EXCESS MORTALITY ESTIMATES OVER EUROPE: UNCERTAINTIES FROM MODELLING, EMISSIONS AND AEROSOL SOURCES

JONILDA KUSHTA & JOS LELIEVELD

EEWRC, THE CYPRUS INSTITUTE

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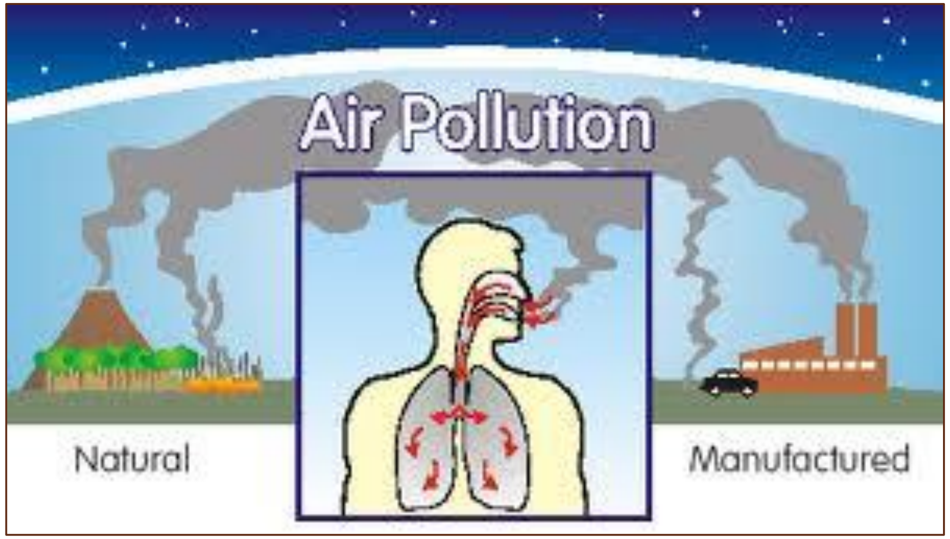
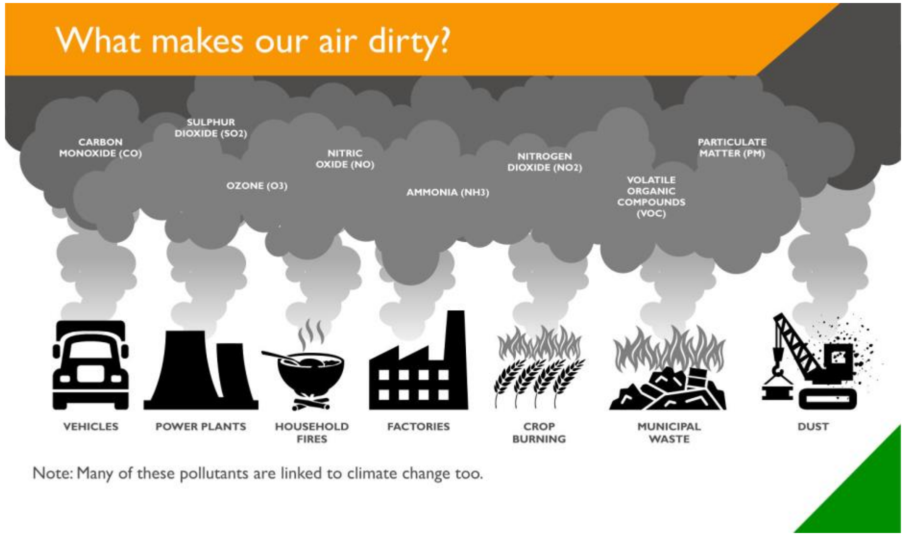
Air pollution and health

Exposure to airborne fine particulate matter (diameter less than 2.5 µm – PM2.5) has been associated with many short- and long-term adverse health outcomes varying from respiratory illnesses to premature death .

Predominant sources of fine particulates are fossil fuel and biomass combustion, industry, agriculture, and wind-blown dust.





Concept

The assessment of health impacts from ambient air pollution relies on an integrated methodology that uses:

Step 1: observations and/or air quality models to determine pollutant concentration distributions
Step 2: synthesize this information with exposure and population vulnerability on national and global scales

Use of atmospheric modelling systems is necessary to fill the gap in regions where air quality is not monitored, and to investigate alternative scenarios related to factors such as emissions, air quality regulations and population development.

Limitations: The use of coarse grid resolutions, forced by computational resource limitations and global model parameterizations, <u>may result in underestimation of peak concentrations</u> in densely populated and industrialized areas.

This could influence mortality estimates by misrepresenting the gradients between pollution and population distributions leading to errors in estimates of health impacts.

Model configuration

Weather Research and Forecast model coupled with Chemistry (WRF-Chem)

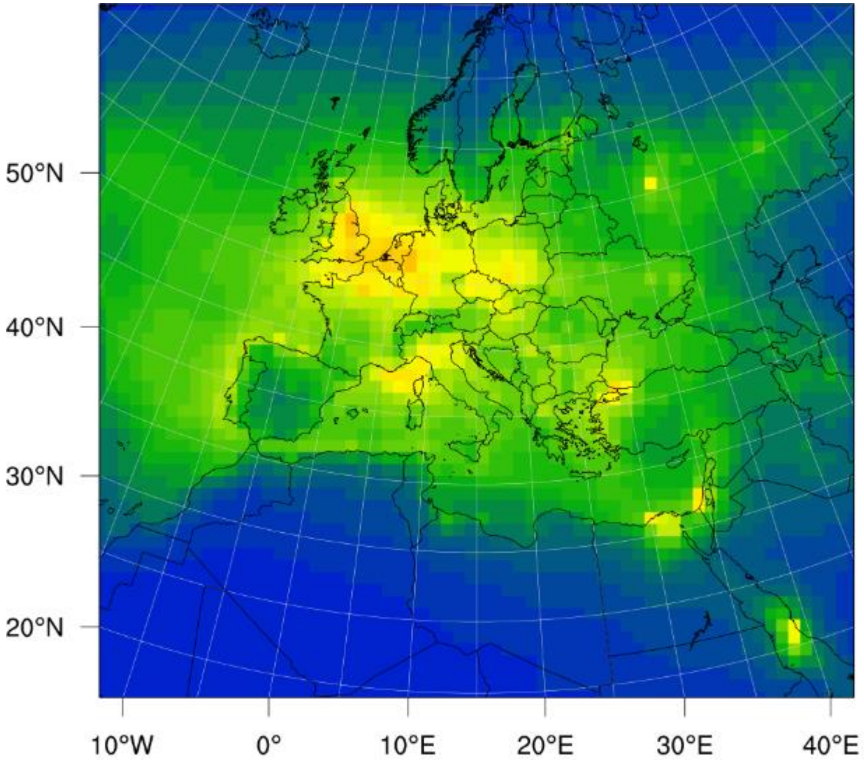
- two domains, one with a horizontal resolution of 100km and the other with 20km
- NCEP global forecast system (GFS) at a resolution of 0.5° x 0.5° for meteorology
- MOZART-4 (Model for Ozone And Related chemical Tracers version 4) model for chemistry
- Global emission dataset EDGAR-HTAP v2 that consists of 0.1° x 0.1° gridded annual anthropogenic emissions of NOx, SOx, non-methane volatile organic compounds (NMVOC), CO, NH_3, PM2.5 and PM10.

