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Annex 2
Selection of scenarios for assessing spatially targeted mitigation

Ulli Dragosits, Tom Misselbrook, Kathryn Hampshire, Tim Williamson, Laurence Jones, Ben Marner, Duncan Laxen, Edward Carnell, Samuel Tomlinson, Alison Pridmore, William Bealey & Chris Dore

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For further information please contact:

Joint Nature Conservation Committee
Monkstone House
City Road
Peterborough PE1 1JY
www.jncc.gov.uk

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Contents

Glossary

Acronym	Meaning
AAE	Annual Average Exceedance
ASSI	Area of Special Scientific Interest (Northern Ireland), equivalent of SSSI in Great Britain
AENEID	Atmospheric Emissions for National Environmental Impacts Determination. A model to produce high-resolution (1 km grid) maps of agricultural ammonia, methane and nitrous oxide emissions for the UK, annual maps available through the NAEI
BAU	Business As Usual - includes only those policies that have already been adopted or implemented at the time of the project projection compilation. It does not include additional measures set out in the NAPCP which are designed to meet NECD/NECR targets.
CBED	Concentration-Based Estimated Deposition, a model generating maps of deposition of sulphur, oxidised and reduced nitrogen
CCE	Coordination Centre for Effects, of the WGE
CNCBs	Country Nature Conservation Bodies (Natural England, Scottish Natural Heritage, Natural Resources Wales, Council for Nature Conservation and the Countryside)
CL	Critical Load, an amount of deposition per unit area and time. The formal definition is "a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson & Grennfelt 1988)
CLe	Critical Level, a concentration in air e.g. of ammonia, below which harmful effects do not occur according to present knowledge
CL_{empN}	Empirical critical load for nutrient-nitrogen, as defined in Bobbink *et al*. (2011) and refined for the UK by Hall *et al*. (2011)
CLRTAP	Convention on Long Range Transboundary Air Pollution
DA	Devolved Administration
Daera	Department of Agriculture, Environment and Rural Affairs
Defra	Department for Environment, Food & Rural Affairs
ECA	Emission Control Area
EDZ	Emission Displacement Zone
ELM	Environmental Land Management
ERC	Emission Reduction Commitments
ERZ	Emission Reduction Zone
EU	European Union
FAPRI	Food and Agricultural Policy Research Institute
FRAME	Fine Resolution Atmospheric Multi-pollutant Exchange (atmospheric chemistry and transport model)
ha	Hectares. One hectare is 100 m x 100 m
ICP-M&M	International Cooperative Programme for Modelling and Mapping critical loads and critical levels.
IED	Industrial Emissions Directive
LEZ	Low Emission Zone (a defined area where access by some polluting vehicles is restricted with the aim of improving air quality)
MCPD	Medium Combustion Plant Directive
N	Nitrogen. Strictly, reactive N, i.e. including oxidised and reduced forms of N but not dinitrogen gas, N_2.
NAEI	UK National Atmospheric Emissions Inventory
NAMN	UK National Ammonia Monitoring Network
NARSES	UK agricultural emission model (spreadsheet based), developed by Rothamsted Research
NAPCP	National Air Pollution Control Programme
NE	Natural England
NECD	EU Directive on the Reduction of National Emissions (2016/2284)
NECR	UK National Emission Ceilings Regulations (2018 No 129) transposing NEC Directive 2016/2284/EU.
NFC	UK National Focal Centre, under ICP-M&M

NFR	Nomenclature for Reporting (Format for reporting of national emission data in accordance with the CLRTAP)
NH_3	Ammonia
NMVOC/VOC	Non-Methane Volatile Organic Compounds/Volatile Organic Compounds
NO_x	Nitrogen Oxides
NRMM	Non-Road Mobile Machinery
NRW	Natural Resources Wales
MCPD	Medium Combustion Plant Directive
PaMs	Policies and Measures
PCM	Pollution Climate Mapping (model)
PM	Particulate Matter
SAC	Special Area of Conservation, designated site protected under the Habitats Directive
SEPA	Scottish Environment Protection Agency
SNAP	Shared Nitrogen Action Plan
SNAP (sectors)	Selected Nomenclature for reporting of Air Pollutants. Pollution sources categorised into sectors for reporting. For example: S3 – Combustion in manufacturing industry, S7 – Road Transport, or S10 Agriculture.
SNCBs	Statutory Nature Conservation Bodies (Joint Nature Conservation Committee, Natural England, Scottish Natural Heritage, Natural Resources Wales, Northern Ireland Natural Environment Division)
SNH	Scottish Natural Heritage
SO_2	Sulphur Dioxide
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
UAN	Urea Ammonium Nitrate (a liquid fertiliser combining urea, nitric acid, and ammonium)
WAM	With Additional Measures. This scenario includes policies that have been adopted and implemented as well as those that are planned.
WGE	Working Group on Effects, within CLRTAP
WM	With Measures. This scenario includes policies that have been adopted and potentially implemented at the time of projection compilation.
WP	Work Package

1 Introduction

This document describes the emission reduction scenarios developed for modelling and summarises the process of selecting scenarios among the project team and the Steering Group (Defra, Statutory Nature Conservation Bodies and Devolved Administrations).

The development of draft scenarios and selection of the most interesting set for modelling in the project was carried out in the following stages:

- Circulation of initial long list of possible options, to help frame the discussion on the most useful scenarios to be modelled and assessed in more detail;
- Discussions among the project team and Steering Group, informing on options available, to build consensus and narrow the options towards those of most interest to the Steering Group; and
- Selection of scenarios preferred by the Steering Group for full high-resolution modelling and analysis.

