessment (HIA) analysis?
   - What kinds of questions does it help answer?
   - How does it fit within a policy analysis?
2. How do we count benefits?
   - What are the air pollution-related benefits?
   - What data do we need to estimate benefits?
3. What are the sources of uncertainty?
   - How do we quantify or characterize these uncertainties?
   - Communicating uncertainties, assumptions and caveats to decision-makers?

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Definitions….

- Health Risk Assessment (HRA): **process** of estimating potential **impacts** of a **chemical, physical, microbiological or psychosocial hazard** on a specific **human population** under a **specific set of conditions for a certain time period**.
- Health Impact Assessment (HIA): **procedures, methods and tools** by which a policy, program or project may be judged as to its **potential effects (positive or negative, direct or indirect) on the health of a population**, and the distribution of those effects within the population.
- HIA attempts to look at the social, economic, lifestyle and behavioural **costs and benefits to the immediate community** as well as the **'downstream' direct and indirect impacts that will occur in other communities**.

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What is a HIA

- A means of estimating and communicating the health impacts of a risk factor (environmental, social, behavioral……)
  - Annual average exposure to human made (anthropogenic) air pollution in Sydney increases the mortality risk of the population by 6%
  - Annual average term exposure to human made (anthropogenic) air pollution in Sydney is associated with 450 attributable deaths and 6000 years of life lost
- HIA has two main parts:
  - Assessment of the "exposure" of a population to the "risk factor"
  - Estimation of the health burden/ impacts related to the "exposure"
    - A concentration-response relationship between the risk factor ("exposure") and a health outcome
    - The current health status of that population.

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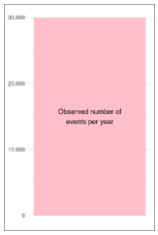
The Environmental Burden of Disease

- EBD is an estimate of the amount of ill-health that a population experiences as a result of past and current exposure to environmental risk factors
- Scale can be global, country-level, regional or local
- To calculate the burden, the **observed** amount of ill health is compared to a **counterfactual** situation where it is assumed there had been no (or reduced) exposure to the risk factor



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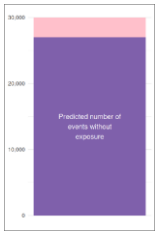

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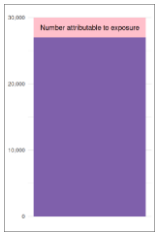
- To calculate the burden, the **observed** amount of ill health is compared to a **counterfactual** situation where it is assumed there had been no (or reduced) exposure to the risk factor
- The **difference** between the observed and the counterfactual is the **attributable number**



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The Environmental Burden - Calculation

Attributable Number = $[y_0 \times Pop] - [y_0 \times Pop \times (1/RR\Delta x)]$

AN = $[y_0 \times Pop] - [y_0 \times Pop \times e^{-\beta\Delta x}]$

AN = $y_0 Pop(1 - e^{-\beta\Delta x})$

RR Δx = Relative Risk associated with a change in a risk factor for health (Δx)

$e^{-\beta\Delta x}$ = relative risk associated with a change in a risk factor for health (Δx)

y_o = Baseline health outcome incidence

Pop = exposed population

LE_i = is the life expectancy of a person aged i without exposure to risk factor.

$$YLL = \sum_{i=30}^{85+} AN_i \times LE_i$$

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HIA – Health Burden

- Common metrics for describing health burden
  - Attributable number of deaths, hospital admissions or cases of disease
  - Years of life lost (YLL)
  - Years lived with disability (YLD)
  - Disability-adjusted life years (DALYs) (=YLL + YLD)
  - Loss of life expectancy (LE)
- ***Attributable number of deaths*** - focus of many reports/ papers
- **YLL's (and DALY's) due to premature deaths**- more relevant metric

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WHO Youtube video

- https://youtu.be/GVBeY1jSG9Y

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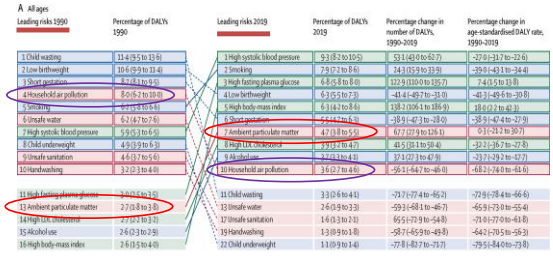
Global Burden of Disease – Air Pollution



GBD 2019 Risk Factors Collaborators. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. The Lancet. 17 October 2020. doi:10.1016/S0140-6736(20)30752-2.

