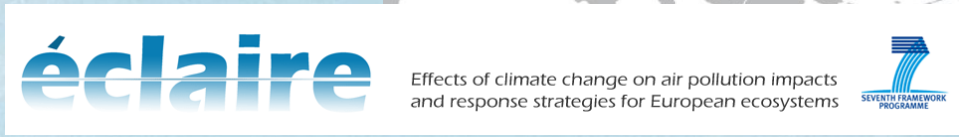
Benefits analysis – major questions and recent advances related to co-benefits / CIRCLE update



Mike Holland

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Task Force on Integrated Assessment Modelling

May 2016

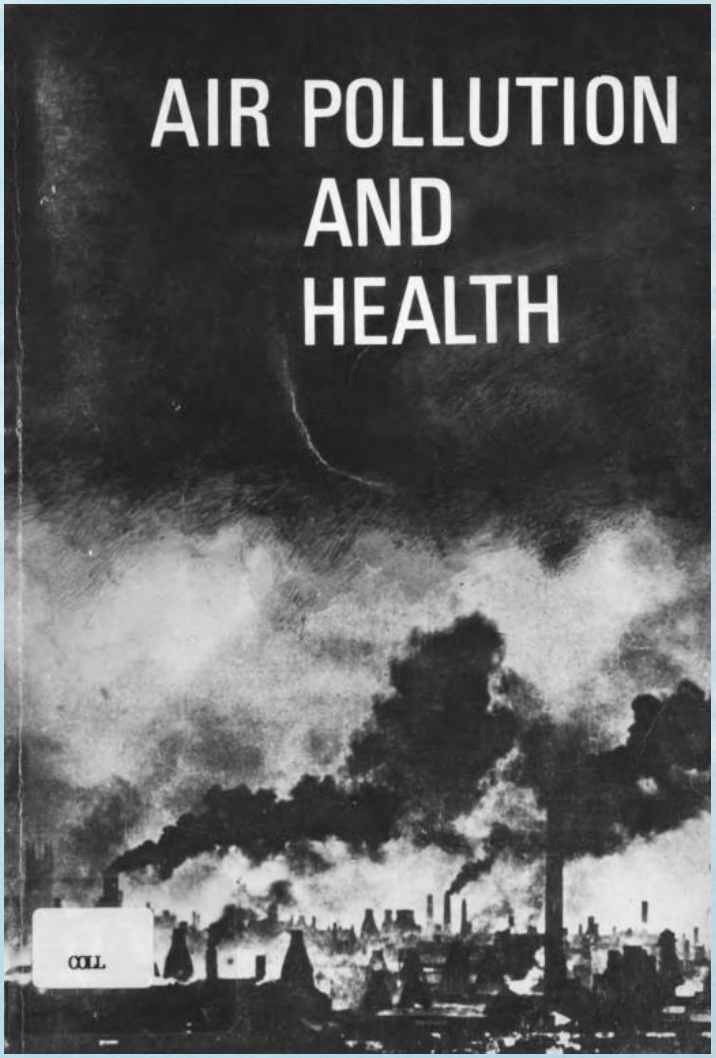
New studies and results

- Health studies
  - Royal College of Physicians
  - COMEAP bronchitis and NO_2 reports
  - HEAL Balkan coal study
  - OECD CIRCLE Project
- Environmental studies
  - ECLAIRE (EC DG Research)

Previous RCP report on air pollution

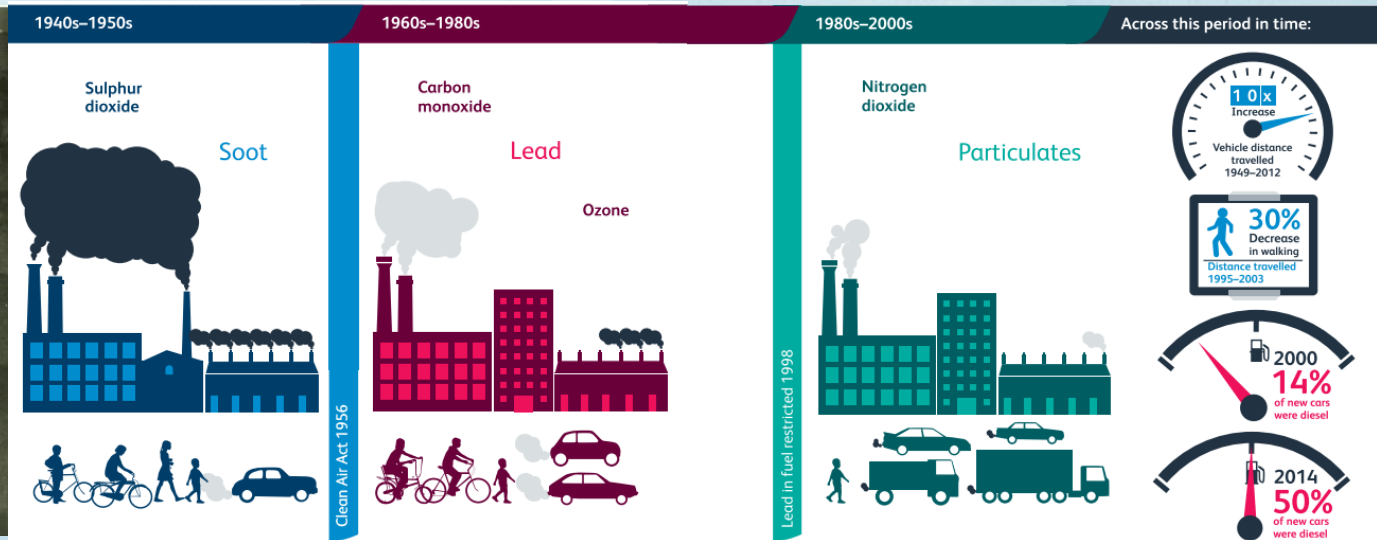
- Commissioned 1959
- Published 1970

- Two concerns:
  - Smoking
  - Solid fuel use



Previous RCP report on air pollution

- Based on a different world
  - Much coal burning
  - Less traffic
  - Little emission control
  - Little health data to inform the work

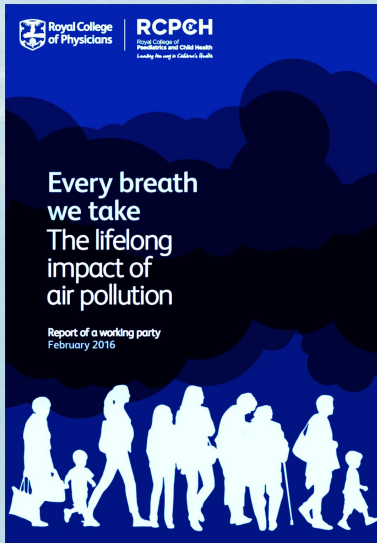


The new report

- Produced by RCP and RCPH
- Written by Royal College members and invited experts
- Released February 2016
- Available at: https://www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution

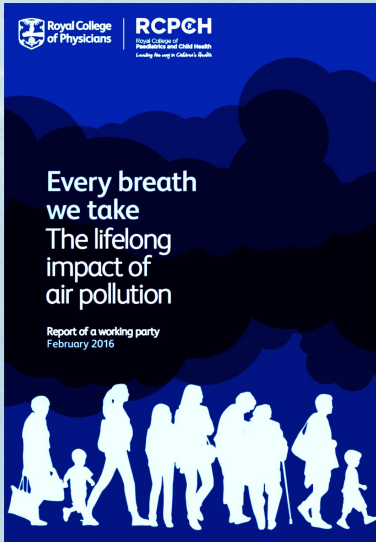
Key messages

- Air pollution affects health over the full life-course
- Air pollution affects health in many ways
- The role of indoor air pollution is important but needs further research
- Air pollution has a major impact on health in the UK
  - Discussion is of much wider relevance than the UK
- The medical profession needs to be more aware of the effects of air pollution



New report headlines: Health burden

- Each year, 40,000 deaths (+/-25%) in the UK from outdoor air pollution, valued at >£20 billion
  - $PM_{2.5}$
  - NO_2
- More linked to indoor air pollutants
  - Radon: 2,300
  - Second hand smoke: 2,800 – 11,000



