

# **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/>

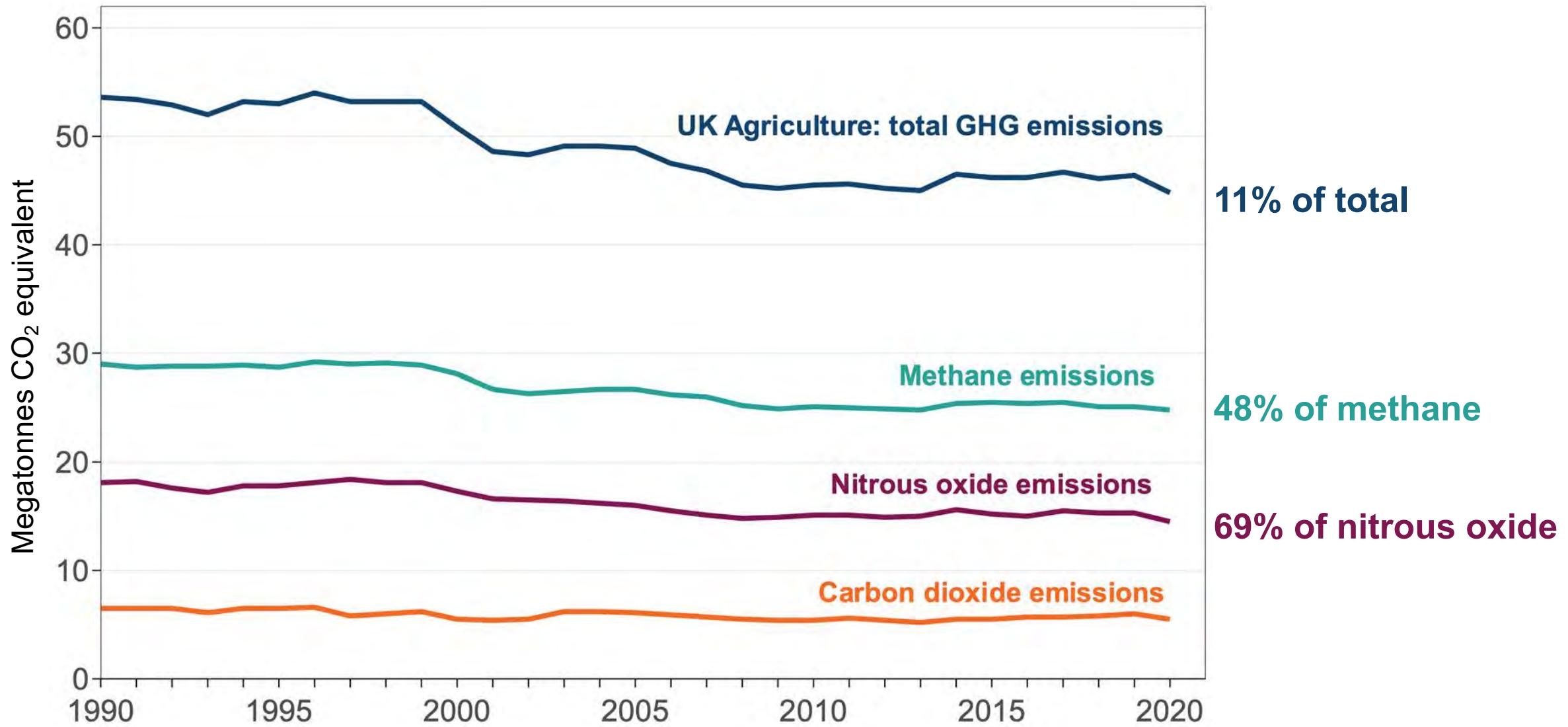


NWW  
106

Karn, Gongda, Connor,

Bex, Eleanor, Nana

# UK Agriculture a Large Source of Greenhouse Gases



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

# Agriculture a Large Source of Ammonia ( $\text{NH}_3$ )



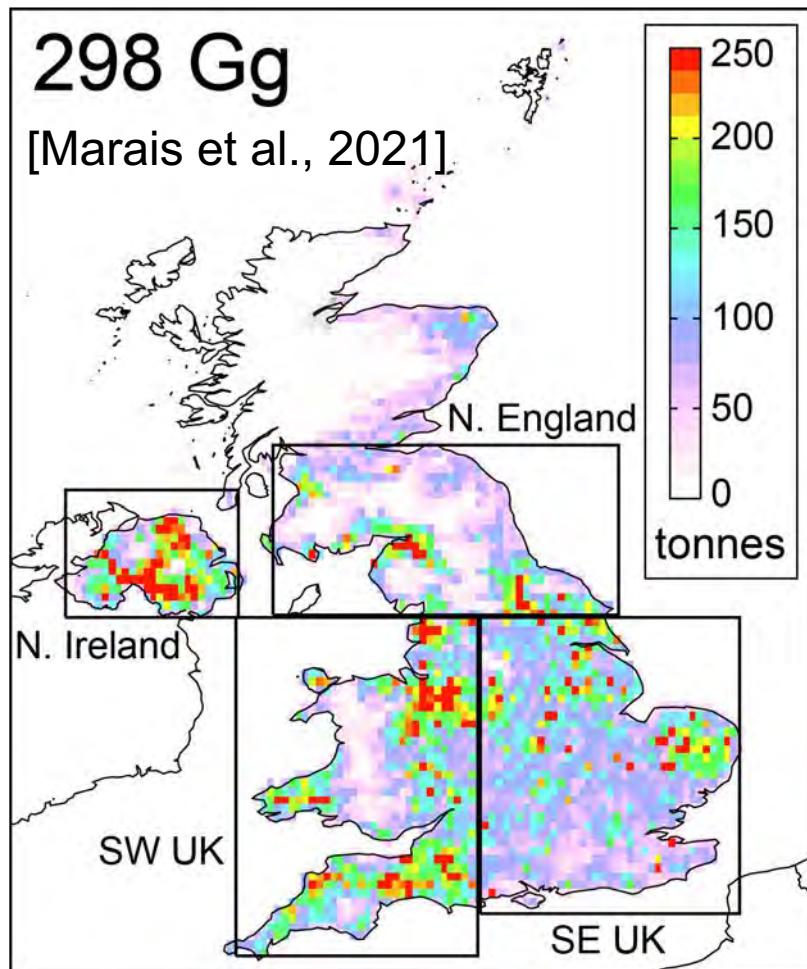
~80% nitrogen (N) wasted due to inefficient use

200 million tonnes costing USD 200 billion

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

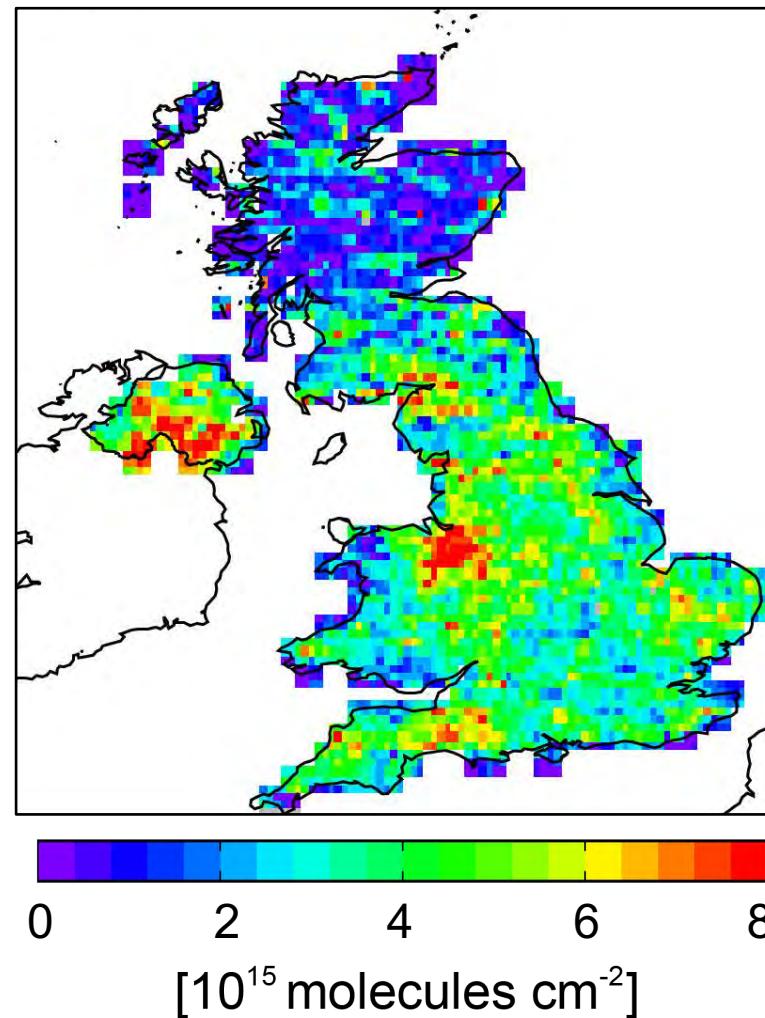
# UK Agriculture a Large Source of Ammonia ( $\text{NH}_3$ )

## Spatial distribution of $\text{NH}_3$ emissions



84% of all  $\text{NH}_3$   
90% anthropogenic  $\text{NH}_3$

## Spatial distribution of $\text{NH}_3$ abundances as seen from space

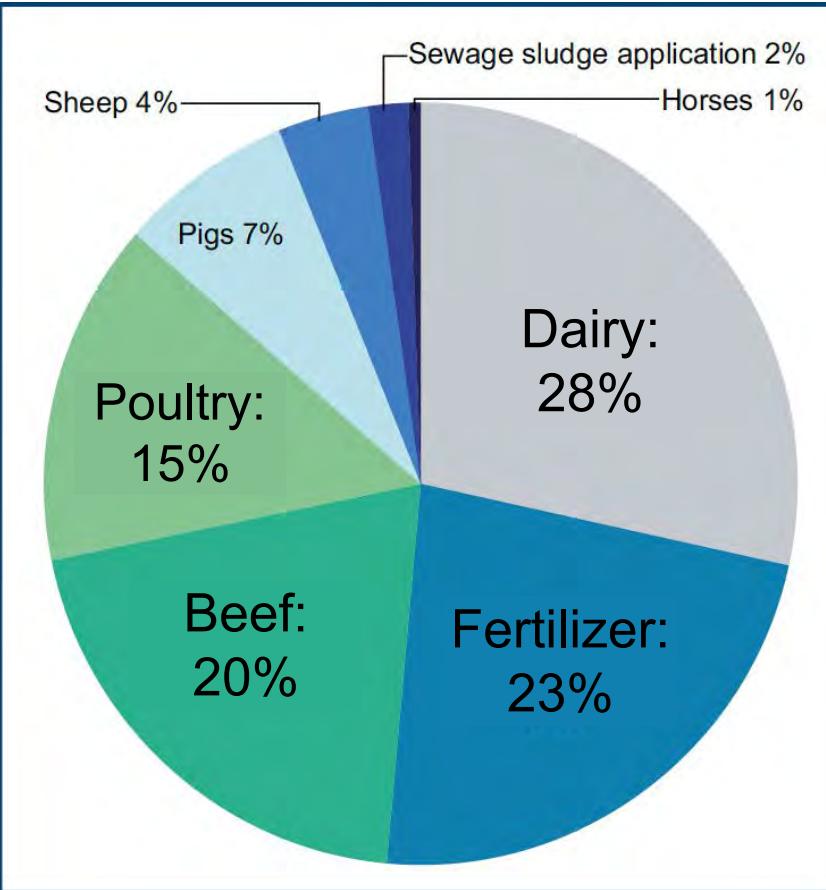


IASI  
IR Interferometer

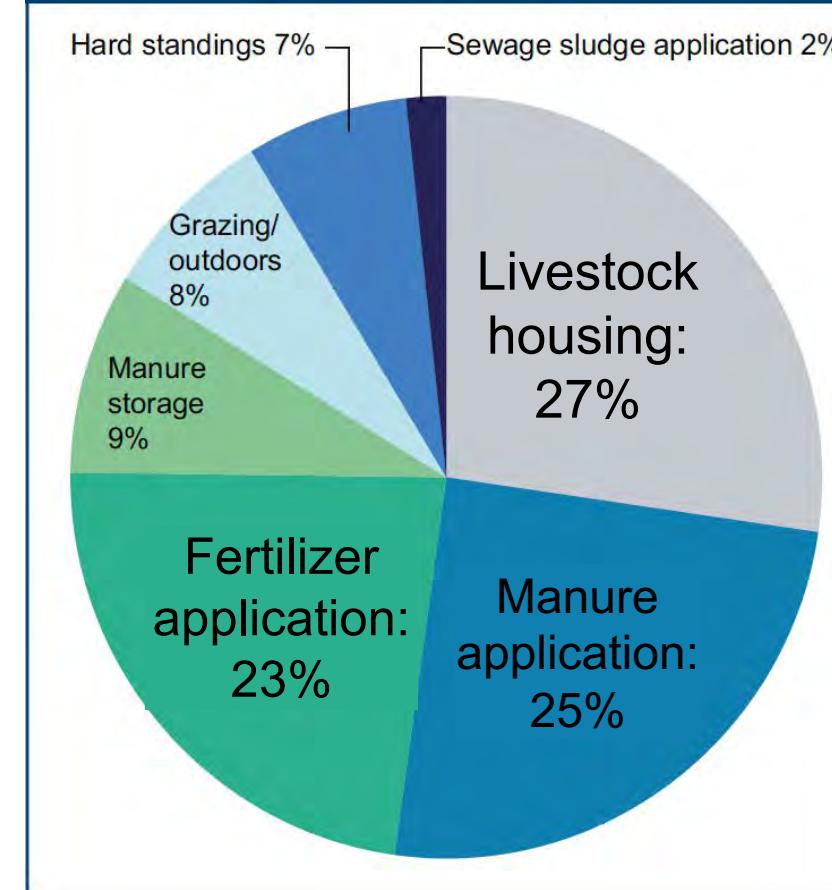
# Farming Practices that Releasing NH<sub>3</sub>