Two 2030 baseline scenarios were developed, against which to test the spatially targeted and more ambitious UK-wide mitigation scenario (see main report and details in Annex 1):

- 2030 Business as Usual With Measures (BAU WM) projection (NO_x, NH_3, SO_2) - i.e. the projection data submitted to the European Commission which do not include the National Air Pollution Control Programme (NAPCP) policies; and
- 2030 NAPCP /measures required for meeting National Emissions Ceilings Regulations (NECR) targets, combined with any more recent policy developments and thinking by the DAs (since the publication of the NAPCP, provided by project Steering Group members, Annex 1). This scenario is referred to as “NAPCP+DA” here.

The selected emission reduction scenarios developed are described in detail in this annex with the high-resolution spatial modelling of emissions, concentrations, deposition and effects metrics presented in Annex 4 (see main report for selected key details and results). Modelling for each scenario included:

- preparation of high-resolution emission maps;
- atmospheric concentration and deposition modelling; and
- calculation of effects metrics for sensitive habitats and designated sites.

The following sections of this annex describe the scenarios selected in more detail, with additional information provided on the initial larger number of scenario options (“long list”).

2 Development of spatially targeted and post-2030 scenarios

2.1 Overview

Potential UK mitigation scenarios for 2030 and beyond (2040-2050 timeframe) that meet the aims and objectives of the Nitrogen Futures project can be grouped around four key themes:

1. **NO_x emission reduction** e.g. measures related to transport, domestic combustion;
2. **NH_3 emission reduction** i.e. primary mitigation measures aimed at reducing emissions at source, e.g. low-emission slurry spreading techniques;
3. **NH_3 emission displacement** i.e. moving emission sources elsewhere (no slurry/manure spread around designated sites, and applied elsewhere instead, at a greater distance – representing de-intensification options near sensitive sites more generally); and

4. **Secondary mitigation measures** i.e. recapture of nitrogen emitted to the air from a multitude of sources, for example through tree planting around emission sources**.**

In addition to being able to analyse sector- or pollutant-focused individual scenarios relating to the themes above, an objective of the project was to combine a selection of these individually tested scenarios into optimised scenarios. This approach for optimising scenarios was carried out in two stages and therefore the second stage used the most effective solutions found in the model analysis from the first stage. Combining measures into optimised scenarios required careful accounting for any measures that are not additive.

The following approach was taken for scenario development:

- All four themes, NH_3 emission reduction, NH_3 displacement, NO_x emission reduction and secondary mitigation were considered of interest and included in the selection of scenarios;
- To maximise the potential policy options that could be tested with detailed modelling, it was agreed that "blending" of scenarios could take place. For example, NH_3 and NO_x scenarios could be combined rather than run as separate scenarios, as the model results provide separate outputs for NO_x and NH_x concentrations, and oxidised vs. reduced N deposition, respectively. This approach enables the modelling exercise to focus on different levels of ambition in terms of measures and implementation rates/targeting zones;
- Mitigation ambitions can generally be summarised into low/medium/high, and the preferences of the different UK countries for options or measures taken into account, for example to suit prevailing farming systems and practices. For the purposes of this project, "medium" and "high" ambitions were defined as the UK Government's "central" and "high" estimates under the NAPCP, respectively. This information was integrated with DA input regarding the level of ambition and types of measures that would be tested in spatially targeted vs. more uniformly applied (UK-/DA-wide) approaches (see following sections for details);
- The need to test different widths of emission reduction zones was due to the high spatial variability of atmospheric emissions, concentrations and deposition across the country and the effect this has on sensitive vegetation. Designated sites may experience relatively clean conditions locally, where spatially targeted mitigation will not make a big difference, or a range of medium to high emission densities, Depending on local conditions, narrower ERZ may be sufficient to decrease atmospheric N input to the sites, or wider zones may be required to make a difference for higher levels of N input or wider elevated regional background concentrations and dry deposition.
  The variable-width scenario testing was used to demonstrate how wide such zones might need to be to decrease deposition or concentration at designated sites to below critical thresholds. If achieving non-exceedance was not possible due to high levels of regional and long-range atmospheric N input, the modelling would still quantify the difference spatial targeting could make;
- Scenario options for 2030 and towards 2040 and beyond were considered, to allow testing for appropriate future time frames. Scenarios labelled as "2040+" refer to a 2040-2050 time-horizon, and relate to, e.g.:
  - tree planting-based options, where trees would need to grow to the optimum size to be effective in recapturing emissions; or
  - higher ambitions for NH_3, NO_x (beyond 2030); or
  - both.

  Baseline projections of activity data such as livestock populations and crop areas are not available beyond 2030 which meant that trends beyond 2030 were flat-lined towards 2040/2050. The only differences in model input for 2040+ scenarios were levels of ambition of potential measures being tested, and allowances for slower processes such as tree growth to take place where this applied. This longer time frame also makes allowance for currently less well-developed measures that are not yet ready for implementation but are expected to have significant uptake rates by 2030.