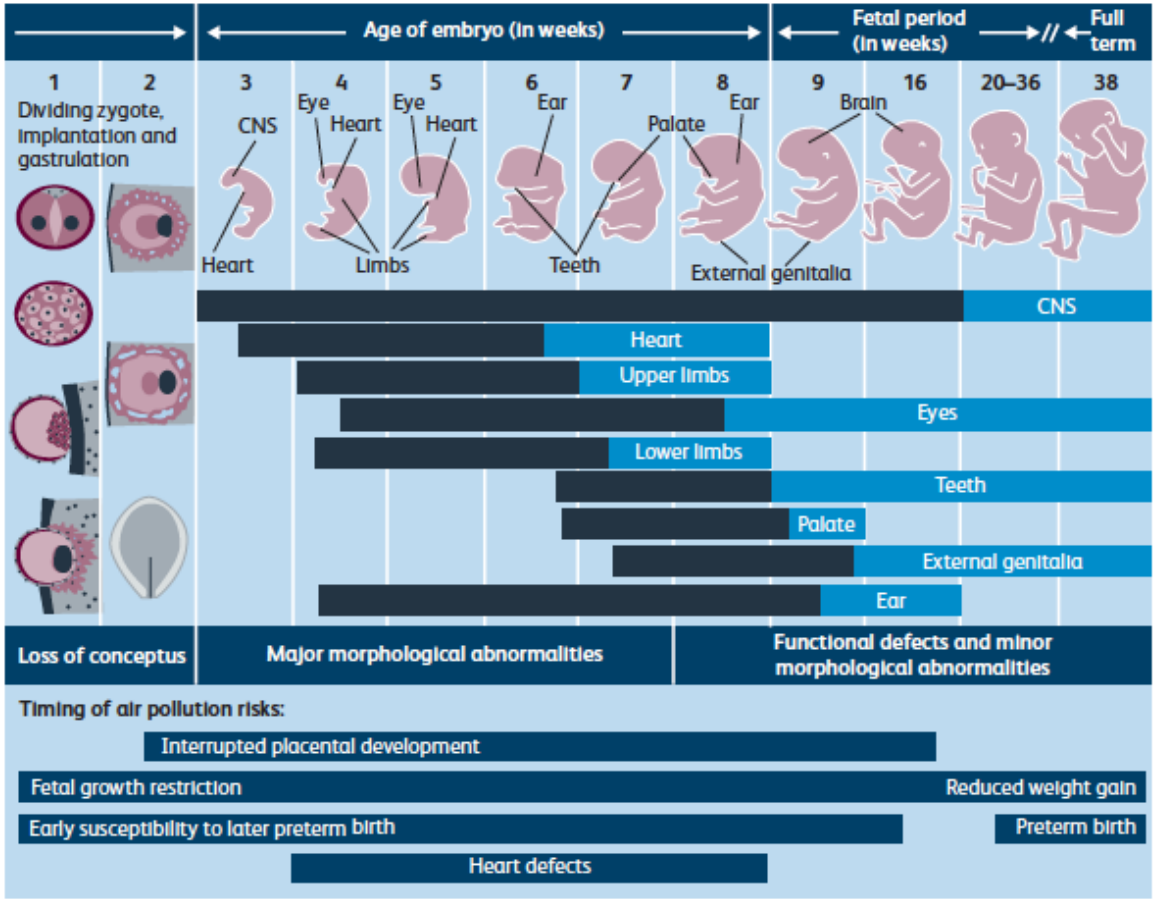
New report headlines: Range of impacts linked to air pollution

- Link to many diseases including:
  - Cancer
  - Asthma
  - Stroke
  - Heart disease
  - Diabetes
  - Obesity
  - Dementia

New report headlines: Range of impacts linked to air pollution

- What is quantified most thoroughly in assessments?
  - Impact on mortality via all-cause functions
- What is quantified less thoroughly?
  - Morbidity effects generally
  - Effects on the young
  - Associated costs (utility, healthcare, productivity)

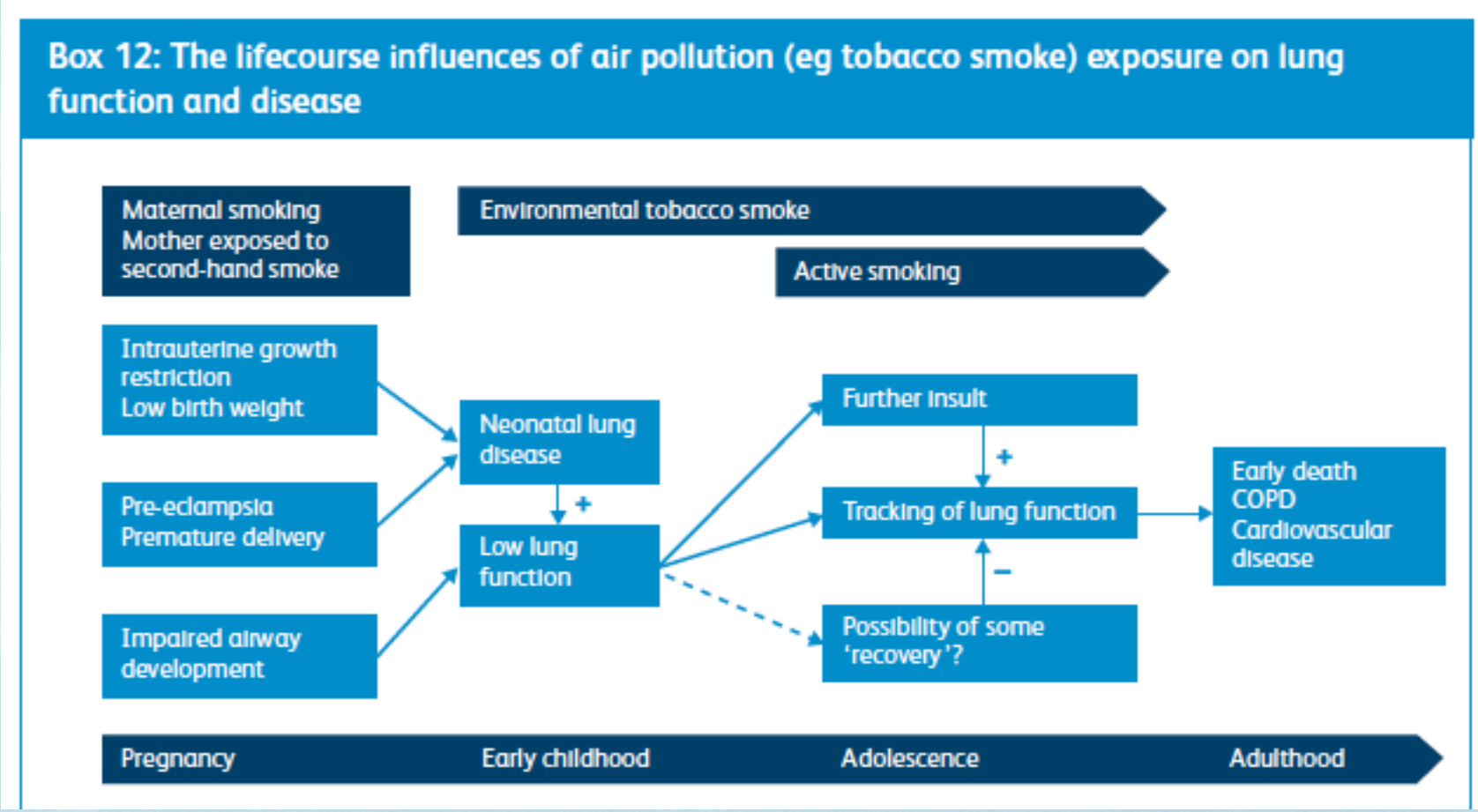
Development of disease during foetal development



Note: Grey bars indicate time periods when major morphological abnormalities can occur, while light-blue bars correspond to periods at risk from minor abnormalities and functional defects.

