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Nitrogen Futures
Annex 4
UK and country scale scenario modelling

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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

Summary

This document forms Annex 4 to the main Nitrogen Futures project report. The main purpose of this annex is to provide more details of the methodology and results of the high-resolution UK/country scale modelling carried out under work package 3 (WP3).

Fifteen scenarios were modelled using the latest available projections and policy targets for 2030 and beyond, by comparing two main approaches: a) uniform UK-wide application of mitigation measures, or b) spatially targeting the same measures near designated sites. The focus was on Sites of Special Scientific Interest (SSSI), with concentric buffer zones representing scenarios that can be summarised as a) Emission Reduction Zones (ERZ), b) Emission Displacement Zones (EDZ), and c) combined optimised scenarios.

For the UK-scale assessment, the tools, models and datasets used for annual UK Government reporting were applied, at a 1 km grid resolution. This included detailed emission modelling to determine the magnitude and spatial patterns of atmospheric N emissions, chemical transport modelling to estimate atmospheric concentrations and deposition, and calculation of critical loads and critical levels exceedances.

The insights derived from the detailed scenario modelling shown in this annex are summarised in the main report which also contains further assessments, discussion and conclusions based on wider outputs from across the Nitrogen Futures project.

1 Methodology – National scale modelling

1.1 Scenario development

The scenarios developed for Nitrogen Futures focused on 2030, with a longer time horizon towards 2040-2050 (referred to as 2040+). The scenarios were all based on the latest available current baseline in autumn 2019, for the year 2017. The derivation of all scenarios and underlying assumptions are described in detail in the parallel Annexes 1 and 2 and summarised in the main report. This section provides a summary as context for high-resolution UK and country-scale modelling that is the focus of this annex. Tables 1-1 and 1-2 provide an overview of the mitigation options and ambitions modelled across all scenarios and the short names used for the scenarios in this report.

For comparing the effectiveness of the 2030 and 2040+ mitigation scenarios, two baselines for 2030 were used (Table 1-1, see Annex 1 for full details):

- Business As Usual (BAU) With Measures (WM) - includes only those policies that have already been adopted or implemented at the time of the projection compilation. It does not include additional measures set out in the NAPCP which are designed to meet NECD/NECR targets. This baseline therefore represents an incomplete set of measures to meet the 2030 NECD/NECR targets and is referred to in the reporting of the high-resolution modelling as *2030 BAU (WM)*.
- The most likely scenario for achieving NECD/NECR targets - includes additional measures (WAM, With Additional Measures) to meet NECD/NECR targets that are still in development, but not yet adopted or implemented, at the time of the projection compilation. These additional measures are represented by the UK's National Air Pollution Control Programme (NAPCP), with some country-specific modifications from consultations by the Devolved Administrations of Scotland, Wales and Northern Ireland. Throughout the reporting of the high-resolution modelling, this is the main 2030 baseline for comparing all mitigation scenarios with and is referred to as *2030 NAPCP+DA (NECR NOx)*.

The 2030 and 2040+ mitigation scenarios represent a range of ambition levels for mitigation, contrast UK-wide with spatially targeted measures in the form of Emission Reduction Zones (ERZ) and Emission Displacement Zones (EDZ) around designated sites. The main designation used in the modelling was Sites of Special Scientific Interest (SSSI), referred to as Areas of Special Scientific Interest (ASSI) in Northern Ireland, with some additional modelling for Special Areas of Conservation (SACs).

Table 1-1. List of selected scenarios taken forward for modelling under work package 3 of the Nitrogen Futures project, with short descriptions. All scenarios are described in detail in Annex 1 (baselines) and Annex 2 (mitigation scenarios).

Year	Short name	Description	No. 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

Year	Short name	Description	No. of scenarios	Comments on selection
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
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 1-2. Summary description of baseline and mitigation scenarios modelled for 2017, 2030, 2040+. 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 NO_x 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 for 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.

Short scenario names	year	NH_3 spatially targeted?	NH3 ambition within ERZ	NH3 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.

