Health impacts of air pollution - burden of disease and other aspects [optimizing] for emission controls

1st INTERNATIONAL REAL-LIFE EMISSIONS WORKSHOP ON SMALL-SCALE COMBUSTION :
The measurement methods and emission components for the solid fuel combustion appliances
2022-11-09

Otto Hänninen
Ph.D., Adj.prof.

Finnish Institute for Health and Welfare (THL)

First Session:
Evaluation of emission components to be measured

Central European times (CET)

08:40 – 09:00	Health impacts of air pollution - burden of disease and other aspects for [optimizing] emission controls. *Otto Hänninen, The Finnish Institute for Health and Welfare (THL)*
09:00 – 09:20	How does the composition of small-scale combustion emissions affect their climate effects? *Harri Kokkola, Finnish Meteorological Institute (FMI)*
09:20 – 10:00	Important physical and chemical properties of particulate and gaseous emissions from small scale solid fuel combustion. *Karna Dahal, University of Eastern Finland (UEF)*

What is toxic in particles?

How about gases:
CO
NO2
O3; OH- etc.
SO2
1C, 2~10C VOCs

PP – BC, OC, PAH… SS
SP – SIA, SOA

- a particle is not a particle: [chemical] composition
  - (heavy) metals; PAHs; (organic|inorganic)HCs; BC
  - combustion particles; particles from specific source(s)

- particle number (PNC, 1 cm^{-3})
- particle surface area (SAC, 1 μm^2 cm^{-3})

- size fraction: [TSP,] PM10, PM2.5
- cf. [number|surface area|volume|mass] size distribution ($dC\ dDp^{-1}$)
- mass ($\mu g\ m^{-3}$)

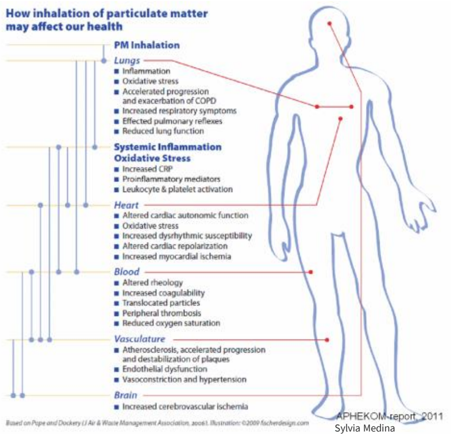
Air pollution and health

Traditional endpoints affecting adults and elderly:

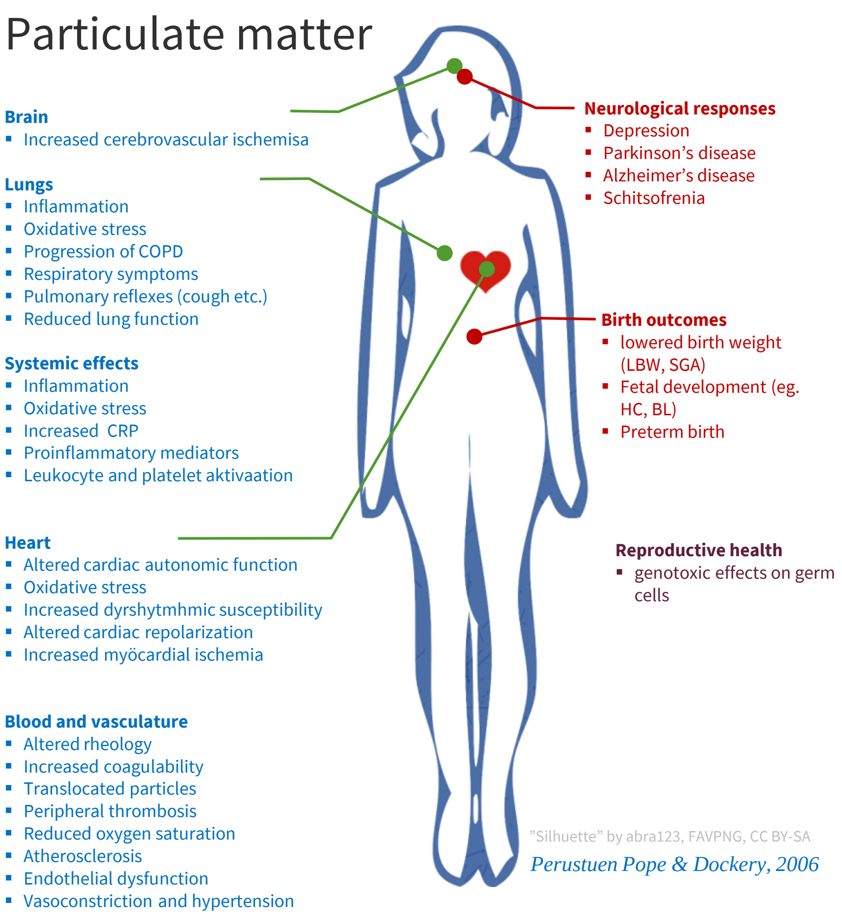
- **Mortality**
- Respiratory diseases
- Cardiovascular diseases
- Lung cancer