## UK NH<sub>3</sub> Emissions by activity and category

by farming activity



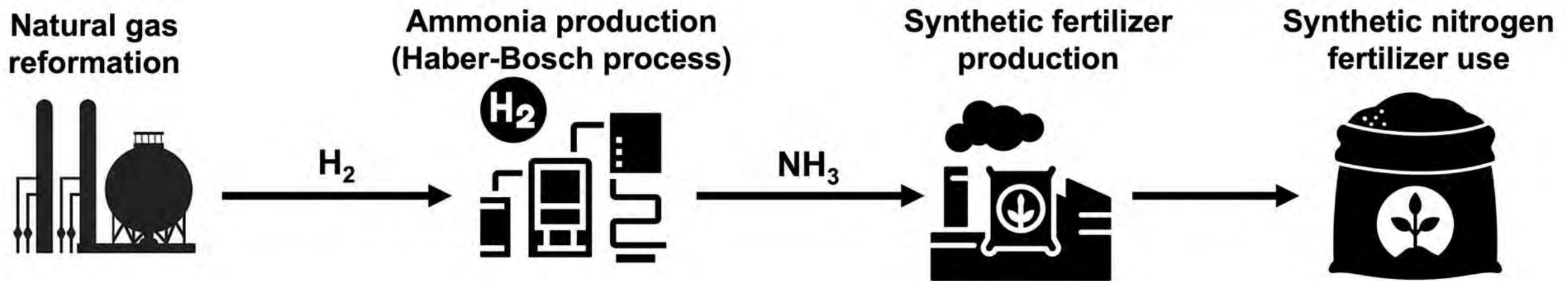
by management category



[UK Clean Air Strategy, 2019]

# Fertilizer is Fossil-Fuel Derived

23% of UK NH<sub>3</sub> emissions from fertilizer and 100% UK NH<sub>3</sub> produced with natural gas



Overwhelming majority of synthetic nitrogen fertilizer from natural gas

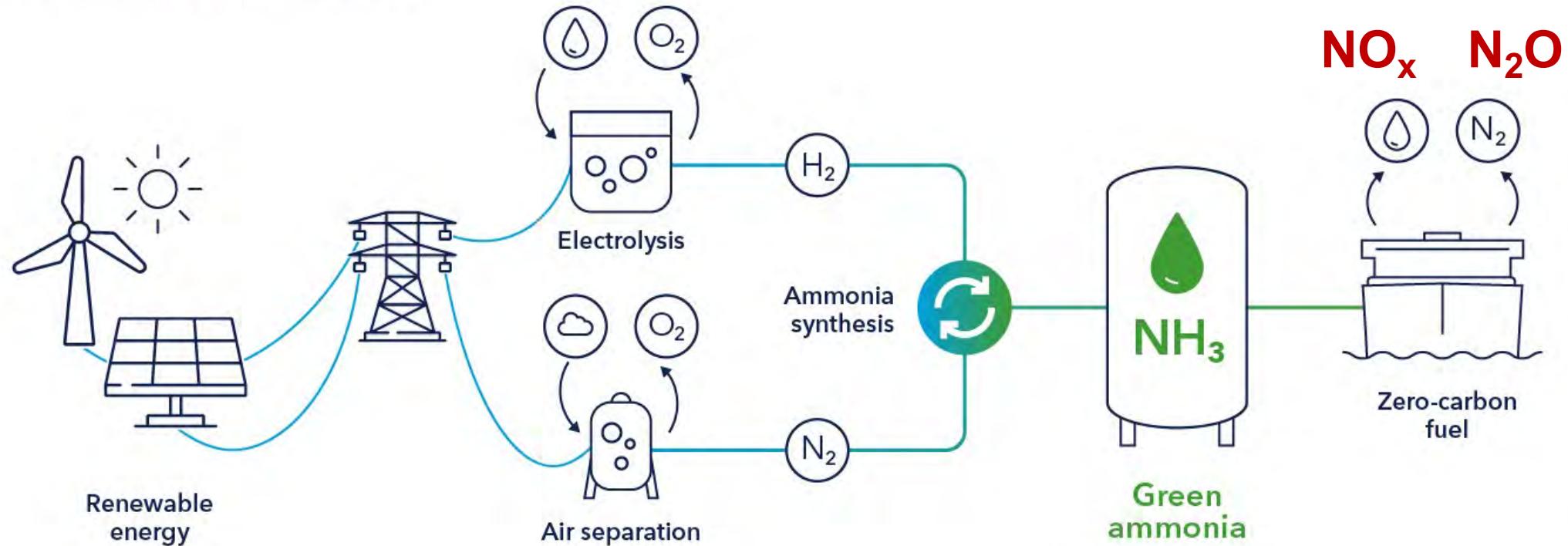
Globally, 20% of industrial natural gas used to make NH<sub>3</sub>

[Vohra et al., in progress]

# Ammonia as a Zero-Carbon Fuel of the Future

Additional incentive to study the environmental effects of NH<sub>3</sub>

Green ammonia - production and use



# UK NH<sub>3</sub> Emission Trends Compared to Emissions

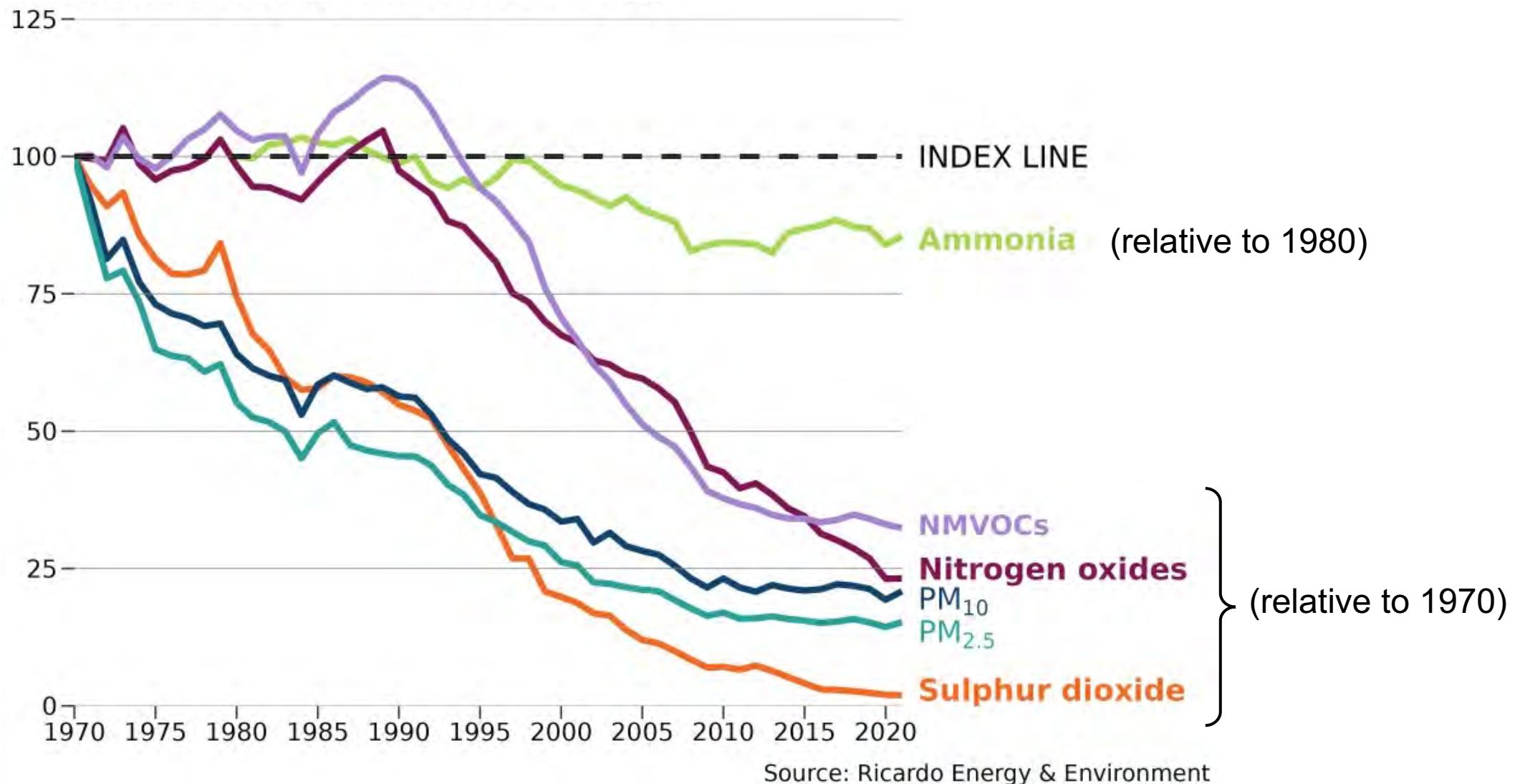


Image source: <https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-summary>

# UK NH<sub>3</sub> Emissions Regulations



**8% decline** relative to 2005 in 2020 to 2029

(**59%** for SO<sub>2</sub>; **42%** for NO<sub>x</sub>)

**16% decline** relative to 2005 from 2030

(**79%** for SO<sub>2</sub>; **63%** for NO<sub>x</sub>)



[Code of Good Agricultural Practice  
\(COGAP\) for Reducing Ammonia  
Emissions \(print version\)](#)

Ref: PB14506

PDF, 4.93 MB, 30 pages

# UK NH<sub>3</sub> Emissions Regulations

UK not meeting the emissions targets? Alter the inventory!

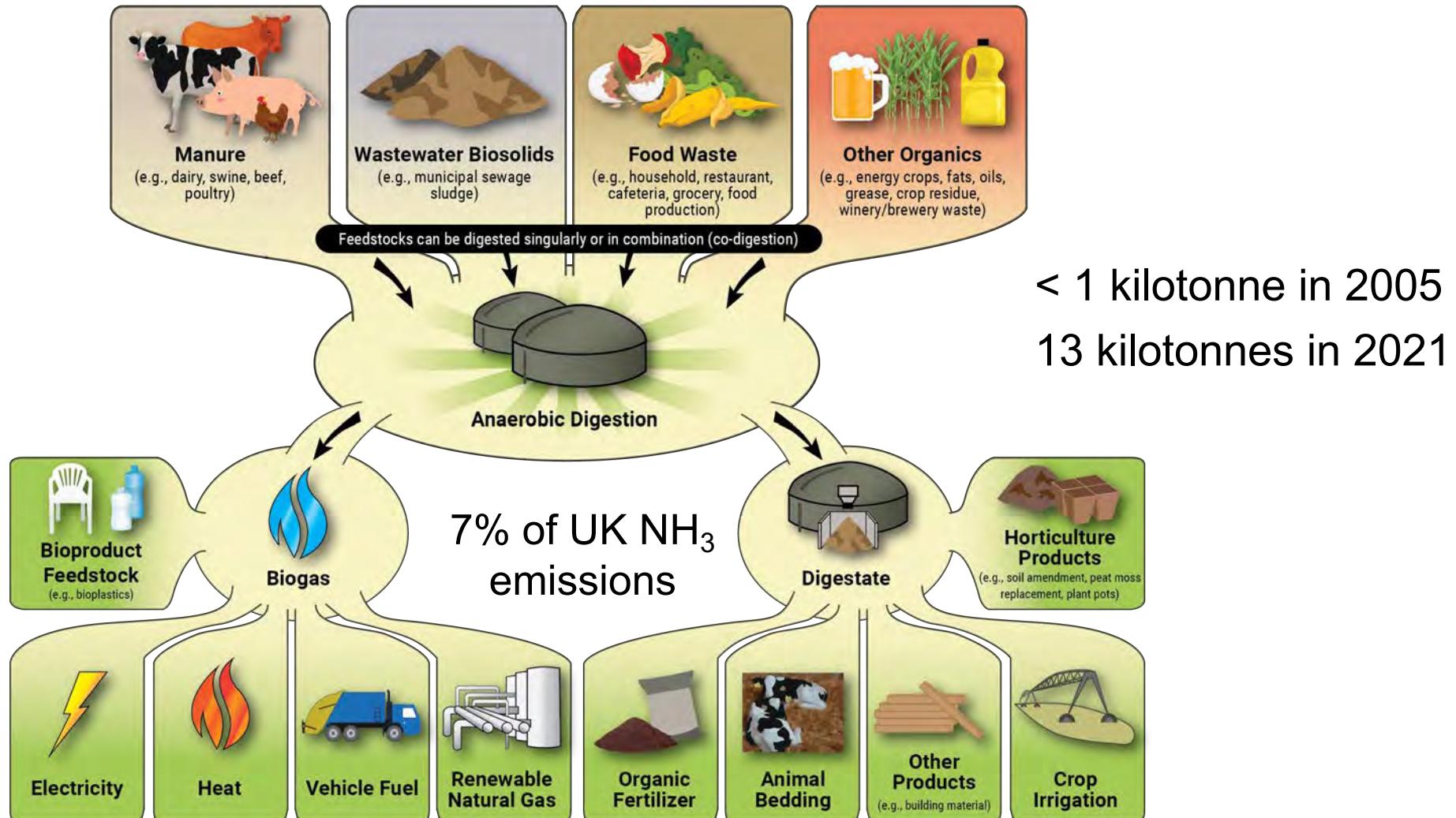


Image source: <https://www.epa.gov/agstar/how-does-anaerobic-digestion-work>

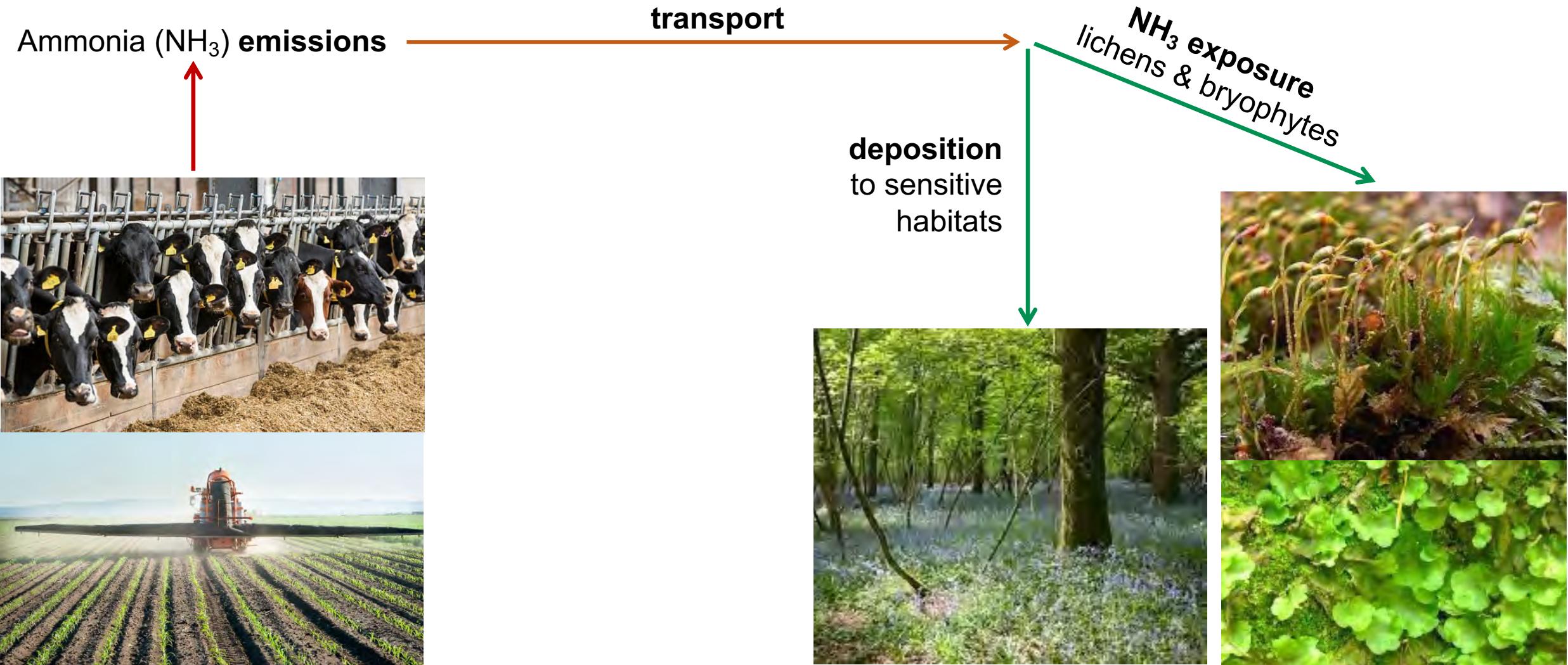
More here: <https://www.endsreport.com/article/1846831/regulatory-capture-nfu-lobbied-defra-lower-its-global-air-quality-ambitions>

