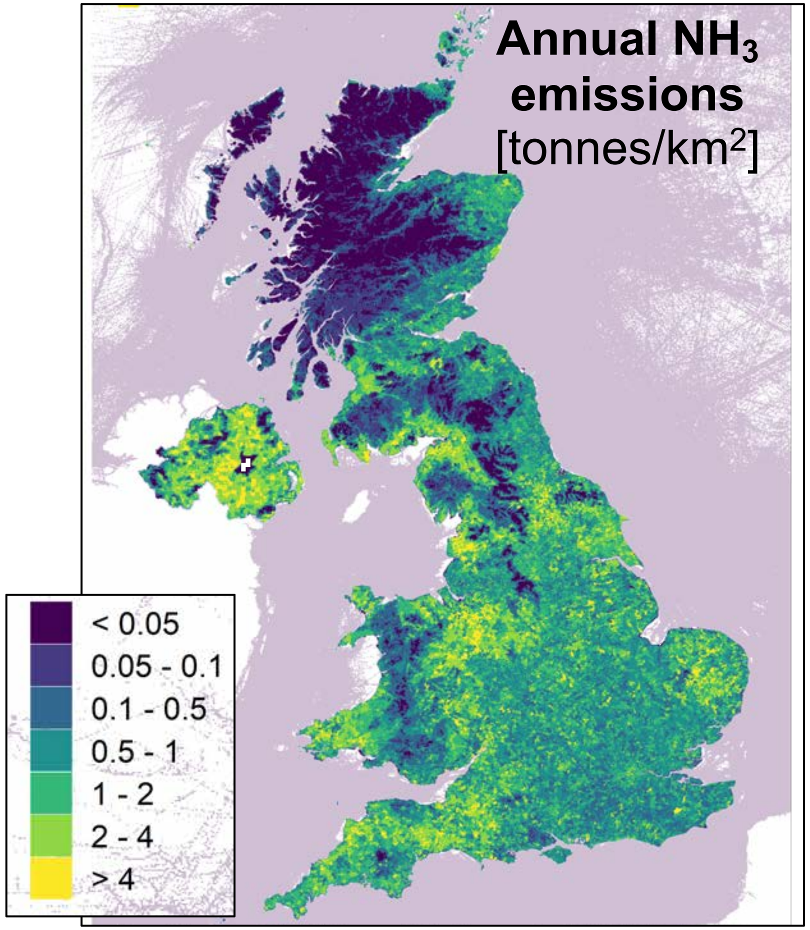
UK public health and ecosystem benefits from adopting technically feasible emissions controls across Europe

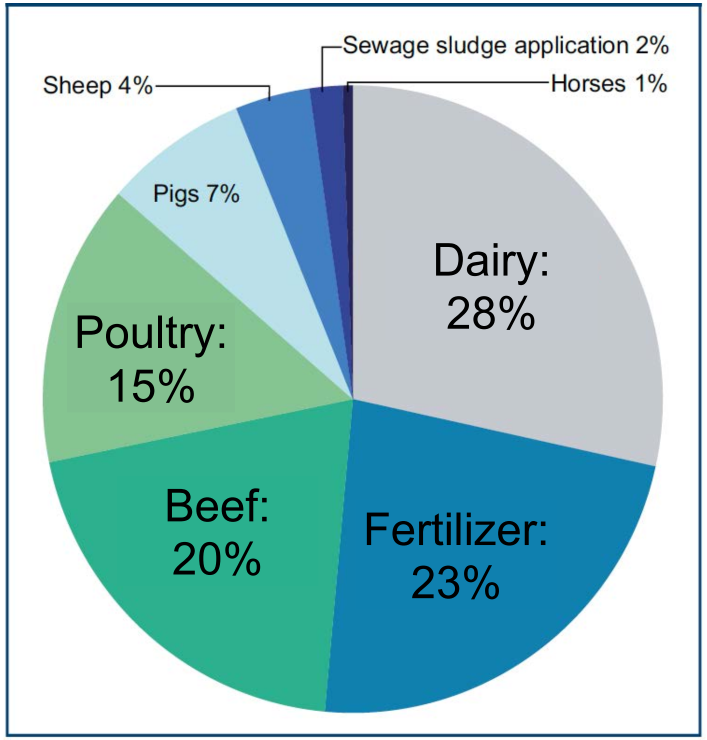
Eloise A. Marais with J. M. Kelly, K. Vohra, Y. Li, G. Lu, N. Hina, E. C. Rowe



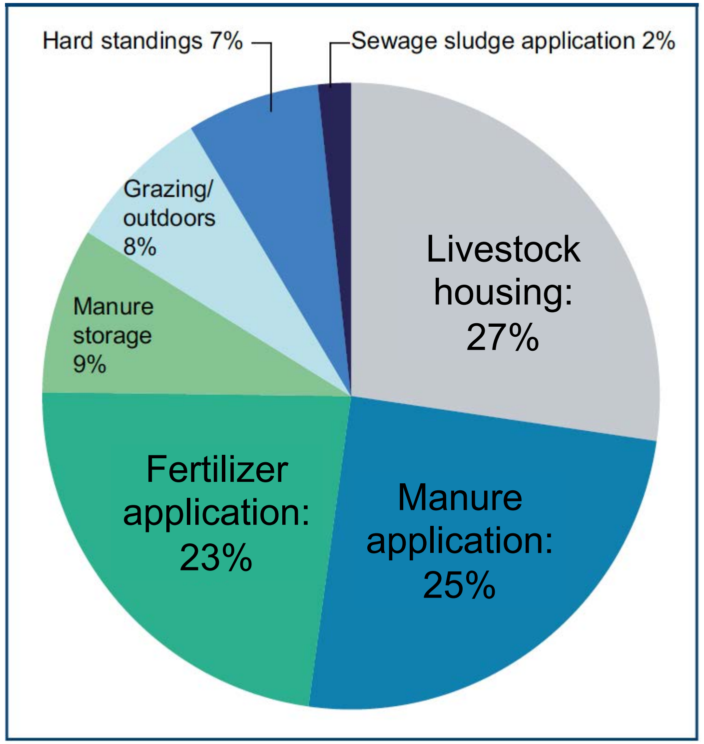
[https://naei.beis.gov.uk/data/map-uk-das?pollutant_id=21]

UK Emissions of Ammonia (NH_3)

by farming activity



by management category



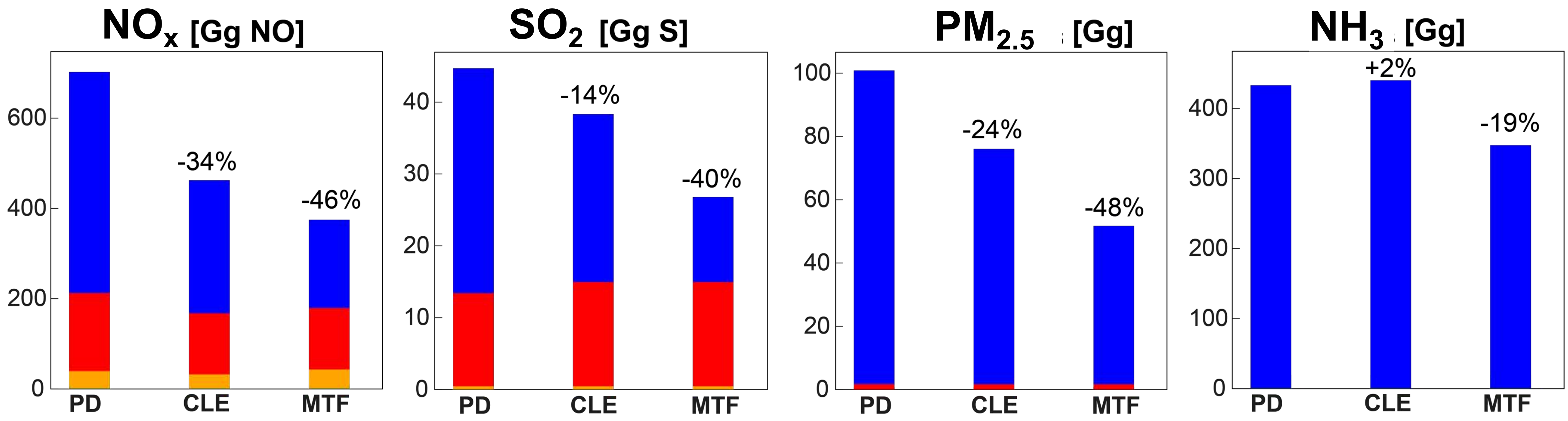
[UK Clean Air Strategy, 2019]