- The Steering Group expressed preference for investigating SSSIs/ASSIs rather than SACs, as these are related to targets under the 25 Year Environment Plan. As most SACs are underpinned by SSSIs/ASSIs, this was agreed as an appropriate way forward. One scenario, however, was implemented separately for both SAC and SSSI/ASSI boundaries, to illustrate the possible spatial implications and to quantify spatial targeting examples for both types of designated sites. While measures applied around SACs can be assessed for impacts on SSSIs and vice versa, this is not straightforward, with potential implications due to the spatial pattern and presence/absence of the different site types. An option was considered for combining SAC and SSSI designations into a single “designated sites” data layer. However, this is not feasible, as the designated features of overlapping sites of different types are not necessarily aligned, making it impossible to quantify critical loads exceedance/excess nitrogen deposition for a merged “designations” dataset, with the data available;
- Some scenarios in the long list were of less interest to the Steering Group and were therefore removed from the list to fit in with the project’s limited time frame and resources. These are outlined briefly in Section 2.2., for reference.

Table 1 shows the final selected scenarios taken forward for UK-wide high-resolution modelling and assessment (described in the main report, and in more detail in Annexes 4 and 5). Table 2 summarises the same information in a more intuitively comparable way. Further details of the scenario development, measures and considerations are provided below.

Table 1. List of selected scenarios developed and taken forward for high-resolution modelling in the Nitrogen Futures project, with short descriptions. See Annex 6 of the main report for further detail on measures used for each scenario.

Year	Short name	Description	Number of scenarios	Comments on selection
2017	Baseline	Best estimate of present time	1	NAEI 2017 with small updates where available)
2030	BAU (WM)	Business As Usual With Measures (WM) baseline (no spatial targeting)	1	2030 baseline (not meeting NECR); data provided by Defra
2030	NAPCP+DA (NECR NO_x)	UK-wide emission reductions – NAPCP+DA measures for NH_3 & no extra NO_x reduction beyond NECR target (no spatial targeting)	1	NOx: NECR target NH_3: NAPCP central estimate with DA medium ambitions; NAPCP data provided by Defra, modified with DA input for NH_3 as part of this project
2030	NAPCP+DA	UK-wide emission reductions – NAPCP+DA for NH_3 & -10 % for NO_x (targeted across agglomerations)	1	NH_3: as above, non-spatially targeted medium ambition for comparison against targeted scenarios NO_x: -10% across agglomerations, otherwise as NECR target
2030	ERZ SAC 2km ERZ SSSI 1km ERZ SSSI 2km ERZ SSSI 5km	Spatially targeted emission reductions – high ambitions (maximum feasible) for NH_3 in ERZ around sites, outside ERZ: NAPCP+DA. -10 % NO_x reduction on baseline for agglomerations	4	Testing different widths of ERZ, mainly for SSSIs (as preferred by Steering Group), but with 1 SAC-based scenario to enable quantitative efficiency estimates for both types of sites
2030	High Ambition exc. Cattle	High ambitions for NH_3 everywhere (i.e. as for ERZ above, UK-wide); [excl. the additional more ambitious cattle measures described in the 2040+ scenario below]	1	To enable a fully quantitative comparison across the selected scenarios
2030	EDZ SSSI 1km	Spatially targeted displacement of NH_3 emissions around designated sites, with NAPCP+DA for NH_3, & 10 % reduction in NO_x emissions	1	EDZ can also represent land use de-intensification, but modelled here as moving of slurry/manure spreading away from designated sites
2040+	High Ambition inc cattle	UK-wide emission reductions - high ambitions for NH_3 (*inc. higher ambitions for cattle*) & additional 15 % reduction in overall NO_x emissions compared with NAPCP+DA	1	Useful for understanding what overall highest ambition everywhere for 2040+ could achieve, inc. possible additional measures for larger beef (>100 cows) and dairy (>150 cows) farms

Year	Short name	Description	Number of scenarios	Comments on selection
2040+	ERZ SSSI 2km inc cattle	Spatially targeted emission reductions – high ambitions (maximum feasible + cattle ambitions) for NH_3 emissions around SSSIs/ASSIs, elsewhere NAPCP+DA; additional 15 % reduction in NO_x emissions compared with NAPCP+DA;	1	2 km zone preferred to other ERZ widths for testing
2040+	Trees SSSI 2km	Tree planting surrounding emission sources in addition to UK-wide NH_3 emission reductions (NAPCP+DA) & additional 15 % reduction in NO_x emissions compared with NAPCP+DA	1	Model shelter belt effect for all livestock housing and manure storage facilities for cattle, pigs & poultry, but not sheep, horses, goats and farmed deer (uptake 75-80%); for 2 km zone around SSSIs
2030	CLe opt. ERZ (no urea) CL opt. ERZ (no urea)	Optimised spatial targeting with efficient combinations of measures (based on 1st round of modelling); optimised minimum ERZ widths, combined with 1 km EDZ and replacing all urea/UAN fertiliser with lower emission alternatives	2	Critical Level (CLe) targets easier to achieve than Critical Loads (CL), as concentrations tail off faster; long-range transport influences N deposition and therefore CL exceedance more;

Table 2. List of selected scenarios for modelling in the Nitrogen Futures project, highlighting similarities and differences between scenarios, grouped by year, ambition level, spatially targeted vs. UK-wide application, and types of measures, for NOx and ammonia. *ERZ* are spatially targeted Emission Reduction Zones around designated sites, and EDZ Emission Displacement Zones (see Table 2 for more details and Nitrogen Futures Annex 2 for fully detailed scenario definitions). ***Cattle reg.* refers to additional regulatory measures fo**r larger cattle farms, *agglom*. refers to agglomerations, i.e. large urban areas used by Defra to report air quality. *BAU* refers to Business As Usual and *NAPCP* is the National Air Pollution Control Programme, with modifications by the Devolved Administrations (DA) - see Annex 1 for detailed descriptions of the 2030 baseline scenarios. See Annex 6 of the main report for further detail on measures used for each scenario.