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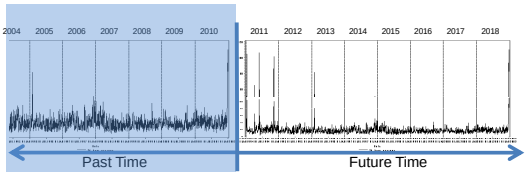
Air pollution HIA – Questions to answer

- Impact assessments may describe the **burden** of disease related to exposure or the **impact** of a change in exposure.
- Assessments of **burden** look **backwards** in time. They quantify how much ill-health among the current population is attributable to past exposure to a risk factor.
- Assessments of **impact** look **forward** in time. They quantify the improvements in health might be expected if exposure to a risk factor is reduced.
- uses the epidemiological concept of attributable fraction to generate estimates



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Air pollution HIA – Questions to answer

- The HEALTH BURDEN of **current air pollution exposure** (eg: $PM_{2.5}$)
  - What proportion/ number of current health outcomes are attributable to **past/ current exposure?**
  - ***Counterfactual*** -
    - compares current health status of population to hypothetical one - had the same population been less exposed,
    - Eg: compare current exposure to situation of no human made air pollution exposure, ie: the health burden due to historical exposure to "anthropogenic" air pollution

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Air pollution HIA – Questions to answer

- What is the HEALTH IMPACT of a **future change in air pollution exposure** from current (eg: $PM_{2.5}$)
  - ***Counterfactual*** - What if policy relevant scenarios
    - Eg: domestic wood heater emissions reduced due to improved emissions control standards
    - Eg: coal fired power station closure due to increased energy generation from solar and wind.
  - An important effect of reducing exposure to air pollution into the future is that people live longer: All else being equal, the population increases in size and age.
  - Age-specific risk of a health event is reduced (but more people will survive longer to be exposed to the risk in the future)
- ***Predictive approach requires*** additional assumptions, eg:
  - The success of policy implementations
  - Baseline disease rate changes due to other causes,
  - Important that those are stated clearly.

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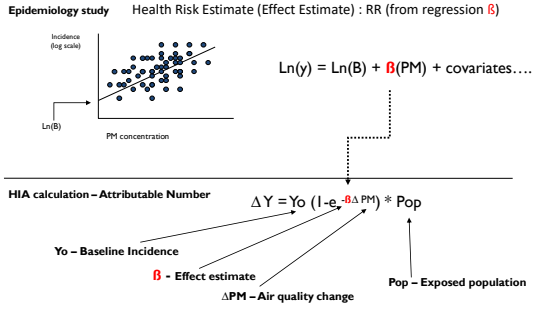
HIA Calculations/ Data Inputs – air pollution



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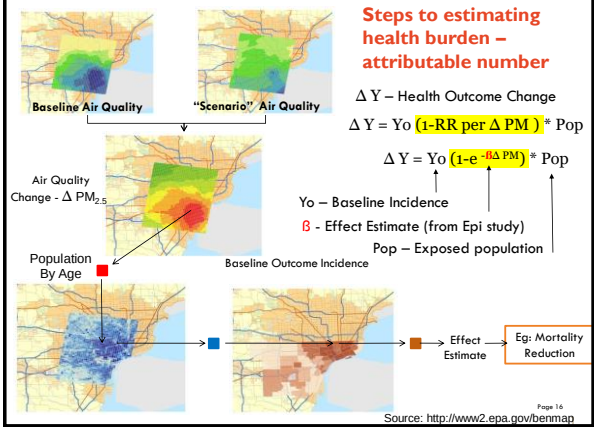

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How do we value reduced health risks?

Quantification of cases:

$\Delta Y = Yo\ (1\text{-}e^{-\beta \Delta PM})\ Pop$

ΔY = attributable cases

Estimation of Costs:

$Costs = Cases \times Unitary_{costs}$

$Unitary_{costs}$: unit costs ($AUD/case)

- Cost of illness (COI)
  - How much does it cost to go to the hospital?
  - Do mom or dad have to stay home and miss work because a child is sick?
  - How much pay do you lose because you are sick and can't go to work?
- Willingness to Pay (WTP)
  - How much is it worth to you to reduce your risk of death?
  - How much is it worth to you to not get a chronic disease?
  - How much is it worth to you to not be sick?

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Questions…….