1.2 Overview national scale modelling (UK & countries)

The modelling framework used joins together the UK's high-resolution capability for emissions and projections, atmospheric concentrations and deposition, as well as the "effects" assessment metrics (Figure 1-1). The individual components of the modelling framework are briefly introduced below and described in more detail in subsequent sections.

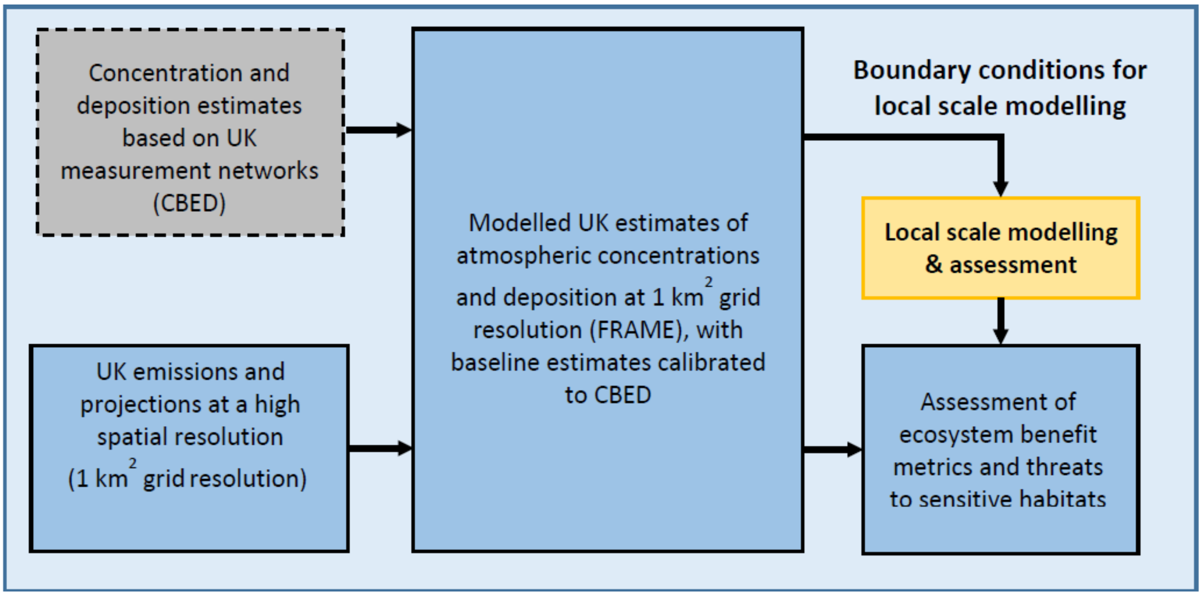

Figure 1-1. Overview of modelling framework used for UK high resolution scenario modelling.