Short scenario names	**year**	**NH_3 spatially targeted?**	**NH_3 ambition within ERZ**	**NH_3 ambition outside ERZ**	**NH_3 EDZ**	**NH_3 Trees**	**urea/UAN replacement**	**NO_x measures**
2017 Baseline	2017	UK-wide	-	-	-	-	-	baseline
2030 BAU (WM)	2030	UK-wide	BAU	BAU	-	-	-	BAU (WM)
2030 NAPCP+DA (NECR NOx)	2030	UK-wide	NAPCP+DA	NAPCP+DA	-	-	-	NECR
2030 NAPCP+DA	2030	UK-wide	NAPCP+DA	NAPCP+DA	-	-	-	NECR -10% in agglom.
2030 ERZ SAC 2km	2030	2 km	high scenario	NAPCP+DA	-	-	-	NECR -10% in agglom.
2030 ERZ SSSI 1km	2030	1 km	high scenario	NAPCP+DA	-	-	-	NECR -10% in agglom.
2030 ERZ SSSI 2km	2030	2 km	high scenario	NAPCP+DA	-	-	-	NECR -10% in agglom.
2030 ERZ SSSI 5km	2030	5 km	high scenario	NAPCP+DA	-	-	-	NECR -10% in agglom.
2030 High Amb. exc. cattle	2030	UK-wide	high scenario	high scenario	-	-	-	NECR -10% in agglom.
2030 EDZ SSSI 1km	2030	1 km	NAPCP+DA	NAPCP+DA	y	-	-	NECR -10% in agglom.
2040+ High Amb. inc. cattle	2040+	UK-wide	high + cattle reg.	high + cattle reg.	-	-	-	NECR -10% & addit. -15%
2040+ ERZ SSSI 2km inc. cattle	2040+	2 km	high + cattle reg.	NAPCP+DA	-	-	-	NECR -10% & addit. -15%
2040+ Trees SSSI 2km	2040+	2 km	NAPCP+DA	NAPCP+DA	-	y	-	NECR -10% & addit. -15%
2030 CLe opt. ERZ SSSI (no urea)	2030	variable	high scenario	NAPCP+DA	y	-	y	NECR -10% in agglom.
2030 CL opt. ERZ SSSI (no urea)	2030	variable	high scenario	NAPCP+DA	y	-	y	NECR -10% in agglom.

2.1.1 UK scenario options for NO_x mitigation

For NO_x emission reduction scenarios, two scenario options were selected for implementation across all 2030 and 2040+ mitigation scenario runs:

a. Reduction of NO_x emissions by 10 % from all key sectors within agglomerations (urban areas with population >250,000), implemented in all 2030 scenarios beyond the baselines [BAU (WM); NAPCP+DA (NECR NOx)], and
b. Reduction of NO_x emissions by a further amount (15 %) for 2040 and beyond, implemented across all sectors in all scenarios for 2040+.

The rationale for these scenarios is explained below.

Scenario a (implemented for NO_x across all 2030 mitigation scenarios)
Clean Air and Low Emissions Zones (CAZ and LEZ) are designed to accelerate vehicle fleet renewal and bring forward the fleet make-up which is predicted to occur by 2030. Thus, by 2030 their effect will largely be exhausted because the fleet will be consistent with the requirements of the current CAZs and LEZs. Because the outcomes of CAZ and LEZ are effectively captured in the 2030 baseline scenarios (see Annex 1; BAU (WM), NAPCP+DA (NECR NOx)), plausible further NO_x reduction measures were explored, over and above the 2030 baseline, building on the principles of CAZ and LEZ.

NO_x emissions could be reduced in the transport sector through the increased use of electric vehicles, traffic reduction and/or modal shift to walking and cycling. Over time, the contribution from different sectors to NO_x emissions is expected to change: road transport would still be an important contributor, but by 2030 the relative importance of other sectors is expected to increase. The sectors gaining in importance include combustion from energy, i.e. power plants and energy production, industry (including construction) and non-road transport (see Annex 1). The use of an overarching indicative emission reduction of 10% would account for these changes and the introduction of associated mitigation measures, noting that some sectors are likely to be more amenable to change than others.

Scenario a. takes a simple approach by applying a 10 % NO_x emission reduction within agglomerations (Figure 1) on top of the 2030 baseline, i.e. the large urban areas that have been used by Defra for reporting air quality to the European Commission[1]. These are also the areas where there may be strong centralised action to bring about large NO_x emission reductions if appropriate policy drivers were in place.

[1] https://uk-air.defra.gov.uk/assets/documents/annualreport/air_pollution_uk_2018_issue_1.pdf.

Figure 1. UK zones for ambient air quality reporting. Source: Defra 2019 (p.40).

This scenario has the potential to be causally linked with changes in emissions outside of the target areas. For example, promoting cleaner vehicles within an urban area might mean that the same cleaner vehicles are used in rural areas, or it might mean that non-compliant vehicles are displaced to rural areas. This has been highlighted, for example, in the business case analyses for Clean Air Zones including Bristol and Bath. It is not possible to take account of such effects in detail easily, as this would require detailed policy analysis at a level that is not envisaged within this project.

Scenario b (implemented for NO_x across all 2040+ mitigation scenarios)
Scenario b. considers an additional 15 % reduction in NO_x emissions on a 2040+ timescale, on top of the extra -10 % by 2030 under Scenario a. Scenario b. was applied across all sectors, UK-wide, assuming that lower emission transport and combustion options would be available through technological advances and further policy measures (as yet undefined).

