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Seminar 19: The Harm Paradigm for IAQ

The harm paradigm for IAQ

Dr Benjamin Jones, Eng.D, ACIBSE

Associate Professor
University of Nottingham

benjamin.jones@nottingham.ac.uk

Acknowledgements

1. Giobertti Morantes, EURAC, Italy
2. Constanza Molina, PUC, Chile
3. Max Sherman, University of Nottingham, UK (via San Francisco)

indoor air quality

Acceptable indoor air quality: *air in which there are no known contaminants at harmful concentrations, as determined by cognizant authorities, and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.*

Emission → Dispersion (concentration) → Exposure → Intake (inhalation) → Dose → Response (acute) → Response (chronic)

Contaminants and emission sources

Place

Person/receptor

Chronic harm

Metrics Overview: AIVC VIP#36

Ventilation Information Paper n° 36

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Operating Agent and Management
Boulevard Poincaré 79
B-1060 Brussels – Belgium
inive@bbri.be - www.inive.org

International Energy Agency
Energy Conservation in Buildings and Community Systems Programme

AIVC

Air Infiltration and Ventilation Centre

Metrics of Health Risks from Indoor Air

Dr. Benjamin Jones
University of Nottingham, UK

Abstract

In a recent review of 31 green building certification schemes used around the world, IAQ was found to contribute to only 7.5% of the final score on average[1]. As policy makers strive to reduce the energy demands of buildings by sealing or reducing outdoor air ventilation rates, an unintended consequence could be the reduction in the quality of indoor air with corresponding negative health effects at a population scale. This article summarizes the discussions of an Air Infiltration and Ventilation Centre workshop on IAQ metrics held in March 2017[2]. It first identifies the types of contaminants found in many buildings today, the mechanisms of exposure to them, and methods of mitigating their effects. It then explores metrics that could be used to quantify the quality of indoor air.

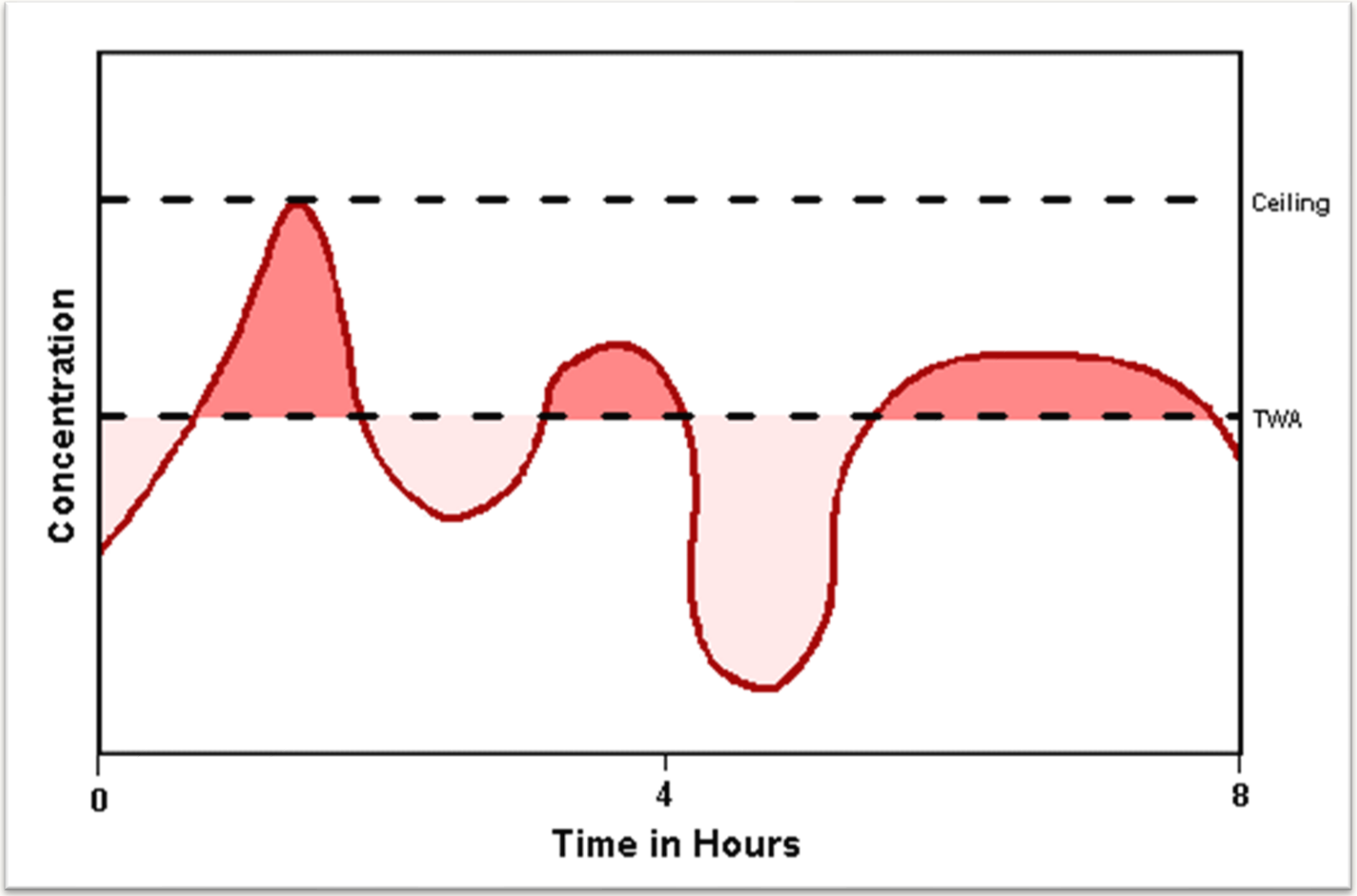
1 Problems

Building materials and systems, and the activities carried out in them, can be a source of contaminants that are harmful to human health. For example, there is evidence that some of the materials used to construct and furnish buildings emit harmful gases and harbour biological organisms. Unvented combustion processes for space and food heating emit gaseous and particulate contaminants and can be a source of moisture that is a primary driver of biological growth. Human activities, such as cooking and vacuum cleaning, also emit particulates, cleaning and deodorizing products emit gaseous contaminants and particulates, and smoking emits over 7000 different compounds of which many are harmful[3]. Pets harbour and transport biological contaminants, and can themselves be allergens. People and pets also emit gaseous bio-effluents that are disagreeable to smell, and harbour pathogens that produce disease. These examples show the many potential hazards and contaminant sources in buildings, for which there are multiple exposure pathways, and not all of them are airborne.

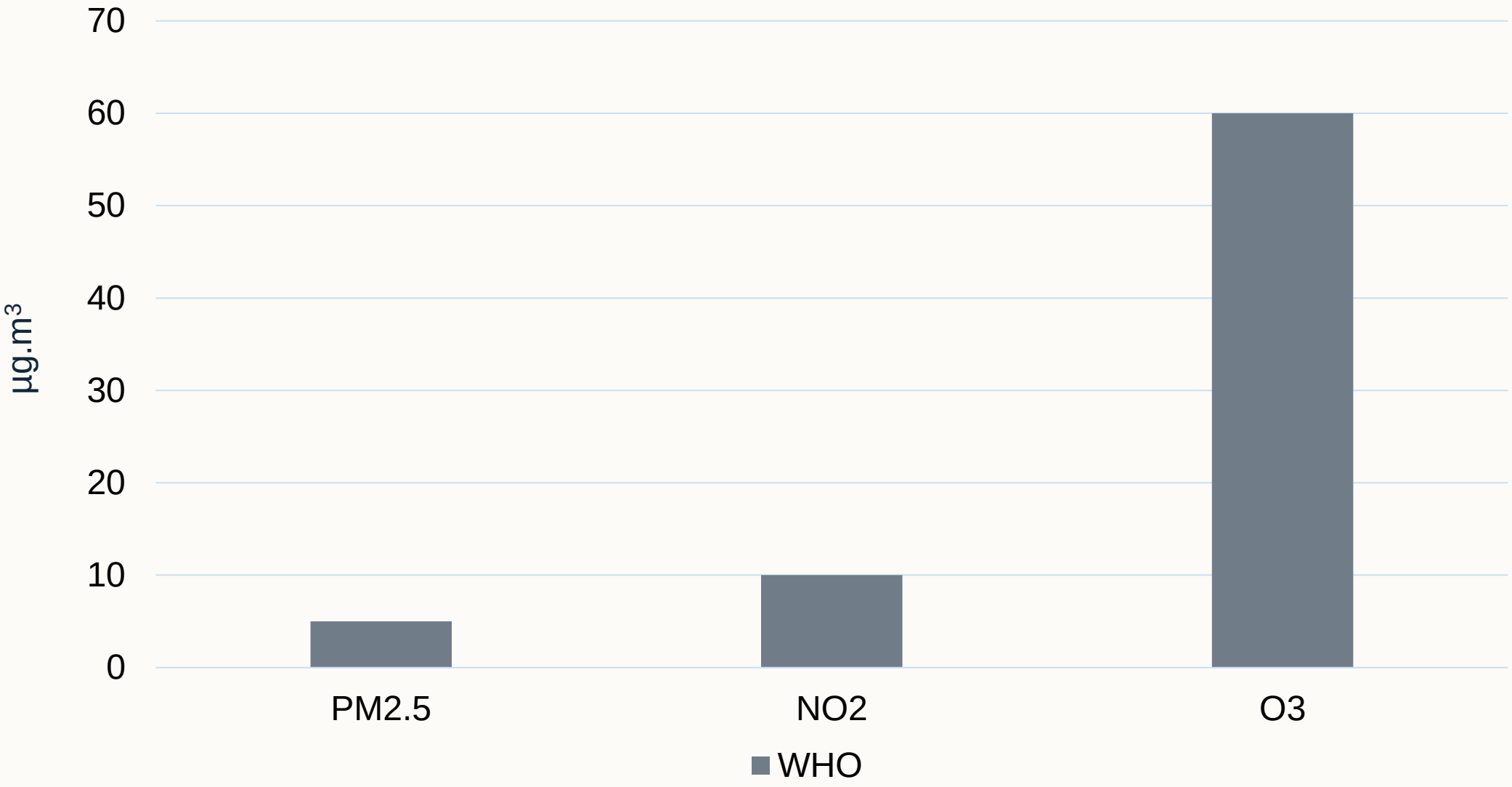
[1] Wei W, Ramalho O, Mandin C. Indoor air quality requirements in green building certifications. Building and Environment. 2015;92:10-9.
[2] AIVC. Is ventilation the answer to indoor air quality control in buildings? Do we need performance-based approaches? AIVC Workshop held in Brussels, Belgium. 14th-15th March, 2017.
[3] CfDC. How Tobacco Smoke Causes Disease. The Biology and Behavioral Basis for Smoking-Attributable Disease. Centers for Disease Control. Atlanta, Georgia, U.S.A.: U.S. Public Health Service; 2010.