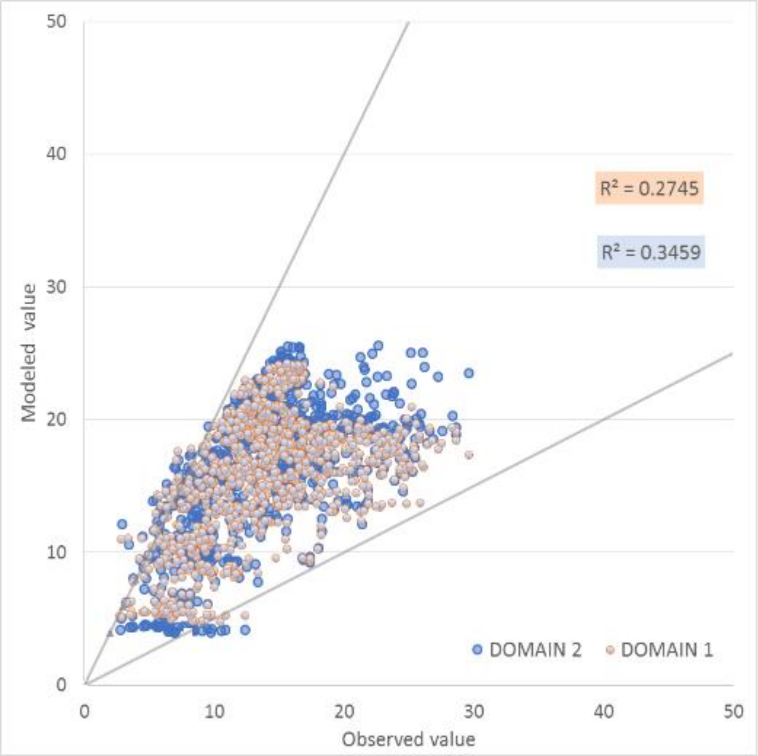
Simulated PM2.5 concentrations are used to derive estimates of mortality from ischemic heart disease, cerebrovascular disease from ischaemic and haemorrhagic stroke, chronic obstructive pulmonary disease, lung cancer, and acute lower respiratory infections using:

✓ country level baseline mortality rates for the diseases and population data (adopted from the WHO Global Health Observatory for 2010) and

✓ concentration – response functions calculated following the methodology of Burnett et al. (2014).

Base case evaluation with surface data



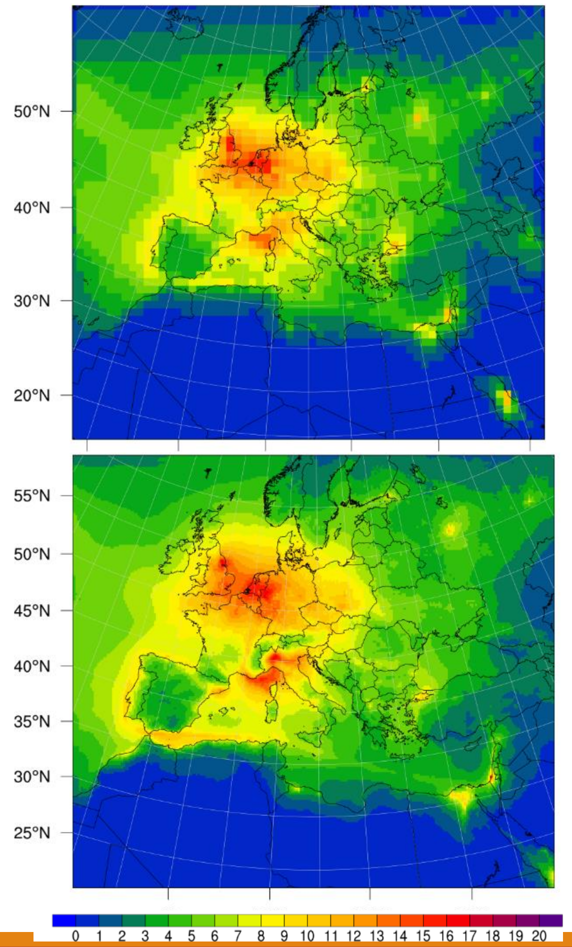


Domain utilized in the study (left) and modelled versus observed mean annual PM2.5 concentrations over AirBase stations over Europe for the year 2014 (right). 100km/20km domains in orange/blue-contoured circles.

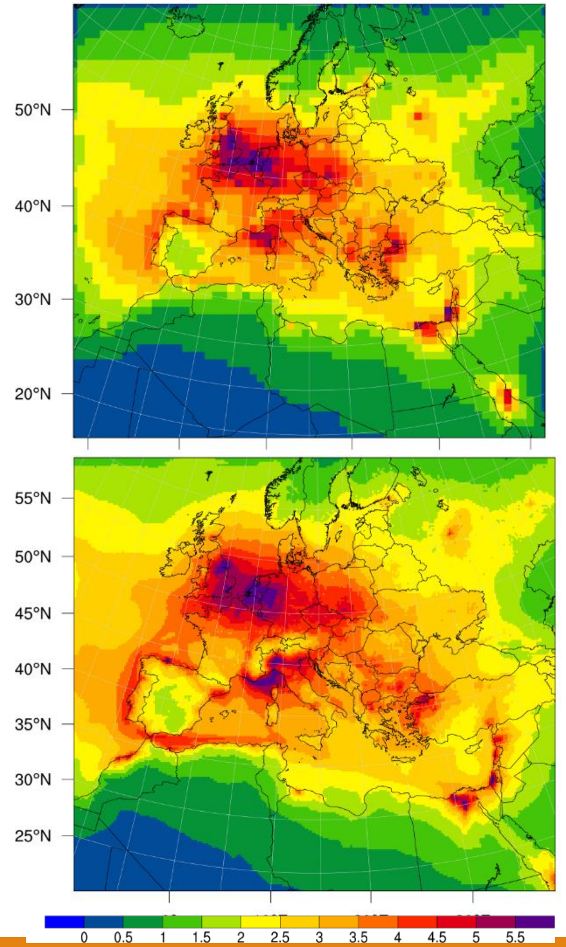
Kushta et al., 2018: Uncertainties in estimates of mortality attributable to ambient PM2.5 in Europe, ERL, DOI: 10.1088/1748-9326/aabf29