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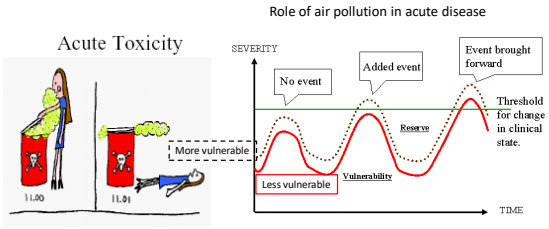
Short term exposure and health



Short term exposure

Source: unknown

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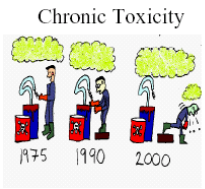
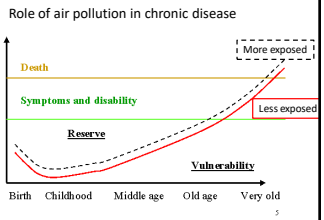
Long term exposure and health



Long term exposure



Source: unknown

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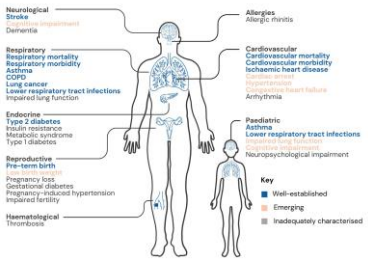
Air Pollution – affects multiple body systems, contributes to the risk of wide range of health conditions



Pillay et al. Safer Air, Healthier Communities: Ten reasons for investment in Australia. Centre for Safe Air. 2023

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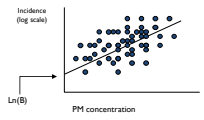
HIA Calculations/ Data Inputs – air pollution

Epidemiology study Health Risk Estimate (Effect Estimate) : RR (from regression ß)



$Ln(y) = Ln(B) + \beta(PM) + covariates....$

HIA calculation – Attributable Number

$\Delta Y = Yo\ (1 - e^{-\beta \Delta PM}) * Pop$

Yo – Baseline Incidence

ß - Effect estimate

ΔPM – Air quality change

Pop – Exposed population

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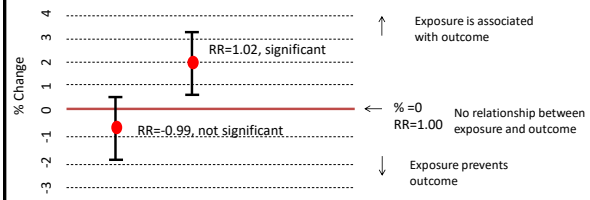
Health effect estimates: RR



% Change in Relative risk (RR): the risk of developing the health outcome related to exposure (exposed vs. non-exposed, or per incremental increase in exposure)

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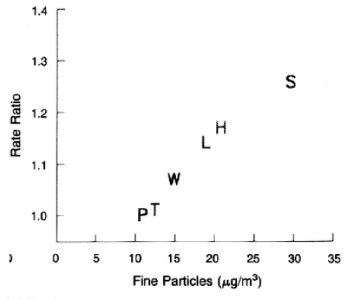
Cohort Studies – Harvard Six Cities Study



Dockery et al. NEJM 1993. Laden et al AJRCCM 2006

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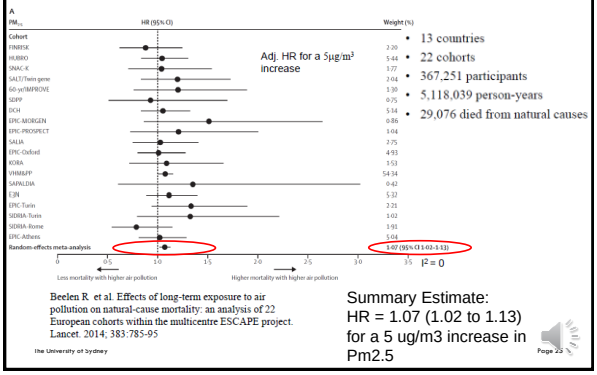
Air pollution and mortality – meta analysis



- 13 countries
- 22 cohorts
- 367,251 participants
- 5,118,039 person-years
- 29,076 died from natural causes

Beelen R et al. Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project. Lancet. 2014; 383:785-95

The University of Sydney

Summary Estimate:
HR = 1.07 (1.02 to 1.13) for a 5 ug/m3 increase in Pm2.5

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Weight of evidence – $PM_{2.5}$ and health

Long term $PM_{2.5}$ exposures – years / decades

- Reproductive / developmental
- Respiratory Morbidity
- Mortality: reduced life expectancy
- Cardiovascular Morbidity

Not likely | Inadequate | Suggestive | Likely | Causal

- Central Nervous System / Neurological
- Respiratory Morbidity
- Premature Mortality.
- Cardiovascular Morbidity

Short term $PM_{2.5}$ exposures - days

IARC 2013 classification of air pollution and particulates as a carcinogen
(ref: Loomis, D, The carcinogenicity of outdoor air pollution, The Lancet Oncology, 2013;14(13):1262–1263)

Recent research - Metabolic disease? Ear disease? Kidney disease?

