“Global characterization factors for damage to human health due to particulate matter – based on the TM5-FASST model”

2013

Lecture on "Global characterization factors for damage to human health due to particulate matter – based on the TM5-FASST model"

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Presentation overview

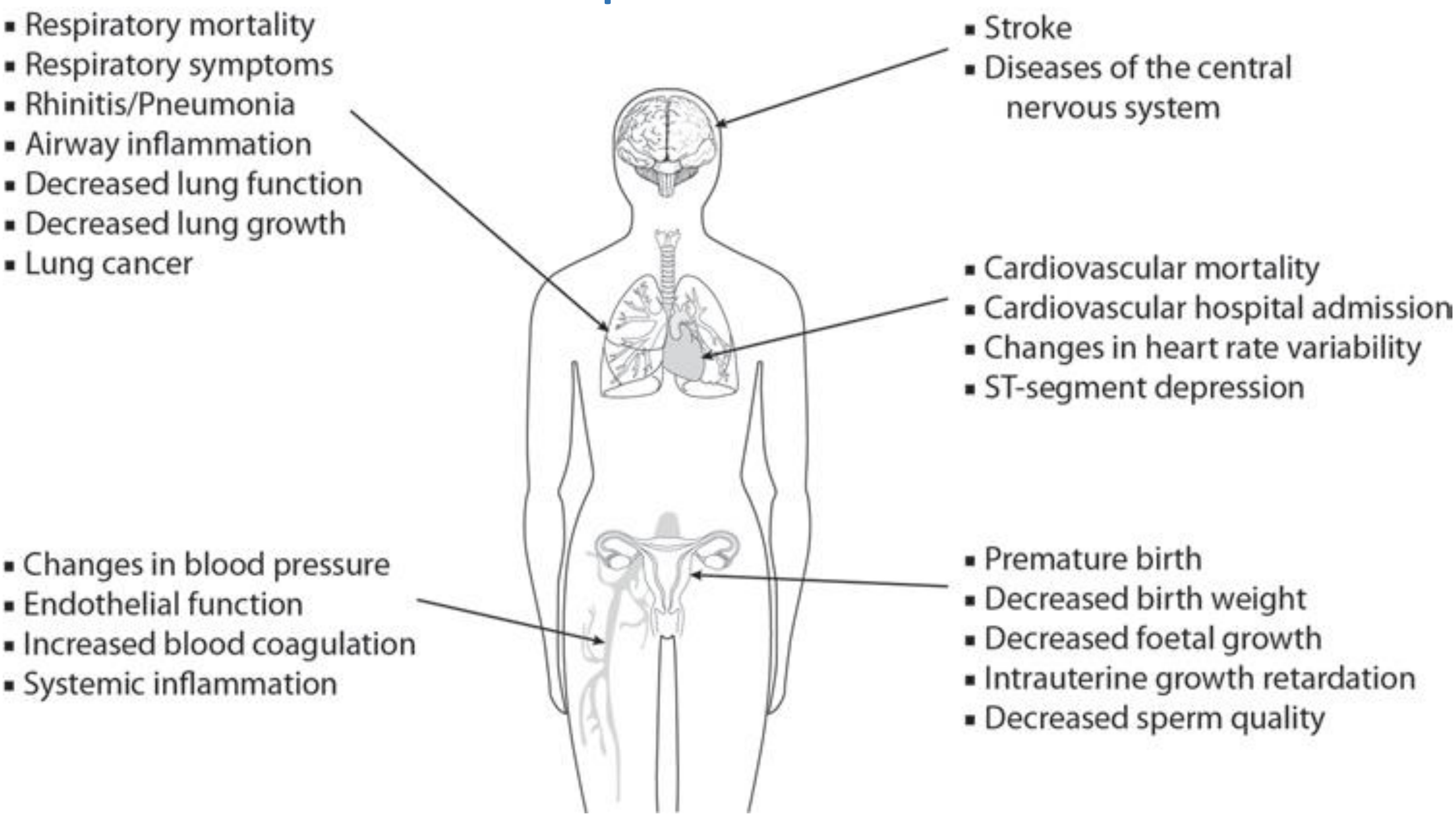
- Human health impacts due to particulate matter
- Impact Pathway Approach
- PPM & SIA (primary and secondary particulate matter)
- Additional emission from source regions lead to concentration increment → everywhere!
- Population distribution → Exposure
- Definition of characterisation factors
- Concentration-response functions
- “Disability adjusted life years” - DALY weighting
- Mortality & Morbidity: YLL+YLD=DALY
- Results and Normalisation
- Summary & Conclusions

Area of Protection

Endpoint: Human Health

What is the impact of emission of primary particulate matter and precursors of secondary inorganic aerosols on human health per unit of emission [kg per year] at different locations?

Organs of the human body that can be affected by air pollution



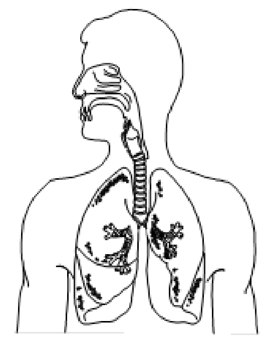
Source: Peters et al., J Occup Environ Med. 2011 Jun; 53 (6 Suppl):S8-S13)

Impact Pathway Approach

Emissions

Transport and Chemical Transformation;

Differences of Health Risks



Calculation is made twice: with and without power plant!

www.ExternE.Info

Particulate Matter – Sources & Emissions

- Emissions of primary particulate matter (black carbon, organic carbon, fly ash…), e.g. from agriculture, combustion processes, e.g. electricity production, ...
- Emissions of precursor substances SO_2, NH_3, NO_x and NMVOC, e.g. from combustion processes such as transport activities lead to **S**econdary **I**norganic **A**erosols (SIA), i.e. ammonium nitrates & sulfates (secondary particulate matter).