More recent additions

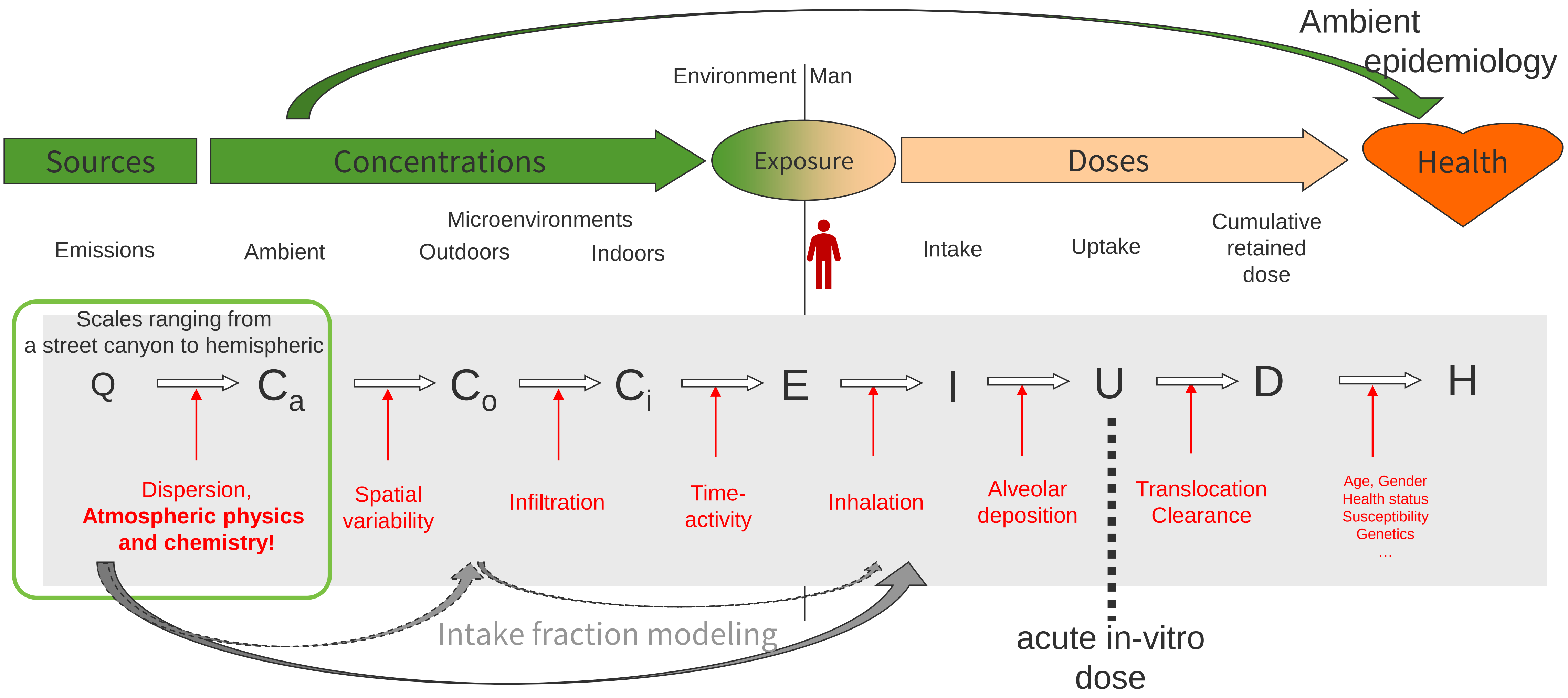
- Birth outcomes
- Reproductive health
- Neurological diseases



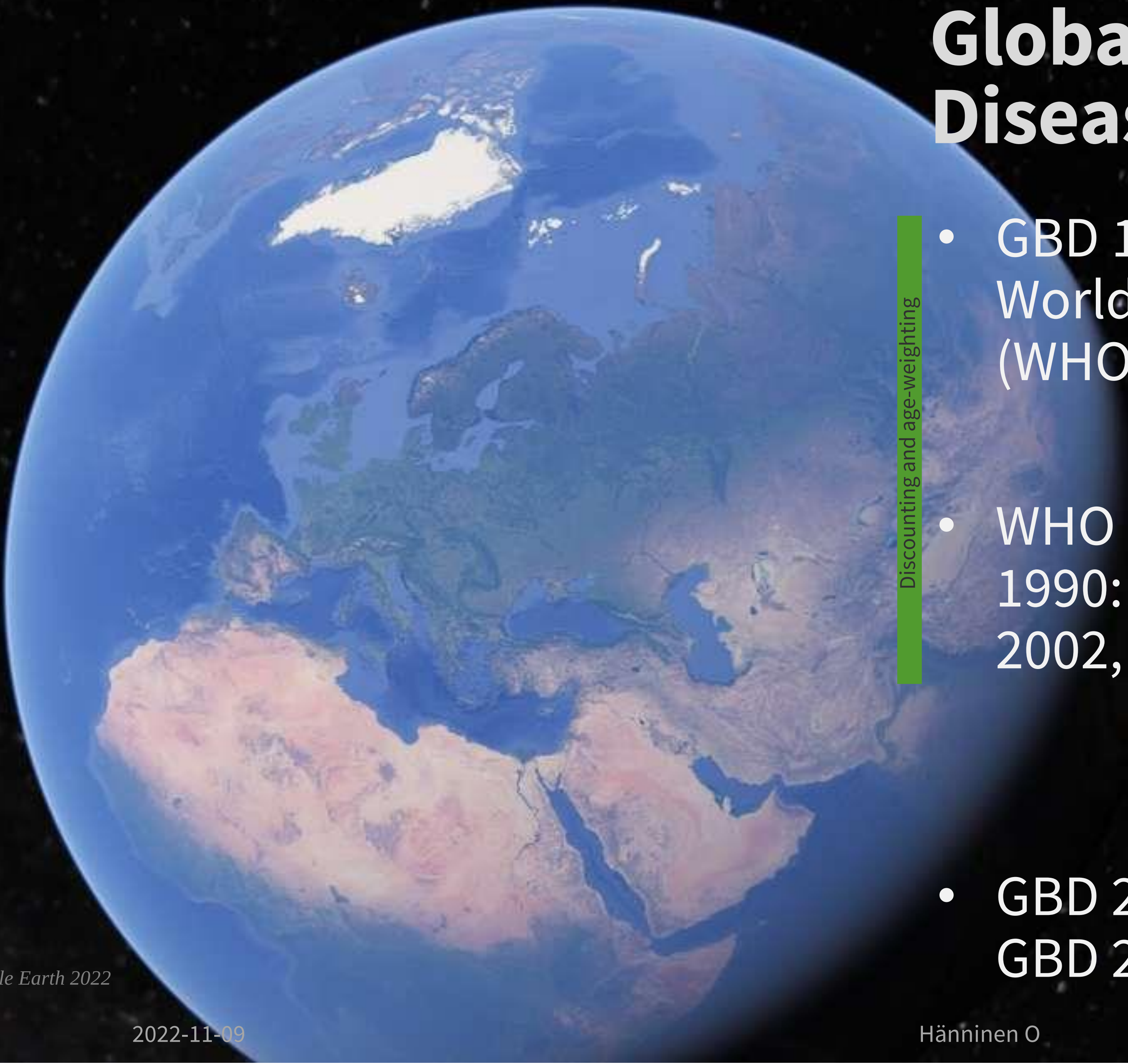
How inhalation of particulate matter may affect our health?