Source: US EPA 2009, Integrated science assessment for particulate matter

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Which Health Effects to Evaluate?

- Requires Addressing a Series of Questions:
  - What is our overall level of confidence that exposure to an air pollutant can cause the health effect being evaluated?
  - Are there epidemiologic studies that examine the relationship between the air pollutant and health effect?
  - How generalizable are the results form the location / context of the epidemiological study to the HIA location
  - Is there corresponding incidence data available at similar spatial / temporal scales as the epidemiological study for the health outcome of interest (e.g., national, city-specific, etc.)?

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What epi study risk estimate/s?

- Minimum requirements:
  - Non-overlapping health endpoints (e.g. do not combine all cardiovascular hospital admissions and ischemic heart disease hospital admissions)
- Prefer:
  - Study populations matching the HIA location - population attributes similar to those affected by air pollution
  - Sufficient HIA location population size
  - Multi-city studies
  - Multi-pollutant models
- Hundreds of health impact functions to choose from……

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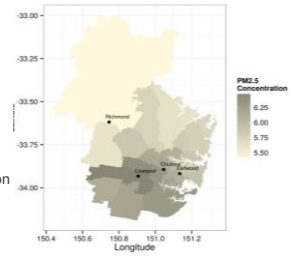
Selecting Air Pollution

$\Delta Y = Yo\ (1\text{-}e^{-\beta\Delta PM}) * Pop$

- Depends on the policy question
  - Analysis for the past?
  - Analysis for the future?
  - Local or regional impacts?
- Data availability:
  - monitoring data (interpolated..)
  - model data
  - data that simulates a concentration change.
- Air quality data must be at same time scale as the epi study, eg: both use
  - annual mean, or 8hr max, etc.
  - City wide, subregion
- Uncertainty?



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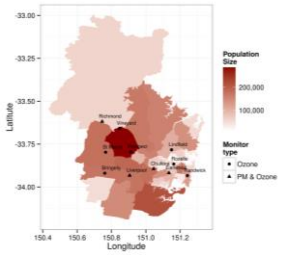
Selecting Population Data

$\Delta Y = Yo\ (1\text{-}e^{-\beta\Delta PM}) * Pop$

- Match population data to population characteristics of the epi study
- Historical or projected population levels
- Uncertainty?



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Selecting Incidence Rates

$\Delta Y = Yo * Pop\ (1\text{-}e^{-\beta\Delta PM})$

- Baseline rates (of death or disease) match the characteristics of the health endpoint to be calculated:
  - Location
  - Demographic characteristics
  - Year (historical/projected)
- Uncertainty?

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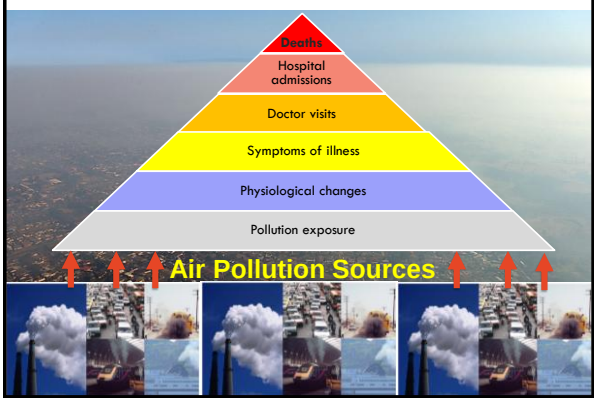
Impacts of exposure to air pollution



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Health Impact Assessment – Questions

- What is the HEALTH BURDEN of current ambient air pollution exposure (eg: PM2.5, PM10, O3)
  - Above normal "background" exposure
  - Monetised burden $$$ - INTERPRETATION ISSUES

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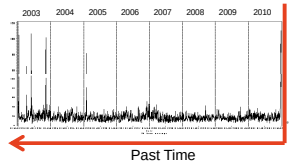
Health BURDEN of CURRENT air pollution

- What is the annual health BURDEN associated with exposure to CURRENT anthropogenic PM2.5 in Sydney?
  - Current air pollution = anthropogenic + background
- Assume each PM2.5 attributable death is responsible for the number of YLL equal to change in life expectancy at age of death.