PM2.5 components

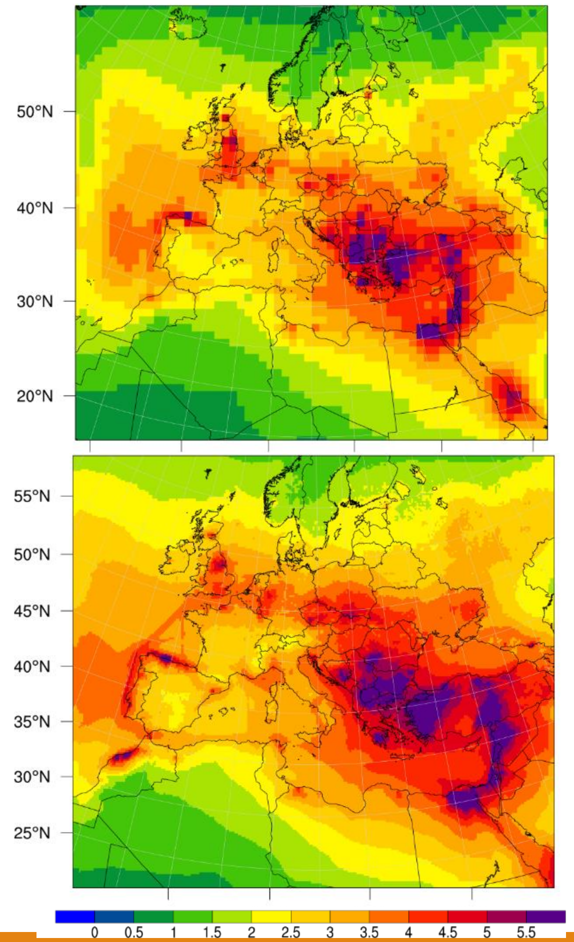
NO_3^-



NH_4^+



SO_4^{-2}



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Results listed from largest to smallest M_{diff}

COUNTRY	POPULATION x10^3	MORTALITY 20km	MORTALITY 100km	Relative difference %
Portugal	10585	4786.5	4389.1	8.30
Spain	46601	12879.4	11830.5	8.14
Italy	59588	28912.6	27124.5	6.18
Slovenia	2052	1066.8	1007.2	5.59
Malta	412	132.0	125.7	4.76
Israel*	7420	1640.8	1576.7	3.90
Luxembourg	508	198.5	191.6	3.44
Romania	20299	17604.1	17054.2	3.12
Cyprus	1104	254.3	246.5	3.05
Bulgaria	7407	7983.0	7802.6	2.25
France	62961	20734.4	20308.9	2.05

COUNTRIES MOSTLY AFFECTED those with small territories and countries with better representation of pollution with respect to densely populated areas

Results listed from largest to smallest population

COUNTRY	POPULATION x10^3	MORTALITY 20km	MORTALITY 100km	Relative difference %
Germany	80435	52300.8	51462.3	1.60
Turkey	72310	19391.4	19033.1	1.84
France	62961	20734.5	20308.9	2.05
United Kingdom	62717	33725.2	34000.8	-0.81
Italy	59588	28912.6	27124.5	6.18
Spain	46601	12879.4	11830.5	8.14
Ukraine	45647	58954.6	58298.1	1.11
Poland	38575	25534.6	25446.8	0.34
Romania	20299	17604.1	17054.2	3.12
Netherlands	16632	8367.7	8270.5	1.16
Belgium	10930	6727.0	6663.8	0.93
Portugal	10585	4786.5	4389.1	8.30

In the largest European countries the resolution changes mortality estimates by less than 2%. HOWEVER in two large countries, Italy and Spain, the difference can reach 6-8%.