GCE2 **UCL, London** **15 August 2023**

Emission Control Options for the UK (and EU)

Legislated emissions targets or adoption of best readily available technology

Emissions for present-day (**2019**) and future (**2030**) for legislation (**CLE**) vs best-available technology (**MTF**)



Terrestrial Anthropogenic
Shipping
Aviation

Projections from **ECLIPSE v6b** for all but aviation (from **IPCC**)

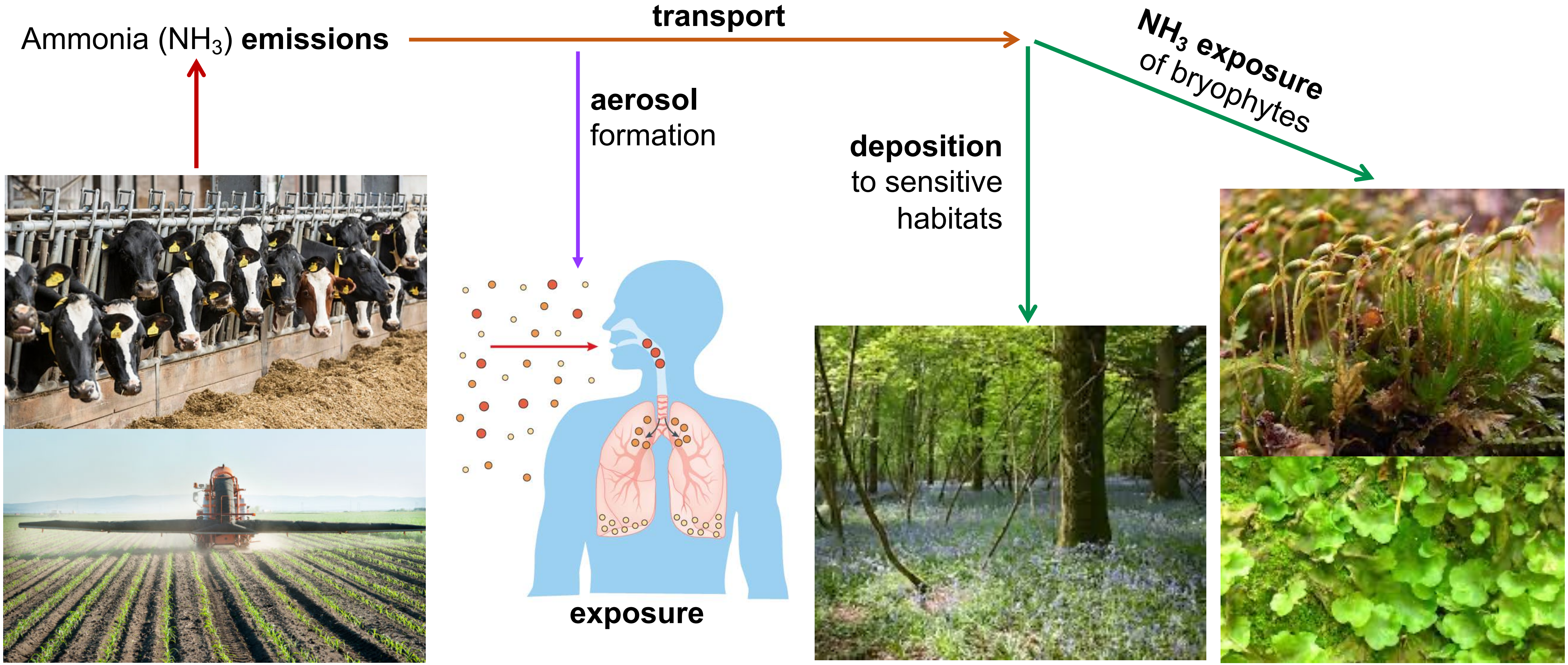
Best technology decreases all precursors except ammonia (NH_3) by 40-48%

NH_3 controls limited to suggested rather than enforced measures

Ammonia (NH_3) from agricultural activity

Impacts health as $PM_{2.5}$ precursor

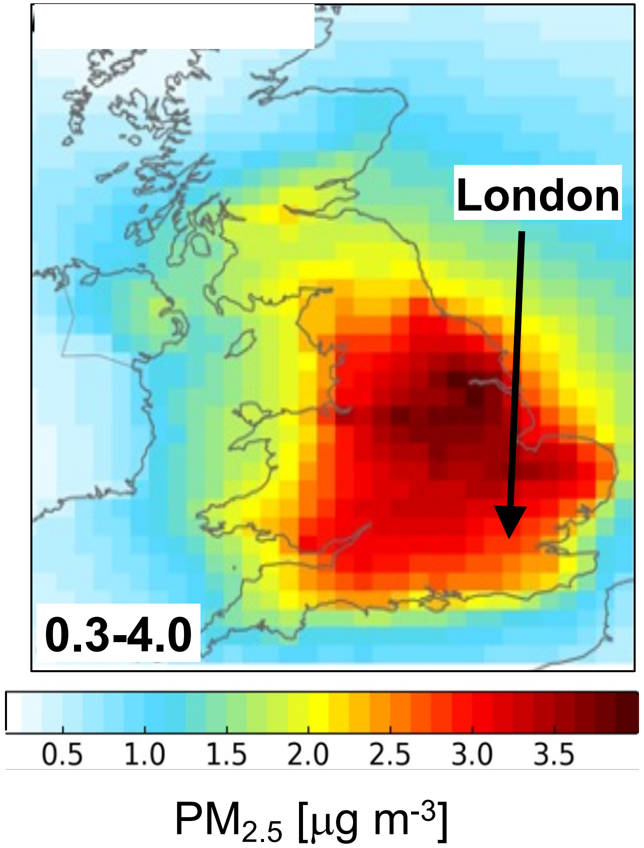
Offsets ecosystem balance via nitrogen deposition and direct exposure



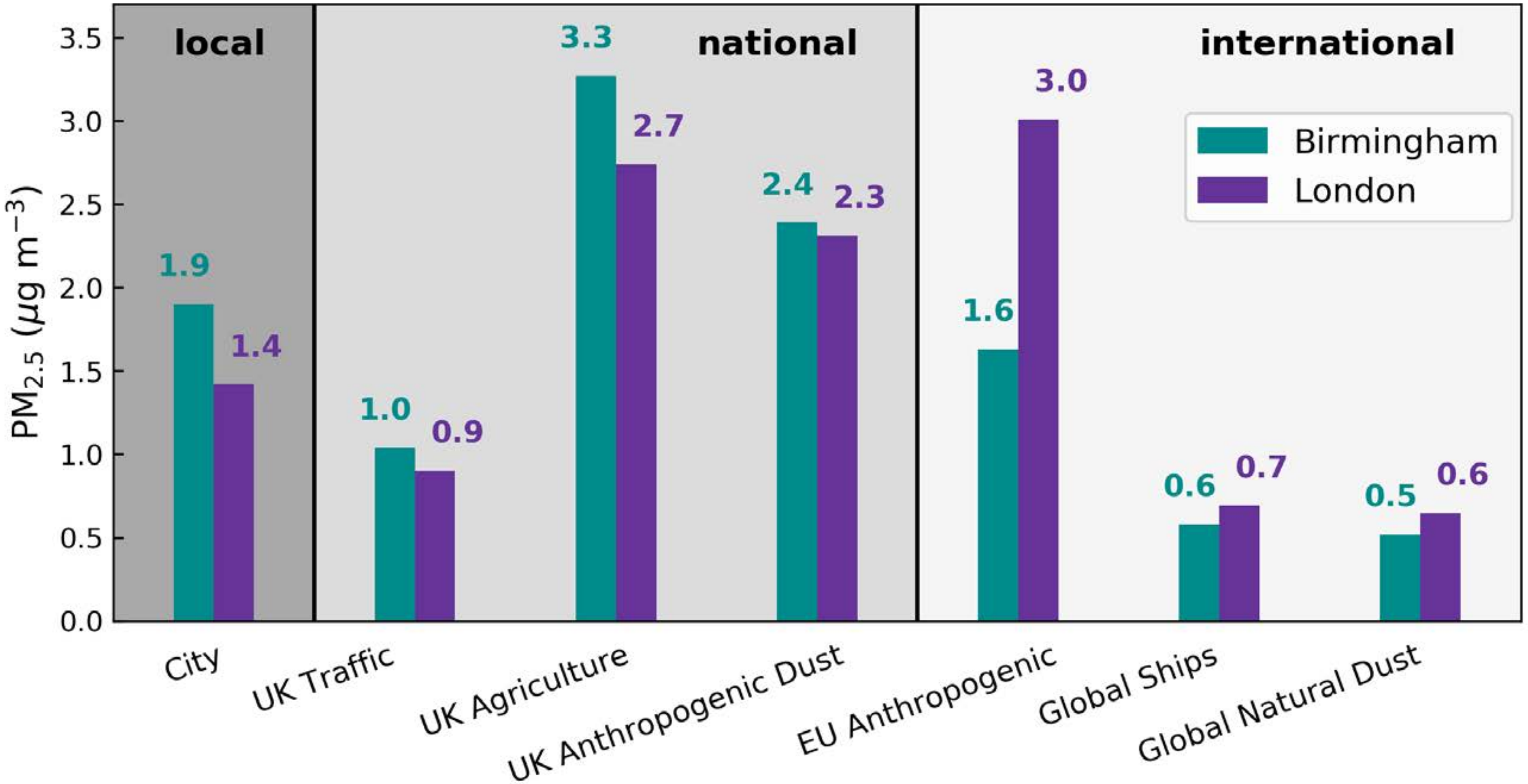
Ammonia (NH_3) influence on urban $PM_{2.5}$

