



# Developments in benefits assessment

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TFIAM, 2025

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# Status of EMAPEC, HRAPIE2 outputs

- Two studies managed by WHO:
  - EMAPEC – largely as an ‘umbrella’ review (reviews of earlier systematic analyses) for morbidity
  - HRAPIE2 – meta-analysis for mortality
- Peer reviewed papers published so far:
  - Mortality: Orellano et al 2024, Kasdagli et al 2024
  - Morbidity: Forastiere et al 2024, Orellano et al 2023
- These (and other?) papers are currently under discussion. Final conclusions on EMAPEC, HRAPIE2 yet to be published hence there is no official WHO or TFH update of functions at the present time

# Changes in effects that are quantifiable

## Previous analysis for the Convention

- PM<sub>2.5</sub> : Effect / (age group)
  - Chronic exposure
    - Mortality (age 30+)
    - Infant mortality (1 month to 1 year)
    - Bronchitis (27+)
  - Acute exposure
    - Bronchitis in children (6-12)
    - Respiratory hospital admissions (all ages)
    - Cardiac hospital admissions (18+)
    - Asthma symptom days (5-19)
    - Restricted activity days (all ages)
    - Work loss days (18-64)
- O<sub>3</sub> : Effect / (age group)
  - Acute exposure
    - Mortality (all ages)
    - Respiratory hospital admissions (>64)
    - Cardiac hospital admissions (>64)
    - Minor restricted activity days (all ages)

Key source: HRAPIE 2013

## Possible future analysis for the Convention

- PM<sub>2.5</sub> : Effect / (age group)
  - Chronic exposure
    - Mortality (age 30+)
    - Infant mortality (1 month to 1 year)
    - Asthma (new incidence (0-18)
    - COPD (>30)
    - Ischaemic heart disease events (>30)
    - Lung cancer (>30)
    - Stroke (>30)
    - Autism spectrum disorder (2-12)?
    - Dementia (>60)?
    - Hypertension ((>30)?
    - T2 diabetes (>30)?
  - Acute exposure ?
    - Bronchitis in children (6-12)
    - Respiratory hospital admissions (all ages)
    - Cardiac hospital admissions (18+)
    - Restricted activity days (all ages)
    - Work loss days (18-64)
- NO<sub>2</sub> / (age group) ?
  - Chronic exposure
    - Mortality (>30)
    - ALRI in children (0-12)
    - Asthma in children (0-18)
    - Asthma in adults (>19)
  - Acute exposure?
    - Bronchitis in children (5-14)
    - Respiratory hospital admissions (all ages)
- O<sub>3</sub> : Effect / (age group)
  - Chronic exposure
    - Mortality
  - Acute exposure
    - Mortality (all ages)
    - Respiratory hospital admissions (>64)
    - Cardiac hospital admissions (>64)
    - Minor restricted activity days (all ages)

Key sources: WHO AQ Guidelines 2021, EMAPEC papers, HRAPIE2 papers, HRAPIE

# Questions for deriving sets of response functions

- How robust is the evidence for each effect?
  - Some EMAPEC functions given lower confidence rating
    - Dementia, autism, diabetes
  - Acute exposure functions based on older literature if we use HRAPIE\_1
- Is there double counting?
  - Between pollutants? E.g.
    - Mortality for PM<sub>2.5</sub>, NO<sub>2</sub>, O<sub>3</sub>
  - Between effects? E.g.
    - Hypertension and stroke, IHD, etc
    - Restricted activity days and new incidence of chronic disease
    - Hospital admissions and new incidence of respiratory and cardiac illness
  - Where double counting is suspected, can it be quantified well? If not, what options are available to account for it?
  - Does double counting potential emerge in impact quantification or valuation?

