The Burden of Disease attributable to Ambient Air Pollution: estimates from the GBD 2010 project

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on behalf of the GBD 2010 Ambient Air Pollution Expert Group and

the GBD Collaboration

The Global Burden of Disease attributable to Ambient Air Pollution: estimates from the GBD 2010 project

- What is GBD 2010?
- Drivers of global health patterns relevant to the ambient air pollution-attributable burden
- Methods for estimating exposure and risk
- The global and regional burdens attributable to ambient air pollution
- Conclusions and implications

Global Burden of Disease 2010

- **A *systematic scientific* effort to quantify the *comparative* magnitude of *health loss* for 187 countries from 1990 to 2010. Last major update was for 2000 under the auspices of WHO**
- **Covering 291 diseases and injuries, 1,160 sequelae of these diseases and injuries, and 67 risk factors or clusters of risk factors**
- **GBD 2010 study initiated in 2007 funded by Bill and Melinda Gates Foundation**
- **Summary papers published in a dedicated triple issue of the Lancet December 15th, 2012**

THE LANCET

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The Global Burden of Disease Study 2010

A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010

Stephen S Lim†‡, Theo Vos, Abraham D Flaxman, Goodarz Danaei, Kenji Shibuya, Heather Adair-Rohani, Markus Amann*, H Ross Anderson*, Kathryn G Andrews*, Martin Aryee*, Charles Atkinson*, Loraine J Bacchus*, Adil N Bahalim*, Kalpana Balakrishnan*, John Balmes*, Suzanne Barker-Collo*, Amanda Baxter*, Michelle L Bell*, Jed D Blore*, Fiona Blyth*, Carissa Bonner*, Guilherme Borges*, Rupert Bourne*, Michel Boussinesq*, Michael Brauer*, Peter Brooks*, Nigel G Bruce*, Bert Brunekreef*, Claire Bryan-Hancock*, Chiara Bucello*, Rachelle Buchbinder*, Fiona Bull*, Richard T Burnett*, Tim E Byers*, Bianca Calabria*, Jonathan Carapetis*, Emily Carnahan*, Zoe Chafe*, Fiona Charlson*, Honglei Chen*, Jian Shen Chen*, Andrew Tai-Ann Cheng*, Jennifer Christine Child*, Aaron Cohen*, K Ellicott Colson*, Benjamin C Cowie*, Sarah Darby*, Susan Darling*, Adrian Davis*, Louisa Degenhardt*, Frank Dentener*, Don C Des Jarlais*, Karen Devries*, Mukesh Dherani*, Eric L Ding*, E Ray Dorsey*, Tim Driscoll*, Karen Edmond*, Suad Eltahir Ali*, Rebecca E Engell*, Patricia J Erwin*, Saman Fahimi*, Gail Falder*, Farshad Farzadfar*, Alize Ferrari*, Mariel M Finucane*, Seth Flaxman*, Francis Gerry R Fowkes*, Greg Freedman*, Michael K Freeman*, Emmanuela Gakidou*, Santu Ghosh*, Edward Giovannucci*, Gerhard Gmel*, Kathryn Graham*, Rebecca Grainger*, Bridget Grant*, David Gunnell*, Hialy R Gutierrez*, Wayne Hall*, Hans W Hoek*, Anthony Hogan*, H Dean Hosgood III*, Damian Hoy*, Howard Hu*, Bryan J Hubbell*, Sally J Hutchings*, Sydney E Ibeanusi*, Gemma L Jacklyn*, Rashmi Jasrasaria*, Jost B Jonas*, Haidong Kan*, John A Kanis*, Nicholas Kassebaum*, Norito Kawakami*, Young-Ho Khang*, Shahab Khatibzadeh*, Jon-Paul Khoo*, Cindy Kok*, Francine Laden*, Ratilal Lalloo*, Qing Lan*, Tim Lathlean*, Janet L Leasher*, James Leigh*, Yang Li*, John Kent Lin*, Steven E Lipshultz*, Stephanie London*, Rafael Lozano*, Yuan Lu*, Joelle Mak*, Reza Malekzadeh*, Leslie Mallinger*, Wagner Marcenes*, Lyn March*, Robin Marks*, Randall Martin*, Paul McGale*, John McGrath*, Sumi Mehta*, George A Mensah*, Tony R Merriman*, Renata Micha*, Catherine Michaud*, Vinod Mishra*, Khayriyyah Mohd Hanafiah*, Ali A Mokdad*, Lidia Morawska*, Dariush Mozaffarian*, Tasha Murphy*, Mohsen Naghavi*, Bruce Neal*, Paul K Nelson*, Joan Miquel Nolla*, Rosana Norman*, Casey Olives*, Saad B Omer*, Jessica Orchard*, Richard Osborne*, Bart Ostro*, Andrew Page*, Kiran D Pandey*, Charles D H Parry*, Erin Passmore*, Jayadeep Patra*, Neil Pearce*, Pamela M Pelizzari*, Max Petzold*, Michael R Phillips*, Dan Pope*, C Arden Pope III*, John Powles*, Mayuree Rao*, Homie Razavi*, Eva A Rehfuess*, Jürgen T Rehm*, Beate Ritz*, Frederick P Rivara*, Thomas Roberts*, Carolyn Robinson*, Jose A Rodriguez-Portales*, Isabelle Romieu*, Robin Room*, Lisa C Rosenfeld*, Ananya Roy*, Lesley Rushton*, Joshua A Salomon*, Uchechukwu Sampson*, Lidia Sanchez-Riera*, Ella Sanman*, Amir Sapkota*, Soraya Seedat*, Peilin Shi*, Kevin Shield*, Rupak Shivakoti*, Gitanjali M Singh*, David A Sleet*, Emma Smith*, Kirk R Smith*, Nicolas J C Stapelberg*, Kyle Steenland*, Heidi Stöckl*, Lars Jacob Stovner*, Kurt Straif*, Lahn Straney*, George D Thurston*, Jimmy H Tran*, Rita Van Dingenen*, Aaron van Donkelaar*, J Lennert Veerman*, Lakshmi Vijayakumar*, Robert Weintraub*, Myrna M Weissman*, Richard A White*, Harvey Whiteford*, Steven T Wiersma*, James D Wilkinson*, Hywel C Williams*, Warwick Williams*, Nicholas Wilson*, Anthony D Woolf*, Paul Yip*, Jan M Zielinski*, Alan D Lopez†, Christopher J L Murray†, Majid Ezzati†*

Lancet 2012; 380: 2224–60

See Comment pages 2053, 2054, 2055, 2058, 2060, 2062, and 2063

See Special Report page 2067

See Articles pages 2071, 2095, 2129, 2144, 2163, and 2197

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See Online for appendix

For interactive versions of figures 3, 4, and 6 see http://healthmetricsandevaluation.org/gbd/visualizations/regional

Institute for Health Metrics and Evaluation

(S S Lim PhD, A D Flaxman PhD, K G Andrews MPH, C Atkinson BS, E Carnahan BA, K E Colson BA, R E Engell BA, G Freedman BA, M K Freeman BA, E Gakidou PhD, R Jasrasaria BA,

Summary

Background Quantification of the disease burden caused by different risks informs prevention by providing an account of health loss different to that provided by a disease-by-disease analysis. No complete revision of global disease burden caused by risk factors has been done since a comparative risk assessment in 2000, and no previous analysis has assessed changes in burden attributable to risk factors over time.

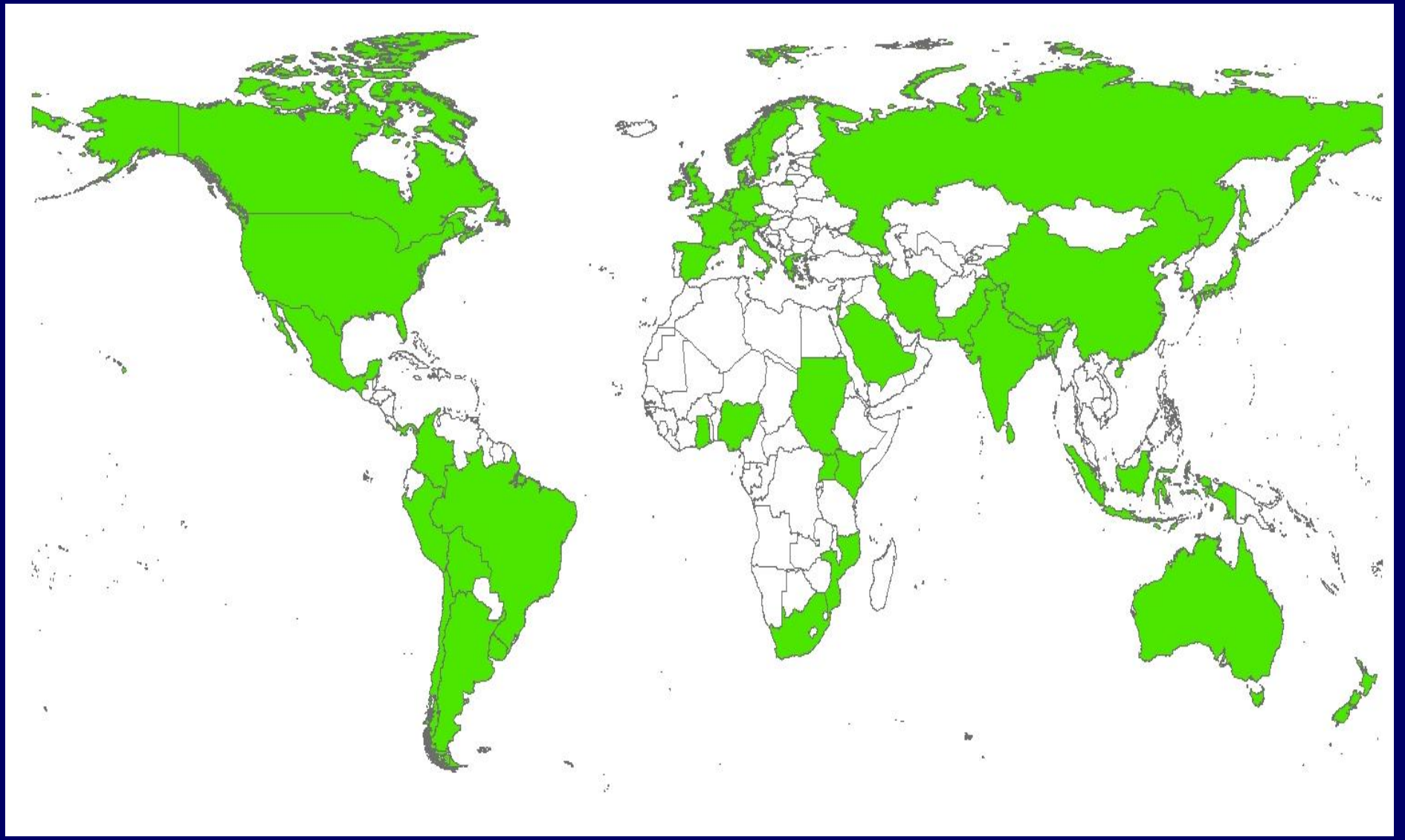
Methods We estimated deaths and disability-adjusted life years (DALYs; sum of years lived with disability [YLD] and years of life lost [YLL]) attributable to the independent effects of 67 risk factors and clusters of risk factors for 21 regions in 1990 and 2010. We estimated exposure distributions for each year, region, sex, and age group, and relative risks per unit of exposure by systematically reviewing and synthesising published and unpublished data. We used these estimates, together with estimates of cause-specific deaths and DALYs from the Global Burden of Disease Study 2010, to calculate the burden attributable to each risk factor exposure compared with the theoretical-minimum-risk exposure. We incorporated uncertainty in disease burden, relative risks, and exposures into our estimates of attributable burden.