Contribution of agricultural emissions of NH_3 to UK-wide and urban annual mean $PM_{2.5}$

Hotspots coincident with acidic sulfate and nitrate sources



Agricultural NH_3 emissions large and often dominant component of $PM_{2.5}$ in UK urban areas



[Figures from Kelly et al., doi:10.1016/j.cacint.2023.100100, 2023]

Increasingly relevant component of urban $PM_{2.5}$, even in cities as large as London

Influence of emissions controls on $PM_{2.5}$, NH_3, and N deposition

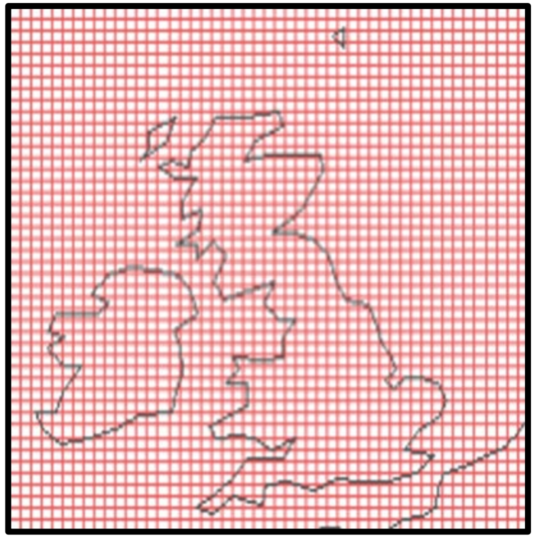
Emissions

Present-day: UK National Atmospheric Emission Inventory (NAEI)

Future: scale NAEI with projections

GEOS-Chem

FlexGrid nested over the UK at 0.25° x 0.3125°



Gas- and aerosol-phase chemistry, transport, wet+dry deposition

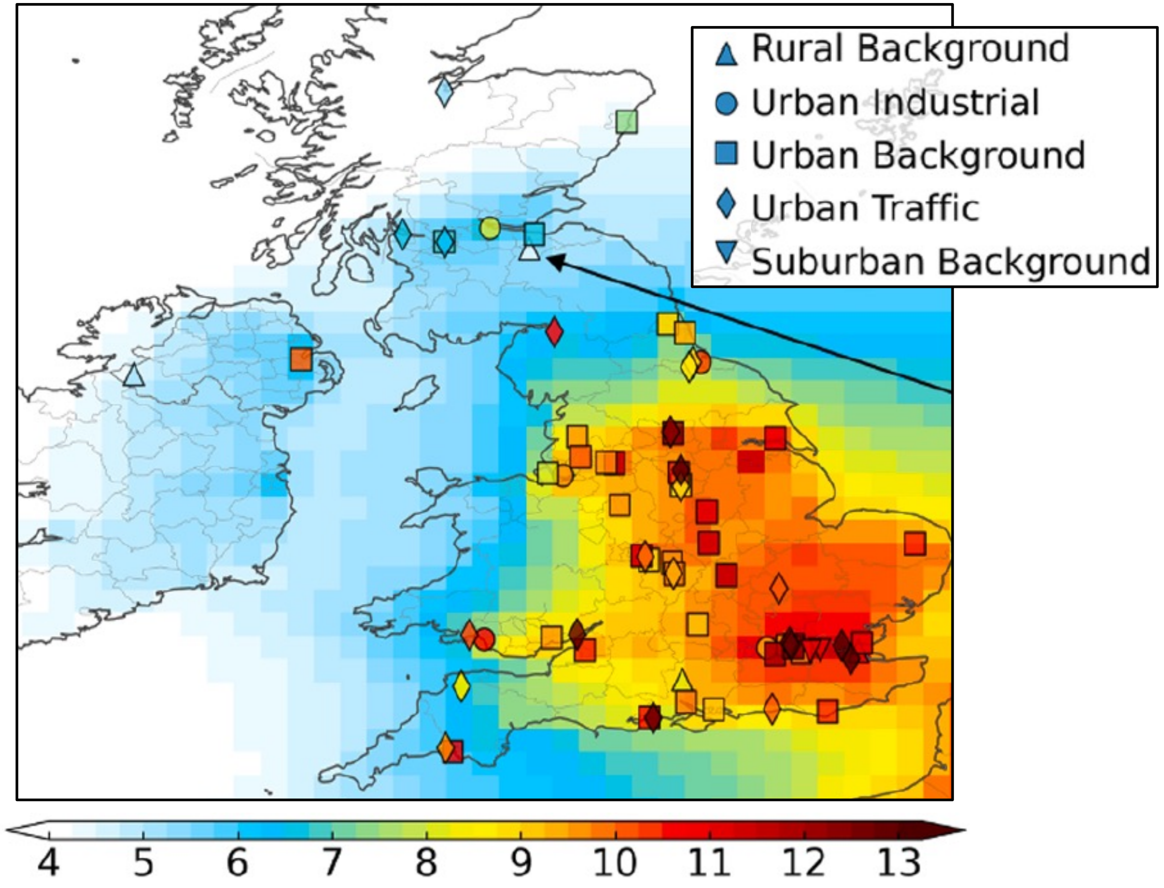
Surface NH_3 and $PM_{2.5}$ components
Nitrogen wet and dry deposition

NASA GEOS-FP Meteorology

2019 throughout

Evaluation of GEOS-Chem $PM_{2.5}$

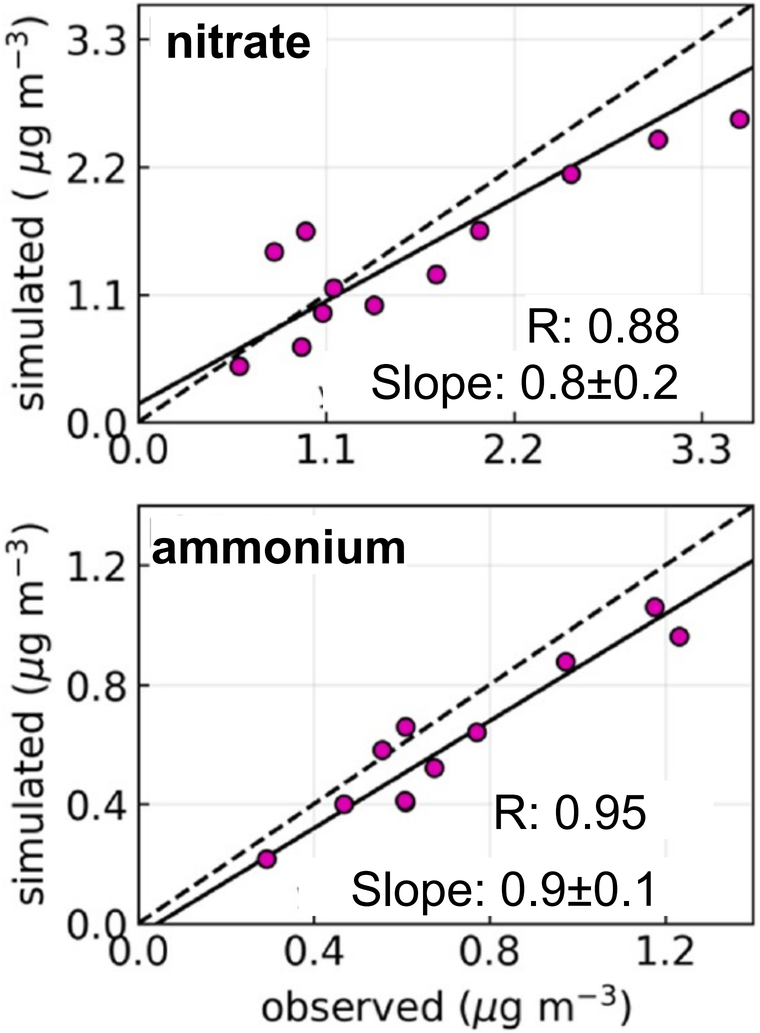
GEOS-Chem versus regulatory network annual (2019) mean $PM_{2.5}$