# Mortality functions

## PM<sub>2.5</sub> (Orellano)

Pollutant	Outcome (mortality)	Current syste	
		N	RR (95% CI)
PM <sub>2.5</sub>	All-cause	53	1.095 (1.064–1.127)
	Circulatory	42	1.127 (1.102–1.152)
	IHD	34	1.143 (1.102–1.186)
	Cerebrovascular	28	1.146 (1.101–1.192)
	ALRI	12	1.204 (1.095–1.325)
	Lung cancer	26	1.093 (1.053–1.135)
	Respiratory	28	1.136 (1.079–1.197)
	COPD	19	1.138 (1.080–1.198)

## NO<sub>2</sub> (Kasdagli)

	N	Pooled RR (95% CI)
All-cause	34	1.05 (1.03, 1.07)
Circulatory disease	28	1.05 (1.03, 1.08)
IHD	20	1.05 (1.03, 1.08)
Cerebrovascular disease	20	1.08 (0.99, 1.19)
Respiratory disease	25	1.05 (1.03, 1.07)
COPD	15	1.04 (1.02, 1.06)
ALRI	9	1.08 (1.04, 1.12)
Lung cancer	20	1.07 (1.04, 1.10)

All functions per 10 µg.m<sup>-3</sup> annual average exposure

# Mortality: WHO 2021 and more recent estimates (all-cause mortality)

**Table 2-2: Comparison of relative estimates (with 95% confidence intervals) per 10 ug/m<sup>3</sup> from recent PM<sub>2.5</sub> and NO<sub>2</sub> mortality studies.**

Study	PM <sub>2.5</sub>	NO <sub>2</sub>
WHO (2021) (used here)	1.08 (1.06-1.09)	1.02 (1.01-1.04)
Orellano et al (2024)	1.095 (1.064-1.127)	
Kasdagli et al (2024)		1.05 (1.05-1.07)
Chen et al (2024) 1 pollutant models	1.106 (1.068-1.142)	1.032 (1.014-1.049)
Chen et al (2024) 2 pollutant models	1.070 (1.028-1.104)	1.024 (1.000-1.049)

# Morbidity functions (Forastiere et al 2024)

Relative risk estimates for incidence of diseases from selected systematic reviews recommended for health risk assessment of PM<sub>2.5</sub> and NO<sub>2</sub>

Outcome (incidence)	ICD-10 codes	Age (yrs)	List	RR (95% CI) per 10 µg/m <sup>3</sup>	Mean exposure range (µg/m <sup>3</sup> )	SR reference
Long-term exposure to PM <sub>2.5</sub>						
Asthma in children	J45	0–18	A	1.34 (1.10, 1.63)	5–38	Khreis et al <sup>37</sup>
COPD	J41–J44	30+	A	1.18 (1.13, 1.23)	5–26	Park et al <sup>38</sup>
IHD events <sup>a</sup>	I21–I22	30+	A	1.13 (1.05, 1.22) <sup>b</sup>	5–65	Zhu et al <sup>39</sup>
Stroke	I60–I64	30+	A	1.16 (1.12, 1.20) <sup>b</sup>	5–36	Yuan et al <sup>40</sup>
Hypertension	I10–I11	30+	A	1.17 (1.05, 1.30) <sup>b</sup>	5–77	Qin et al <sup>41</sup>
Diabetes (type 2)	E11–E14	30+	B+	1.10 (1.03, 1.18) <sup>b</sup>	5–79	Yang et al <sup>42</sup>
Dementia	F00–F03, G30	60+	B+	1.46 (1.20, 1.78) <sup>b</sup>	5–25 <sup>c</sup>	Cheng et al <sup>43</sup>
ASD	F84.0, F84.1, F84.5, F84.8, F84.9	2–12	B+	1.66 (1.23, 2.25) <sup>b</sup>	5–30 <sup>c</sup>	Lin et al <sup>44</sup>
Lung cancer	C34	30+	A	1.16 (1.10, 1.23)	5–44	Yu et al <sup>36</sup>
Long-term exposure to NO <sub>2</sub>						
Asthma in children	J45	0–18	A	1.10 (1.05, 1.18)	10–39	Khreis et al <sup>37</sup>
Asthma in adults	J45	19+	A	1.10 (1.01, 1.21)	10–40	HEI <sup>34</sup>
ALRI in children	J12–J18, J20–J22	0–12	A	1.09 (1.03, 1.16)	10–56	HEI <sup>34</sup>

