Assessing Particulate Health Impacts: Power Industry Experience

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The Joint Environmental Programme

- Future environmental regulation in the most significant source of risk factors affecting plant operation and asset strategy
- Key factors include air quality, health effects & ecosystem effects
- Eight companies – cover majority of the UK coal and oil-fired generation
- Investigate environmental issues of relevance to the power industry
- Sector level discussions with the Environment Agency & DEFRA

Health effects of air pollution

- Population exposure historically regulated through AQ standards

- New Ambient Air Quality Directive includes
  - Average exposure indicator (3 year mean for urban background)
  - Exposure reduction targets (0%-20% dep. on $PM_{2.5}$ AEI by 2020)
  - Exposure concentration obligation ($20gm^{-3}$ by 2015)

- Exposure quantification is a key component of cost-benefit analysis – drives TSAP, NECD, Gothenburg Protocol
- Health impacts dominated by particulate matter chronic mortality

- UK Power stations contribute ~ 5.5% of primary $PM_{2.5}$ emissions
- Secondary precursor species ~ 55% SO_2 and 23% of NO_x emissions

Which component of particulate is toxic?

- $PM_{2.5}$ is a complex mixture of sulphate, nitrate, ammonium, acidity, metals, carbon, VOCs – plus a range of particle sizes
- COMEAP (2007) “We accept that there may be variations in toxicity, per µg/m^3 pollutant, between the various components of $PM_{2.5}$. However, we have not recommended the quantification of the effects of components of $PM_{2.5}$ separately.”
- AQEG (2005) “The balance of evidence currently available suggests that it is combustion derived components of PM_{10} – which are comprised predominantly of fine and ultrafine carbon-containing particles and may be enriched with trace metals or specific organic compounds - that are primarily responsible for the harmful effects.”

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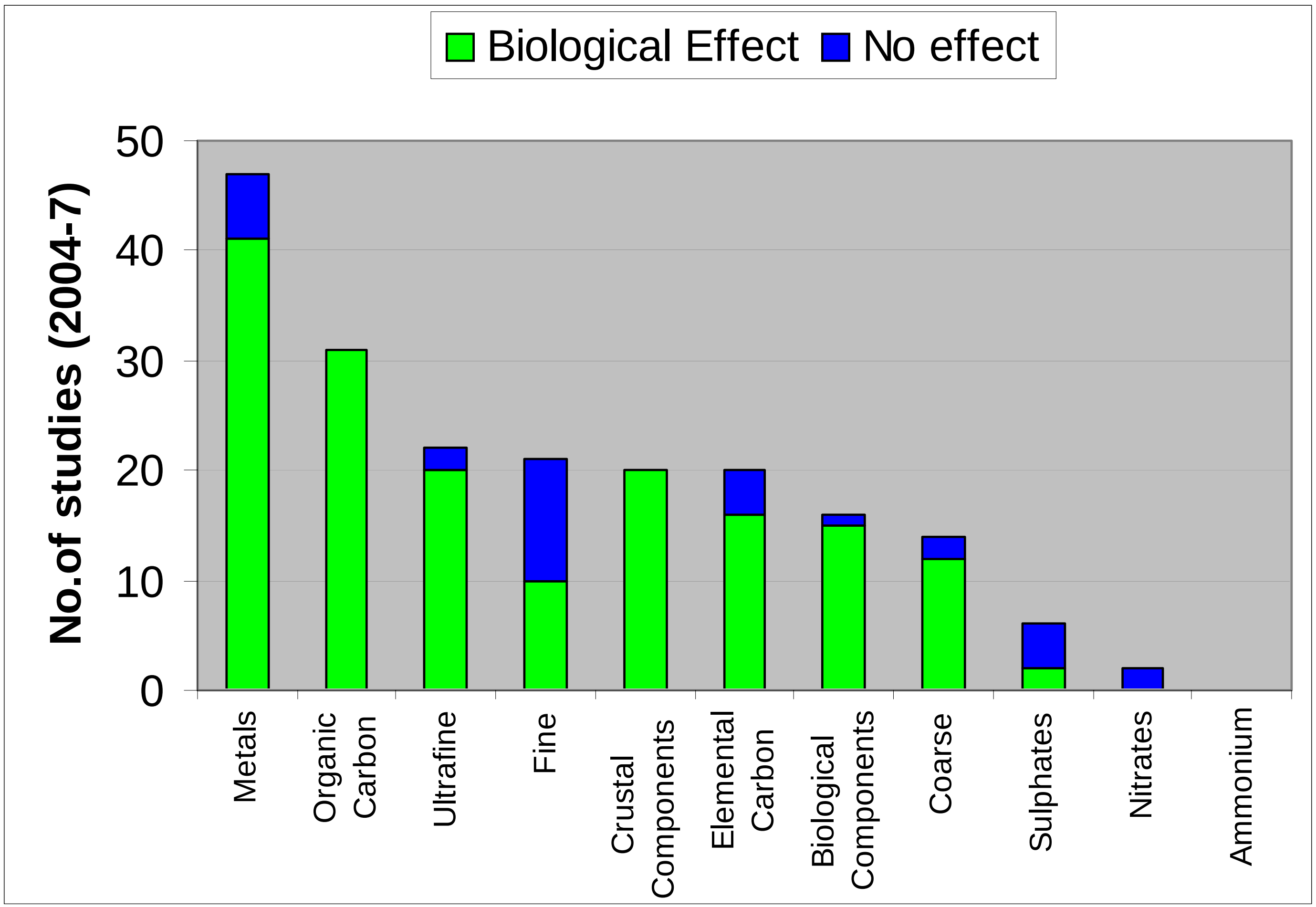

Ref: Data from Kelly F & Fussell J C, (2007). Particulate toxicity ranking report. Kings College London, No 02/07, July 2007.