Spatial Correlation: 0.66

Model Bias: -11% (network mostly in cities)

GEOS-Chem versus rural network annual (2019) mean aerosol nitrate and ammonium

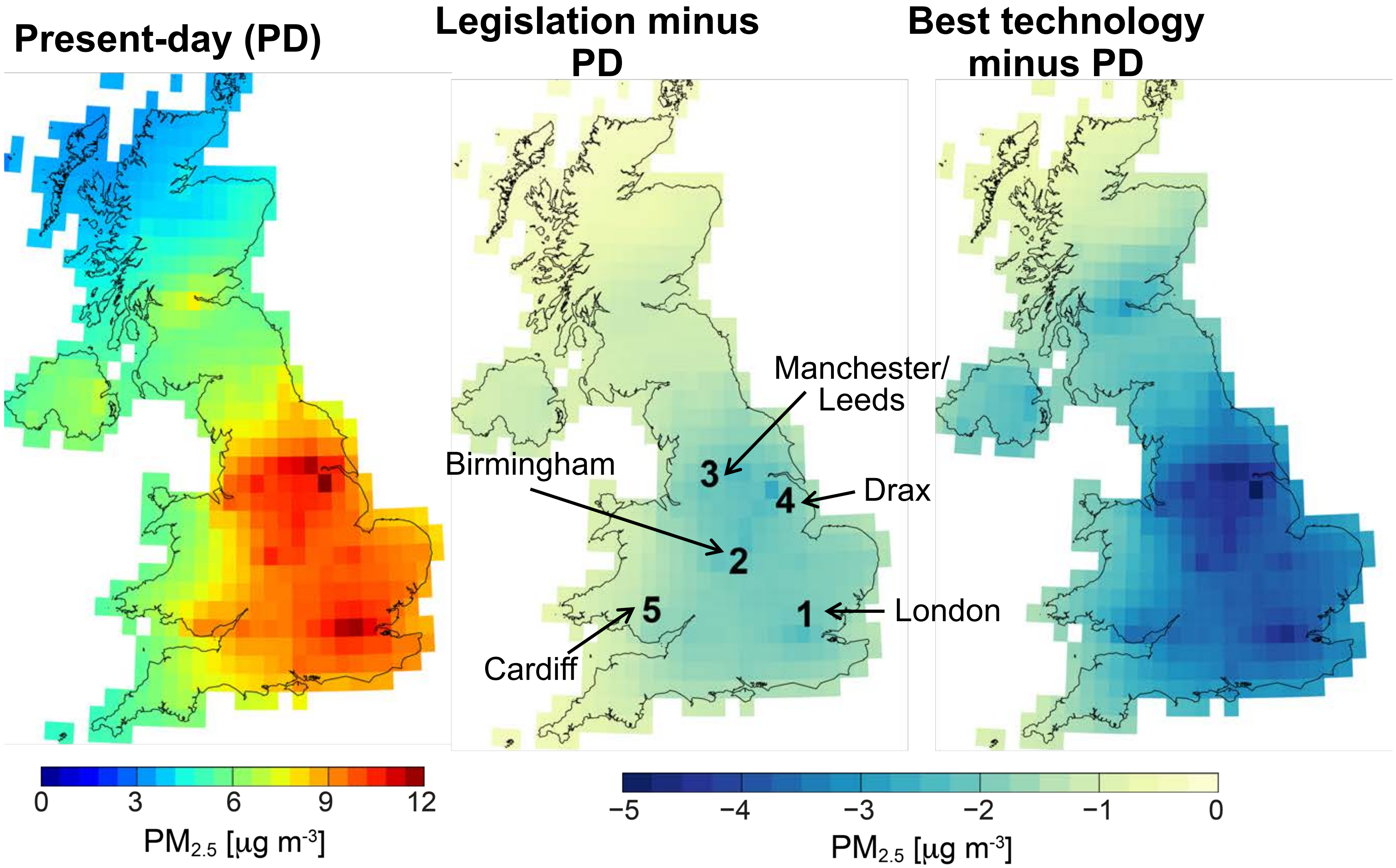


~40% of $PM_{2.5}$

~15% of $PM_{2.5}$

[Figures from Kelly et al., 2023]

Influence of emission controls on $PM_{2.5}$



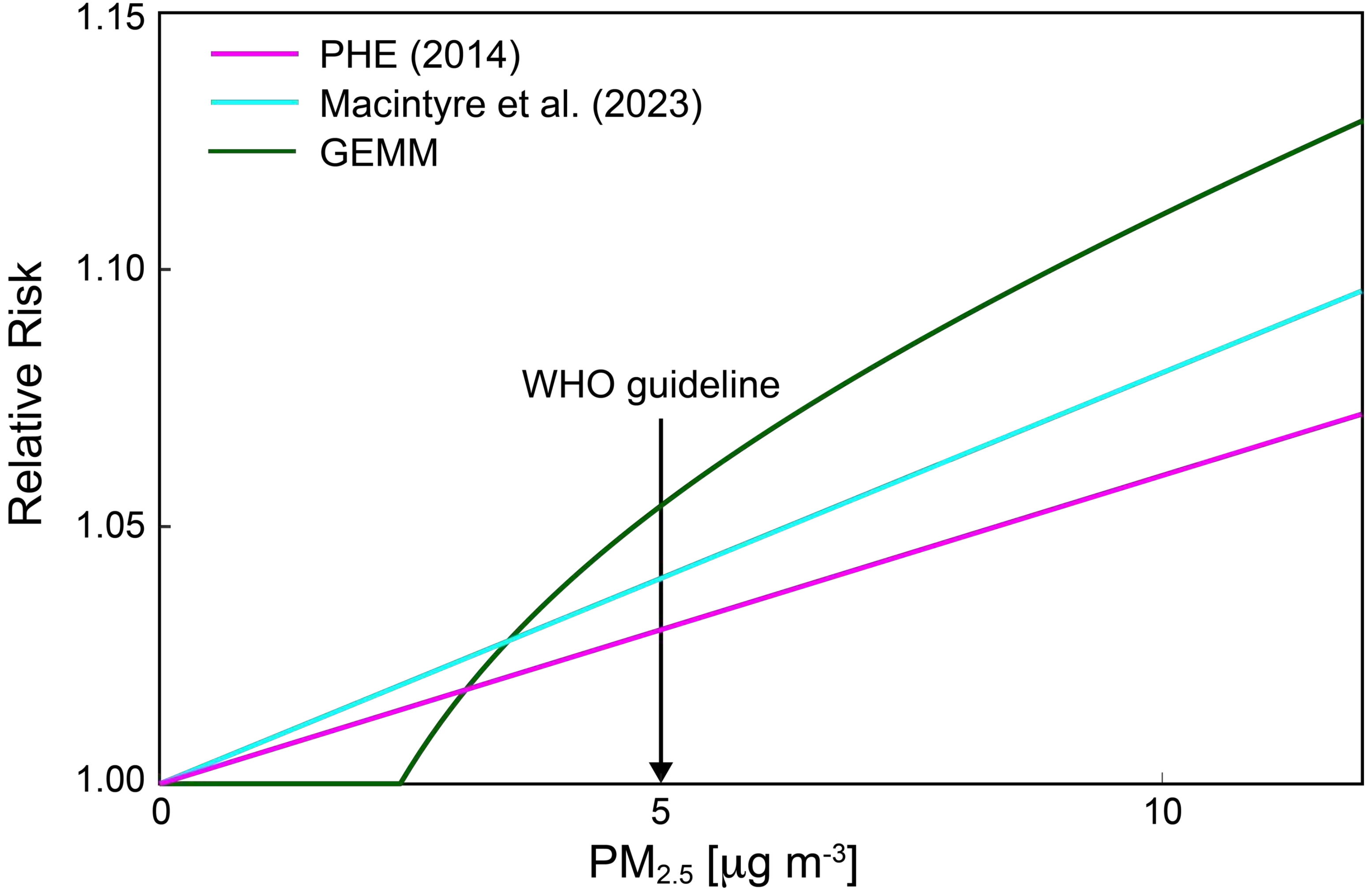
Current legislation controls cause $PM_{2.5}$ decline of at most **2 μg m^{-3}** compared to **5 μg m^{-3}** for best technology