# Incidence data

- *Incidence: New cases of illness in the population each year*
- *Prevalence: Total cases of illness in the population in any year*
  
- Incidence data taken from:
  - Global Burden of Disease (IHME)
  - Eurostat / UN World Population Prospects population data
  - WHO
  - National sources

# Thresholds, counterfactuals and cut-points

- No evidence of thresholds for health impacts of the major air pollutants
- But limited epidemiological evidence for effects at very low concentrations
- Proposal for Gothenburg Analysis:
  - Focus on benefits associated with change in exposure, not total impact without counterfactual
  - Include as sensitivity benefits above WHO Guideline limits

# Lags between exposure and impact

- Chronic disease and natural-cause death involves some lag between exposure and effect
- Some evidence on lag duration available from (e.g.) smoking cessation studies
- Lags proposed in UK Net Zero analysis for a range of effects (Walton et al 2025)

# Ozone and mortality

- Results from Kasdagli et al 2024
- Significant results only for annual O<sub>3</sub> and respiratory mortality (**Note: not yet a final recommendation from HRAPIE2**)
- Differs to recommendation from 2021 WHO Guidelines

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## A) Annual O<sub>3</sub>

	N	RR (95% CI)
All-cause	9	1.01 (0.96, 1.06)
Respiratory disease	6	1.05 (1.02,1.08)
COPD	2	1.06 (1.03, 1.08)
ALRI	2	1.04 (0.97, 1.11)