Fig 7. Critical periods of risk from air pollution during fetal development. CNS = central nervous system. *Figure reprinted with permission.* Ritz B, Willhelm M. Air pollution impacts on infants and children. UCLA Institute of the Environment: Southern California Environmental Report Card – Fall 2008, Los Angeles, CA: 2008.

Development of disease during the life course



New report headlines: AQ limits and public protection

- Neither the concentration limits set by government nor the World Health Organization's air quality guidelines are fully protective of health

Risk of Nonaccidental and Cardiovascular Mortality in Relation to Long-term Exposure to Low Concentrations of Fine Particulate Matter: A Canadian National-Level Cohort Study

Dan L. Crouse,[1] Paul A. Peters,[2] Aaron van Donkelaar,[3] Mark S. Goldberg,[4] Paul J.Villeneuve,[1,5] Orly Brion,[1] Saeeda Khan,[2] Dominic Odwa Atari,[2] Michael Jerrett,[6] C. Arden Pope III,[7] Michael Brauer,[8] Jeffrey R. Brook,[5,9] Randall V. Martin,[3,10] David Stieb,[1] and Richard T. Burnett[1]

[1]Environmental Health Science and Research Bureau, Health Canada, Ottawa, Ontario, Canada; [2]Health Analysis Division, Statistics Canada, Ottawa, Ontario, Canada; [3]Department of Physics and Atmospheric Science, Dalhousie University, Halifax, Nova Scotia, Canada; [4]Department of Medicine, McGill University, Montreal, Quebec, Canada; [5]Dalla Lana School of Public Health, University of Toronto, Toronto, Ontario, Canada; [6]School of Public Health, University of California–Berkeley, Berkeley, California, USA; [7]Department of Economics, Brigham Young University, Provo, Utah, USA; [8]School of Population and Public Health, University of British Columbia, Vancouver, British Columbia, Canada; [9]Air Quality Research Division, Environment Canada, Downsview, Ontario, Canada; [10]Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts, USA

Background: Few cohort studies have evaluated the risk of mortality associated with long-term exposure to fine particulate matter [≤ 2.5 μm in aerodynamic diameter ($PM_{2.5}$)]. This is the first national-level cohort study to investigate these risks in Canada.

Objective: We investigated the association between long-term exposure to ambient $PM_{2.5}$ and cardiovascular mortality in nonimmigrant Canadian adults.

Methods: We assigned estimates of exposure to ambient $PM_{2.5}$ derived from satellite observations to a cohort of 2.1 million Canadian adults who in 1991 were among the 20% of the population mandated to provide detailed census data. We identified deaths occurring between 1991 and 2001 through record linkage. We calculated hazard ratios (HRs) and 95% confidence intervals (CIs) adjusted for available individual-level and contextual covariates using both standard Cox proportional survival models and nested, spatial random-effects survival models.

Results: Using standard Cox models, we calculated HRs of 1.15 (95% CI: 1.13, 1.16) from nonaccidental causes and 1.31 (95% CI: 1.27, 1.35) from ischemic heart disease for each 10-μg/m^3 increase in concentrations of $PM_{2.5}$. Using spatial random-effects models controlling for the same variables, we calculated HRs of 1.10 (95% CI: 1.05, 1.15) and 1.30 (95% CI: 1.18, 1.43), respectively. We found similar associations between nonaccidental mortality and $PM_{2.5}$ based on satellite-derived estimates and ground-based measurements in a subanalysis of subjects in 11 cities.

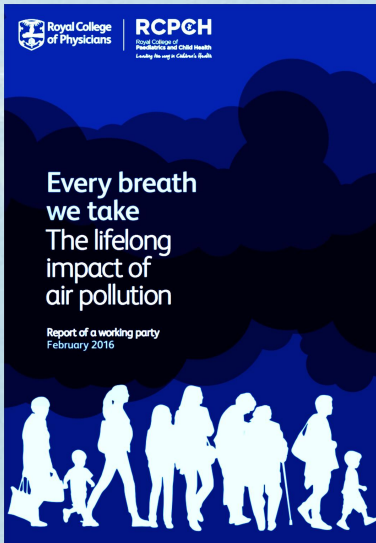
Conclusions: In this large national cohort of nonimmigrant Canadians, mortality was associated with long-term exposure to $PM_{2.5}$. Associations were observed with exposures to $PM_{2.5}$ at concentrations that were predominantly lower (mean, 8.7 μg/m^3; interquartile range, 6.2 μg/m^3) than those reported previously.

Key words: Canada, cardiovascular mortality, cohort study, fine particulate matter. *Environ Health Perspect* 120:708–714 (2012). http://dx.doi.org/10.1289/ehp.1104049 [Online 7 February 2012]

monitoring stations in 11 of Canada's largest cities; this necessitated using only a subset of the cohort for which exposure could reasonably be assigned from the network data. Then, to include the whole cohort, we applied estimates of concentrations of ground-level $PM_{2.5}$ throughout the country from satellite observations of aerosol optical depth (van Donkelaar et al.

New report headlines: Role of the medical profession

- "*When our patients are exposed to such a clear and avoidable cause of death, illness and disability, it is our duty as doctors to speak out*."
  - Medical profession is good at dealing with symptoms
  - Barriers on acting on causal factors like air pollution
  - Need to act on health service footprint



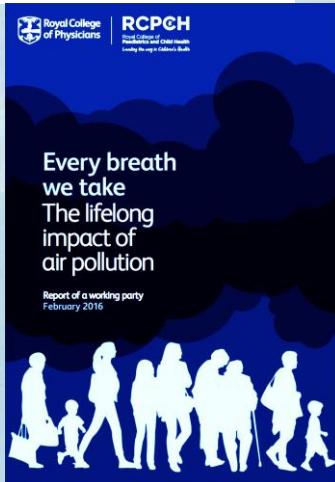
COMEAP results in more detail

Table 1. COMEAP results for effects of outdoor $PM_{2.5}$ exposure on mortality for the UK[2]

Measure of mortality	Impact
Number of attributable deaths	28,861
Attributable deaths per 100,000 aged over 30 years	75
Burden on total survival (life-years lost)	340,000
Difference in life expectancy for the 2008 cohort (days)	
Females	194
Males	182

Highlights different ways of representing mortality impacts of air pollution

Averages at ~12 years of lost life expectancy per equivalent attributable death



Interpretation of causality for mortality estimates

- COMEAP considers the meaning of estimated numbers of deaths, noting:
  - Effects are principally from cardiovascular disease, which has multiple established and likely causes at the population level, and almost certainly has a complex mixture of factors affecting initiation and progression at the individual level.
- Estimates of deaths are a statistical construct, with air pollution playing some role in bringing forward the deaths of a larger number of people than the estimate of 40,000 deaths per year.
- However, the 40,000 figure provides an indication of the burden on mortality that can be compared with estimates from other factors

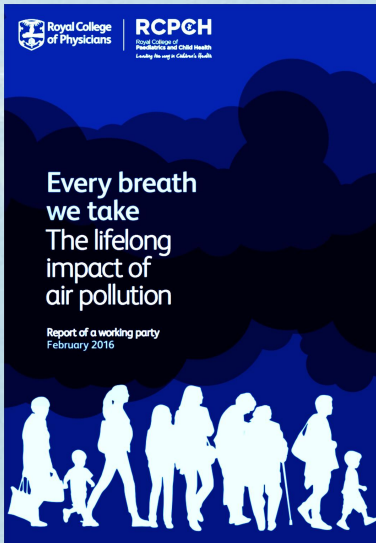
Bronchitis and PM

- Differences in disease
  - Adult bronchitis: long lasting disease, potentially severe effect, may be permanent (depending on definition of effect)
  - Child bronchitis: temporary (2 weeks), recoverable
- Differences in adult bronchitis estimates for UK:
  - EC estimate: 26,000 (incidence, new disease, value £850 million/year)
  - New COMEAP estimate: 722,000 (prevalence, total burden) out of 4.5 million affected individuals in the UK (value?)
- Differences in use
  - For EC, recommended for core analysis by WHO HRAPIE study
  - For UK, recommended for sensitivity analysis by COMEAP