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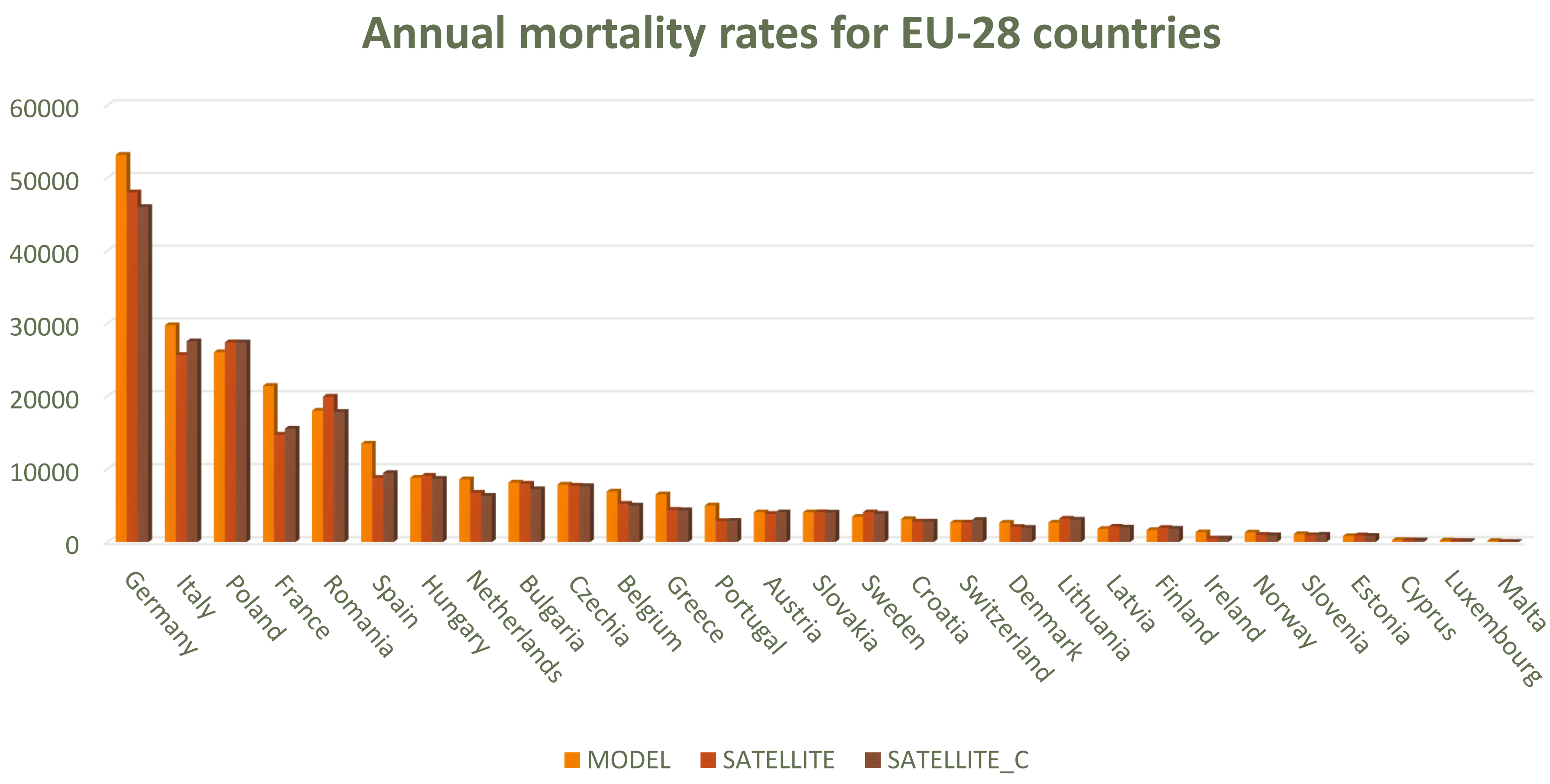
Comparison with satellite data



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Impact of model configuration

Using coarse spatial resolution modelling (100km) yields about 535 000 annual premature deaths over the extended European domain (242 000 within the EU-28), while approximately 2.4 % higher numbers are derived by using finer resolution (20km).

In general, the countries with the largest biases cover small geographical areas where the use of a higher resolution for PM2.5 is important to represent national boundaries.

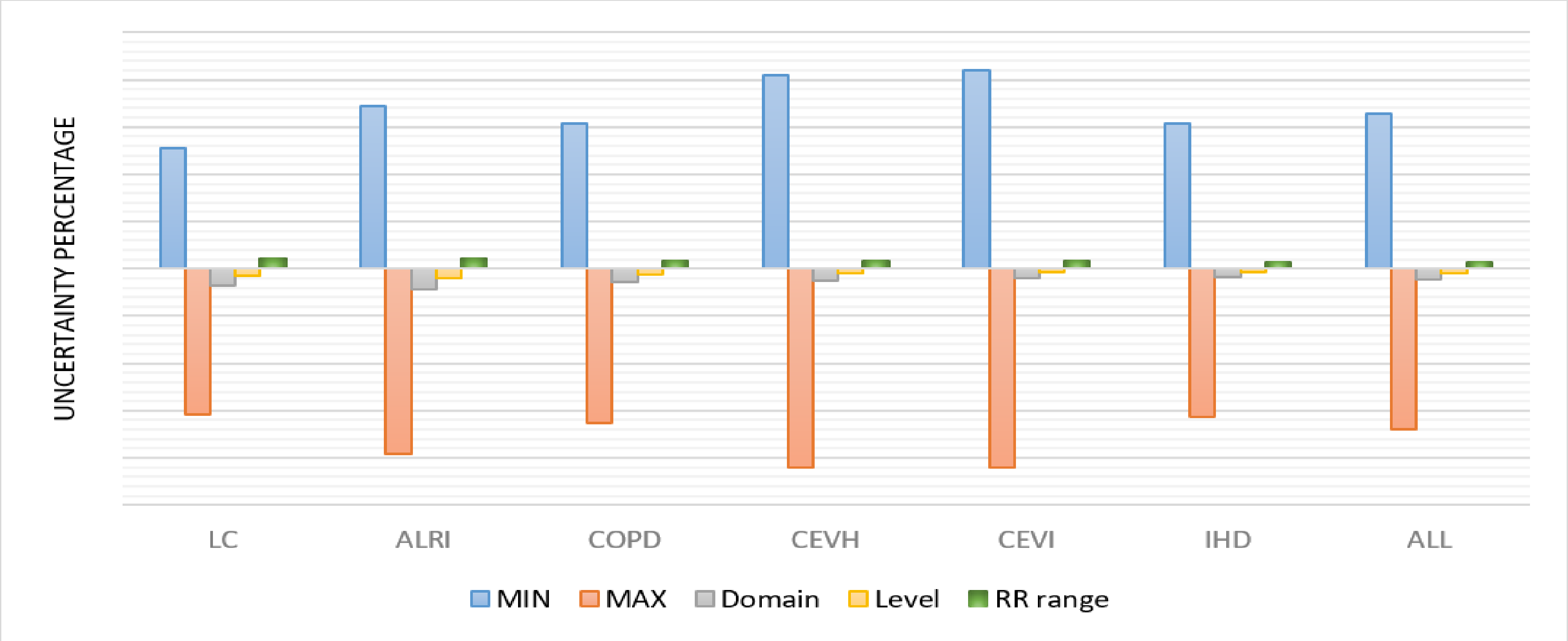
Using the surface (i.e. lowest) layer of the model for PM2.5 yields about 0.6 % higher mortality rates compared with PM2.5 averaged over the first 200m above ground.

The calculation of relative risks (RR) or hazard ratios from PM2.5, using 0.1 $\mu g/m^3$ size resolution bins compared to 1 $\mu g/m^3$ (commonly used) is associated with ±0.8 % uncertainty in estimated deaths.

Kushta et al., 2018: Uncertainties in estimates of mortality attributable to ambient PM2.5 in Europe, ERL, DOI: 10.1088/1748-9326/aabf29

Impact of model configuration

Model uncertainties contribute a small part of the overall uncertainty expressed by the 95% confidence intervals, which are of order ±30%, mostly related to the RR calculations based on epidemiological data.