Findings In 2010, the three leading risk factors for global disease burden were high blood pressure (7·0% [95% uncertainty interval 6·2–7·7] of global DALYs), tobacco smoking including second-hand smoke (6·3% [5·5–7·0]), and alcohol use (5·5% [5·0–5·9]). In 1990, the leading risks were childhood underweight (7·9% [6·8–9·4]), household air pollution from solid fuels (HAP; 7·0% [5·6–8·3]), and tobacco smoking including second-hand smoke (6·1% [5·4–6·8]). Dietary risk factors and physical inactivity collectively accounted for 10·0% (95% UI 9·2–10·8) of global DALYs in 2010, with the most prominent dietary risks being diets low in fruits and those high in sodium. Several risks that primarily affect childhood communicable diseases, including unimproved water and sanitation and childhood micronutrient deficiencies, fell in rank between 1990 and 2010, with unimproved water

http://www.thelancet.com/themed/global-burden-of disease

GBD 2010 Team

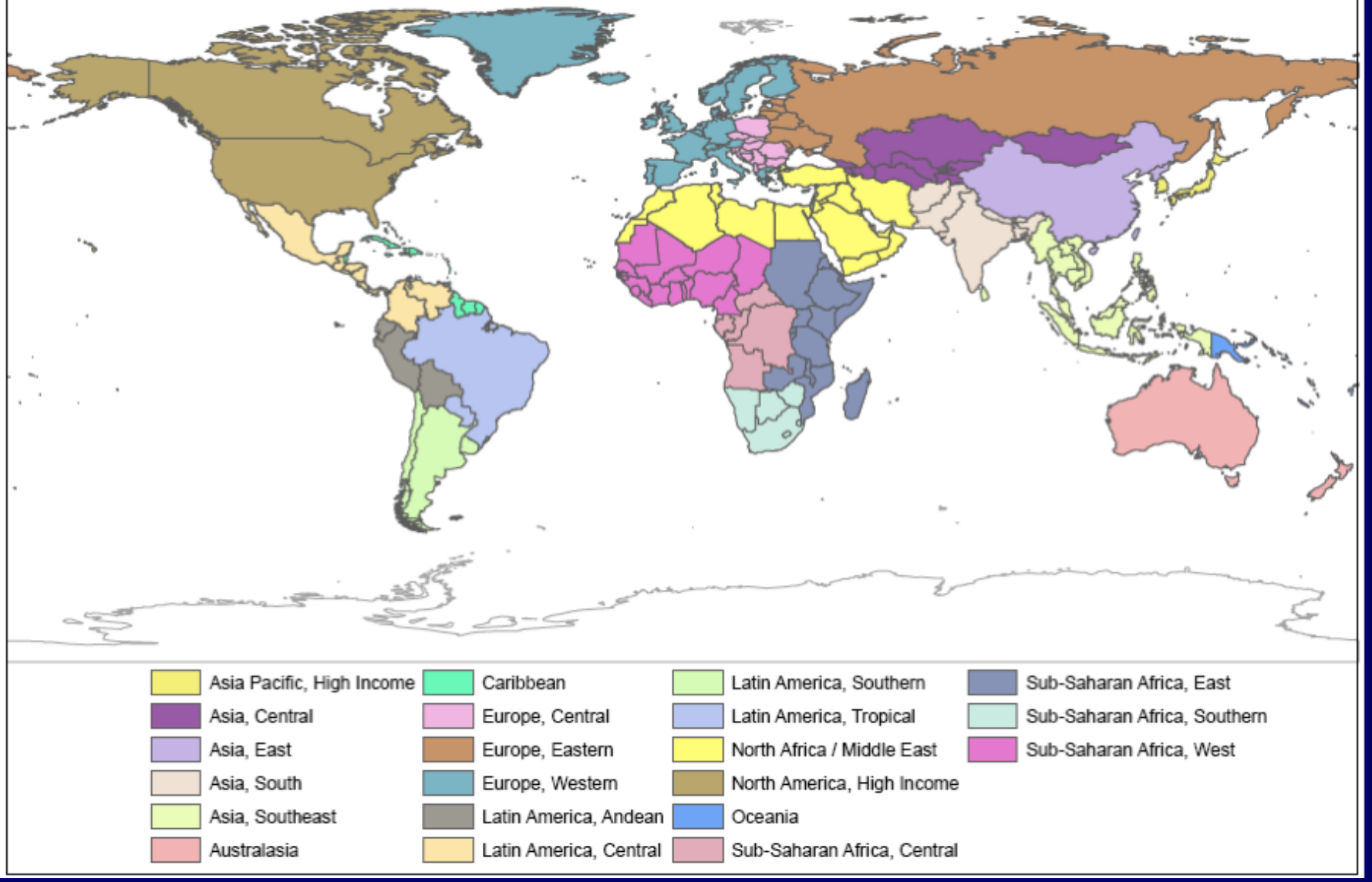
488 authors from 303 institutions in 50 countries



Outdoor Air Pollution Expert Group

H Ross Anderson (Co-Chair)	***SGHMS U London***
Markus Amann	***IIASA/Vienna***
Richard Atkinson	***SGHMS U London***
Michelle Bell	***Yale University***
Michael Brauer	***U British Columbia***
Bert Brunekreef	***U Utrecht***
Richard Burnett	***Health Canada***
Aaron Cohen (Co-Chair)	***Health Effects Institute***
Frank Dentener	***EC-JRC***
Majid Ezzati	***Harvard University***
Bryan Hubbell	***USEPA***
Haidong Kan	***Fudan University***
Michal Krzyzanowski	***WHO/Euro-Bonn***
Stephanie London	***NIEHS***
Randall Martin	***Dalhousie University***
Sumi Mehta	***UN Clean Stoves Program***
Bart Ostro	***California EPA***
Kiran Dev Pandey	***World Bank***
Arden Pope	***Brigham Young U***
Beate Ritz	***UCLA***
Isabelle Romieu	***IARC***
Amir Sapkota	***U Maryland***
Kirk Smith	***UC Berkeley***
George Thurston	***New York University***
Rita van Dingenen	***EC –JRC***
Aaron van Donkelaar	***Dalhousie University***

Global Burden of Diseases, Injuries, and Risk Factors
Regions



Dramatic Demographic Shifts: Mean Age of Death Rising Rapidly

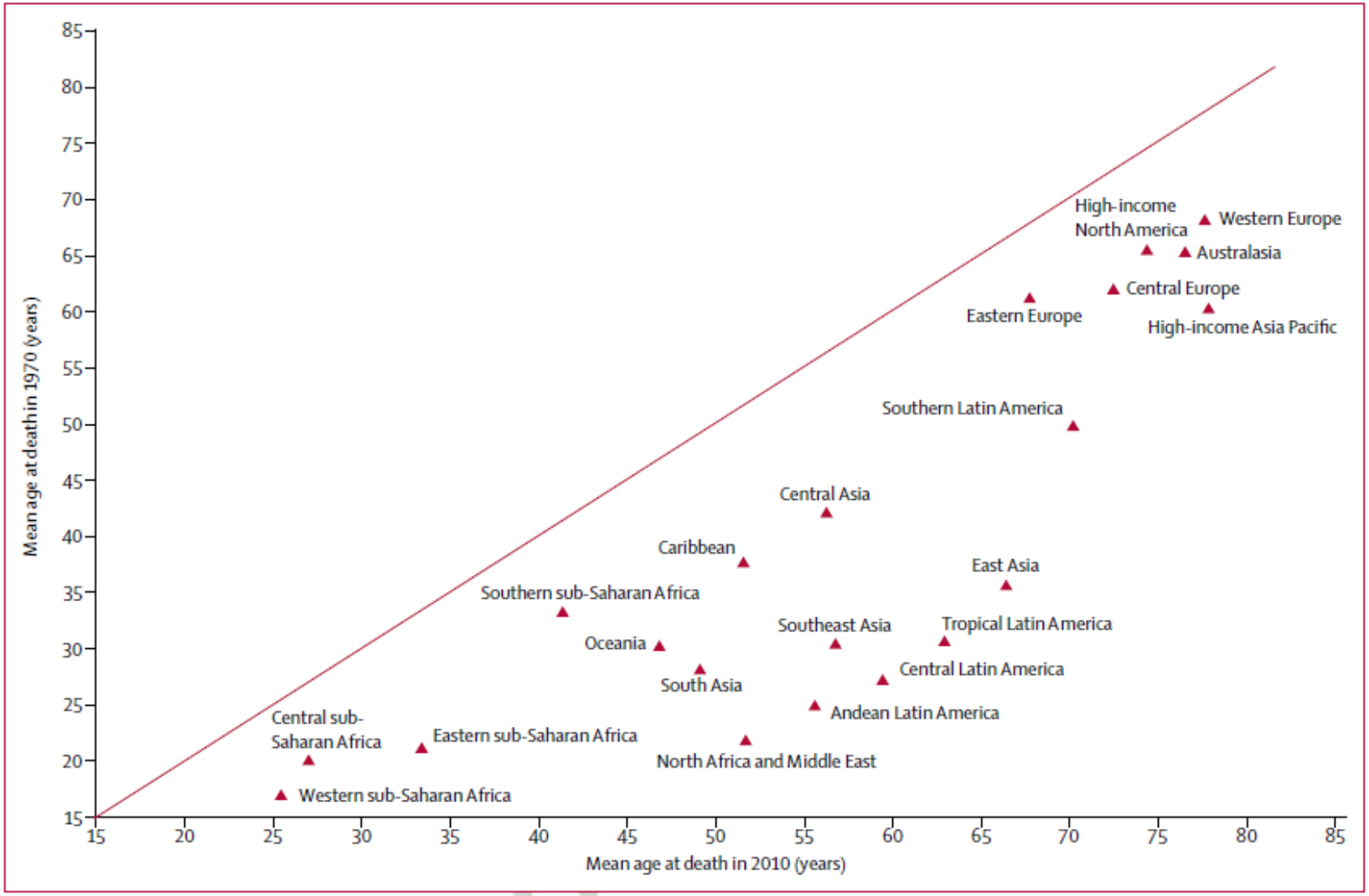
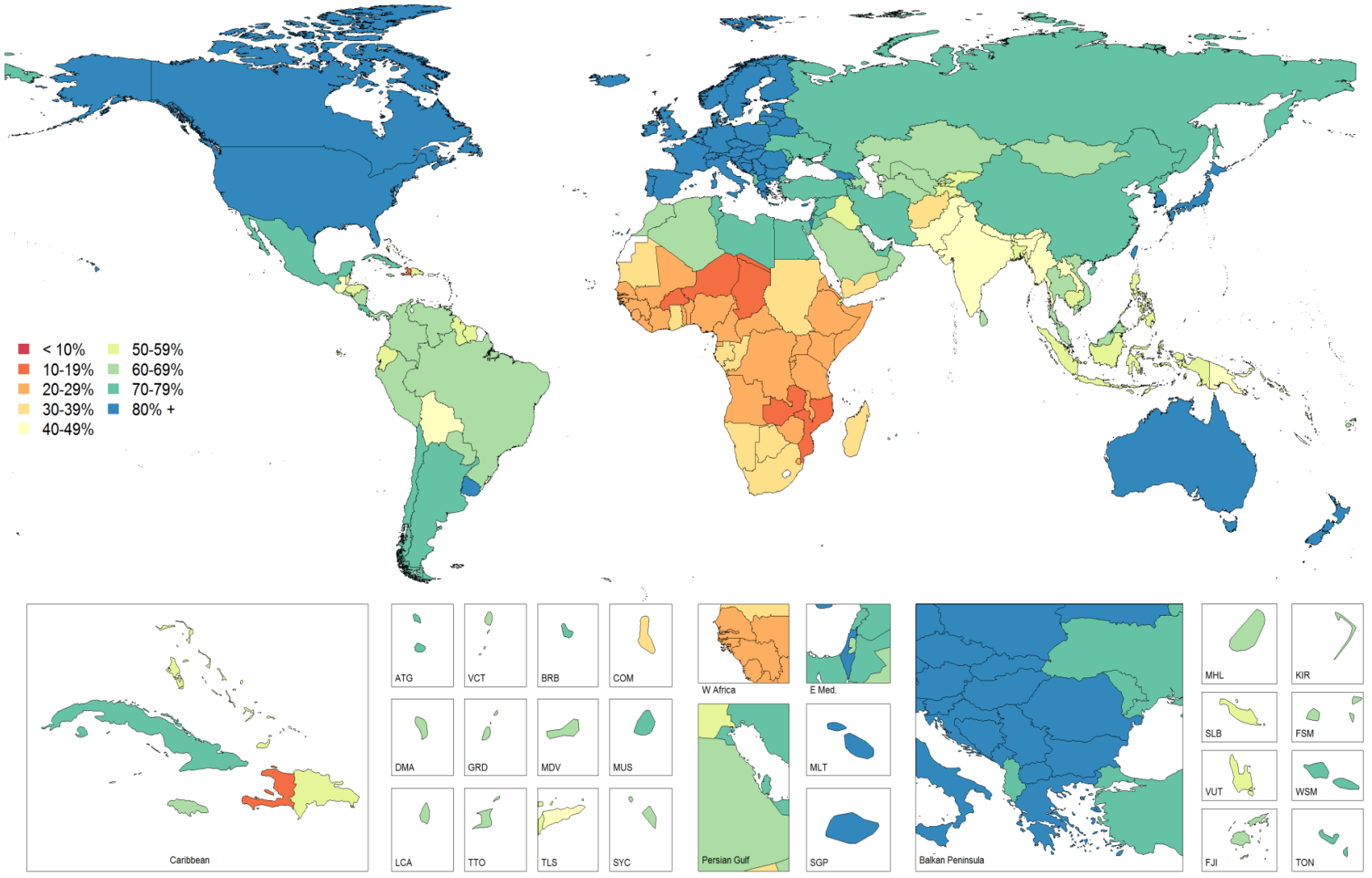


Figure 8: **Mean age of death in Global Burden of Disease regions in 1970 compared with 2010**

Percent of DALYs* from Non-Communicable Diseases in 2010: Over 60% in Nearly All Countries Outside of Sub-Saharan Africa



Disease Burden = Disability-Adjusted Life Years (DALYs) or *healthy years of life lost*

General approach

- Define risk factor (exposure metrics: $PM_{2.5}$, O_3)
- Estimate exposure (P)
- Select health outcomes
  - Systematic reviews
  - Weight of evidence
  - Meta analyses
- Exposure – response functions (RR)
- Counterfactual (P')