# Environmental Concerns over NH<sub>3</sub> Emissions

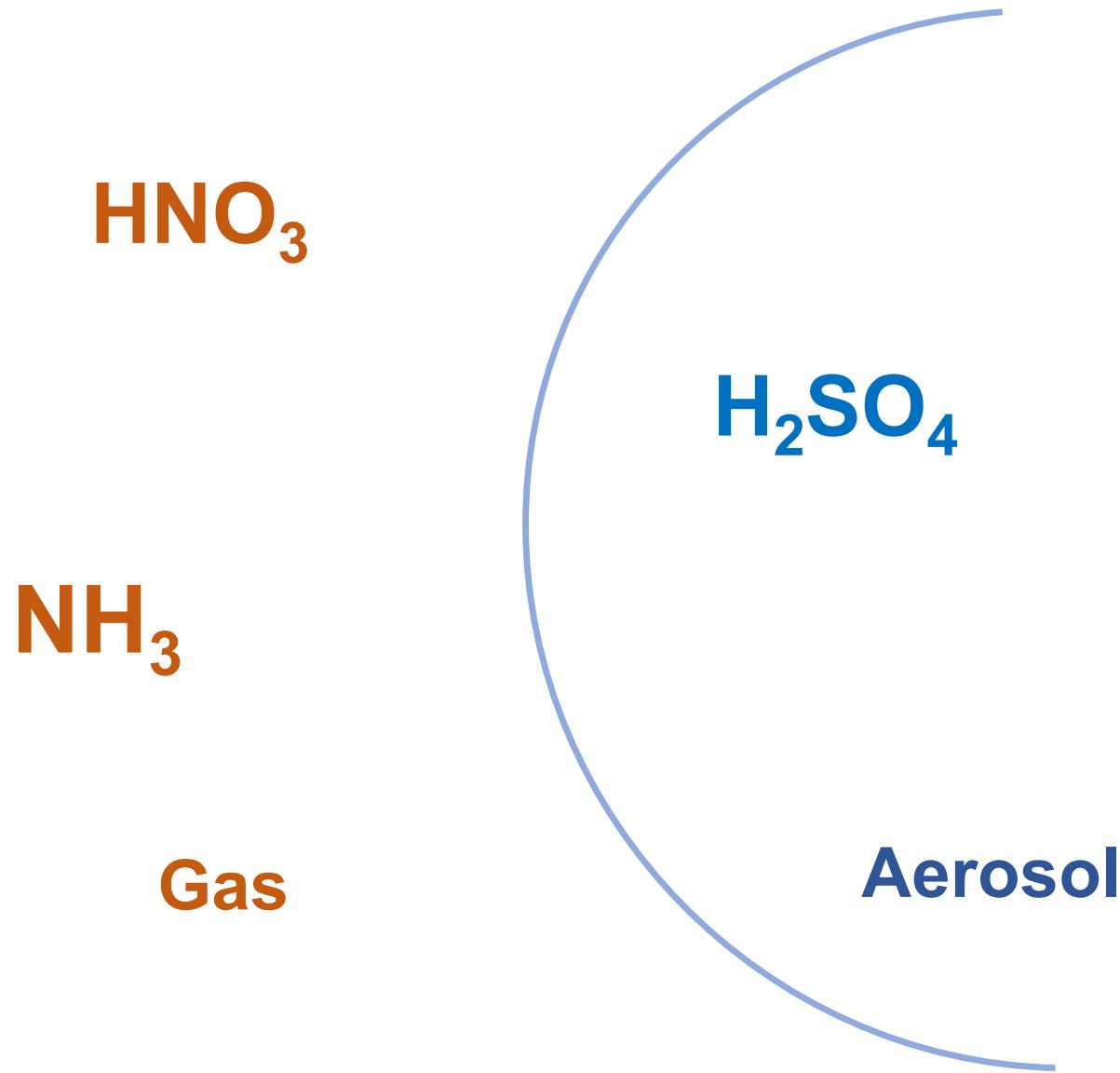


# Environmental Concerns over NH<sub>3</sub> Emissions

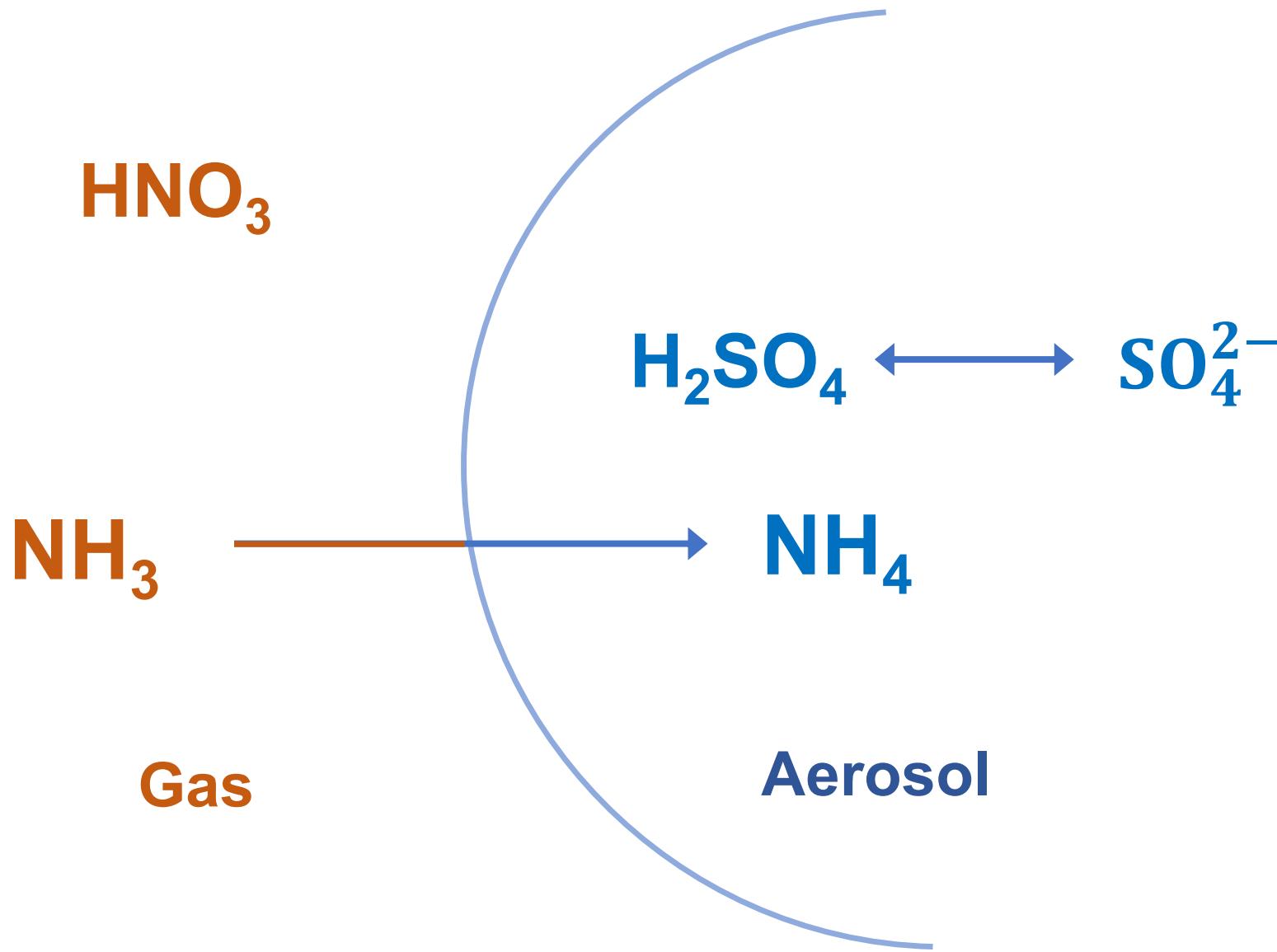
Offsets ecosystem balance via direct exposure and nitrogen deposition



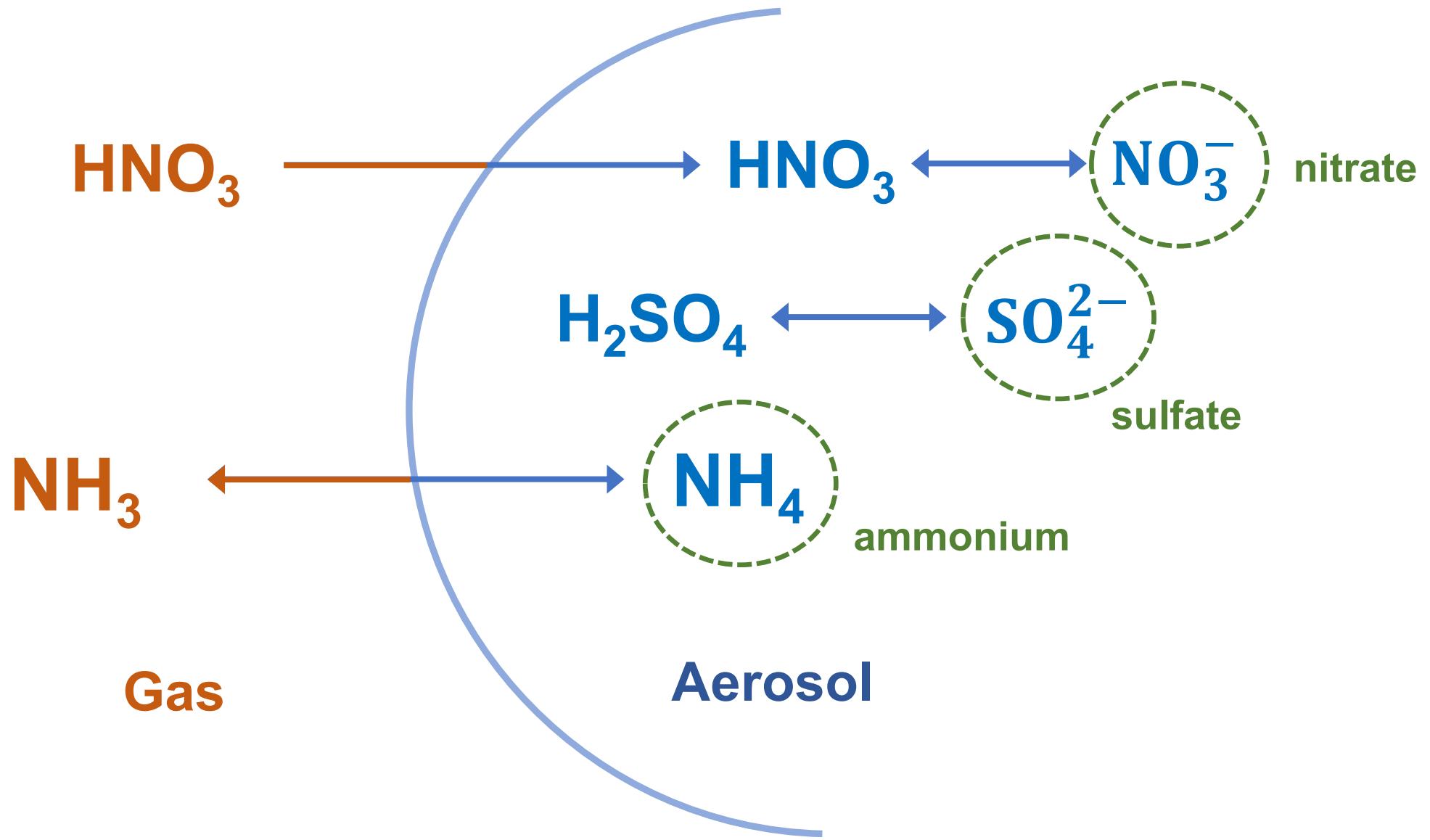
# $\text{NH}_3$ Contribution to Particulate Matter (PM)