$$NO_2 + NH_3 + OH \rightarrow NH_4 NO_3$$

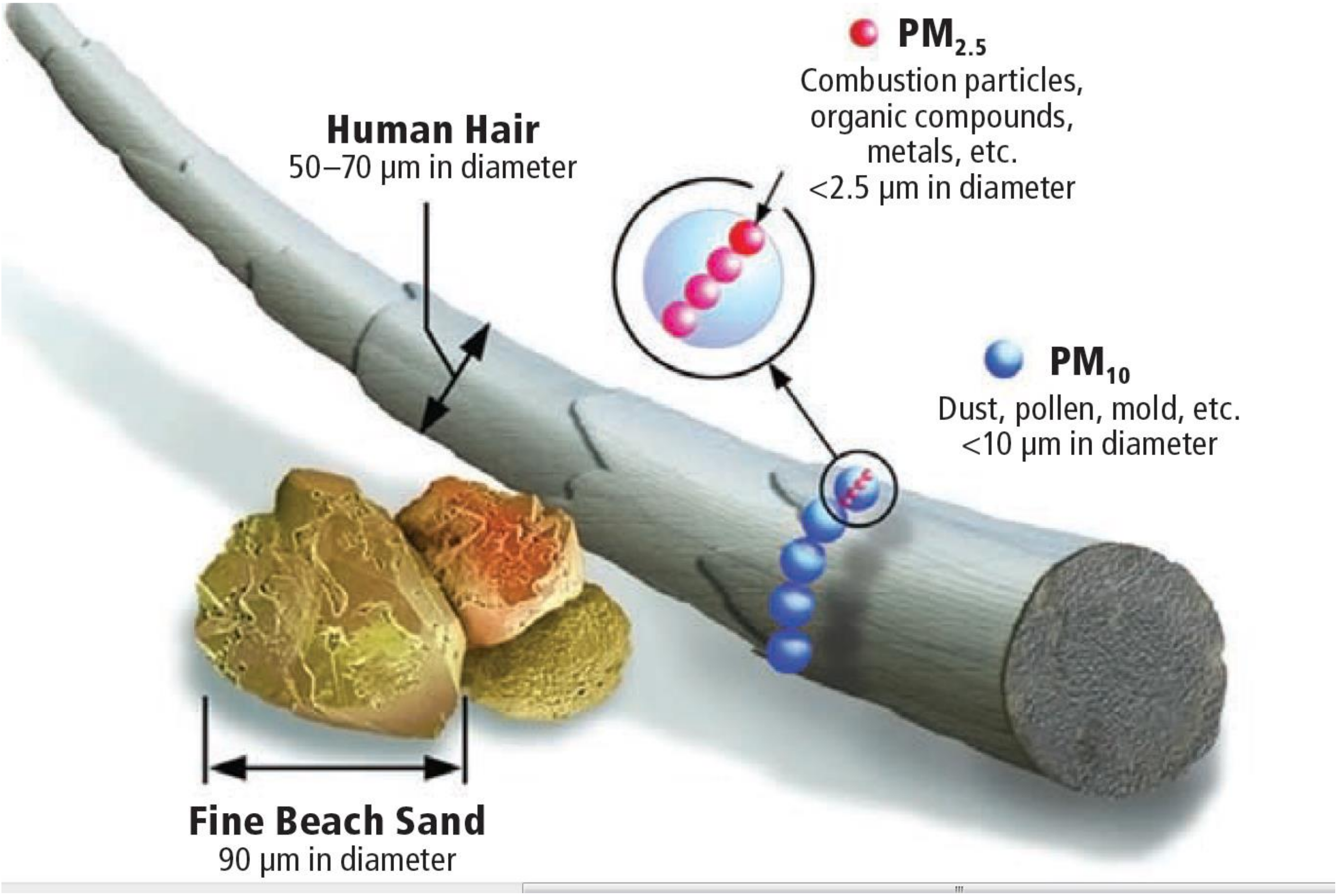
$$SO_2 + NH_3 + OH + \ldots \rightarrow (NH_4)_2SO_4$$

PM10: particulate matter with 10 µm in aerodynamic diameter and smaller

PMcoarse: particulate matter with aerodynamic diameters between 2.5 and 10 µm

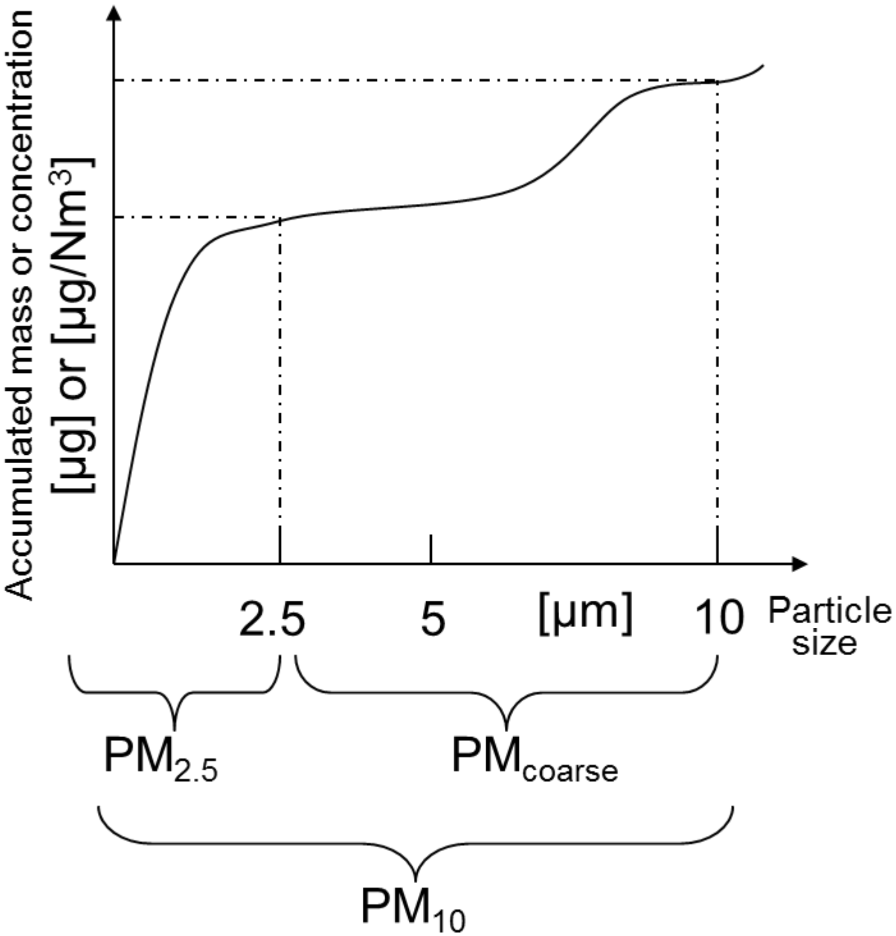
Fine Mode PM2.5: particulate matter with 2.5 µm and smaller.

Size matters….