Environmental Science & Technology

Article

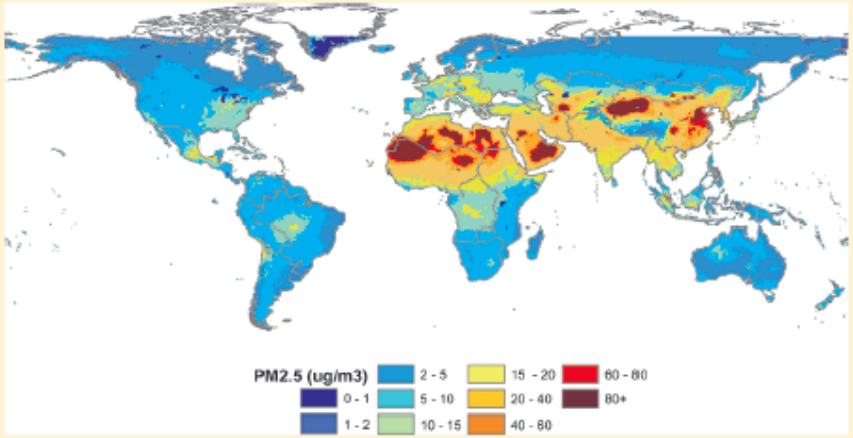
pubs.acs.org/est

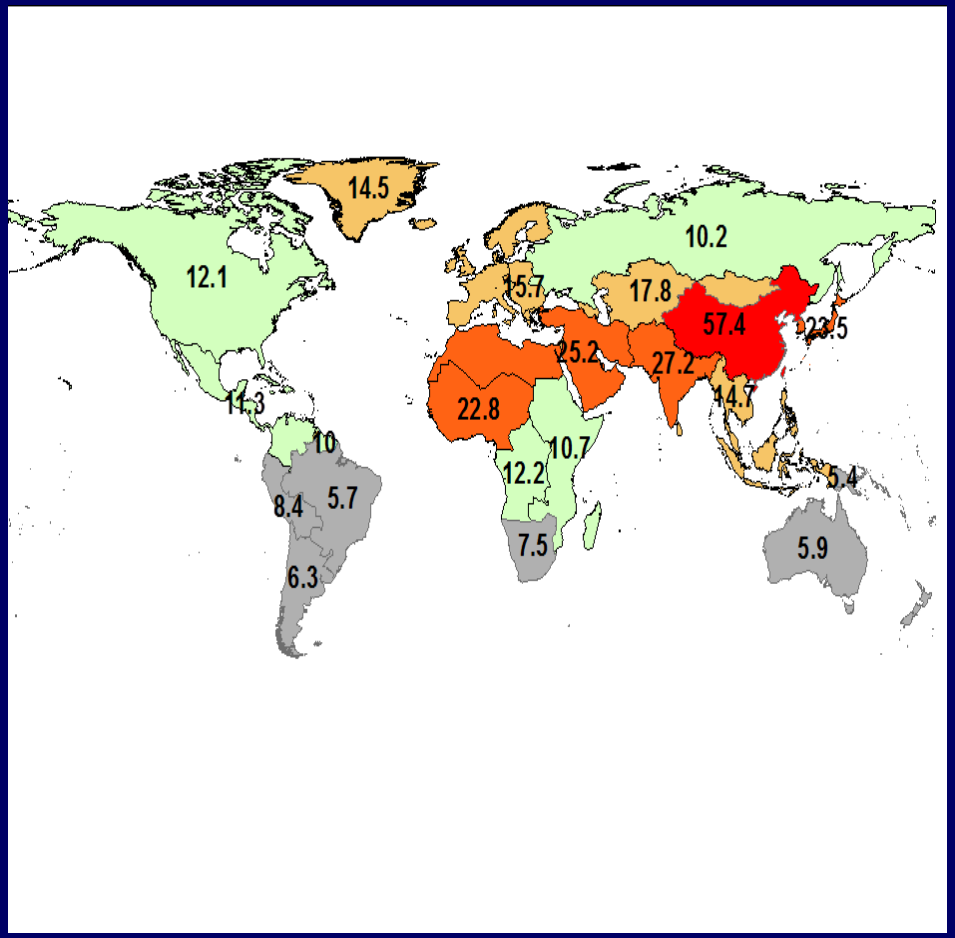
Exposure Assessment for Estimation of the Global Burden of Disease Attributable to Outdoor Air Pollution

Michael Brauer,*[,†] Markus Amann,[‡] Rick T. Burnett,[§] Aaron Cohen,[∥] Frank Dentener,[⊥] Majid Ezzati,[#] Sarah B. Henderson,[▽] Michal Krzyzanowski,[○] Randall V. Martin,[◆,¶] Rita Van Dingenen,[⊥] Aaron van Donkelaar,[◆] and George D. Thurston[+]

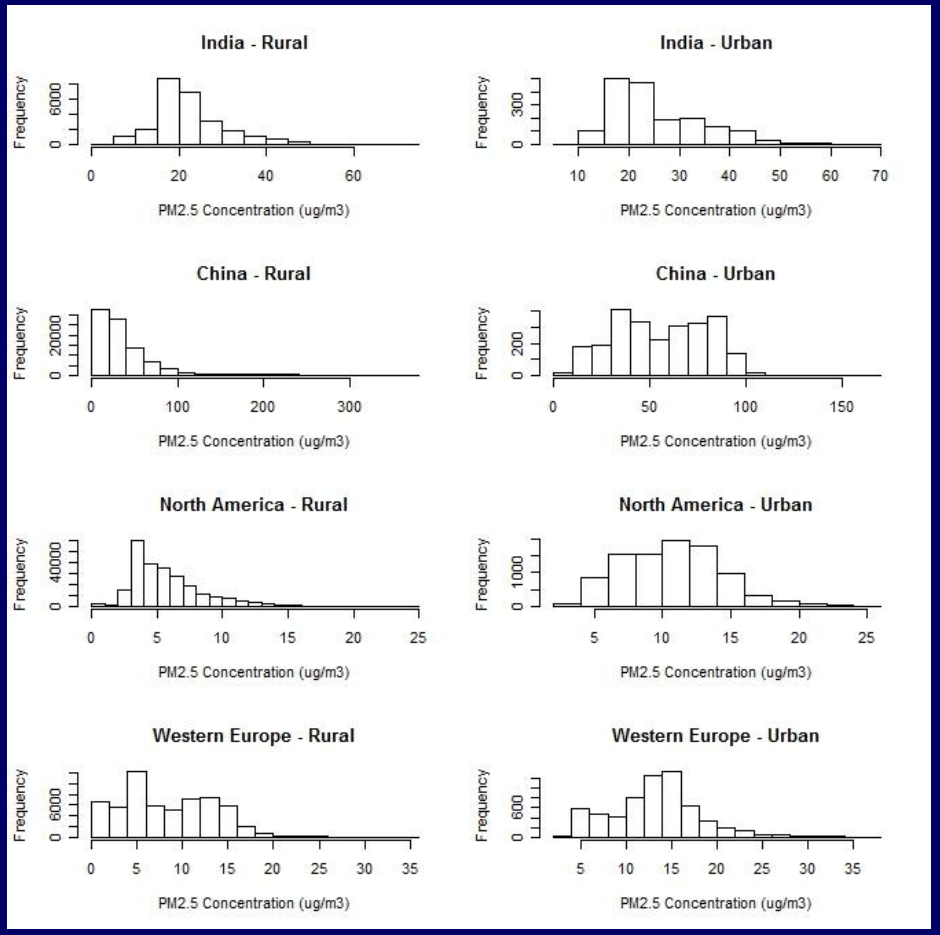
Environ. Sci. Technol. 2012, 46, 652–660

ABSTRACT: Ambient air pollution is associated with numerous adverse health impacts. Previous assessments of global attributable disease burden have been limited to urban areas or by coarse spatial resolution of concentration estimates. Recent developments in remote sensing, global chemical-transport models, and improvements in coverage of surface measurements facilitate virtually complete spatially resolved global air pollutant concentration estimates. We combined these data to generate global estimates of long-term average ambient concentrations of fine particles ($PM_{2.5}$) and ozone at $0.1° \times 0.1°$ spatial resolution for 1990 and 2005. In 2005, 89% of the world's population lived in areas where the World Health Organization Air Quality Guideline of 10 $\mu g/m^3$ $PM_{2.5}$ (annual average) was exceeded. Globally, 32% of the population lived in areas exceeding the WHO Level 1 Interim Target of 35 $\mu g/m^3$, driven by high proportions in East (76%) and South (26%) Asia. The highest seasonal ozone levels were found in North and Latin America, Europe, South and East Asia, and parts of Africa. Between 1990 and 2005 a 6% increase in global population-weighted $PM_{2.5}$ and a 1% decrease in global population-weighted ozone concentrations was apparent, highlighted by increased concentrations in East, South, and Southeast Asia and decreases in North America and Europe. Combined with spatially resolved population distributions, these estimates expand the evaluation of the global health burden associated with outdoor air pollution.





2005 population-weighted regional estimated average $PM_{2.5}$

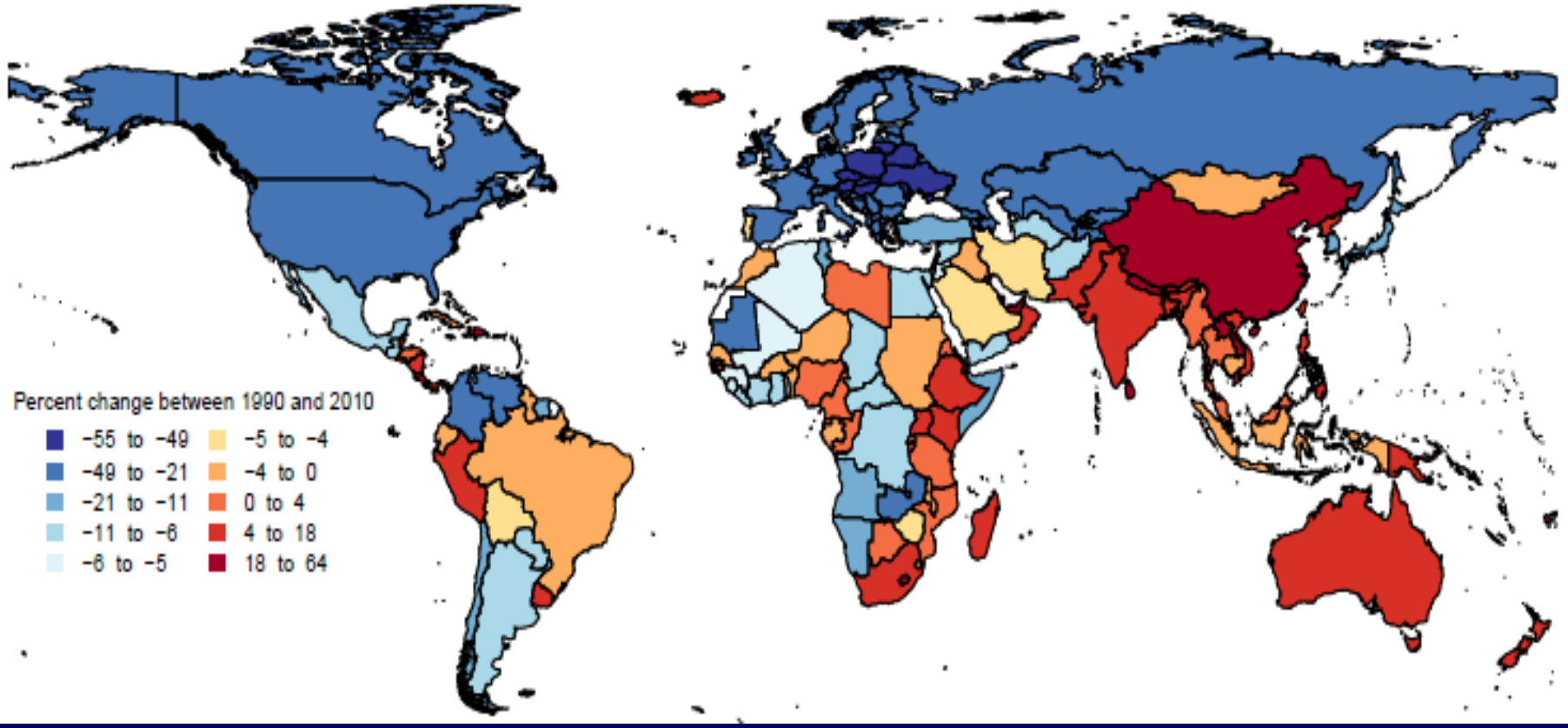


Distributions of selected regional 2005 estimated $PM_{2.5}$ by urban and rural areas

Brauer M, et al *Env Sci Technol* 2012

Changes in estimated population-weighted ambient air pollution levels - $PM_{2.5}$ 1990 - 2010