- The new version of the detailed agricultural emission inventory model (coded in C#) is not suited to running scenarios, with many hundreds of input parameters required and long run times. For this project, therefore, a simplified spreadsheet version of the model was developed, based on the existing NARSES spreadsheet model (Webb & Misselbrook 2004; Misselbrook *et al.* 2004) but with updated activity data and parameter values. This model gives an output for each agricultural sector, which is consistent with the official inventory model at the country level (difference of 0.13 kt NH_3 at the UK level, representing 0.1% of the estimated total for 2030).
- The high-resolution modelling system for agricultural NH_3 emissions is part of the UK's agricultural emission inventory (currently Defra project SCF0107) and provides the annual 1 km grid resolution emission maps that are freely available from the NAEI[1]. The model, AENEID (Dragosits *et al.* 1998; Hellsten *et al.* 2008) uses detailed agricultural census/survey statistics in combination with emission factors from the NARSES model across the UK, using land cover information to create non-disclosive emission maps. Until the 2016 inventory year, these maps were only available at a 5 km grid resolution, with a comprehensive model revision now enabling 1 km output to be published (Carnell *et al.* 2019). This model is fully compatible with the wider agricultural emission model under Defra project SCF0107, for implementing scenarios. It has been used under the predecessor project on spatial targeting (Defra AC0109) to implement scenarios of several spatially targeted mitigation scenarios developed for designated sites.
- The UK FRAME model (Dore *et al.* 2007; Fournier *et al.* 2004; Singles *et al.* 1998; Vieno *et al.* 2010) is currently used to derive high-resolution atmospheric concentrations (NH_3, NO_x, SO_2) and N deposition data for future scenario assessment under a number of Defra and agency projects. It benefits from both high 1 km resolution as well as a fast run time allowing multiple scenarios to be rapidly calculated.
- NH_3 concentrations calculated with FRAME were calibrated against the National Ammonia Monitoring Network (NAMN), developed and operated by UKCEH, for calculation of exceedance of the NH_3 critical level. The median bias in the model-measurement comparison was used to bring modelled concentrations in line with measured values. For NO_2 concentrations, calibration to the Pollution Climate Mapping (PCM) model was carried out.
- The system used to calculate S and N deposition and the exceedance of critical loads over recent and historic years for official Defra purposes employs the CBED (Concentration Based Estimated Deposition) inferential model (Smith *et al.* 2000). The inferential modelling approach differs fundamentally from an atmospheric chemistry transport model (i.e. FRAME) as it relies on measurements (from the UKEAP Eutrophying and Acidifying Pollutants monitoring network) and interpolation techniques. Deposition data for emission scenarios calculated with the FRAME model are therefore calibrated relative to CBED deposition such that the simulated reduction in deposition is consistent with the official estimates. Previously (e.g. under Defra AC0109), it was not possible to calibrate the modelled deposition output on a 1 km grid due to the restriction of the 5 km CBED resolution. However, UKCEH recently developed a 1 km calibration approach for N deposition, which was available for use under this project. This enabled retaining the high resolution of the FRAME model simulations whilst ensuring deposition data is normalised to the official CBED estimates at a 1 km resolution.
- The UK National Focal Centre's (Rowe *et al.* 2019) well-established methodology for assessing effects of atmospheric N on vegetation, through critical loads and critical levels exceedance, was used for quantifying environmental benefits of the scenarios developed under this project. The methodology provides a comprehensive set of statistics at the UK, country, habitat and designated-sites level, including excess

[1] naei.beis.gov.uk

nitrogen deposition (Annual Average Exceedance - AAE). The critical loads and levels methodologies have been updated to a 1 km grid resolution for operational use. Other metrics used for assessing the scenarios are described in Section 1.5.

The high-resolution (1 km grid) modelling methodology described above was implemented for all 15 scenarios. The following steps were followed for all scenarios:

1. Development of high-resolution emission maps (1 km by 1 km grid) - this required input of projections of activity data (e.g. agricultural livestock and crops, road and other transport statistics), and emission projections (taking account of agricultural management practice, vehicle fleet changes, *etc.*) for the range of future scenario measures and ambitions modelled under this project.
2. The FRAME model was run, using the emission maps prepared under Step 1, to produce concentration and deposition maps. The high-resolution UK modelling required the wider boundary conditions to be modelled for Europe, to account for import of pollution into the UK domain for 2030 (the main future year modelled). All model runs were scaled relative to the calibrated 2017 baseline.
3. Outputs were assessed against a subset of metrics, following a wide-ranging review of ecosystem benefit metrics described in Section 1.5. The metrics used include the suite of models available at the UK National Focal Centre (UKCEH Bangor), to calculate exceedance statistics, at the UK, country, habitat and designated site level, emission reductions, costs, *etc.*

For some more complex spatially targeted scenarios, such as the optimised variable width emission reduction zones (Section 7), it was necessary to assess key metrics for the main batch of scenarios before the final optimised emission scenarios could be produced, run through the FRAME model, calibrated and assessed.

