Impact of UK farming on air quality, health and habitats

UCL PG Seminar **Eloise A Marais** **6 December 2023**

With ... Karn Vohra, Gongda Lu, Jamie Kelly (current/former group members)
And ... collaborators at CEH, ULB, AER, Environ. Canada, SUNY Albany, Rothamsted, LCC

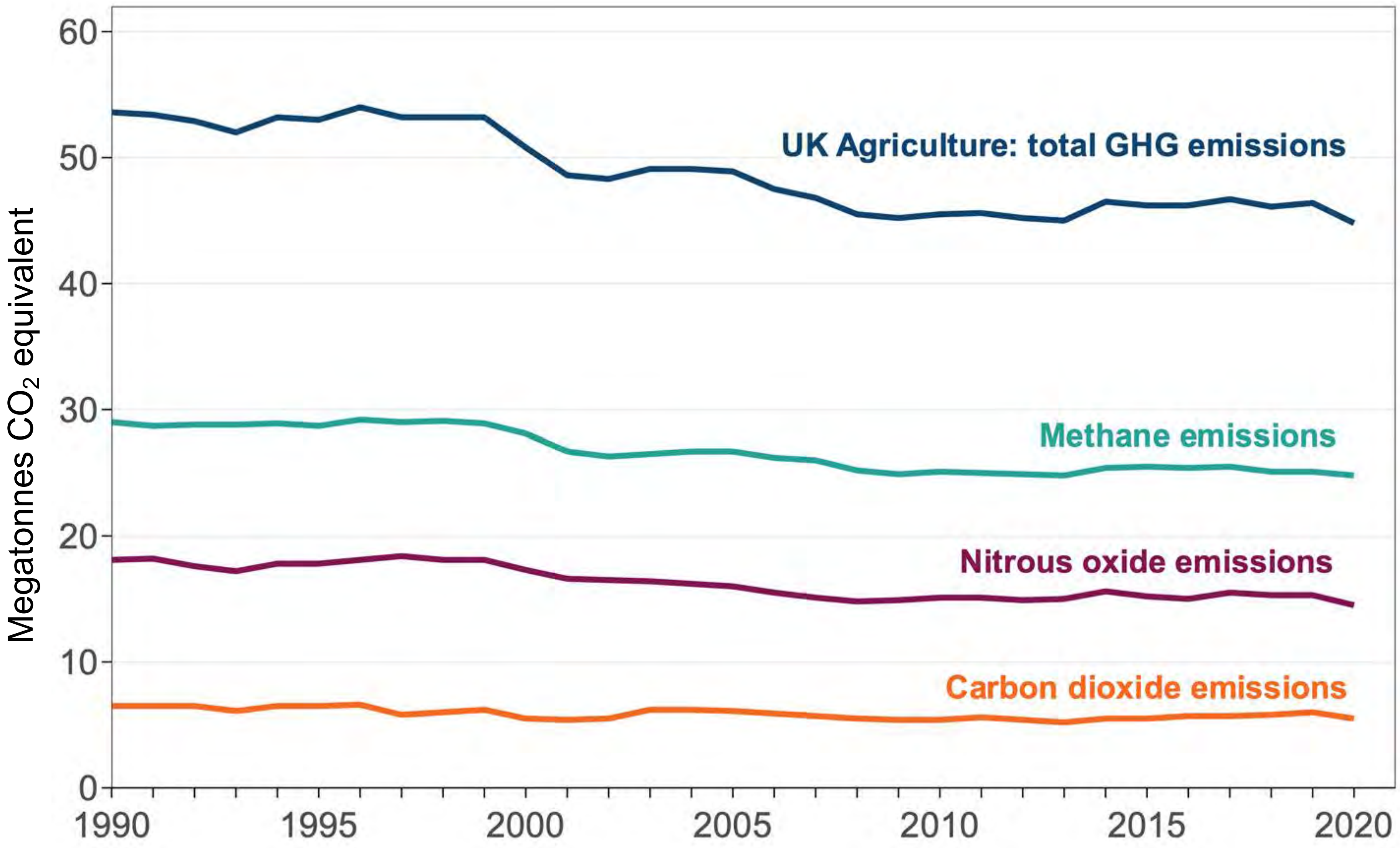
UCL Atmospheric Chemistry and Air Quality Group

https://maraisresearchgroup.co.uk/

NWW
106

Karn, Gongda, Connor, Bex, Eleanor, Nana

UK Agriculture a Large Source of Greenhouse Gases



11% of total

48% of methane

69% of nitrous oxide

[Image source: https://www.gov.uk/government/statistics/agri-climate-report-2022/agri-climate-report-2022]

Agriculture a Large Source of Ammonia (NH_3)

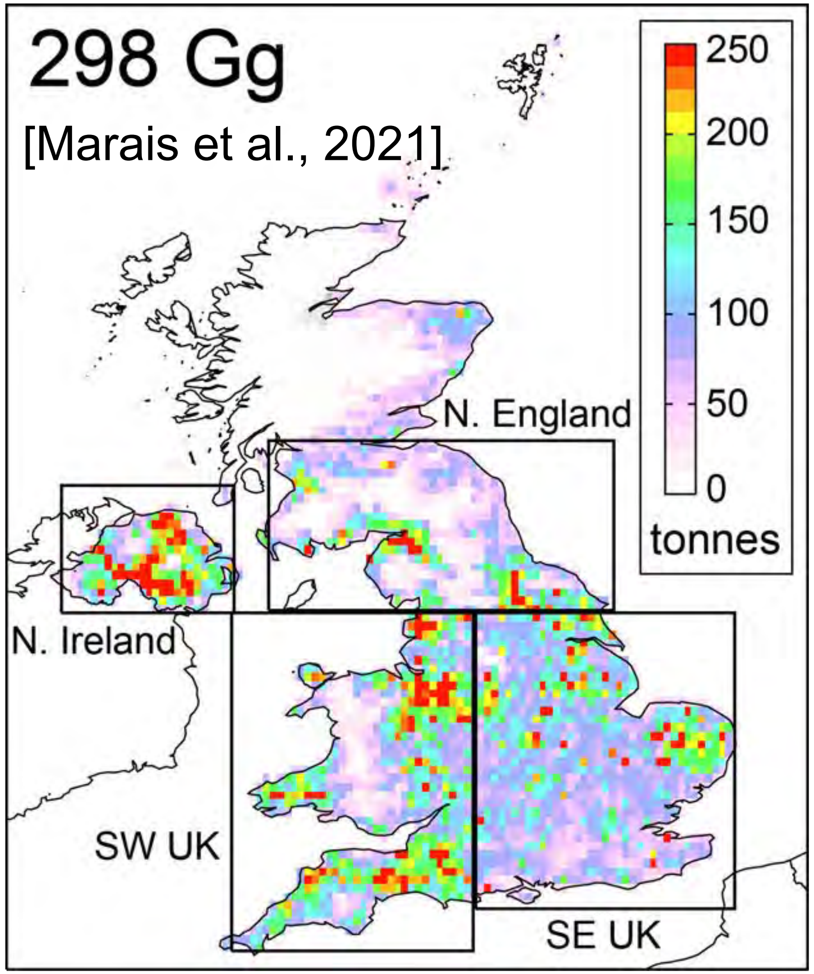
~80% nitrogen (N) wasted due to inefficient use

200 million tonnes costing USD 200 billion

(https://www.ceh.ac.uk/reducing-ammonia-emissions-improve-air-quality-would-be-cost-effective)

UK Agriculture a Large Source of Ammonia (NH_3)