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Component	Ability to cause oxidative stress and inflammation	Important sub-components
Diesel Soot	++++	Surfaces, organics, metal
Petrol Soot	+++?	Surfaces, organics, metal
Tyre dust	+?	?
Brake dust	+?	?
Natural gas particles	++?	? Organics
Point sources e.g. steel mills	+ to +++	Metals
Mineral dusts, sand, soil dust	+ to +++	Quartz
Plant debris (harvesting)	- to +++	lipopolysaccharide
Sea/road salt	-	
Sulphuric acid and sulphates	-	
Ammonium nitrate	-	

Ref: Donaldson K, (2006). Which particle characteristics are important in view of health effects? Presentation to COST 633 Conference, April 3 to 5, 2006, Vienna

Implications for emissions reduction policy

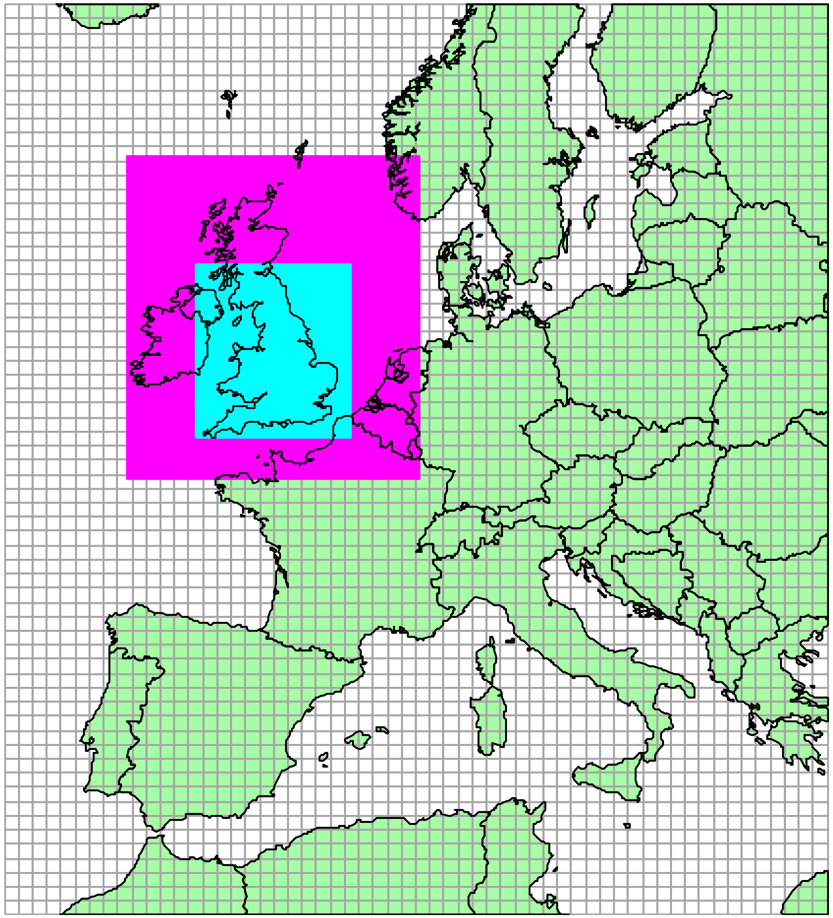
- European legislation developed based on cost-benefits studies of population exposure
- Damage costs dominated by particulate health effects
- Based on the assumption that all $PM_{2.5}$ mass is equally toxic

- Toxicology does not support a role for secondary inorganic mass in particulate toxicity
- How does this assumption affect policy development?
- Potentially no health benefits from reducing this component
- Potential over-estimation of damage costs
- Which emission sectors should be targeted

- Need to use a detailed model to assess exposure to different components for different emission sources

Study exposure using Models-3/CMAQ

- 3-D gridded Eulerian model
- Set up to run on three nested grids (54, 18, and 6 km resolution)
- 21 vertical layers (15km)
- Hourly gridded emissions
- Hourly gridded meteorology
- Chemical Scheme: RADM2+aerosols+aqueous chemistry
- Time-dependent size distribution & size specific chemical composition for particulate



Sectors for which impacts have been assessed

- Model runs based on 2010 emission scenario, 1999 meteorology
- Used 54km European grid
- Ran model with and without each selected emission sector
- Ground-level PM concentrations due to 7 different sectors compared

Sectors:

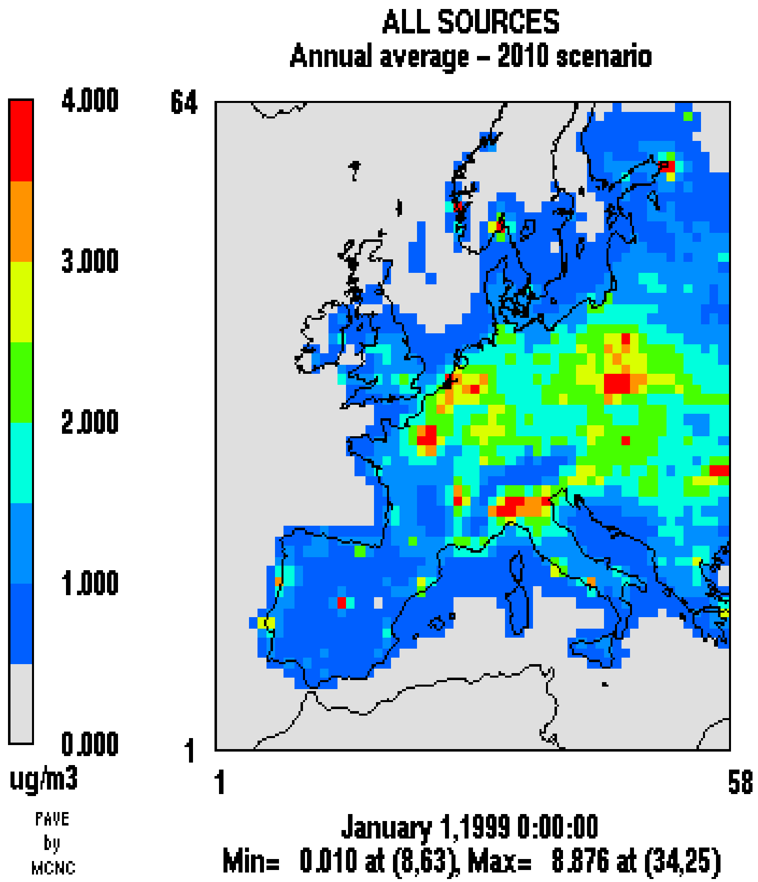
• **Energy**	**SNAP 1**
• **Residential**	**SNAP 2**
• **Industry**	**SNAP 3,4,5,6,9**
• **Shipping**	**SNAP 8**
• **Transport**	**SNAP 7,8**
• **Agriculture**	**SNAP 10**
• **Natural**	**SNAP 11**

Ground-level concentration output:

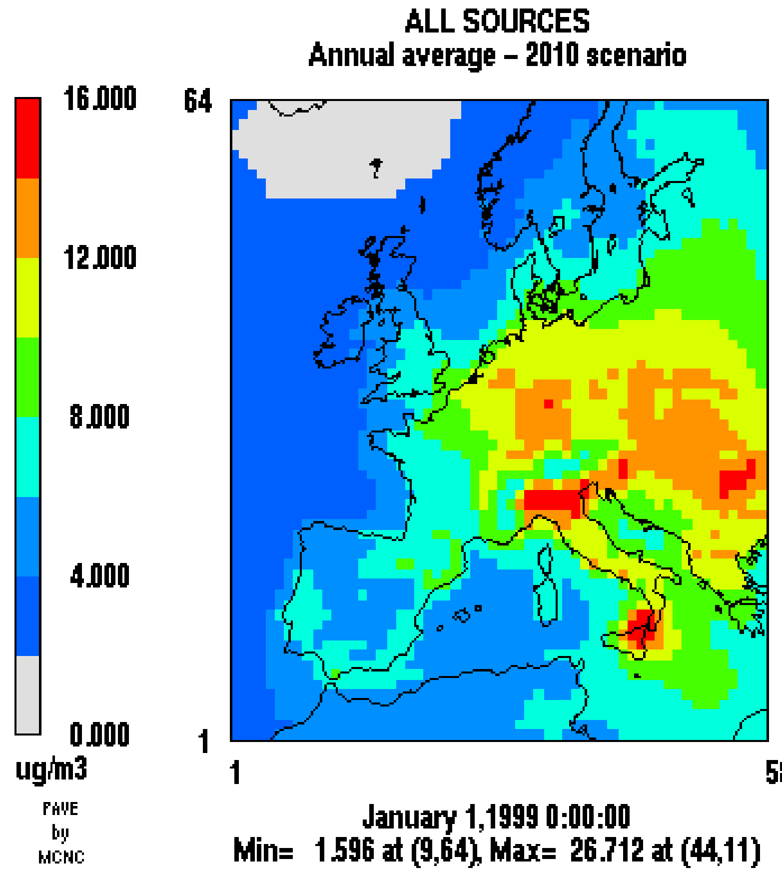
- **Total $PM_{2.5}$**
- **Primary $PM_{2.5}$**
- **Secondary $PM_{2.5}$**
- **Individual components**
- **Ratio scaled primary**