"Particle size is an important factor in how PM affects human health. Larger PM10 is deposited mostly in the nose and throat. Because PM2.5 can penetrate much deeper into the lung, it poses a greater health threat." http://ehp.niehs.nih.gov/wp-content/uploads/2012/08/ehp.120-a348a.pdf

Size matters!



Commonly used indicators describing fine dust emissions refer to the mass concentration of PM10 (particles with a diameter up to10 µm) and PM2.5 (particles with a diameter up to 2.5 µm). The difference (i.e., PM10-PM2.5) is commonly referred to as the coarse fraction (PMco).

It has to be emphasised that the composition of PM10 concentration depends on the locations (e.g. at the sea or in a city centre). Moreover, the composition of PM10 emissions vary between sources. In case of emission from a gas turbine the share of PM2.5 from PM10 is close to 100%.
PM emission from a wood burning oven may have a much higher share of PMco, and hence, a lower share of PM2.5.

Possible Impacts to Human Health due to Inhalation of PM

- **Mortality:** reduced life time expectancy (years of life lost – YLL)

- **Morbidity:** different disease such as, chronic bronchitis, cough days, ... (summariesed to YLD - Year equivalent Lost Due to morbidity)

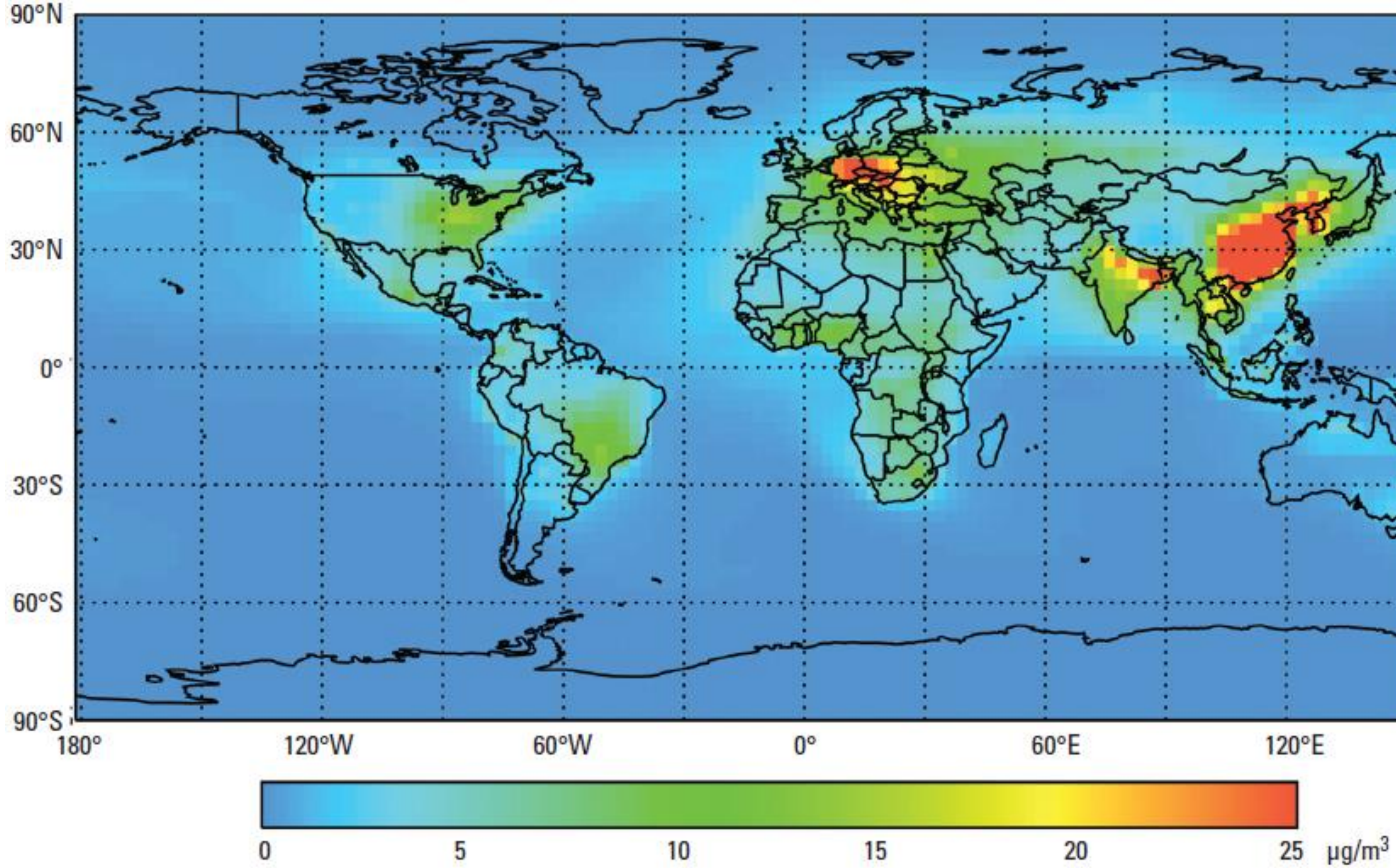
Mortality and Morbidity can be aggregated into **D**isability **A**djusted **L**ife **Y**ears: **DALY=YLL + YLD**

Current recommendations

Impact category	*Model*	*Indicator*	*Recomm level*
Particulate matters, midpoint	RiskPoll model (Rabl and Spadaro, 2004) and Greco et al 2007	PM2.5eq	II/III
Particulate matters, endpoint	Adapted DALY calculation applied to midpoint (Van Zelm et al 2008, Pope et al 2002)	DALY	II