1990 → 2010:
10% increase in global population-weighted $PM_{2.5}$



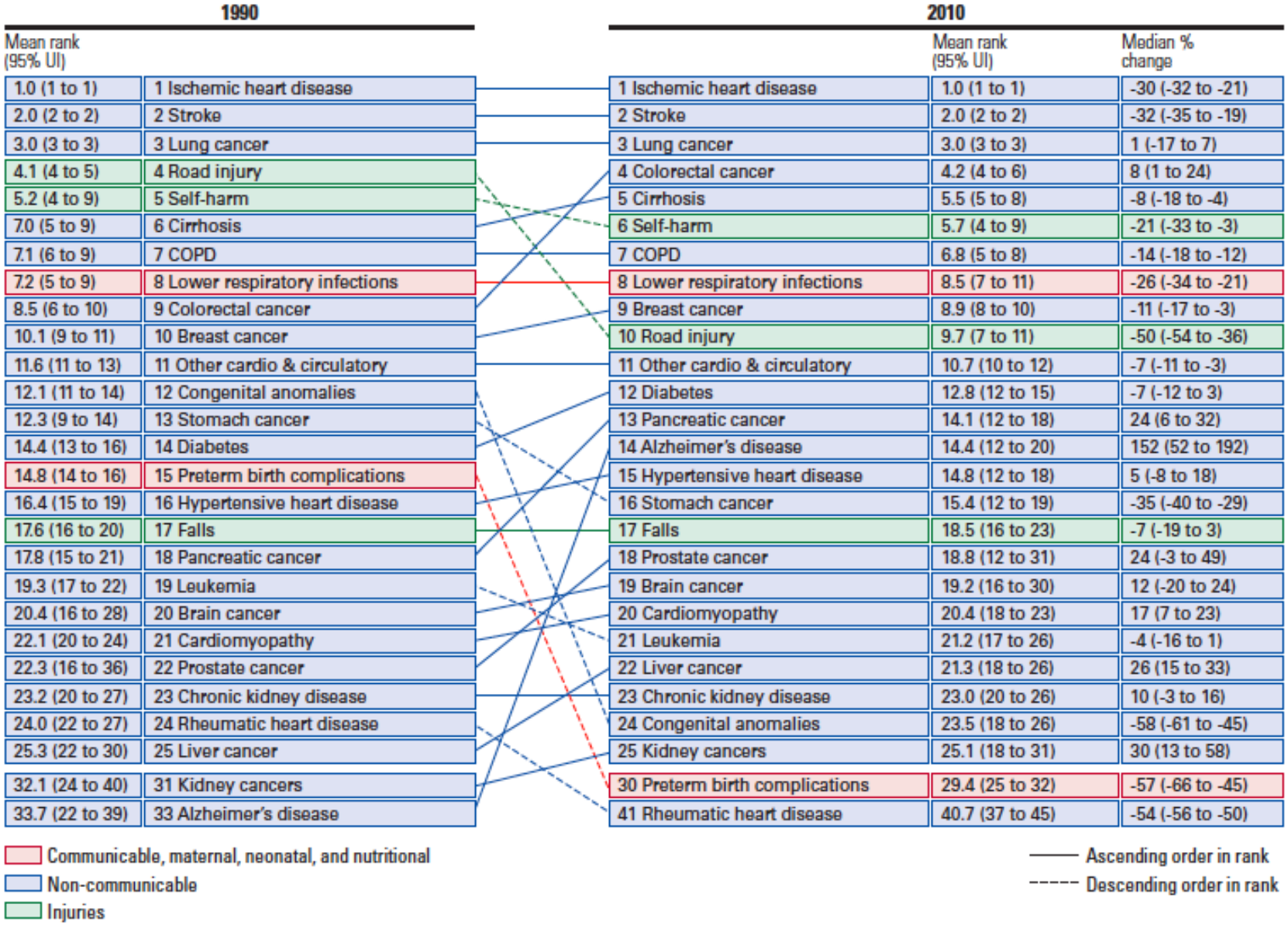
Diseases affected by air pollution are the top 5 causes of the global burden of disease in 2010

- **Ischemic Heart Disease mortality/incidence: PM**
- **Stroke mortality/incidence: PM**
- **COPD mortality: PM, ozone**
- **Lung Cancer mortality: PM**
- **ALRI (0-5 year) mortality/incidence: PM**
  - **Also considered asthma, adverse reproductive outcomes (term low birthweight, preterm delivery)**

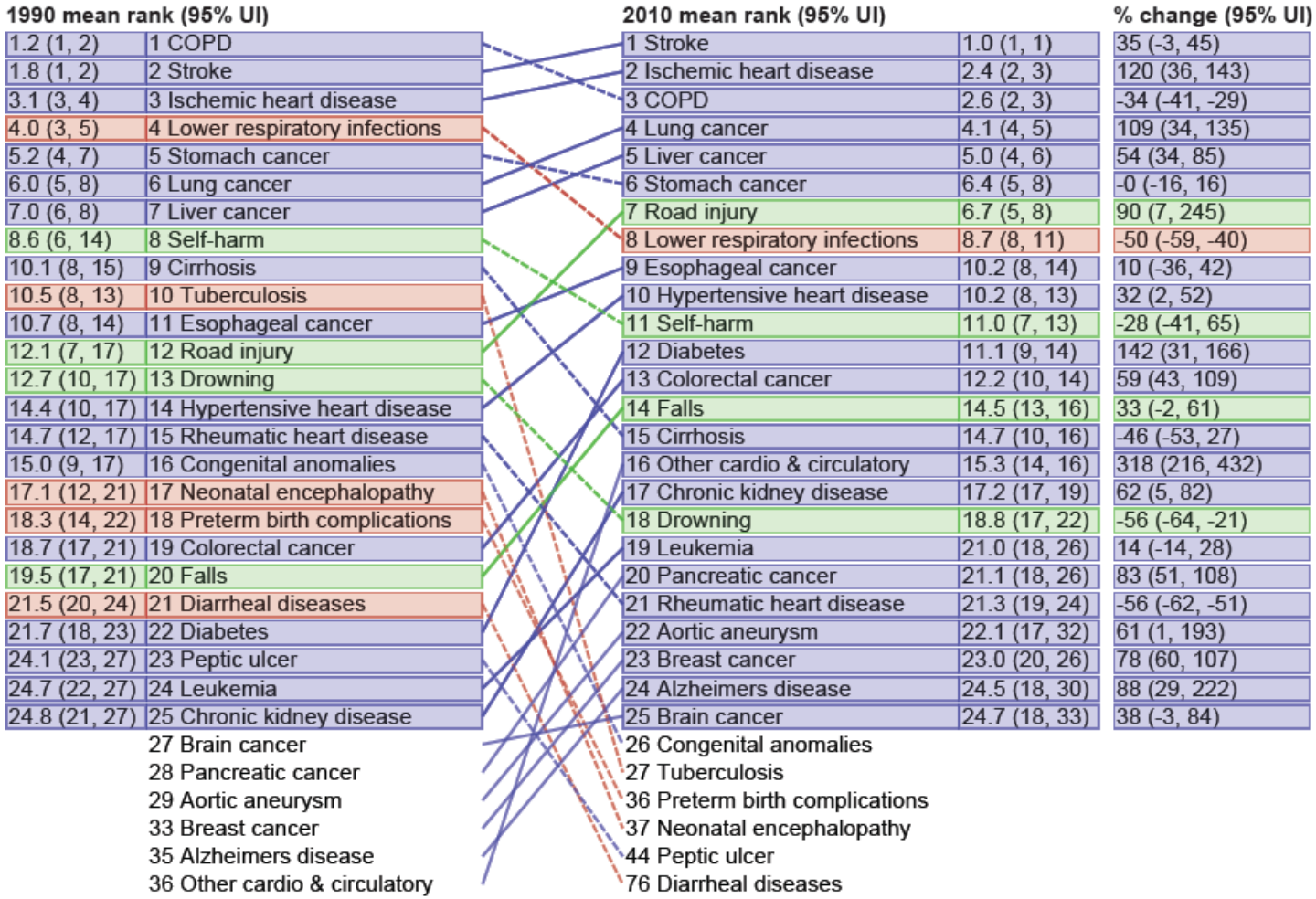
2010		
Disorder	Mean rank (95% UI)	% change (95% UI)
1 Ischaemic heart disease	1·0 (1 to 1)	35 (29 to 39)
2 Stroke	2·0 (2 to 2)	26 (14 to 32)
3 COPD	3·4 (3 to 4)	–7 (–12 to 0)
4 Lower respiratory infections	3·6 (3 to 4)	–18 (–24 to –11)
5 Lung cancer	5·8 (5 to 10)	48 (24 to 61)
6 HIV/AIDS	6·4 (5 to 8)	396 (323 to 465)
7 Diarrhoea	6·7 (5 to 9)	–42 (–49 to –35)
8 Road injury	8·4 (5 to 11)	47 (18 to 86)
9 Diabetes	9·0 (7 to 11)	93 (68 to 102)
10 Tuberculosis	10·1 (8 to 13)	–18 (–35 to –3)
11 Malaria	10·3 (6 to 13)	21 (–9 to 56)
12 Cirrhosis	11·8 (10 to 14)	33 (25 to 41)
13 Self-harm	14·1 (11 to 20)	32 (8 to 49)
14 Hypertensive heart disease	14·2 (12 to 18)	48 (39 to 56)
15 Preterm birth complications	14·4 (12 to 18)	–28 (-39 to -17)
16 Liver cancer	16·9 (14 to 20)	63 (49 to 78)
17 Stomach cancer	17·0 (13 to 22)	–2 (–10 to 5)
18 Chronic kidney disease	17·4 (15 to 21)	82 (65 to 95)
19 Colorectal cancer	18·5 (15 to 21)	46 (36 to 63)
20 Other cardiovascular and circulatory	19·7 (18 to 21)	46 (40 to 55)
21 Protein–energy malnutrition	21·5 (19 to 25)	–32 (–42 to –21)
22 Falls	23·3 (21 to 29)	56 (20 to 84)
23 Congenital anomalies	24·4 (21 to 29)	–22 (–40 to –3)
24 Neonatal encephalopathy*	24·4 (21 to 30)	–20 (–33 to –2)
25 Neonatal sepsis	25·1 (15 to 35)	–3 (–25 to 27)
29 Meningitis		
33 Rheumatic heart disease		
62 Measles		

Lozano et al. Lancet 2012

Figure 4: Shifts in top 25 causes of YLLs, EU and EFTA, 1990–2010

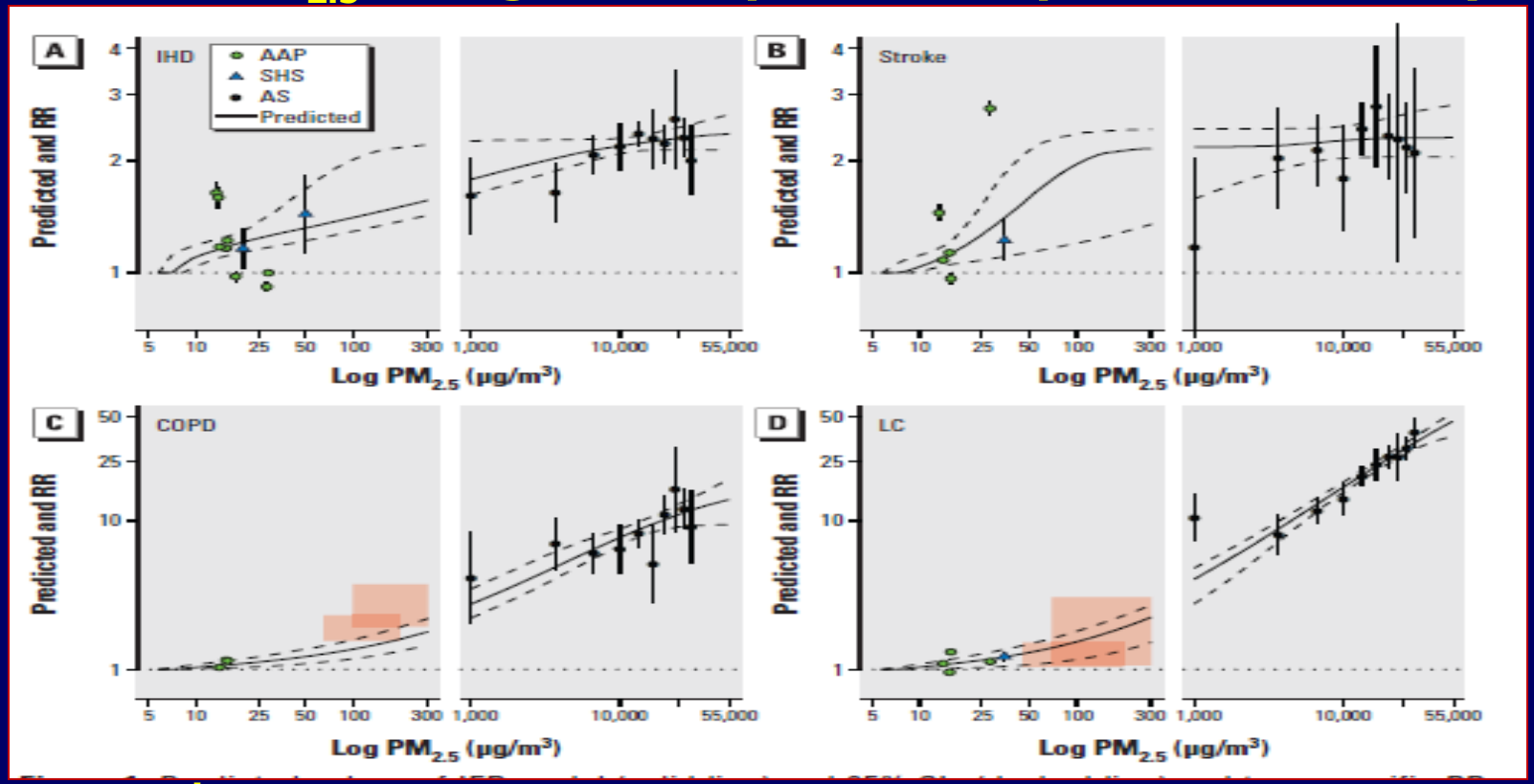


China leading causes of death, all ages, 1990 to 2010



Burnett et al. 2014

Integrating risk from multiple sources to estimate risk due to ambient $PM_{2.5}$ Integrated Exposure-Response functions (IER)