All source primary and secondary $PM_{2.5}$ concentrations

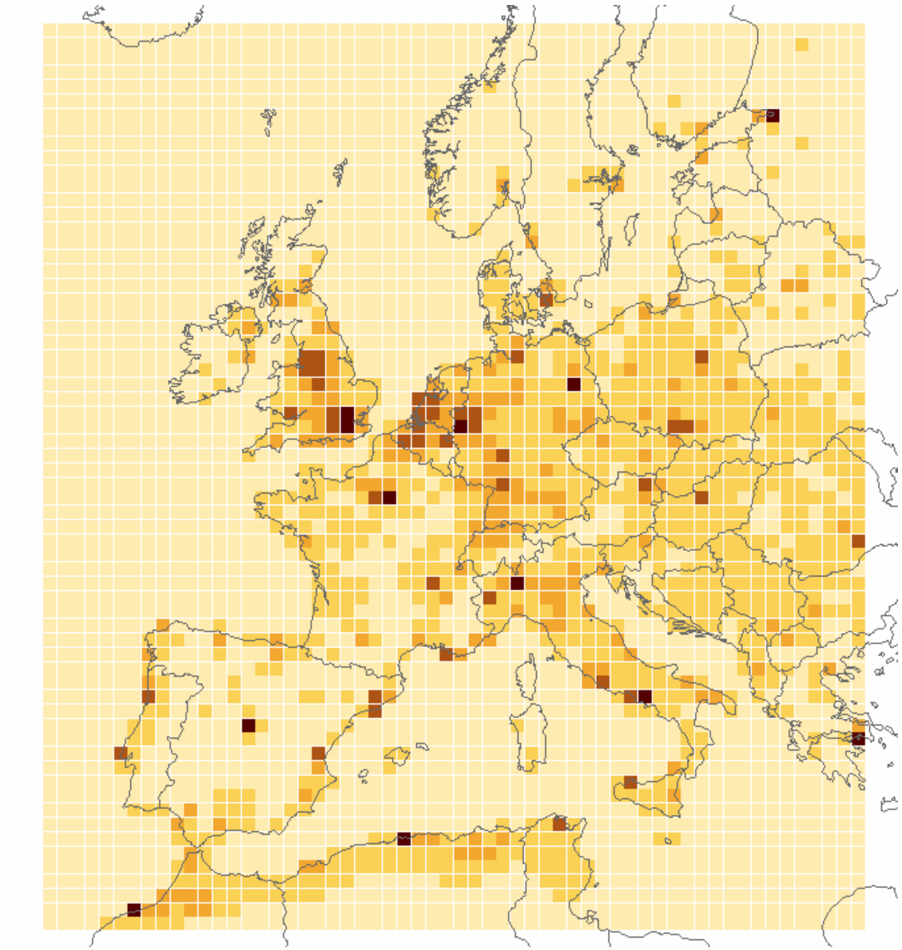
Primary PM2.5 concentration



Secondary PM concentration



Exposure approach – population data



Based on Gridded Population of the World (GPW) dataset, available from Centre for International Earth Science Information Network (CIESIN) website