Exposure metrics and processes



Global Burden of Disease (GBD) -studies



Google Earth 2022

Discounting and age-weighting

- GBD 1990: by World Bank, with World Health Organization (WHO)
- WHO Disease Burden Unit in 1990: GBD estimates 2000, 2001, 2002, 2004
- GBD 2010: 1990-2010 (IHME)
  GBD 2013-2015-2016-2017-2019

THE WORLD BANK IBRD • IDA

World Health Organization

BILL & MELINDA GATES foundation

IHME

GBD 2019 Risk factors

GBD 2019 Risk Factors Collaborators*

- 204 countries
- 369 diseases and injuries
- 87 risk factors
- subnational level (12 countries)
- 1990-2010-2019
- Deaths, YLL, YLD, DALY
- Summary exposure values (SEV)
- Annualized rate of change (ARC)

Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019

GBD 2019 Risk Factors Collaborators*

Summary

Background Rigorous analysis of levels and trends in exposure to leading risk factors and quantification of their effect on human health are important to identify where public health is making progress and in which cases current efforts are inadequate. The Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2019 provides a standardised and comprehensive assessment of the magnitude of risk factor exposure, relative risk, and attributable burden of disease.

Methods GBD 2019 estimated attributable mortality, years of life lost (YLLs), years of life lived with disability (YLDs), and disability-adjusted life-years (DALYs) for 87 risk factors and combinations of risk factors, at the global level, regionally, and for 204 countries and territories. GBD uses a hierarchical list of risk factors so that specific risk factors (eg, sodium intake), and related aggregates (eg, diet quality), are both evaluated. This method has six analytical steps. (1) We included 560 risk–outcome pairs that met criteria for convincing or probable evidence on the basis of research

Lancet 2020; 396: 1223–49

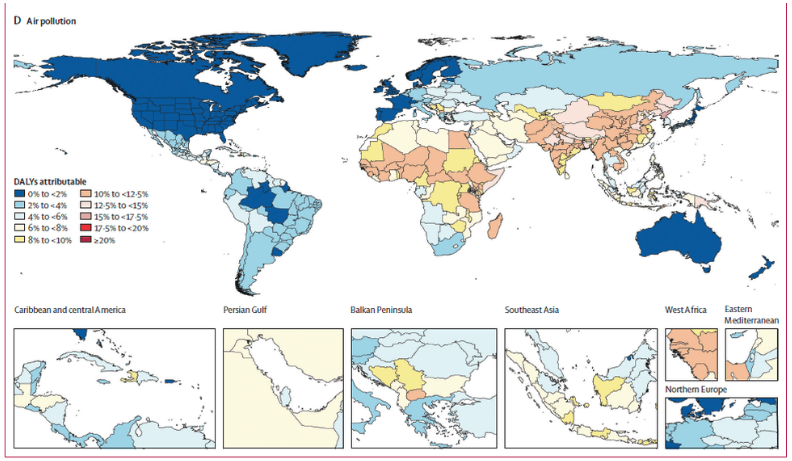
*For the list of Collaborators see

Viewpoint Lancet 2020; 396: 1135–59

Correspondence to: Prof Christopher J L Murray, Institute for Health Metrics and Evaluation, University of Washington, Seattle, WA 98195, USA cjlm@uw.edu

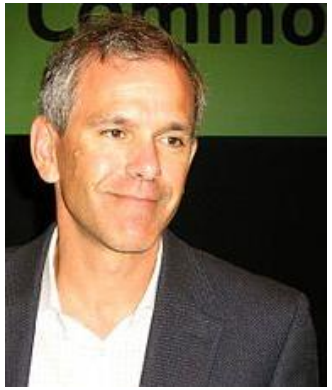
IHME

Dominant role of household air pollution (indoor air):



(Figure 6 continues on next page)

Figure 6: Percentage of all DALYs attributable to the five leading Level 2 risk factors, 2019
DALYs attributable to child and maternal malnutrition (A), high systolic blood pressure (B), tobacco (C), air pollution (D), and dietary risks (E). DALYs=disability-adjusted life-years.