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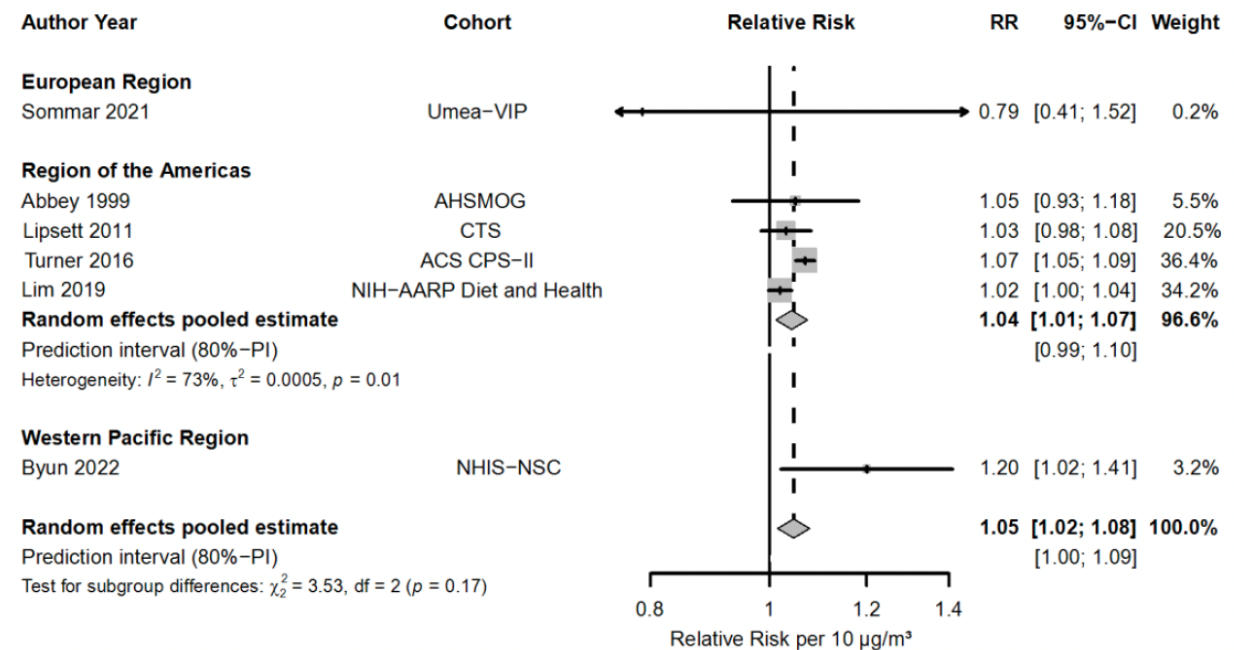
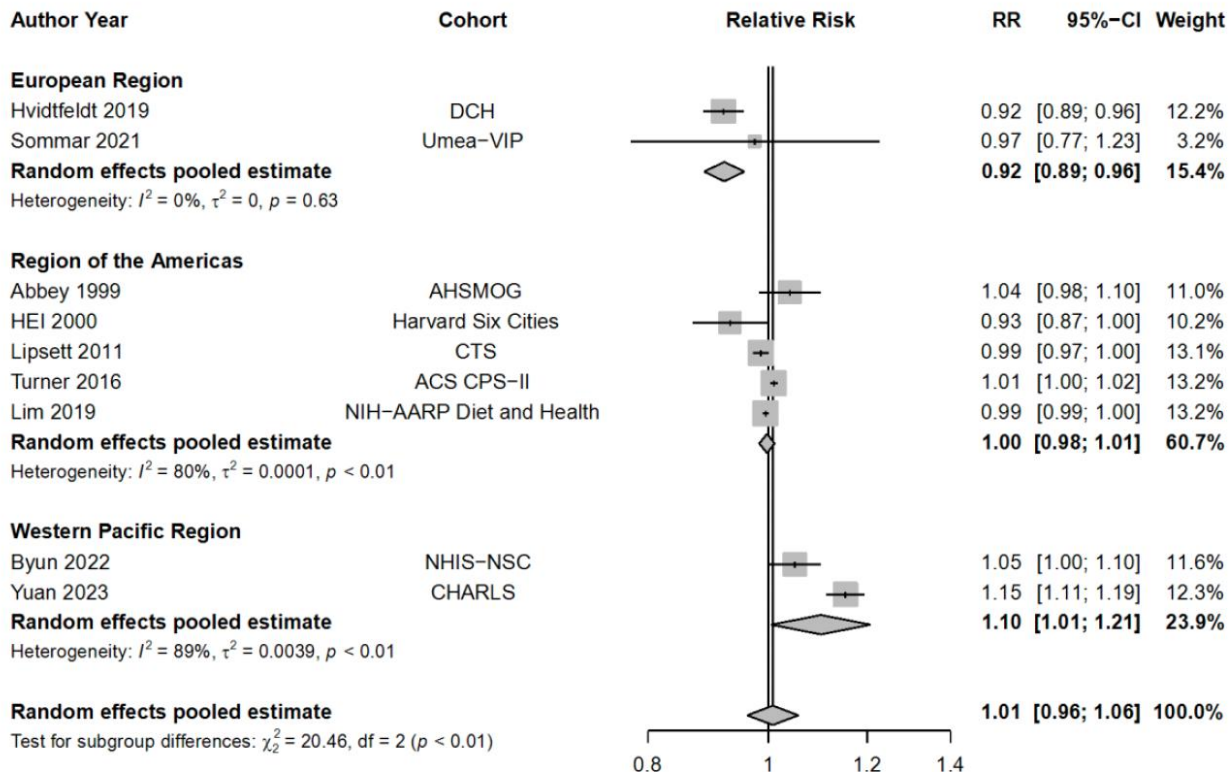
## B) Peak/warm season O<sub>3</sub>

	N	RR (95% CI)
All-cause	12	1.01 (0.97, 1.04)
Respiratory disease	9	1.01 (0.98, 1.03)
COPD	7	1.00 (0.96, 1.04)
ALRI	4	1.02 (0.99, 1.04)

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# Ozone and mortality

- Forest plot for the relative risk (RR) in (left) all-cause mortality and (right) respiratory disease mortality associated with  $10\mu\text{g}/\text{m}^3$  increase in annual  $\text{O}_3$  by WHO region from Kasdagli et al
- No (all cause) or weaker (respiratory) evidence from Europe
- Strongest evidence from Western Pacific