Projected to Lambert Conformal Projection appropriate for CMAQ

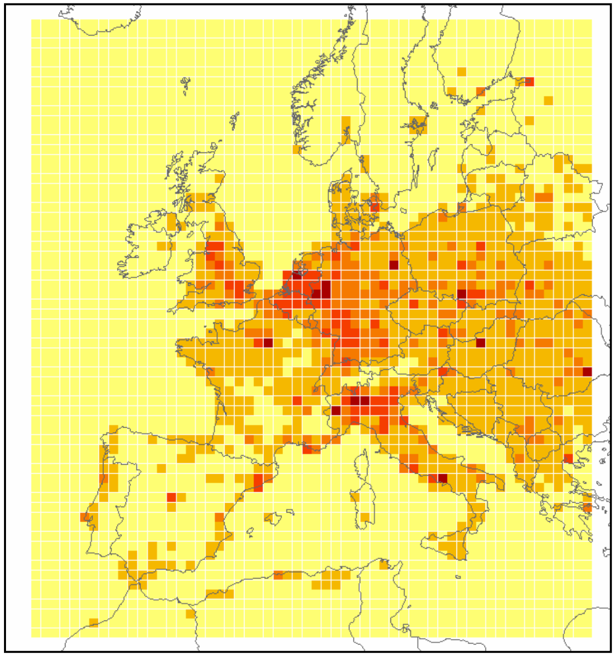
Population density in persons per km^2

0 - 50	50 - 200	200 - 500	500 - 1000	> 1000

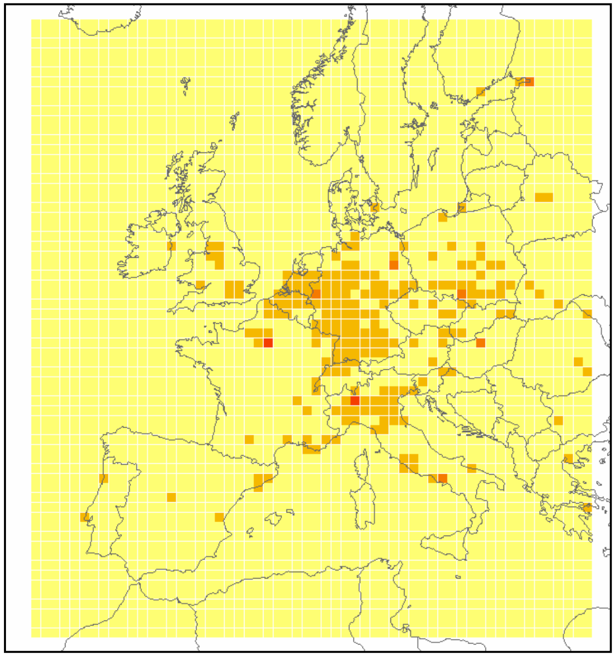
Population exposure – Secondary $PM_{2.5}$

Exposure = Population x concentration
(person.µgm^{-3}km^{-2})

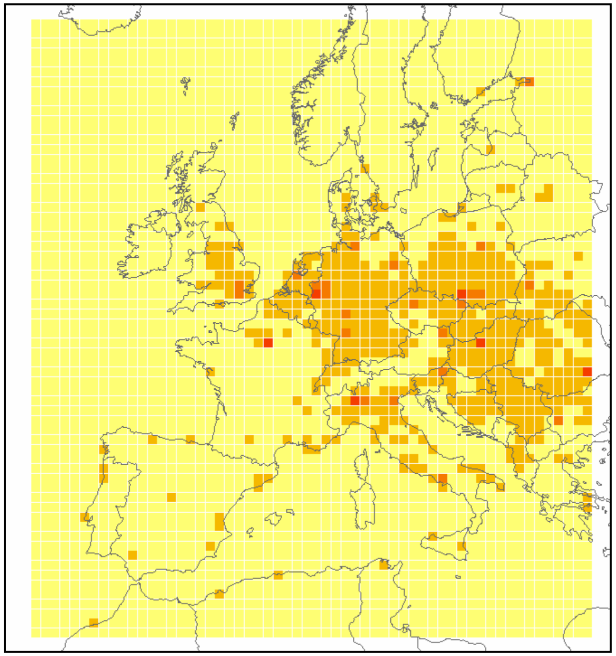
0 – 150	150 – 850	850 - 1750	1750 – 4250	> 4250



Agriculture



Residential

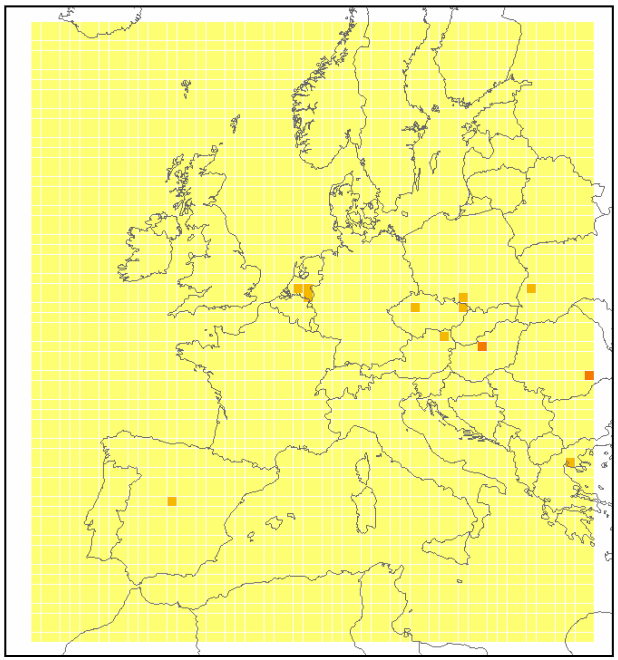


Energy

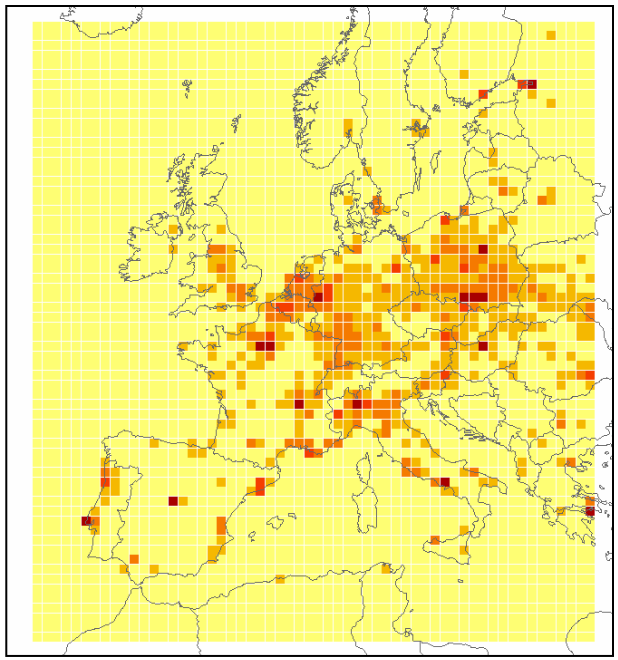
Population exposure – Primary $PM_{2.5}$