Following the completion of the model runs, the scenario outputs were analysed and interpreted as follows, for emissions, concentrations, deposition and effects:
- Comparison of current (2017) vs the 2030 baseline scenarios (BAU (WM), NAPCP+DA (NECR NO_x)) – this enabled an evaluation of the likely effects of currently active and planned NECR-related policies on atmospheric N inputs to sensitive vegetation.
- Comparison of 2030 NAPCP+DA (NECR NO_x) baseline with spatially targeted scenarios (for 2030 and/or beyond) – this enabled an evaluation of a) the potential of spatial targeting vs. UK-wide scenarios, b) the development of optimised mitigation scenarios for maximum ecosystem benefit, and c) testing different levels of ambition for mitigation.
- Separate quantification of benefits for each country and the UK (for sensitive vegetation, priority habitats and designated sites).
- Effects due to NH_3 and NO_x were analysed separately for atmospheric concentrations and N deposition. Each model run contains N deposition data split into oxidised (NO_x related) vs. reduced (NH_3 related) deposition, regardless of the scenario definition. Therefore, the relative contribution of reduced and oxidised N to total N deposition can be determined for all scenarios.
- Interpretation of spatial patterns in terms of reduced emissions, concentrations, deposition and effects, relating to current and planned policies (where applicable to scenarios), as well as likely impact of optimised spatial planning scenarios.
- Through the UK-wide high-resolution (1 km grid) modelling and assessment, many of these outputs can be used for assessment at the scale of designated sites. The concentration and deposition data informed the local scale demonstration case studies (see Annex 5), by providing materials for initial assessments as well as boundary conditions for nesting within the UK and country context, including long and medium-range transport input to the local study areas, from the wider region and internationally.

Local information on agricultural practice, exact location of emission hotspots, road traffic statistics, *etc*., was used, where available, for a fuller site assessment.

1.3 High-resolution emission modelling

UK NH_3 and NO_x emissions for 2017 were produced as 1 km by 1 km gridded data and as a point source database, per SNAP (Selected Nomenclature for reporting of Air Pollutants) reporting sector, by the National Atmospheric Emissions Inventory[2]. These data were processed for use in the UK Fine Resolution Atmospheric Multi-pollutant Exchange (FRAME, version 9-15-0) model. For all the future scenarios in 2030 and 2040+, emissions were adjusted spatially to suit the scenario description. Table 1-3 outlines the adjustments made to NO_x and NH_3 emissions, per scenario. Emissions in the Republic of Ireland, as reported to the CLRTAP and spatially distributed by the MapEire project at 1km, were required for the FRAME model due to their proximity to the UK and are projected to 2030 in line with 2030 NECR projections.

Table 1-3. Adjustments to NO_x and NH_3 emissions, per scenario. All scenario definitions and assumptions are explained in detail in Annex 1 (2030 baseline scenarios) and Annex 2 (future mitigation scenarios).

Scenario	Year	NO_x emissions	NH_3 emissions
• **2017 Baseline**	2017	NAEI 2017 diffuse & point data	NAEI 1 km by 1 km data
• **2030 BAU (WM)**	2030	Sectors scaled to sector-specific projections for 2030 All emissions from coal power station point sources removed	Livestock sector population and crop/grass area projections used from FAPRI projections to 2027, flat lining to 2030 and beyond) Emissions calculated for specific measures and implementation rates by DA Non-agricultural sectors scaled to 2030 projections
• **2030 NAPCP+DA (NECR NOx)**	2030	All sectors in UK 2030 BAU (WM) emissions scaled by same ratio to meet NECR target With Added Measures All emissions from coal power station point sources removed. All point sources scaled to meet NECR target With Added Measures.	Livestock and crop area projection as for 2030 BAU (WM) Emissions calculated for specific measures and implementation rates by UK country Non-agricultural sectors scaled to NECR target
• **2030 NAPCP+DA** • **2030 ERZ SAC 2km** • **2030 ERZ SSSI 1km** • **2030 ERZ SSSI 2km** • **2030 ERZ SSSI 5km**	2030	UK emissions in 2030 NAPCP+DA (NECR NO_x) scenario are reduced by 10% in urban/metro agglomeration areas[3] across all sectors (more details in Annex 2)	Livestock and crop area projection as for 2030 BAU (WM), i.e. FAPRI data Emissions calculated for specific measures and implementation rates by DA Non-agricultural emissions unchanged from NECR target