1

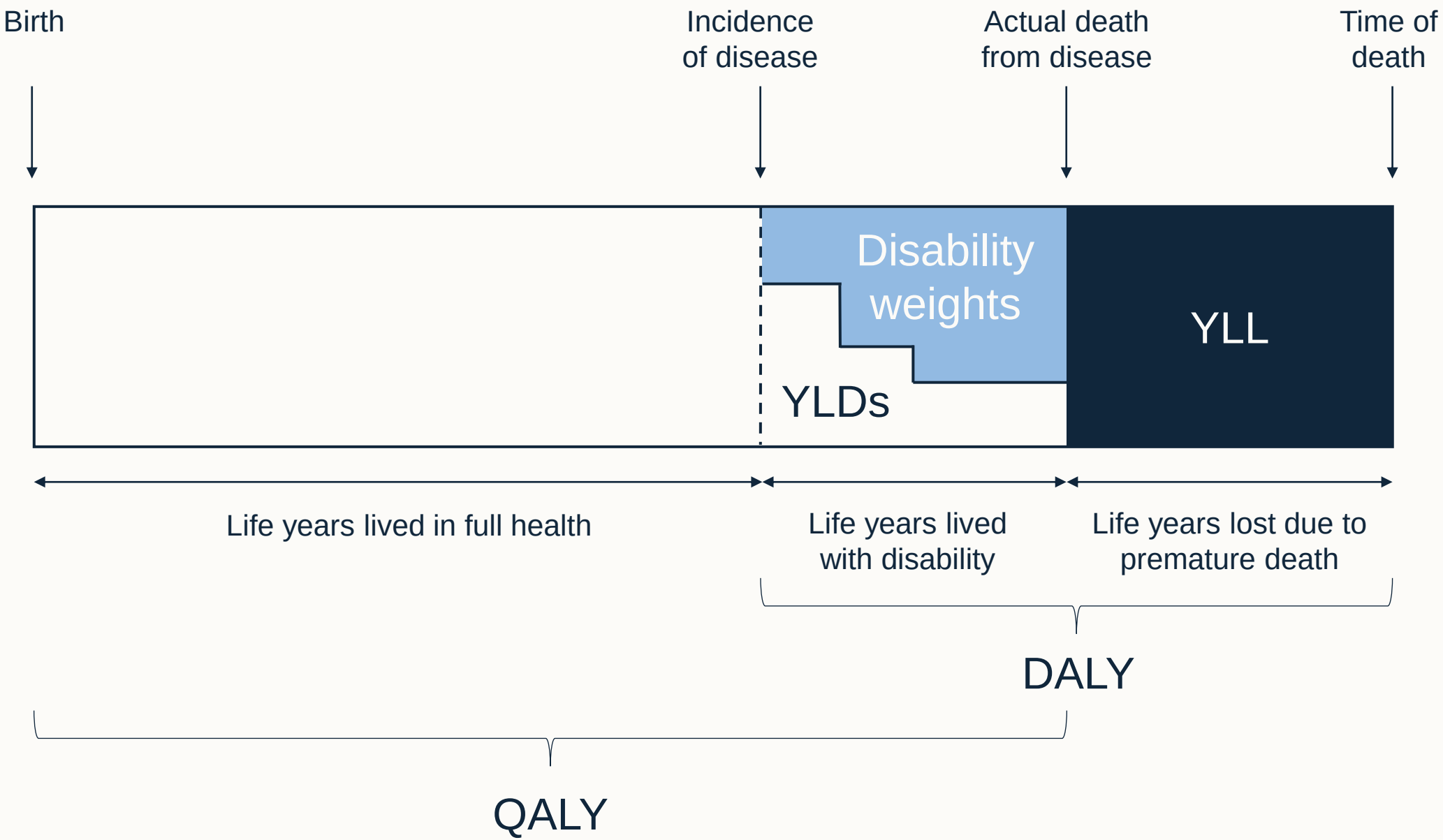
Current acceptability



WHO threshold values



Health Adjusted Life Years

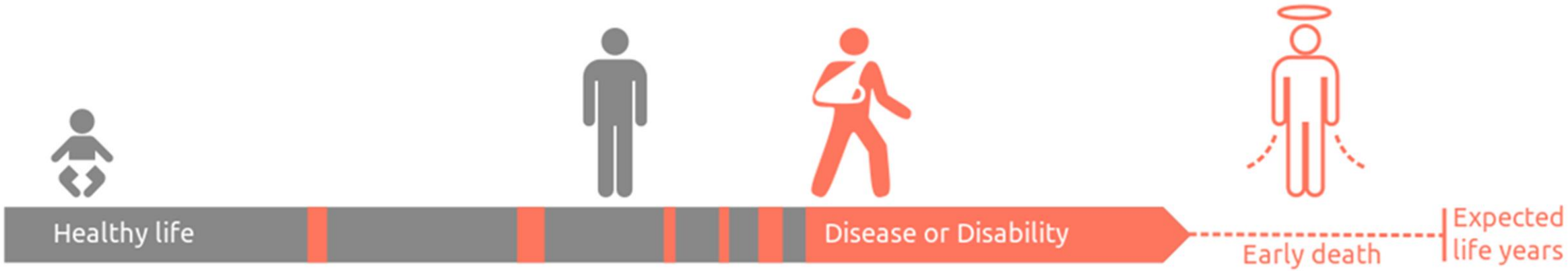


Disability Adjusted Life Years (DALYs)

DALY

Disability Adjusted Life Years is a measure of overall disease burden, expressed as the cumulative number of years lost due to ill-health, disability or early death

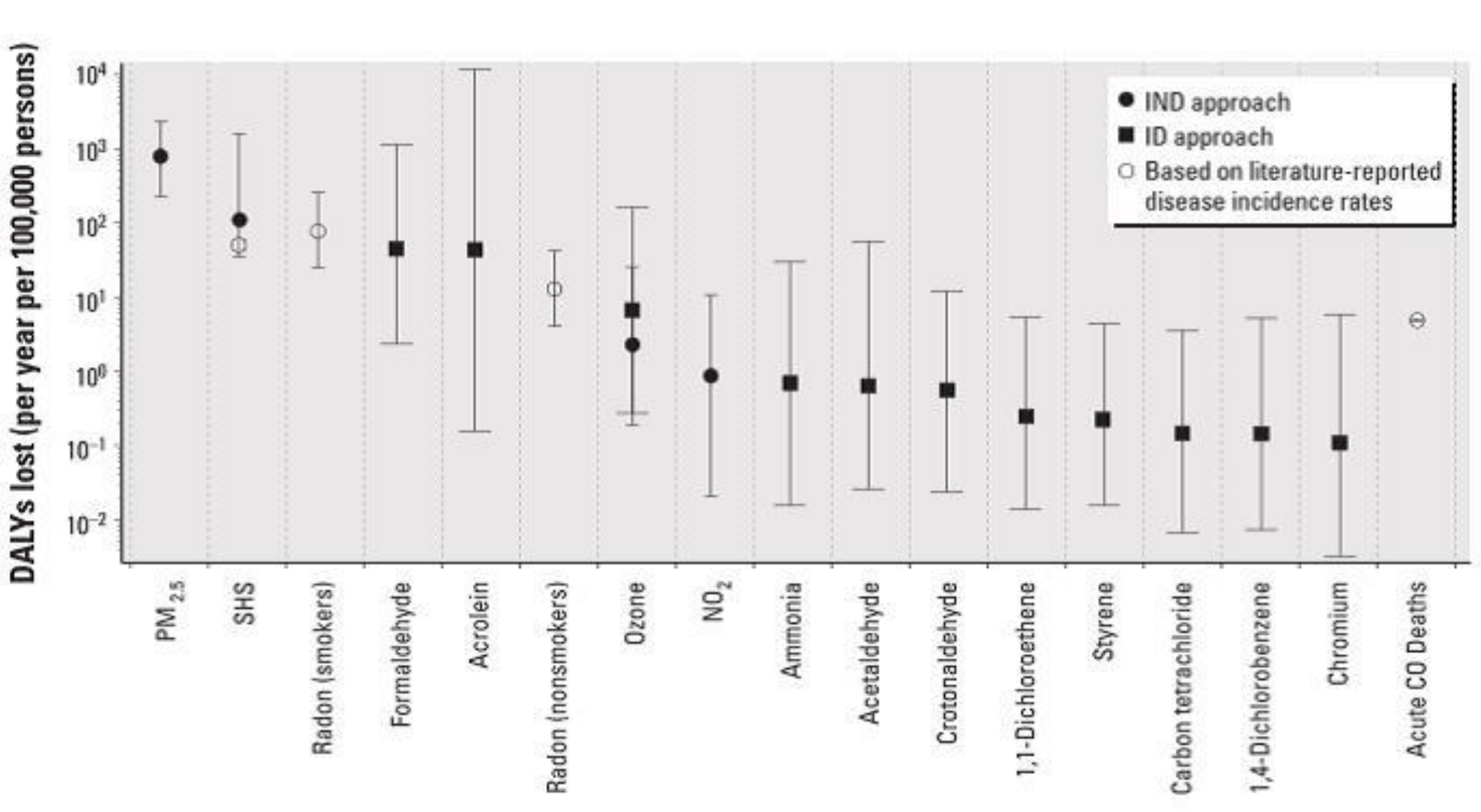
= **YLD** Years Lived with Disability + **YLL** Years of Life Lost



Acceptable harm? (DALYs)

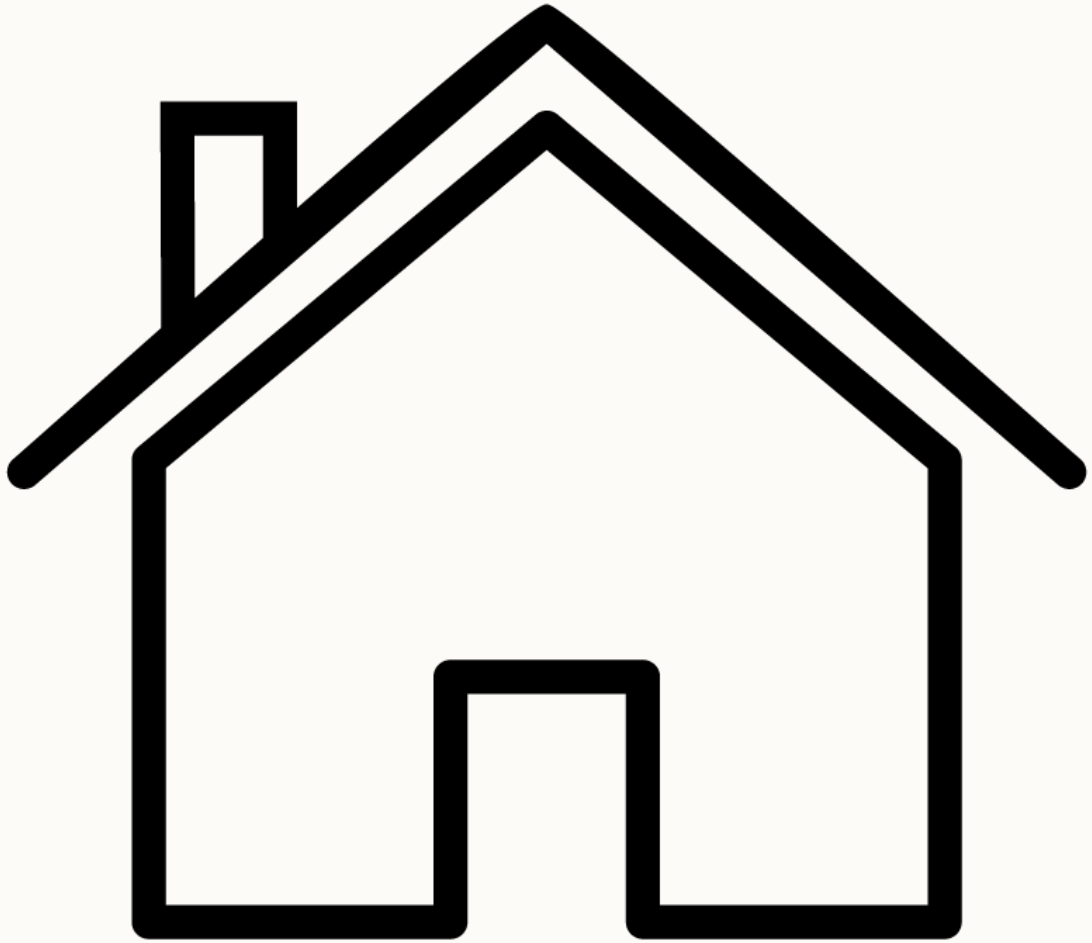
Alcoholism	Smoking	Transport injuries
1,200	2,600	1,000