Year=2010			
Age	Pop	Deaths	Life expectancy
0	e_0	d_0	LE_0
1	e_1	d_1	LE_1
2	e_2	d_2	LE_2
.....			
98	e_{98}	d_{98}	LE_{98}
99	e_{99}	d_{99}	LE_{99}
100	e_{100}	d_{100}	LE_{100}

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Health Impact Assessment – Questions

- What is the HEALTH IMPACT of a change in air pollution exposure from current (eg: PM2.5, PM10, or O3?)
  - What if scenarios
    - PM2.5 concentrations reduced / increased in Sydney, eg: 20%
    - Fire smoke exposure reduced/ increased
    - Wood heater emissions reduced/ increased
    - Shipping emissions were reduced
    - Monetised impact / benefits $$$ - more robust interpretation
    - Policy relevant exposure reduction scenarios
- Method developed by the UK Institute of Occupational Medicine - Miller and Hurley, 2003

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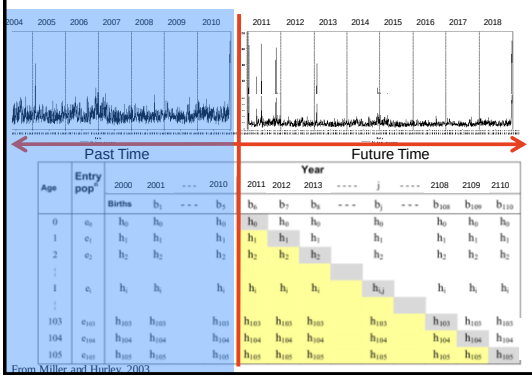
IMPACT Question – Life Table methodology



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HIA Examples

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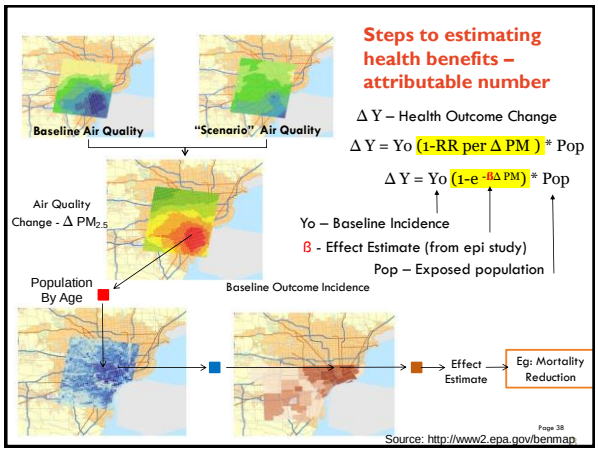

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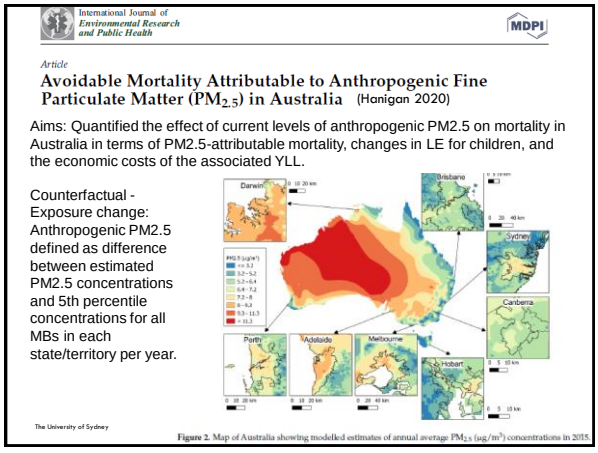

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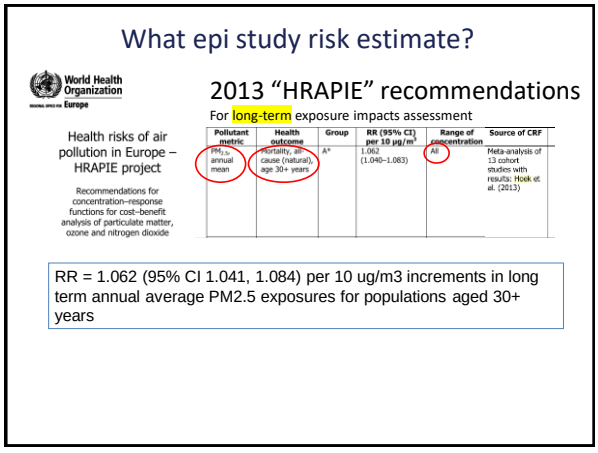

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International Journal of Environmental Research and Public Health

MDPI

Article

Avoidable Mortality Attributable to Anthropogenic Fine Particulate Matter ($PM_{2.5}$) in Australia