http://lct.jrc.ec.europa.eu/assessment/LCIA-CF-09-02-2012-def.pdf

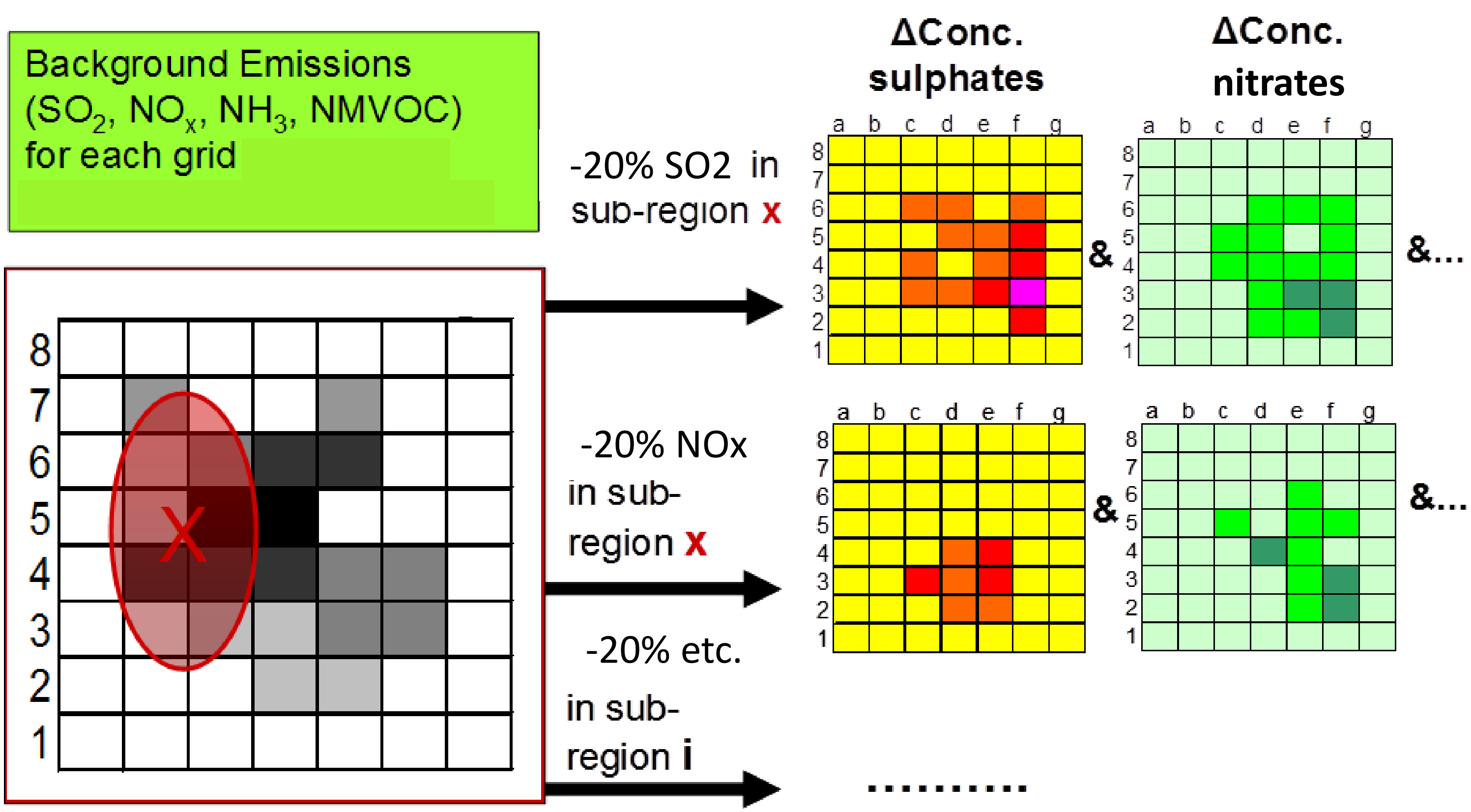
State: Estimated change - annual average PM2.5 [µg/m³] (present minus preindustrial)



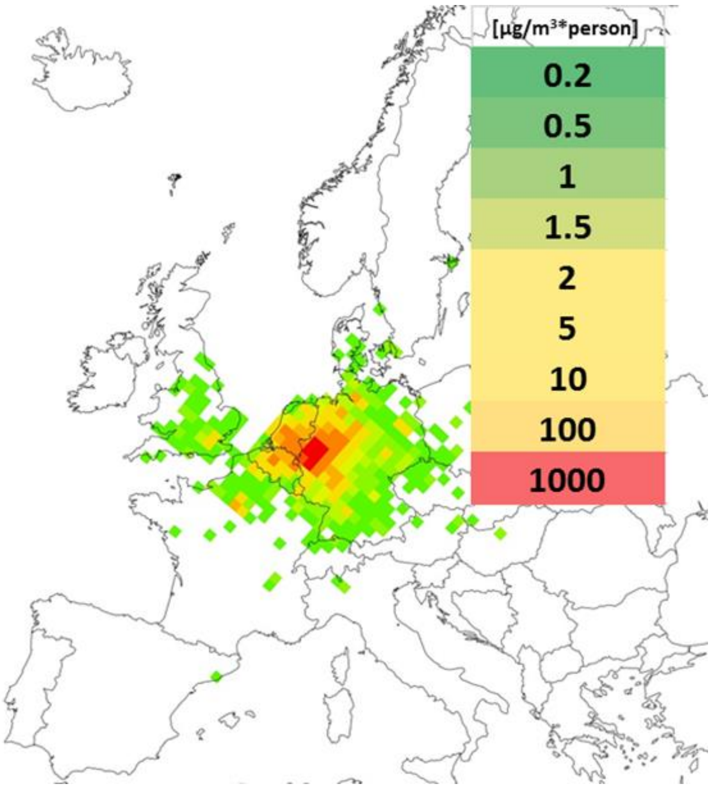
Anenberg, S. C., et. al (2010) “An Estimate of the Global Burden of Anthropogenic Ozone and Fine Particulate Matter on Premature Human Mortality using Atmospheric Modeling”. *Environ Health Perspect*

From emission to concentration....
Source Receptor Approach

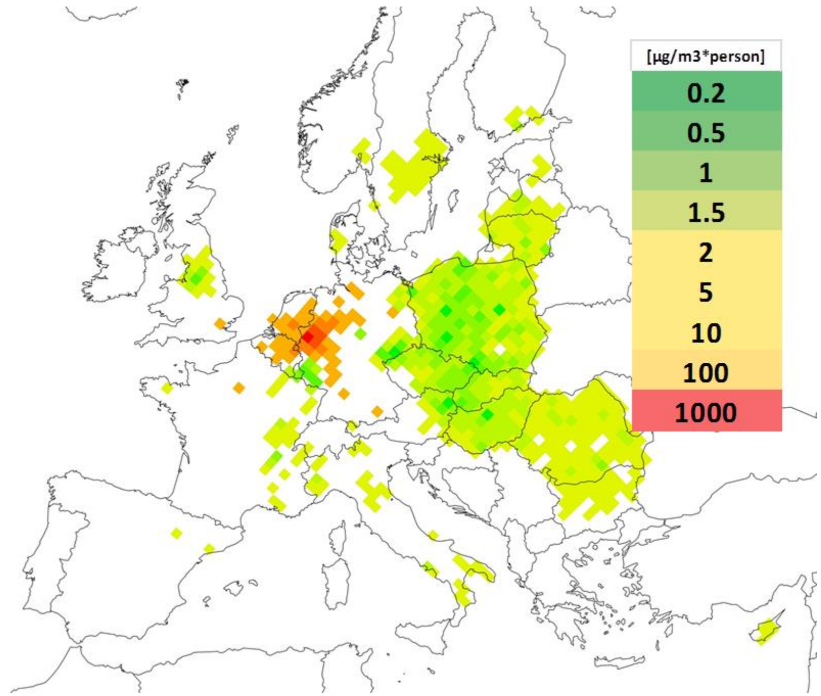
ΔConc = c(Scen -20%) – c(Background Szenario)