COMEAP report on chronic bronchitis available at:
https://www.gov.uk/government/publications/comeap-long-term-exposure-to-air-pollution-and-chronic-bronchitis

Role of the medical profession

- "*When our patients are exposed to such a clear and avoidable cause of death, illness and disability, it is our duty as doctors to speak out*."
- Recommendations:
  - Increase awareness of the effects of air pollution
  - Support actions to reduce emissions
  - Recognise threat to health to properly advise patients
  - Recognise and act on the environmental burdens of health care

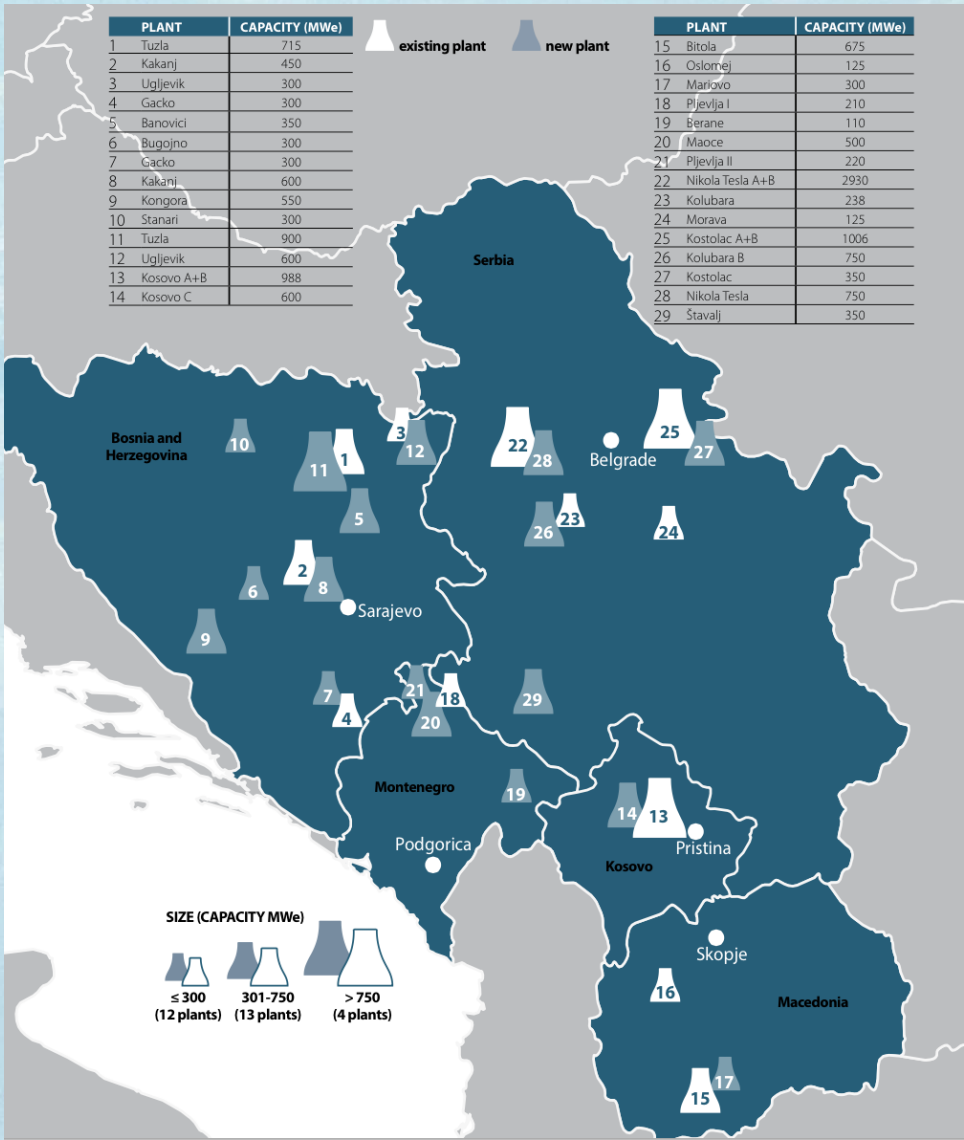


Impacts of coal fired generation in the Balkans

- Western Balkan Air Report
- Commissioned by HEAL
- Objectives
  - Stimulate debate on energy choices
  - Assess impacts of existing coal fired power generation on health…
  - …and of new plant built to higher standards
- http://www.env-health.org/resources/projects/coal-s-unpaid-health-bill/coal-s-unpaid-health-bill-in-the/

Scope

- 39 existing and 24 planned coal / lignite power generating units in…
- …Bosnia and Herzegovina, Kosovo, Macedonia, Montenegro, Serbia



	PLANT	CAPACITY (MWe)
1	Tuzla	715
2	Kakanj	450
3	Ugljevik	300
4	Gacko	300
5	Banovici	350
6	Bugojno	300
7	Gacko	300
8	Kakanj	600
9	Kongora	550
10	Stanari	300
11	Tuzla	900
12	Ugljevik	600
13	Kosovo A+B	988
14	Kosovo C	600

	PLANT	CAPACITY (MWe)
15	Bitola	675
16	Oslomej	125
17	Mariovo	300
18	Pljevlja I	210
19	Berane	110
20	Maoce	500
21	Pljevlja II	220
22	Nikola Tesla A+B	2930
23	Kolubara	238
24	Morava	125
25	Kostolac A+B	1006
26	Kolubara B	750
27	Kostolac	350
28	Nikola Tesla	750
29	Štavalj	350

Aggregate emissions data tonnes/year

	CURRENT/PLANNED OPERATION		
	SO_2	NO_x	$PM_{2.5}$
EXISTING PLANT	**(t)**	**(t)**	**(t)**
Bosnia and Herzegovina	307,033	26,274	2,240
Kosovo	20,220	20,760	7,537
Macedonia	82,632	18,733	3,342
Montenegro	25,681	3,818	196
Serbia	313,700	48,799	6,799
Existing total	**749,266**	**118,384**	**20,114**
NEW, PLANNED PLANT			
Bosnia and Herzegovina	15,312	15,730	436
Kosovo	2,778	2,778	56
Macedonia	1,389	1,389	28
Montenegro	3,843	3,843	76
Serbia	10,186	10,186	204
New total	**33,508**	**33,926**	**800**

Monetised health damage estimates, Western Balkans only

	ANNUAL DAMAGE, LOWER BOUND (VOLY), IN EUR MILLION/YEAR				ANNUAL DAMAGE, UPPER BOUND (VSL), IN EUR MILLION/YEAR			
	SO_2	NO_x	$PM_{2.5}$	TOTAL	SO_2	NO_x	$PM_{2.5}$	TOTAL
EXISTING PLANT								
Bosnia and Herzegovina	365	17	7	390	1068	46	20	1134
Kosovo	29	11	29	70	74	26	69	169
Macedonia	89	9	11	109	245	23	28	297
Montenegro	39	2	1	43	101	6	2	109
Serbia	528	39	33	600	1551	108	97	1756
Existing total	**1051**	**79**	**81**	**1211**	**3039**	**210**	**216**	**3464**
NEW, PLANNED PLANT								
Bosnia and Herzegovina	18	10	1	30	53	28	4	85
Kosovo	4	1	0	6	10	4	1	14
Macedonia	2	1	0	2	4	2	0	6
Montenegro	6	2	0	9	15	6	1	22
Serbia	17	8	1	26	50	23	3	76
New total	**47**	**23**	**3**	**73**	**133**	**61**	**8**	**203**

Conclusions of the Western Balkans study

- Coal fired power generation creates a significant burden on health (in addition to impacts on climate, etc.)
- This will be reduced by replacement of old plant with new operating to better standards
- But development of new plant commits to continued impacts into the future
- Results can be factored into the future energy planning debate for the region

OECD CIRCLE Project

- Objective
  - Factor air pollution effects into OECD's ENV-Linkages Model (https://www.oecd.org/env/45334643.pdf)
  - Quantify health impacts of air pollution ($PM_{2.5,}$ O_3) for scenarios out to 2060
  - Whole world
- Scenario: Full implementation of existing legislation, no subsequent legislation (e.g. to meet climate goals)
- To be launched at 8th Environment for Europe Ministerial Conference at Batumi, Georgia, in June
  - Hence little detail on results in this presentation