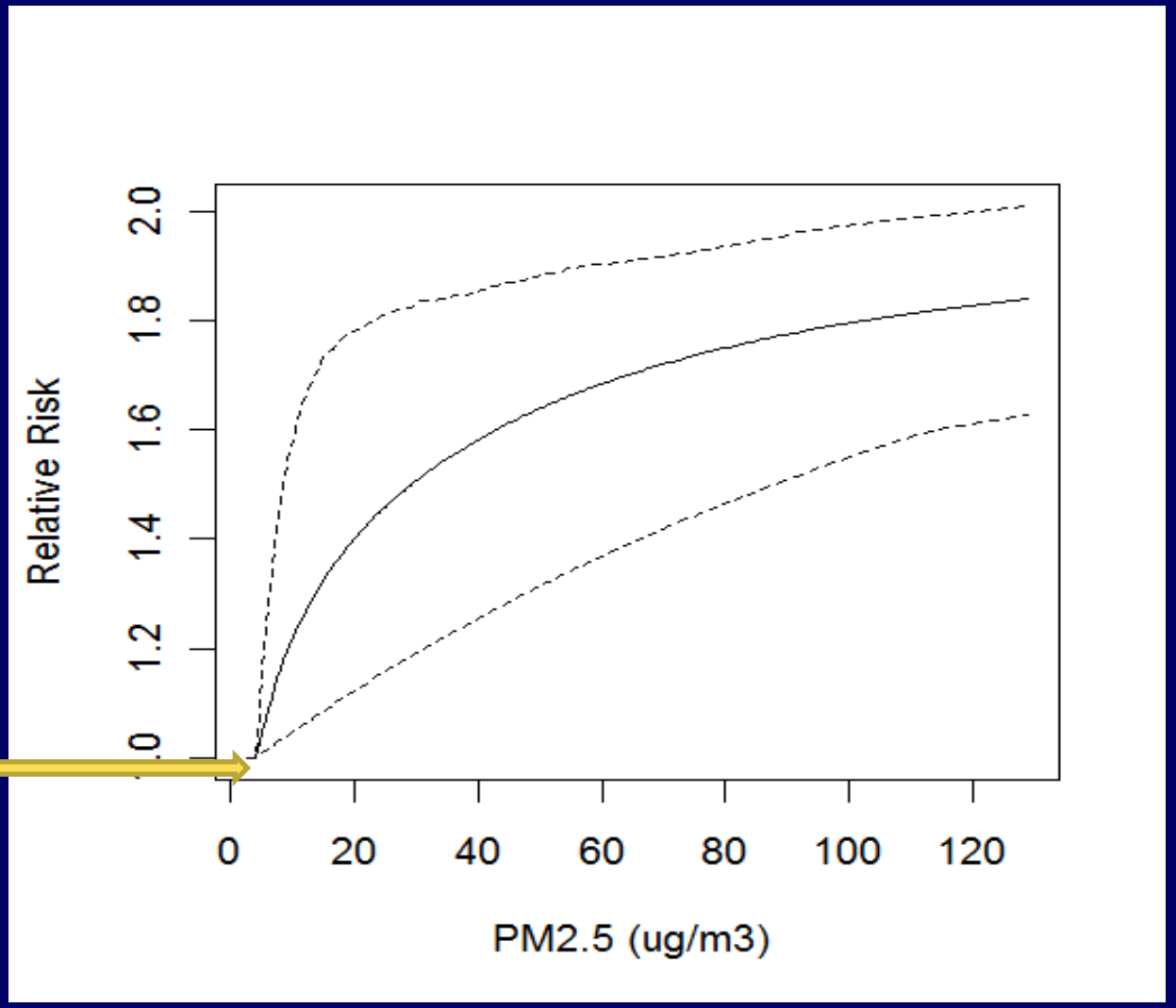
Key assumption

Risk is function of $PM_{2.5}$ inhaled dose regardless of source

Extrapolation model

- reflect change in risk observed in cohort studies at low concentrations
- near-linear at low concentrations
- predict risk for highest $PM_{2.5}$ consistent with risks from smoking (Pope et al.2011)

IER Relative Risk Model for IHD



7 µg/m³

Burnett RT, et al. 2014

GBD risk functions predict risks from recent Chinese cohort study

Journal of Hazardous Materials 186 (2011) 1594–1600

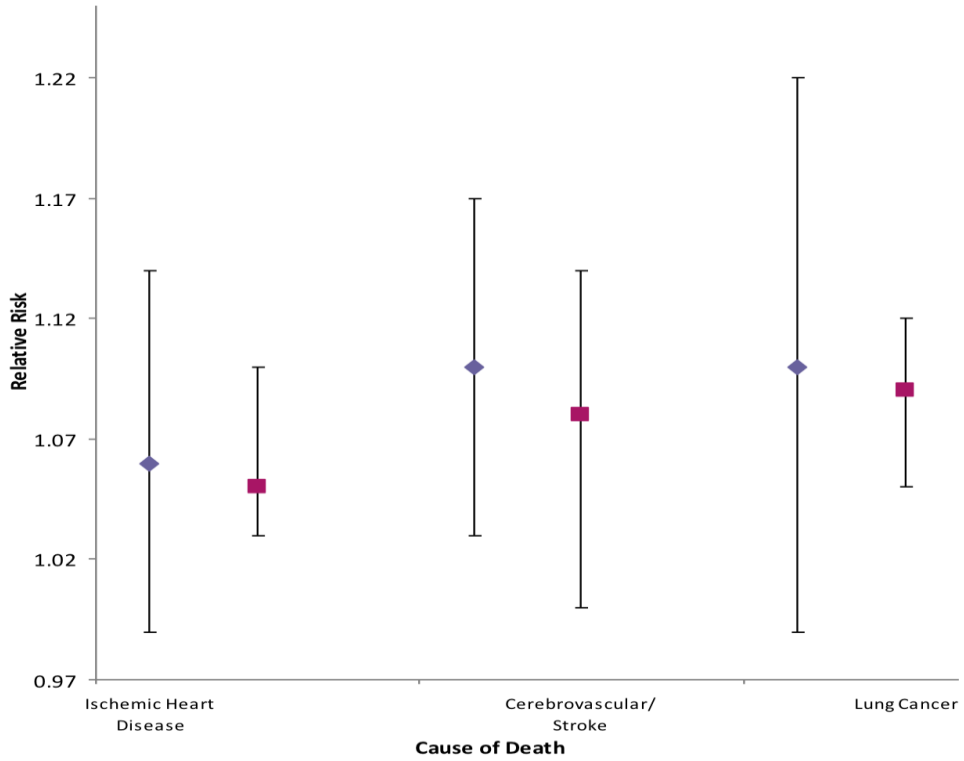
Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Association between long-term exposure to outdoor air pollution and mortality in China: A cohort study

Jie Cao[a,1], Chunxue Yang[b,c,1], Jianxin Li[a], Renjie Chen[b,c], Bingheng Chen[b], Dongfeng Gu[a,**], Haidong Kan[b,c,*]



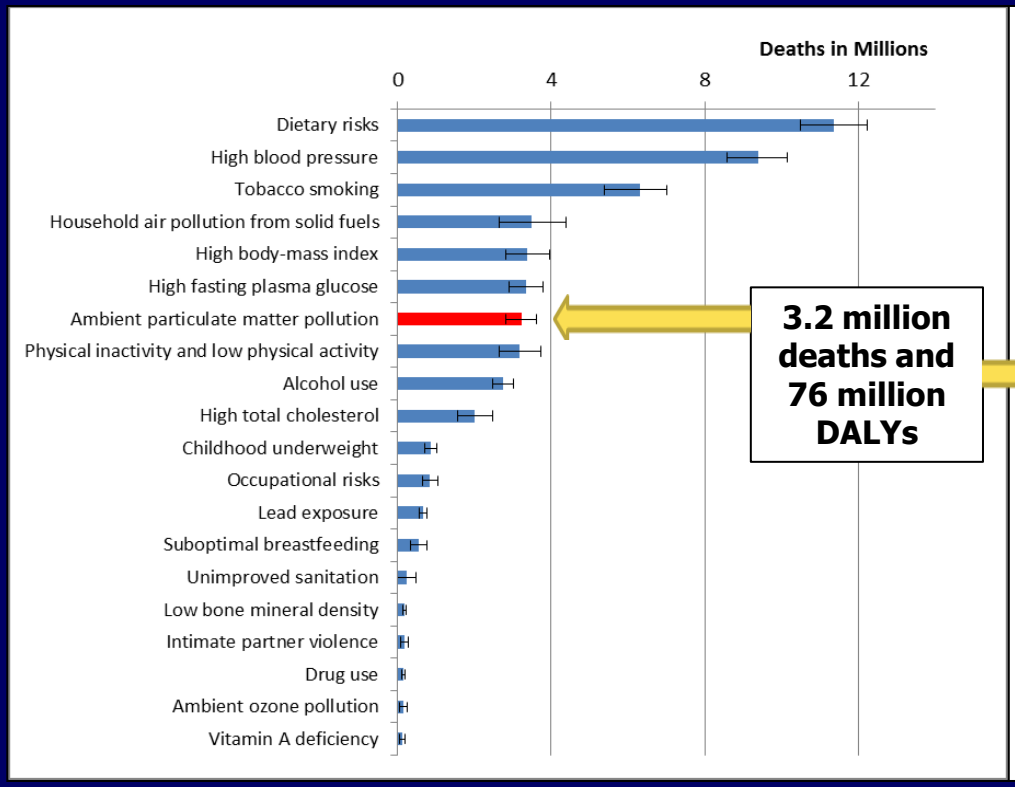
GBD risk functions

Cao et al. 2011

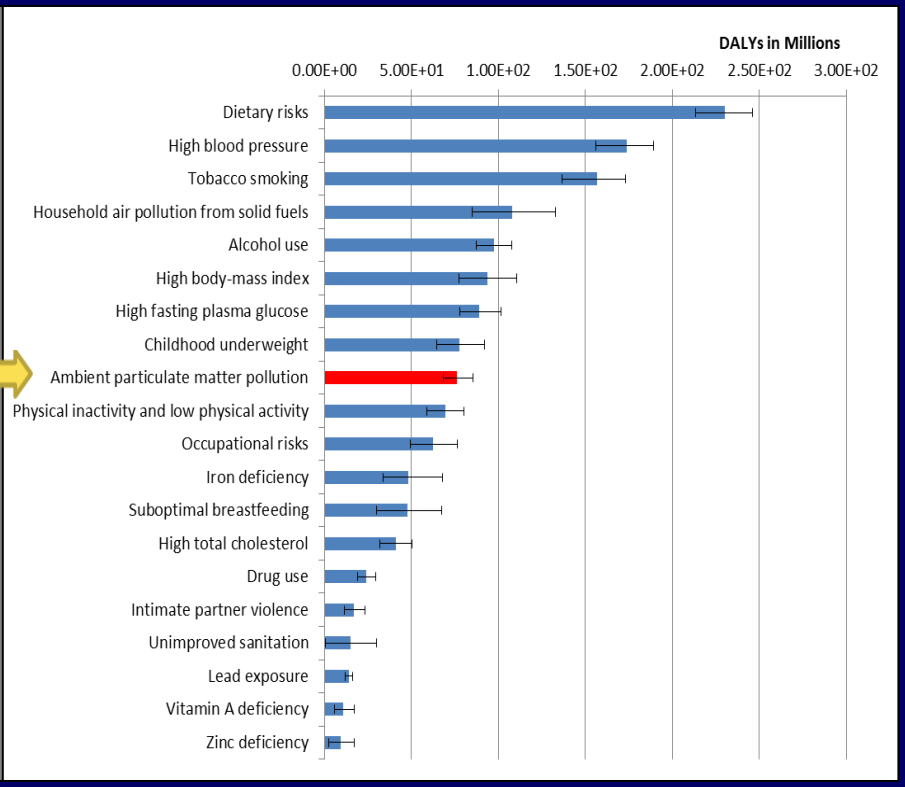
Quantifying Uncertainty

- Multiple sources of uncertainty for both the risk function and estimated attributable burden of disease quantified and expressed as uncertainty intervals
  - Uncertainty in the estimated risk function parameters
  - Uncertainty in the estimate of PM2.5
  - Uncertainty in the counterfactual concentration
  - Uncertainty in the estimated baseline mortality rates
- Sensitivity analyses
  - Uncertainty due to model form explored via sensitivity analysis comparing different model forms
  - The influence of wind-blown dust on the burden estimates will be addressed by an analysis in which the counterfactual is increased in dusty regions