From concentration to exposure

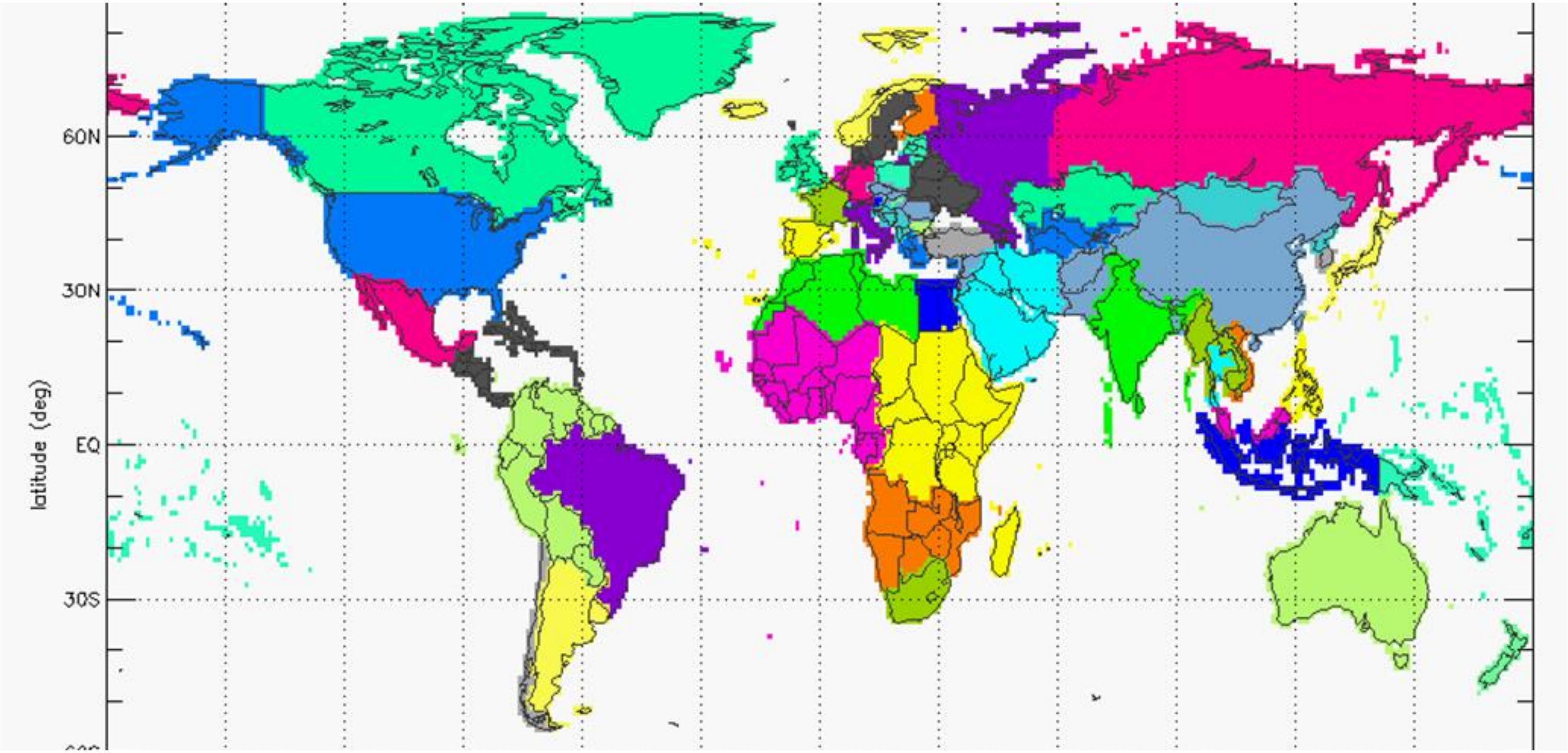


Change of accumulated exposure of PM2.5 per Mg of PPM2.5 released in German sub-region



Change of accumulated exposure of SIA per Mg of NOx released in German sub-region

Regions of the TM5-FASST



TM5-FASST is based on the standard TM5 version as documented in (Krol et al. 2005). The world is divided into 56 regions. The regions correspond to countries or a group of countries. Each region serves as a source region and each grid cell (resolution 1°x1°) of the whole world serves as receptor region. The receptor grid cells have been aggregated to the same source regions as the source again.

Characterization factors

Factors to consider	*Intermediary and final output metrics*	*Environmental and physiological factors*
Particle size of primary PM Precursors & source country Stack height	Emission to air [kg_{em}/a]	
		Fate (CTM)
Meteorology Chemical background Emissions & concentrations	Concentration in ambient air [µg per m³]	
		Exposure
Exposure Population density Breathing rate	Intake [kg per a]	
		Dose-response (based on CRF) [cases per kg intake]
Health effects based on epidemiological studies: mortality and morbidity	Disease incidence [cases per a per kg]	
		Severity - duration & weight [DALY per case]
	Damage to human health [YLL] & [DALY]	

Intake Fraction kg_{in} / kg_{em}

Effect factors

Damage Factors

Character-isation Factor DALY / kg_{em}

based on (Humbert et al. 2011)

$$CF_{s,a,p,i} = \sum_{i} \left(iF_{i,p,s,a} \sum_{e} (EF_{i,d} * DF_d) \right)$$

where,
s is the source region (country of region)
a is a certain archetypical characteristic (high stack, urban…)
p is the emitted pollutant (e.g. NOx, or PPM2.5)
i is the pollutant taken in (nitrate or PPM2.5)