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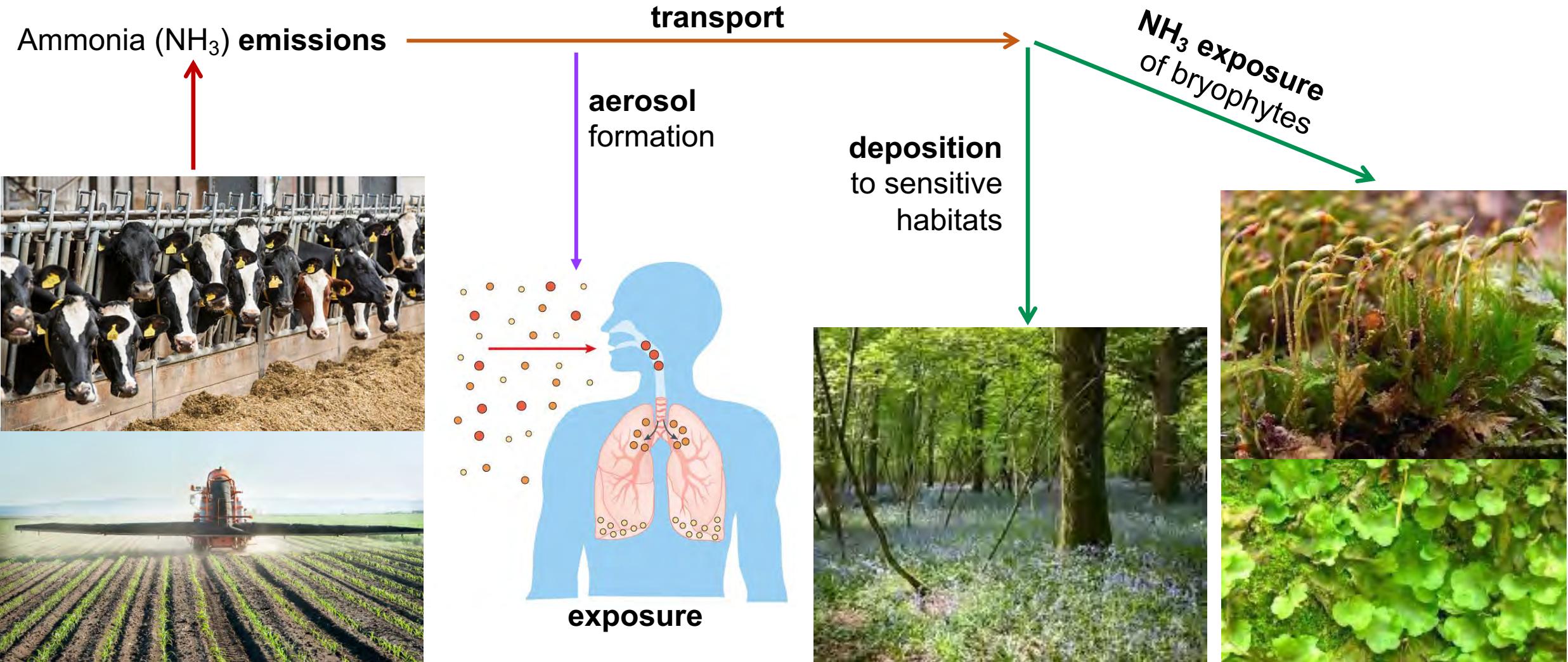


# $\text{NH}_3$ Contribution to Particulate Matter (PM)



# Environmental Concerns over NH<sub>3</sub> Emissions

Impacts health as fine particulate matter (PM<sub>2.5</sub>) precursor



# Research Questions

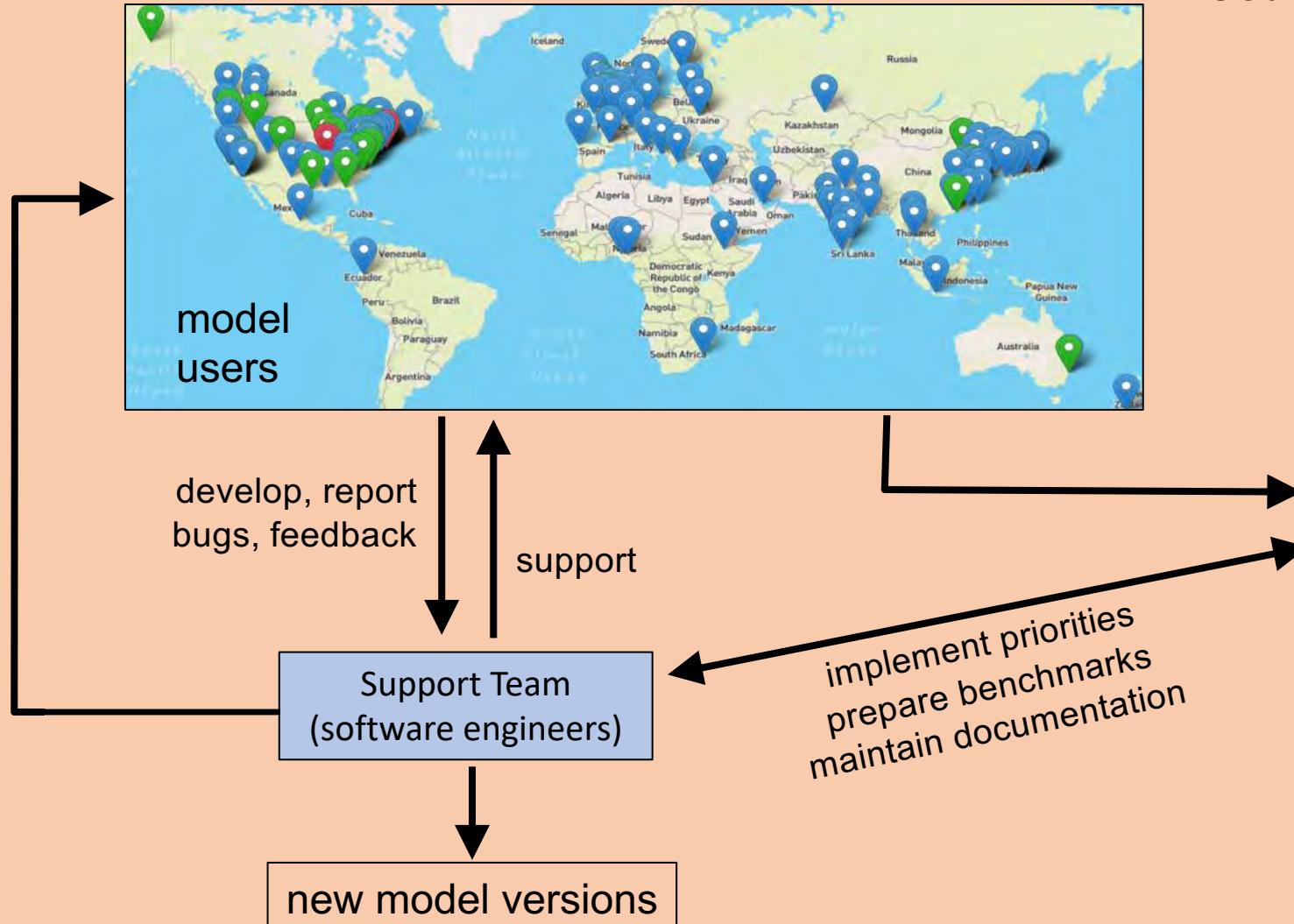
How large is the present-day impact on public and ecosystem health?

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>

## 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

# GEOS-Chem Simulation of PM<sub>2.5</sub>, NH<sub>3</sub>, and N deposition

Emissions

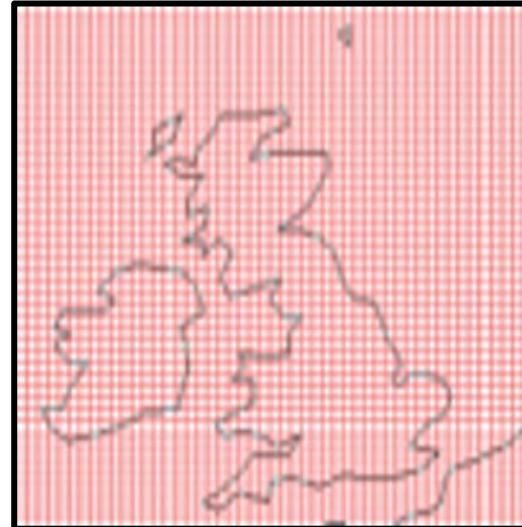


**Present-day:**

UK National Atmospheric  
Emission Inventory (NAEI)

**GEOS-Chem**

FlexGrid nested over the UK at 0.25° x 0.3125°



**NASA GEOS-FP  
Meteorology**

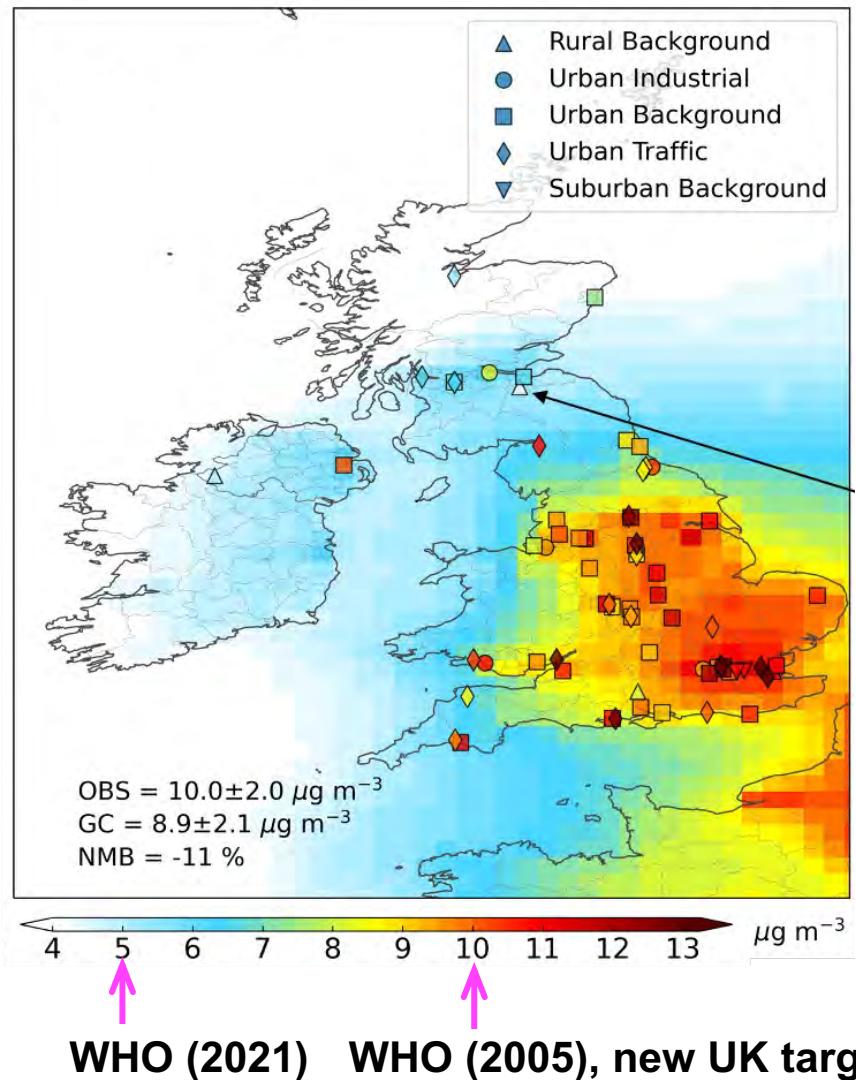
Gas- and aerosol-phase chemistry,  
transport, wet+dry deposition



**Present-day surface NH<sub>3</sub> and PM<sub>2.5</sub> components  
and nitrogen wet and dry deposition**

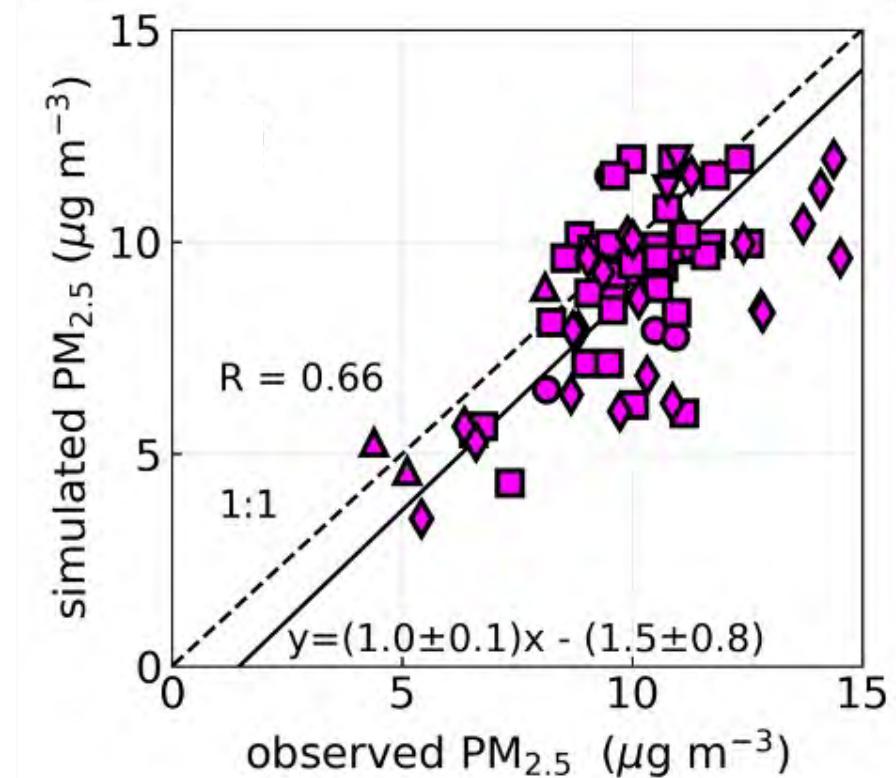
# Model Validation Against Network Measurements

Use total PM<sub>2.5</sub> observations from the Automatic Urban and Rural Network (AURN) to assess model