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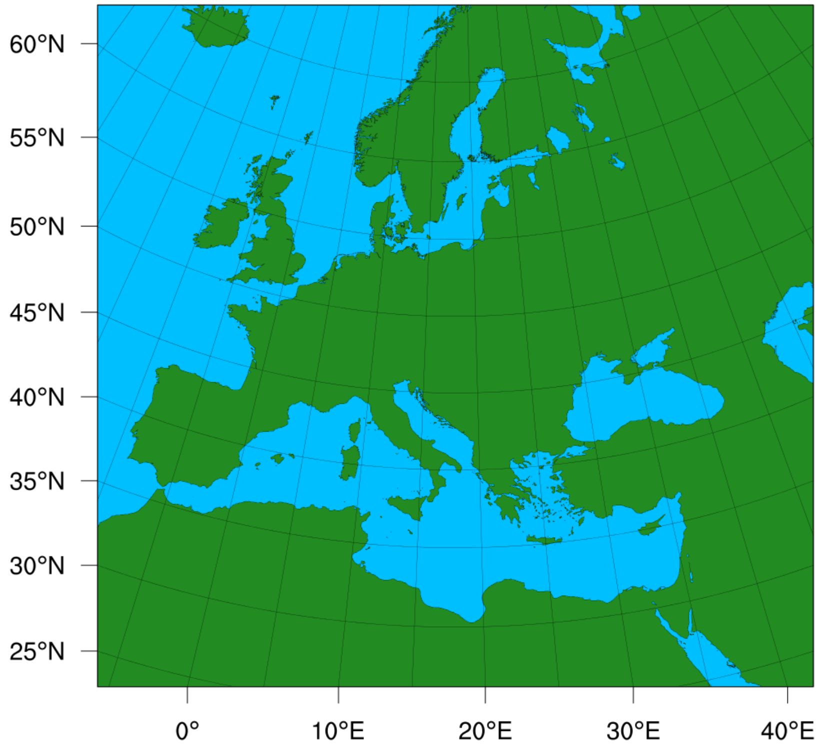
Main pollution sources in Europe

<u>Coal Power Plants</u>: estimate the excess pollution and related excess mortality from the operation of approximately 250 coal-fired power plants (CPPs) in Europe

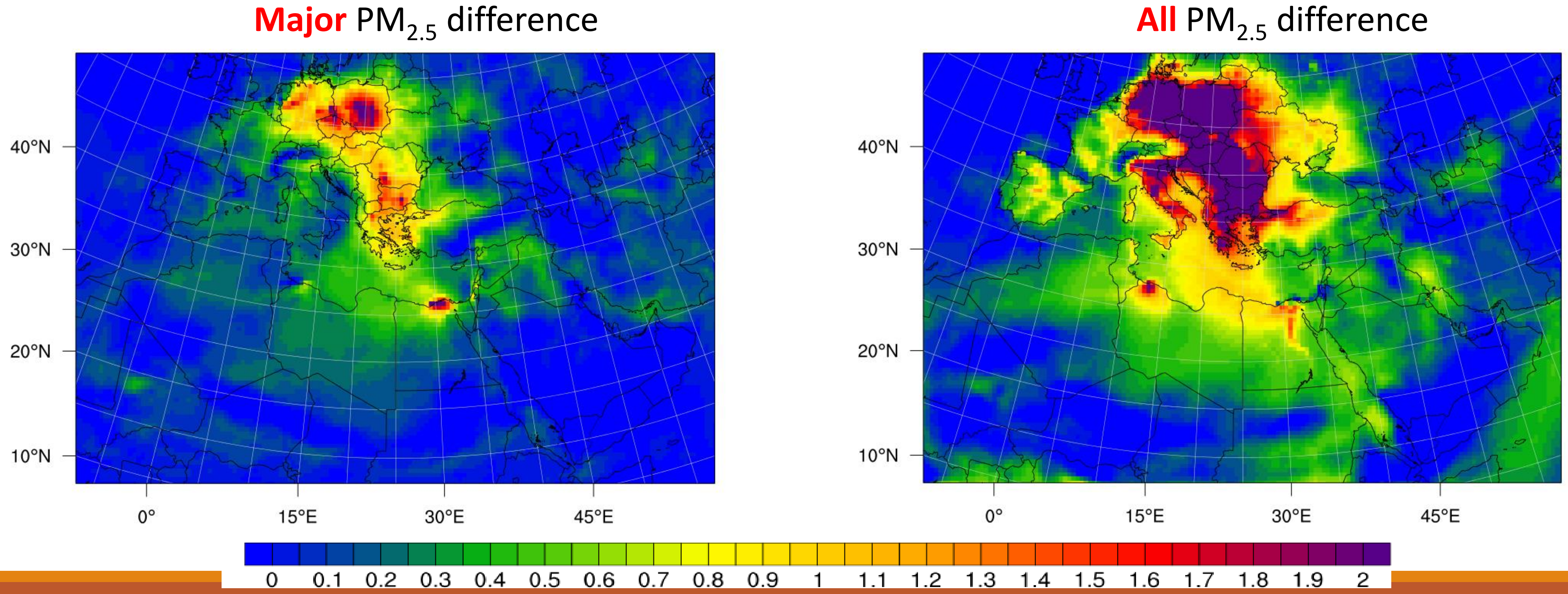
<u>Agriculture</u>: impact of an enhancement of 20% applied to the agricultural sector productivity, and the direct and indirect changes in emissions of all industrial sectors linked to agriculture using Input-output analysis (IOA)