Region	AN (95%CI)	YLL (95%CI)
NSW and ACT	940 (615–1241)	13,956 (9094–18509)
VIC	650 (425–858)	9366 (6103–12421)
QLD	517 (338–682)	7925 (5165–10509)
WA	197 (129–260)	3178 (2072–4213)
SA	188 (123–249)	2683 (1729–3518)
TAS	102 (67–135)	1419 (925–1882)
NT	21 (14–28)	464 (303–615)
National	2616 (1712–3455)	38,962 (25391–51669)

- Conclusions: Annually, anthropogenic PM2.5-pollution associated with
  - 2616 (95% confidence intervals 1712, 3455) deaths,
  - corresponding to a 0.2-year (95% CI 0.14, 0.28) reduction in LE for children aged 0–4 years,
  - corresponding to 38,962 (95%CI 25,391, 51,669) YLL
  - Corresponding to average annual economic burden of $6.2 billion (95%CI $4.0 billion, $8.1 billion).

Anthropogenic PM2.5-related costs of mortality in Australia are higher than community standards should allow, and reductions in emissions are recommended.

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Source specific air pollution and health in Sydney

Aims

- What is the health burden due to source specific PM2.5 in Sydney
- What are the health impact of reducing emissions from solid fuel heaters and coal fired power stations

Methods

- Assume health risks of source specific PM2.5 equivalent to health risks due to all PM2.5
- Sydney GMR 2010/11
- Source specific PM2.5 estimated using CSIRO CTM model.

Source: Broome et al. The mortality effect of ship-related fine particulate matter in the Sydney greater metropolitan region of NSW, Australia. Environment International 2016; 87: 85–93.

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Source-specific $PM_{2.5}$ concentrations

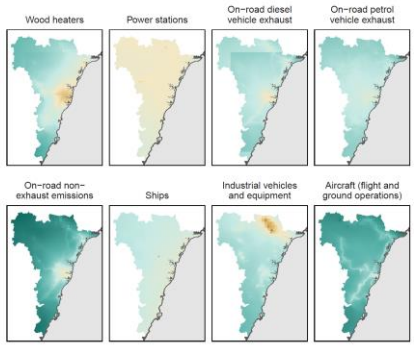

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Table 2: Primary $PM_{2.5}$ emissions from individual sources in 2008 and the modelled population weighted annual average $PM_{2.5}$ (primary and secondary) in 2010/11.

Source	$PM_{2.5}$ emission*		$PM_{2.5}$ concentration†	
	Tonnes	%	$\mu g/m^3$	%
Wood heaters	7,400	19.0	0.49	24.0
Power stations	3,400	8.8	0.22	10.6
On-road mobile sources	2,100	5.3	0.35	16.9
Exhaust from petrol vehicle	180	0.5	0.08	4.1
Exhaust from diesel vehicles	1,100	2.9	0.16	7.6
Non-exhaust emissions	770	2.0	0.11	5.3
Off-road mobile sources	2,900	7.5	0.22	10.4
Industrial vehicles and equipment	2,000	5.2	0.06	3.0
Ships	850	2.2	0.12	5.7
Aircraft (flight and ground operations)	64	0.2	0.03	1.7
Other anthropogenic sources	16,000	41.0	0.79	38.1

* Emissions of primary $PM_{2.5}$ in 2008.[15]
† Population weighted annual mean concentration.

Broome et al. Source-specific impacts of PM2.5 on mortality in the Greater Metropolitan Region of Sydney, Australia (Environment International, under review)

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Table 3: The annual burden of mortality related to long-term exposure to $PM_{2.5}$ from major sources in the Greater Metropolitan Region of NSW.

Source	Attributable number of deaths		YLL		Loss of life expectancy*	
	N	95% CI†	Years	95% CI†	Days	95% CI†
Wood heaters	100	67 - 140	1,400	920 - 1,900	12	8 - 16
Power stations	45	29 - 60	620	400 - 830	5	3 - 7
On-road mobile sources	72	47 - 97	990	650 - 1,300	8	6 - 11
Exhaust from petrol vehicle	17	11 - 23	240	160 - 320	2	1 - 3
Exhaust from diesel vehicles	32	21 - 43	440	290 - 590	4	2 - 5
Non-exhaust emissions	22	15 - 30	310	200 - 410	3	2 - 4
Off-road mobile sources	45	29 - 60	610	400 - 820	5	3 - 7
Industrial vehicles and equipment	13	8 - 17	180	120 - 240	2	1 - 2
Ships	25	16 - 33	340	220 - 450	3	2 - 4
Aircraft (flight and ground operations)	7	5 - 10	97	63 - 130	1	1 - 1
All anthropogenic sources	**420**	**280 - 570**	**5,900**	**3,800 - 7,900**	**50**	**32 - 67**

* Loss of life expectancy at birth.
† 95% CIs are for the statistical imprecision in the concentration-response coefficient only.