The ENV-Linkages model

- Computable General Equilibrium (CGE) model
  - Multi-regional, multi-sectoral
  - All economic activity is part of a closed, linked system
  - Simultaneous equilibrium on all markets
  - Structural trends, no business cycles
- Dynamics
  - Solved iteratively over time (recursive-dynamic)
  - Capital vintages
- Economic consequences of outdoor air pollution
  - Projections of economic activities and emissions
  - Macroeconomic costs of outdoor air pollution (economic feedbacks)

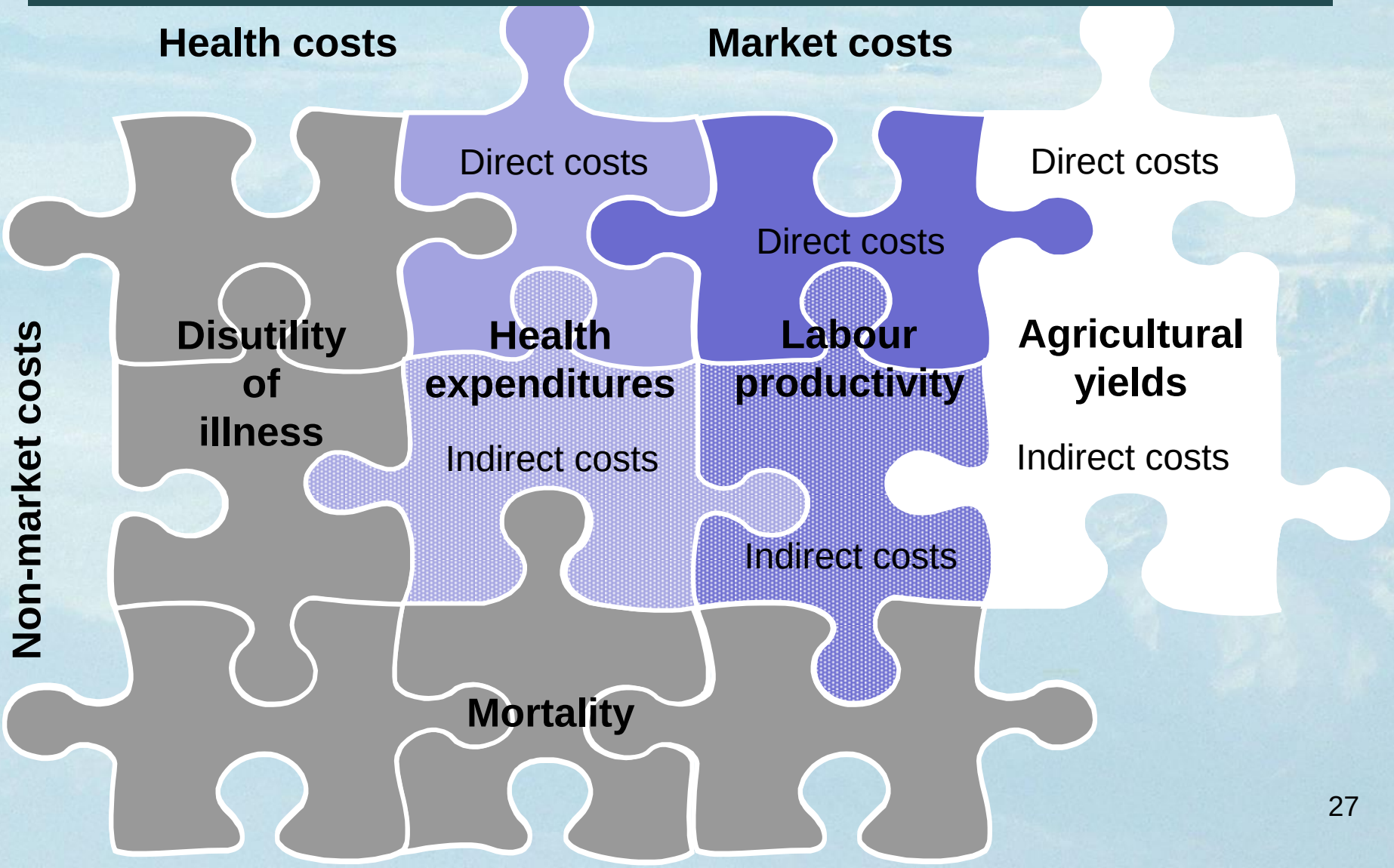
Complications

- Extrapolation beyond Europe
  - HRAPIE or GBD for mortality?
  - Limited availability of:
    - Morbidity data
    - Valuation data
  - Variation in access to healthcare
  - Lack of data for some countries (e.g. Sudan, North Korea)

Solutions

- Selected GBD for mortality
  - Adapted functions to generate a range for future impacts (curved and straight line fits)
- Morbidity data: extrapolated from European analysis
  - Assuming changes in morbidity rates will be reflected in changes in mortality
- Valuation data: Extrapolated using OECD (2012) guidance
  - Investigated sensitivity to income elasticity
- Variation in access to healthcare (e.g. for hospital admissions):
  - Adjusted valuation to reflect national data on healthcare spend as a fraction of GDP (US, Arabian Gulf State anomalies)
  - People likely more unwell if they cannot go to hospital!