79% of UK exceeds updated WHO guideline

Compare annual mean surface concentrations of PM<sub>2.5</sub> for 2019

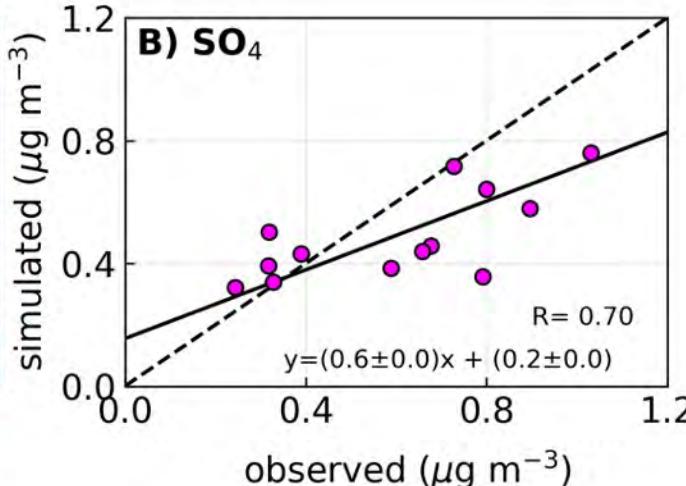
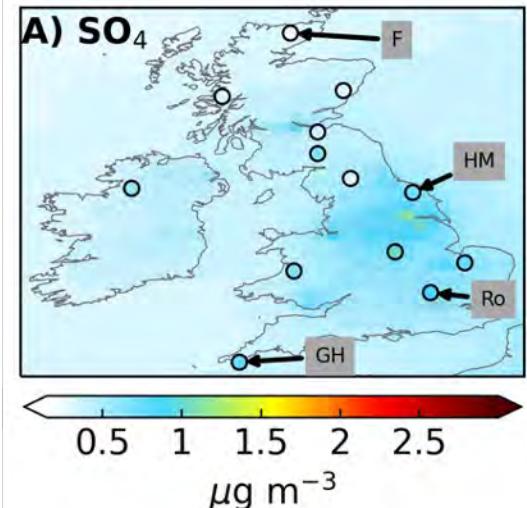
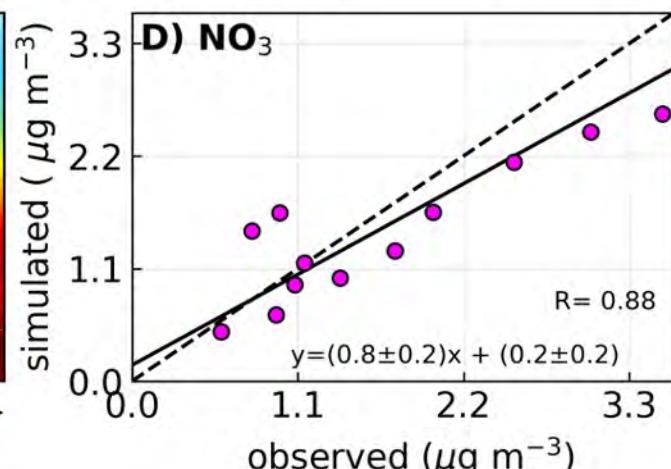
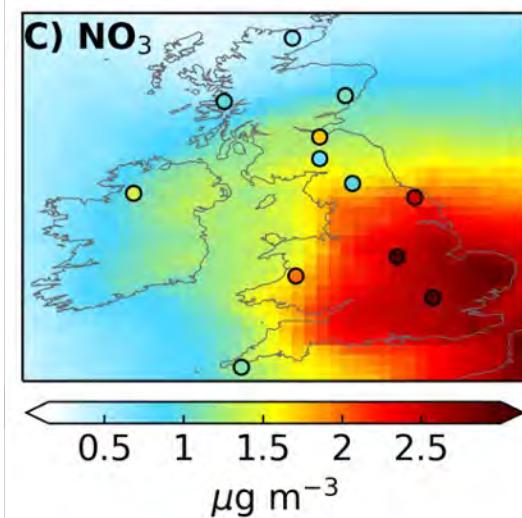
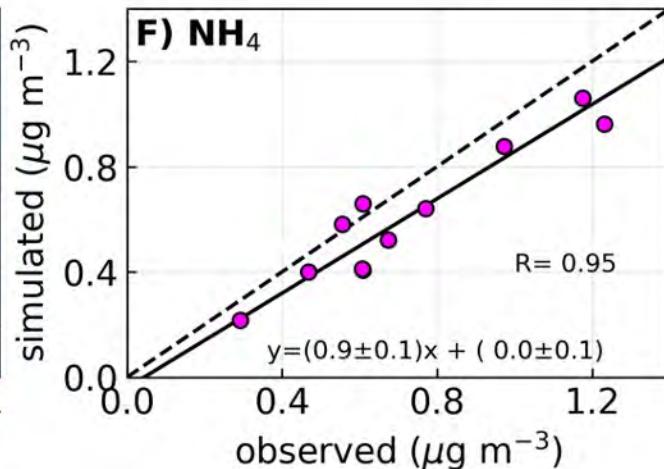
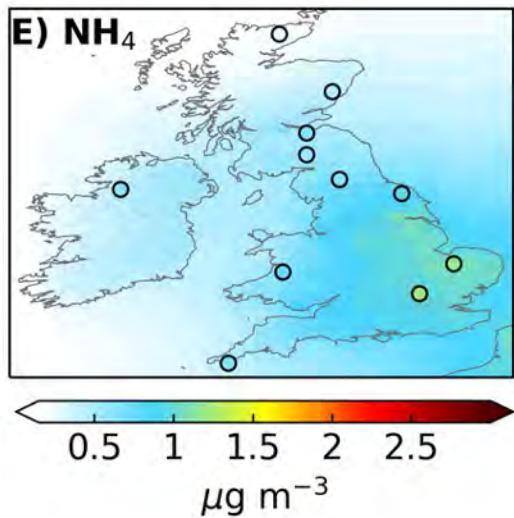


Consistent spatial pattern ( $R = 0.66$ ) and variance (slope = 1.0). Model 11% less than observations

[Kelly et al., 2023]

# Assess Validity of Model using Permanent Networks

Use PM<sub>2.5</sub> composition measurements from UKEAP and EMEP sites to assess model



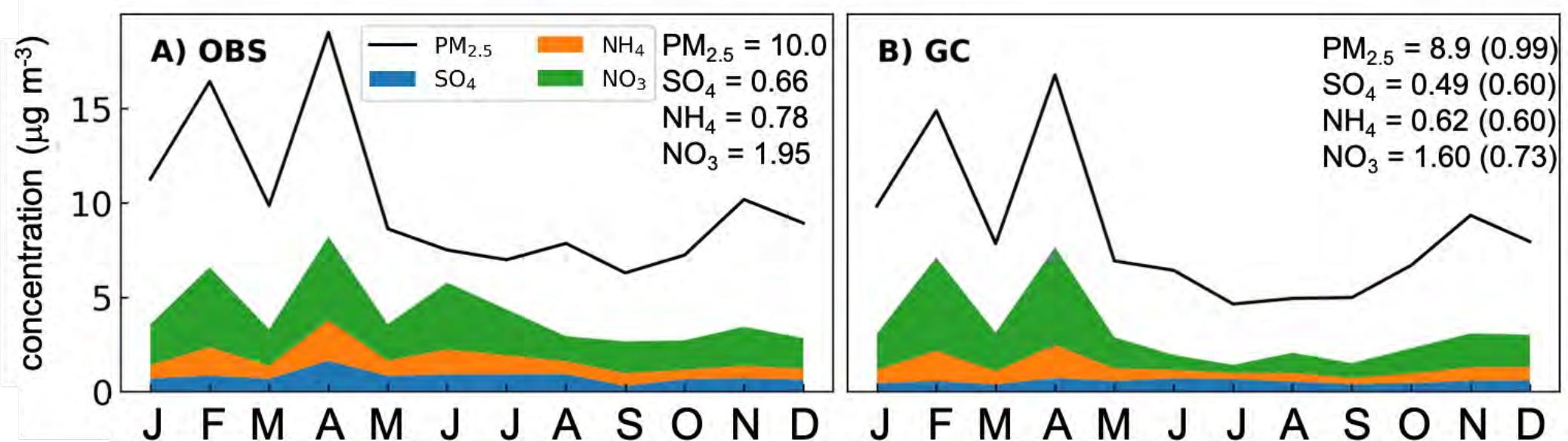
Model underpredicts observed (sulfate, nitrate, ammonium) and possibly overpredicts unobserved (dust) components.

Model captures variance of components from NO<sub>x</sub> (nitrate) and ammonia (ammonium)

# Assess Validity of Model using Reference Monitors

Also evaluate model skill at reproducing observed seasonality in PM<sub>2.5</sub>

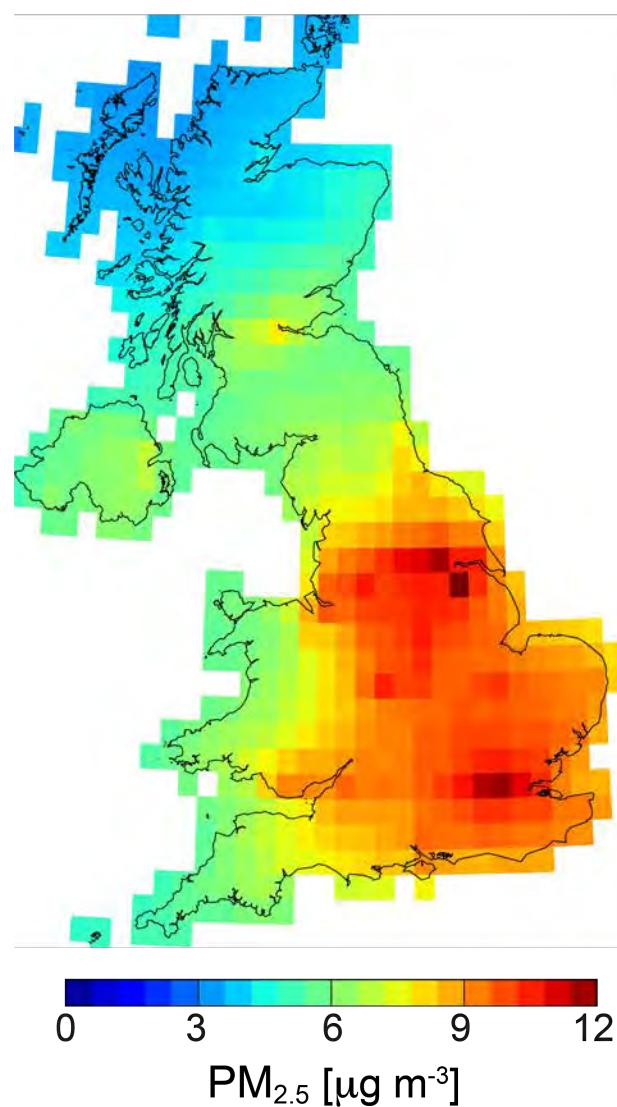
**SO<sub>4</sub>:** sulfate; **NO<sub>3</sub>:** nitrate; **NH<sub>4</sub>:** ammonium



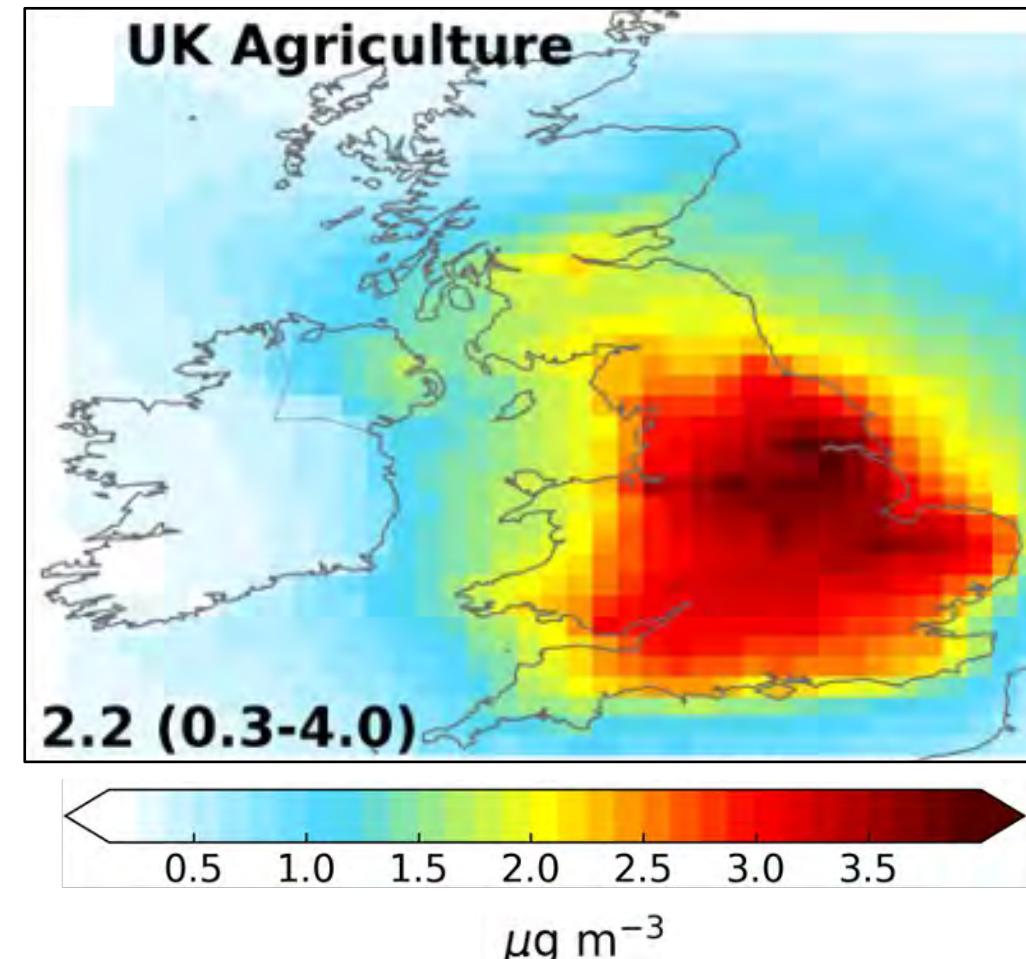
Enhancements in cold months and when ammonia emissions from agriculture peak due to application of synthetic fertilizer in March-April

# GEOS-Chem Present-Day PM<sub>2.5</sub>

Present-day PM<sub>2.5</sub>



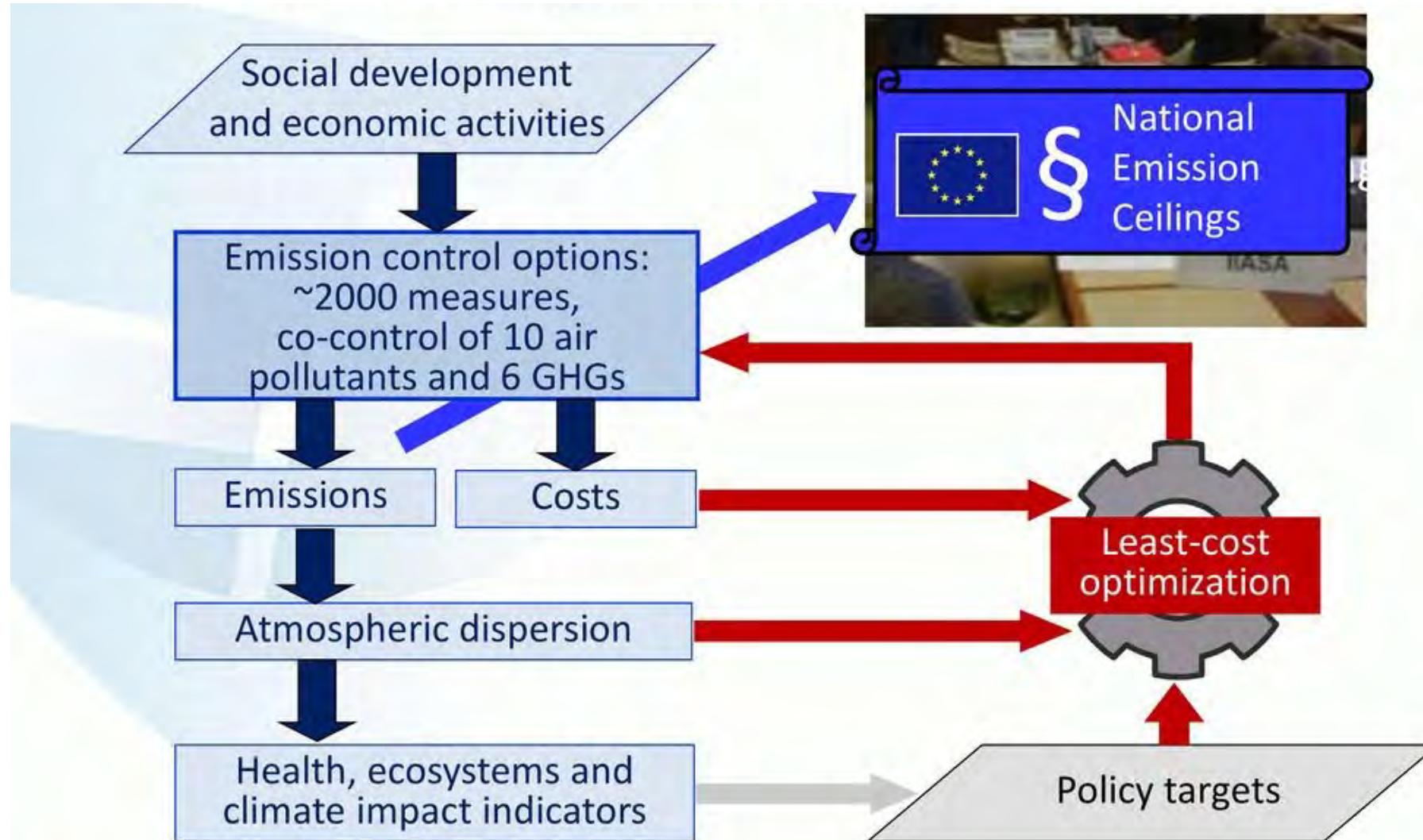
Large contribution of agricultural NH<sub>3</sub> emissions to PM<sub>2.5</sub>