Previous work

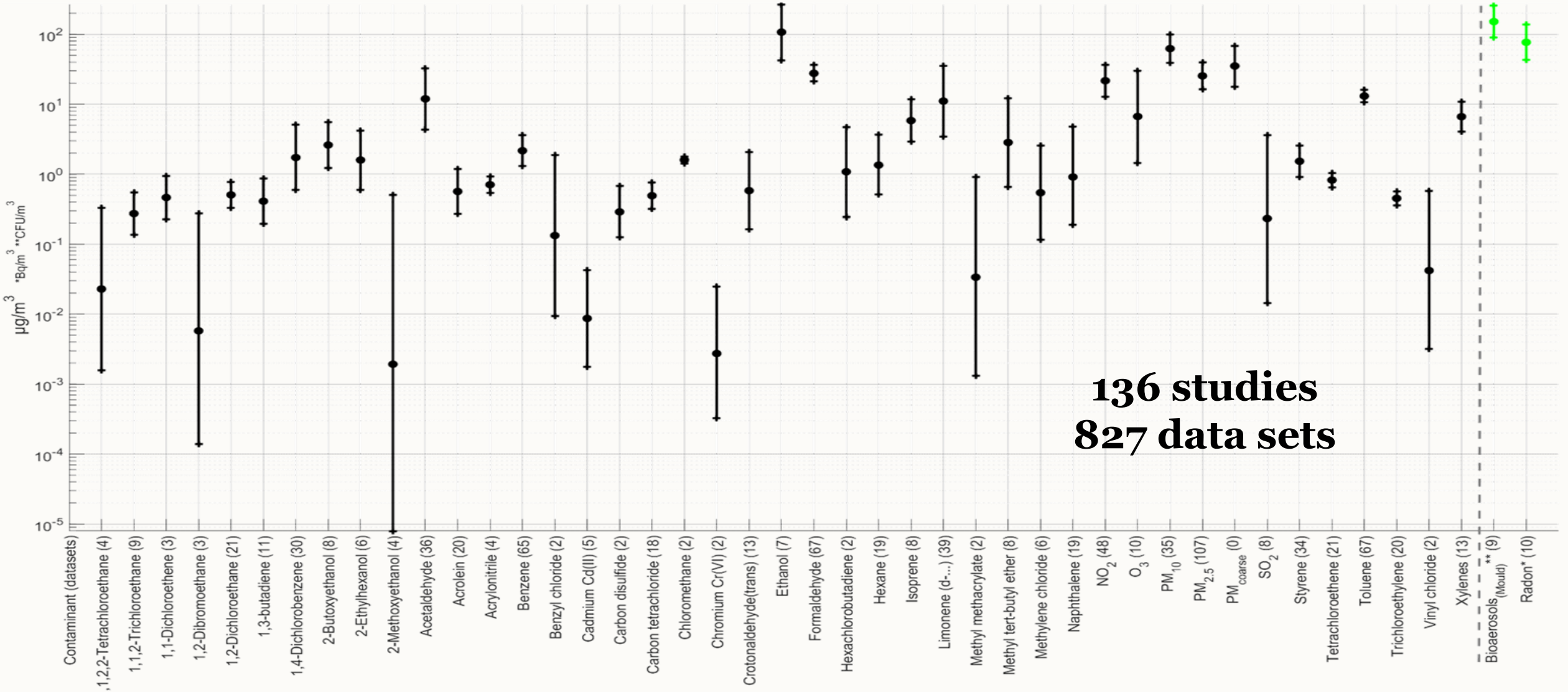


Logue JM, Price PN, Sherman MH, Singer BC. A Method to Estimate the Chronic Health Impact of Air Pollutants in U.S. Residences. Environmental Health Perspectives. 2011;120(2):216-22.

Chronic harm in houses

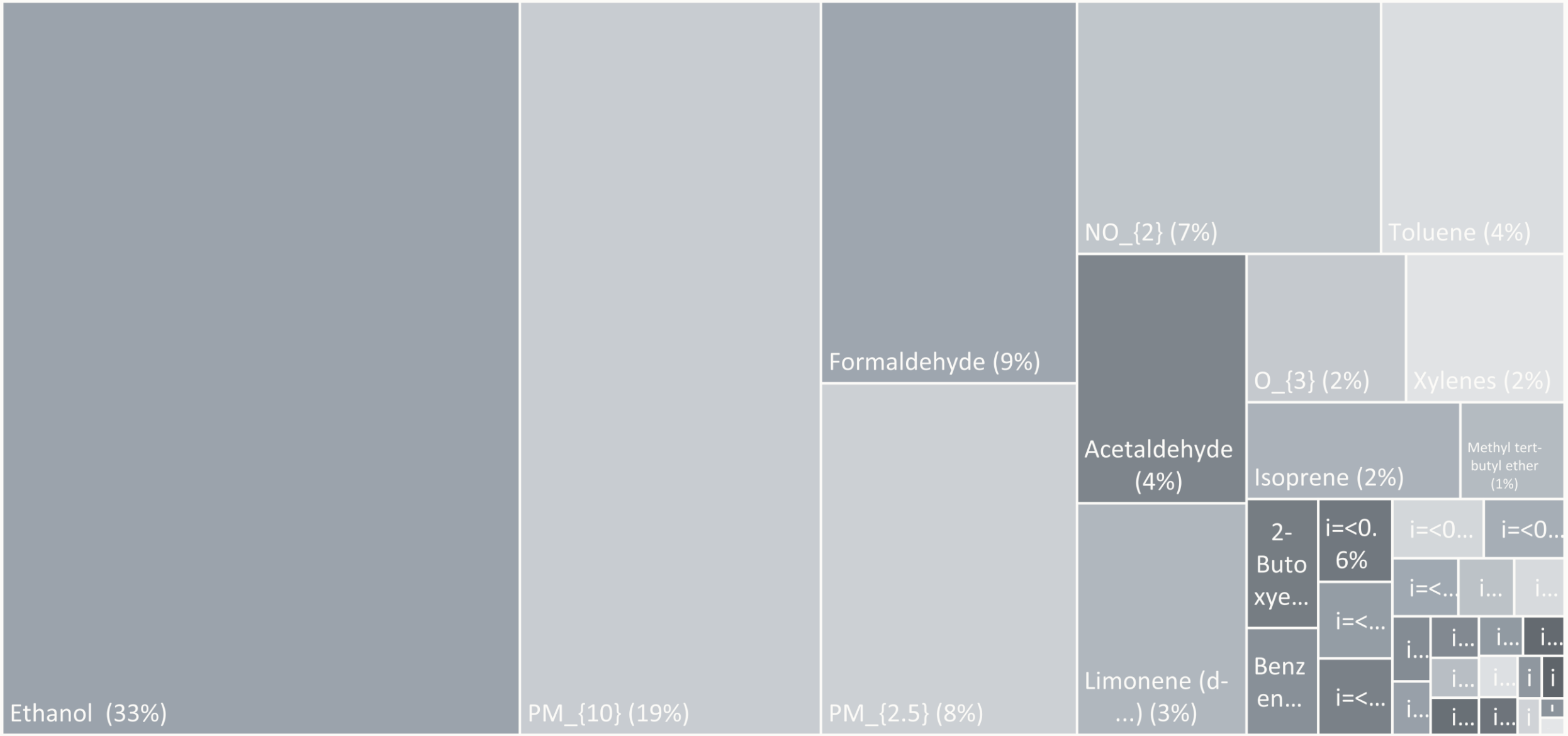


Concentrations

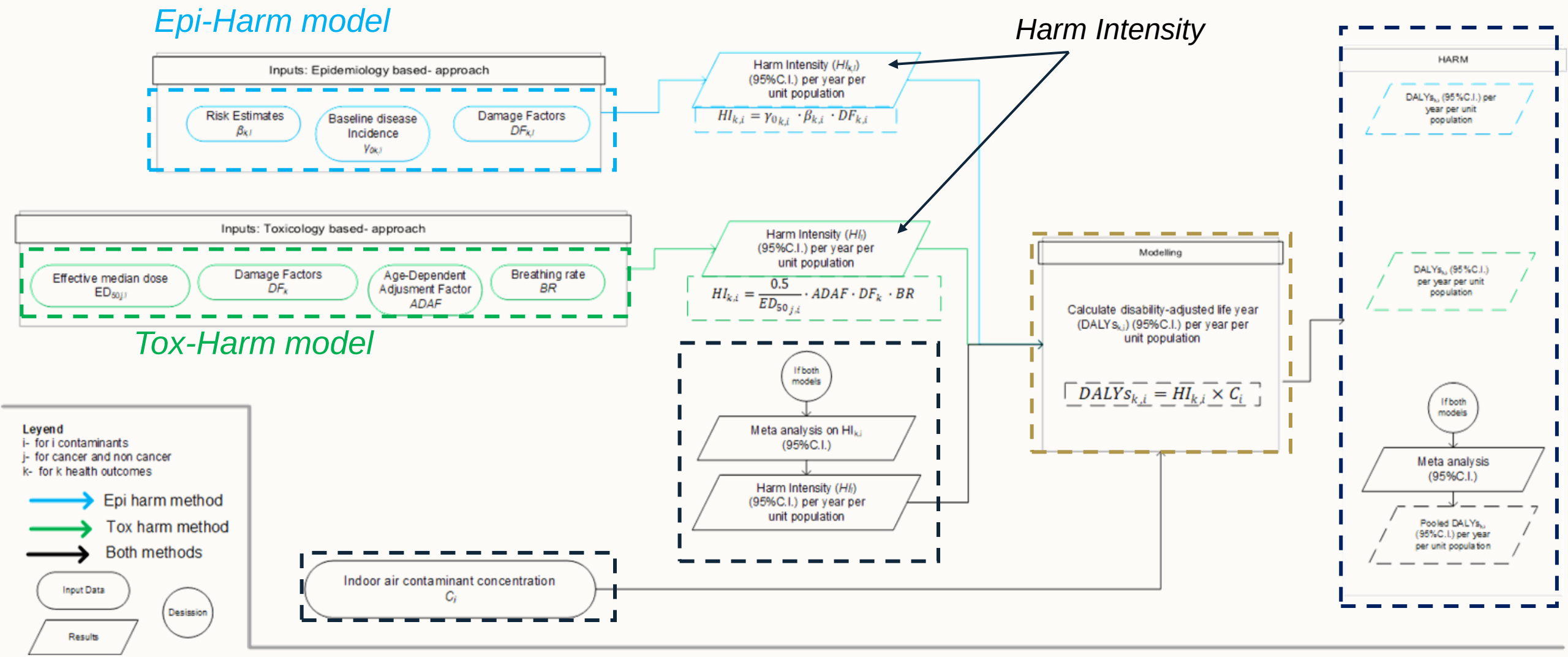


[µg/m³ or Bq/m³ or CFU/m³]