[2] naei.beis.gov.uk
[3] urban areas with population >250,000: https://uk-air.defra.gov.uk/assets/documents/annualreport/air_pollution_uk_2018_issue_1.pdf (page 40)

• **2030 High Amb. exc. cattle** • **2030 EDZ SSSI 1km** • **2030 CLe opt. ERZ SSSI (no urea)** • **2030 CL opt. ERZ SSSI (no urea)**		All point sources reduced by 10% in urban/metro agglomeration areas across all sectors	
• **2040+ High Amb. inc. Cattle** • **2040+ ERZ SSSI 2km inc. Cattle** • **2040+ Trees SSSI 2km**	2040+	UK diffuse and point emissions reduced a further 15% nationally, across all sectors, from 2030 NAPCP+DA scenario	Livestock and crop area projection as for 2030 BAU (WM), i.e. FAPRI data flat-lined beyond 2027 Emissions calculated for specific measures and implementation rates by UK country (details in Annex 2) Non-agricultural emissions unchanged from NECR target

Emissions are the primary driving data for the modelling of NH_3 and NO_x concentration and N deposition surfaces, via the UK FRAME model, for each scenario listed in Table 1-1. Emissions of SO_x are also a required input for the model due to atmospheric chemistry.

1.4 Atmospheric concentration and N deposition modelling

The UK FRAME model was used to provide 1 km by 1 km resolution NH_3 concentration data for the UK, as described for critical level exceedance calculations in the most recent UK Trends Report (Rowe *et al.* 2019). This relatively high resolution is needed to spatially separate source (agricultural) areas from sink (natural ecosystems) areas (Hallsworth *et al.* 2010). Modelled NH_3 concentrations were calibrated relative to annually averaged measurements from the NAMN, using the median bias to adjust the concentrations. Data from all stations in the monitoring network were used for the calibration, with the exception of one station very close to a point source that was not representative of the surrounding area. As well as emissions, the model requires wind-rose information (frequency and speed), land cover, precipitation and European boundary conditions as input data.

For NO_2 concentrations, the Pollution Climate Mapping (PCM) model was used to provide background concentrations of NO_2 as part of Defra's Modelling of Ambient Air Quality (MAAQ) contract (Brookes *et al.* 2019). This 2017 baseline PCM NO_2 surface was adjusted with respect to relative differences in the NO_2 output from the FRAME model in 2017 and any given scenario FRAME output, on a cell-by-cell basis.

Regarding N-deposition, the Concentration Based Estimated Deposition (CBED) model was used to provide wet and dry deposition of oxidised and reduced nitrogen using measurements of air concentrations of gases and aerosols as well as concentrations in precipitation, and particulate concentration maps were combined with spatially distributed estimates of vegetation-specific deposition velocities (Smith *et al.* 2000) to generate dry deposition, while wet deposition includes deposition from precipitation as well as direct deposition of cloud droplets to vegetation. The four 2017 CBED surfaces of wet and dry deposition of oxidised and reduced nitrogen were individually adjusted with respect to relative differences in the respective outputs from the FRAME model in 2017 and any given scenario FRAME output, on a cell-by-cell basis.

1.5 Ecosystem effects modelling methodology for selected metrics

Different ways of measuring the benefits of decreases in N pollution were reviewed in a consultation with pollution scientists and policy experts, as described in Annex 3. These can be grouped as metrics that reflect:

1. Pollutant emissions, i.e. overall indicators of pressure on ecosystems;
2. Exposure, i.e. site and habitat-specific indicators of pressure;
3. Risks to sites designated for their nature conservation interest;
4. Vegetation effects metrics, i.e. the likely effects on habitats over the short or long term, such as exceedance of critical load or critical level; and
5. Direct effects on ecosystem condition, such as species richness.