It is important to note that NH_3 is emitted by technology intended to reduce NO_x emissions from combustion sources such as road transport, heating and power generation. Measures to reduce NO_x emissions, such as the increased use of Selective Catalytic Reduction or a shift from diesel cars to petrol cars or to petrol-hybrid vehicles using internal combustion engines are therefore more likely to increase NH_3 emissions. These effects are expected to be small in relation to national NH_3 emission budgets but potentially significant on a local scale. Conversely, measures that remove entirely NO_x and NH_3 emission sources entirely, such as modal shift to walking or the use of electric vehicles, will cause commensurate reductions in NH_3 emissions. In practice, it is reasonable to assume that the overarching NO_x emission reduction targets would be achieved through a combination of measures. The scenarios thus assumed that the net effect on NH_3 emissions would be neutral.

2.1.2 UK scenario options for NH_3 mitigation – spatially targeted (Emission Reduction Zones)

Mitigation measures and bundles of measures can be applied in two main approaches:

- Evenly across the country - with the same % reduction applied across all sources, on average, e.g. covering all above-ground slurry tanks; or
- Spatially targeted - reduction measures applied preferentially in areas where emission reductions provide the largest benefit in terms of reduced atmospheric concentrations and deposition of nitrogen to sensitive habitats or designated sites. These zones are referred to as Emission Reduction Zones (ERZ).

Hence, for the same amount of overall emission reduction, targeted mitigation within ERZ only achieves maximum cost-benefits compared with evenly distributing mitigation across the country (Dragosits *et al.* 2014). This is due to the large gradients in pollutant concentrations and deposition resulting in variation of effects on vegetation with distance from local sources.

Ammonia mitigation scenarios were tested in this project using two main options:

a) 2030 baseline (NAPCP+DA (NECR NO_x)) + spatial targeting of additional measures around designated sites: These scenarios were implemented in the modelling by applying the additional targeted mitigation measures within concentric zones (ERZ), away from the boundaries of designated sites (at distances of 1 km, 2 km & 5 km); and

b) UK-wide more ambitious measures i.e. implementing the same measures as under a) across the UK rather than only in targeted areas (2030 High Amb. exc. cattle; 2040+ High Amb. inc. cattle).

Using the spatial targeting approach, measures modelled in the target zones were either more ambitious than the baseline or applied with a higher implementation rate, or a combination of both (Table 3). This higher ambition level is based on the definition of the 2030 baselines and projections relating to the “high ambition” NAPCP data provided by Defra for the project (see Annex 1). Table 3 shows applicability and implementation rates of the emission reductions.

Table 3. Higher ambition measures tested in 2030 mitigation scenarios (2030 High Amb. exc. cattle UK-wide, and the related targeted ERZ scenarios), with details on applicability and implementation rates used across the UK (provided by Defra for the project, pers. comm).

Policy	Applicability	Implementation rate (%)
Urease inhibitors	Urea fertiliser only (not UAN, ammonium nitrate)	100
Rapid incorporation (within 12h) of Farmyard manure (FYM) applied to arable soils	Dairy, beef and pig FYM applied to arable land. Assumes incorporation method is the same as the existing mix (plough, disc and tine)	70
Rapid incorporation (within 12h) of poultry manure applied to arable	Assumes incorporation method is the same as the existing mix (plough, disc and tine)	80
Low emission slurry spreading to grassland	Small amount (c5%) by shallow injection; remainder by trailing shoe	70
Low emission slurry spreading to arable	Small amount (c10%) by injection; remainder by trailing hose	70
Slurry store covers – above ground tanks	Rigid covers applied to tanks	100
Slurry store covers – earth-banked lagoons	Floating covers applied to lagoons	100
Washing dairy collecting yards	Dairy cattle associated with outdoor collecting yards	80

Acid air scrubbers	Livestock housing for intensive pig and poultry housing	100
Grooved flooring for dairy cattle housing	Assume retro-fitting is possible	80
Low protein diets - dairy	Dairy only; assume that pig and poultry already close to ideal	60

2.1.3 UK scenario option for Emission Displacement (EDZ) away from sensitive habitats/sites

The displacement scenario (*2030 EDZ SSSI 1km*) considered the impact of moving emission sources from the immediate vicinity of designated sites to locations further afield, rather than reducing overall emissions. The example modelled was the implementation of exclusion zones for spreading manure/slurry and digestates near designated sites. Exclusion zones (or Emission Displacement Zones, EDZ) of 1 km from the boundaries of designated sites were modelled in which no slurry or manure was applied. These materials and their emissions were redistributed further away, e.g. on land at least 2 km from other designated sites. However, this scenario also broadly tests other land use changes such as de-intensification zones around designated sites. Measures to achieve this could include reversion of intensive arable land or improved grassland to more semi-natural vegetation, or low nutrient input systems.

2.1.4 UK scenario options for secondary mitigation measures

Post-2030 scenarios, referred to as “2040+”, were selected to investigate potential longer-term measures. These included targeted tree planting for NH_3 recapture and policy considerations including regulation of large dairy and beef farms along the lines of the Industrial Emissions Directive for large pig and poultry farms. Tree planting scenarios are considered “beyond 2030” because trees take time to grow and achieve optimal mitigation potential in terms of ammonia recapture.