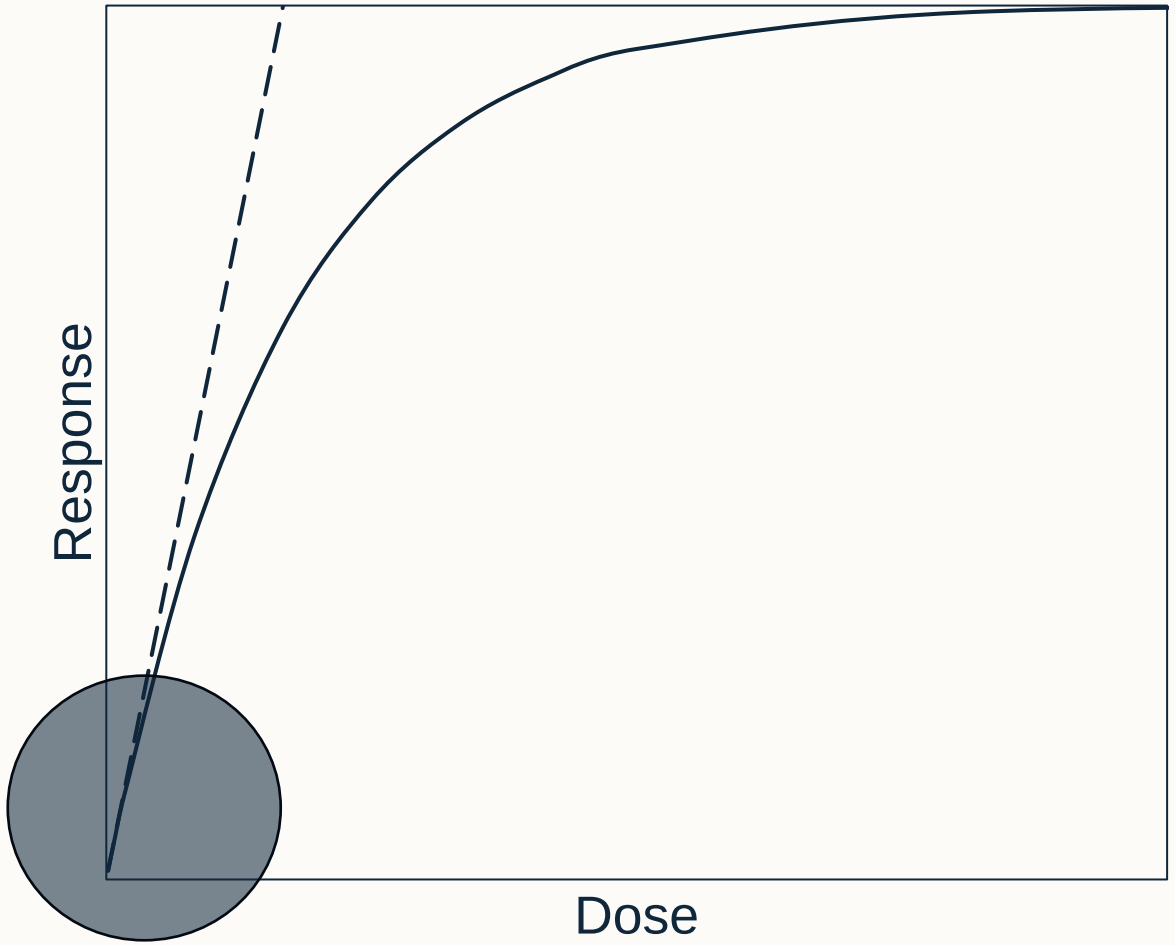
Concentrations



Harm model


Epi-Harm model
Harm Intensity
Inputs: Epidemiology based- approach
Risk Estimates $\beta_{k,i}$
Baseline disease Incidence $\gamma_{0k,i}$
Damage Factors $DF_{k,i}$
Harm Intensity ($HI_{k,i}$) (95%C.I.) per year per unit population
$HI_{k,i} = \gamma_{0\,k,i} \cdot \beta_{k,i} \cdot DF_{k,i}$
Inputs: Toxicology based- approach
Effective median dose $ED_{50\,j,i}$
Damage Factors DF_k
Age-Dependent Adjusment Factor $ADAF$
Breathing rate BR
Harm Intensity (HI_j) (95%C.I.) per year per unit population
$HI_{k,i} = \frac{0.5}{ED_{50\,j,i}} \cdot ADAF \cdot DF_k \cdot BR$
Tox-Harm model
If both models
Meta analysis on $HI_{k,i}$ (95%C.I.)
Harm Intensity (HI_j) (95%C.I.) per year per unit population
Modelling
Calculate disability-adjusted life year ($DALYs_{k,i}$) (95%C.I.) per year per unit population
$DALYs_{k,i} = HI_{k,i} \times C_i$
HARM
$DALYs_{k,i}$ (95%C.I.) per year per unit population
$DALYs_{k,i}$ (95%C.I.) per year per unit population
If both models
Meta analysis (95%C.I.)
Pooled $DALYs_{k,i}$ (95%C.I.) per year per unit population
Indoor air contaminant concentration C_i
Leyend
i- for i contaminants
j- for cancer and non cancer
k- for k health outcomes
Epi harm method
Tox harm method
Both methods
Input Data
Desission
Results

Linearity

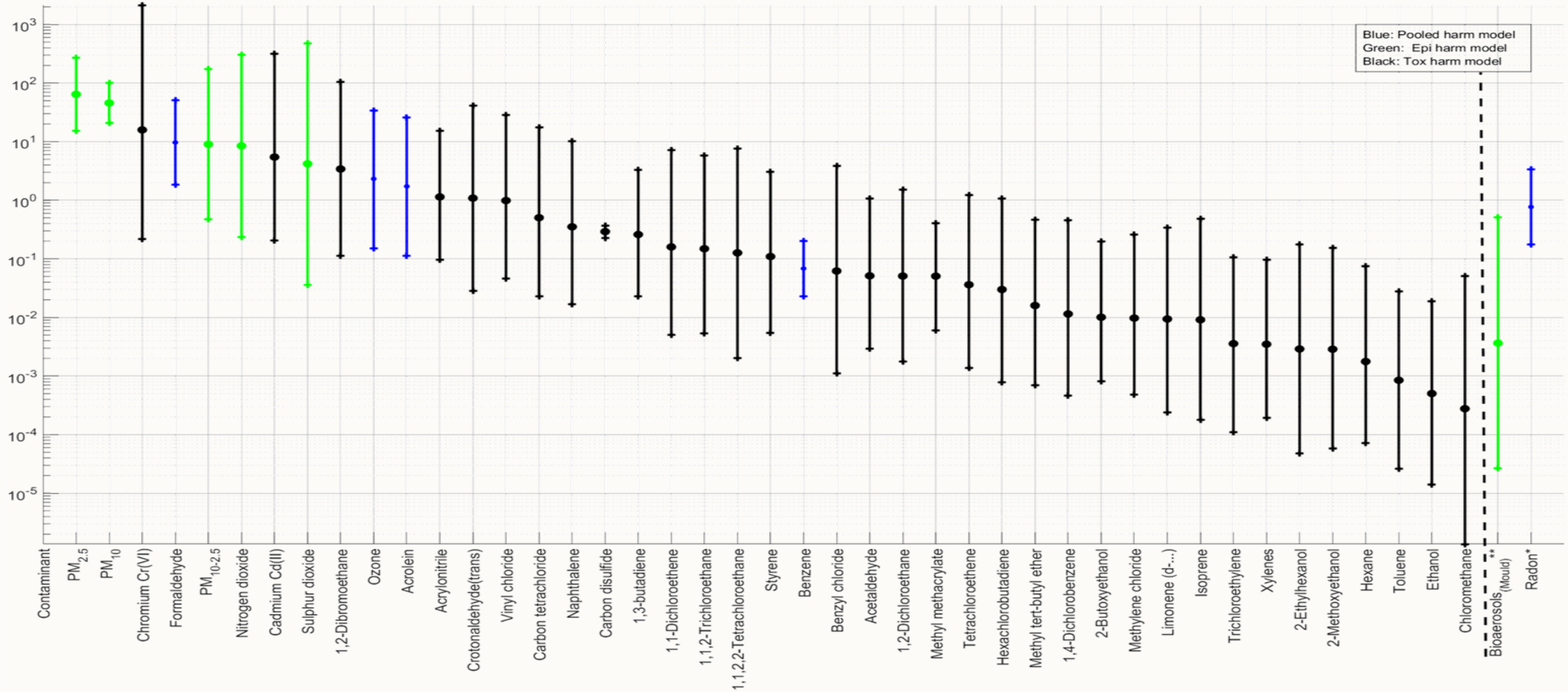


$$Harm = C \times HI$$

[DALYs/person/year] = [μg/m^3] × [DALYs/μg/m^3/person/year]

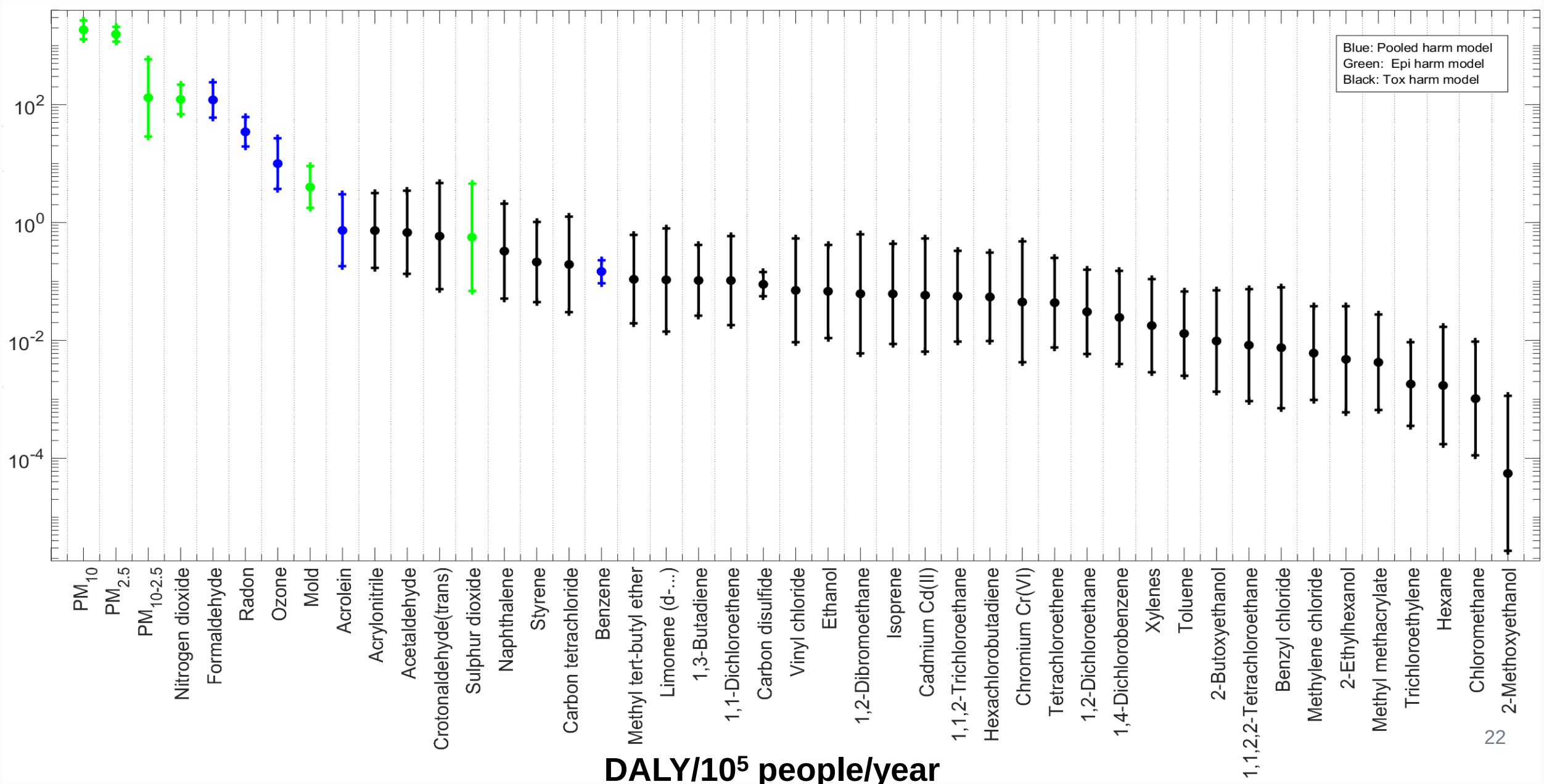
(or per Bq/m^3 or per CFU/m^3)