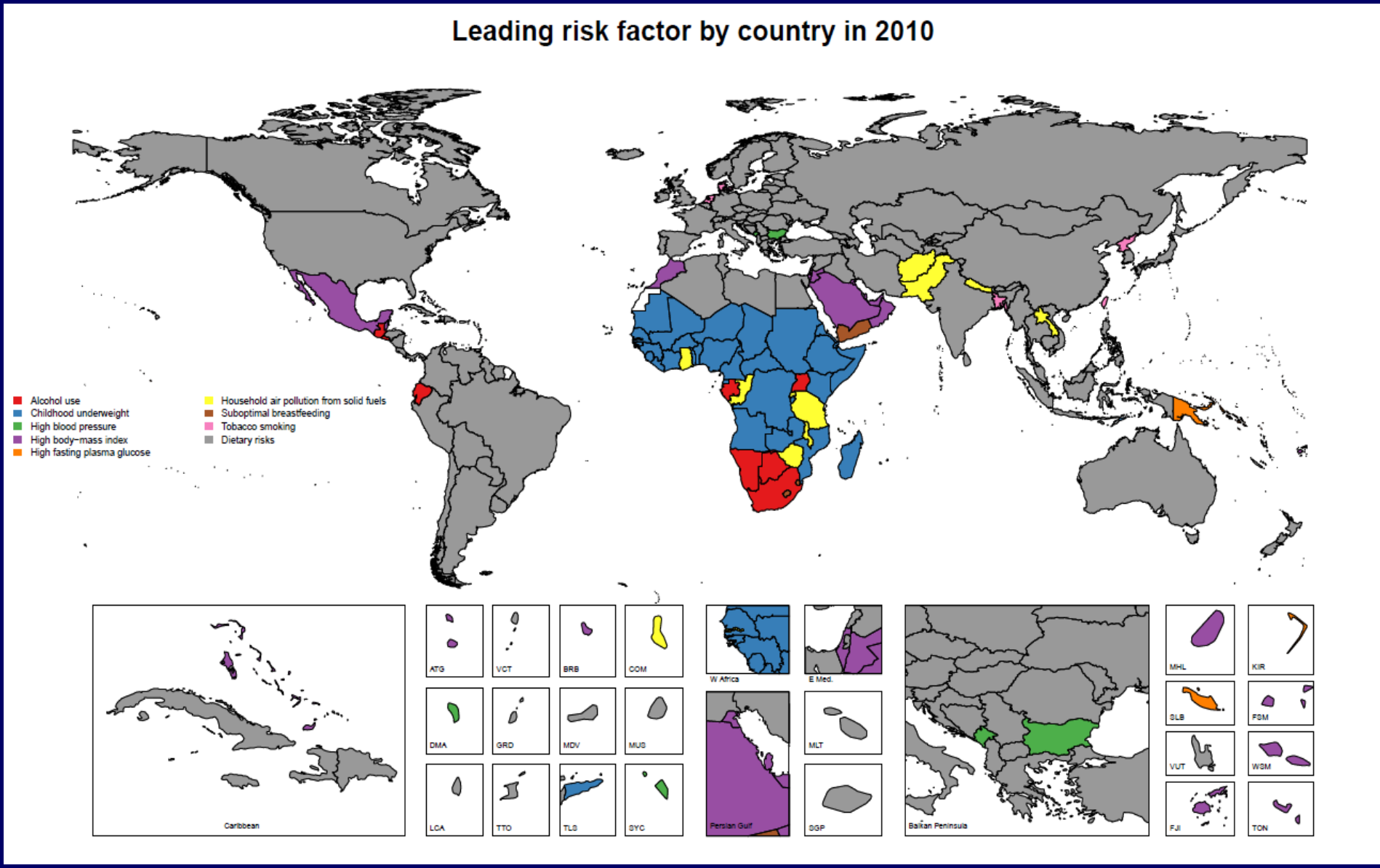
Risk Factors for global deaths and DALYs in 2010



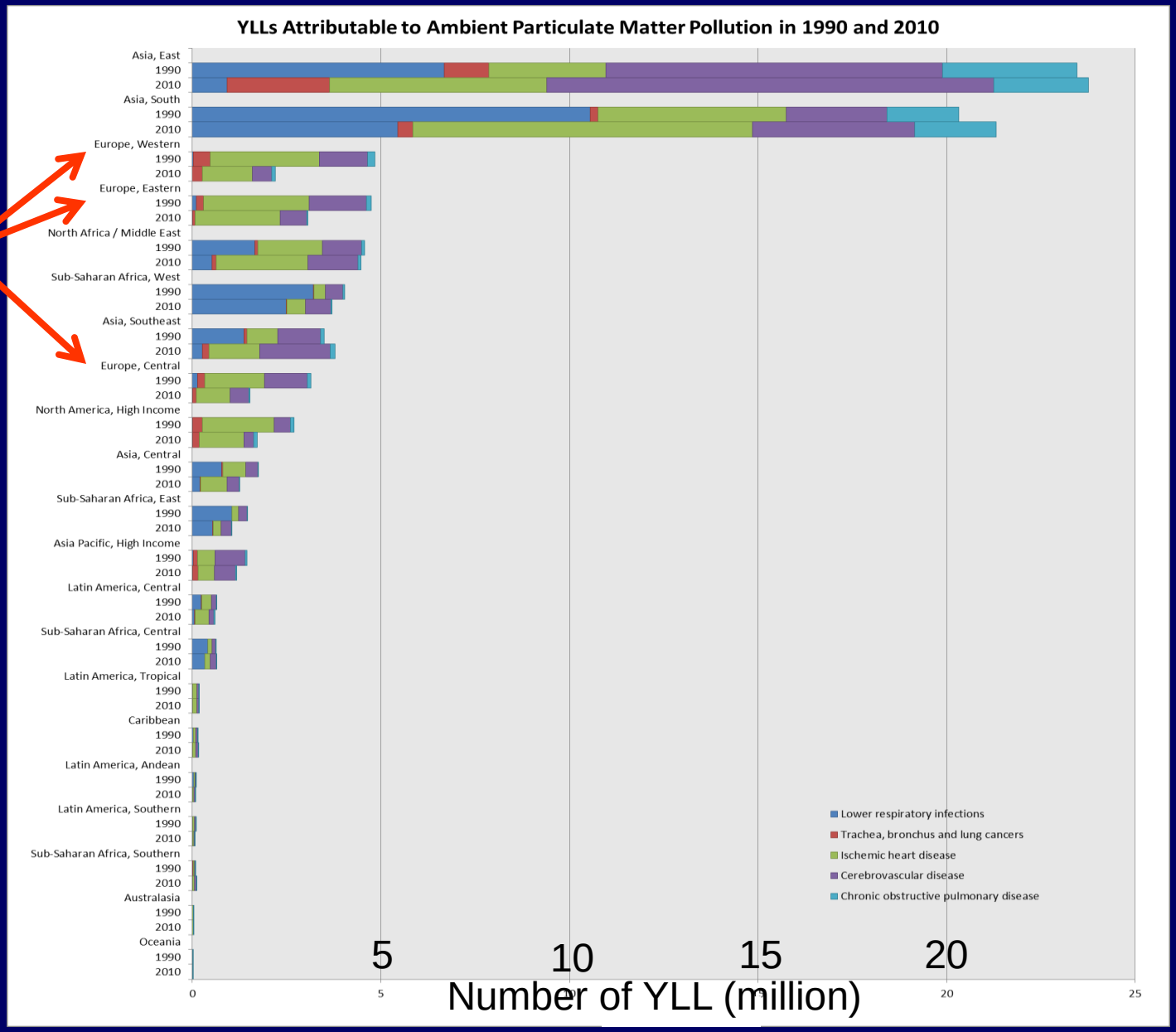
3.2 million deaths and 76 million DALYs



Leading risk factor by country in 2010



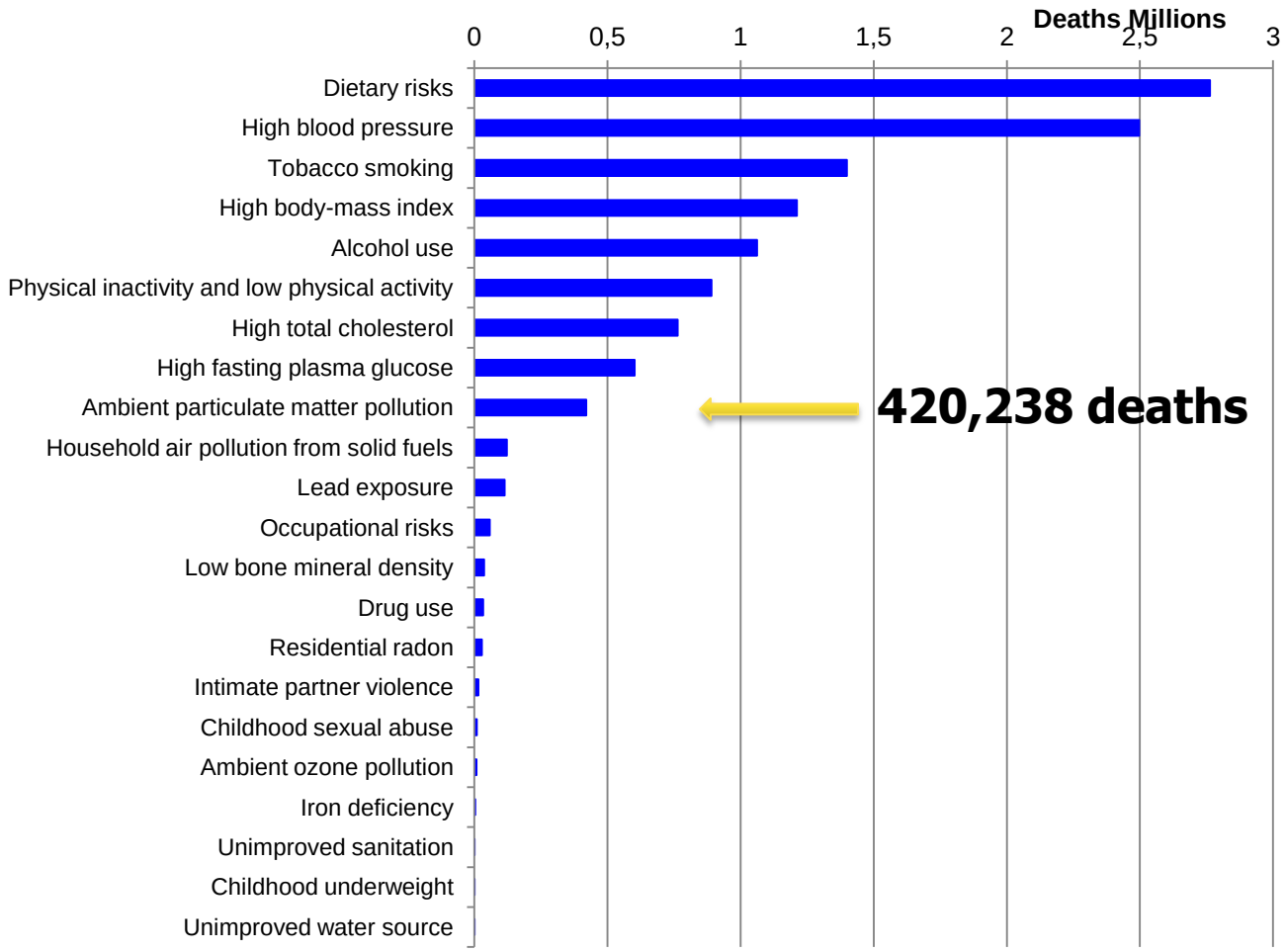
Years-of- Life-Lost Attributable to $PM_{2.5}$ by Global Region in 1990 and 2010