Tree planting for ammonia mitigation can be implemented close to protected sites or close to emission sources. Such measures are usually applied as small shelterbelts downwind of livestock units or planting schemes for ranging livestock, e.g. free-range chickens. For the Nitrogen Futures project, the emphasis was on primary emission reductions, therefore only one tree planting scenario was selected, and wider landscape planning options were not prioritised. However, some of the discussions were summarised and can be found in Section 2.2 (long list of initial scenarios for selection).

Tree planting close to sources (farms)
Work to date from some small-scale field studies, wind tunnel experiments and modelling approaches at local scale suggests that screening woodland may capture up to 20 % of local ammonia concentration passing through the woodland (Defra project AC0201[2]). The amount recaptured depends on the type, size and configuration of the woodland planting in relation to the emission source and on the characteristics of the emission source. Essentially, the deeper the tree shelter belt (e.g. 20, 50 or 100 m) the more NH_3 capture can be realised, with the height and Leaf Area Index of the canopy also being key parameters. The percentage ammonia capture will be greater for free-range hens under a woodland than for large cage or barn systems, as the birds spend more time outside, under cover, and the NH_3 volatilisation potential is generally smaller under a tree canopy than for bird droppings accumulated in housing, stored and later spread to land.

[2] Bealey W.J., Braban C.F., Famulari D., Dragosits U., Dore A.J., Nemitz E., Tang Y.S., Twigg M., Leeson S., Sutton M.A., Loubet B., Valatin G, Wheat A., Helfter C., Coyle M., Williams A. and Sandars D.L. (2012) Agroforestry for ammonia abatement summary report. Final Report on Defra Project AC0201. CEH Report, 19pp.

For national scale (1 km resolution) scenario modelling to capture these optimised tree belts near sources (i.e. the exact spatial constellation), the re-captured emissions had to be included in the emission scenario rather than within the atmospheric transport and deposition modelling stage. This was necessary to reflect the mitigation benefits appropriately, as the atmospheric transport and deposition model averages across the 1 km grid cells. The different aspects of this secondary mitigation measure (recapture, dispersion, dilution) had to be considered carefully, to enable the scenario outputs to show a realistic representation of the measure without double-counting or omitting likely savings (see Annex 4 for details of the implementation).

The single selected tree planting scenario was implemented for 2 km zones around SSSIs (*2040+ Trees SSSI 2km*). The following assumptions on effectiveness were made, based on Bealey *et al.* (2014), taking into account what may be achieved in imperfect conditions rather than optimal placement and width of tree belts to maximise NH_3 recapture:

- Tree belts would be planted in a suitable constellation for the sources, with “back stop” design[3] as laid out by Bealey *et al.* (2014).
- In the model, livestock houses or manure stores are assumed to be of average type, size and ventilation height, as such data are only available for small numbers of farms, through surveys.
- On most farms, it would not be possible to plant tree belts in the ideal locations, in terms of distance from source, depth and width of tree belt, due to constellations of buildings on a farm in relation to each other and available land.
- Emissions attributed to livestock housing were reduced by an average 15% for relevant livestock sectors; optimal implementation is estimated to achieve ca. 25% with 75m wide tree belts, and 7-12% for narrower tree belts;
- Emissions attributed to slurry lagoons/stores were reduced by an average 12% for relevant livestock sectors (i.e. cattle and pig farms); optimal implementation is estimated to achieve ca. 19% with 30m wide tree belts, and 5-14% for narrower tree belts. Manure storage emissions associated with farmyard manure remain unchanged.

2.1.5 Higher ambition agricultural measures post-2030 (2040+)

Implementation of higher effectiveness mitigation measures for livestock housing (cattle housing in particular) are likely to require replacement of existing livestock housing with new builds rather than retrofitting existing installations. Such a scenario was explored to represent a phased implementation over a 20-30 year period of low emission livestock housing facilities.

The scenario tested includes both dairy and beef measures, related to housing and diet (Table 4). It was implemented UK-wide (*2040+ High Amb. inc. cattle)* and spatially targeted for 2 km zones around SSSIs (*2040+ ERZ SSSI 2km inc. cattle*).

[3] The optimal design for a tree belt downwind of a source is made up of two parts: a) trees with dense canopies but bare trunks closer to the source, with the ammonia enriched air from the source being blown into the tree belt (lollipop-shape trees) and b) a second belt or “backstop” of trees immediately adjacent, with dense branches all the way to the ground, which filter the air blown through the more open first part, recapturing ammonia.

Table 4. Cattle measures tested in higher ambition 2040+ scenarios, with details on applicability and implementation rates used across the UK.

Policy	Applicability	Implementation rate (%)
Grooved flooring for dairy cattle housing	Lower proportion than the previous scenario – more is assumed to have a higher mitigation option (below)	15
'High mitigation' dairy housing	System not defined, but assumed to give 75% emission reduction compared with conventional dairy house	65
Mitigated beef housing	System not defined, but assumed to give 35% emission reduction compared with conventional beef housing	25
Low protein diets - dairy	Increase the proportion of the dairy herd to cover all large farms and a proportion of smaller farms	75
Low protein diets - beef	Assume measure implemented for some housed beef	25

For this scenario, it would have been interesting to consider incorporating longer-term likely changes across the wider modelling domain towards 2050. This is due to the potential of significant further emission changes across Europe over the longer time frame, which would influence UK atmospheric concentrations and long-range transport. Some datasets are available that could be analysed for such longer-term scenarios. For example, the ECLIPSE V5 global emission fields are available in five-year intervals from 1990 to 2030 and for 2040 and 2050 from the International Institute for Applied Systems Analysis (IIASA). However, including such an analysis within the current project's time frame and resources this would have been too resource-intensive, and this scenario was therefore not taken forward.