Murray et al., 2022

Pollution and health

Published online October 19, 2017

The Lancet Commissions

The *Lancet* Commission on pollution and health

Philip J Landrigan, Richard Fuller, Nereus J R Acosta, Olusoji Adeyi, Robert Arnold, Niladri (Nil) Basu, Abdoulaye Bibi Baldé, Roberto Bertollini, Stephan Bose-O'Reilly, Jo Ivey Boufford, Patrick N Breysse, Thomas Chiles, Chulabhorn Mahidol, Awa M Coll-Seck, Maureen L Cropper, Julius Fobil, Valentin Fuster, Michael Greenstone, Andy Haines, David Hanrahan, David Hunter, Mukesh Khare, Alan Krupnick, Bruce Lanphear, Bindu Lohani, Keith Martin, Karen V Mathiasen, Maureen A McTeer, Christopher J L Murray, Johanita D Ndahimananjara, Frederica Perera, Janez Potočnik, Alexander S Preker, Jairam Ramesh, Johan Rockström, Carlos Salinas, Leona D Samson, Karti Sandilya, Peter D Sly, Kirk R Smith, Achim Steiner, Richard B Stewart, William A Suk, Onno C P van Schayck, Gautam N Yadama, Kandeh Yumkella, Ma Zhong

Executive summary

Pollution is the largest environmental cause of disease and premature death in the world today. Diseases caused by pollution were responsible for an estimated 9 million premature deaths in 2015—16% of all deaths worldwide—three times more deaths than from AIDS, tuberculosis, and malaria combined and 15 times more than from all wars and other forms of violence. In the most severely affected countries, pollution-related disease is responsible for more than one death in four.

Pollution disproportionately kills the poor and the vulnerable. Nearly 92% of pollution-related deaths occur

Pollution endangers planetary health, destroys eco-systems, and is intimately linked to global climate change. Fuel combustion—fossil fuel combustion in high-income and middle-income countries and burning of biomass in low-income countries—accounts for 85% of airborne particulate pollution and for almost all pollution by oxides of sulphur and nitrogen. Fuel combustion is also a major source of the greenhouse gases and short-lived climate pollutants that drive climate change. Key emitters of carbon dioxide, such as electricity-generating plants, chemical manufacturing facilities, mining operations, deforestation, and petroleum-powered vehicles, are also

Published Online October 19, 2017 http://dx.doi.org/10.1016/S0140-6736(17)32345-0

See Online/Comment http://dx.doi.org/10.1016/S0140-6736(17)32588-6 and http://dx.doi.org/10.1016/S0140-6736(17)32545-X

Arnhold Institute for Global Health (Prof P J Landrigan MD), Mount Sinai Heart (V Fuster MD), and Department of Environmental Medicine