Harm intensity

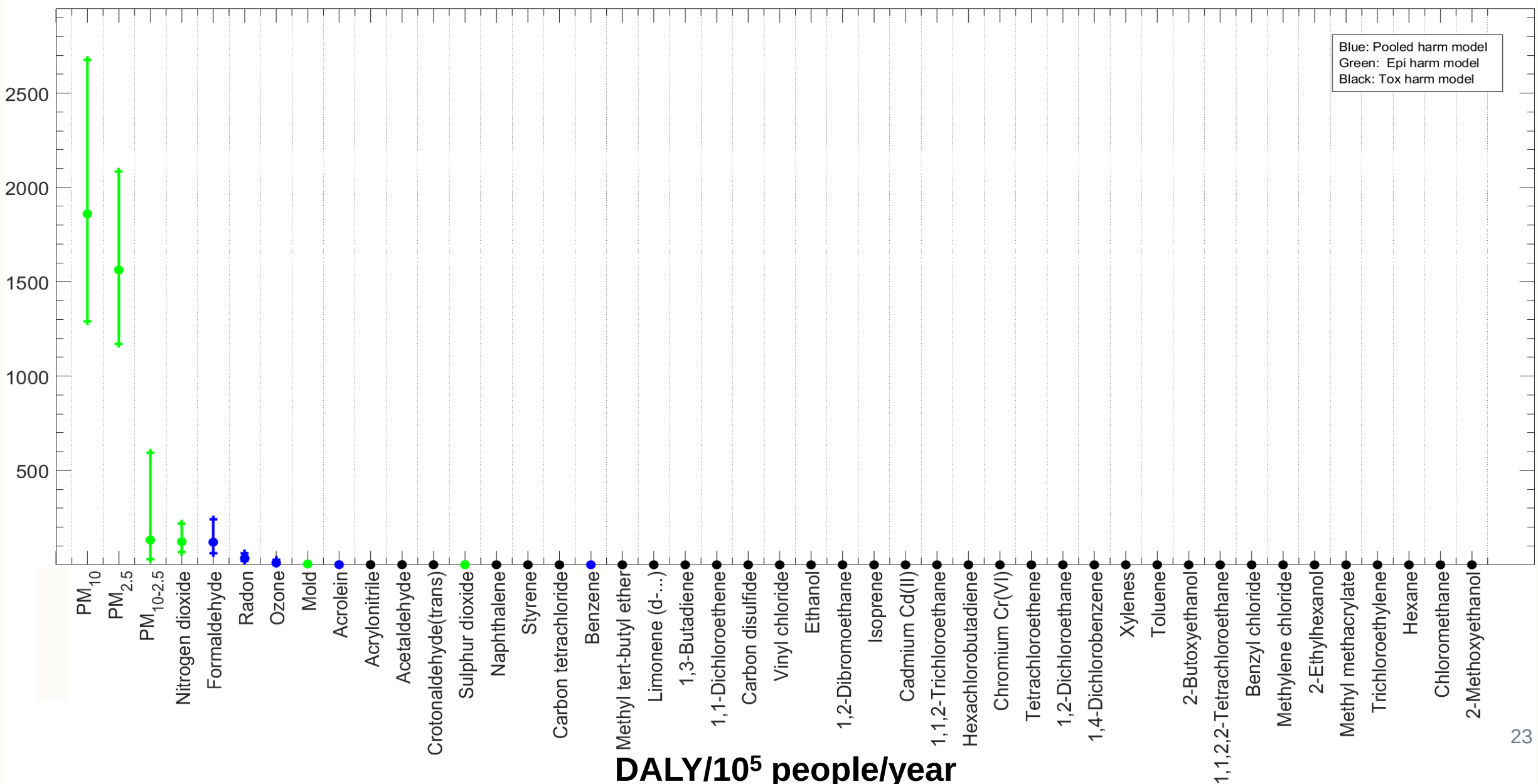


DALY/(μg/m³)/10⁵ people/year [or per Bq/m³ or per CFU/m³]

Total harm

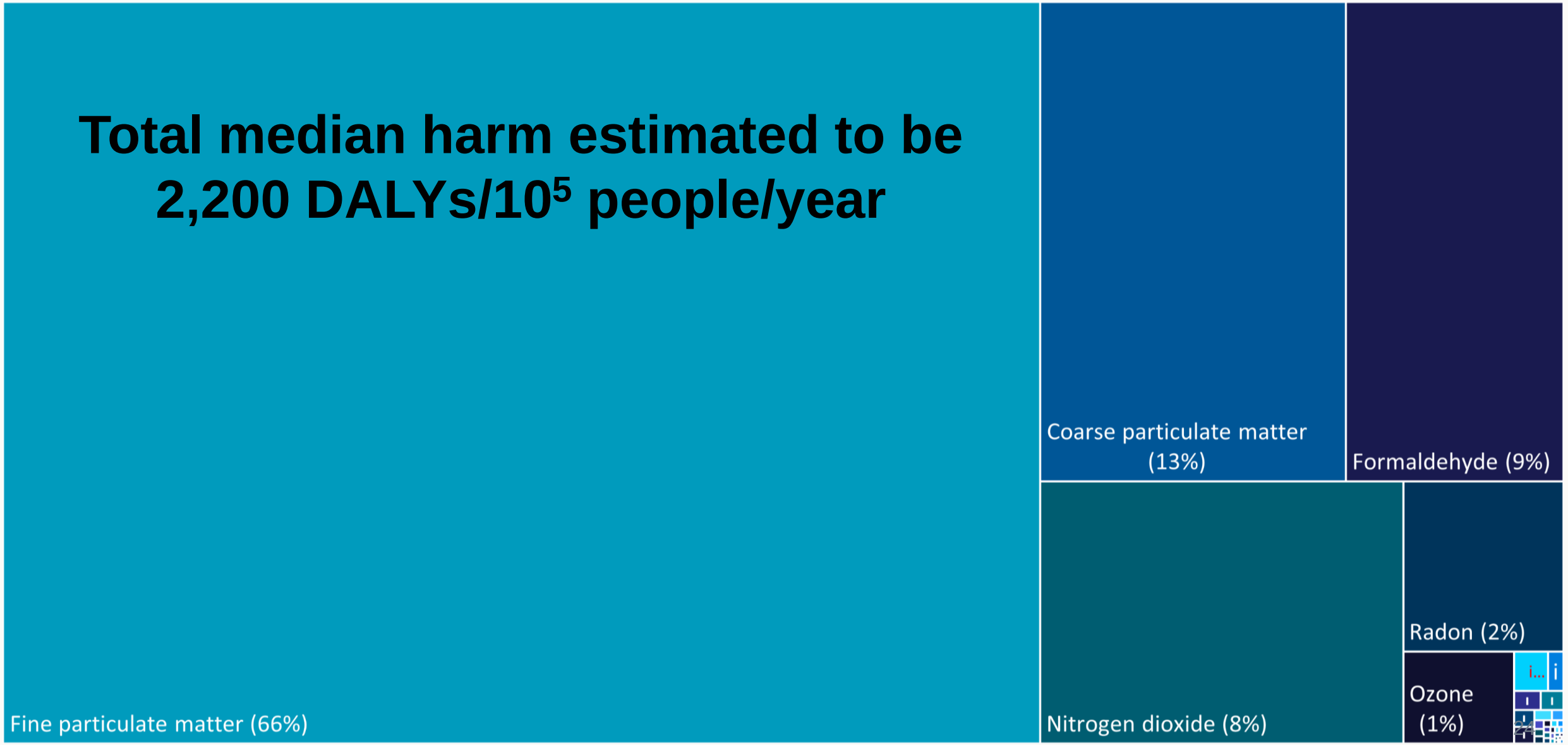

Blue: Pooled harm model
Green: Epi harm model
Black: Tox harm model
10^2
10^0
10^{-2}
10^{-4}
PM10
PM2.5
PM10-2.5
Nitrogen dioxide
Formaldehyde
Radon
Ozone
Mold
Acrolein
Acrylonitrile
Acetaldehyde
Crotonaldehyde(trans)
Sulphur dioxide
Naphthalene
Styrene
Carbon tetrachloride
Benzene
Methyl tert-butyl ether
Limonene (d-...)
1,3-Butadiene
1,1-Dichloroethene
Carbon disulfide
Vinyl chloride
Ethanol
1,2-Dibromoethane
Isoprene
Cadmium Cd(II)
1,1,2-Trichloroethane
Hexachlorobutadiene
Chromium Cr(VI)
Tetrachloroethene
1,2-Dichloroethane
1,4-Dichlorobenzene
Xylenes
Toluene
2-Butoxyethanol
1,1,2,2-Tetrachloroethane
Benzyl chloride
Methylene chloride
2-Ethylhexanol
Methyl methacrylate
Trichloroethylene
Hexane
Chloromethane
2-Methoxyethanol
DALY/10^5 people/year

Total harm


Blue: Pooled harm model
Green: Epi harm model
Black: Tox harm model
2500
2000
1500
1000
500
PM10
PM2.5
PM10-2.5
Nitrogen dioxide
Formaldehyde
Radon
Ozone
Mold
Acrolein
Acrylonitrile
Acetaldehyde
Crotonaldehyde(trans)
Sulphur dioxide
Naphthalene
Styrene
Carbon tetrachloride
Benzene
Methyl tert-butyl ether
Limonene (d-...)
1,3-Butadiene
1,1-Dichloroethene
Carbon disulfide
Vinyl chloride
Ethanol
1,2-Dibromoethane
Isoprene
Cadmium Cd(II)
1,1,2-Trichloroethane
Hexachlorobutadiene
Chromium Cr(VI)
Tetrachloroethene
1,2-Dichloroethane
1,4-Dichlorobenzene
Xylenes
Toluene
2-Butoxyethanol
1,1,2,2-Tetrachloroethane
Benzyl chloride
Methylene chloride
2-Ethylhexanol
Methyl methacrylate
Trichloroethylene
Hexane
Chloromethane
2-Methoxyethanol
DALY/10^5 people/year

Total harm

Total median harm estimated to be 2,200 DALYs/10^5 people/year



Total Harm (DALYs)

Dwelling IAQ	Alcoholism	Smoking	Transport injuries
2,200	1,200	2,600	1,000

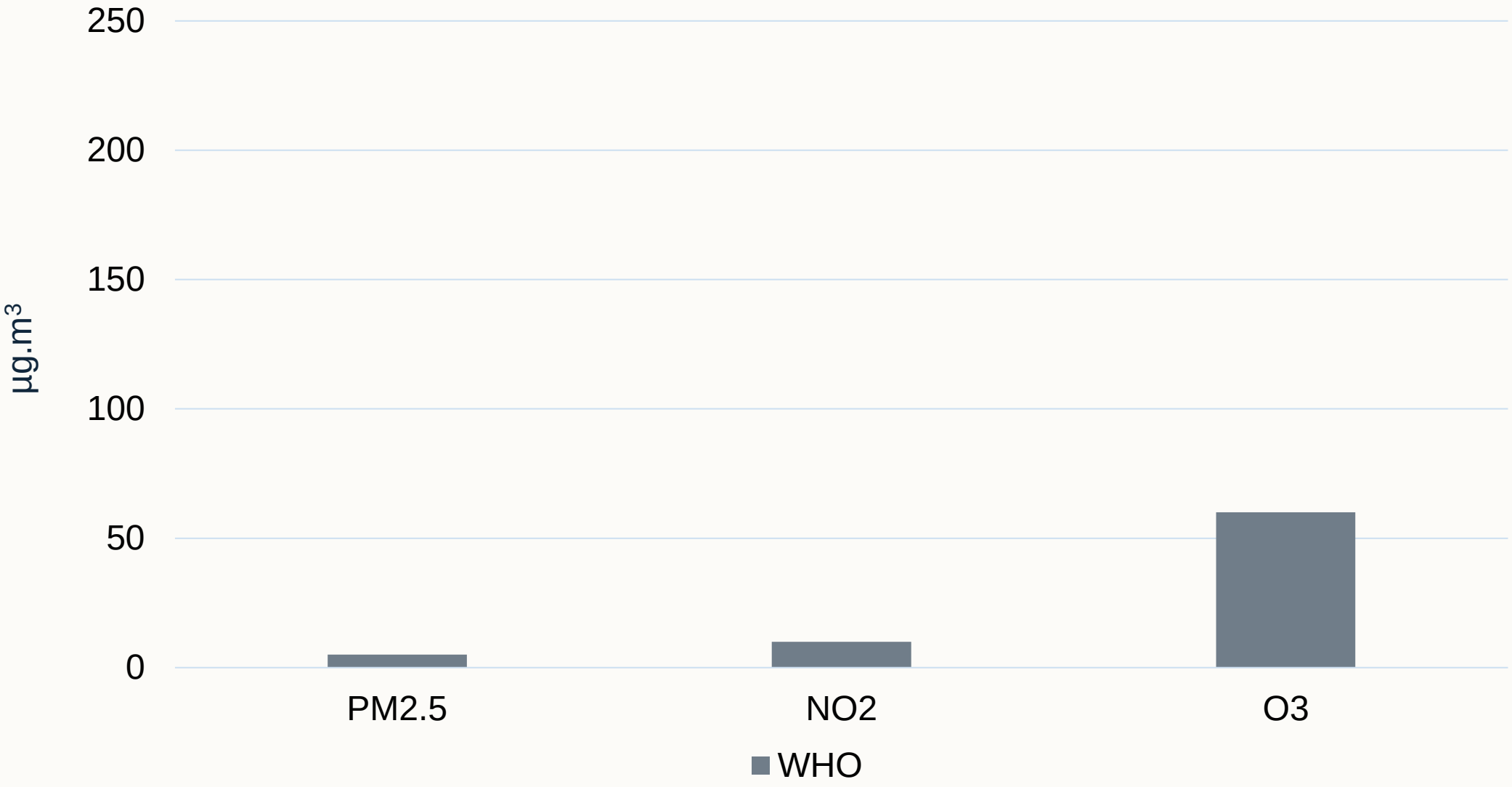
Contaminants of Concern

	Harm (DALYs/10^5 people/year)	Harm Intensity (DALYs/$\mu g.m^{-3}/10^5$ people/year)
$PM_{2.5}$	1600	60
$PM_{10-2.5}$	130	3.8
Nitrogen Dioxide (NO_2)	120	5.7
Formaldehyde (HCHO)	120	4.3
Radon (Rn)	34	0.44
Ozone (O_3)	10	1.3