Fate Factor

$$FF_{x,i \rightarrow j} = \frac{\Delta PM2.5_j}{\Delta M_i}$$

Partial Fate Factor (in µg/m³/kg):

- represents the change in concentration of particulate matter in a receiving compartment cell j [µg/m³] due to a change of emission of precursor x in region i
- derived with the TM5 atmospheric fate model → parametrised into TM5-FASST source receptor matrices
- emissions were decreased by 20% compared to the baseline emission inventory

Effect Factor:
Concentration-response functions and severity

	CRF PM2.5	CRF PM10	Disability weight per endpoint*	Duration [a]	DALY per case	RGF EU %	AGF EU %
YLL chronic (mortality)	101	-	1	1	1	100	64.6
Infant mortality	-	0.58	1	80	80	100	0.9
Bronchodilator usage children	-	1460	0.22	0.00274	0.0006028	14.4	10.1
Cardiac Hospital Admissions	-	0.43	0.71	0.038	0.02698	100	100.0
Chronic bronchitis	-	8.6	0.099	10	0.99	90	82.3
LRS adults	-	13100	0.099	0.00274	0.00027126	30	82.3
LRS children	-	18600	0.099	0.00274	0.00027126	100	10.1
Work loss day	2070	-	0.099	0.00274	0.00027126	100	68.4
Bronchodilator usage adults	-	9130	0.22	0.00274	0.0006028	10.2	78.8
Cough days	-	-	0.07	0.00274	0.0001918	100	10.1
LRS children excl. cough	-	-	0.099	0.00274	0.00027126	100	10.1
MRAD	5770	-	0.07	0.00274	0.0001918	100	68.4
Respiratory Hospital Admissions	-	0.56	0.64	0.038	0.02432	100	100.0
Restricted Activity Day	9020	-	0.099	0.00274		100	68.4

LRS: Lower Respiratory Symptoms
MRAD: Minor Restricted Activity Days

based on (Torfs et al. 2007)

Toxicity of different substances contributing to particulate matter

- The toxicity of different sources of particles may vary due to difference in shape, chemical composition, etc.
- World Health Organisation (WHO) states that based on current evidence, it is not possible to quantify reliably this difference, e.g. between secondary inorganic aerosols (sulfates and nitrates) and primary particulate matter (black carbon or ash) http://www.euro.who.int/__data/assets/pdf_file/0007/78658/E90672.pdf
- The only distinction made is between very fine particulate PM2.5 and PMcoarse (i.e. the fraction particles with a size between 2.5µm and 10µm aerodynamic diameter)
- The finer particles (<2.5µm) are the main cause of chronic mortality.

Chronic Exposure
Mortality → life expectancy reduction

The CRFs are based on epidemiological studies, i.e. on studies finding a statistically significant relation between concentrations of pollutants and health effects.

Most important is chronic mortality from particulates, “ACS study” (Pope et al. 2002).

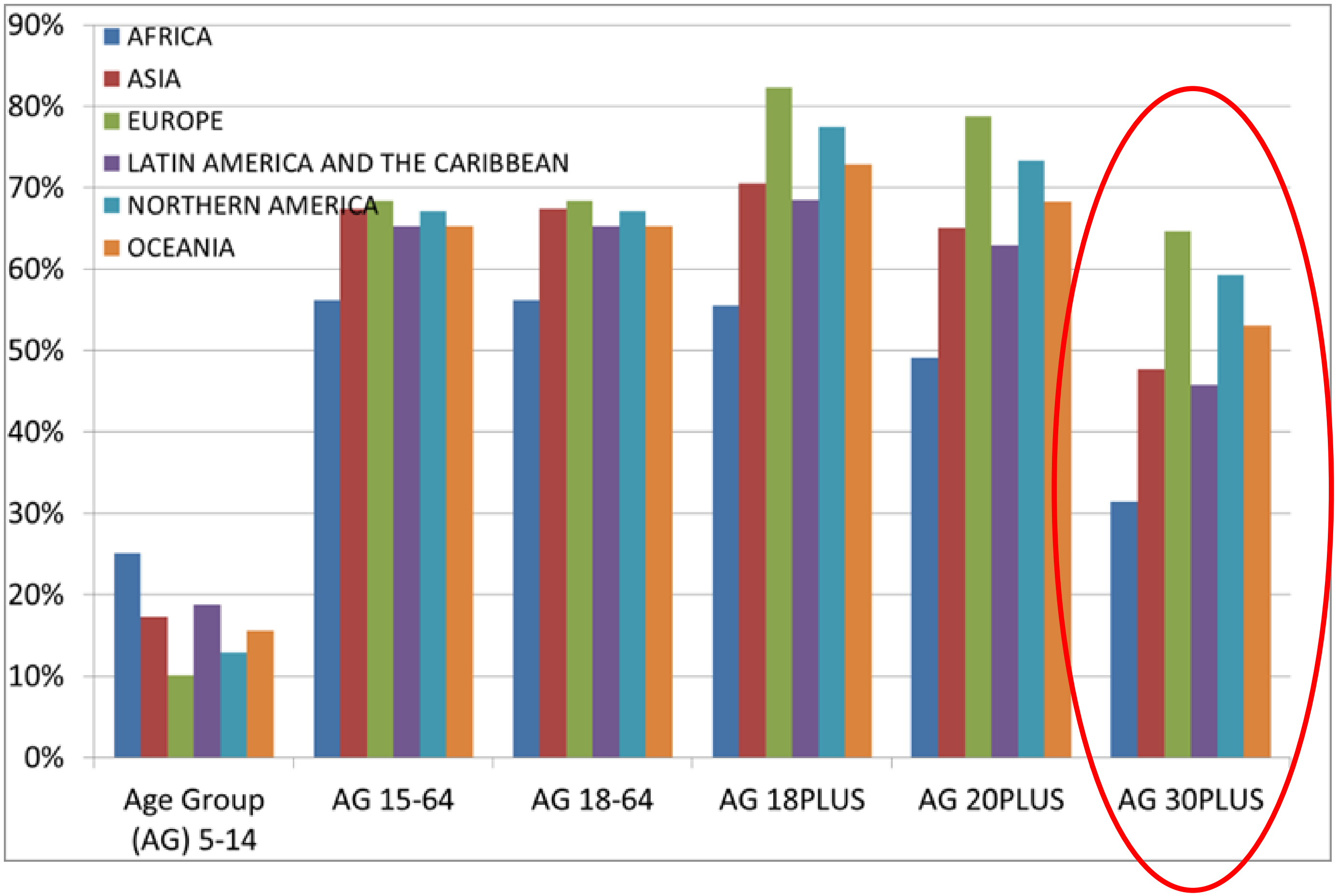
The resulting concentration-response function due to PM2.5 is applied to the age group of people 30 years and older
– because the epidemiological study included only those age group.

per 10 $\mu g/m^3$ PM2.5 increase and exposure of 100,000 people:

651 years of lifetime are lost!