2.1.6 Optimised spatial targeting

Optimised scenarios required an additional iteration of modelling, i.e. were carried out after the assessment of exceedances of critical loads (deposition, CL) and critical levels (atmospheric concentration, CLe) from all other modelled scenarios. For example, spatially variable ERZ widths were modelled, taking into account the minimum width of ERZ required to take a site below the respective CL or CLe. For sites that are not exceeding their relevant thresholds, no ERZ was implemented in the optimisation (see main report and Annex 3 for further details).

2.2 Further information - detailed "long list" of scenarios

Table 5 below lays out an initial wider list of scenario options that was considered at the start of the project. Additional information on scenarios not selected for modelling in the project is provided below. The table shows the scenario options as they were presented to the Steering Group for discussion. Slight changes in the scenarios that were co-designed by the project team and Steering Group between this version (Table 5) and the final agreed version (Tables 1, 2) are intentional, to show how the thinking developed during this project-internal discussion process between the Steering Group and the team.

Table 5. Initial list of scenarios discussed with the Steering Group for choosing options to take forward for spatial modelling. Scenarios selected, or very similar to those selected, with slight modifications, are highlighted in grey. These initial tentative scenario names deliberately do not match the final set selected for modelling, which is shown in Tables 2 and 3, as they were not fully formed, and various changes were made. The purpose of this table is to show the wider thinking on potential scenarios under consideration.

ID	Name	Expected impacts	Feasibility/drawbacks	Potential number of scenarios
0	**2030 NAPCP+DA (NECR NOx** *(not optional)*	Most realistic 2030 baseline Reduced NO_x and NH_3 concentrations and N deposition across the UK	n/a	1
1a	**NOx reduction 2030**: further 10% emission reduction across all key emission sectors across agglomerations	Reduced NO_x concentrations and oxidised dry N deposition for habitats close to agglomerations; some reduction in wet N deposition further afield	Very simple to implement and would give indicative impacts on sensitive habitats/designated sites of further emission reductions; different bundles of measures could be associated with this scenario	1
1b	**NOx reduction 2030**: Zero emission zones in targeted areas (e.g. current and potential candidate CAZ/LEZ)	Further reduction in concentrations and deposition compared with 1a	Simple to implement; could represent diesel/petrol vehicle bans; could be widened to other key NO_x emission sectors (e.g. domestic combustion)	1
1c	**NO_x reduction 2040**: further 15 % reduction from 1a	Further reduction in concentrations and deposition compared with 1a	Very simple to implement and would give indicative impacts on sensitive habitats/designated sites of further emission reductions; different bundles of measures could be associated with this scenario	1
2a	**Spatial targeting for NH_3 reduction on top of baseline**	Effective reduction in concentrations and deposition for designated sites, compared with similar overall emission reduction spread across the UK	A more complex scenario due to DA differences requiring additional calculations and checking (up to 6 scenarios, 3 buffer zone widths for SAC and SSSI/ASSI, respectively)	Up to 6
2b	**Spatial targeting for NH_3 reduction on top of medium ambition UK measures**	Likely the most ambitious single scenarios to be tested, with largest reduction in impacts overall (apart from the optimised scenarios)	Slightly more complex than 2a; For both 2a and 2b, there could be further permutations in terms of bundles of measures/ ambitions/ uptake, but these multiply quickly if applied for different widths of buffer zones (e.g. 1, 2, 5 km) and different types of designated sites (e.g. SAC, SSSI/ASSI)	Up to 6 (as 2a)

ID	Name	Expected impacts	Feasibility/drawbacks	Potential number of scenarios
2c	**Optimised NH_3 targeting**	A combination of the most effective (spatially variable) widths of buffer zones from 2a or 2b, to bring designated sites out of exceedance (critical levels and/or critical loads)	Requires 2a or 2b being fully analysed through the model chain before optimisation can be carried out (2 stage modelling process) Up to 4 scenarios, if optimised for SAC & SSSI/ ASSI, separately for critical loads & critical levels)	Up to 4
3	**NH_3 emission displacement** (e.g. slurry spreading only at a specified distance from designated sites)	Localised reduction in emissions and therefore local concentrations and dry deposition; with emissions increasing elsewhere	Relatively easy to model; hypothetical; rules for where slurry can be applied would need to be considered e.g. emissions removed from a 1 km zone around sites and spread between 2-5 km away. (could be done separately for SAC, SSSI/ASSI and different displacement distances)	1 or more
4a	**Secondary mitigation: tree planting around emission sources**; for effectiveness to be tested, this would have to refer to 2040+ (slow tree growth)	Partial emission recapture in source areas; reduced concentrations and dry deposition at nearby sensitive habitats & designated sites	To model the impact of this measure, estimated emission reductions achieved through recapture would be included in the emission scenario rather than modelled through chemical transport modelling (see full explanation in Section 4 below)	1 or more (levels of ambition)
4b	**Secondary mitigation: tree planting around designated sites**; for effectiveness to be tested, this would have to refer to 2040+ (slow tree growth)	Partial emission recapture from the air mass moving from source areas towards sinks; reduced concentrations and dry deposition at sensitive habitats & designated sites	This measure would be less straightforward to model at a national scale. We would recommend that the potential of this measure is modelled on a site by site basis (see full explanation in Section 4)	1 or more (levels of ambition)
4c	**Secondary mitigation: wider tree planting** (larger areas) 2040+ (trees growing slowly)	Large additional areas of woodland would a) potentially displace other land use that is currently a significant emission source; additional woodland acts as a sink for atmospheric N	Detailed spatial considerations would be required for testing this in a realistic manner (many options, depending on ambition and spatial targeting)	1 or more
4d	**Higher ambition agricultural measures post-2030**	Larger impacts than under 2030 scenarios, but no detailed deliberations in early “long-list” stage	Development of policies currently focusing on nearer time horizon, scenarios would (have to) be very broad brush (many options, depending on ambition and spatial targeting)	1 or more