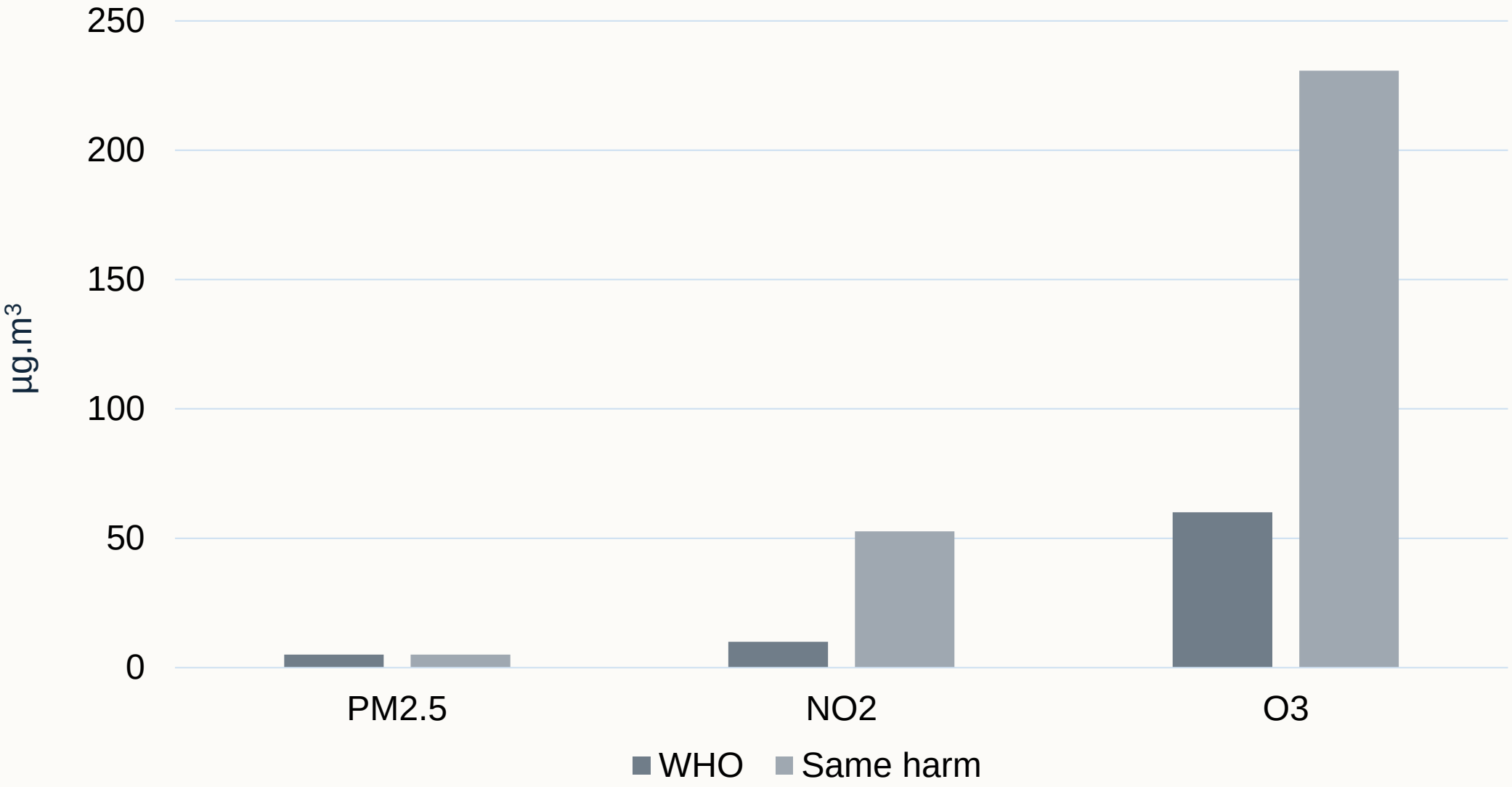
Harm Intensities for CoCs

	Harm Intensity (HI) (DALYs/µg.m^{-3}/10^{5} people/year)	HI Limiting Concentration (µg.m^{-3} or bq.m^{-3})
$PM_{2.5}$	60	50
$PM_{10-2.5}$	3.8	25
Formaldehyde (HCHO)	4.3	50
Nitrogen Dioxide (NO_2)	5.7	240
Ozone (O_3)	1.3	500
Radon (Rn)	0.44	450

Harm from WHO threshold values



Harm from WHO threshold values



Harm budget

Harm budget

Reference scenario

- Singer *et al.* 2020. Indoor air quality in California homes with code-required mechanical ventilation. Indoor air 30(5).
- N=70
- *All* comply with CalEnergyCode

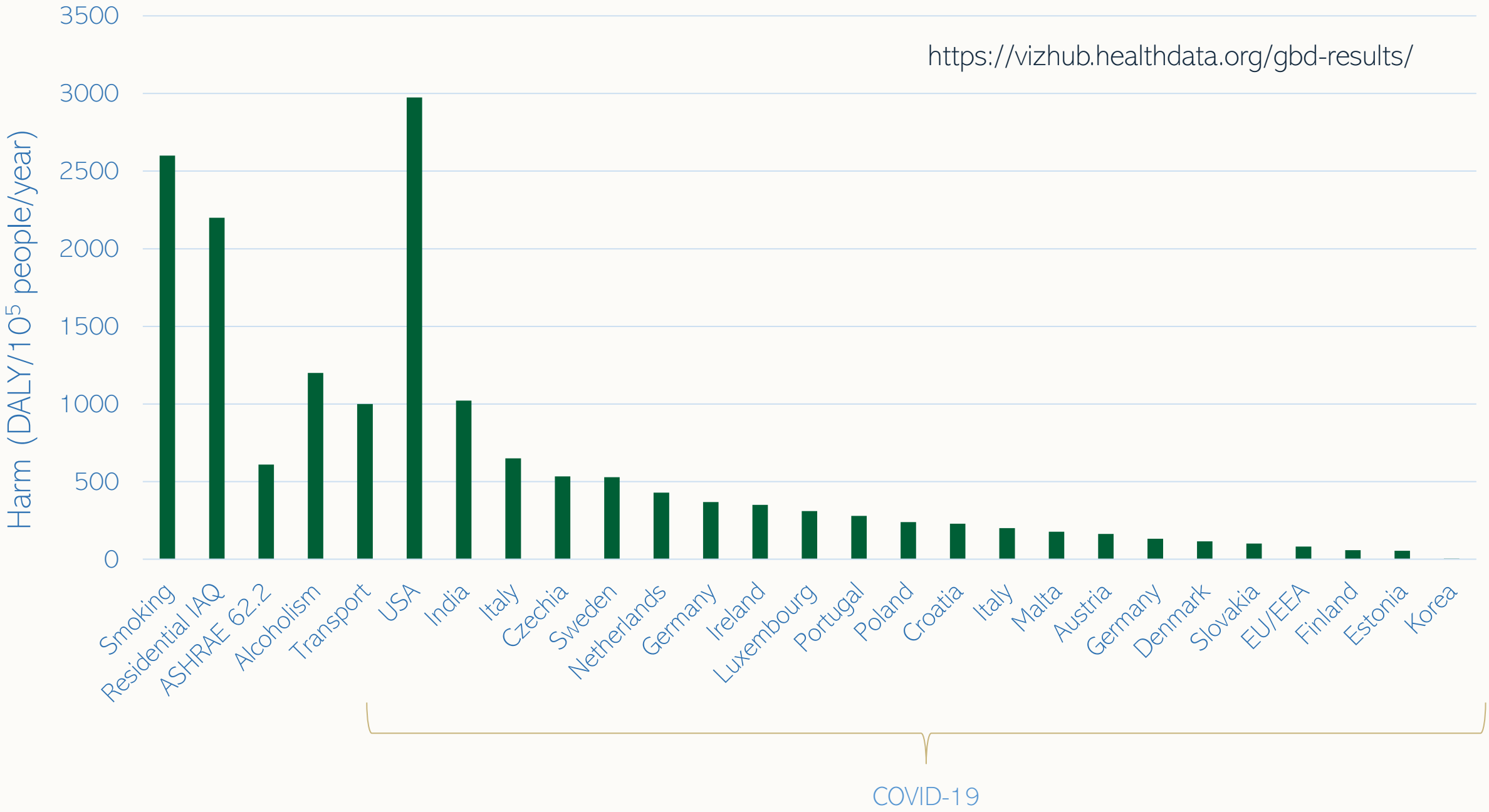
$PM_{2.5}$	$5\mu g.m^{-3}$
HCHO	$23\mu g.m^{-3}$
NO_2	$9\mu g.m^{-3}$

Guideline values used for Rn ($100Bq/m^3$) and for O_3 ($40\mu g.m^{-3}$).

- Total harm of 610 DALYs/10^5 people/year

Harm (DALYs)

Reference	Dwelling IAQ	Alcoholism	Smoking	Transport injuries
610	2,200	1,200	2,600	1,000


https://vizhub.healthdata.org/gbd-results/
Harm (DALY/10^5 people/year)
3500
3000
2500
2000
1500
1000
500
0
Smoking
Residential IAQ
ASHRAE 62.2
Alcoholism
Transport
USA
India
Italy
Czechia
Sweden
Netherlands
Germany
Ireland
Luxembourg
Portugal
Poland
Croatia
Italy
Malta
Austria
Germany
Denmark
Slovakia
EU/EEA
Finland
Estonia
Korea
COVID-19

References

1. Morantes G, Jones B, Molina C, Sherman MH. Harm from Residential Indoor Air Contaminants. Environmental Science & Technology. 2024;58(1):242-57.
2. Jones, B. Metrics of Health Risks from Indoor Air. VIP 36. Air Infiltration and Ventilation Centre. 2017.
3. Jones B. Dallying with DALYs: A Proposed Harm-Based IAQ Procedure for Standard 62.2. ASHRAE Journal. February 2023