UK grids > **5 μg m^{-3}**: 79% in the PD, 58% with legislated controls, and 36% with best technology

Relating long-term exposure to $PM_{2.5}$ to adverse health outcomes

Available curves relating $PM_{2.5}$ to premature mortality unconstrained at $PM_{2.5}$ < 5 μg m^{-3}

UK $PM_{2.5}$ range is 2.5-12 μg m^{-3}



PHE (2014):
Public Health England report

MacIntyre et al. (2023):
doi:10.1016/j.envint.2023.107862

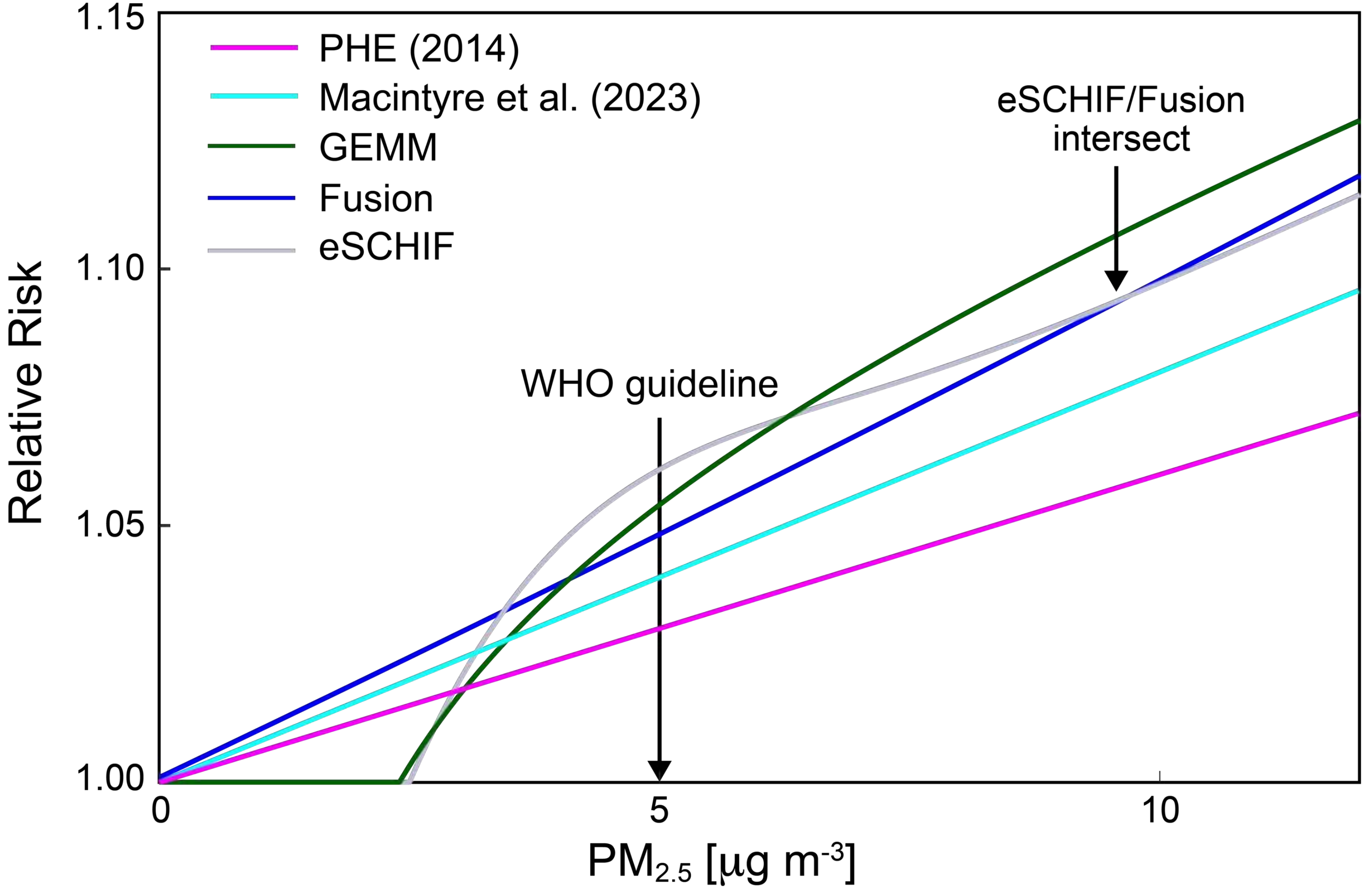
GEMM:
Global Exposure Mortality Model

All curves relate adult (mostly 25+ years old) premature mortality and annual mean $PM_{2.5}$

Relating long-term exposure to $PM_{2.5}$ to adverse health outcomes

Recent curves combine best of 3 well-established curves (Fusion)

Recent epidemiological study in Canada (CanCHEC) provides low-concentration constraints (eSCHIF curve)



Fusion:
Burnett et al. (2022), doi: 10.1016/j.envres.2021.112245

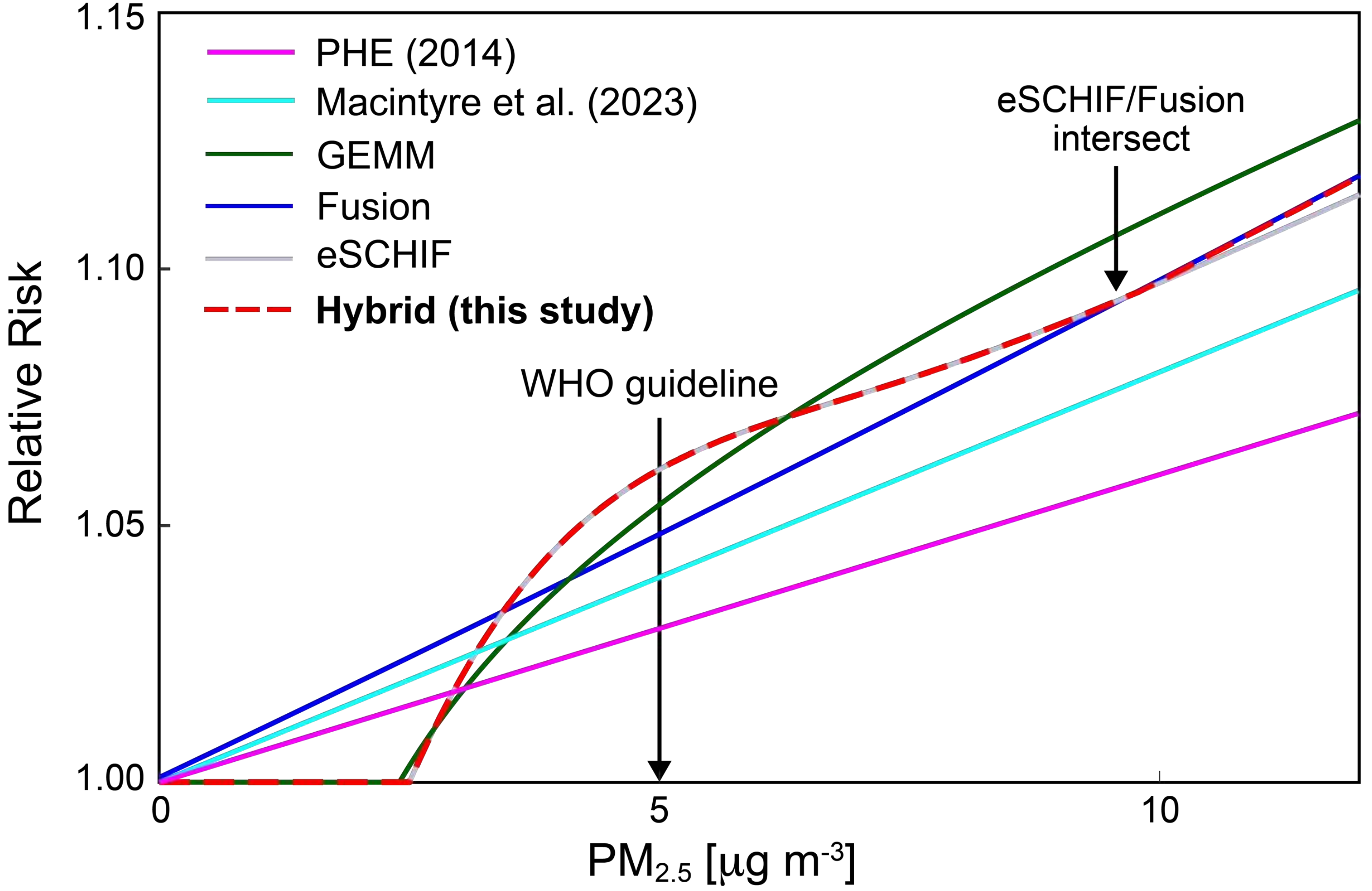
eSCHIF:
extended Shape Constrained Health Impact Function (Brauer et al., 2022 US HEI report)