# Valuation of health impacts

- Elements:
  - Health care costs
  - Changes in productivity
  - Lost utility
- Challenge: ensuring impact valued = impact quantified
  - Severity, interpretation of effect, completeness of valuation...
- Review of 'cost-of-illness' studies and WTP estimates ongoing in HORIZON-funded VALESOR study
  - Identified good quality studies for each effect
  - Investigating approaches to extrapolation via benefits transfer
- Approach for Gothenburg: use average values across UN/ECE
- Sensitivity analysis with country-specific values could be included

# Valuation of health impacts

- VALESOR reviewing available evidence
- From Walton et al 2024
- GBP 2022
- UK sources

Effect	Care	Productivity	Utility	Total
ALRI (acute lower respiratory infection)	210	No data	300	<b>510</b>
Asthma in adults	5,500	18,000	150,000	<b>173,500</b>
Asthma in children	7,700	18,000	210,000	<b>235,700</b>
Cardiovascular hospital admissions	6,700	Not assessed	Not assessed	<b>6,700</b>
COPD (chronic obstructive pulmonary disease)	18,000	10,000	52,000	<b>80,000</b>
Dementia	240,000	30,000	180,000	<b>450,000</b>
Diabetes (T2)	17,000	16,000	220,000	<b>253,000</b>
AMI / Ischaemic heart disease	9,800	1,900	140,000	<b>151,700</b>
Lung cancer	34,000	110,000	40,000	<b>184,000</b>
Respiratory hospital admissions	15,000	Not assessed	Not assessed	<b>15,000</b>
School loss days	Not assessed	100	Not assessed	<b>100</b>
Stroke	220,000	13,000	210,000	<b>443,000</b>

# Valuation of health impacts

- VALESOR currently assessing data on differential costs across countries and the reasons for them
- Example: Luengo-Fernandez 2013, for cancers, data expressed as cost per head of population (not per case)