R. Fuller

P. Landrigan

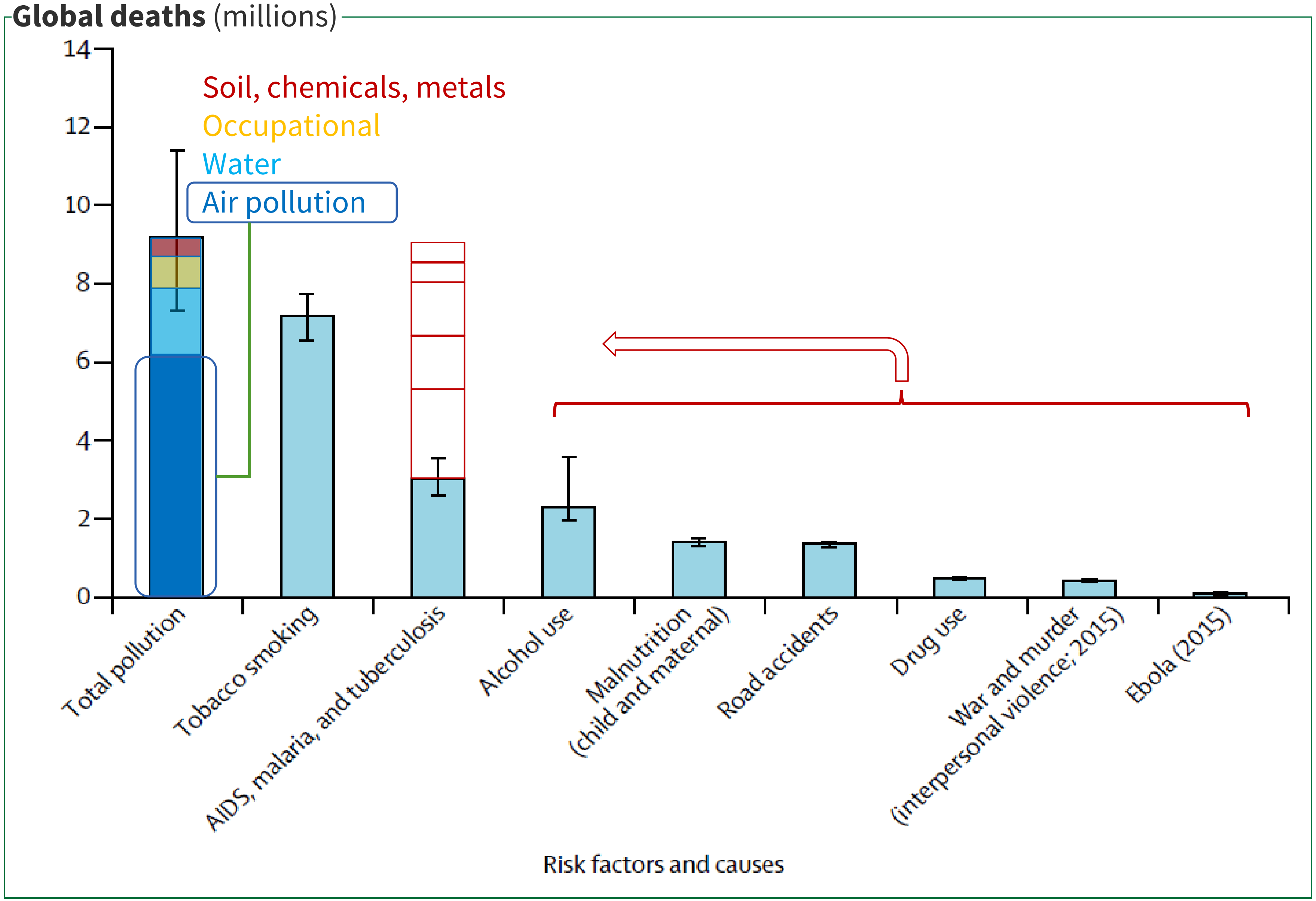


***Figure 5*: Global estimated deaths by major risk factor and cause, 2015**
Using data from the GBD Study, 2016.[41]

	GBD study best estimate (95% CI)	WHO best estimate (95% CI)
Air (total)	6·5 (5·7–7·3)	6·5 (5·4–7·4)
Household air	2·9 (2·2–3·6)	4·3 (3·7–4·8)
Ambient particulate	4·2 (3·7–4·8)	3·0 (3·7–4·8)
Ambient ozone	0·3 (0·1–0·4)	..
Water (total)	1·8 (1·4–2·2)	0·8 (0·7–1·0)
Unsafe sanitation	0·8 (0·7–0·9)	0·3 (0·1–0·4)
Unsafe source	1·3 (1·0–1·4)	0·5 (0·2–0·7)
Occupational	0·8 (0·8–0·9)	0·4 (0·3–0·4)
Carcinogens	0·5 (0·5–0·5)	0·1 (0·1–0·1)
Particulates	0·4 (0·3–0·4)	0·2 (0·2–0·3)
Soil, heavy metals, and chemicals	0·5 (0·2–0·8)	0·7 (0·2–0·8)
Lead	0·5 (0·2–0·8)	0·7 (0·2–0·8)
Total	9·0	8·4

Note that the totals for air pollution, water pollution, and all pollution are less than the arithmetic sum of the individual risk factors within each of these categories because these have overlapping contributions—eg, household air pollution also contributes to ambient air pollution and vice versa.

***Table 1*: Global estimated deaths (millions) due to pollution risk factors from the Global Burden of Disease study (GBD; 2015)[42] versus WHO data (2012)[99,101]**

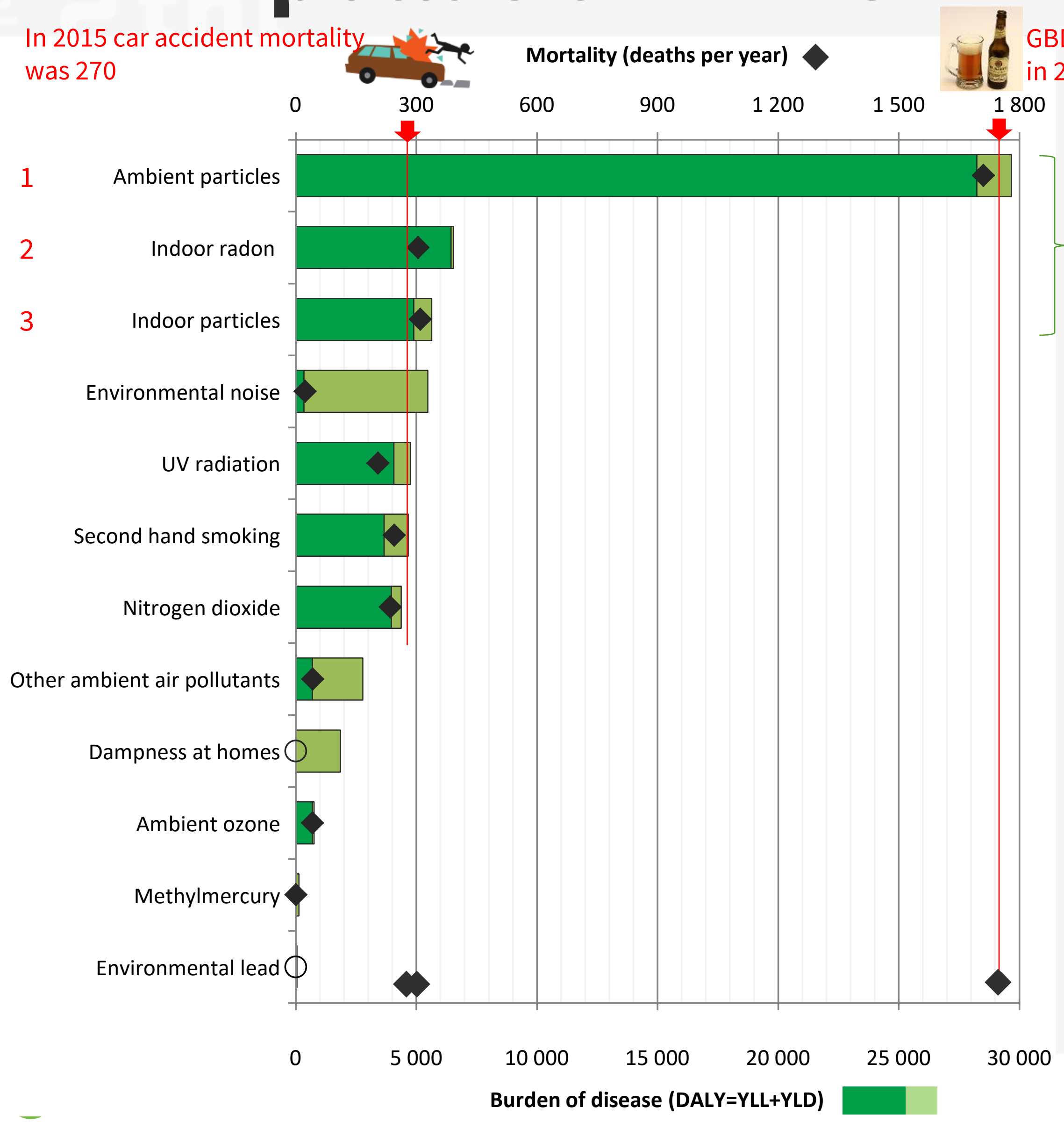
Landrigan et al., 2017

(extract): Millions of deaths, by

	House-hold AP[1]	Ambient PM
GBD	2.9	4.2
WHO	4.3	3.0

[1] unvented solid fuel use indoors

Finland: Air pollution in TOP12 env. health risks



Y&T 2020 nr 1

- Air pollutants dominate: TOP3 is
  - ambient particles
  - indoor radon and particles
- Total burden of these 12 factors is 3100 deaths,
  - 53 000 years of life lost and
  - 13 000 equivalent years lived with disability
- vs 270 in car accidents
  vs 1700 due to alcohol
  vs 5000 due to smoking

  ca. 5k due to COVID19 (2020-2022/6)