79% of UK grids > 5  $\mu\text{g m}^{-3}$  (WHO PM<sub>2.5</sub> 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



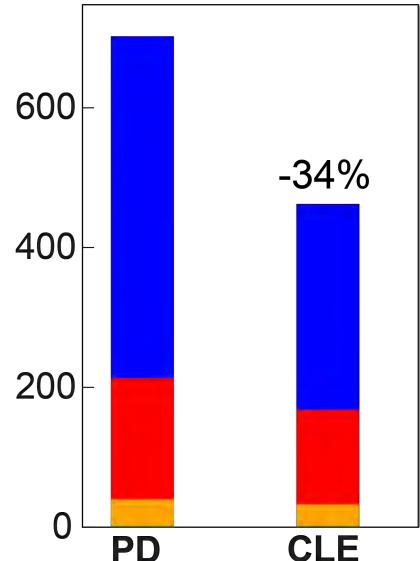
[Slide credit: adapted from slide by M. Amman (IIASA)]

# Emission Control Options for the UK

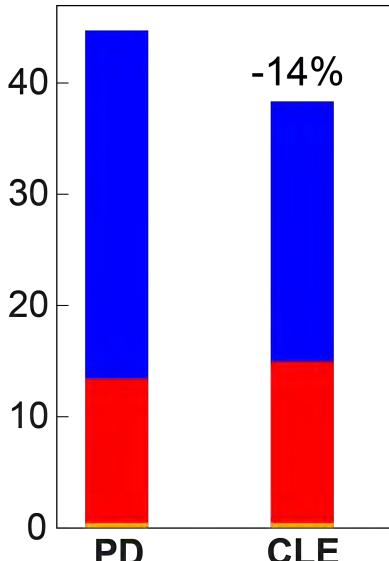
## Legislated emissions targets (CLE)

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

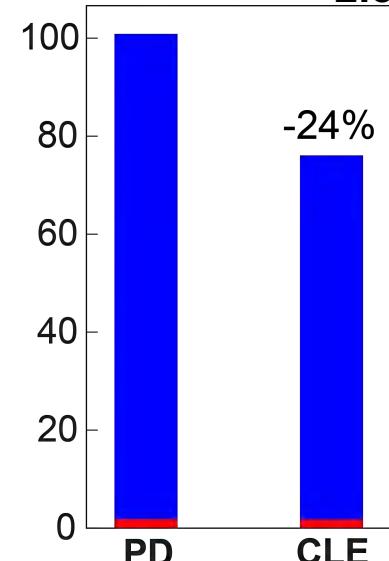
**NO<sub>x</sub> [Gg NO]**



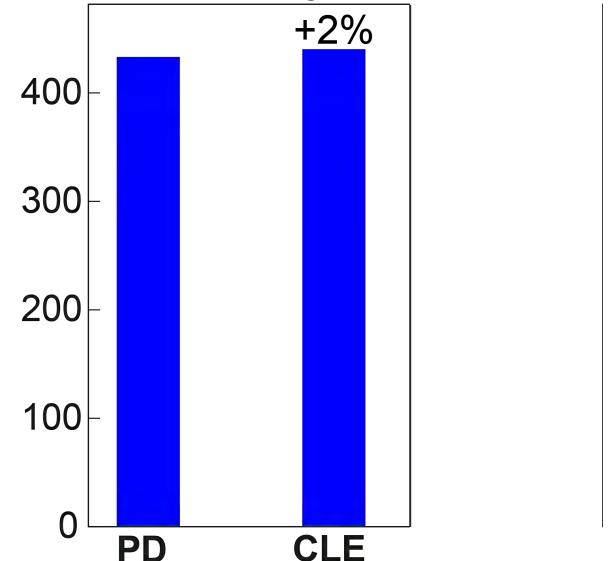
**SO<sub>2</sub> [Gg S]**



**PM<sub>2.5</sub> [Gg]**



**NH<sub>3</sub> [Gg]**



- Terrestrial Anthropogenic
- Shipping
- Aviation

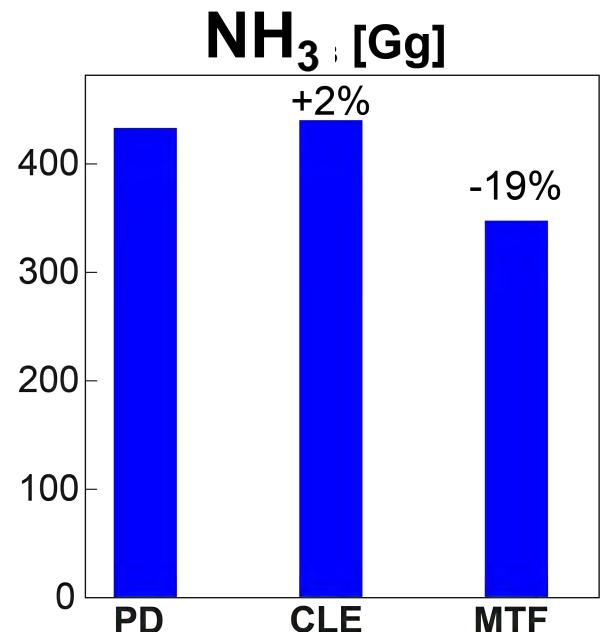
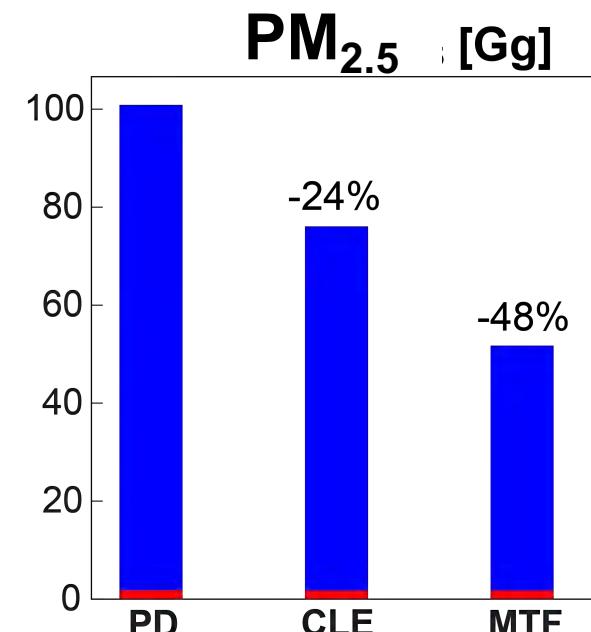
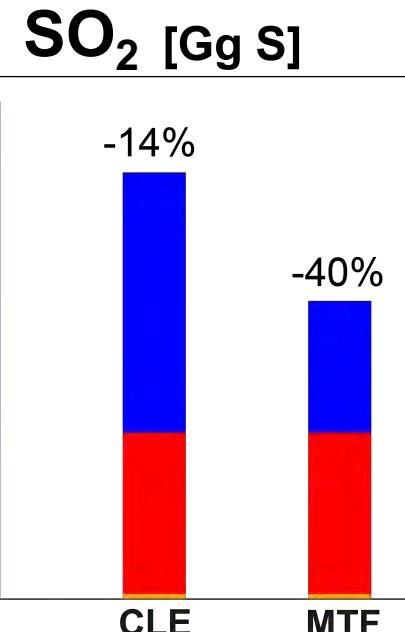
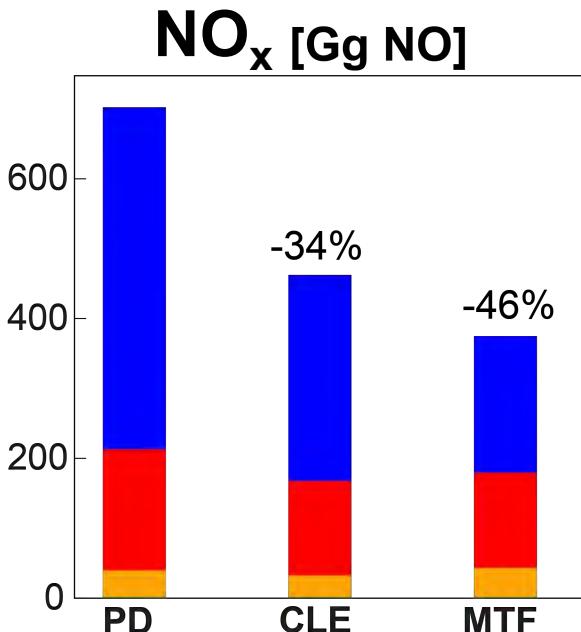
Projections from **ECLIPSE v6b** for all but aviation (from **IPCC**)

NH<sub>3</sub> 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**)



- Terrestrial Anthropogenic
- Shipping
- Aviation

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

Best technology decreases all precursors except ammonia (NH<sub>3</sub>) by 40-48%