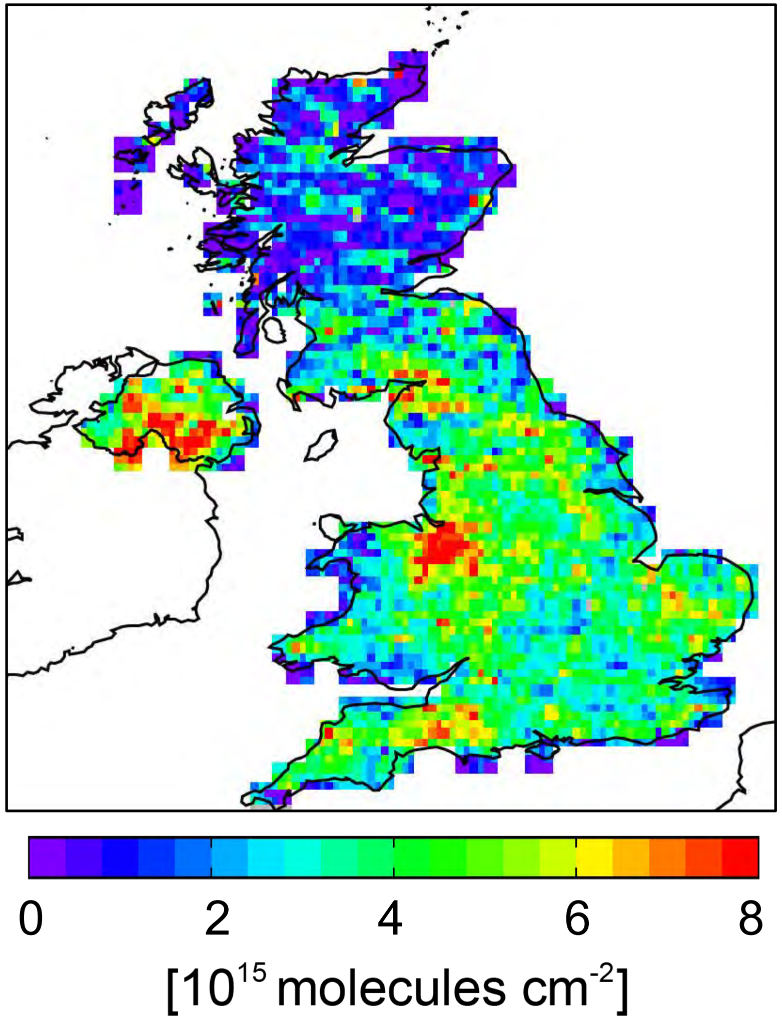
Spatial distribution of NH_3 emissions



84% of all NH_3

90% anthropogenic NH_3

Spatial distribution of NH_3 abundances as seen from space



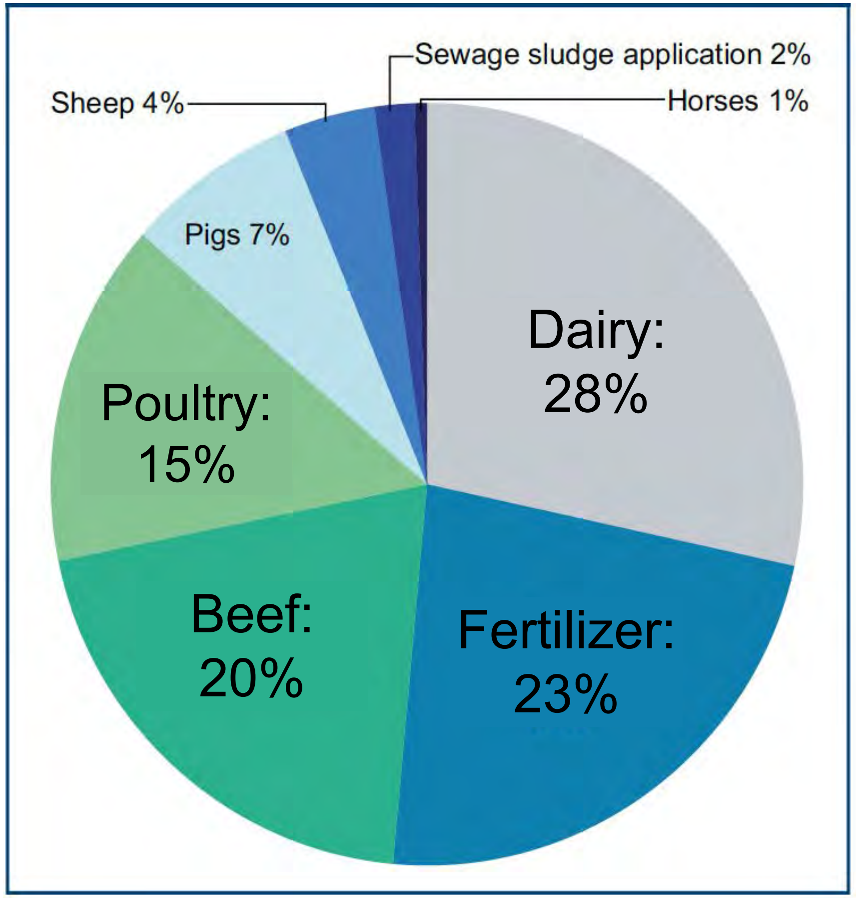
IASI

IR Interferometer

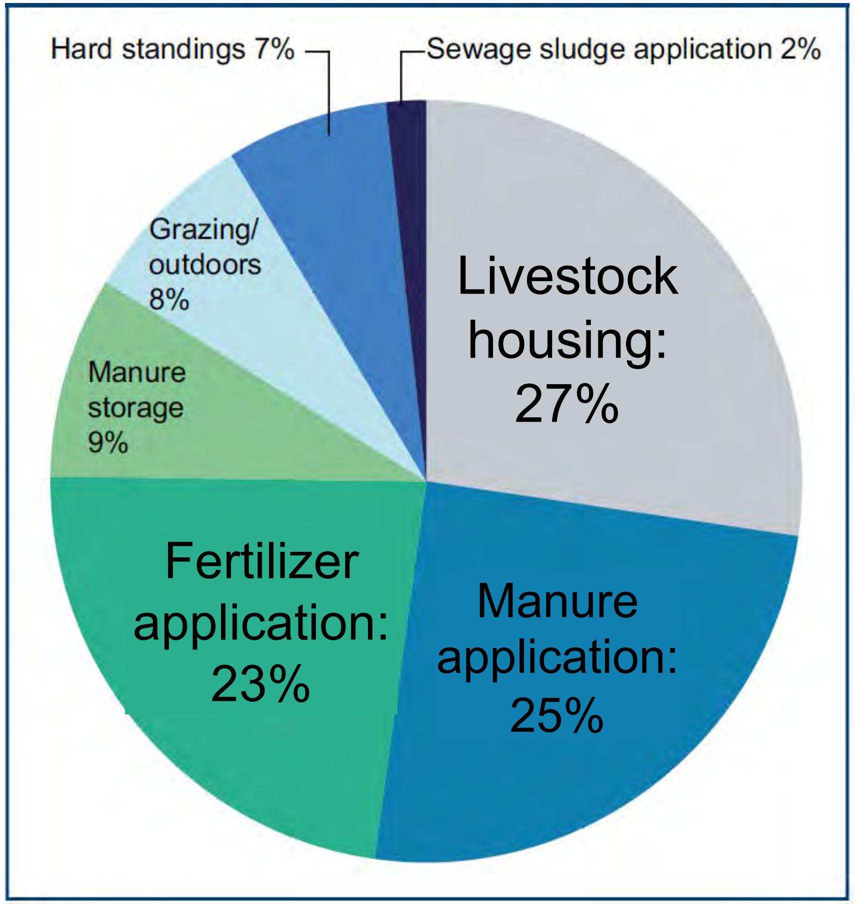
Farming Practices that Releasing NH_3

UK NH_3 Emissions by activity and category

by farming activity



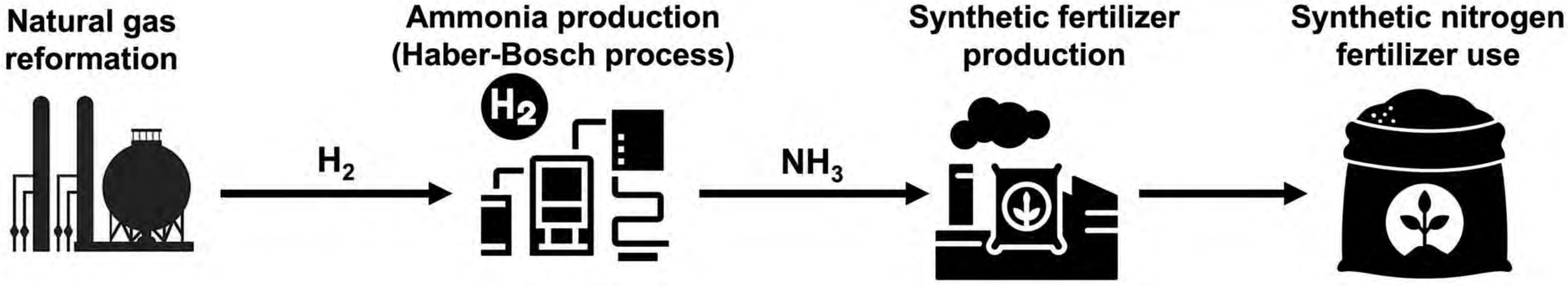
by management category



[UK Clean Air Strategy, 2019]

Fertilizer is Fossil-Fuel Derived

23% of UK NH_3 emissions from fertilizer and 100% UK NH_3 produced with natural gas



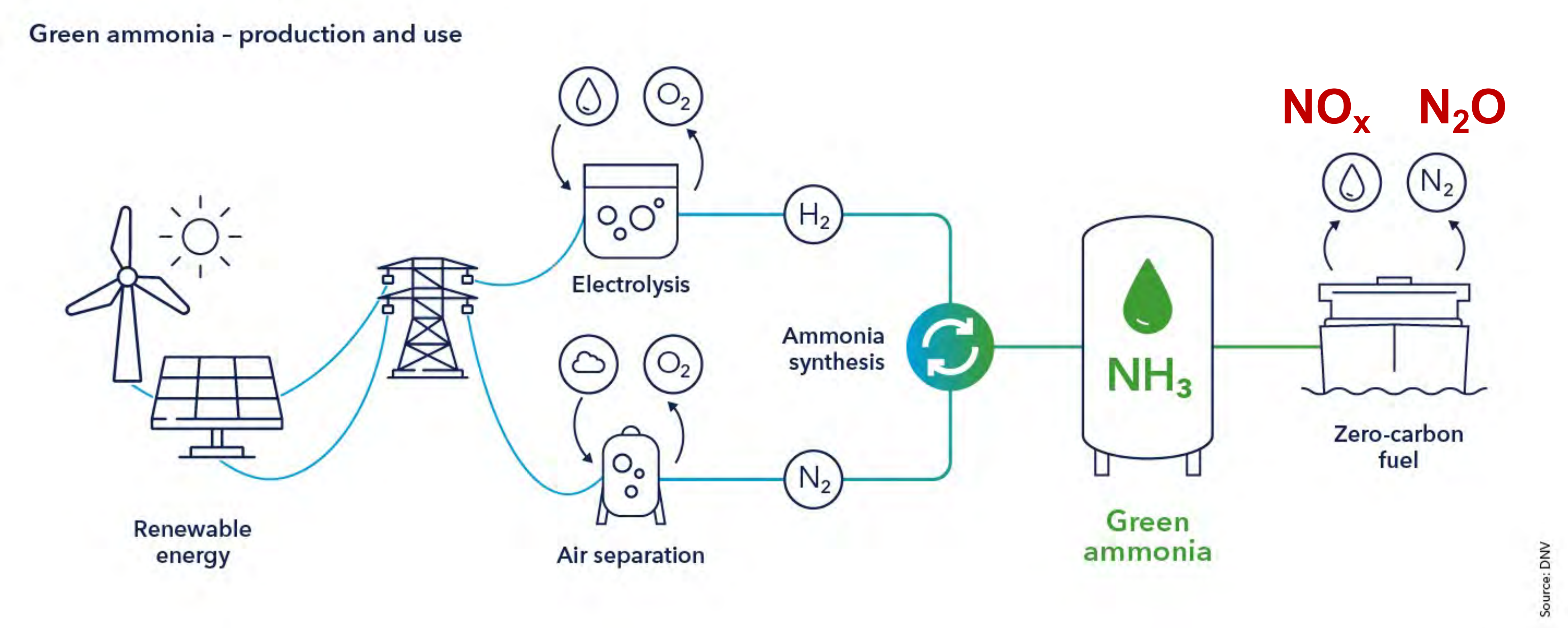
Overwhelming majority of synthetic nitrogen fertilizer from natural gas

Globally, 20% of industrial natural gas used to make NH_3

[*Vohra et al., in progress*]

Ammonia as a Zero-Carbon Fuel of the Future

Additional incentive to study the environmental effects of NH_3



UK NH_3 Emission Trends Compared to Emissions

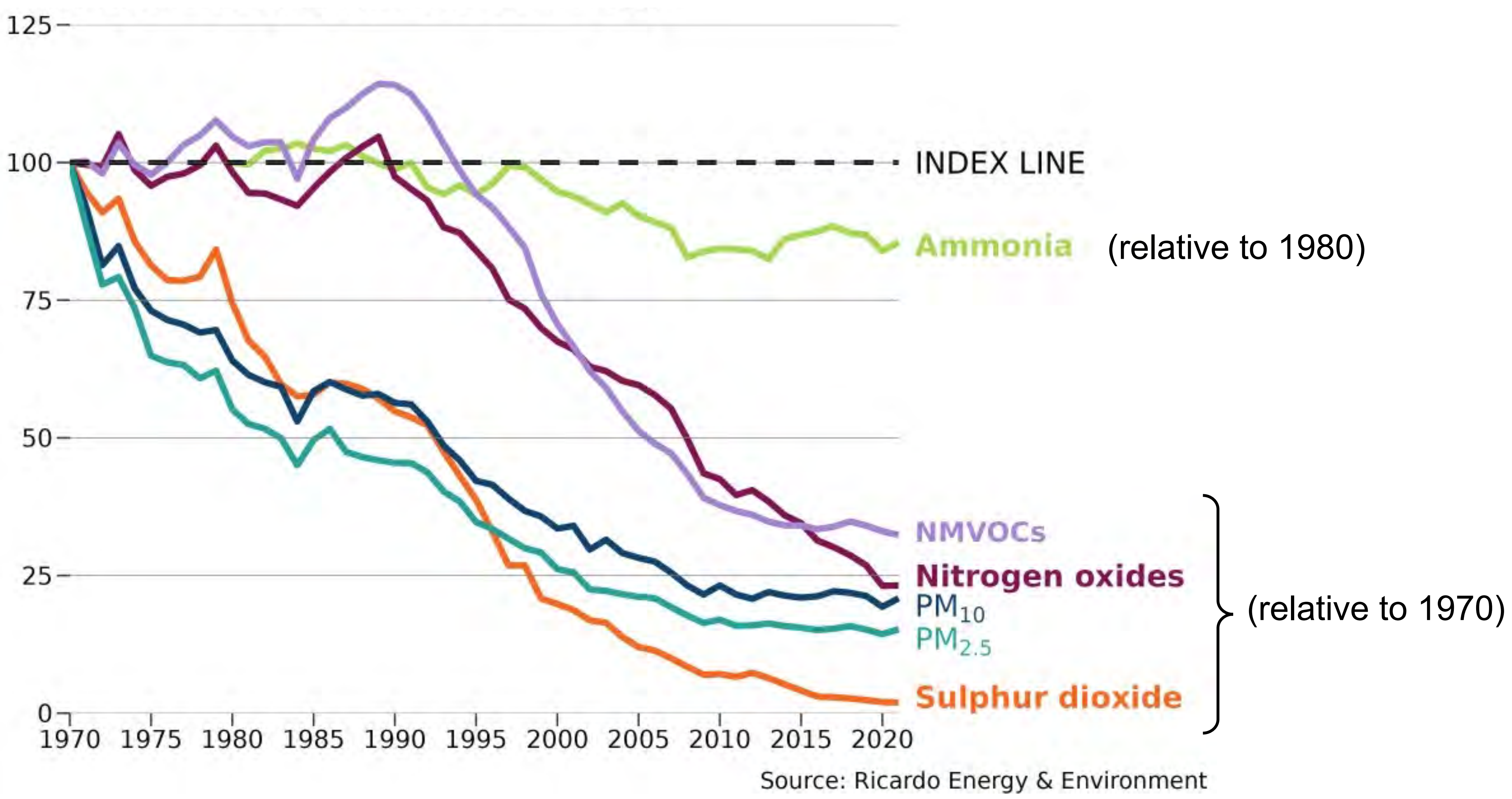


Image source: https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-summary

UK NH_3 Emissions Regulations

UNECE

LRTAP
Long-range Transboundary Air Pollution

8% decline relative to 2005 in 2020 to 2029
(**59%** for SO_2; **42%** for NO_x)