Hänninen O, Lehtomäki H, Korhonen A, **2020**. Ilmansaasteet ja kuolleisuus kärjessä, tautitaakka yli kaksinkertainen: Ympäristöaltisteiden kansanterveysvaikutukset. Ympäristö ja Terveys-lehti, 1/2020 ss. 6-13. http://urn.fi/URN:NBN:fi-fe202002246282 (2020-02-24)

Howabout estimates for known toxic components?

- ?

WHO 2021-09-22
Global Update of Air Quality Guidelines

Table 0.1. Recommended AQG levels and interim targets

Pollutant	Averaging time	Interim target				AQG level
		1	2	3	4	
$PM_{2.5}$, µg/m³	Annual	35	25	15	10	5
	24-hour[a]	75	50	37.5	25	15
PM_{10}, µg/m³	Annual	70	50	30	20	15
	24-hour[a]	150	100	75	50	45
O_3, µg/m³	Peak season[b]	100	70	–	–	60
	8-hour[a]	160	120	–	–	100
NO_2, µg/m³	Annual	40	30	20	–	10
	24-hour[a]	120	50	–	–	25
SO_2, µg/m³	24-hour[a]	125	50	–	–	40
CO, mg/m³	24-hour[a]	7	–	–	–	4

[a] 99th percentile (i.e. 3–4 exceedance days per year).
[b] Average of daily maximum 8-hour mean O_3 concentration in the six consecutive months with the highest six-month running-average O_3 concentration.

World Health Organization. (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. https://apps.who.int/iris/handle/10665/345329.

Epidemiological PM mass responses vs. Known more specific toxic PM components (1/2)

- Cancer risk and hazard quotient for As, Cd, Co, Cr, Mn, Ni, Pb
  - respiratory tract deposition (uptake) accounting for building infiltration: dose-based estimates

- Epi based excess risk and attributable fraction mortality for PM2.5 and PM10
  - outdoor concentration based estimates

atmosphere MDPI

Article

Characterization of Human Health Risks from Particulate Air Pollution in Selected European Cities

Eleftheria Chalvatzaki [1], Sofia Eirini Chatoutsidou [1], Heli Lehtomäki [2,3], Susana Marta Almeida [4], Konstantinos Eleftheriadis [5], Otto Hänninen [2] and Mihalis Lazaridis [1,*]

Table 7. Cancer risk based estimates of cases per lifetime in the three cities.

	Cancer Cases per Lifetime (70 Years)					
	Methodology 1 (US EPA)			Methodology 2 (Lyu et al. [15])		
	Athens	Kuopio	Lisbon	Athens	Kuopio	Lisbon
As	12.2	0.020	1.5	7.7	0.008	0.7
Cd	-	0.003	-	-	0.001	-
Co	31.3	0.018	4.4	18.4	0.015	3.4
Cr	28.3	0.090	210.8	15.3	0.069	118.3
Ni	1.9	0.041	-	1.1	0.014	-
Cumulative	73.7	0.172	216.7	42.5	0.107	122.4

Chalvatzaki E, Chatoutsidou S, Lehtomäki H, Almeida SM, Eleftheriadis K, Hänninen O, Lazaridis M, 2019. Characterization of human health risks from particulate air pollution in selected European cities. *Atmosphere* 10:96; doi:10.3390/atmos10020096. https://www.mdpi.com/2073-4433/10/2/96

Epidemiological PM mass responses vs. Known more specific toxic PM components (2/2)

atmosphere MDPI

Article

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- Cancer cases (two methods)
  - Athens ½-1 cases /year
  - Lisbon 1.5-3 cases/year
- PM2.5 mass based mortality
  - Athens 3930 deaths/year
  - Lisbon 2820 deaths/year
- Insignificant fraction can be attributed to known toxic components!