NH<sub>3</sub> controls limited to suggested rather than enforced measures

# Influence of Emission Controls on PM<sub>2.5</sub>, NH<sub>3</sub>, and N deposition

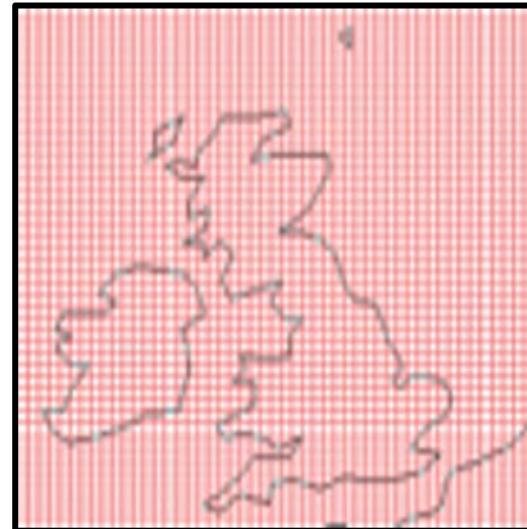
Emissions



**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



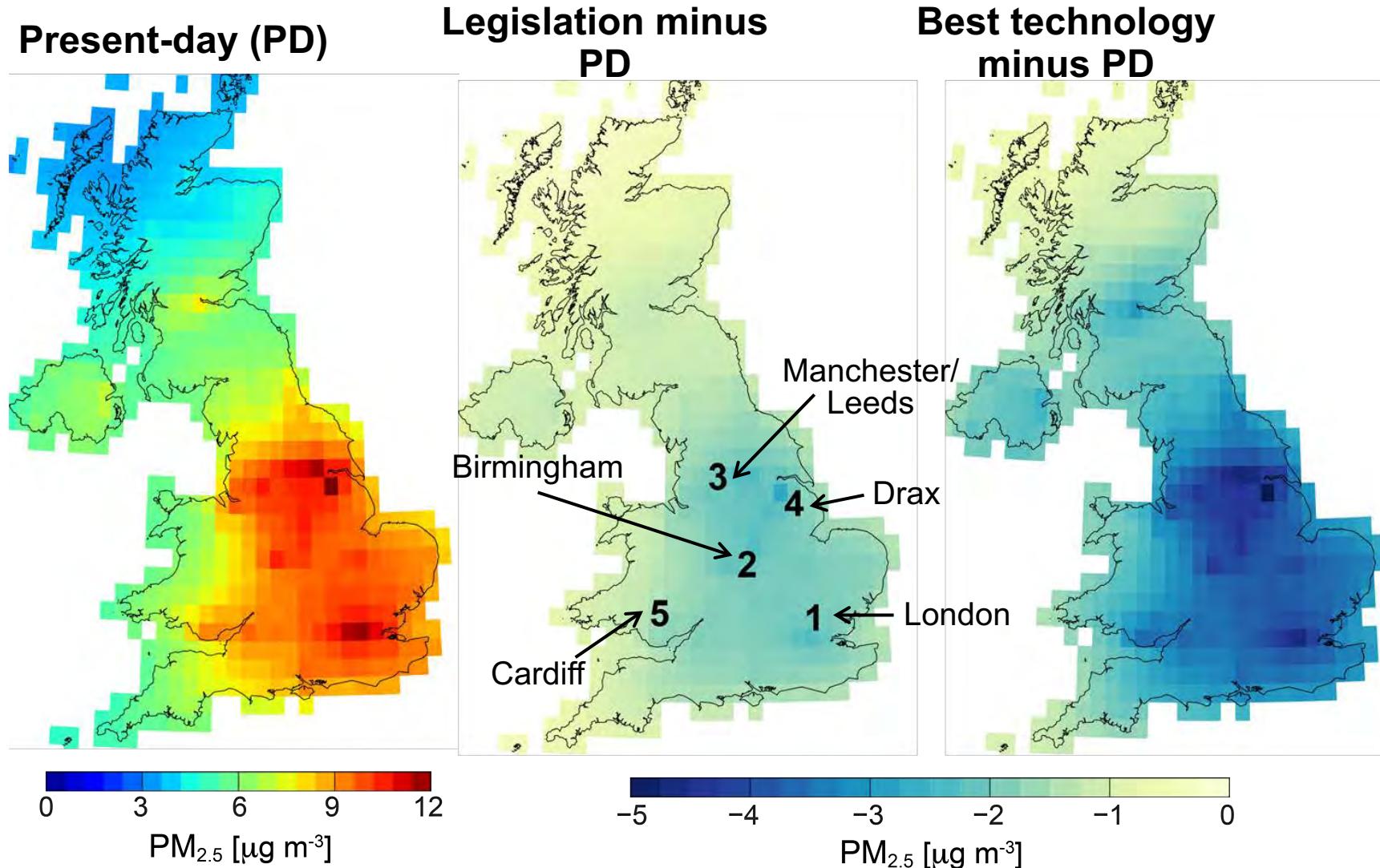
**NASA GEOS-FP  
Meteorology**

2019



**Future surface NH<sub>3</sub> and PM<sub>2.5</sub> components and  
nitrogen wet and dry deposition**

# Influence of emission controls on PM<sub>2.5</sub>

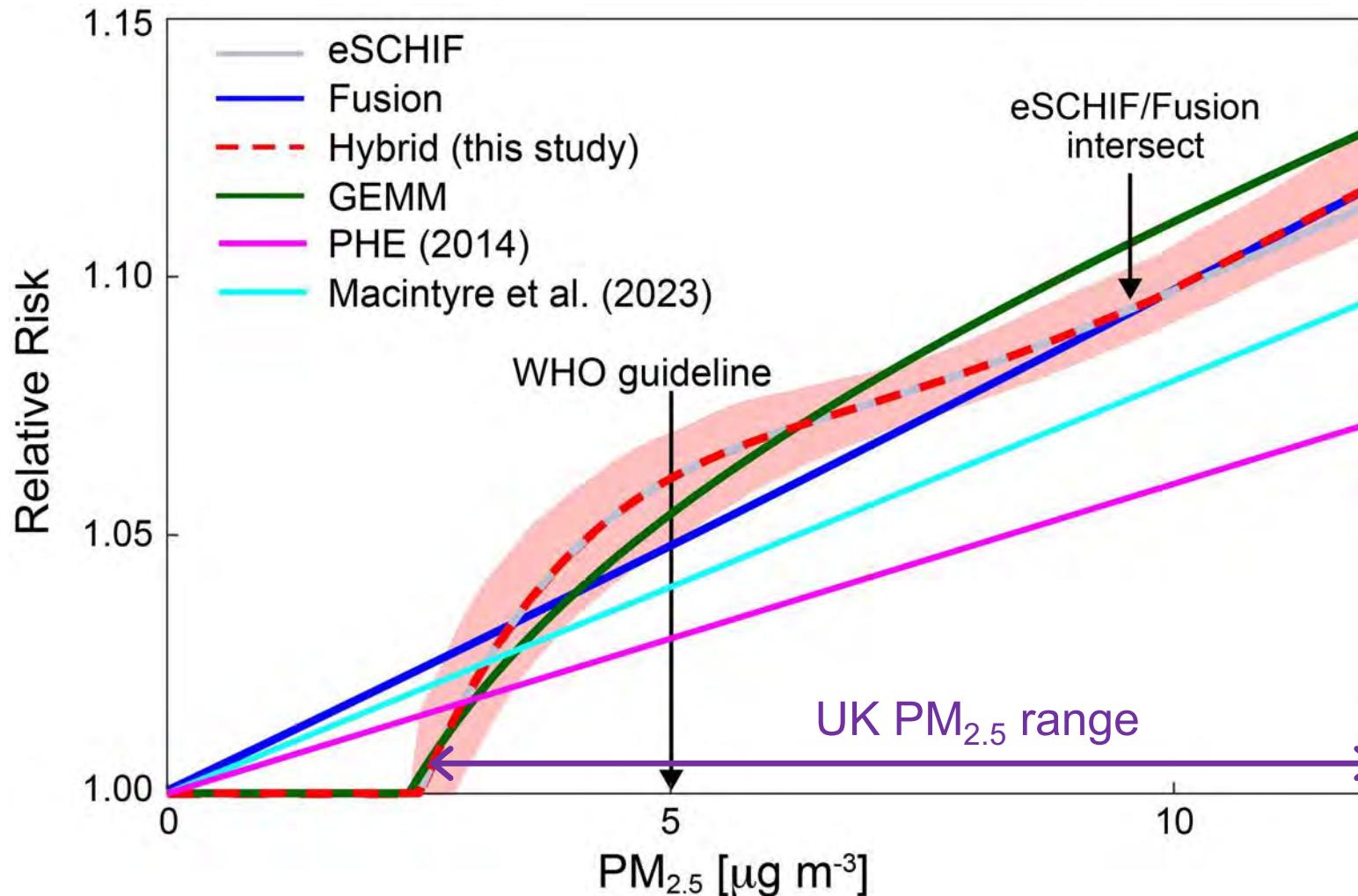


Current legislation controls cause PM<sub>2.5</sub> decline of at most 2  $\mu\text{g m}^{-3}$  compared to 5  $\mu\text{g m}^{-3}$  for best technology  
UK grids > 5  $\mu\text{g m}^{-3}$ : 79% in the PD, 58% with legislated controls, and 36% with best technology

# Relating long-term PM<sub>2.5</sub> 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

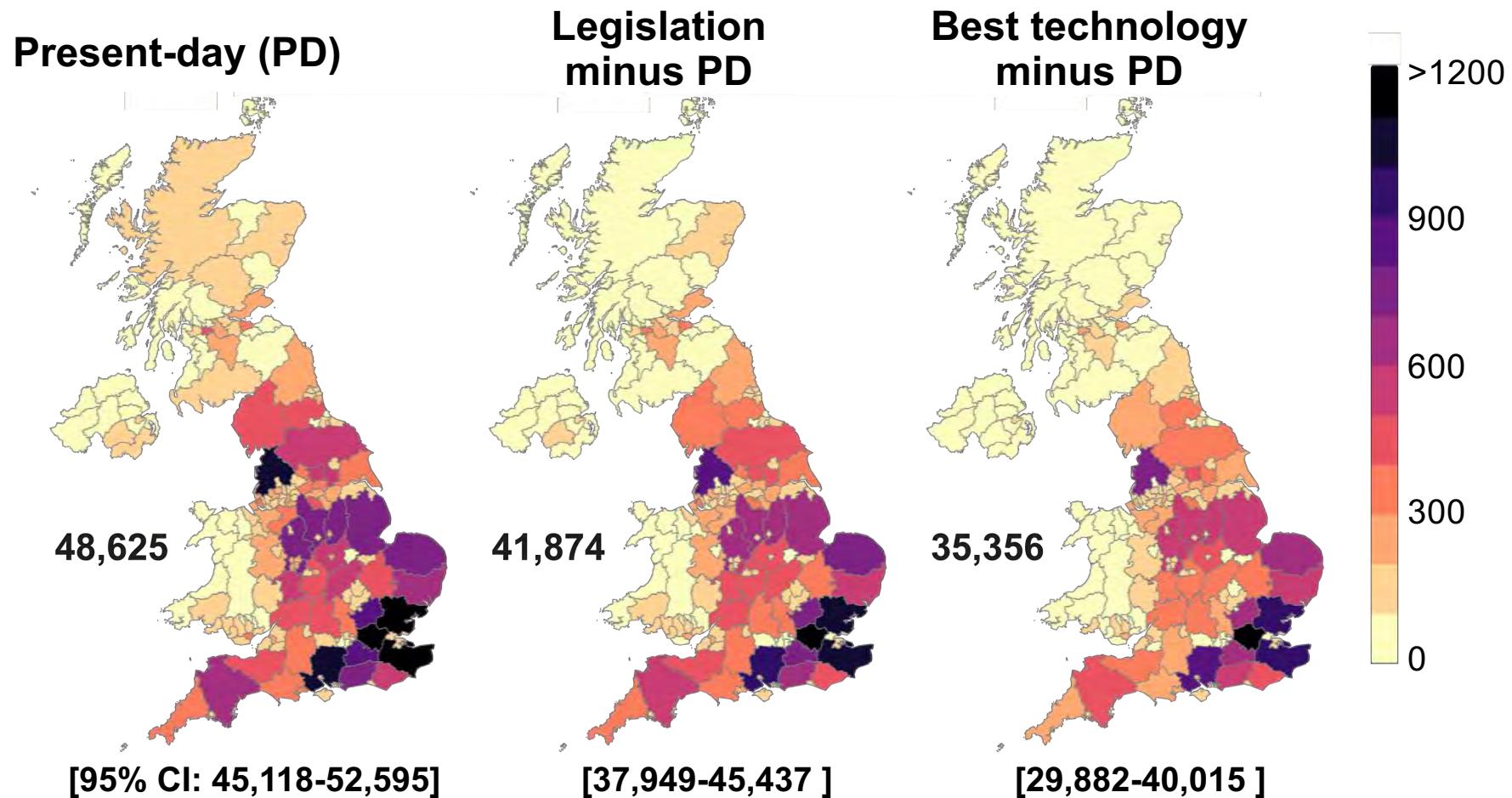
**Hybrid:**

eSCHIF at 2.5-9.8 μg m<sup>-3</sup> and  
Fusion beyond 9.8 μg m<sup>-3</sup>

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

# Adult premature mortality from long-term exposure to PM<sub>2.5</sub>

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

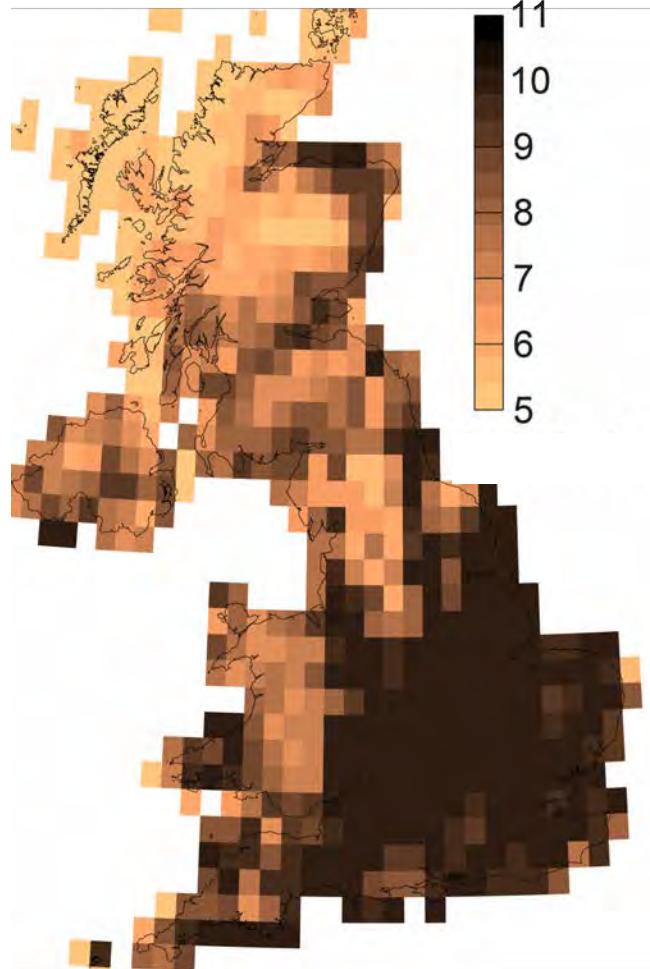


6,751 avoided early deaths with legislated controls, double that (13,269) with best available technology

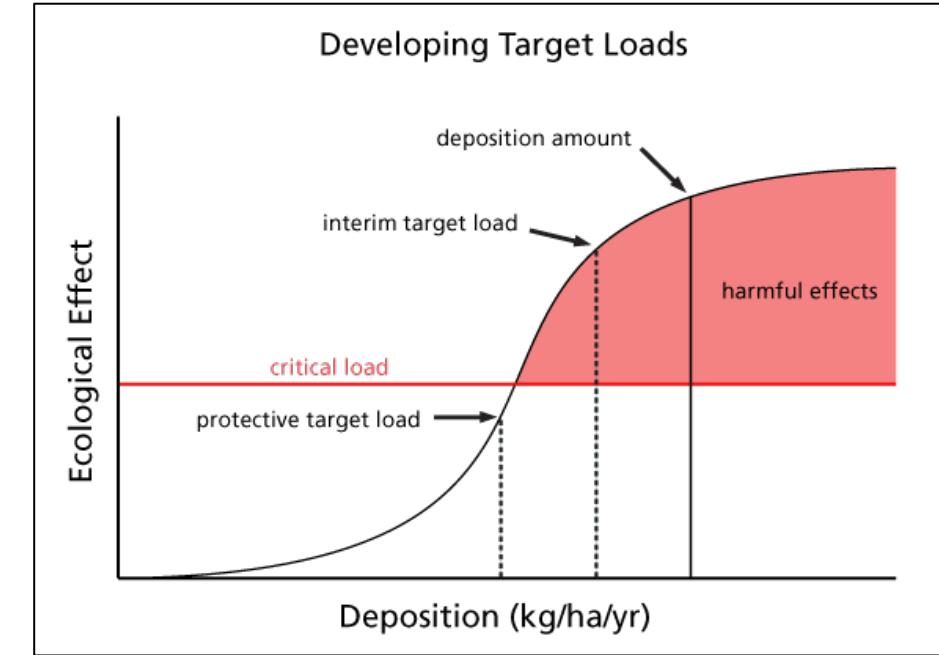
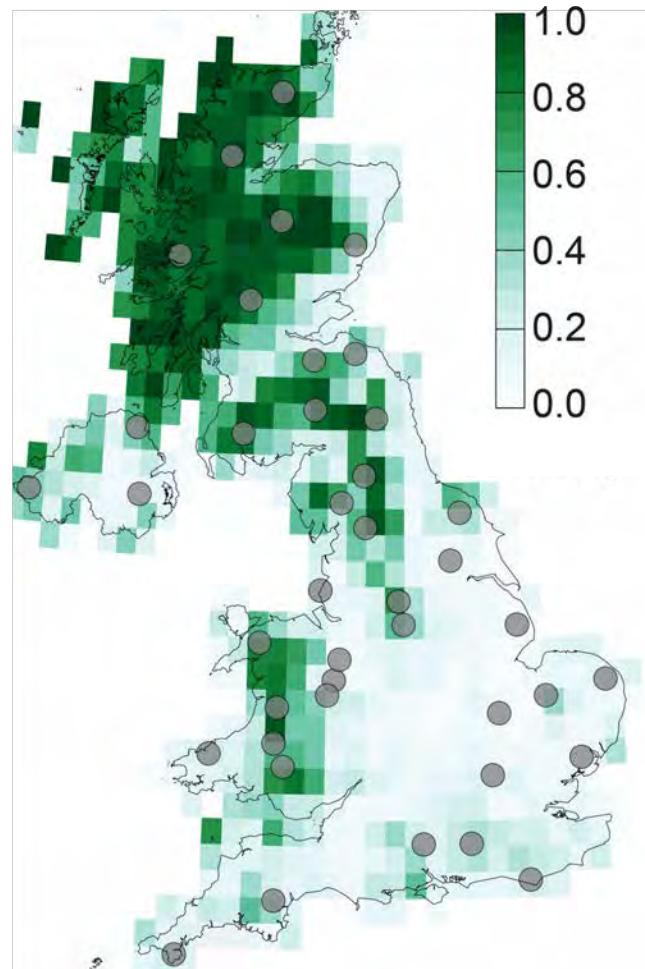
Burden of disease estimates greater than past UK-focused studies and similar to those obtained with GEMM curve