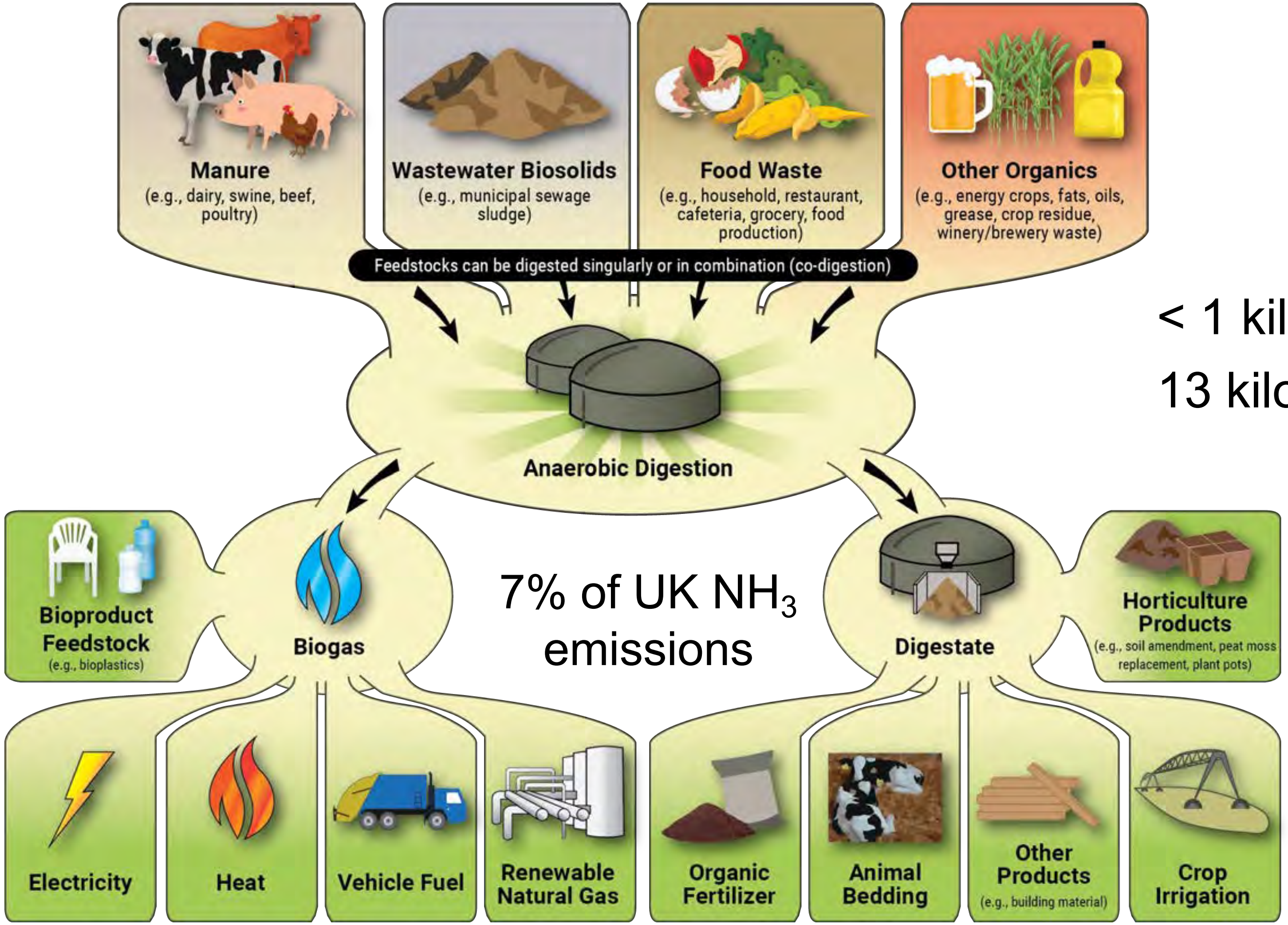
16% decline relative to 2005 from 2030
(**79%** for SO_2; **63%** for NO_x)

Code of Good Agricultural Practice (COGAP) for Reducing Ammonia Emissions (print version)

Ref: PB14506
PDF, 4.93 MB, 30 pages

UK NH_3 Emissions Regulations

UK not meeting the emissions targets? Alter the inventory!



< 1 kilotonne in 2005

13 kilotonnes in 2021

Image source: https://www.epa.gov/agstar/how-does-anaerobic-digestion-work

More here: https://www.endsreport.com/article/1846831/regulatory-capture-nfu-lobbied-defra-lower-its-global-air-quality-ambitions