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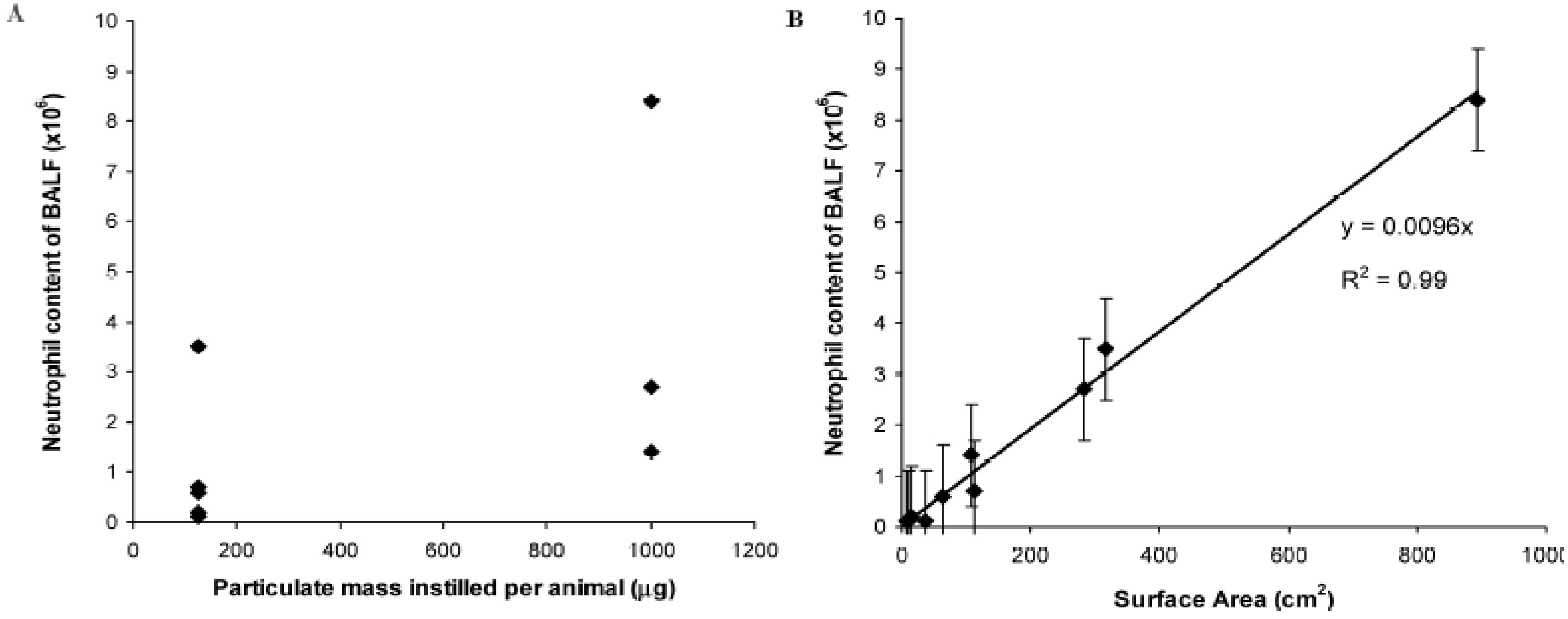
Table 8. Percentages (%) of the excess risks (*ER*) and attributable fractions (AF) along with the number of attributable deaths for (a) all-cause mortality associated with short-term exposure to PM_{10}, (b) cardiopulmonary mortality and (c) lung cancer mortality associated with long term exposure to $PM_{2.5}$ in each city. The corresponding confidence intervals (CI) are given in brackets.

	Athens		Kuopio		Lisbon	
	(a) *All-cause mortality* (PM_{10})					
ER (95% CI)	0.77	(0.58–0.96)	0.02	(0.02–0.03)	2.2	(1.6–2.7)
AF (95% CI)	0.77	(0.57–0.96)	0.02	(0.02–0.03)	2.1	(1.58–2.62)
Deaths (95% CI)	320	(236–398)	0.2	(0.2–0.3)	730	(546–905)
	(b) *Cardiopulmonary mortality* ($PM_{2.5}$)					
ER (95% CI)	19	(6.4–33)	9.5	(3.4–16)	31	(10–55)
AF (95% CI)	15.8	(6.0–24.5)	8.7	(3.2–13.9)	23.4	(9.2–35.4)
Deaths (95% CI)	3450	(1311–5353)	38	(14–61)	2450	(962–3702)
	(c) *Lung cancer mortality* ($PM_{2.5}$)					
ER (95% CI)	29	(9.9–52)	15	(5.2–25)	49	(16–92)
AF (95% CI)	22.7	(9.0–34.2)	12.8	(4.9–20.0)	32.9	(13.7–47.8)
Deaths (95% CI)	480	(190–721)	6.1	(2.3–9.5)	370	(155–540)
Sum of deaths (b+c)	3930		44.1		2820	

Surface area as dose metric

Brunauer–Emmett–Teller (**BET**) surface area represents chemically available reactive surface (https://en.wikipedia.org/wiki/BET_theory) see e.g. Schmid & Stöger, 2016 (JAS), on nanoparticles

Toxicological study on rat instillation
Polystyrene particles (Dp 64, 202 and 535 nm) (inert, non-soluble material)



Duffin et al., 2007
Broncheoalveolar lavage fluid (BALF)

Duffin R, Tran L, Brown D, Stone V, Donaldson K. Proinflammogenic effects of low-toxicity and metal nanoparticles in vivo and in vitro: highlighting the role of particle surface area and surface reactivity. Inhalation toxicology. 2007 Jan 1;19(10):849-56.

BET particle surface area

- Excellent candidate for inert non-soluble particle components
- Real atmospheric particles contain substantial soluble (and volatile) fraction, which is rapidly removed from the deposited particle. These solved ions (and evaporized gases) behave independently and differently from the non-soluble core
- Thus characterization of the non/soluble fractions would make sense!