(95% confidence interval 127 – 1194), (Torfs et al. 2007).

Differences in shares of age groups in the world

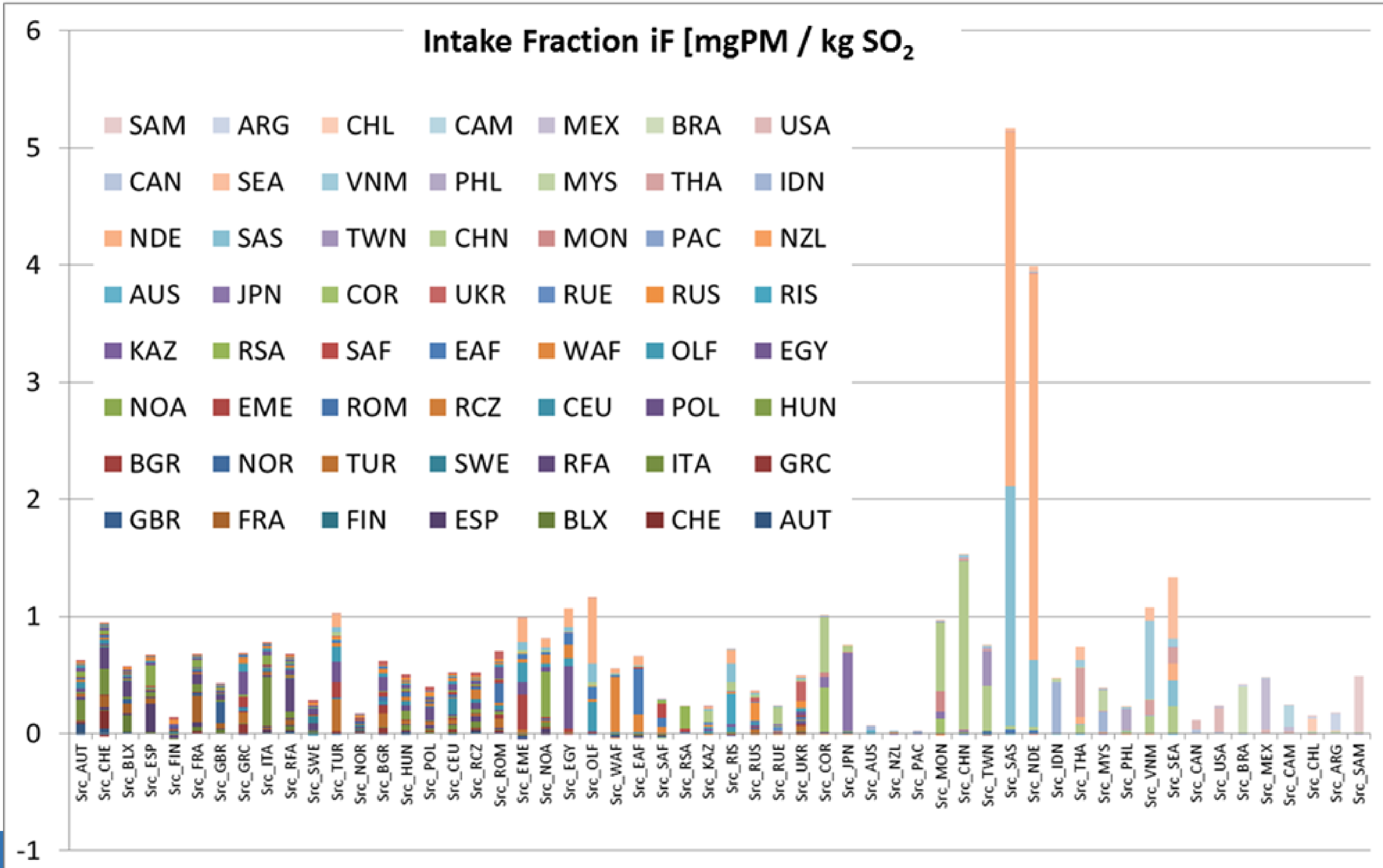


Difference of effect factors per population intake

Region	DALY per kg intake of PM2.5
World Average	120.69
Africa	83.92
Asia	121.23
Europe	158.94
Latin America and Caribbean	116.73
Northern America	146.85
Oceania	132.82