Conclusions

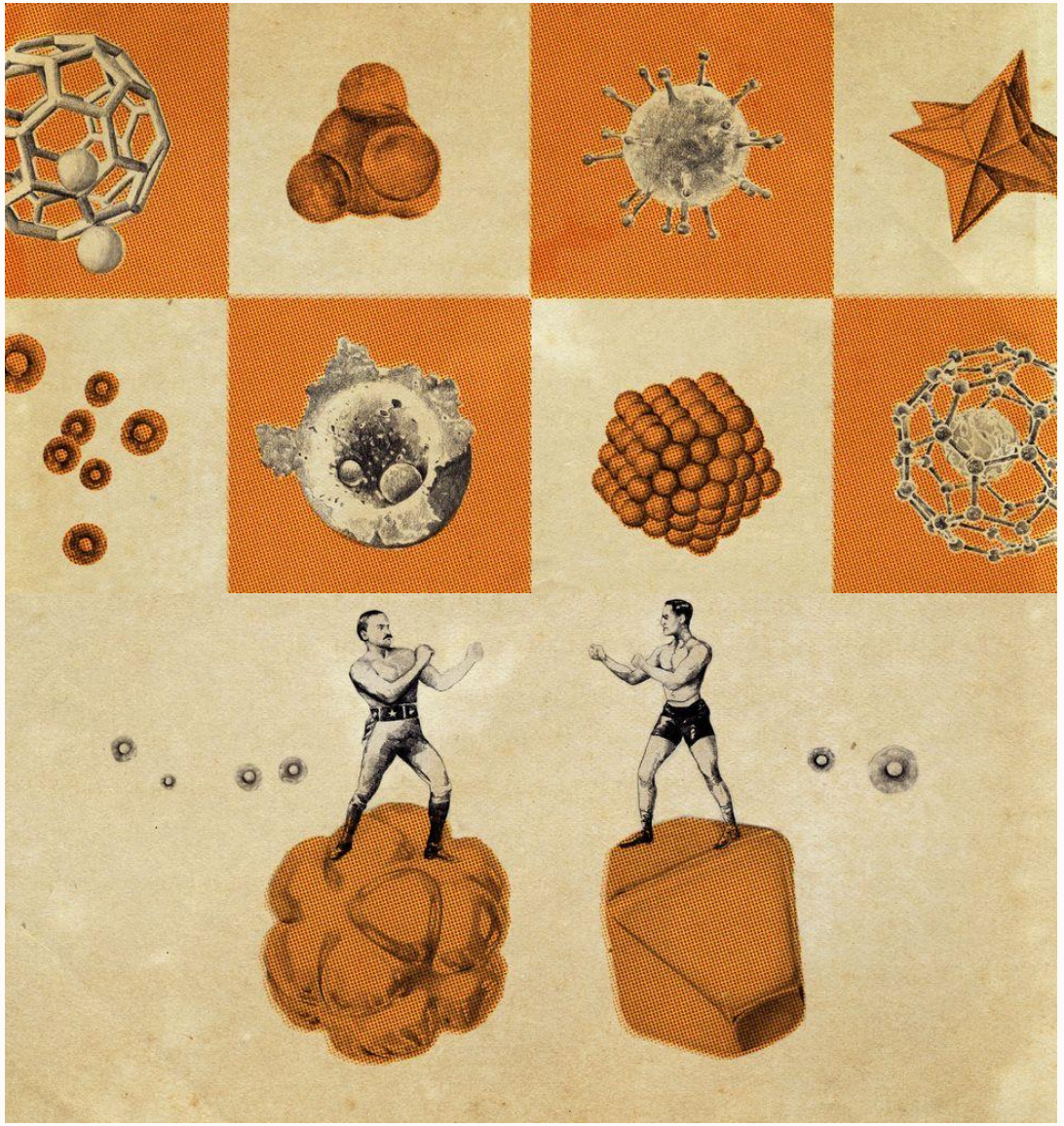
1. Developed a harm intensity metric that quantifies the chronic health impact (in DALYs) per unit concentration of an air contaminant. **They apply to any environment.**
2. Identified the most harmful indoor air contaminants in dwellings that should be prioritized declaring them *Contaminants of Concern*.
3. Estimated the total harm caused by typical exposures to indoor air contaminants in dwellings.
4. Propose the concept of a ***harm budget*** to define acceptable indoor air quality based on the harm caused by priority contaminants.
5. We can include expand our standards to include the harm approach for infectious aerosols.

Questions?

benjamin.jones@nottingham.ac.uk

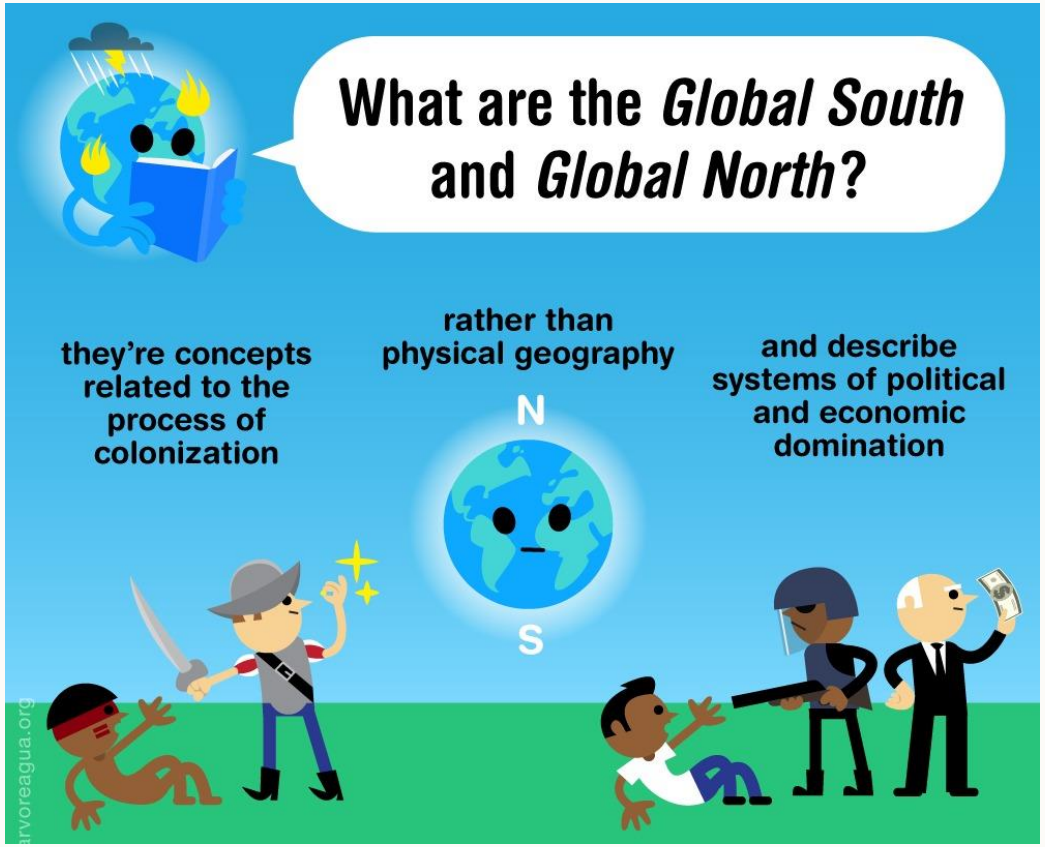
Equitoxicity

- We assume PM equitoxicity
- PM composition does vary
- Separate indoor/outdoor PM risk estimates are unavailable
- PM size predicts long-term harm
- Indoor PM found to be coated in PAHs and other VOCs
- Would have to be 12x less harmful to be equivalent to PM_{10}, HCHO and NO_2
- Precautionary principle



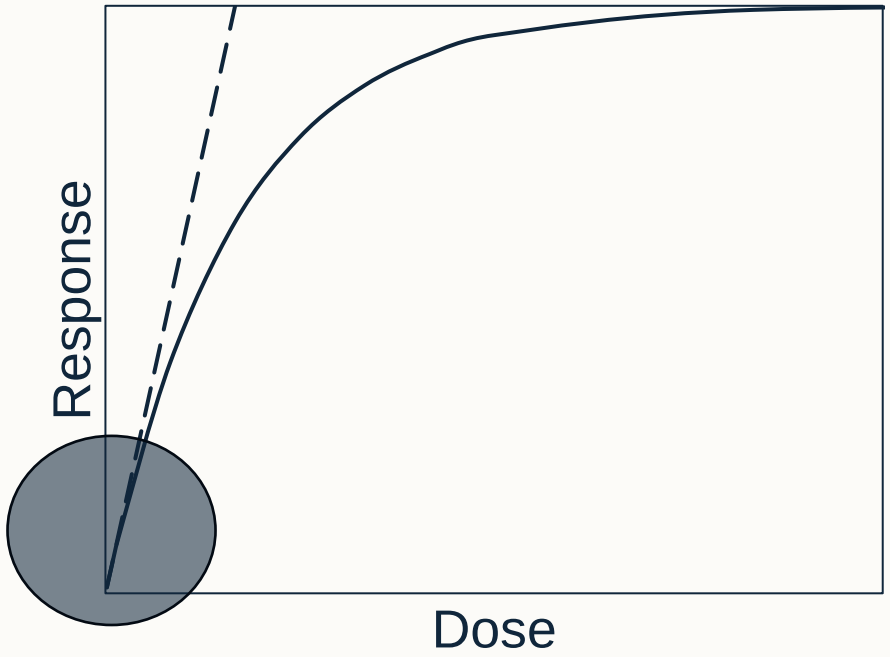
What do these concentrations represent?

- Indoor concentrations represent the Global North
  (USA, China, Canada, UK most represented)
- Caution needed for regional comparisons due to lifestyle/location differences
- Include common household activities
- Avoid niche construction types (e.g. Passivhaus)
- Fieldwork essential to reduce uncertainty



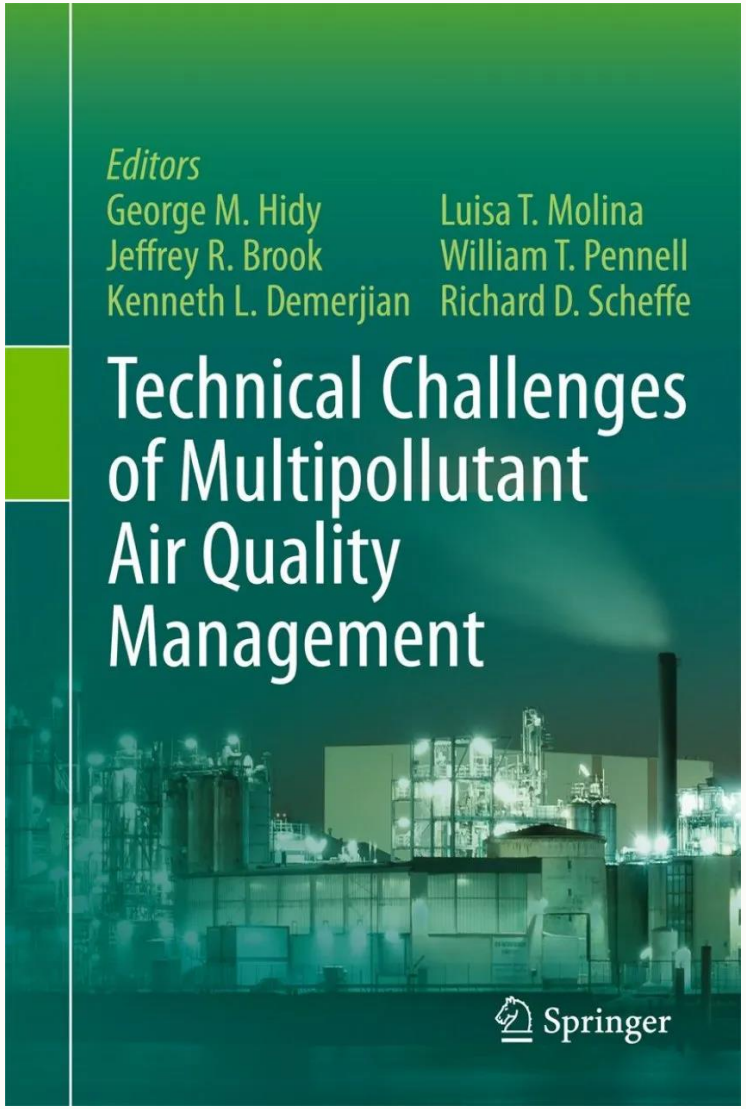
Linearity

- We don’t know if the Poissonian C-R relationship represents these contaminants
- It is good modelling practice to linearise a model, if possible
- It is possible ***here*** because the concentrations commonly found in dwellings are low enough
- Harm Intensities might be given with upper concentration limits
- We have done an error analysis and this will be in the Annex 86 report



Synergistic responses

- We do not do this
- It is not possible to do
- Assumes additivity for indoor pollutant effects.
- Additivity simplifies complex interactions, may underestimate/overestimate impacts.
- Future research should explore pollutant interactions for accuracy.