Fusion addresses deficiencies in individual curves

Relating long-term exposure to $PM_{2.5}$ to adverse health outcomes

Hybrid curve combines Fusion and CanCHEC

Approach motivated by Weichenthal et al. (2022)



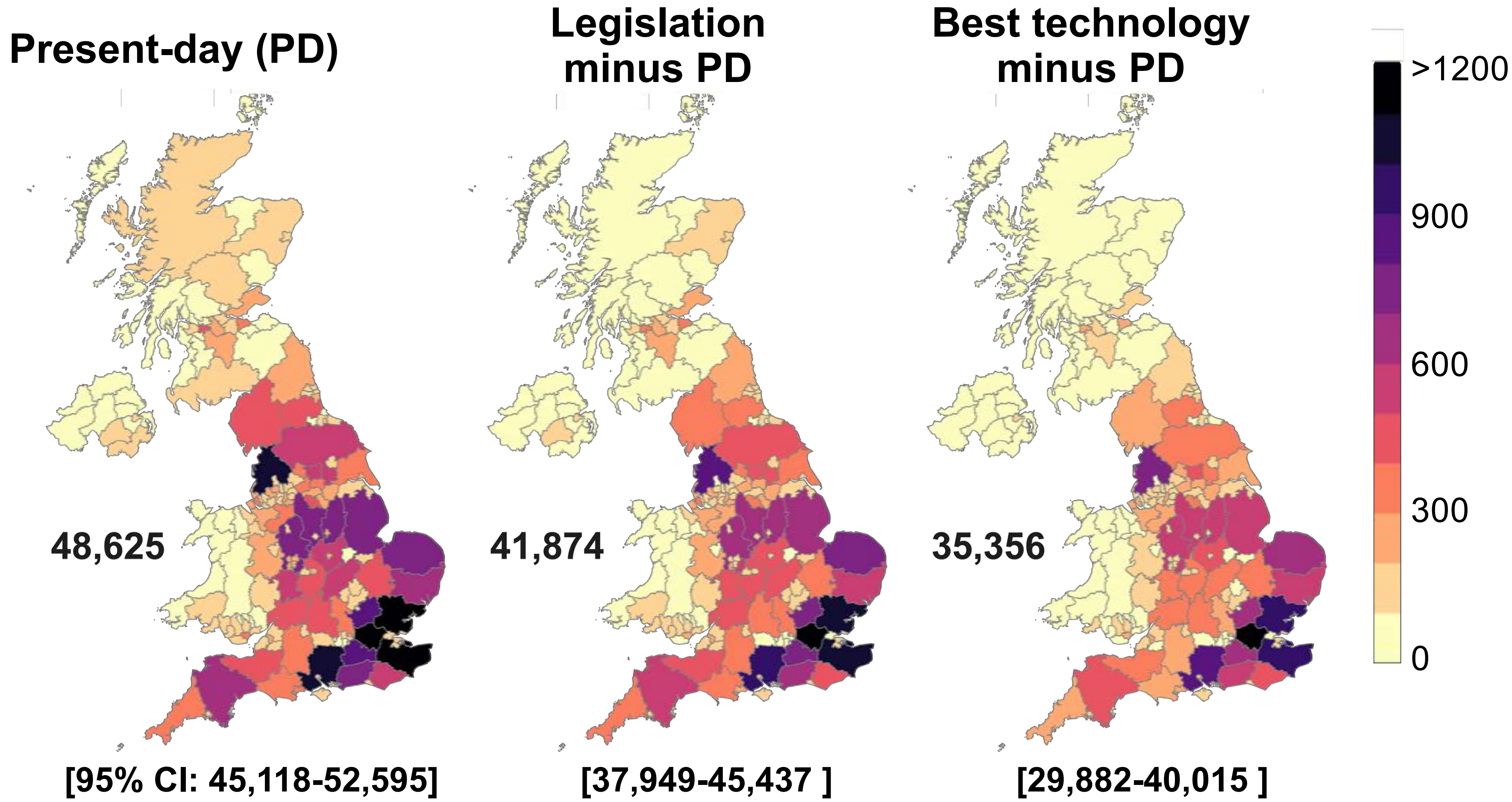
Hybrid:
eSCHIF at 2.5-9.8 μg m^{-3} and Fusion beyond 9.8 μg m^{-3}

Weichenthal et al. (2022) transition between curves at 5 μg m^{-3} requiring an artificial increase in Fusion Relative Risks

85% of UK grids use eSCHIF in the present day; 100% in future for both scenarios. None are < 2.5 μg m^{-3}

Adult premature mortality from long-term exposure to $PM_{2.5}$

Values for all 184 administrative areas in the UK (115 in England, 32 in Scotland, 22 in Wales, 11 in N. Ireland)

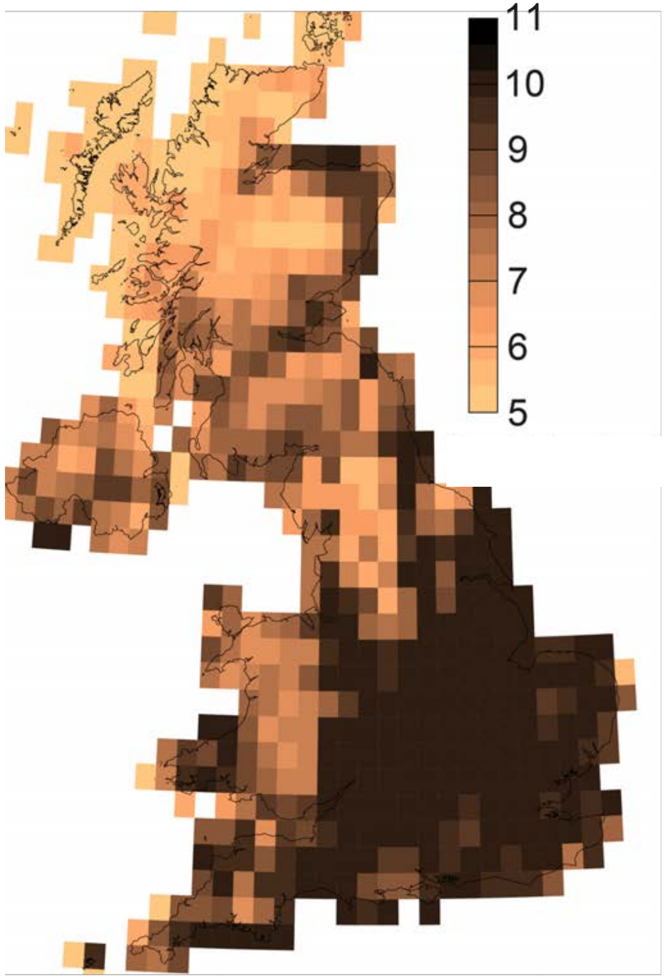


6,751 avoided early deaths with legislated controls, double that (13,269) with best available technology