Exposure = Population x concentration
(person.μgm^{-3}km^{-2})

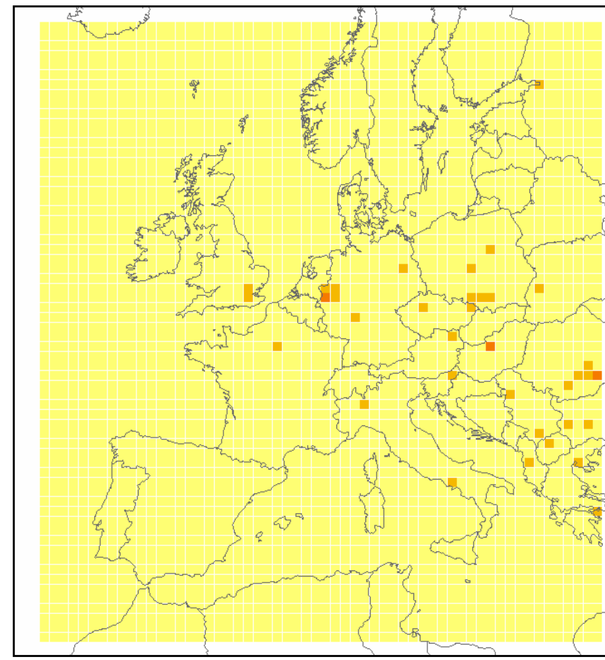
0 – 50	50 – 175	175 - 500	500 – 1000	> 1000