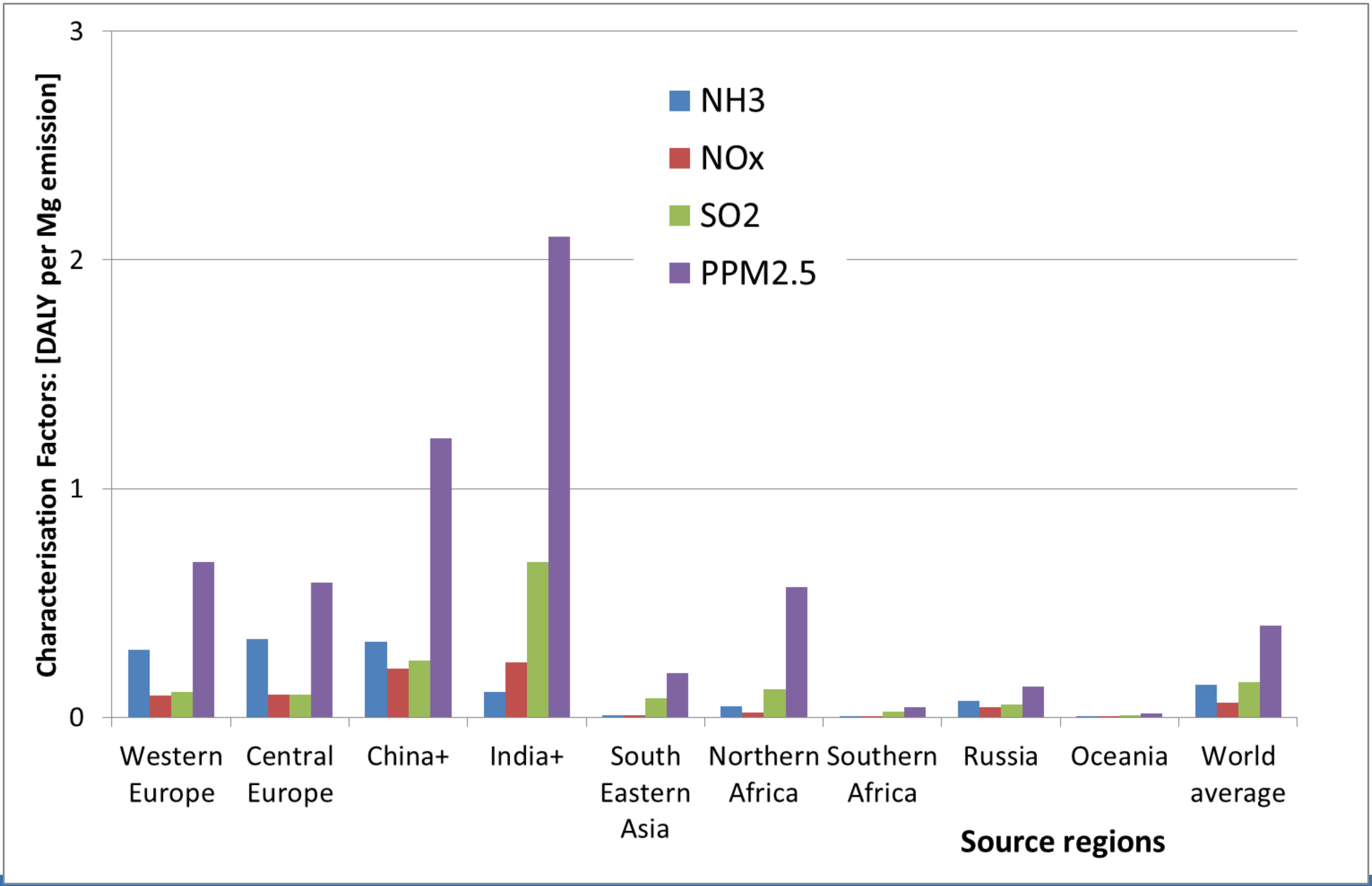
Intake fraction of SO_2 – 56 TM5-FASST regions

- relation between emission of considered air pollutants primary PM, SO2, NOx, NH3 and intake due to respiration of PM in the air



Characterisation factors

The characterisation factors express the health impacts due to emissions of considered air pollutants primary PM, SO_2, NOx, NH_3 → DALY per Mg emission.



Normalization factor

The normalization factor equals the total health impacts - due to emissions of considered air pollutants primary PM, SO_2, NOx, NH_3 per capita (in DALY/capita)

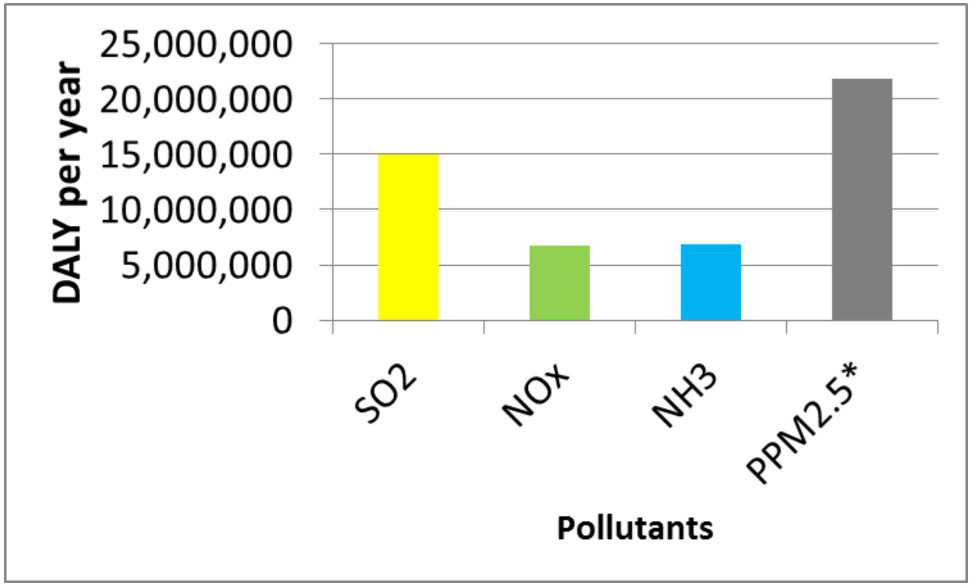
$$NF = \frac{\sum_x \sum_i (M_{x,i} \cdot CF_{x,i})}{\sum_i (N_{pop,i})}$$

- NF is the normalization factor of the summation of all 56 regions
- $M_{x,i}$ is the emission of precursor x in region i (in kg/yr) (based on emission in 2000)
- $CF_{x,i}$ is the characterization factor for substance x in region i
- $N_{pop,i}$ is the number of inhabitants in the world

(in 2000 global population 6,122,770,220 (Goedkoop et al. 2013)

Normalization factor

- Normalization factor (total DALY) for PM impact on human health due to emissions of primary PM, SO_2, NOx, NH_3 in 2000 is 50,400,000 years.
- This corresponds to 0.00823 years per capita – or ca. 3 days per capita each year !
- Primary particulate matter is the main contributor to global DALY, but in sum SO_2, NO_x and NH_3 cause more than 50% of the total DALY.



Outlook

What could be investigated in further projects are:

- Improved chemical transport models (less uncertainty regarding input data such as emission data, meteorology, etc., higher spatial source and receptor resolution, …)
- Non-linearity of CRF depending on different background concentration of PM
- Influence of ozone concentration on the impact of PM
- Influence of chemical composition, shape, etc. on toxicity
- Influence of other co-factors on the CRF such as diet, heat stress, humidity, etc.
- Background incidence rates of the different endpoints in different regions of the world
- …

Conclusions

- Globally, spatially explicit characterization factors for damage to human health due to change of particulate matter concentration caused by anthropogenic emission of primary particulate matter, SO_2, NH_3 and NOx in 56 world regions were derived based on TM5-FASST source-receptor-matrices
- Primary PM is the major contributor to damage caused by PM but secondary PM from precursor SO_2, NH_3, NOx are in sum equally relevant.

Acknowledgement

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