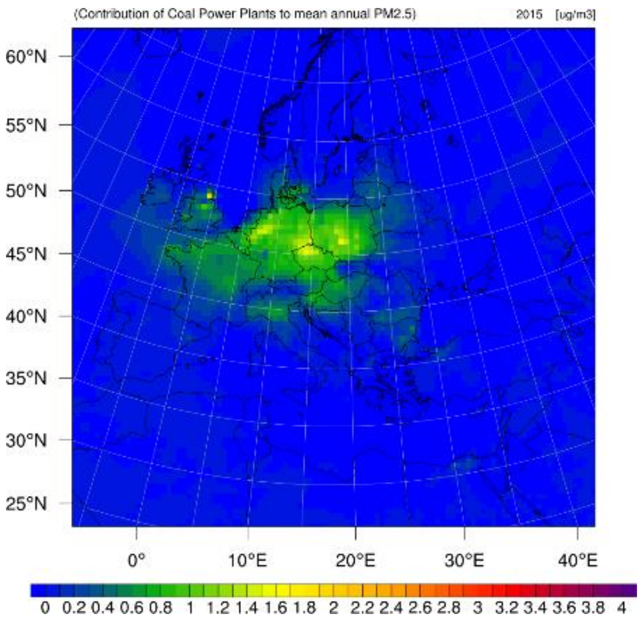
Strength of emission sources

DIFFERENCE IN TOTAL PM2.5 WHEN **MAJOR CPPs** ARE OUT ~ 1-2 μg/m^3

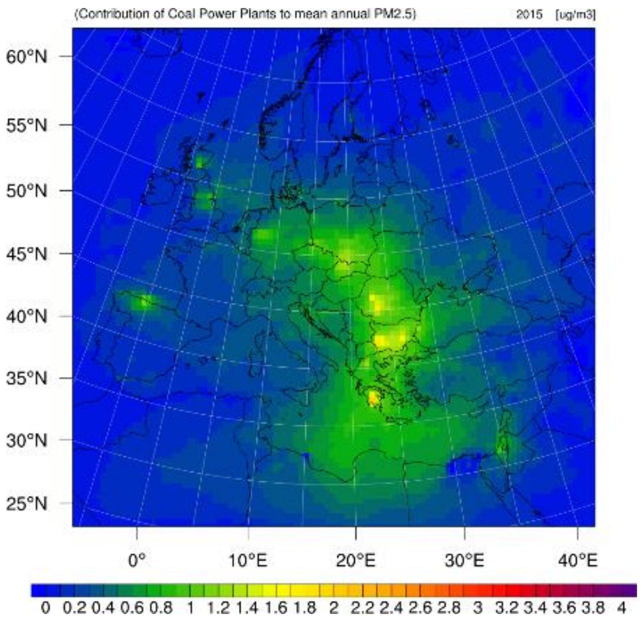
DIFFERENCE IN TOTAL PM2.5 WHEN **ALL CPPs** ARE OUT ~ 3-4 μg/m^3



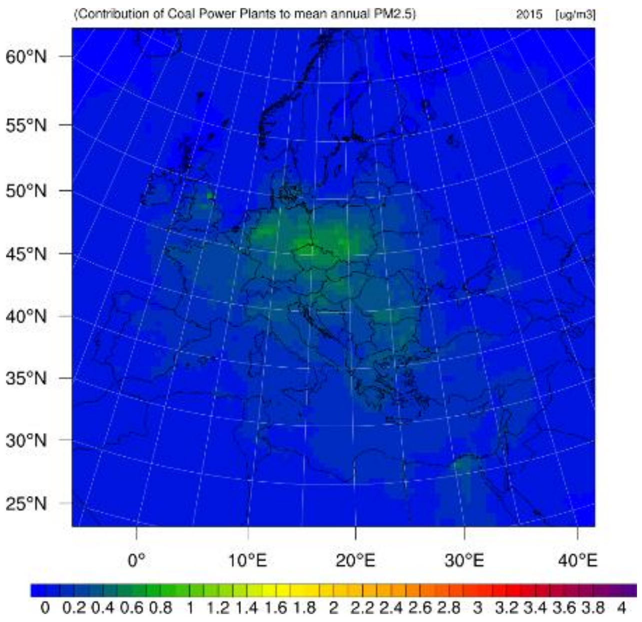
Impact on PM2.5 sub-components



NO_3^-



SO_4^{-2}



NH_4^+

Sulfate aerosols downwind – nitrate near emitting regions – implications for different toxicity

Premature Mortality due to Coal Power Plants

COUNTRY	CONTROL RUN	MAJOR CPPs	DIFF ABS	DIFF PERC	ALL CPPs	DIFF ABS	DIFF PERC
Ukraine	53616.12	52725.54	890.5742	1.69	50049.21	3566.91	7.13
Germany	43539.05	41849.34	1689.715	4.04	39832.05	3707	9.31
Poland	22690.83	21355.96	1334.865	6.25	19717.39	2973.436	15.0
Italy	20959.69	20522.59	437.0938	2.13	18187.84	2771.84	15.24
Romania	16047.91	15333.28	714.6328	4.66	13908.72	2139.194	15.38
France	15642.57	15339.31	303.2578	1.98	15119.04	523.5283	3.46
Hungary	7774.532	7460.082	314.4502	4.21	6751.84	1022.687	15.15
Spain	7611.106	7391.394	219.7119	2.97	6511.72	1099.388	16.88
Bulgaria	6840.979	6375.513	465.4658	7.30	5700.20	1140.778	20.01
Czechia	6727.525	6388.358	339.167	5.31	5907.41	820.1167	13.88
Total	241066.5	233257.5	7809.015	3.35	217588.74	23477.79	10.79

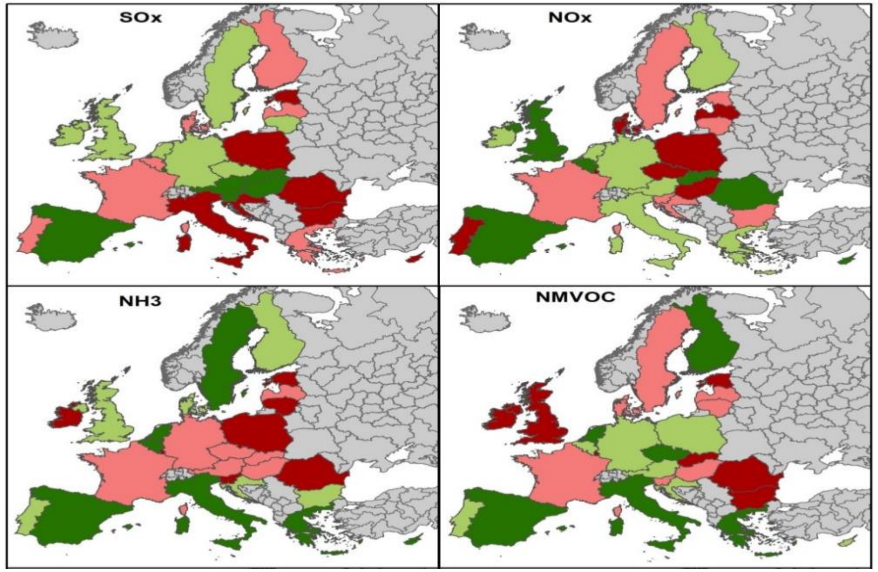
DIFFERENCE IN MORTALITY WHEN **MAJOR CPPs** ARE OUT ~7800 or 3.4% reduction