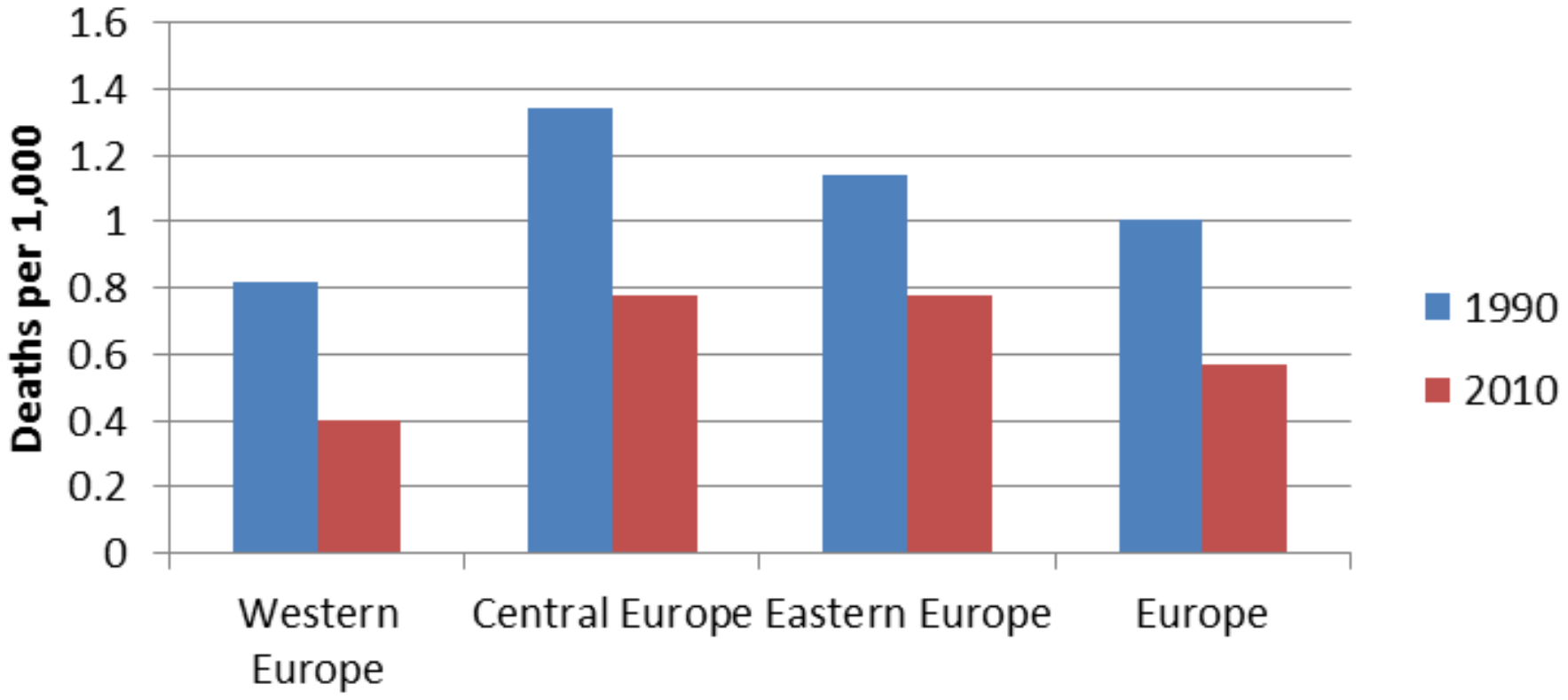
Europe

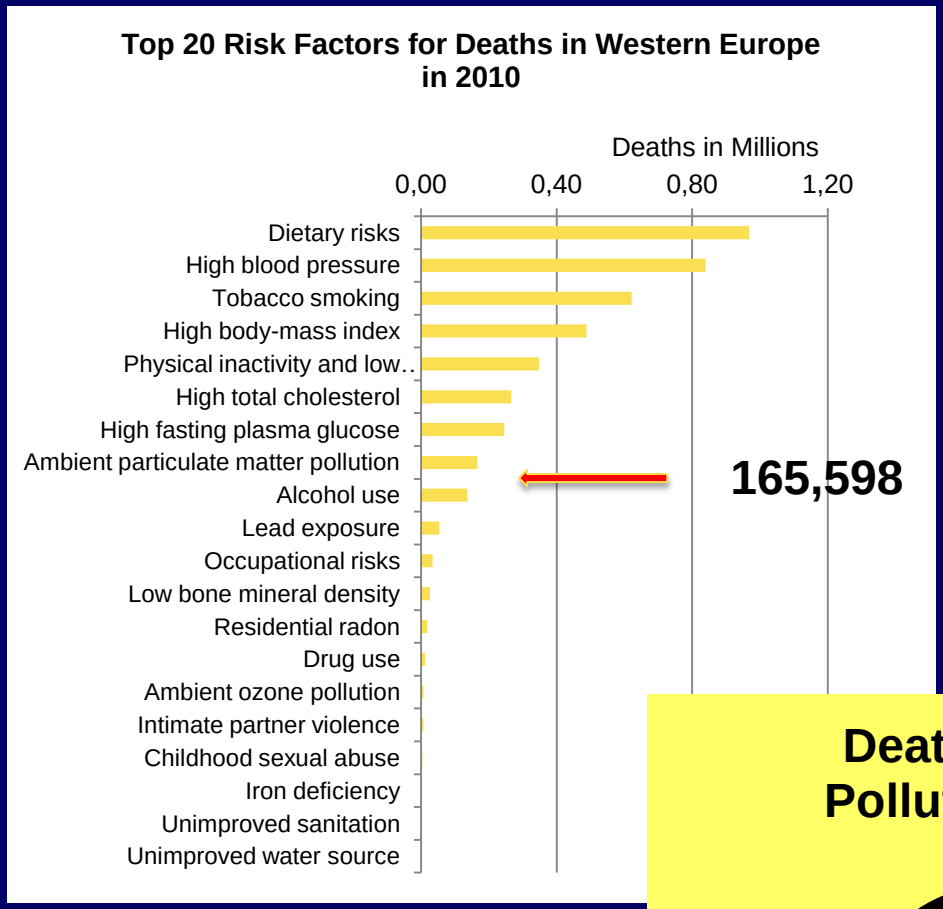
(Lim et al. 2012)

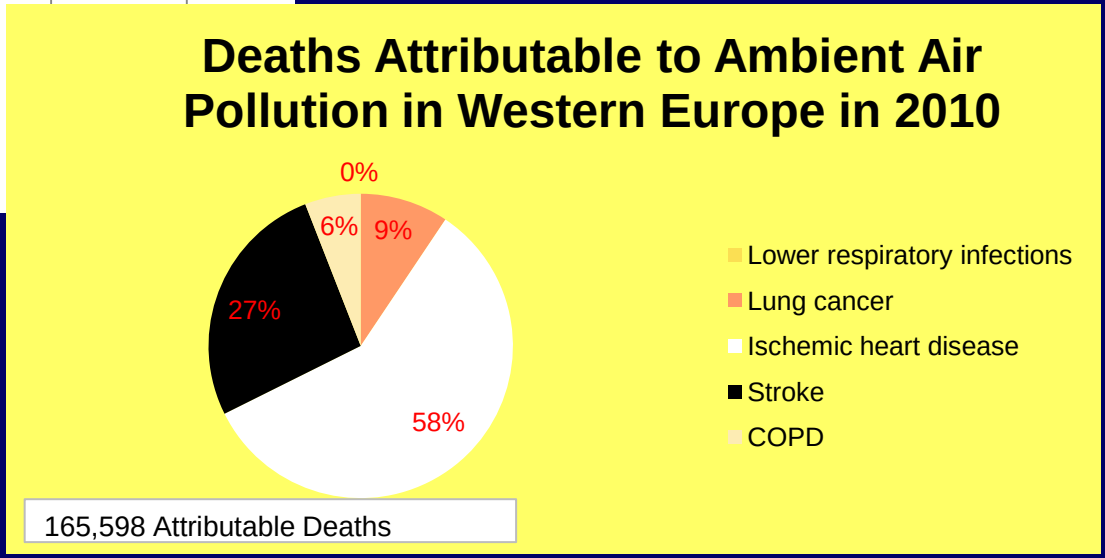
Top Risk Factors for Deaths in Europe in 2010

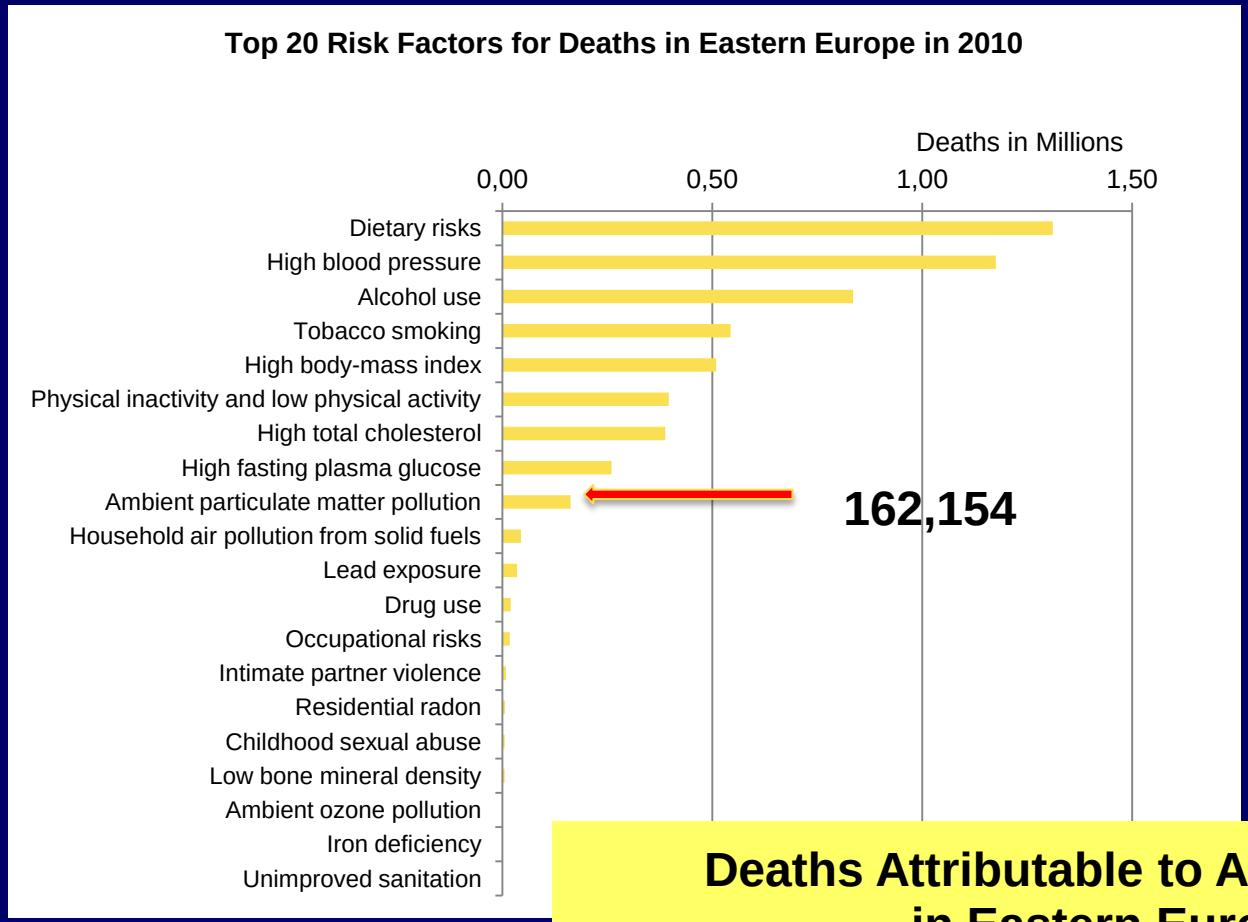


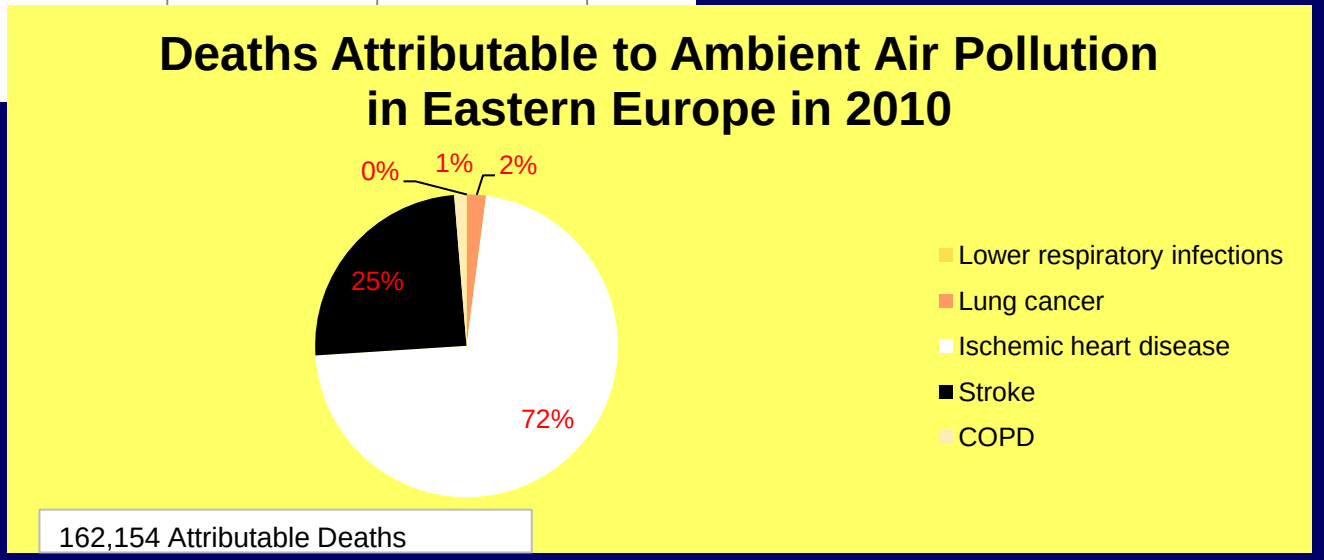
Death Rate Attributable to Ambient Air Pollution in Europe