Types of costs



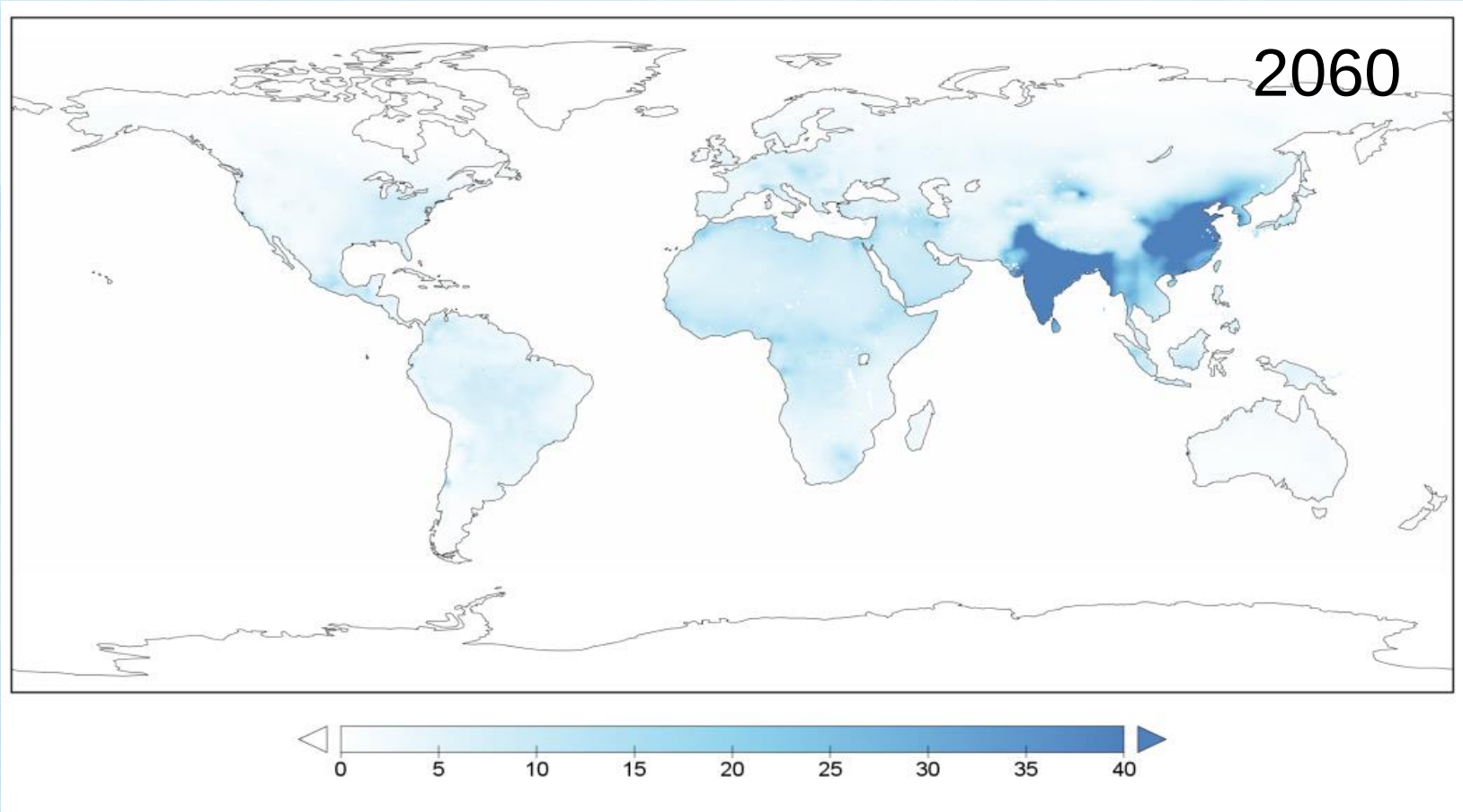
Projections of air pollutants emissions

- Emission data for SO_2, NO_x, OC, BC, CO, VOCs and NH_3 from the GAINS model (IIASA) for the Current Legislation Scenario
- **Link emissions to production activities** in different key sectors (energy, agriculture, industry…)
  - Black carbon – gradual increase
  - CO – Relatively constant
  - Ammonia – medium increase
  - NOx – strong increase
  - Organic carbon – declines
  - SO2 – declines to 2025, then increases
  - VOCs – increase towards end of period

Source: preliminary OECD calculations; not to be cited or quoted

Concentrations of air pollutants

Annual average total anthropogenic $PM_{2.5}$ (µg/m^3)



Concentrations calculated with TM5-FASST (EU JRC Ispra)

Headline impacts

- Total deaths:
  - 3 million 2015
  - At least doubling by 2060
- Market costs (agriculture, healthcare, productivity)
  - Increase from around 0.25% of GDP to 1% by 2060
- Non-market costs
  - $3.3 trillion 2015, increasing substantially by 2060 to account for higher pollution levels, increased population and income growth

VSL valuation, unit values increasing with GDP

ECLAIRE study (WP18)

- Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems
- Funded by European Commission DG Research under the 7th Framework Programme
- WP18 involved EMRC, RIVM, CEH, University of Aarhus, IVL, IIASA, SEI

ECLAIRE Objectives

- Investigate how climate change alters the threat of NOx, NH_3 and ozone on European land ecosystems
- Quantify how climate change alters ecosystem vulnerability to tropospheric O_3 and N deposition, including interaction with increased CO_2.
- Estimate interactions and feedbacks on plant and soil carbon stocks, greenhouse gas balance and plant species change.
- To apply the new risk assessment chain at the European scale, to assess how projected climate change will alter damage estimates, in part through economic valuation of ecosystem services.

WP18 Objectives

- Link the concept of ecosystem services with existing mapping of European ecosystems and pollutant impacts
  - Crops (ozone effects on production, including for different cropping patterns)
  - Forests (production and carbon sequestration)
  - Biodiversity (value of appreciation of biodiversity)
- Characterise the links between pollutant exposure, impact and value to permit quantification of pollutant damage.
- Assess change in the value of ecosystem services across different scenarios using a marginal approach
  - 2030, 2050
  - CLE, BIO75 gap closure, MFR
- Prioritise gaps in the existing knowledge base

Constraint: ECLAIRE did not include original valuation work, but was instead focused on the application of available valuation studies

Crop losses from ozone

- Considered all European crops using POD functions
- Wheat, tomato, potato
- All other crops from extrapolation of wheat function using sensitivity matrix from ICP Vegetation (2011):

Table 1 Grouping of crops by sensitivity of yield to ozone. Values in brackets represent the percentage decrease in yield at a 7h mean ozone concentration of 60 ppb compared to that at 30 ppb.

Sensitive	Moderately sensitive	Tolerant
Peas and beans (including peanut) (30)	Alfalfa (14)	Strawberry (1)
Sweet potato (28)	Water melon (14)	Oat (-3)
Orange (27)	Tomato (13)	Broccoli (-5)
Onion (23)	Olive (13)	
Turnip (22)	Field mustard (12)	
Plum (22)	Sugar beet (11)	
Lettuce (19)	Oilseed rape (11)	
Wheat (18)	Maize (10)	
Soybean (18)	Rice (9)	
	Potato (9)	
	Barley (6)	
	Grape (5)	

Crop production and climate University of Aarhus

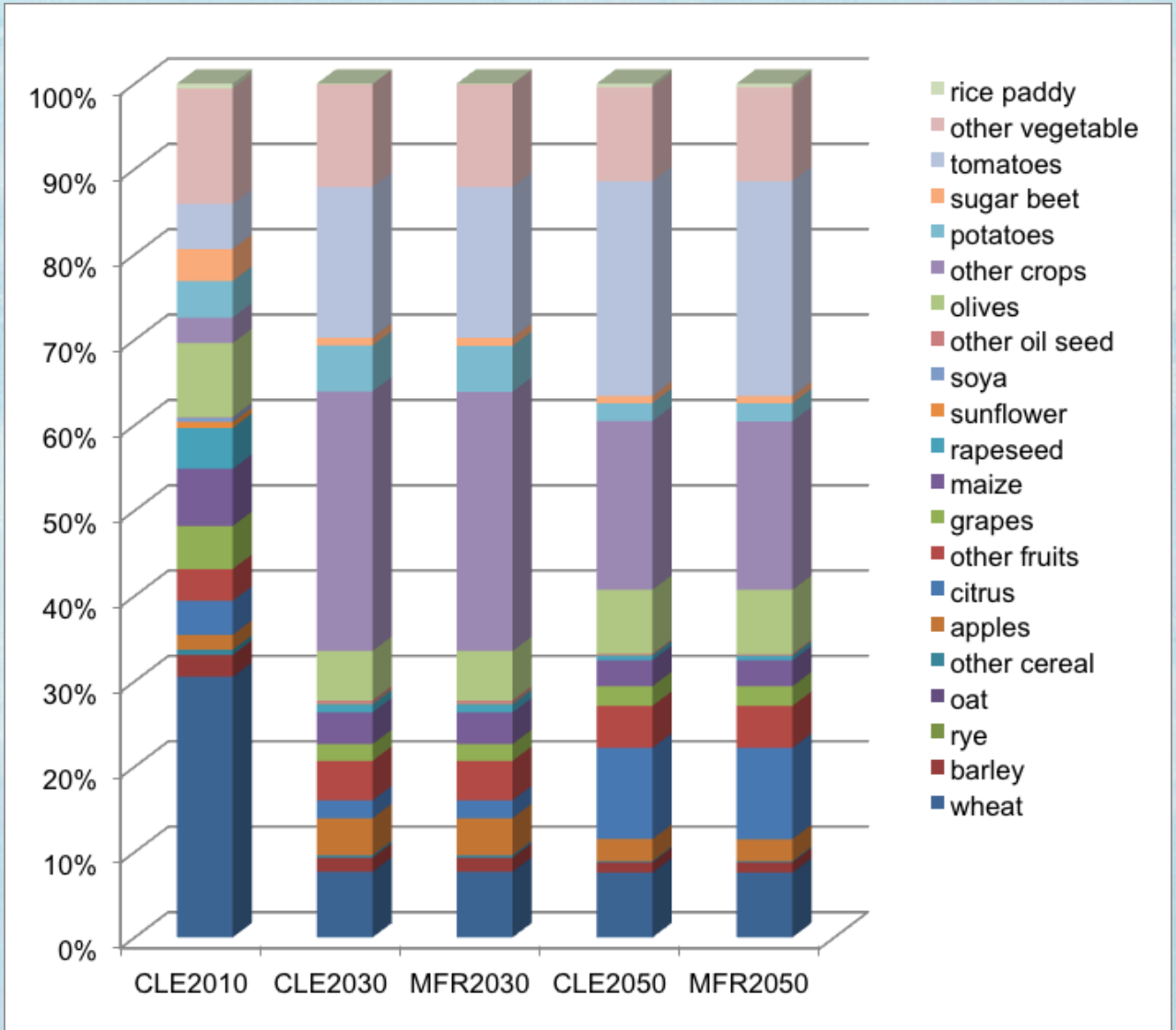
- Assessment with and without changes in land use driven by climate change
  - % feasible changes