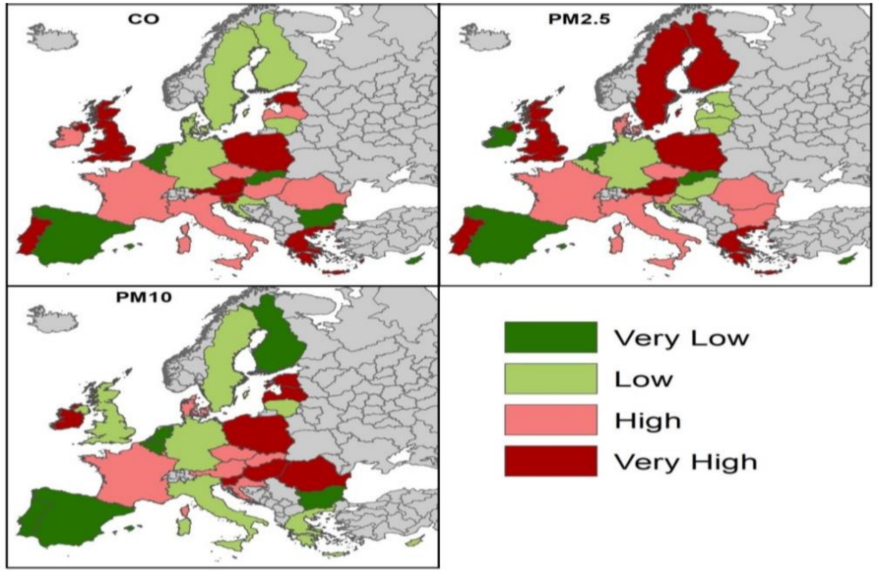
DIFFERENCE IN MORTALITY WHEN **ALL CPPs** ARE OUT ~ 23500* or 10.8% reduction

Agriculture and sector interdependence

The 20% increase in final demand for the output of the agricultural sector across the EU-28 results in:

- SOx emissions increase by 32.3%;
- NOx emissions increase by 25.4%;
- NH3 emissions increase by 23.2%;
- NMVOC emissions increase by 23.9%;
- CO emissions increase by 24.3%;
- PM2.5 emissions increase by 24.5%;
- PM10 emissions increase by 23.7%.

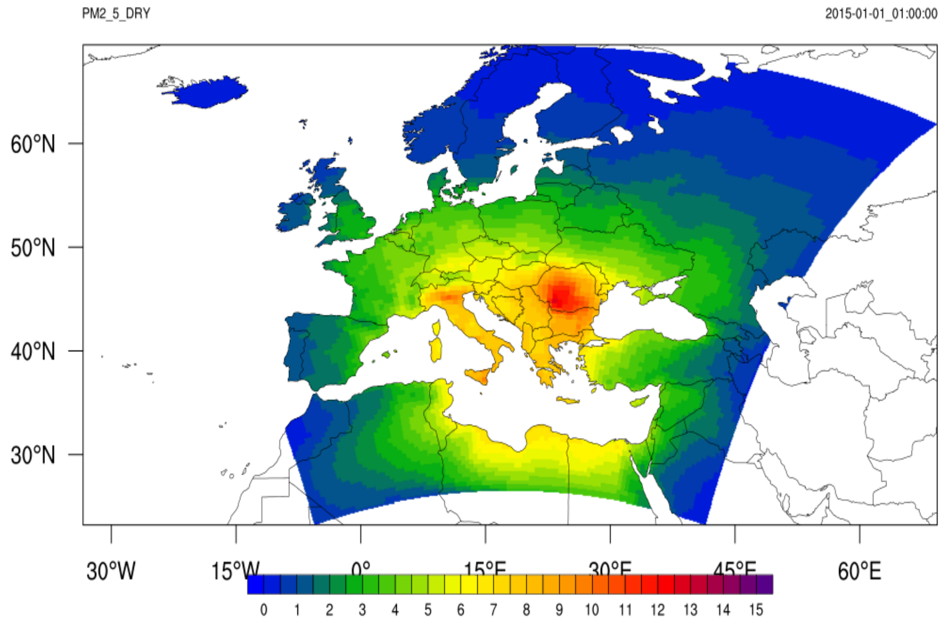




Giannakis et al., 2018:Exploring the economy-wide effects of agriculture on air quality and health, STOTEN

Impact on PM2.5 distribution

- Spatial peak of the mean annual average PM2.5 over East Europe and specifically over the northern Balkan countries reaching 9-10 μg m^{-3} over Bulgaria and Romania (Both countries exhibit large response to the enhancement of the agricultural activity especially for SOx, 461% and 2762%).
- Pronounced PM2.5 excess burden (6–8 μg m^{-3}) due to the modification of emissions especially in northern Italy. Sulphur oxides emissions are increased in Italy by 3003% due to agricultural growth. Additional contribution is from primary PM2.5 emissions that respond strongly to the agricultural enhancement (32.4%).