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Life years produced by reduced emissions into the future

Emisssions scenario	Reduction in $PM_{2.5}$	Life-years produced among those alive in 2011	Life-years produced among those alive in 2011 *and* people born in the future
	$\mu g/m^3$	N	N
Wood heaters			
Emissions of 2.5g/kg	0.22	60,000	81,000
Emissions of 1.5g/kg	0.33	90,000	120,000
No emissions	0.49	140,000	180,000
Powers stations			
No nitrogen oxide emissions	0.14	38,000	52,000
No sulphur oxide emissions	0.05	14,000	19,000

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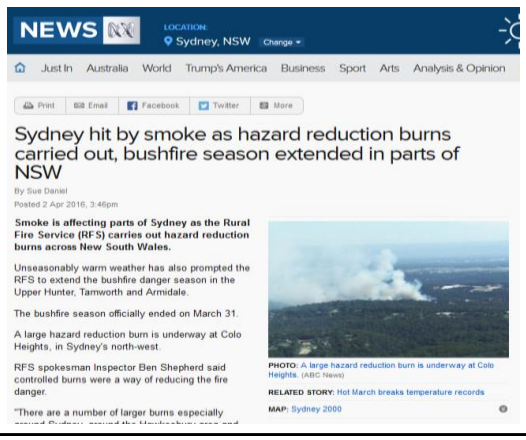

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Health impacts of short term exposure to smoke from hazard reduction burns

- May 2016 Hazard Reduction Burns around Sydney:
  - 6 days of extreme fire smoke pollution
  - 14 Excess Deaths
  - 87 Hospitalisation's
- Serious adverse impacts for a health protection intervention.

Source: Broome et al. Medical Journal of Australia 2016; 205 (9): 407-408.

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Sydney air pollution from scheduled burn led to 14 premature deaths researchers find

By Mazoe Ford and Kathleen Calderwood

Updated 16 Nov 2016, 6:43pm

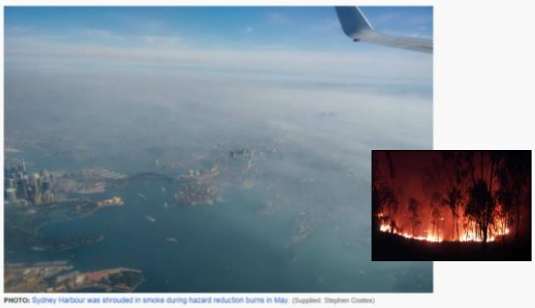

PHOTO: Sydney Harbour was shrouded in smoke during hazard reduction burns in May. (Supplied: Stephen Coates)

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Estimated health burden due to Short term exposure to fire smoke – South Eastern Australia Oct19 to Feb 20

2 Estimated health burden attributable to bushfire smoke, Queensland, New South Wales, the Australian Capital Territory and Victoria, 1 October 2019 – 10 February 2020

	Estimated number of cases (95% confidence intervals)				
Outcome	Queensland	New South Wales	Australian Capital Territory	Victoria	Total
Excess deaths (any cause)	47 (17–77)	219 (81–357)	31 (12–51)	120 (44–195)	417 (153–680)
Hospital admissions, cardiovascular	135 (25–246)	577 (108–1050)	82 (15–149)	331 (62–602)	1124 (211–2047)
Hospital admissions, respiratory	245 (0–513)	1050 (0–2204)	147 (0–308)	585 (0–1227)	2027 (0–4252)
Emergency department attendances, asthma	113 (61–165)	702 (379–1026)	89 (48–131)	401 (217–586)	1305 (705–1908)

- Health burden attributable to bushfire smoke in SE Australia, Oct19-Feb20
  - Excess deaths = 417 (153 to 680); Hospital admissions = 3151 (211 to 6299)
- Population exposure to bushfire smoke almost an order of magnitude greater than the previous two decades – likely longer…..