Agriculture

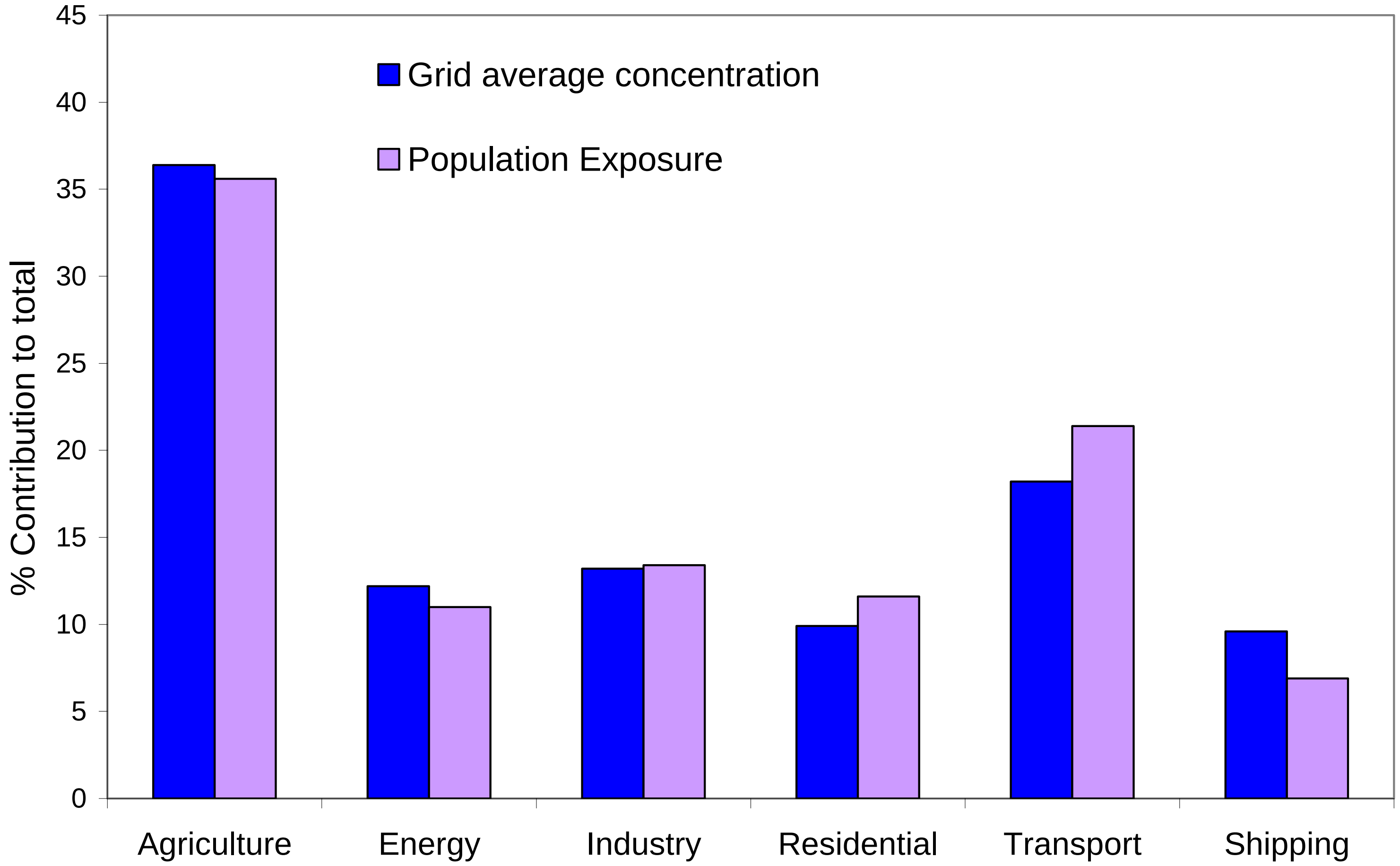


Residential

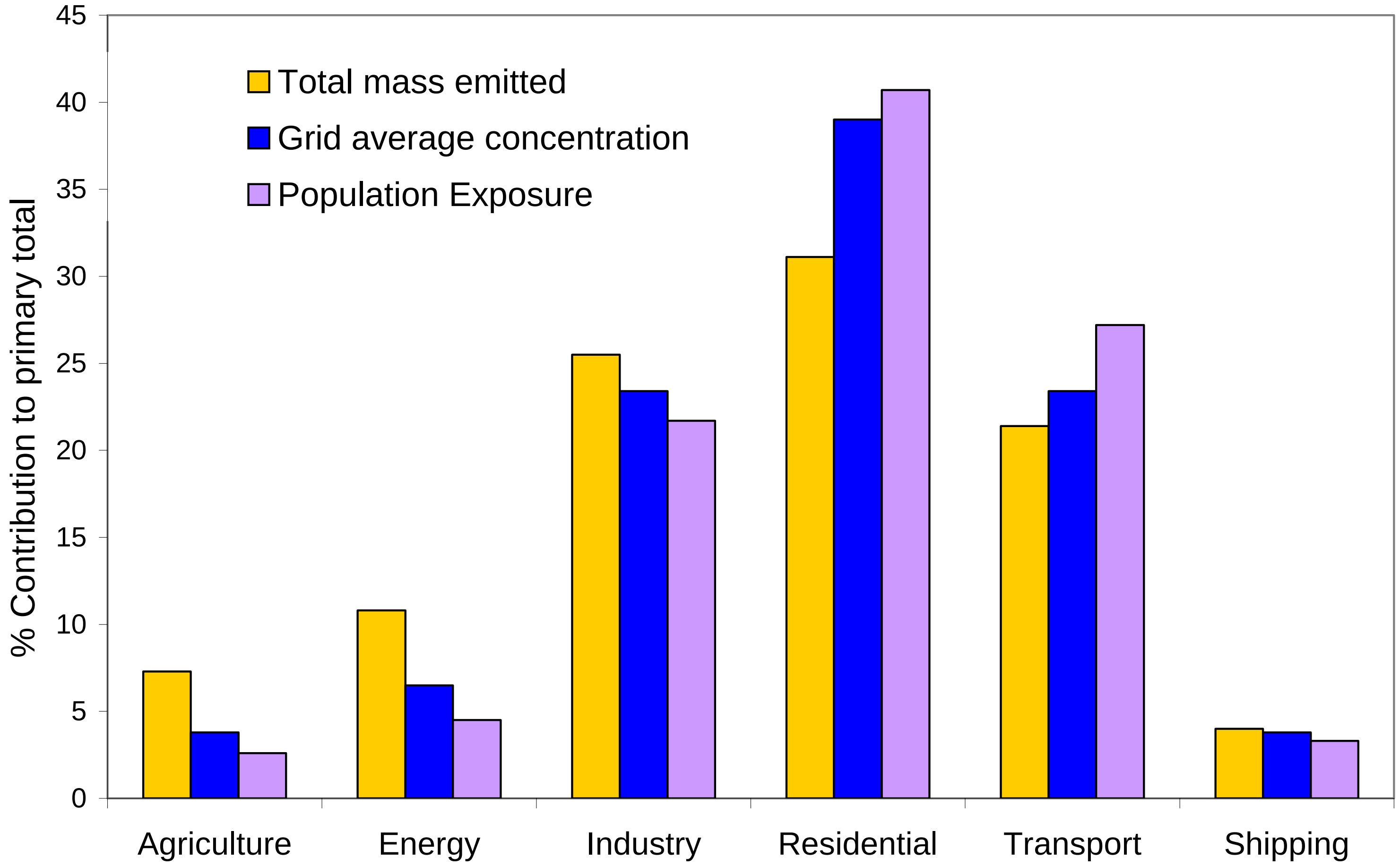


Energy

Impact of considering population exposure – Total $PM_{2.5}$



Impact of considering population exposure – Primary $PM_{2.5}$



Implication for Damage Costs ($PM_{2.5}$ chronic mortality)

Number of additional cases of a health outcome given by:

$$I_R \times CRC \times \textit{Population Exposed} \times \textit{Increase in concentration}$$

I_R is baseline incidence rate in population: 1013 / 100000

CRC is the concentration response co-efficient: 0.6%/μgm^{-3} for $PM_{2.5}$

$$\textit{Damage cost} = \textit{Value of health outcome} \times \textit{Number of additional cases}$$