# 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

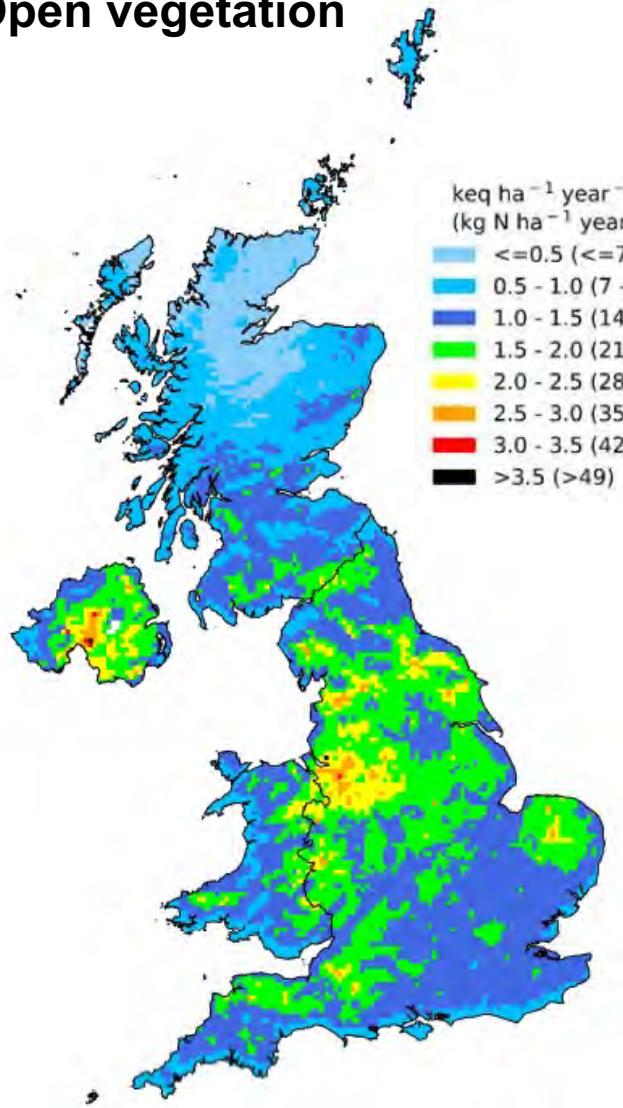
Critical load and sensitive habitat maps from Ed C. Rowe & N. Hina at the UK Centre for Ecology & Hydrology (UKCEH)

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

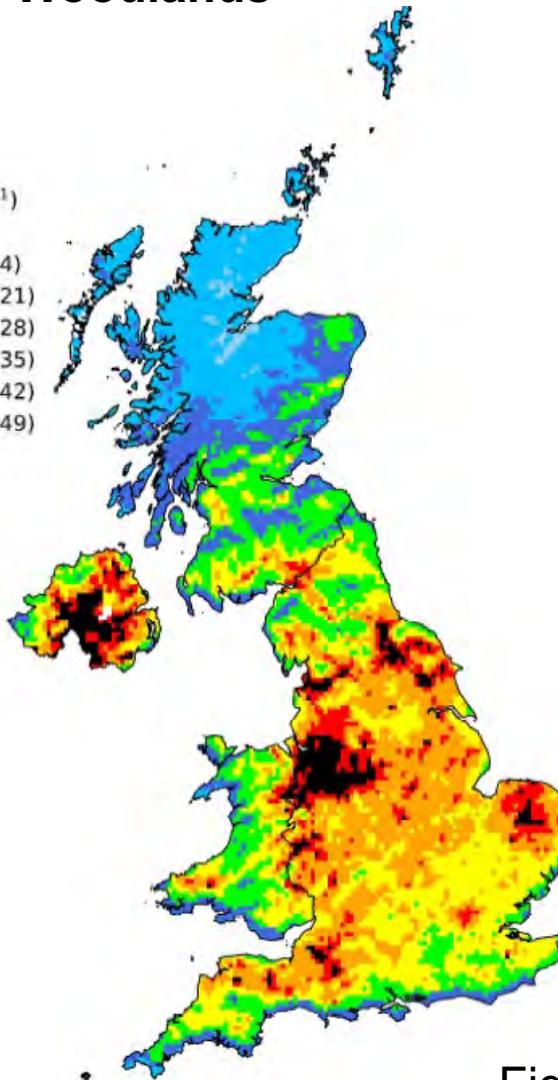
# High Resolution Total Nitrogen Wet + Dry Deposition

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

Open vegetation



Woodlands



GEOS-Chem too coarse to resolve deposition over sensitive habitats

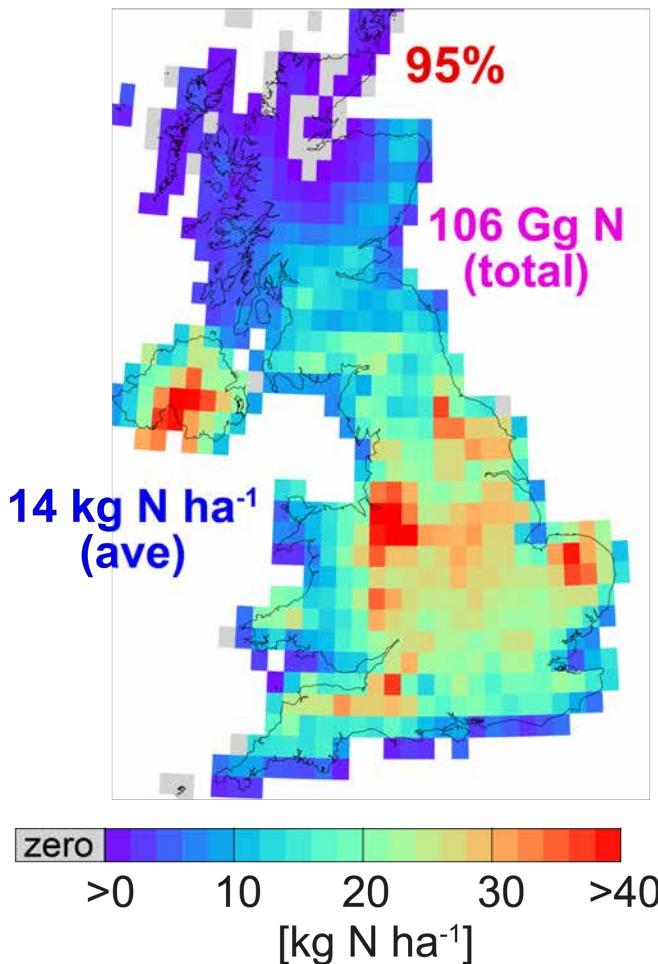
GEOS-Chem also doesn't account for enhanced washout over upland areas or deposition of cloud droplets to vegetation.

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

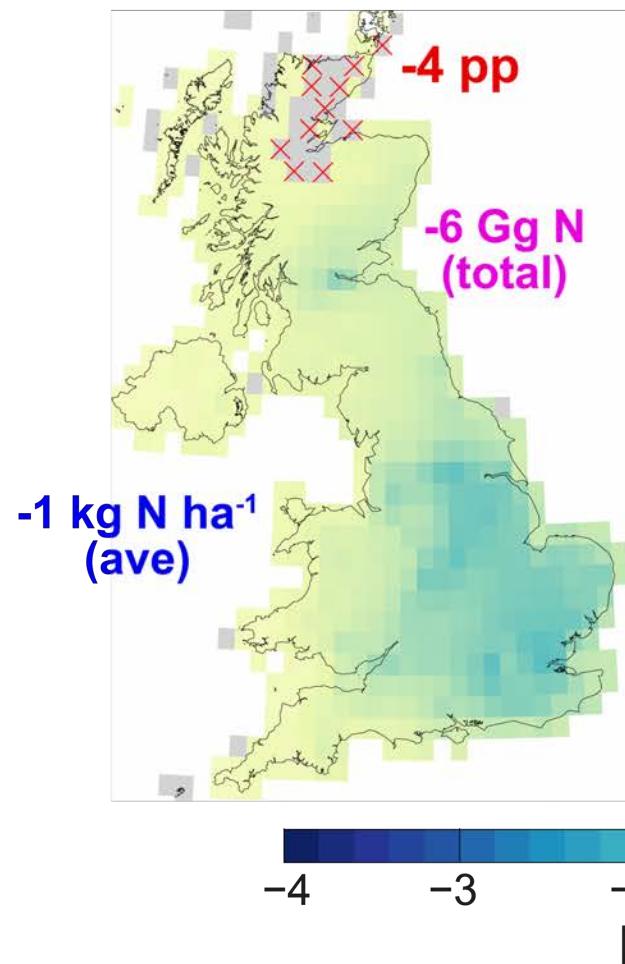
Use CBED for present day and GEOS-Chem for response to emissions controls

# Influence of Emission Controls on Nitrogen Critical Loads

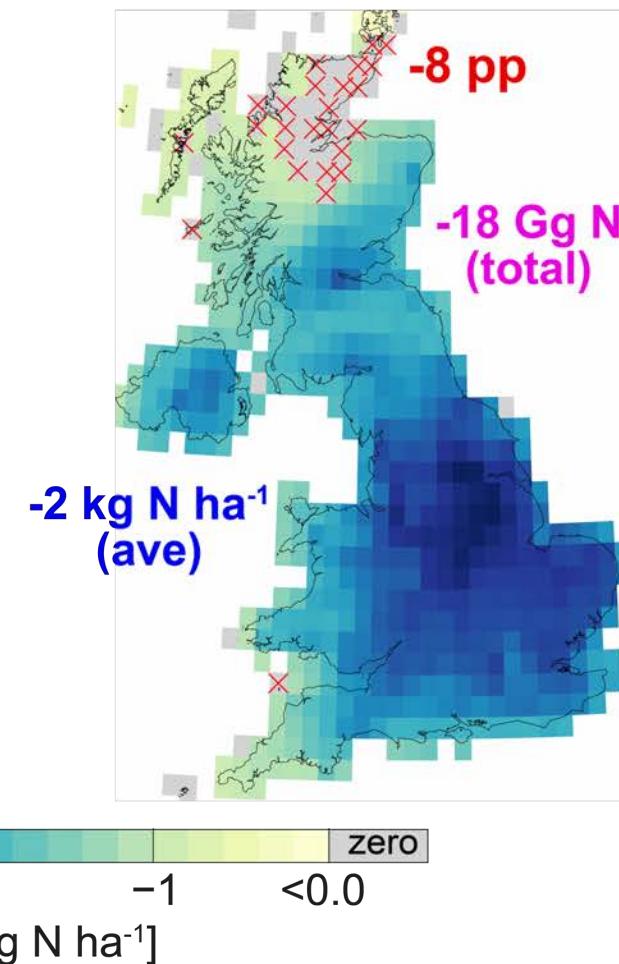
Present-day (PD)



Legislation minus PD



Best technology  
minus PD



Values are **total**, **mean**, and **coverage** of exceedances

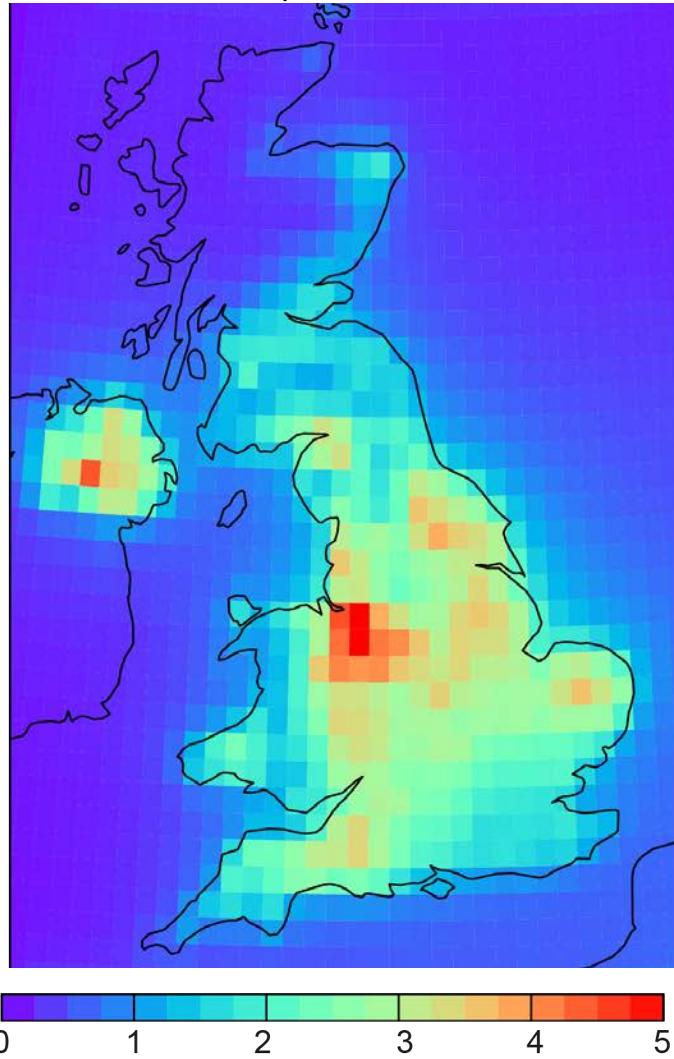
Crosses show grids that fall below critical loads relative to present day

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<sub>3</sub>

Annual mean (2019) NH<sub>3</sub>  
[ $\mu\text{g m}^{-3}$ ]



Lichens and bryophytes show evidence of harm at  
 $\text{NH}_3 > 1 \mu\text{g m}^{-3}$



Alters species composition: favours nitrophytes  
and decreases abundance of acidophytes

Exposure to harmful levels of NH<sub>3</sub>: 73% today, 75% with legislated controls, 69% with best technology

# Takehome Messages

## Present-day impact:

- 79% UK exceeds WHO PM<sub>2.5</sub> guideline
- ~48,000 adults died prematurely from exposure to PM<sub>2.5</sub> 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