Source: Borchers-Arriagada et al 2020. Medical Journal of Australia http://dx.doi.org/10.5694/mja2.50545

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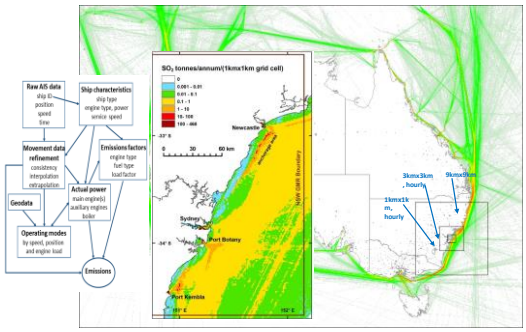
Shipping emissions and mortality, Sydney



Broome et al. The mortality effect of ship-related fine particulate matter in the Sydney greater metropolitan region of NSW, Australia. Environment International 2016; 87: 85–93.

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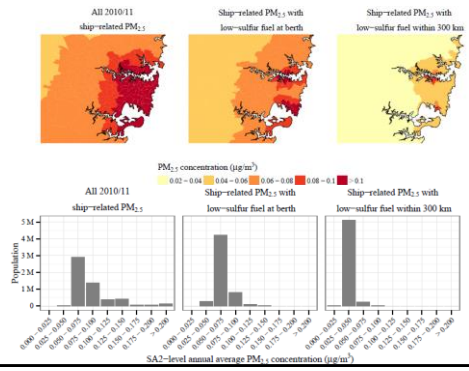
Ship-related PM2.5 exposure change - scenarios



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Shipping emissions and mortality, Sydney

- **Mortality burden of 2010/11 ship related PM2.5**
  - 220 YLL lost due to ship-related PM2.5 exposure (95% CI: 140 – 290).
  - attributable number of deaths in 2010/11 = 17 (95% CI : 11 – 22).
  - As PM2.5 can induce and accelerate chronic cardiopulmonary disease, ship-related PM2.5 likely influenced the timing of death of many more people then the estimated attributable number of deaths in 2010/11, particularly those who died from cardiopulmonary causes.
- **Mortality benefit of low sulphur fuel interventions to 2020**
  - Low-sulfur fuel at berth would, over twenty years result in:
    - gain of 390 life-years (95% CI: 260 – 520),
  - Low-sulfur fuel within 300 km would, over twenty years, result in:
    - gain of 920 life-years (95% CI 309 : 600 –1200).

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Shipping emissions and mortality, Sydney

- Use of low sulphur fuel within 300km of Sydney GMR provides more than double the mortality benefit compared to only use of low sulphur fuel at berth
- Future ship exhaust emissions in the Sydney GMR expected to increase compared to 2010/2011 levels
- Mortality benefit estimates to 2020 (or 2025) likely underestimates as do not account for increased shipping activity.
- In addition to the mortality benefits assessed in this study, reductions in ship emissions would reduce the incidence of other PM2.5-related health effects and health effects related to exposure to other air pollutants emitted by ships.

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Statements

- Health Burden assessment in Sydney:
  - annual average exposure to anthropogenic PM2.5 pollution in Sydney = 5ug/m3
  - AN = 500 attributable deaths
  - YLL = 5500 YLL.
- Annual average exposure to anthropogenic PM2.5 pollution (annual average = 5ug/m3) in Sydney is associated with 500 attributable deaths and 5500 YLL. CORRECT
- Eliminating anthropogenic air pollution in Sydney will save 500 deaths per year and add 5500 years of life each year to the Sydney population. INCORRECT
- The benefits of eliminating anthropogenic PM2.5 pollution (annual average = 5ug/m3) in Sydney would be 500 avoided deaths and 5500 avoided years of life lost. INCORRECT
- Reducing anthropogenic air pollution in Sydney will avoid 500 deaths per year and avoid 5500 years of life lost each year. INCORRECT

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Using the environmental burden to prioritise intervention

- Estimates of the burden of disease give you an idea of how much ill-health is attributable to a particular risk factor
- Metrics like DALYs, and YLL, make it is possible to compare the amount of harm caused by different risk factors
- How should this information be used to prioritise action?
- For example:
  - In Australia tobacco is responsible for a larger burden of disease than air pollution.
  - Does that mean governments should give less priority to air pollution?

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Decisions based on costs, benefit and their distribution

- Generally, the aim of public policy is to maximise welfare, taking into account how that welfare is distributed
- Therefore, what should matter to a governments is:
  - Is their justification for government intervention?
  - What options are available to address the issue?
  - What are the costs and benefits of these options? Do the benefits outweigh the costs?
  - How will these costs and benefits distributed within society?

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Summary

- Environmental Health Impact Assessment is used to translate scientific evidence into information that can be used for decision making
- It is common to assess the burden - how much current ill-health is attributable to past and current exposure
- From a policy perspective, it is generally more useful to focus on modelling the future effects of interventions or changes in exposure.

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THANKS…..

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