Environmental Concerns over NH_3 Emissions

transport

Ammonia (NH_3) **emissions**

Environmental Concerns over NH_3 Emissions

Offsets ecosystem balance via direct exposure and nitrogen deposition

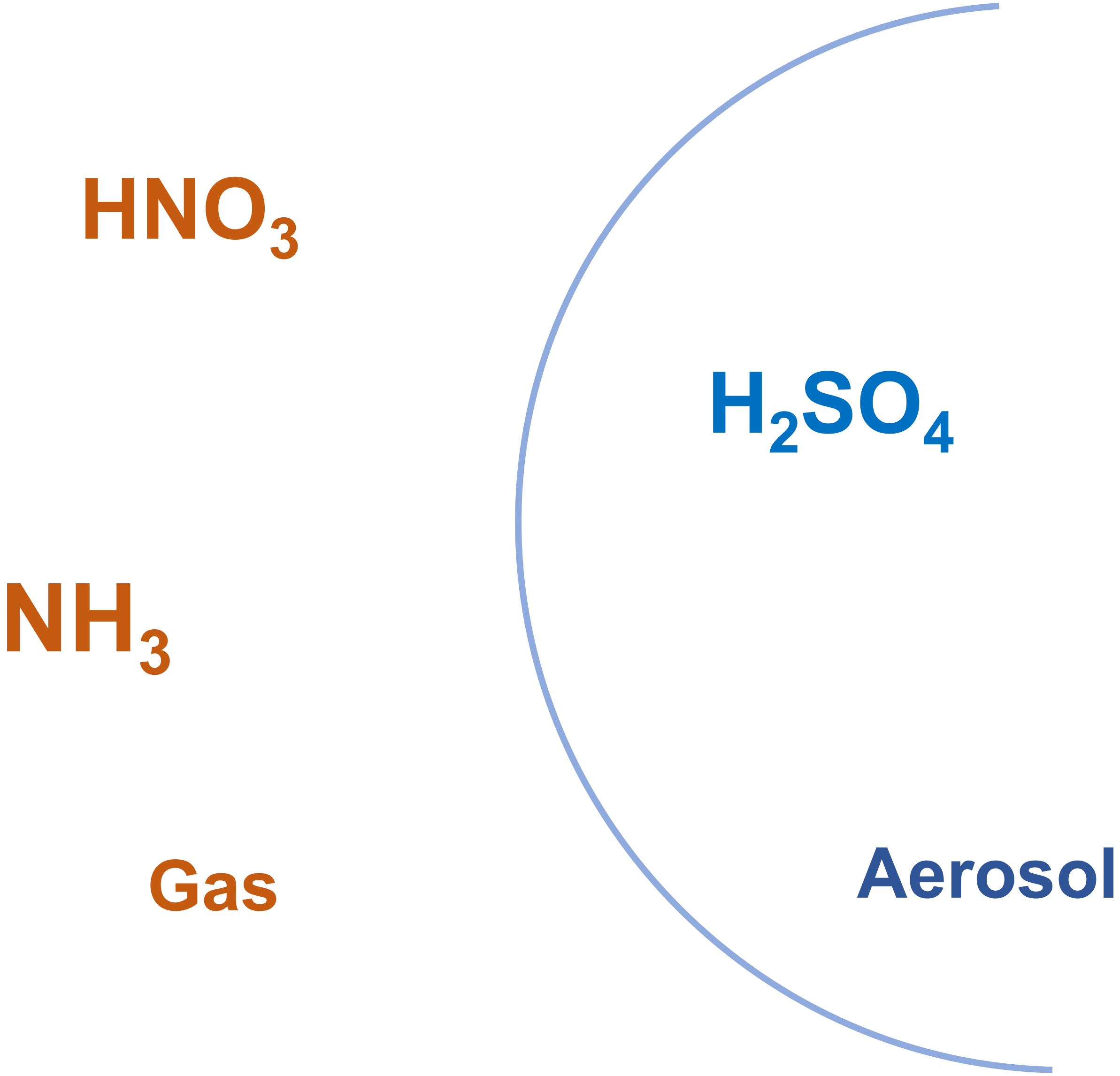
Ammonia (NH_3) **emissions**

transport

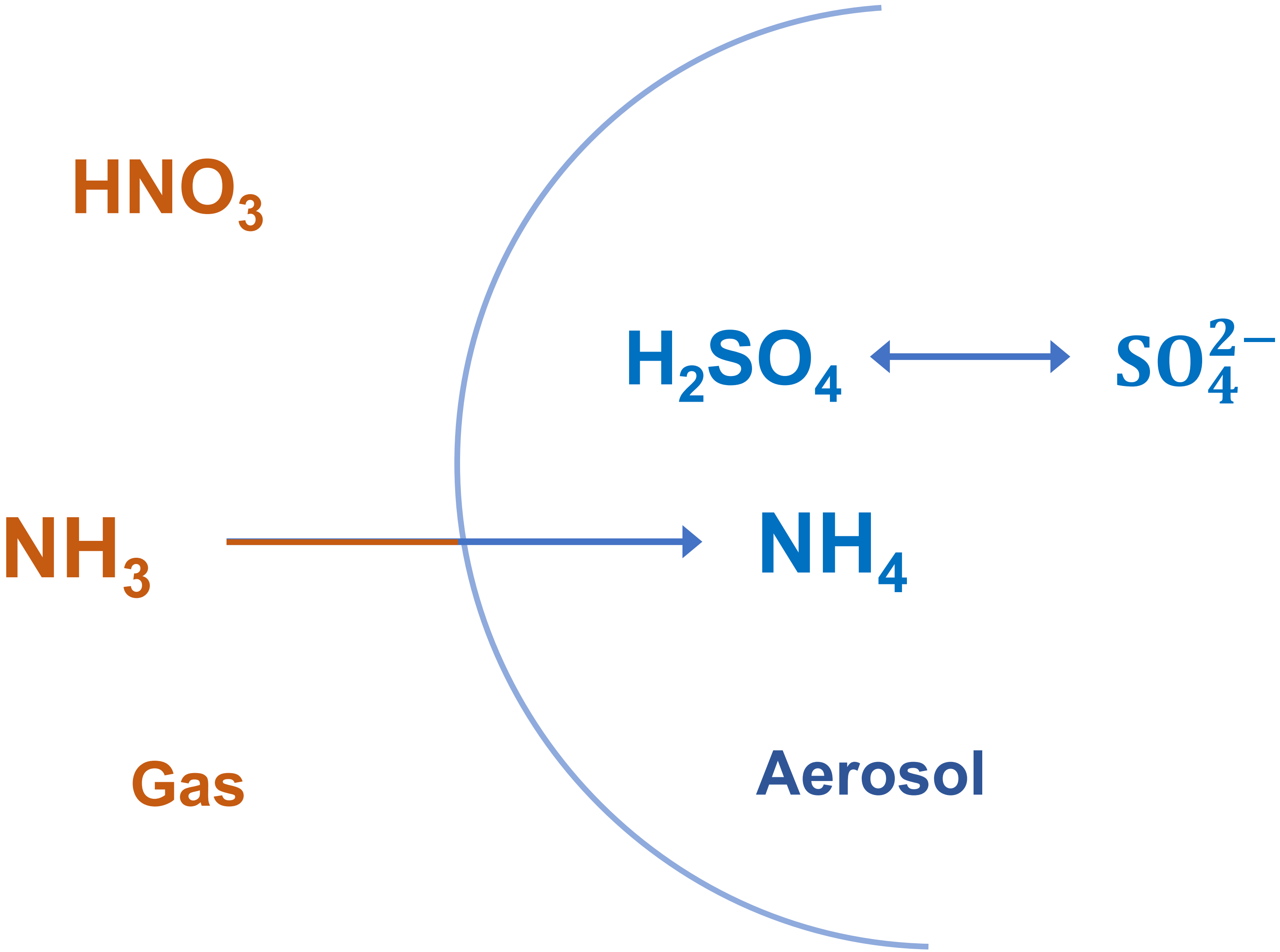
NH_3 exposure
lichens & bryophytes

deposition
to sensitive
habitats

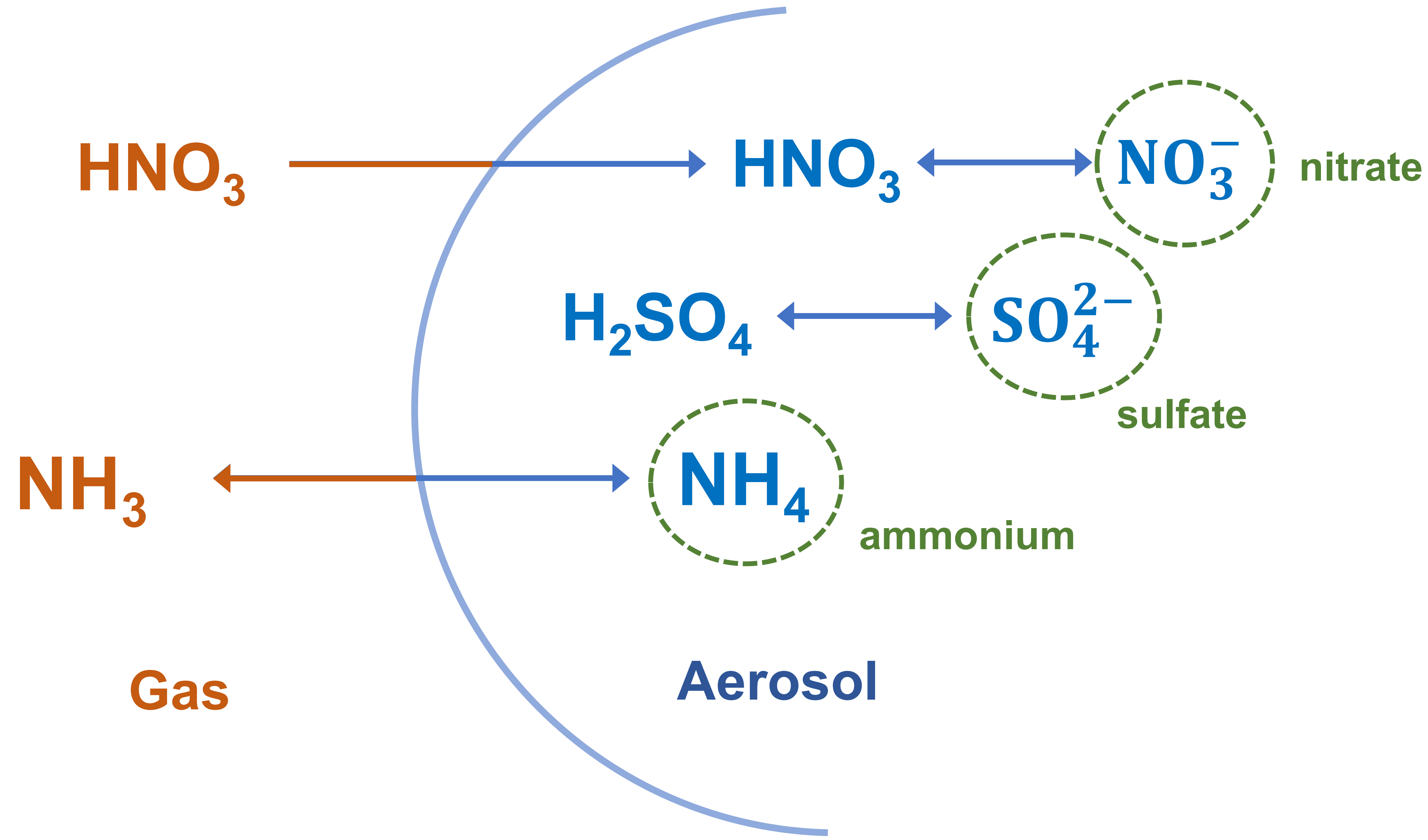
NH_3 Contribution to Particulate Matter (PM)



NH_3 Contribution to Particulate Matter (PM)

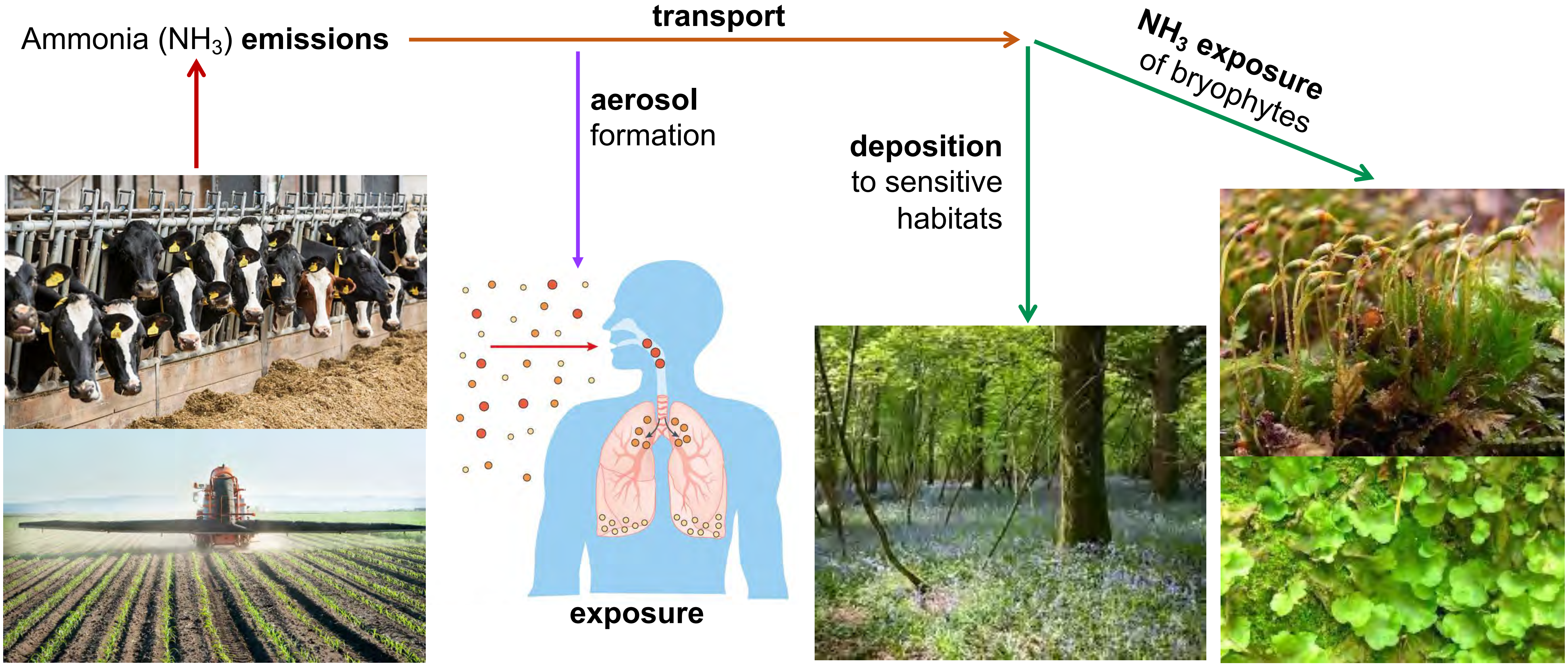


NH_3 Contribution to Particulate Matter (PM)



Environmental Concerns over NH_3 Emissions

Impacts health as fine particulate matter ($PM_{2.5}$) precursor



Research Questions

How large is the present-day impact on public and ecosystem health?

Will it improve 2030 with adoption of legally required emission controls?

What's the efficacy of instead adopting best available technologies?

GEOS-Chem Chemical Transport Model

A model and a community

Manual: https://geoschem.github.io
Codebase: https://github.com/geoschem

develop, report bugs, feedback

support

Support Team
(software engineers)

new model versions

implement priorities
prepare benchmarks
maintain documentation

Leadership Structure:

Co-lead Scientists
Randall Martin, WUSTL
Daniel Jacob, Harvard

Steering Committee
25-30 leading scientists
Set development priorities
Maintain integrity of model

Infrastructure:

Fortran
Python
GitHub

[Slide credit: adapted from slide by Randall Martin (WUSTL)]

GEOS-Chem Simulation of $PM_{2.5}$, NH_3, and N deposition

Emissions

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

GEOS-Chem

FlexGrid nested over the UK at 0.25° x 0.3125°

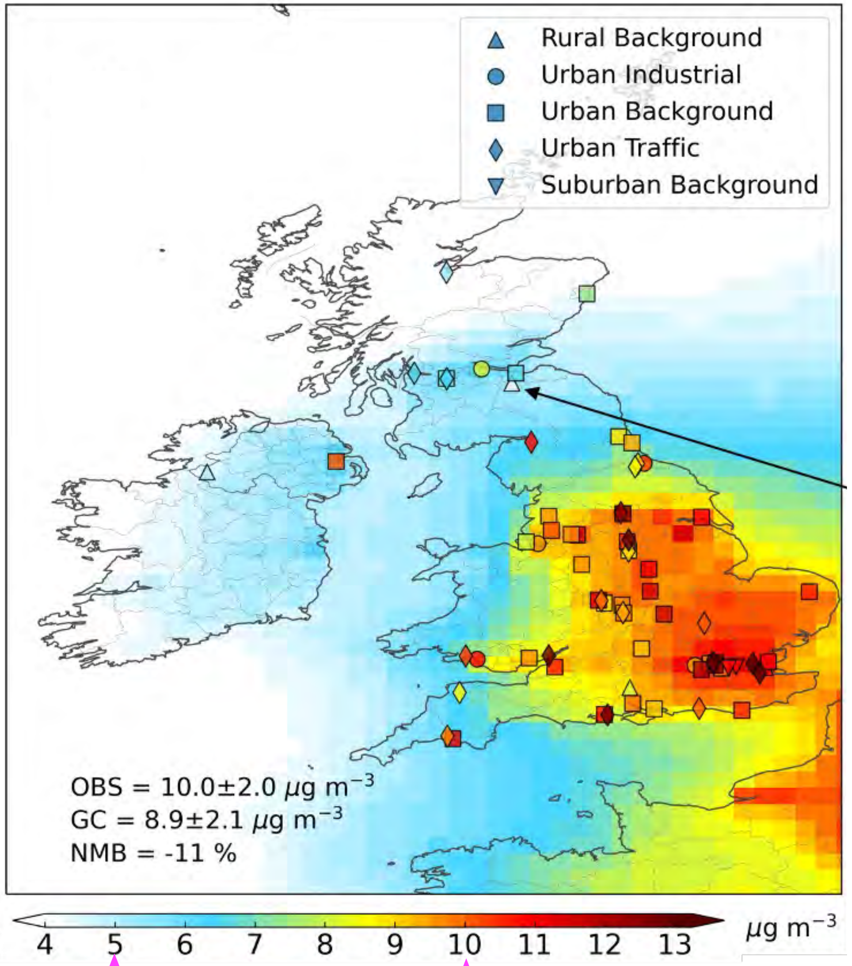
Gas- and aerosol-phase chemistry, transport, wet+dry deposition

NASA GEOS-FP Meteorology

<u>Present-day</u> surface NH_3 and $PM_{2.5}$ components and nitrogen wet and dry deposition

Model Validation Against Network Measurements

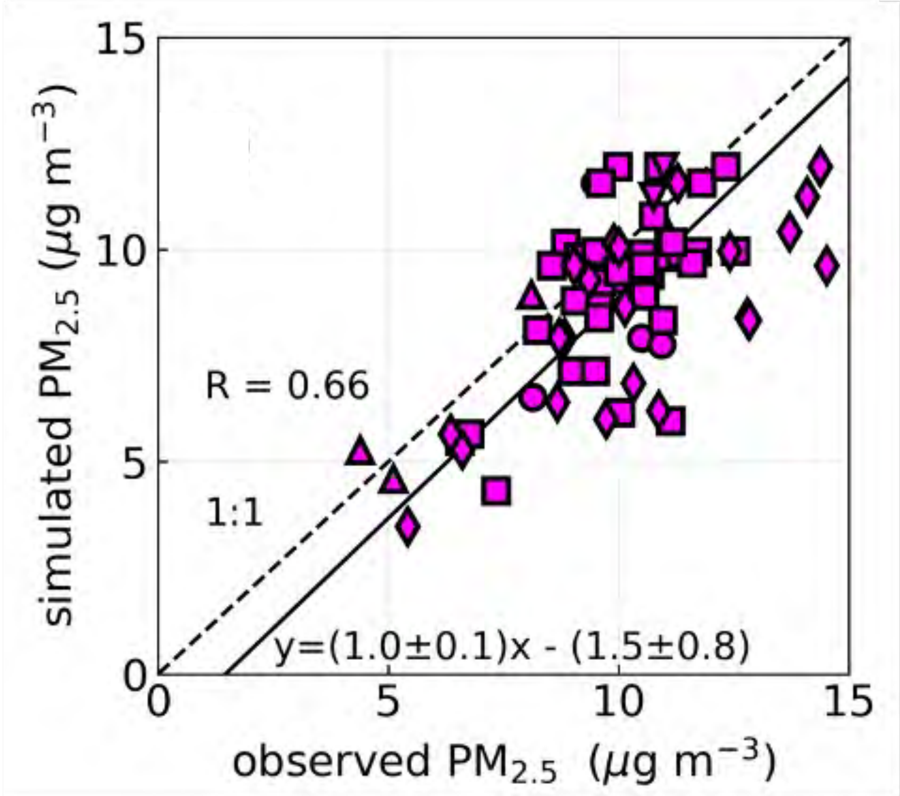
Use total $PM_{2.5}$ observations from the Automatic Urban and Rural Network (AURN) to assess model