Crops	Year 2030	Year 2050
Wheat	-64	-54
Barley	-17	-18
Oats	246	85
Apples	267	185
Citrus	-16	495
Grapes	-46	-16
Maize	-21	-14
Rapeseed	-73	-79
Olives	-18	47
Potatoes	74	-10
Tomatoes	401	839

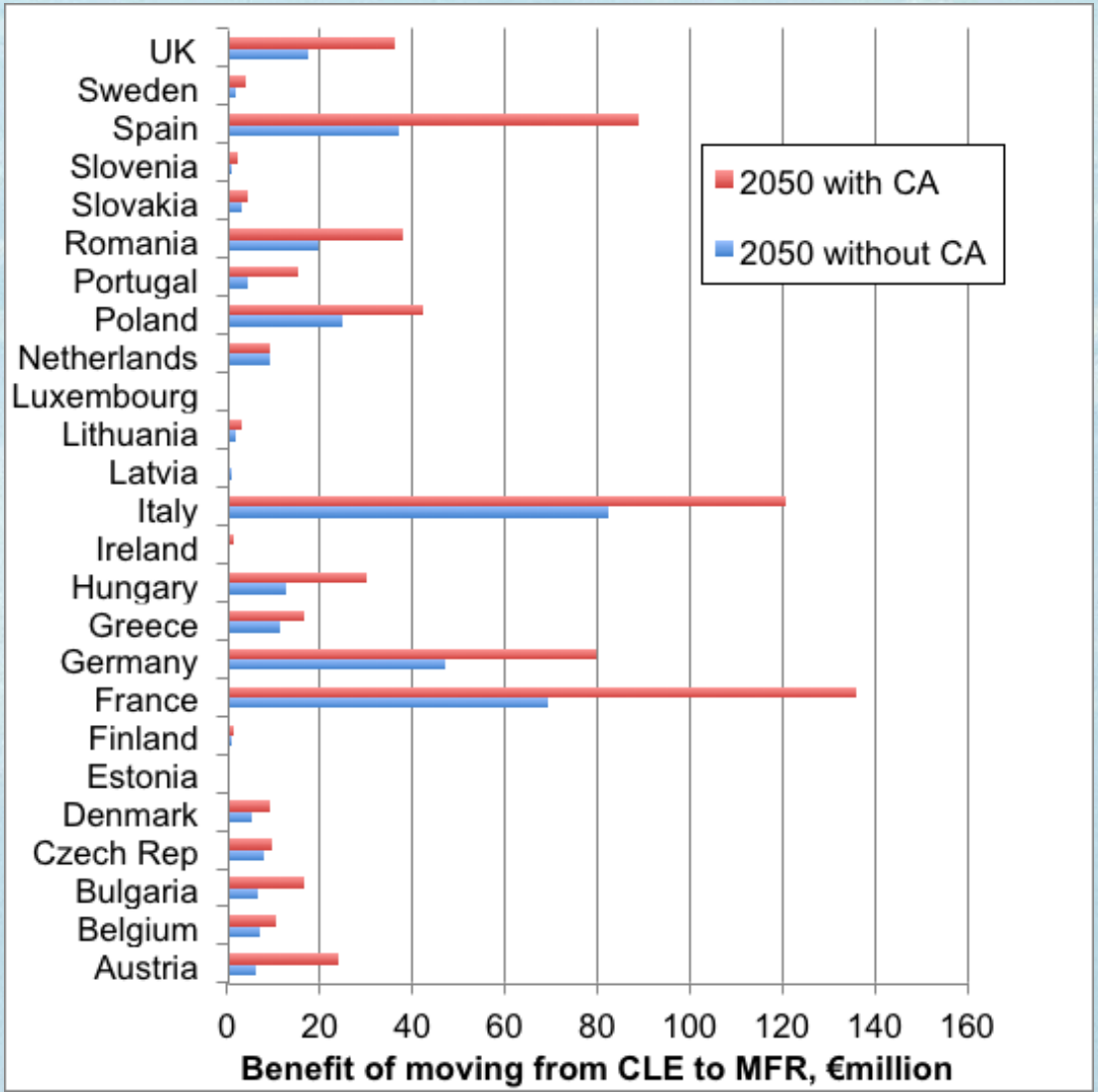
Agricultural land use change trends due to climate change in year 2050 for selected crops

Crop	Countries with expected increase of area	Country with expected decrease of area
Wheat	Spain and Portugal	All other countries (top 5: France, Germany, UK, Poland, Romania)
Barley	Romania, Hungary, Italy, France, Poland, Bulgaria, Slovakia, Portugal, Netherlands, Belgium, Austria, Slovenia	All other countries(top 5: Spain, UK, Denmark, Germany, Finland)
Tomatoes	All countries (top 5: Spain, France, Portugal, Italy, Germany))	None
Potatoes	France, Czech Republic, Germany, Bulgaria, Slovakia, Austria, Lithuania, Hungary, Italy, Estonia, Sweden, Luxembourg	All other countries (top 5: Netherlands, Belgium, Romania, Poland, UK)
Maize	UK, Poland, Lithuania, Denmark, Latvia, Germany, Ireland, Sweden, Netherlands, Estonia, Finland, Luxembourg	All other countries(top 5: Romania, France, Hungary, Italy, Bulgaria)
Grapes	All other countries (top 5: Poland, Germany, Romania, UK, Hungary)	Spain, Italy, Portugal, Greece, France, Slovenia, Luxembourg
Apples	All other countries (top 5: France, Romania, Spain, Bulgaria, Italy)	Poland, Netherlands, Slovenia, Belgium, Estonia

Distribution of economic impacts of ozone on different crops under different scenarios



Crop production benefits in 2050 by implementing MFR (relative to CLE) in million Euros, with and without climate adjustment