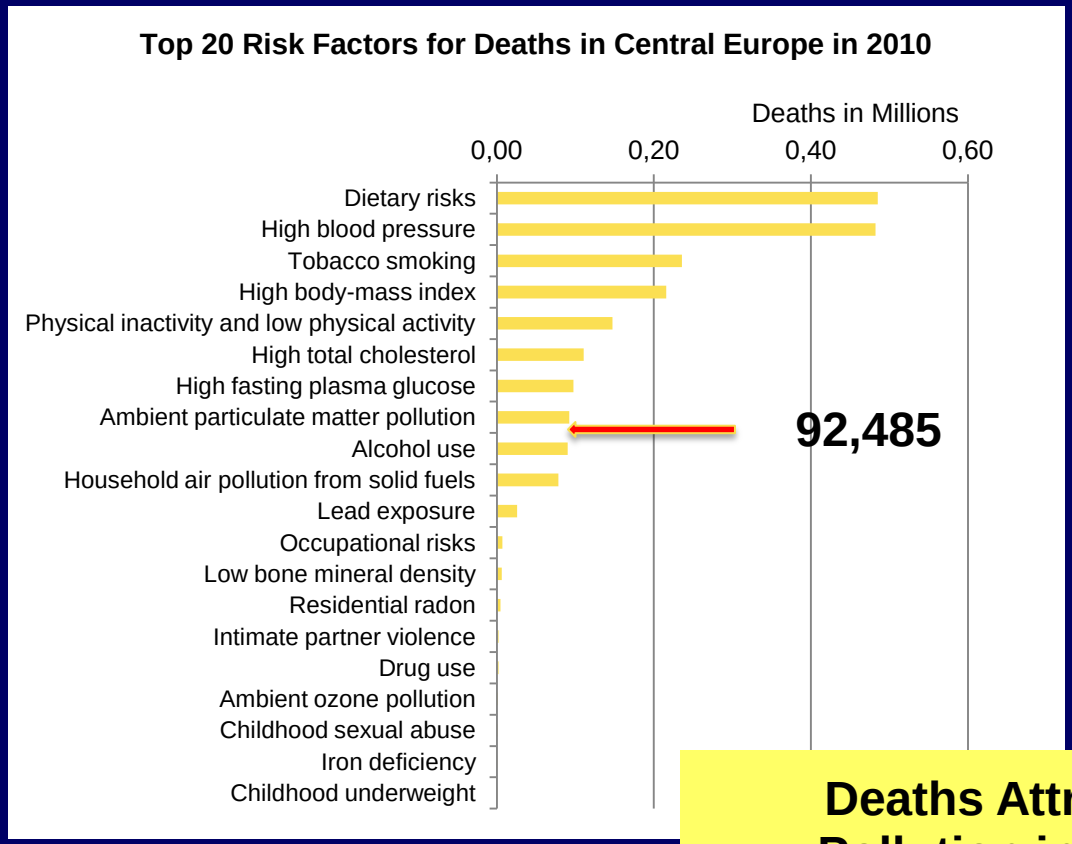


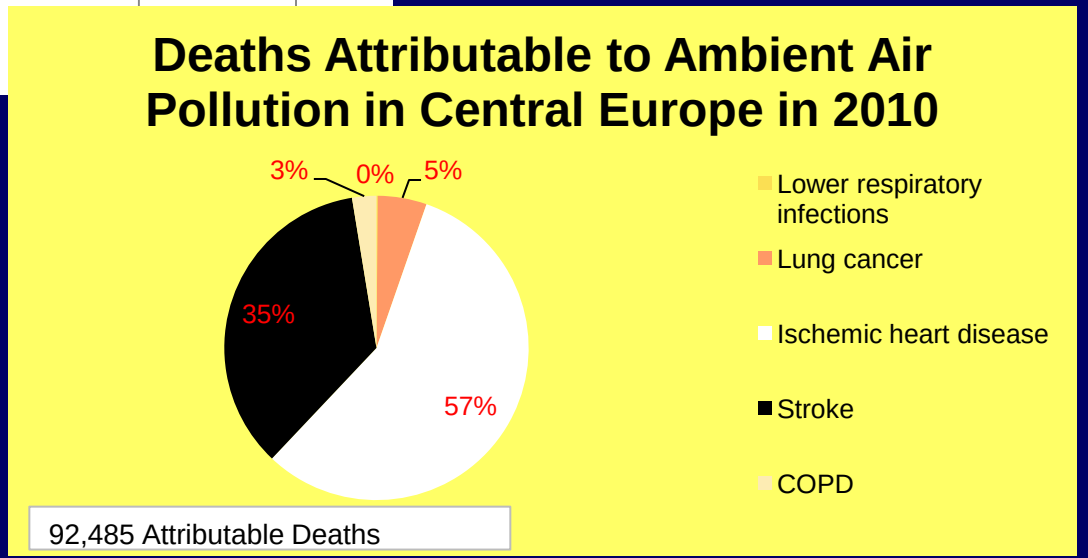

Top 20 Risk Factors for Deaths in Western Europe in 2010
Deaths in Millions
0,00
0,40
0,80
1,20
Dietary risks
High blood pressure
Tobacco smoking
High body-mass index
Physical inactivity and low…
High total cholesterol
High fasting plasma glucose
Ambient particulate matter pollution
Alcohol use
Lead exposure
Occupational risks
Low bone mineral density
Residential radon
Drug use
Ambient ozone pollution
Intimate partner violence
Childhood sexual abuse
Iron deficiency
Unimproved sanitation
Unimproved water source
165,598


Deaths Attributable to Ambient Air Pollution in Western Europe in 2010
0%
6%
9%
27%
58%
Lower respiratory infections
Lung cancer
Ischemic heart disease
Stroke
COPD
165,598 Attributable Deaths


Top 20 Risk Factors for Deaths in Eastern Europe in 2010
Deaths in Millions
0,00
0,50
1,00
1,50
Dietary risks
High blood pressure
Alcohol use
Tobacco smoking
High body-mass index
Physical inactivity and low physical activity
High total cholesterol
High fasting plasma glucose
Ambient particulate matter pollution
Household air pollution from solid fuels
Lead exposure
Drug use
Occupational risks
Intimate partner violence
Residential radon
Childhood sexual abuse
Low bone mineral density
Ambient ozone pollution
Iron deficiency
Unimproved sanitation
162,154


Deaths Attributable to Ambient Air Pollution in Eastern Europe in 2010
0%
1%
2%
25%
72%
Lower respiratory infections
Lung cancer
Ischemic heart disease
Stroke
COPD
162,154 Attributable Deaths


Top 20 Risk Factors for Deaths in Central Europe in 2010
Deaths in Millions
0,00
0,20
0,40
0,60
Dietary risks
High blood pressure
Tobacco smoking
High body-mass index
Physical inactivity and low physical activity
High total cholesterol
High fasting plasma glucose
Ambient particulate matter pollution
Alcohol use
Household air pollution from solid fuels
Lead exposure
Occupational risks
Low bone mineral density
Residential radon
Intimate partner violence
Drug use
Ambient ozone pollution
Childhood sexual abuse
Iron deficiency
Childhood underweight
92,485


Deaths Attributable to Ambient Air Pollution in Central Europe in 2010
3%
0%
5%
35%
57%
Lower respiratory infections
Lung cancer
Ischemic heart disease
Stroke
COPD
92,485 Attributable Deaths

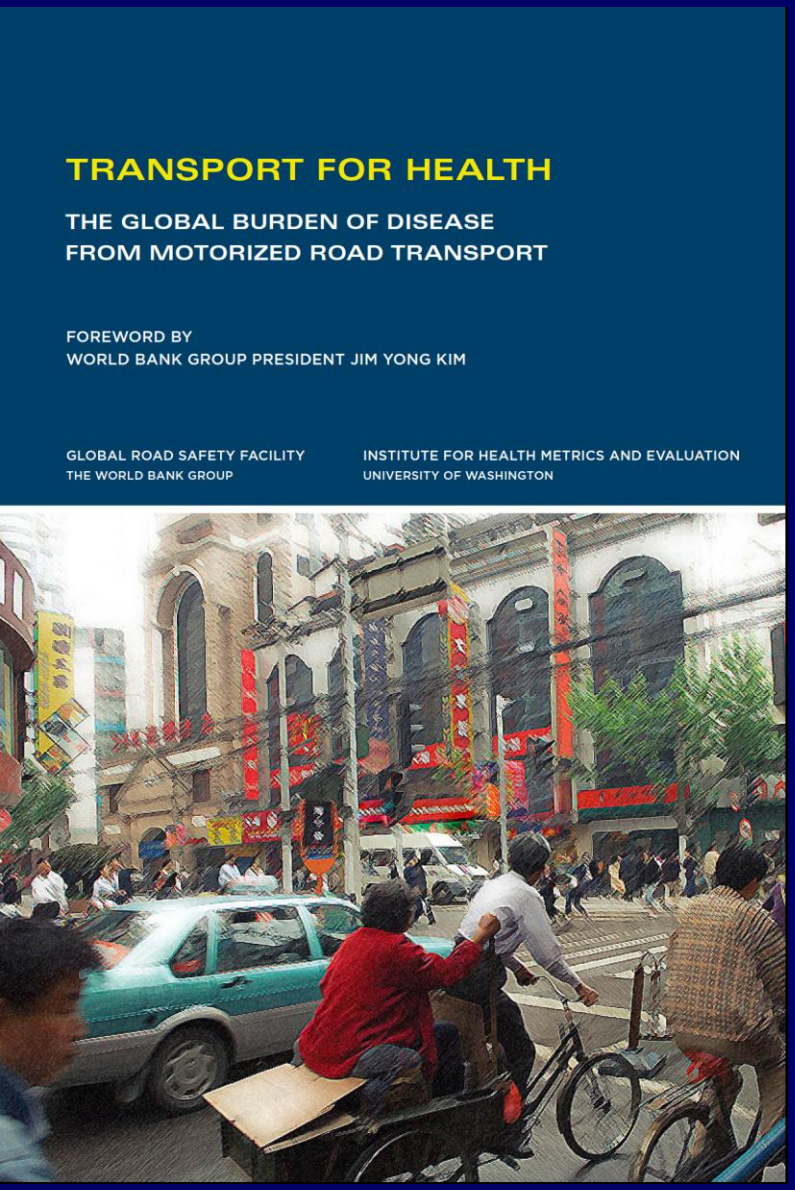
Some conclusions and implications of the GBD 2010 estimates

- Attributable deaths and DALYs much larger than previously estimated: 3.2 million deaths and 76 million DALYs in 2010 due in large part to mortality from IHD and stroke

- Ambient air pollution now ranks among the top 10 risk factors for mortality and lost years of healthy life globally and in Europe

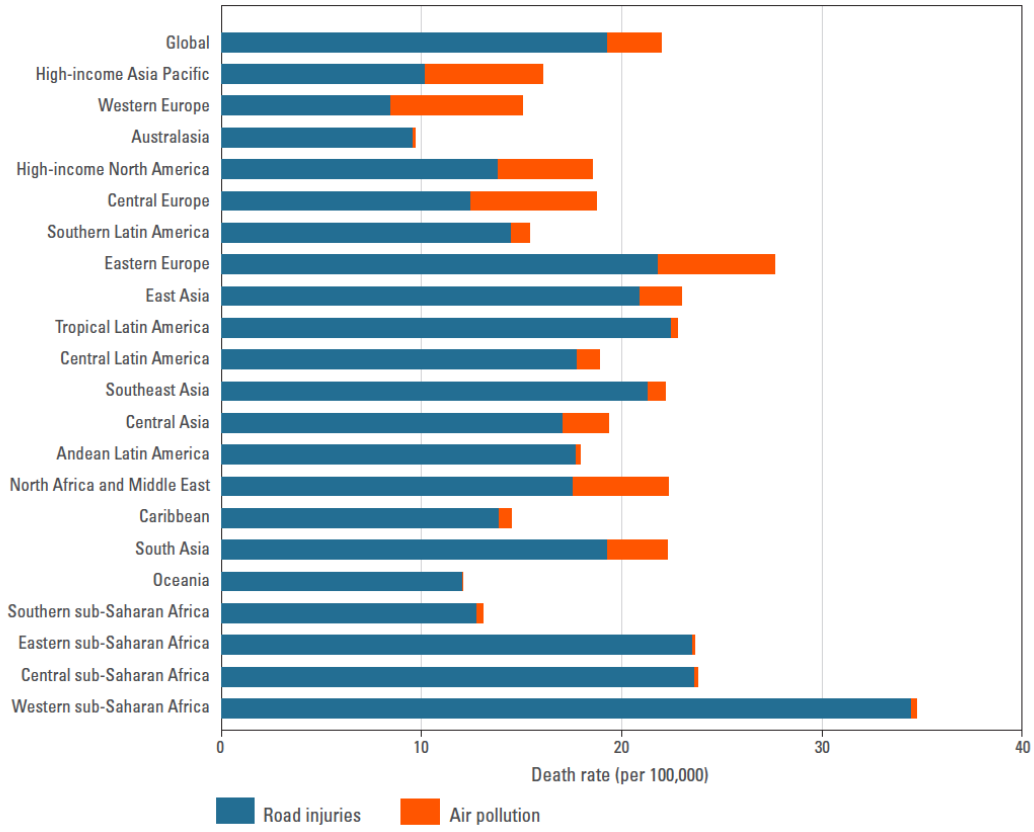
Some conclusions and implications of the GBD 2010 estimates

- The combined public health impact of air pollution, ambient and household, is substantial, and developing Asia experiences some of the highest levels of exposure and the largest burdens of disease from both risk factors in the world
  - With development, increasing size of susceptible, potentially exposed population, burdens likely to increase even if concentrations decrease
- Given widespread exposures, interventions can be very (cost) effective
  - Non-linearity in E-R functions imply that achieving large benefits from air pollution reduction in the most polluted settings requires large improvements in air quality



The burden due to motorized road transport is growing. Over the last two decades, deaths due to road crashes grew by 46%. Deaths attributable to air pollution, to which motor vehicles are an important contributor, grew by 11%.

Figure 7: Death rates from injuries and air pollution due to motorized road transport, 2010



http://documents.worldbank.org/curated/en/2014/01/19308007/transport-health-global-burden-disease-motorized-road-transport

GBD 2013

- More epidemiologic studies –new, large studies in UK and Canada
- Additional measurements
  - Direct appeal to GBD experts, other contacts; WHO database; Literature search
- Satellite-based estimates
  - Annual (1990 – 2012), improved algorithm
- Data integration
  - Model with and w/o estimated (from PM_{10})
  - Random effect for region/country
- GBD beyond 2013
  - NO_2 and/or intra-urban variability
  - Combine satellite based estimates with land use data
  - Refine the IERs
  - Additional health endpoints

Thank You !

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for more information on the GBD Collaboration/detailed GBD 2010 country-level results

http://www.healthmetricsandevaluation.org/gbd

http://www.healthmetricsandevaluation.org/search-gbd-data