WHO (2021) **WHO (2005), new UK target**

79% of UK exceeds updated WHO guideline

Compare annual mean surface concentrations of $PM_{2.5}$ for 2019

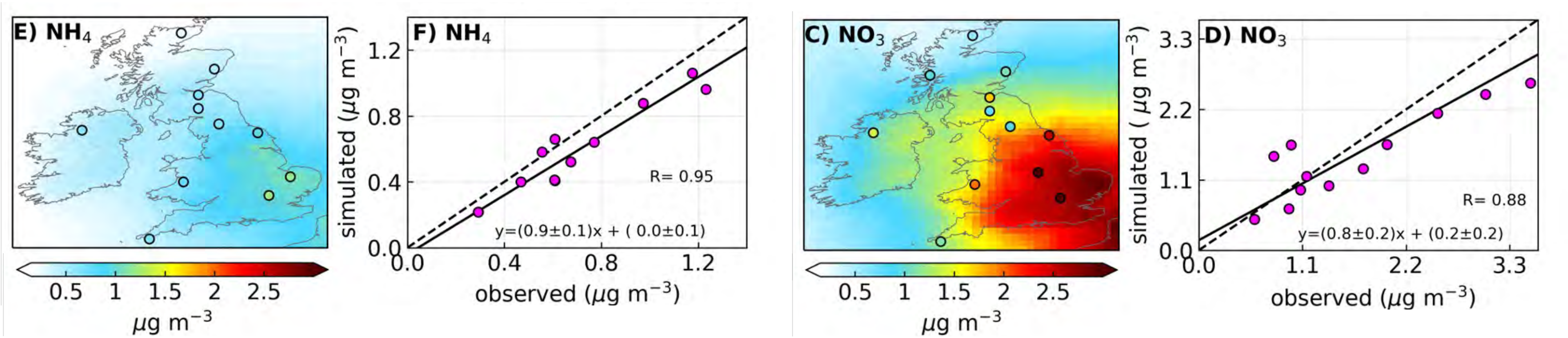


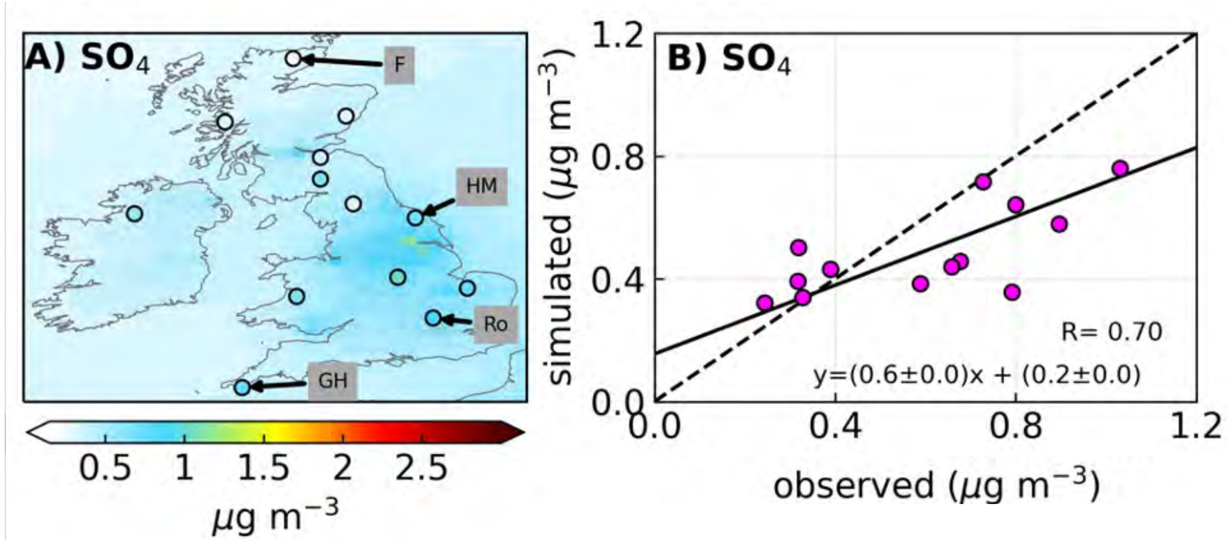
Consistent spatial pattern (**R = 0.66**) and variance (**slope = 1.0**). Model **11% less** than observations

[*Kelly et al., 2023*]

Assess Validity of Model using Permanent Networks

Use $PM_{2.5}$ composition measurements from UKEAP and EMEP sites to assess model





Model underpredicts observed (sulfate, nitrate, ammonium) and possibly overpredicts unobserved (dust) components.

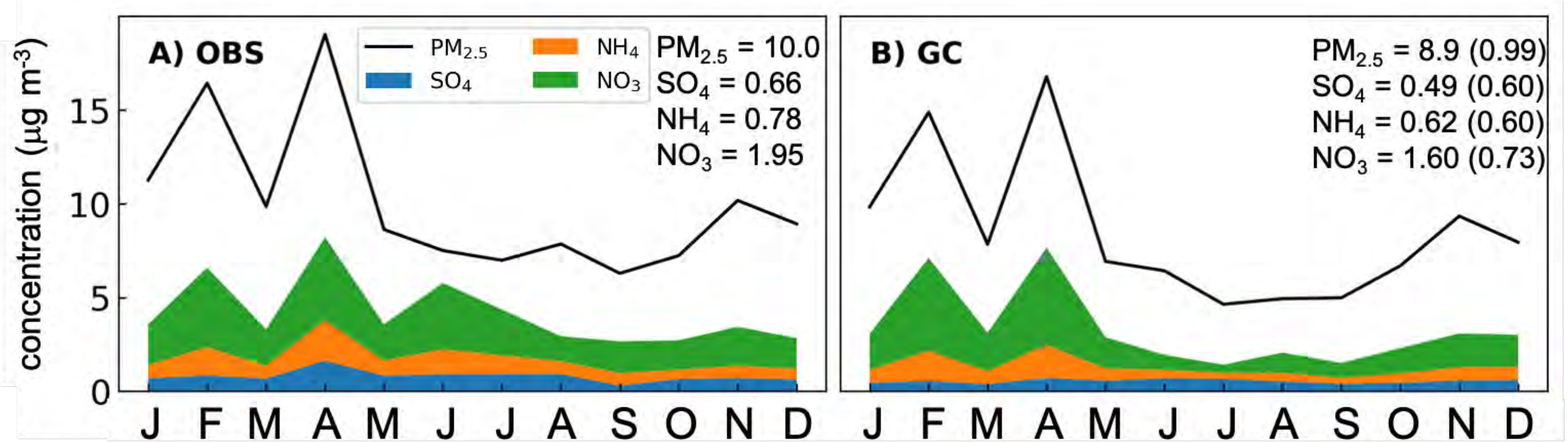
Model captures variance of components from NO_x (nitrate) and ammonia (ammonium)

[*Kelly et al., 2023*]

Assess Validity of Model using Reference Monitors

Also evaluate model skill at reproducing observed seasonality in $PM_{2.5}$

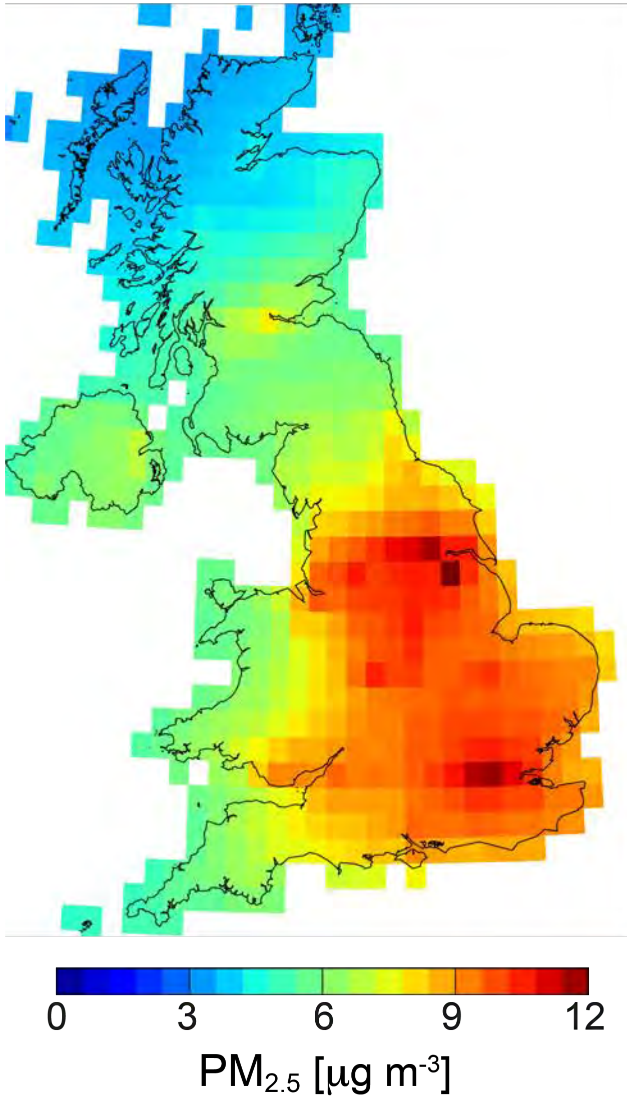
SO_4: sulfate; NO_3: nitrate; NH_4: ammonium



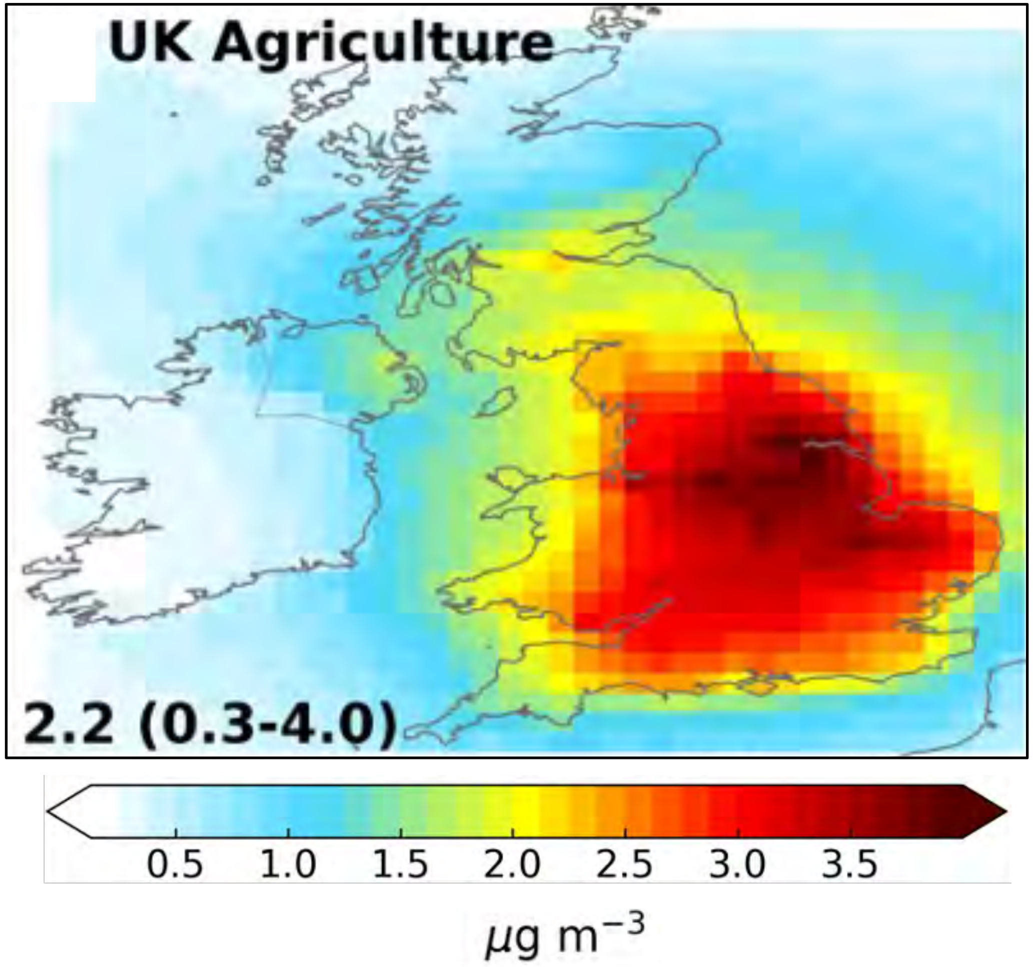
Enhancements in cold months and when ammonia emissions from agriculture peak due to application of synthetic fertilizer in March-April