Additional scenario considerations that were not taken up for modelling in the project included:

Woodland planting close to protected sites (4b in Table 5)
Scenarios considering woodland planting as screening within a set distance of protected sites could be analysed through modelling approaches at national or local scale. These are likely to capture a proportion of local pollutants. Models run at national scale (1 km resolution) are, however, not recommended for this, as the spatial resolution of benefits within the model will be difficult to attribute at site level. The wider benefits at the national level of a scenario where these measures are distributed across multiple areas could be assessed, with increased woodland areas recapturing additional nitrogen, compared with most other land uses. If the focus were on benefits at fine spatial resolution around protected sites, then a different modelling approach would be required.

Free-range layers under trees (4a in Table 5)
On-farm tree-belts in the free-range layer sector already exist, where tree planting is implemented for welfare reasons. UKCEH has been in discussion with members from the egg industry to devise planting plans to cover both welfare and ammonia mitigation. There are around 2,000 farms across the UK that represent the majority of the UK laying industry. Current RSPCA welfare standards use 5% planting of woodland per flock, but a scenario considered among the long list of scenarios was to test 20%, i.e. quadrupling woodland area per flock.

Wider landscape planting (4c in Table 5)
A scenario focusing on tree planting in the wider environment i.e. not specifically targeted at source or receptor areas for ecological damage from NH_3 has resonance with a number of current policy initiatives. Ambitions to achieve Net Zero carbon emissions require large areas of woodland planting, potentially including planting on currently marginal agricultural land, which may in turn displace or replace some NH_3 sources such as grazing sheep or cattle. Location of such plantings may seek to optimise other policy targets including future environmental land management/use scheme outcomes such as reduced nutrient and sediment runoff to watercourses or other non-material benefits such as recreation or air pollution removal. Each of these desired outcomes may suggest different spatial locations. For example, reducing overland flow might focus on riparian planting, planting to optimise recreation potential would be focused around large urban areas, while planting to remove air pollution involves more complex calculations on the locations of agricultural or combustion pollution sources, likely receptors and the wind directions for long-range pollutant transport as well as between the sources and receptors. An additional consideration in relation to human health is the size of the potential beneficiary population for any planned intervention.

Other factors which should be considered regarding such a scenario, are

- ‘leakage’ or displacement issues from changes in land use,
- direct changes in emissions, which result from conversion from another land use type to woodland.

Often the loss of emissions from another land use type, which is converted to woodland, is greater than the active capture of pollutants by the new woodland.

Assessing the likely benefit from landscape scale woodland planting requires a dedicated scenario. Previous modelling work using the EMEP4UK model suggests that all current UK vegetation reduces NH_3 concentrations by around 23% compared with a scenario where there is no vegetation capture of NH_3 in the UK, a reduction of 0.41 $\mu g\ m^{-3}$ (Jones *et al.* 2017). Dry deposition of NH_3 to woodland is responsible for around 27% of that decrease, i.e. a reduction of 0.11 $\mu g\ m^{-3}$ averaged across the UK (Jones *et al.* 2017). Therefore, at a

UK aggregate level, even a doubling in woodland in the landscape may only reduce NH_3 concentrations by around 0.1 µg m^{-3}. However, at individual locations close to new woodland planting, the local benefit is likely to be much greater. To account for woodland planting at a landscape scale, additional woodland cover would have to be included in the input data to the FRAME model in two ways. The change in land use which directly affects dry deposition, as well as any likely changes in emissions which result from land use change, e.g. lower stocking numbers and therefore lower emissions where woodland replaces land previously used for grazing animals.

Broader socio-cultural scenarios
As part of the initial discussions on scenario development, broader socio-cultural changes were also considered but did not make to the "long-list scenario" and therefore are not included in Table 5. Broader socio-cultural changes might influence emission levels including the potential of changes in human diets to influence agricultural production, food imports/exports, land use, *etc*. Overall, there was a view that while such scenarios would be very interesting to follow up, it would be difficult to develop and assess these in the context of this project's timeframe and resources due to the complexities and uncertainties of such scenarios and a lack of concrete information for quantifying concrete impacts on air quality.

An example of unexpected global change and its consequences on air quality are currently ongoing with the COVID-19 outbreak. Lockdown measures in the UK have, for example, substantially and suddenly reduced transport-related activities, for a period, thereby decreasing related combustion emissions of NO_x and NH_3. It is currently not known whether the large behavioural changes will simply rebound to previous levels, whether fear of infection will increase private motorised transport, or whether newly acquired active travel behaviour will be retained, and at what levels. Recent evidence from a rapid review by the Air Quality Expert Group (AQEG) suggests that agricultural NH_3 emissions in the UK are less likely to be affected by COVID-19[4].

[4] Air Quality Expert Group (published 1 July 2020), https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2007010844_Estimation_of_Changes_in_Air_Pollution_During_COVID-19_outbreak_in_the_UK.pdf

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