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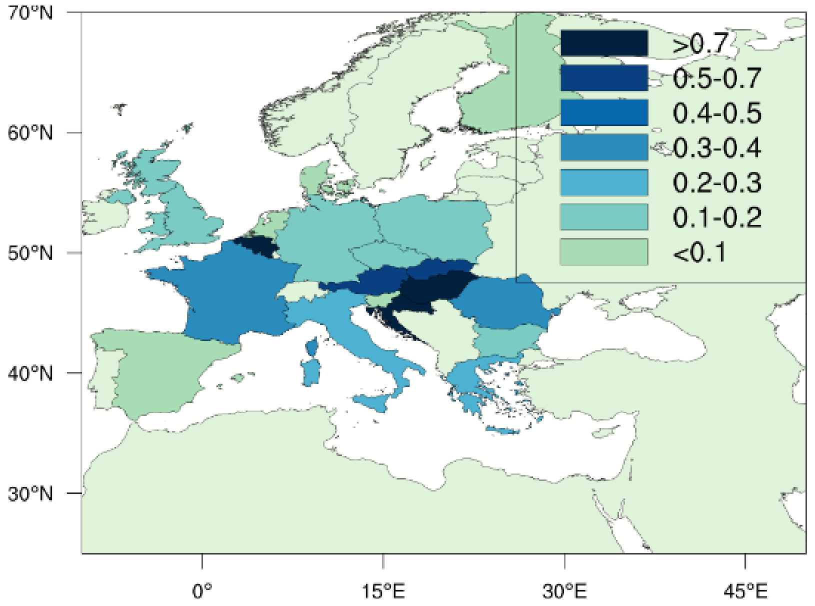
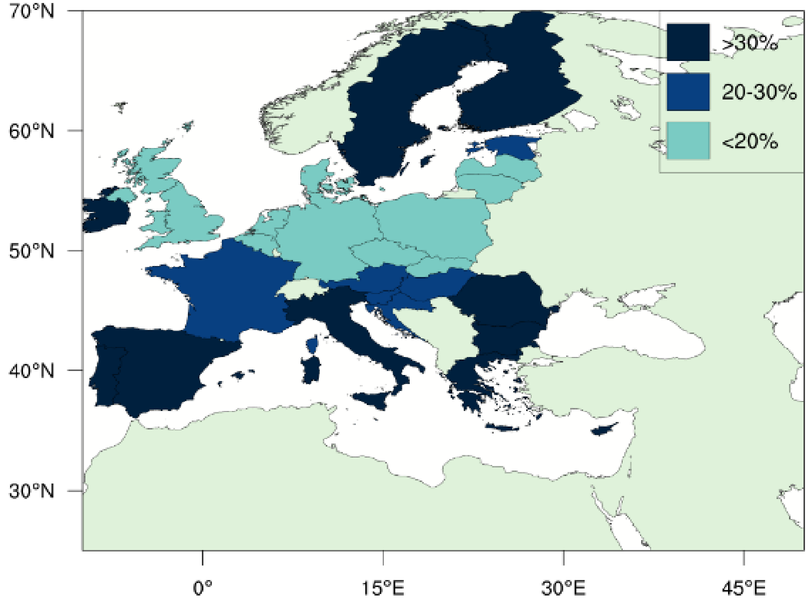
Application and Benefit



Integrating the electrical power of the excluded CPP units per EU-28 MSs, and calculating the number of excess deaths due to emissions from the CPPs of that country to the total electricity power of the country we produce a 'coal phase-out benefit index' expressed as excess deaths per electricity power unit



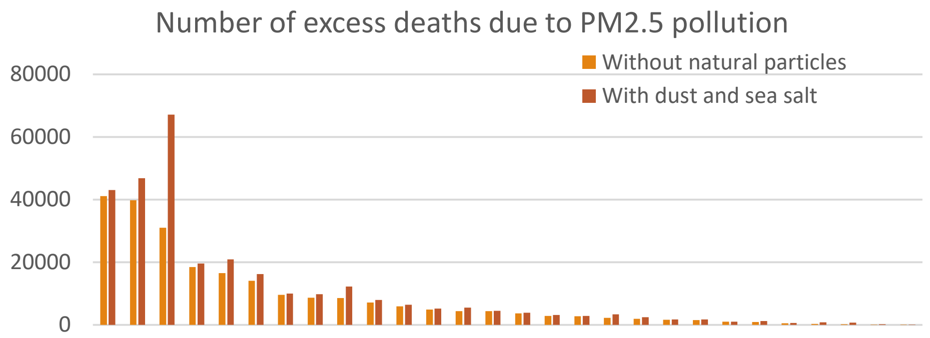
Response of premature mortality estimates over EU-28 countries due to PM2.5 from perturbed emissions relative to the control PM2.5 concentrations, classified into three categories: low sensitivity (mortality increase less than 20%), medium sensitivity (mortality increase between 20 and 30%) and high sensitivity (mortality increase more than 30%)*

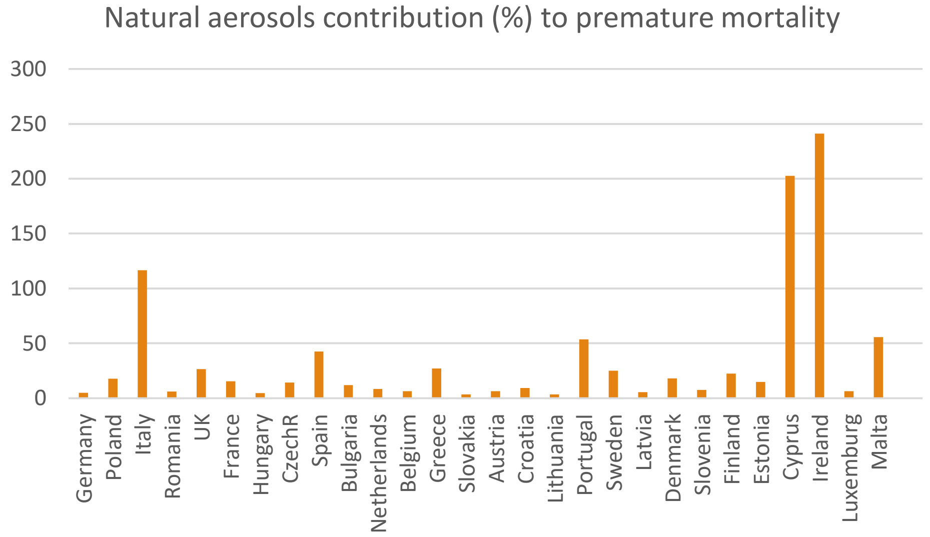
*Giannakis et al., 2018:Exploring the economy-wide effects of agriculture on air quality and health, STOTEN

Particles of natural origin

PM2.5 concentrations derived from satellite retrievals of the aerosol optical depth (AOD) from various satellite instruments (NASA MODIS, MISR, and SeaWIFS) (Van Donkelaar et al., 2016).

Latest available online satellite data (2015) with and without the contribution of natural sources (mineral dust and sea salt) indicate that the presence of natural particles can increase national premature mortality estimates up to threefold the rates without taking into account these particles, especially for countries located in the Mediterranean basin.





Conclusions

- Model uncertainties contribute a small part of the overall uncertainty expressed by the 95% confidence intervals in RR from epidemiological, which are of order ±30%.

- Non-linear response of surface PM2.5 levels to the increase in emission fluxes due to chemical nature of aerosol formation processes and circulation patterns over the European continent.

- The most affected countries from the increase in agricultural activities are those downwind of perturbed emission sources and the ones with an intensified pollution /population collocation gradient.

- The health burden of CPP emission related PM2.5 in Europe is estimated to amount to at least 16,200-21,100 excess deaths per year, which equals to 19.8 - 25.8 deaths per TWh of produced electricity annually.

- Due to the non-linearity of the integrated exposure-response functions, especially at relatively low concentrations, these mortality estimates represent lower limits (consider other measures).