GEOS-Chem Present-Day $PM_{2.5}$

Present-day $PM_{2.5}$



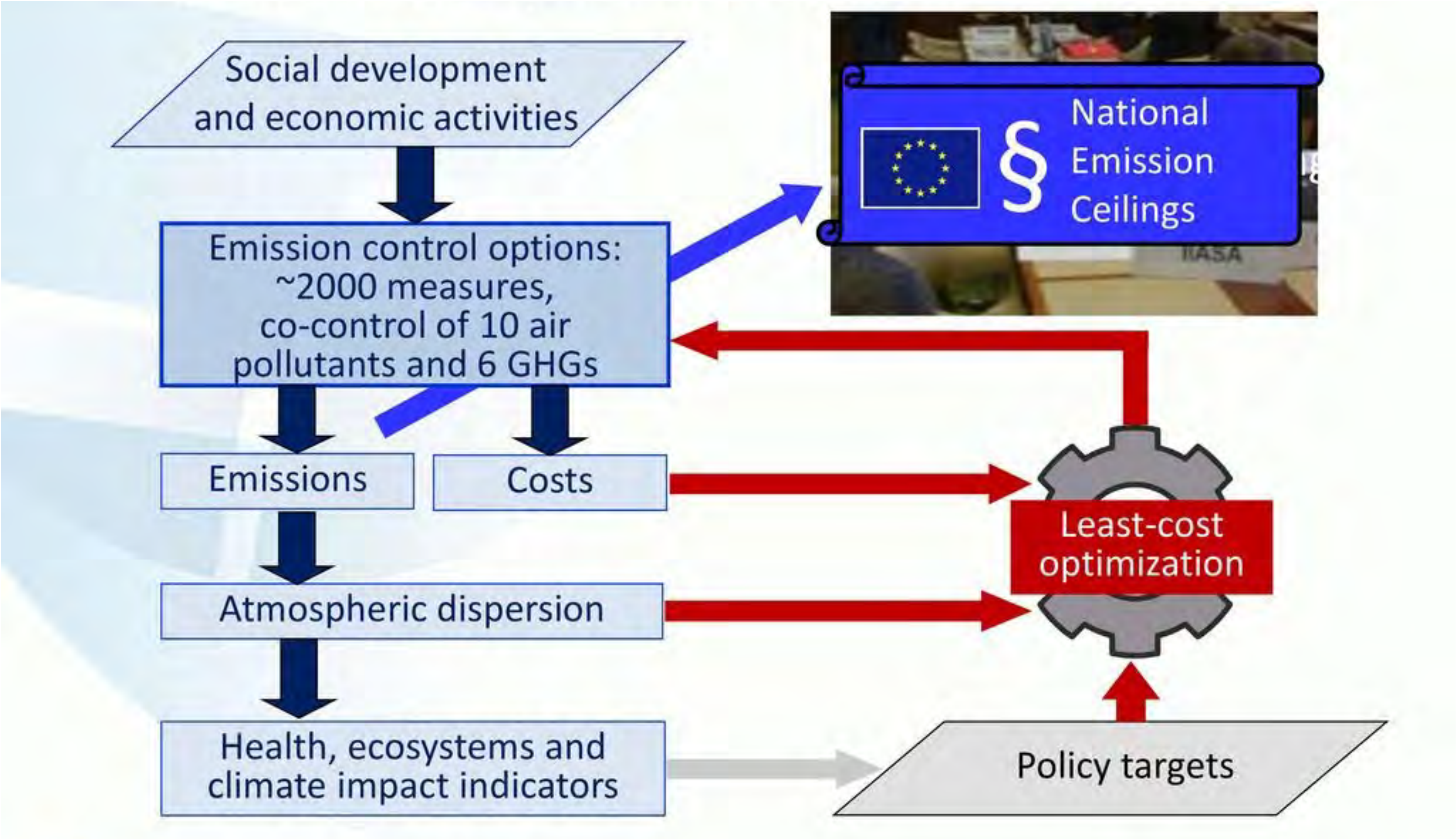
Large contribution of agricultural NH_3 emissions to $PM_{2.5}$



79% of UK grids > **5 μg m^{-3}** (WHO $PM_{2.5}$ guideline) in 2019

Emissions Projections for the UK, Ireland and continental Europe

Developed by the International Institute for Applied Systems Analysis (**IIASA**) with the Greenhouse gas – Air pollution Interactions and Synergies (**GAINS**) model

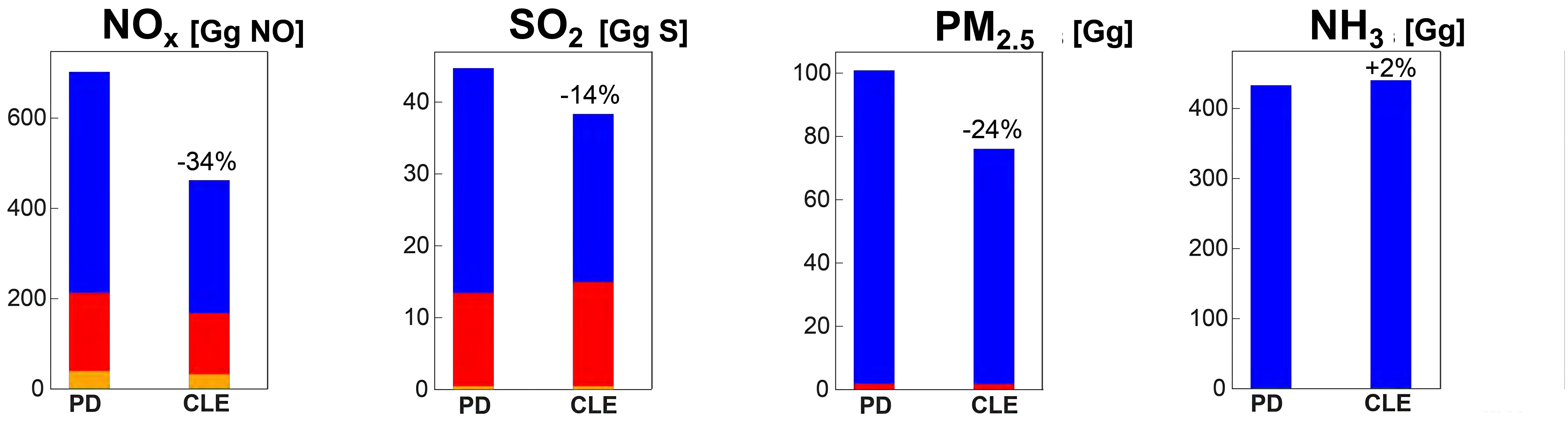


[Slide credit: adapted from slide by M. Amman (IIASA)]

Emission Control Options for the UK

Legislated emissions targets (**CLE**)

Emissions for present-day or PD (**2019**) and future (**2030**) for legislation (**CLE**)



Terrestrial Anthropogenic
Shipping
Aviation

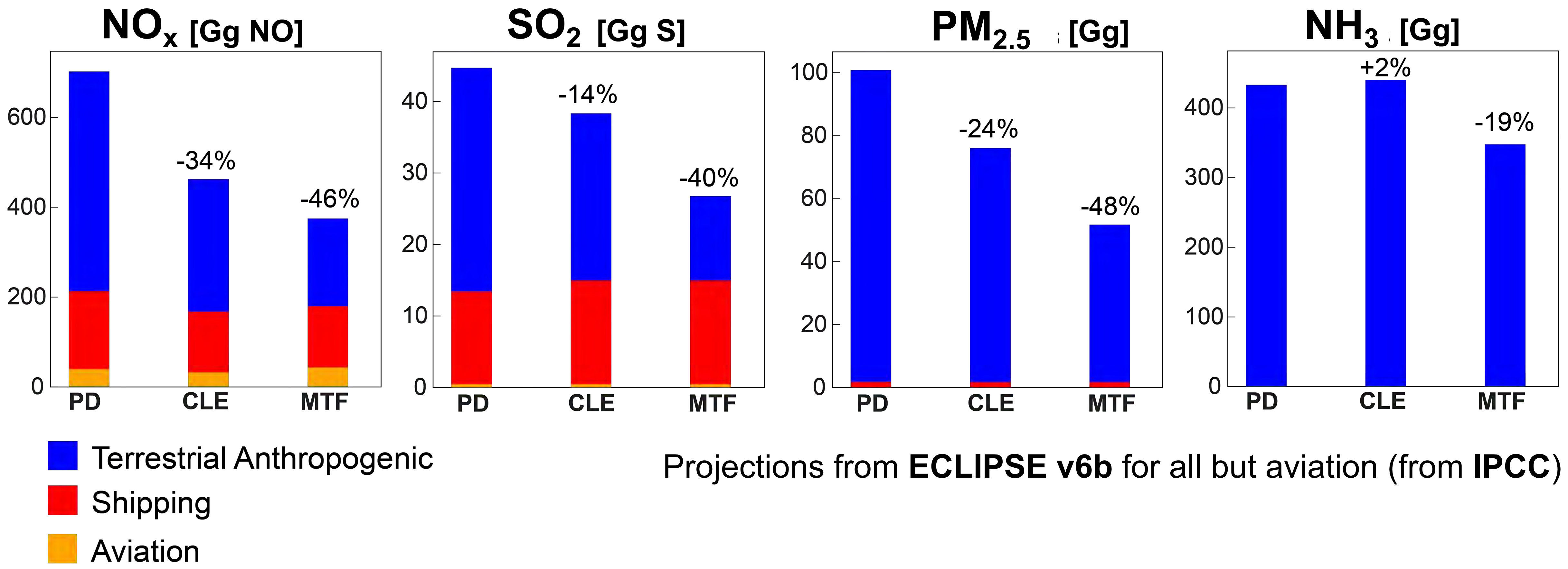
Projections from **ECLIPSE v6b** for all but aviation (from **IPCC**)

NH_3 emissions increase, as controls insufficient to curtail increases from growth in demand

Emission Control Options for the UK

Adoption of best best, readily available technology (**MTF**)

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



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

Influence of Emission Controls on $PM_{2.5}$, NH_3, and N deposition

Emissions

Future:
scale 2019 emissions with projections

GEOS-Chem

Nested over the UK at 0.25° x 0.3125°

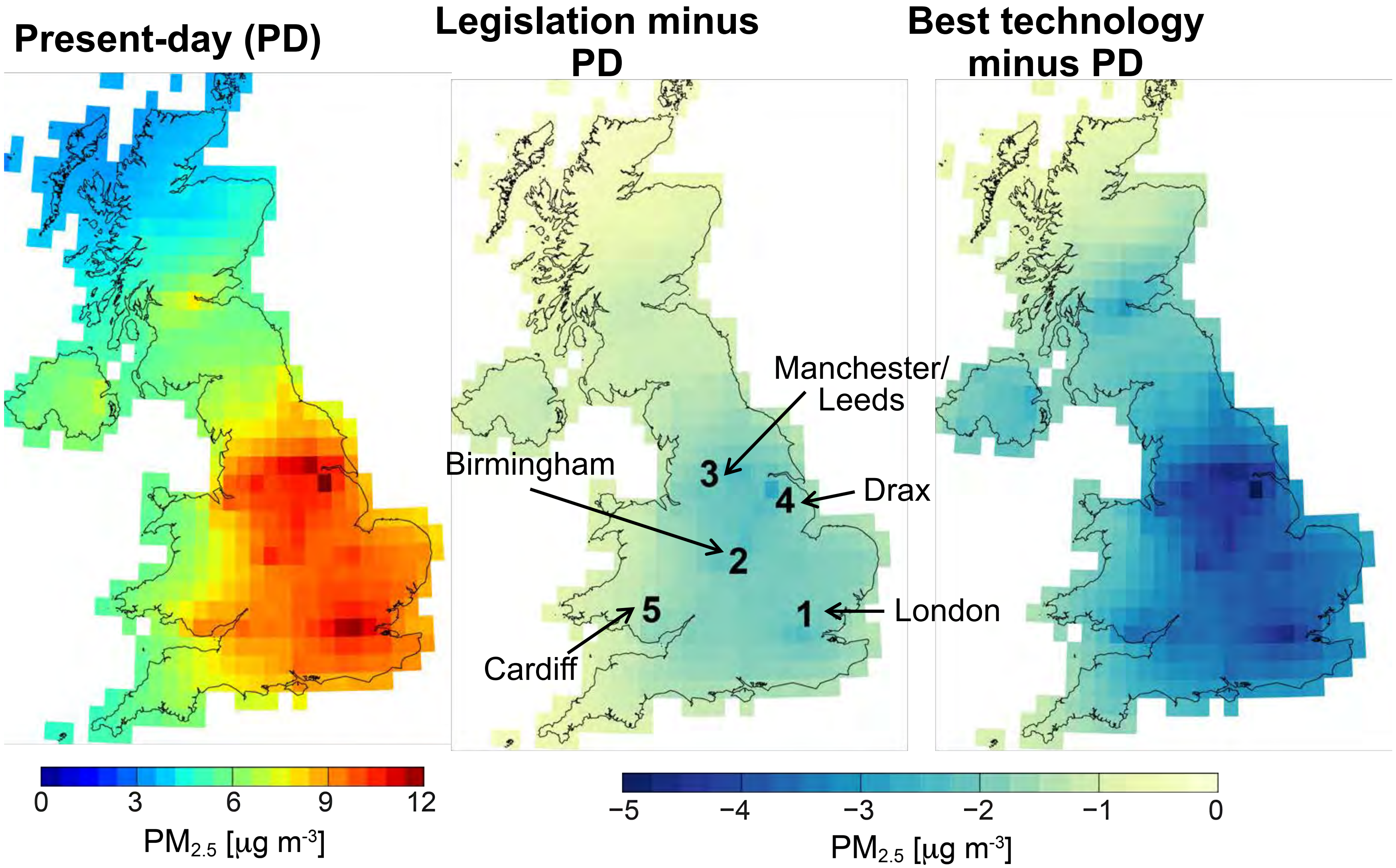
Gas- and aerosol-phase chemistry, transport, wet+dry deposition

NASA GEOS-FP Meteorology

2019

<u>Future</u> surface NH_3 and $PM_{2.5}$ components and nitrogen wet and dry deposition