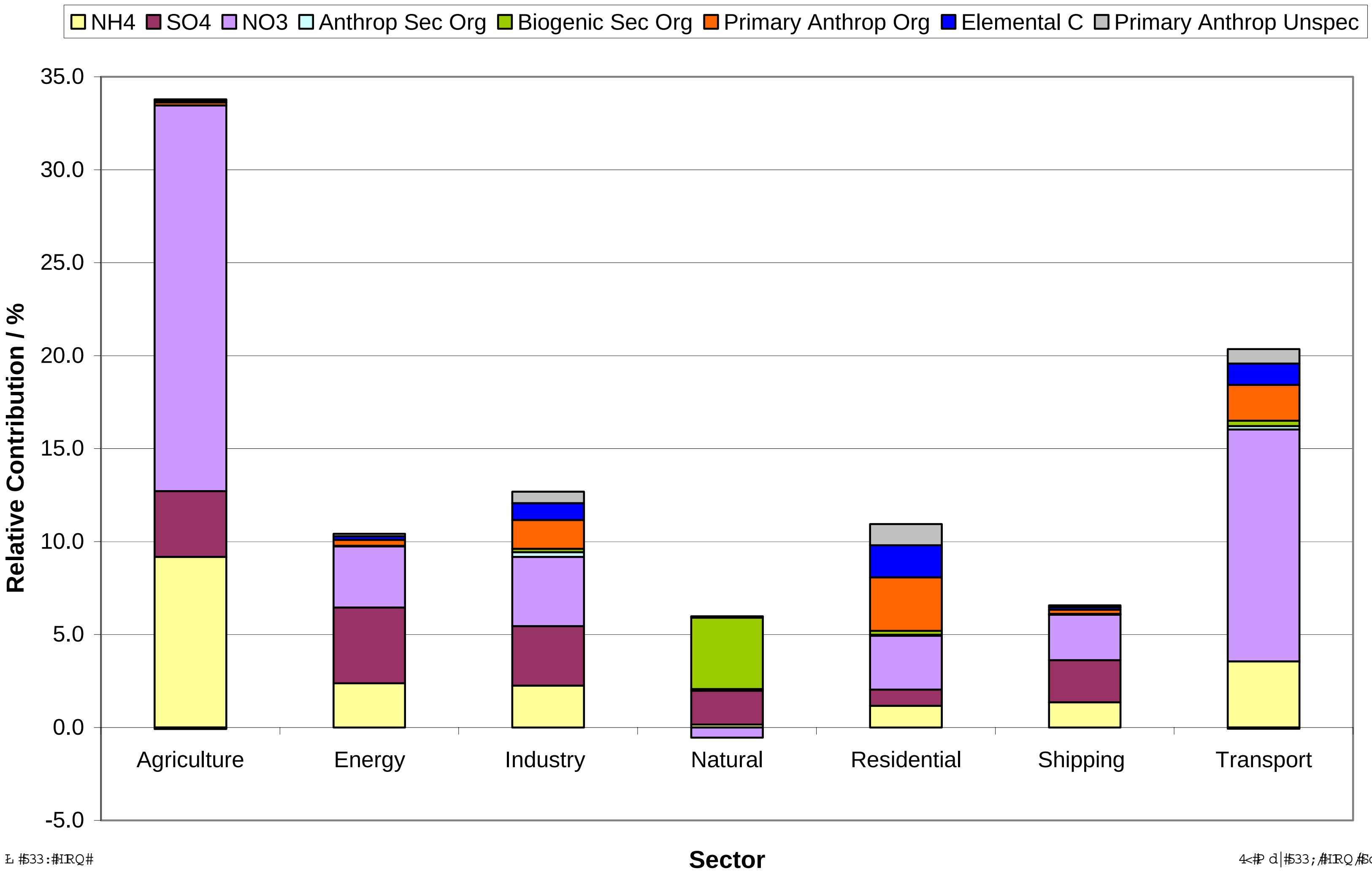
External median value of a statistical life: €980,000

Total damage costs (equal toxicity) = **€375 billion** (€66 billion primary)

Double CRC for primary only toxicity to reflect ambient split

Total damage costs (primary toxicity) = **€112 billion**

Exposure for individual components



Exposure ranking for metal components

Exposure ranking	Agriculture	Energy	Industry	Natural	Residential	Shipping	Transport
Arsenic	=7	3	1	=7	2	5	4
Cadmium	=7	3	1	=7	2	5	4
Chromium	=7	3	1	=7	2	5	4
Copper	=7	4	2	=7	3	5	1
Mercury	=7	2	1	=7	3	5	4
Nickel	=7	3	2	=7	1	4	5
Lead	=7	3	1	=7	2	5	4
Selenium	=7	2	1	=7	4	5	3
Zinc	=7	4	1	=7	3	5	2

Conclusions

- Toxicology implicates primary $PM_{2.5}$ for health impacts
- Exposure currently dominated by secondary particulate
- Assignment of toxicity completely alters abatement strategies
  - Emissions from different sectors dominate health impacts
  - External costs significantly over-estimated
- Individual component analysis can also implicate different sectors

- Policy should be based on best science
- Differential toxicity sensitivity studies should be applied to emission reduction policy development
- Complex models such as Models-3 offer a flexible tool for assessing health impacts