Forest damage

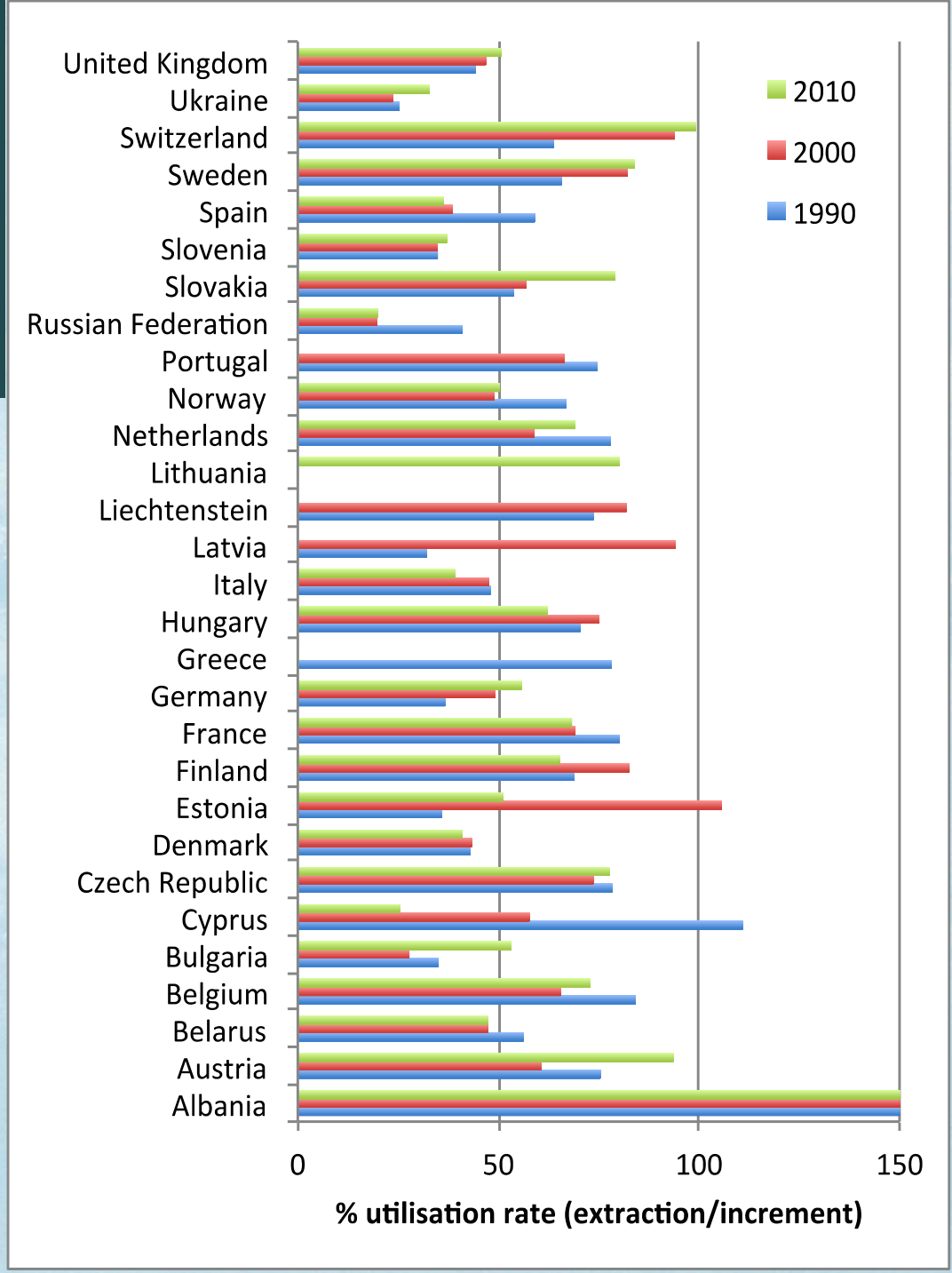
- Lost production of timber for manufacture of wood products
- Lost production of timber for manufacture of paper and pulp
- Lost production of firewood
- Reduced carbon sequestration

Data and functions

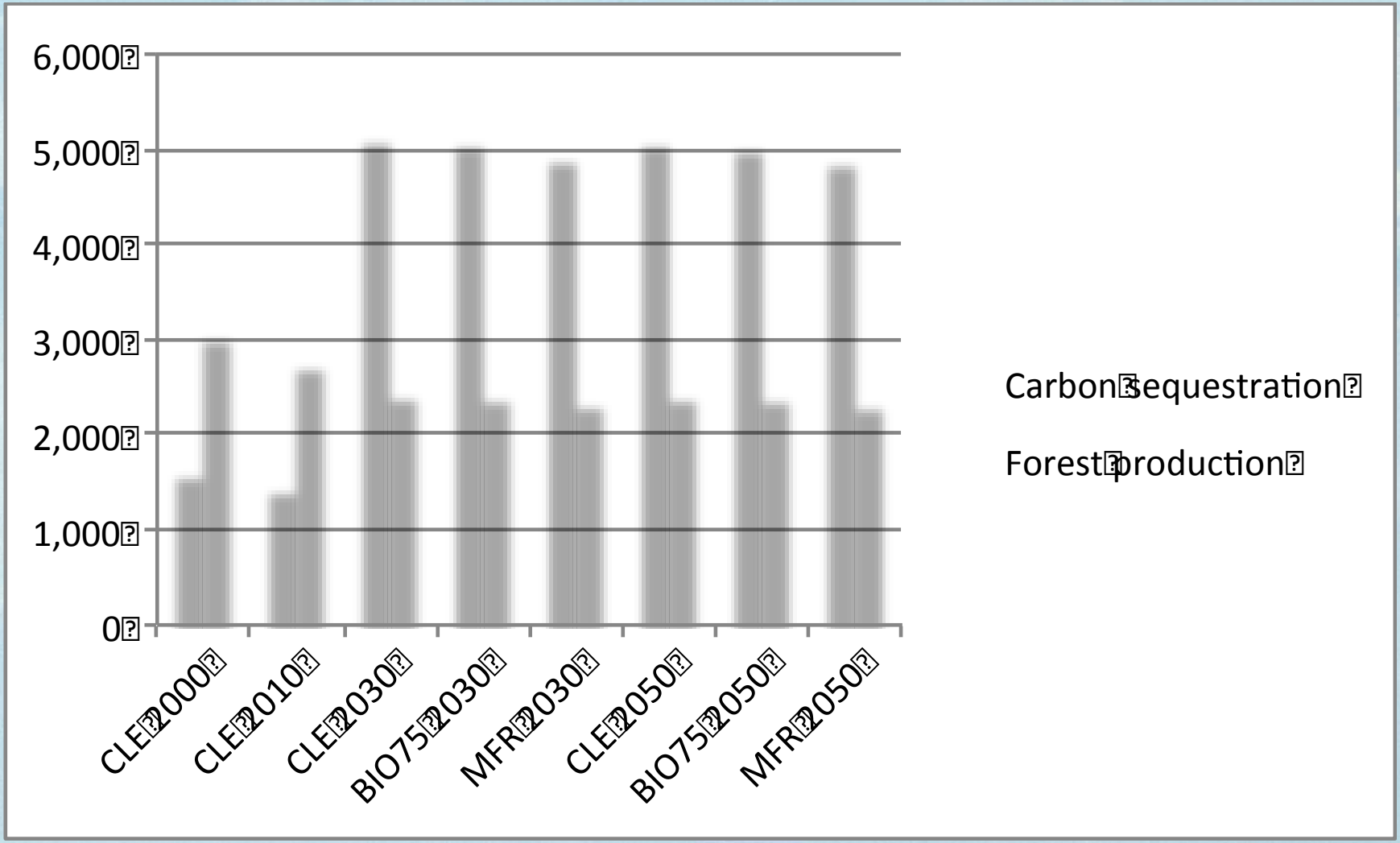
- Response functions
  - POD1, from SEI for various coniferous and broadleaved species
- Forest production: Eurostat
- Carbon sequestration: literature review
  - 2000, 2010: €9.5 - €74 / tonne CO_2
  - 2030, 2050: €39 - €187 / tonne CO_2

Forest production utilisation rate

- Availability of excess production
- But with distributional consequences



Forest related damage, €million/year



Approaches for quantifying biodiversity impacts in economic terms

- Large literature on ecosystem services, little directly relevant to air pollution effects on biodiversity
  - Too site specific
  - Inability to link to ecological change of interest
  - …
- We investigated
  - Stated preference approach (Christie et al)
  - Repair costs
  - Regulatory revealed preference

Benefits relative to CLE scenario, €billions/year

	BIO75 i77	MFR	BIO75 i78	MFR
	2030	**2030**	**2050**	**2050**
Crops	0.10	0.4	0.11	0.4
Crops (climate adj)		0.50		0.70
Forest, climate	0.04 - 3.0	0.16 - 1.2	0.04 - 0.30	0.16 - 1.2
Forest production	0.02 - 0.03	0.07 - 0.11	0.02 - 0.03	0.07 - 0.11
Biodiversity (WTP)	0.51 - 1.5	0.91 - 2.7	0.61 - 1.8	1.0 - 2.9
Biodiversity (repair cost)	1.8	3.0	2.2	3.1
Biodiversity (Reg. rev. pref)		11		11
Ecosystems mid estimate	**1.2**	**2.5**	**1.4**	**2.8**
Health	30	50	30	50
Health (range)	20 - 150	40 - 220	30 - 140	40 - 220

Key gaps in knowledge

- Very limited literature on valuation of ecosystems that is relevant to impacts on biodiversity
  - However, Christie provides a useful model that can be replicated
  - Understanding of how valuation studies like Christie should inform policy
  - Does ‘regulatory revealed preference’ approach provide a more complete assessment?

Conclusions

- Benefits analysis and CBA continue to be used extensively across Europe
- Broader range of health concerns are being addressed
  - But more need to be considered
- Ozone effects on crops could increase in significance through crop production changes
- Ecosystem impacts significant, more valuation work needed
  - But we have a better idea of what needs to be done!