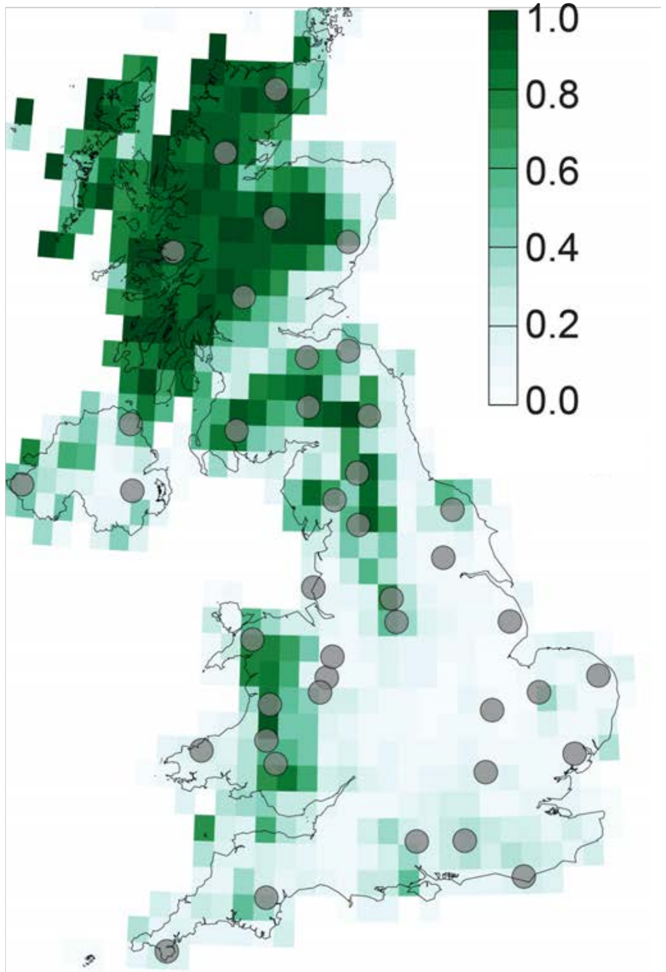
Burden of disease estimates greater than past UK-focused studies and similar to those obtained with GEMM curve

Assessing Adverse Effects on Ecosystem Health

Nitrogen critical loads
[kg N (ha sensitive habitat)$^{-1}$ a^{-1}]



Sensitive habitat cover
[fraction]



- 13 sensitive habitats cover 38% of UK. ~60% in Scotland.
- Use very recently revised critical loads

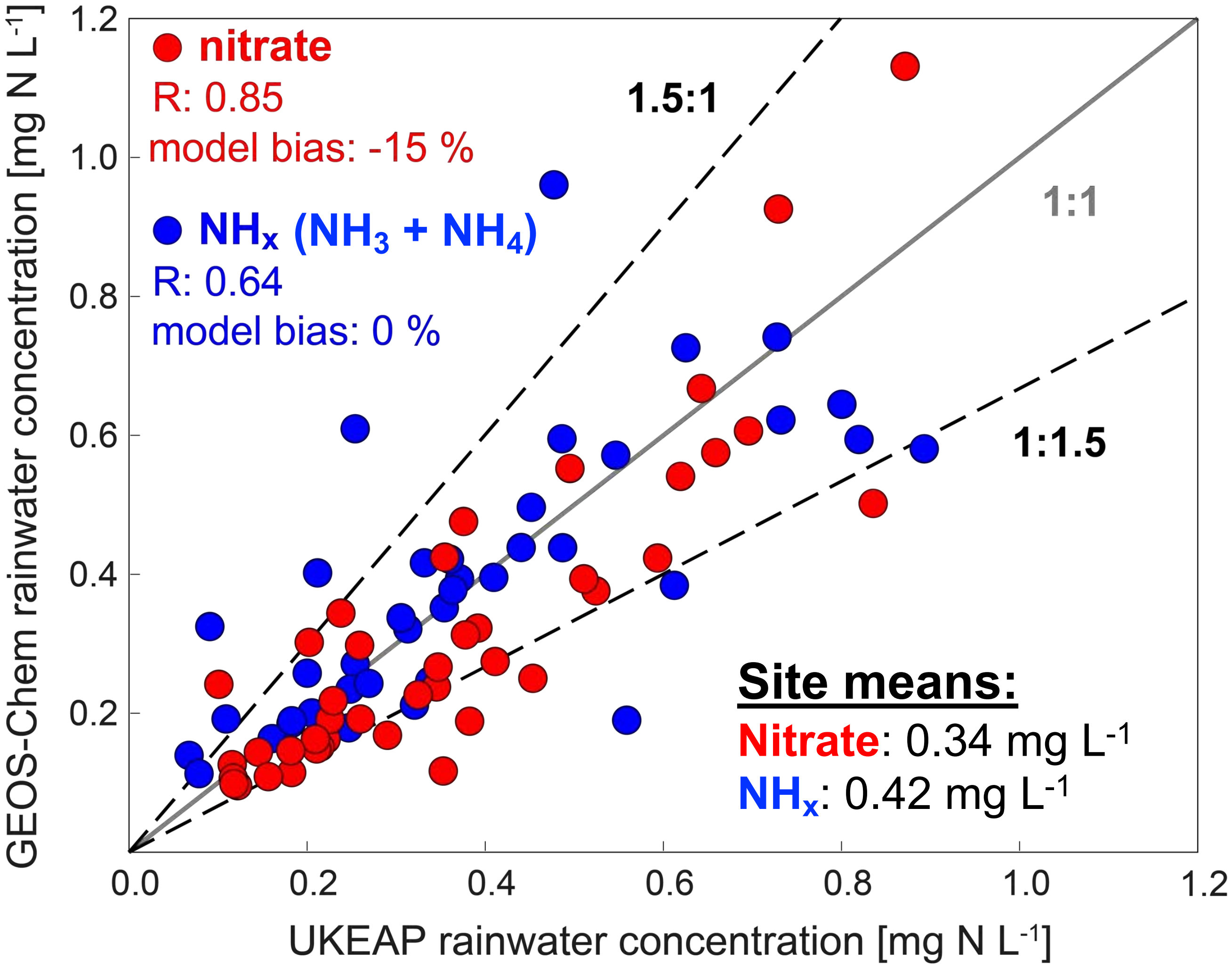
Critical load and sensitive habitat maps from Ed C. Rowe & N. Hina at the UK Centre for Ecology & Hydrology (**UKCEH**)

Quantify annual total nitrogen wet and dry deposition in excess of critical loads

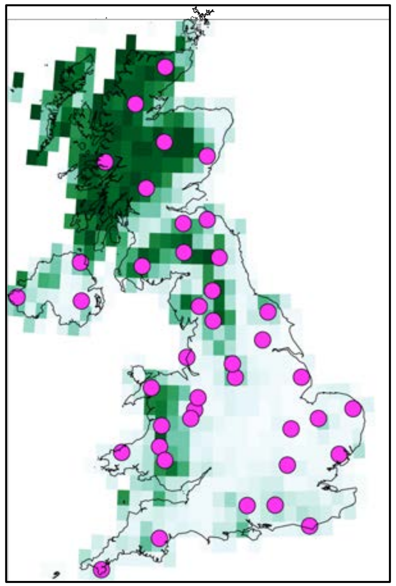
Also assess impact of ambient NH_3 on bryophytes (NH_3 > 1 μg m^{-3})

Evaluate GEOS-Chem nitrogen wet deposition

Modelled vs observed rainwater concentrations of oxidized and reduced nitrogen



Precip-Net sites



Dashed lines bound 50% difference

Requires correction to monthly total GEOS-FP precipitation

Ranges from 40-50% increase to 23-26% decrease.