Influence of emission controls on $PM_{2.5}$



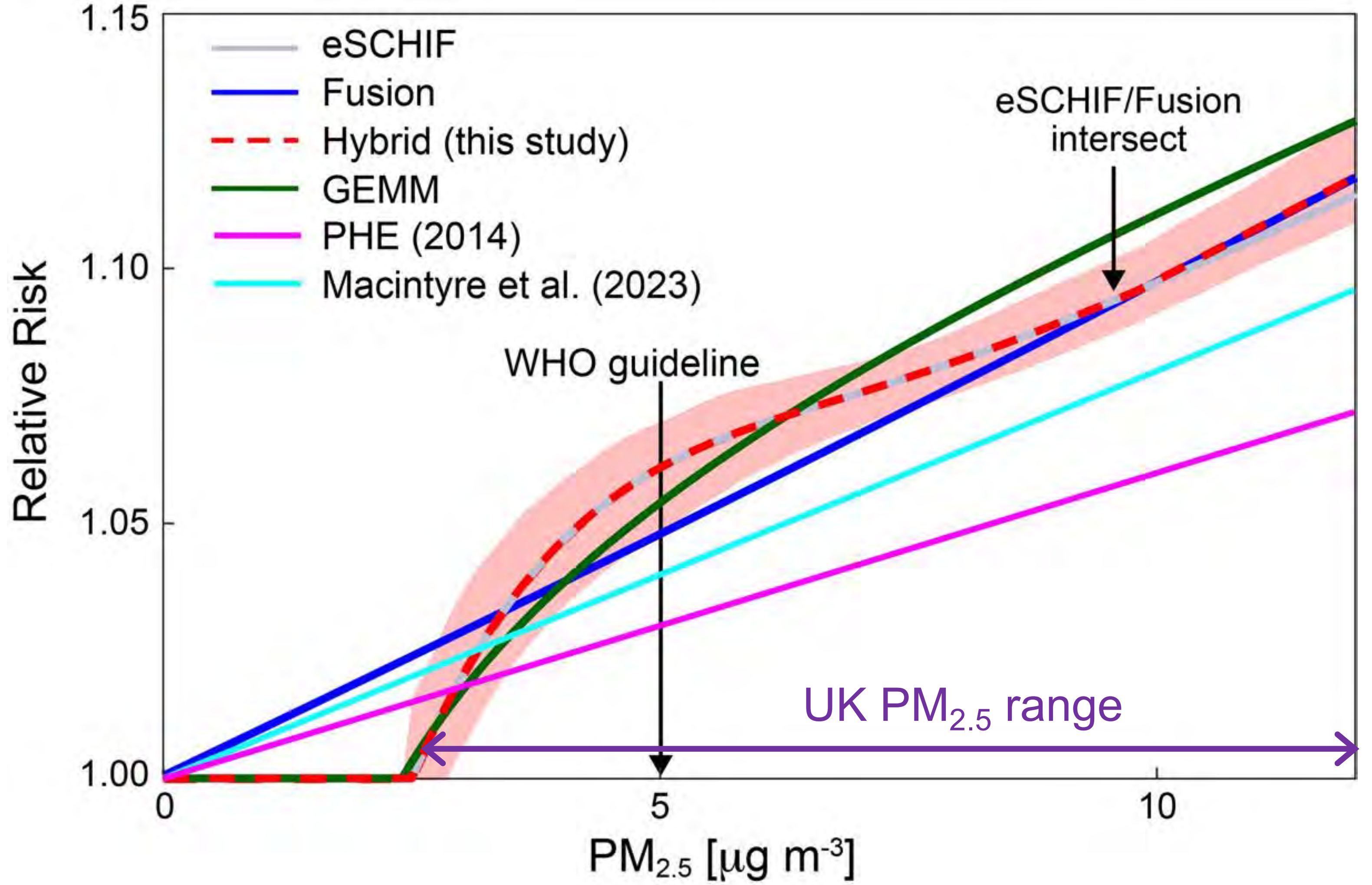
Current legislation controls cause $PM_{2.5}$ decline of at most **2 μg m^{-3}** compared to **5 μg m^{-3}** for best technology

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

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

Hybrid curve combines Fusion and CanCHEC

Approach motivated by Weichenthal et al. (2022)



PHE (2014):
Public Health England report

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

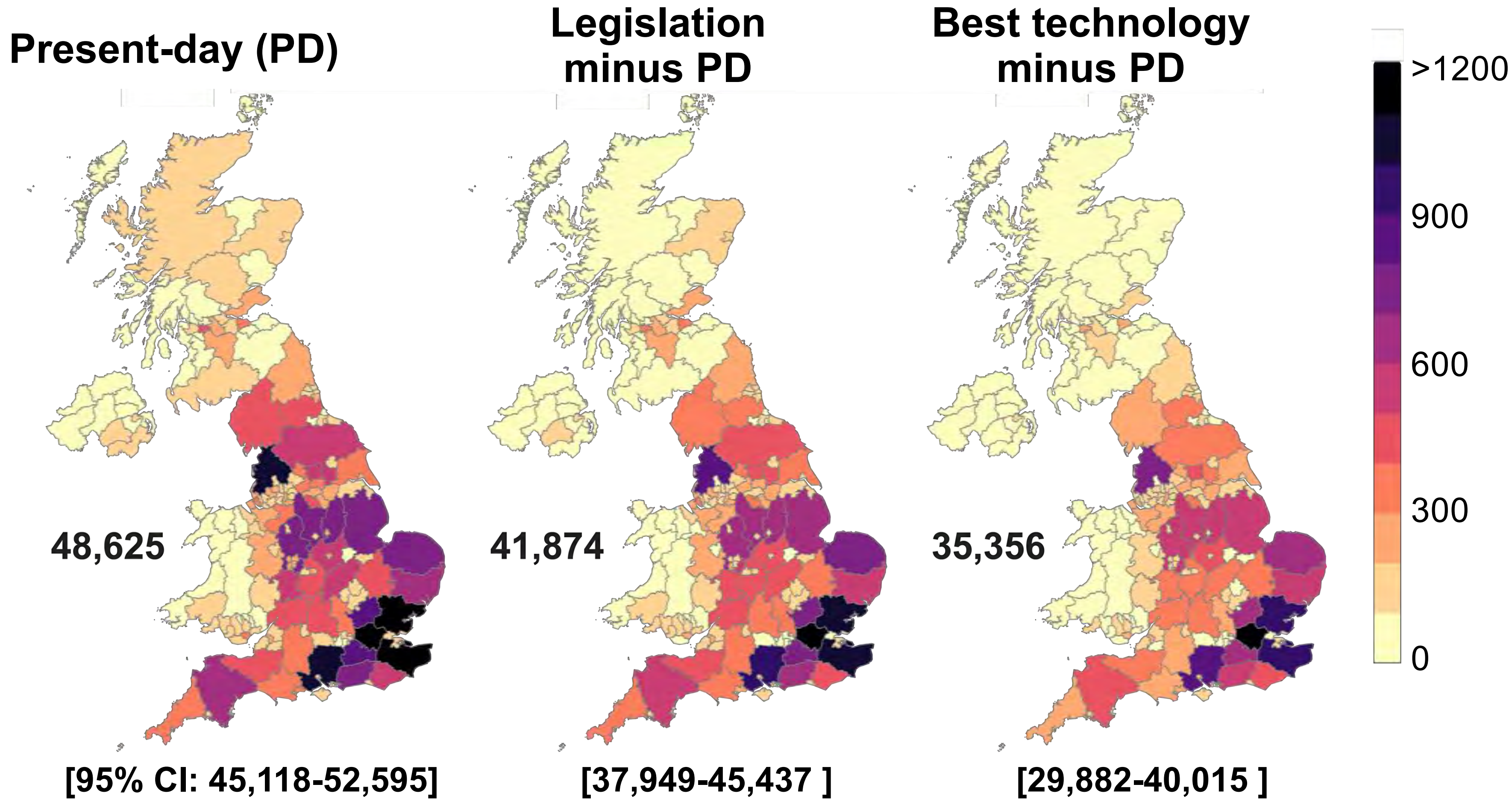
GEMM:
Global Exposure Mortality Model

Hybrid:
eSCHIF at 2.5-9.8 $\mu g\ m^{-3}$ and Fusion beyond 9.8 $\mu g\ m^{-3}$

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

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)

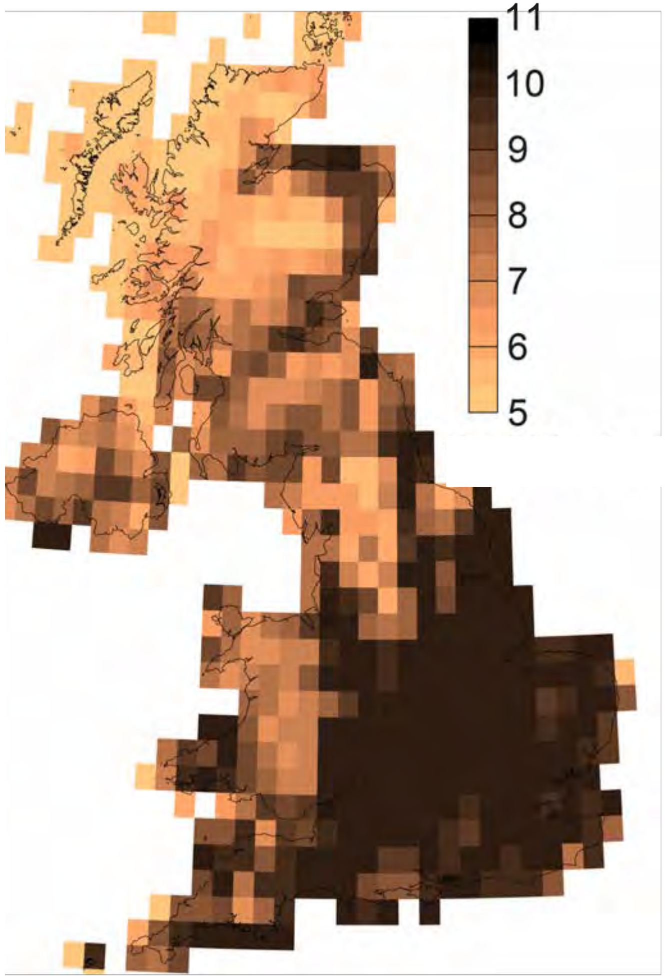


6,751 avoided early deaths with legislated controls, double that (13,269) with best available technology

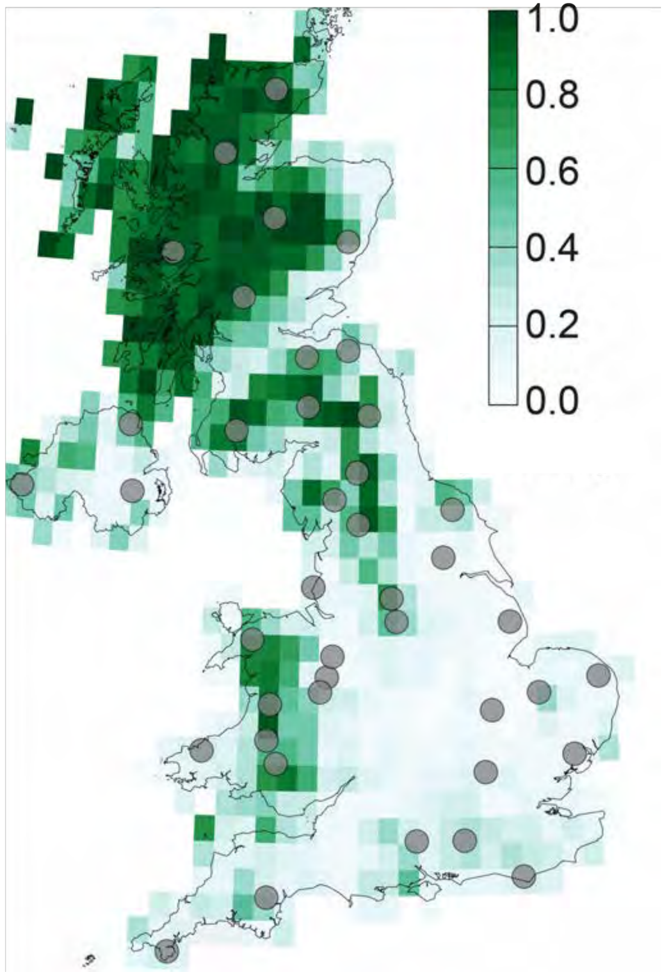
Burden of disease estimates greater than past UK-focused studies and similar to those obtained with GEMM curve