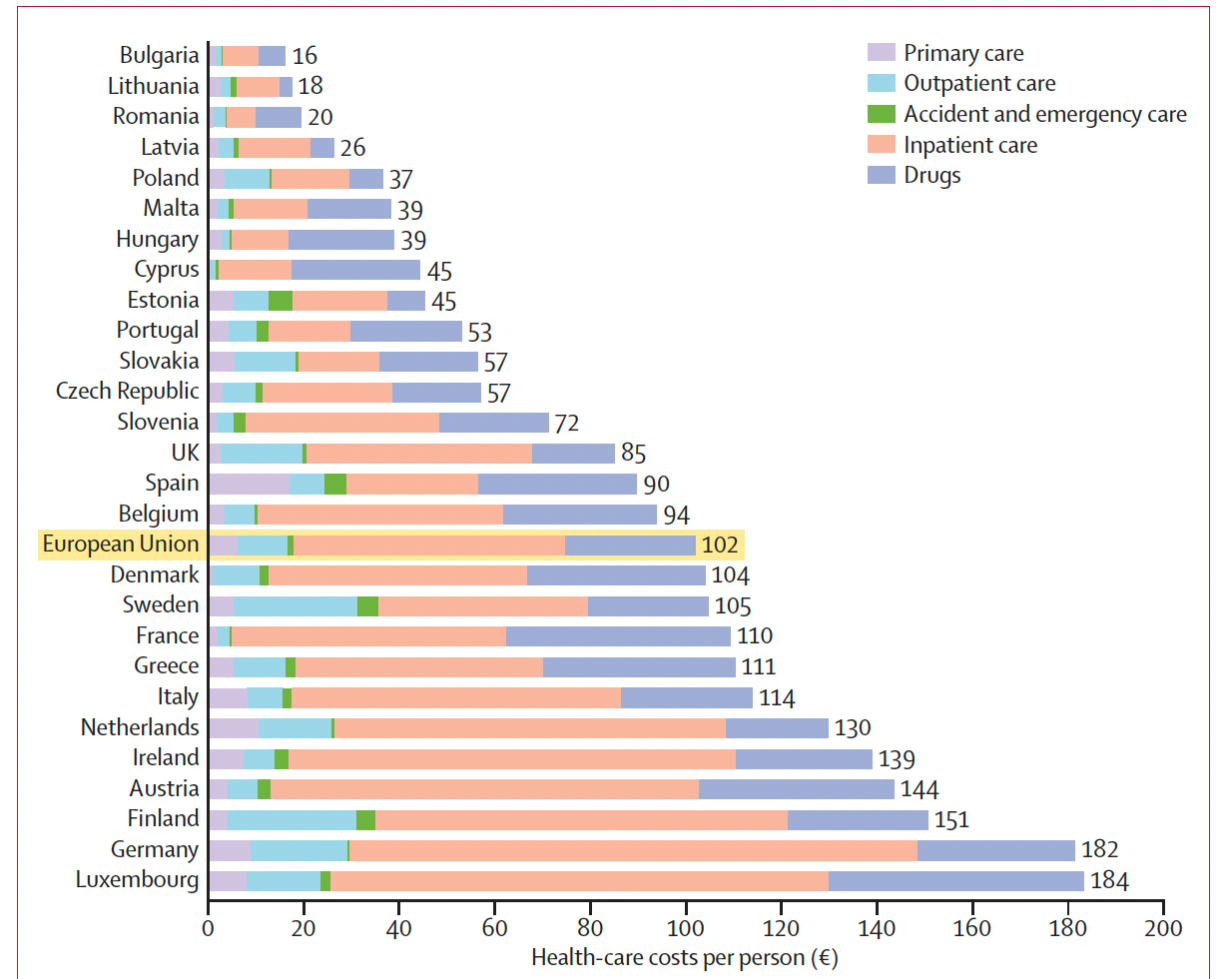


Figure 1: Health-care costs of cancer per person in European Union countries in 2009, by health-care service category

Data not adjusted for price differentials.

# Accounting for deprivation and reducing inequality

- Two elements
  - Differences in exposure to air pollution with deprivation
    - Small in countries with strong regulation of air quality, potentially large in countries with softer legislation
  - Differences in health status with deprivation around Europe
    - 10 year difference in life expectancy
    - 20 year for healthy life expectancy
    - Factor 4 for infant mortality
    - Etc.
- Neither are currently factored into our health analysis at the national level as analysis is based on national average concentrations and national average health effect incidence
- Consequence for our estimates of total impact may be small, but consequences for policy on reduction of inequalities may be substantial

# Non-health effects

- Current estimates from EC work indicate ecosystem damage is small compared to health damage
- Updated information from International Nitrogen Assessment indicates potential for substantially larger estimates for biodiversity loss

# Uncertainty in CBA

- CBA is subject to the whole stream of uncertainties
  - Demand and population projections
  - Dispersion modelling
  - Exposure assessment for health and non-health
  - Impact quantification
  - Valuation of impacts
  - Identification and costing of abatement options
  - Etc.
- Which are most important, and how can uncertainty in these factors be brought through to the CBA outputs?

# Uncertainty in CBA

- **Key questions for the CBA**

- Do benefits exceed costs?
- How big is the benefit:cost ratio?

- **Key uncertainties for CBA (suggestions)**

- Selection of health functions
- Extrapolation of health costing
- Selecting and costing pollution controls
- Impacts omitted from analysis

- **Techniques available**

- Statistical analysis, including Monte Carlo
- Sensitivity analysis
- Review of unquantified biases

# Future activities (assistance welcome!)

- Liaise with TFH on health response functions and other assumptions
- Finalise valuation recommendations (with VALESOR project)
- Further investigate the distribution of health impacts accounting for deprivation
- Review valuation of non-health impacts particularly on biodiversity

# Key references

- 4<sup>th</sup> Clean Air Outlook 2025: <https://op.europa.eu/en/publication-detail/-/publication/4d746ab1-f7de-11ef-b7db-01aa75ed71a1/language-en>
- Chen et al 2024: <https://www.sciencedirect.com/science/article/pii/S0013935124021224?via%3Dihub>
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