GEOS-FP annual total increases by 4%

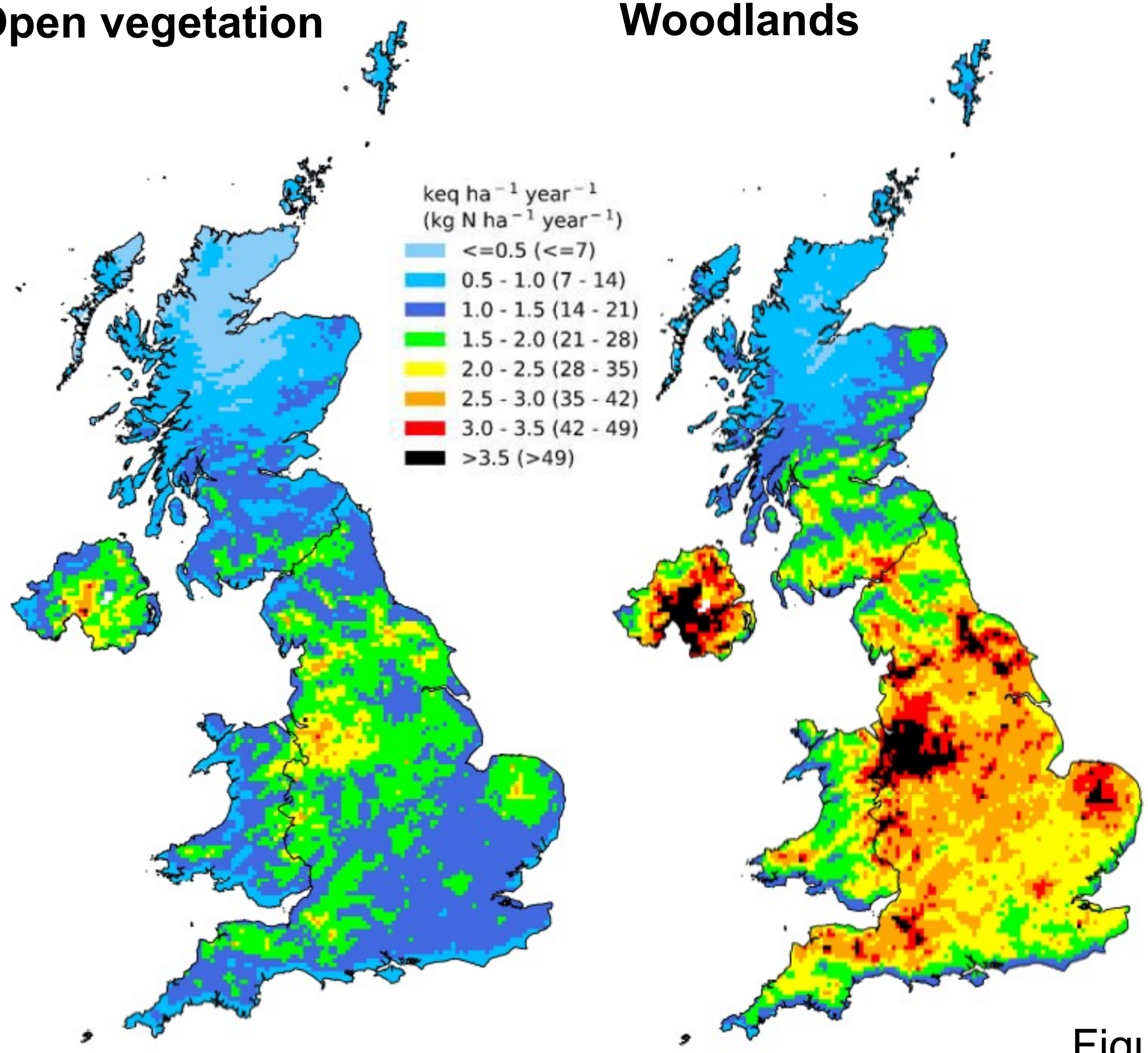
Model 15% underestimate in nitrate may be due to low bias in NO_x emissions

Wet deposition ~60% of total deposition. Unvalidated ~40% dry deposition mostly (64%) NH_3.

High Resolution Total Nitrogen Wet + Dry Deposition

UKCEH Concentration Based Estimated Deposition at high (5 km) spatial resolution

Open vegetation **Woodlands**



GEOS-Chem too coarse to resolve deposition over sensitive habitats

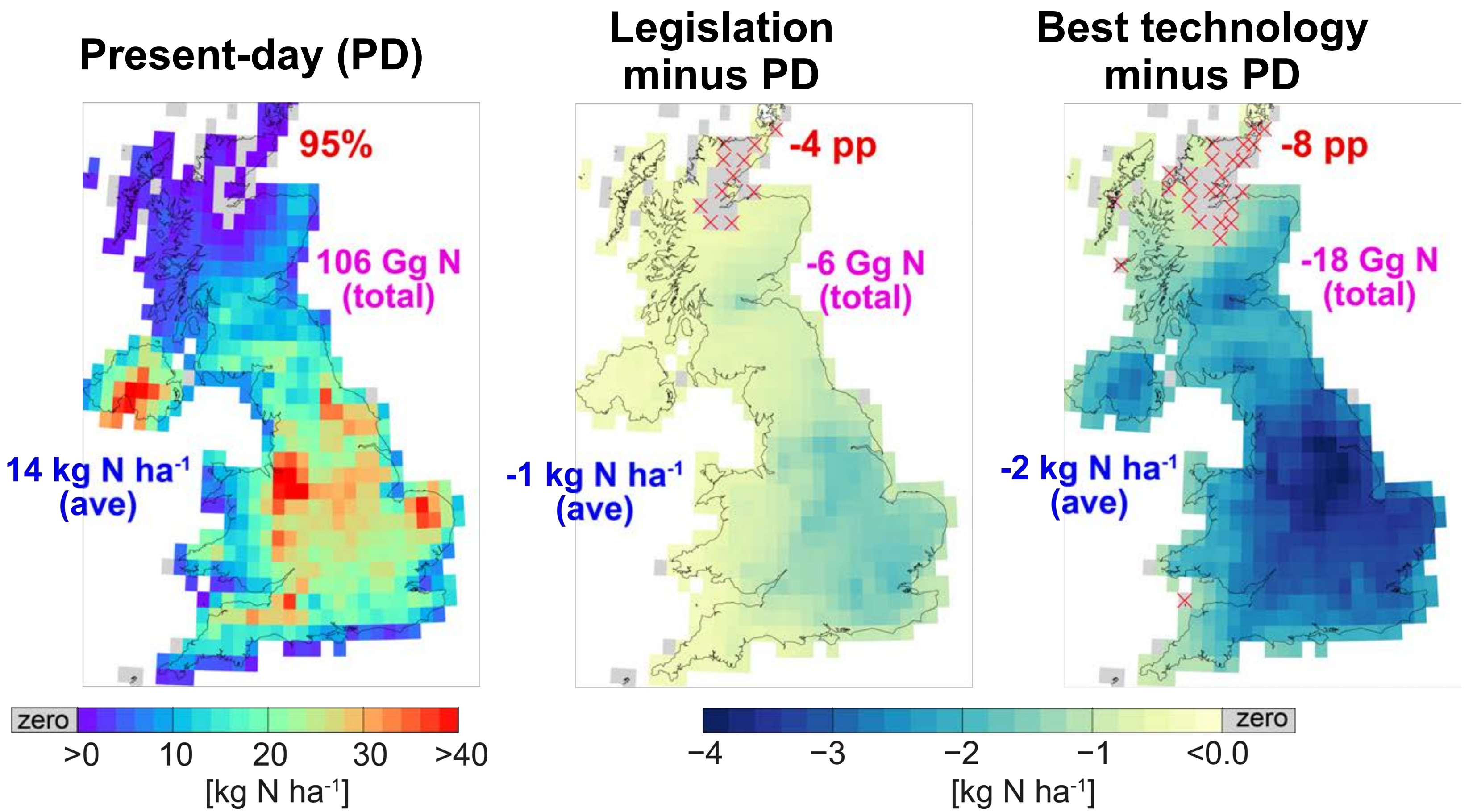
GEOS-Chem also doesn't account for enhanced washout over upland areas or deposition of cloud droplets to vegetation.

GEOS-Chem total N deposition 57 Gg N less than CBED

Use CBED for present day and GEOS-Chem for response to emissions controls

Figures from Rowe et al. (2022) annual UKCEH report

Ecosystem health benefits of emission controls



Values are total, mean, and coverage of exceedances

Crosses show grids that fall below critical loads relative to present day

According to GEOS-Chem, more than half (60%) emitted nitrogen transported offshore

Decline in N deposition with emission controls only one-third of emissions reductions

Decline below critical loads modest. Similarly modest decrease due to past controls (2010-2019)

Exposure to harmful levels of NH_3: 73% today, 75% with legislated controls, 69% with best technology

Concluding Remarks and Recommendations

Substantial improvements to health with emission controls. X avoided deaths with currently legislated controls. Double with best available technology

Majority of early deaths (x%) amongst elderly (aging population, risks of harm may be greater than curves we use)

Decline in harm to sensitive habitats modest

Reducing harm to sensitive habitats requires far more ambitious controls than can be achieved with legislated measured or best-available technology. ~500 Gg N or twice that achieved with best available technology

Work in review in GeoHealth. Available on the ESSO Archive: https://essopenarchive.org/doi/full/10.22541/essoar.168987138.82216108/v1

Data generated as part of study on the UCL Data Repo: https://doi.org/10.5522/04/23540079