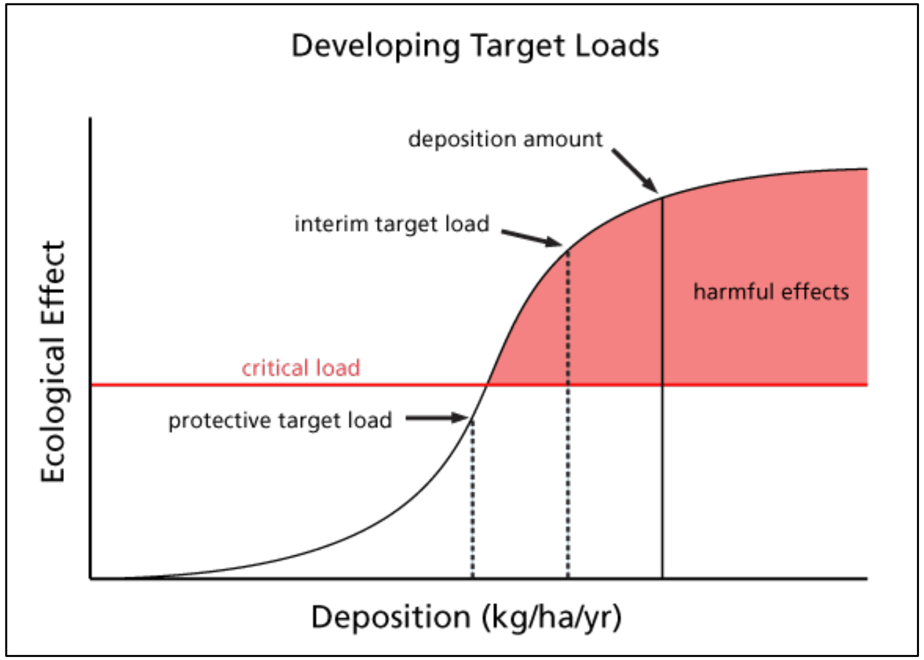
Assessing Adverse Effects to Sensitive Habitats

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



Sensitive habitat cover
[fraction]





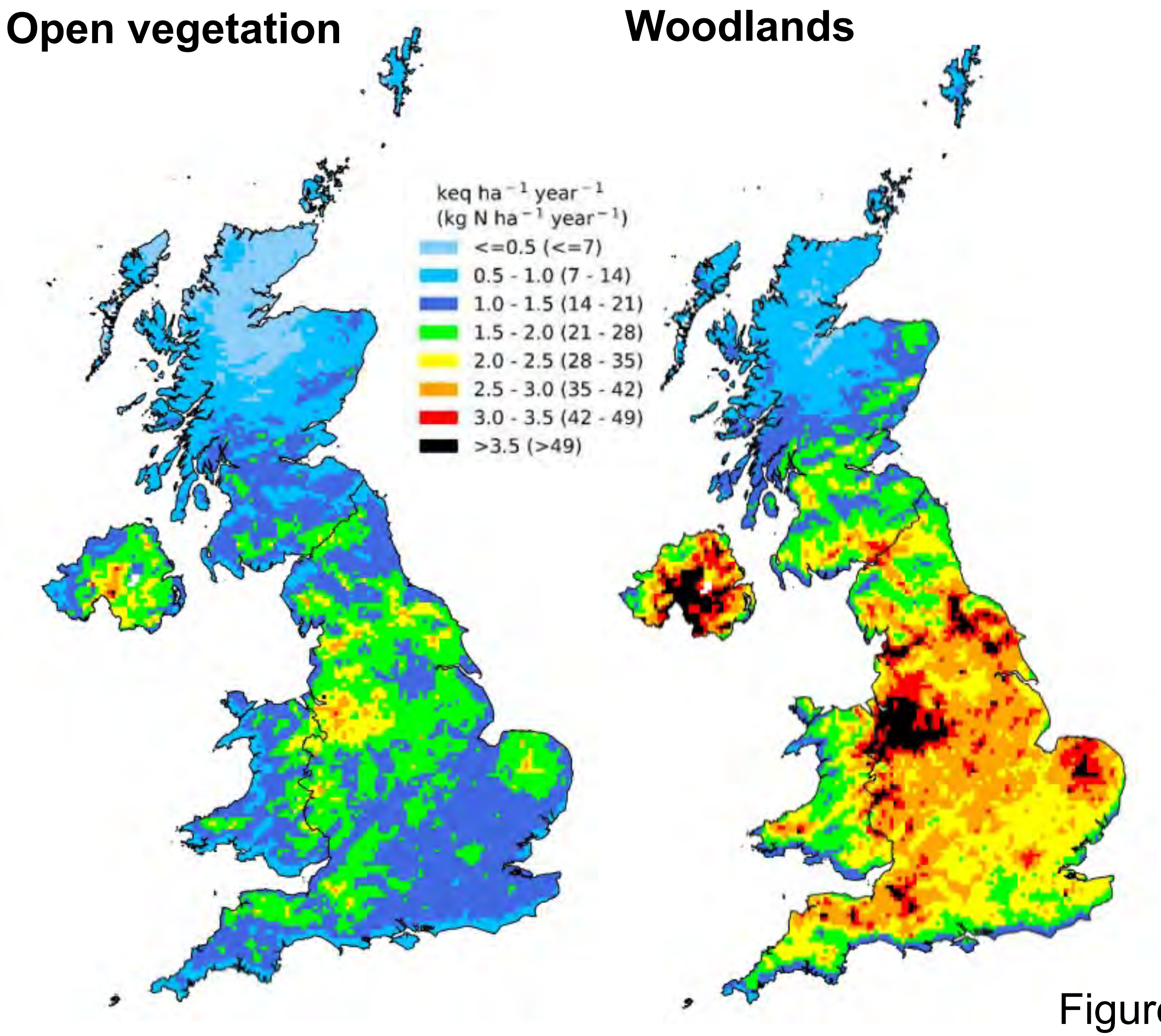
Use very recently revised critical loads

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

13 sensitive habitats cover 38% of UK. ~60% in Scotland

High Resolution Total Nitrogen Wet + Dry Deposition

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



GEOS-Chem too coarse to resolve deposition over sensitive habitats

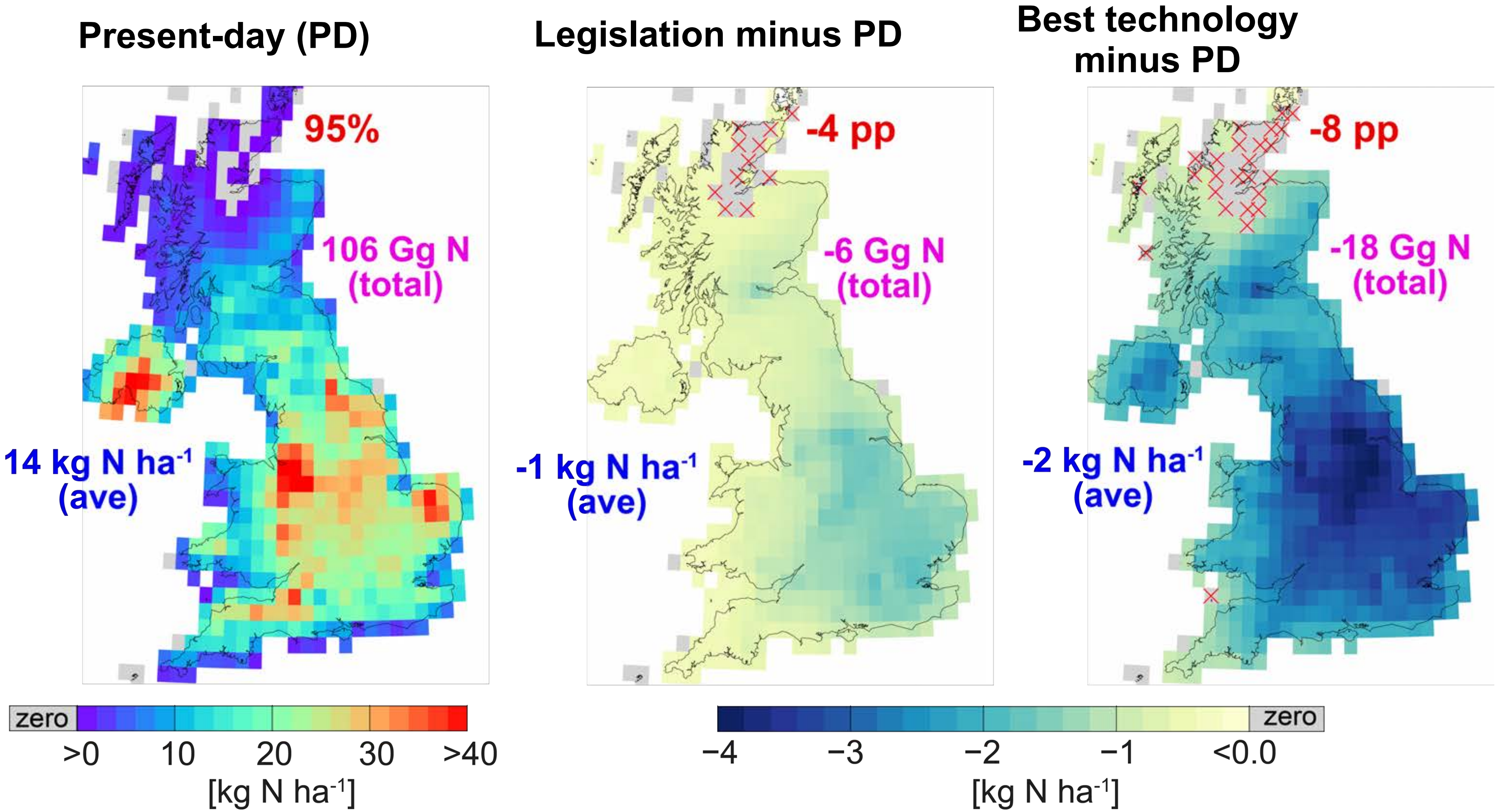
GEOS-Chem also doesn't account for enhanced washout over upland areas or deposition of cloud droplets to vegetation.

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

Influence of Emission Controls on Nitrogen Critical Loads



Values are total, mean, and coverage of exceedances

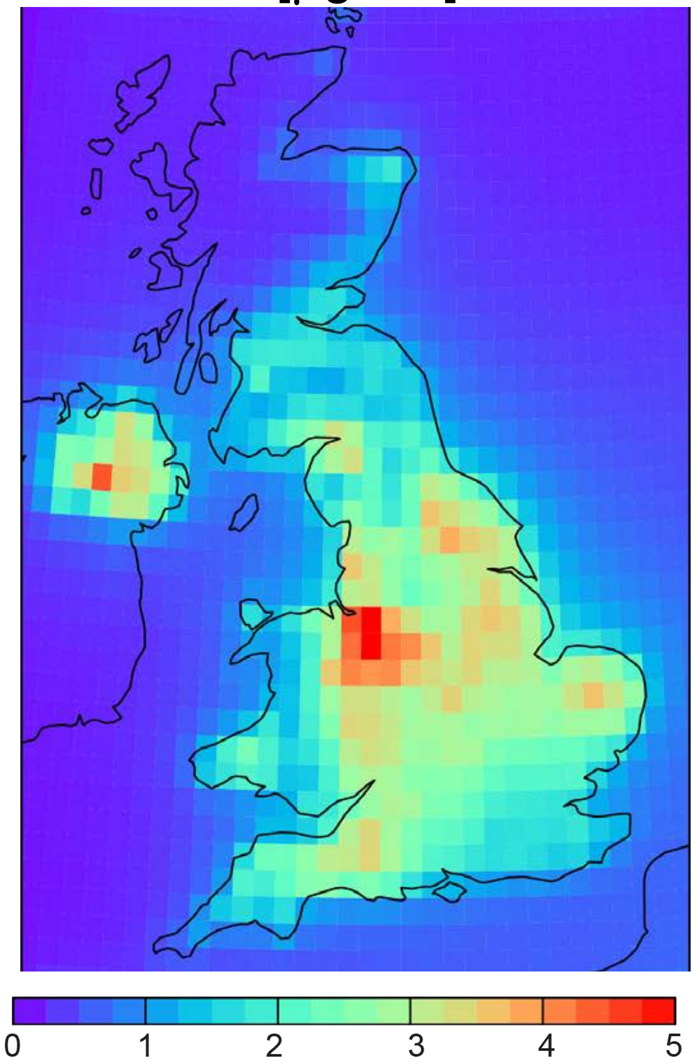
Crosses show grids that fall below critical loads relative to present day

Decline in N deposition with emission controls only one-third of emissions reductions, as most nitrogen exported

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

Influence of Emission Controls on Direct Exposure to NH_3

Annual mean (2019) NH_3 [$\mu g\ m^{-3}$]



Lichens and bryophytes show evidence of harm at $NH_3 > 1\ \mu g\ m^{-3}$

Alters species composition: favours nitrophytes and decreases abundance of acidophytes

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

Takehome Messages

Present-day impact:

- 79% UK exceeds WHO $PM_{2.5}$ guideline
- ~48,000 adults died prematurely from exposure to $PM_{2.5}$ in 2019
- Most (>70%) of UK sensitive habitats at risk of harm from excess exposure to nitrogen

Future adoption of legal and best-available measures:

- Substantial improvements to public health with emission controls, especially with adoption of best available measures
- Decline in harm to sensitive habitats modest to negligible for both

Implications:

- 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

Paper reference: Marais et al., GeoHealth, 2023 (doi:10.1029/2023GH000910)