What about acute effects?

- This data is for chronic harm
- Some contaminants may have significant short-term acute impacts
- Estimate acute harm is a future project

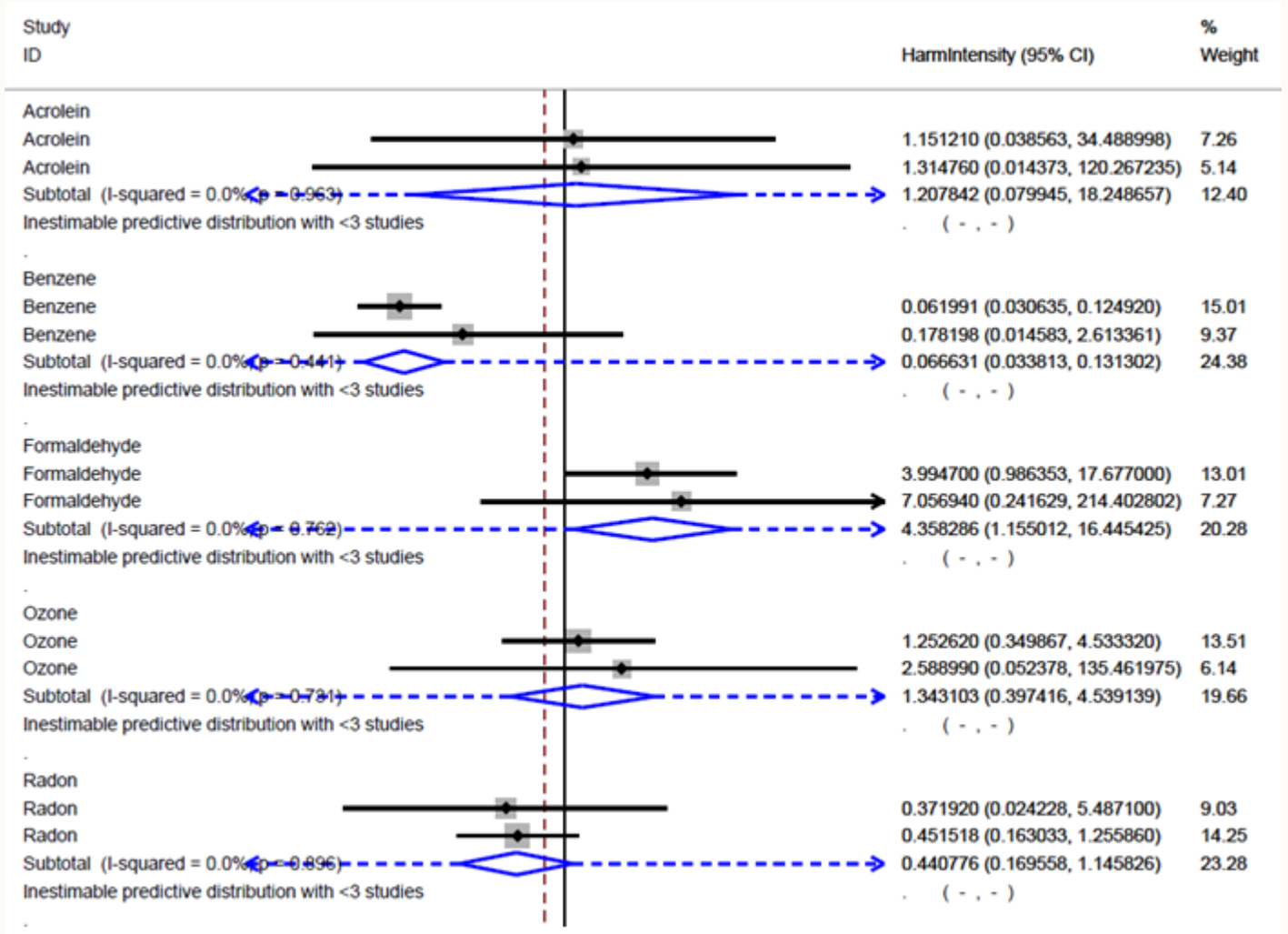
Where does the health data come from?

- Toxicological
  - USEtox 2.0
  - Global burden of disease collaborative network for damage factors
  - Standard breathing rate

- Epidemiological
  - Global burden of disease collaborative network (incidence rates, damage factors))
  - Academic literature (for risk estimates)

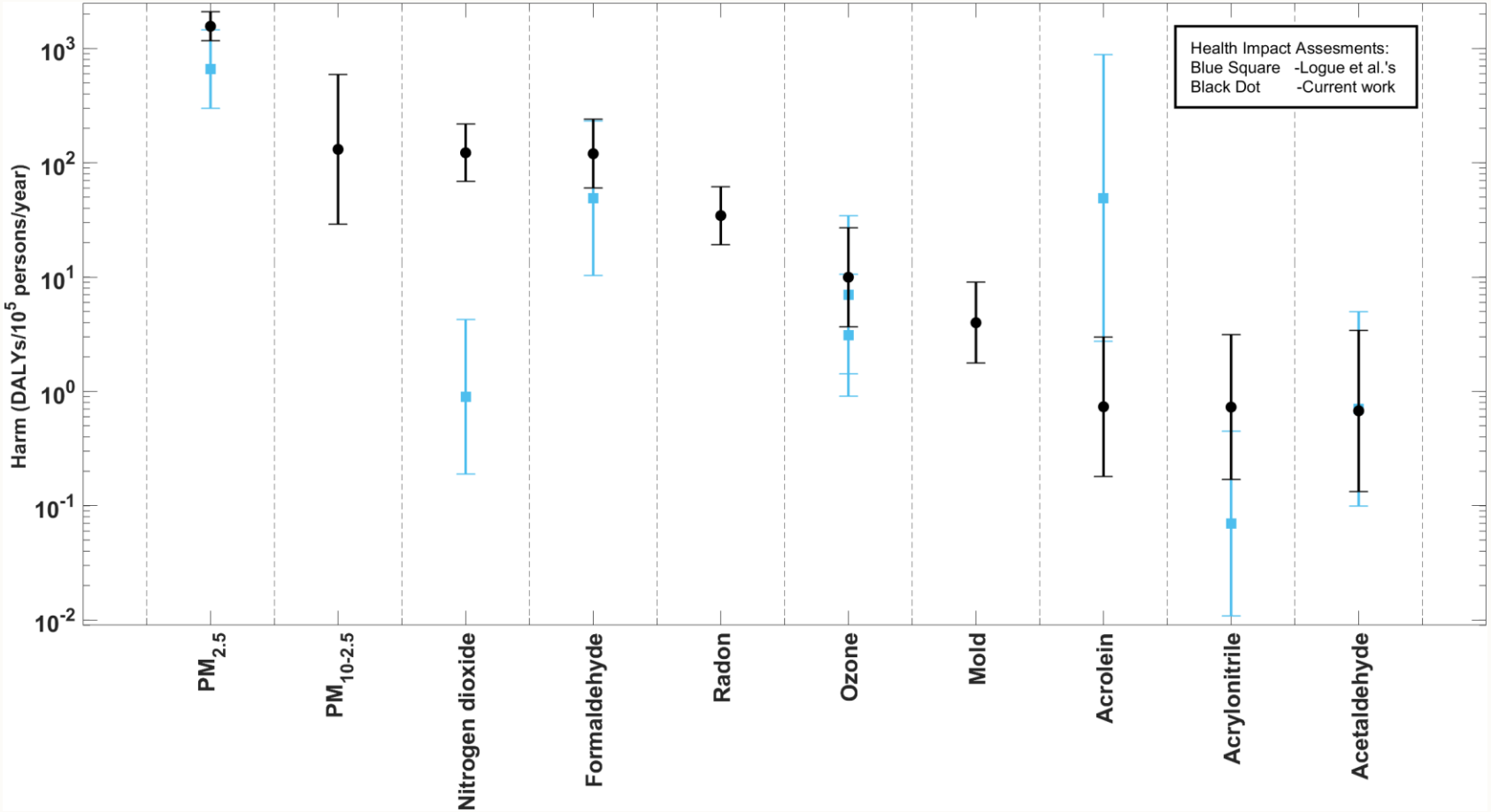
Merging of epi and tox data

- Central estimates may not align due to methodological differences
- Perfect parity is challenging
- Despite challenges, parameters align



Differences from Logue

- Damage factors from 2019 Global Burden of Disease study.
- Consulted toxicology studies with lower uncertainty
- Health data, like PM2.5, became more robust and precise



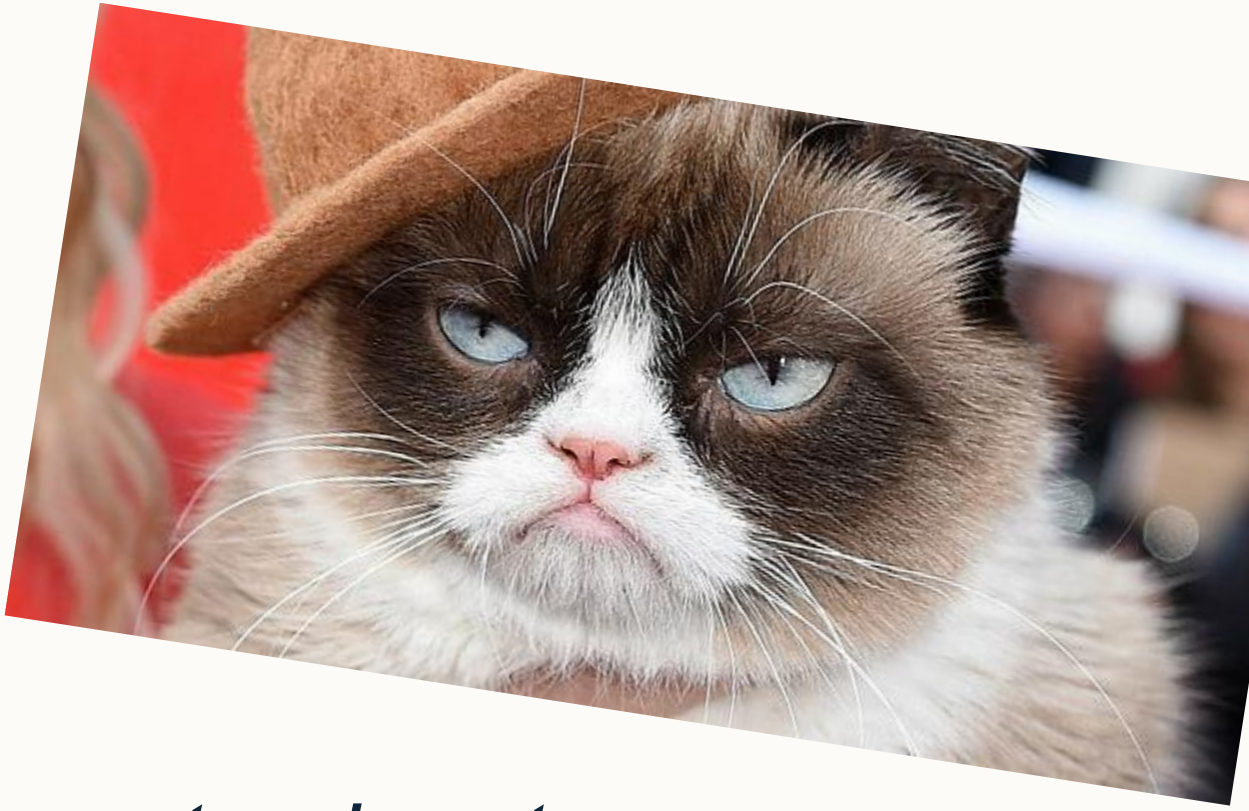
My favourite contaminant isn't on the list ☹

There is either

- insufficient data to determine a harm intensity

OR

- It isn't harmful in the concentrations found in dwellings



People aren't harmed by the contaminant they aren't exposed to….

Questions?

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