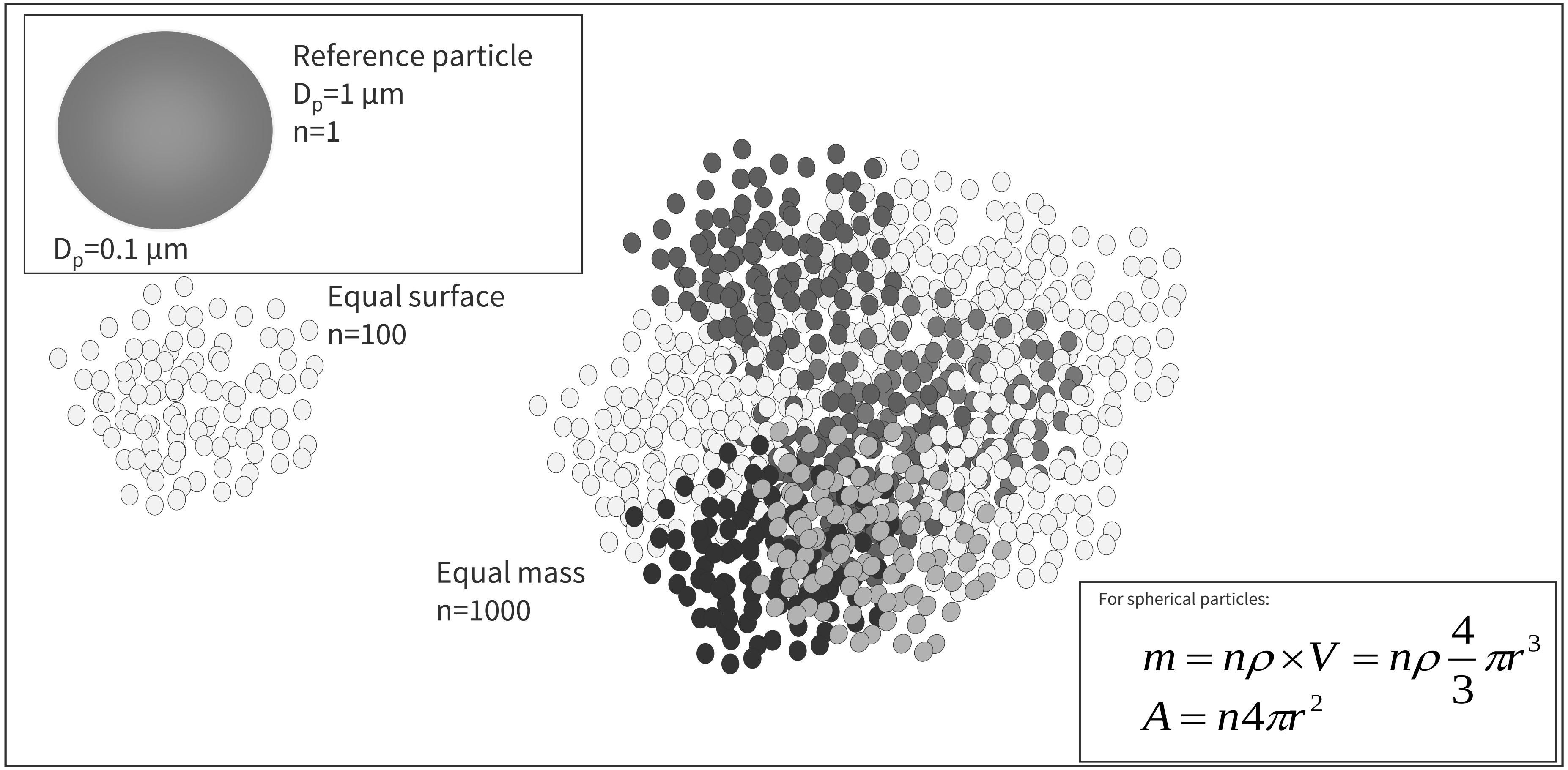
3 Particle Number Concentration (PNC)(≈UFP)

- Epidemiological study in Erfurt, Germany

- Stöltzel et al., 2007. **Daily mortality and particulate matter in different size classes in Erfurt, Germany**.
  J Expos Sci Env Epid 17:458-467.

- daily RR for total mortality 1.029
- (5-day polynomial lag model 1.042)

Mass – number – surface area



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4.3 Ultrafine particles

UFP are generally considered as particulates with a diameter less than or equal to 0.1 µm, that is, 100 nm (typically based on physical size, thermal diffusivity or electrical mobility). There was already considerable evidence on the toxicological effects of UFP at the time that *Global update 2005* was being prepared, which was acknowledged in the document (WHO Regional Office for Europe, 2006). However, it was stated that the evidence from epidemiology was insufficient to recommend guidelines for UFP. Since then, the body of epidemiological evidence has grown, and two systematic reviews have assessed scientific research papers published from 1997 to 2017 (HEI, 2013; Ohlwein et al., 2019), documenting the rising number of studies being conducted. The studies demonstrated short-term effects of exposure to UFP, including mortality, emergency department visits, hospital admissions, respiratory symptoms, and effects on pulmonary/systemic inflammation, heart rate variability and blood pressure; and long-term effects on mortality (all-cause, cardiovascular, IHD and pulmonary) and several types of morbidity. However, various UFP size ranges and exposure metrics were used, preventing a thorough comparison of results across studies (US EPA, 2019a). Therefore, there was a consensus in the GDG that the body of epidemiological evidence was not yet sufficient to formulate an AQG level.

World Health Organization. (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. https://apps.who.int/iris/handle/10665/345329.

Some suggestions for conclusions & discussion

- Quantitative risk assessment (QRA)-> impact as burden
  - Particles [at receptor] seem the dominant risk factor
  - [PM2.5] Mass remains the best established risk indicator

  - Composition: well-known physical factors, health impact not well known
    - volatility; solubility -> biological fate; aerosol size -> infiltration, lung doses

  - Several complementary hypotheses remain relevant for research (e.g PN, PSA)

- Prioritization (research and action)
  - Risk benefit analysis (e.g. Baltic salmon, Tuomisto et al. 2004)
  - Comparative risk assessment (CRA) (e.g. Tainio et al. 2021)
  - Health impact assessment (HIA) [of a third sector policy]
  - Cost-benefit analysis (CBA)
  - SES, age group, geographic and gender analyses

Work conducted by

- Antti Korhonen: Exposure analysis, GIS data

- Isabell Rumrich: Epidemiology
  - Maternal smoking and birth outcomes (PhD 2020)
  - Air pollution and birth outcomes; Parkinson’s Disease

-
- Heli Lehtomäki Zrim:
  - Health impact assessment, burden of disease
  - Concentration-response functions

Thank you for your interest!

<3

Photo: Courtesy of City of Kuopio

Welcome to Kuopio

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