In the consultation, sets of essential and desirable criteria were established for deciding what makes a metric useful for assessing and communicating the benefits to ecosystems of decreased N pollution. Metrics that are potentially useful to report were listed, and those that fulfilled essential criteria (e.g. with an acceptable level of uncertainty, and sufficiently sensitive to express meaningful change over the study period) were ranked according to the desirable criteria. The metrics that were determined to be most informative are described below.

Desirable characteristics used in the selection of informative metrics are listed in Annex 3, along with the weights ascribed to each. In general, metrics were considered more desirable if they are readily understood, sensitive to change, and relevant to stakeholders at different scales such as site managers and policy makers at country or UK scale.

Predictions can be made for different scenarios of changes in ecosystem condition (group 5 above), such as changes in species richness or habitat suitability for positive indicator species. Such endpoint metrics are useful for communicating ecosystem impacts but involve extra uncertainties in terms of modelling changes in soil and vegetation biogeochemistry, and species responses. For this reason, and because of time constraints, in this study we report on scenario impacts in terms of pressure metrics (groups 1 and 2) and indicators of risk to sites and habitats (groups 3 and 4). The metrics used to illustrate the scenarios in this report are summarised in Table 1-4.

Table 1-4. Metrics used in this report. Score = weighted total score for different criteria (e.g. ease of understanding, sensitivity).

Type	Metric	Score	Notes
Emissions	1.1 Agricultural emission density around designated sites (concentric zones) – measure of local pressure	34	Useful as an indicator of pressure on particular sites. May not reflect impacts, which also depend on receptor sensitivity.
	1.2 Local spatial emission reductions (e.g. within buffer zones surrounding designated sites)	31	Indicator of progress towards reducing local hotspots in concentration and dry deposition, although (as for 1.1 above) may not reflect impacts.
	1.3 Sectoral emissions reductions (e.g. NH_3 by livestock category)	28	Useful for identifying sources of decreases in emissions.
	1.4 National (UK) Emissions reductions (NH_3, NO_x)	28	Overall indicator of progress towards decreased pollution, and relevant for national targets, but does not include emissions from other countries and from shipping.
	1.5 Regional emissions (NH_3, NO_x) – Devolved	28	Relevant for understanding DA-specific contributions to pollution but does not include

	Administration level (E, W, Sc, NI)		cross-border pollution from other DAs and countries.
Exposure	2.1 Annual deposition of total N (vegetation specific)	44	Clear indicator of the potential for N impacts on an area, and closely related to the target in the 2019 UK Government's Clean Air Strategy for decreased N deposition onto protected sensitive habitats. Does not take into account differential habitat sensitivity e.g. as represented by critical load.
	2.2 Atmospheric concentration of NH_3	41	Indicates the potential for concentration-based N impacts to a site, although not directly relevant for chronic effects of eutrophying N inputs.
Habitat effects	4.1 Exceedance of critical level (CLe) for ammonia: amount of exceedance	38	A more nuanced indicator of the risk of concentration-based N impacts that can be applied to different targets, e.g. depending on whether lichens and bryophytes are an important aspect of the habitat or site interest. Given widespread high exceedance, the area exceeded is unlikely to change rapidly.
	4.2 Excess Nitrogen	35	Represents the degree to which sensitive habitats within an area are exposed to N above their critical load, so more sensitive than exceeded area to changes in deposition. However, when deposition decreases but remains above the critical load, the resultant changes to damage and risk are not well understood.
	4.3 Exceedance of critical load for nutrient-N: amount of exceedance	34	Readily understood indicator of excess N but can only be calculated for a specific habitat with a single deposition rate e.g. within a single grid cell.
	4.4 Exceedance of critical load for acidity: amount of exceedance	34	Readily understood indicator of excess N and/or sulphur pollution, for a specific habitat with a single deposition rate e.g. within a single grid cell.
	4.5 Area of sensitive habitat where Critical Load (CL) for nutrient N is exceeded (% of total sensitive-habitat area)	33	Indicates the extent of potential damage to ecosystems within a region. Readily understood and widely reported. Given widespread high exceedance, the area exceeded is unlikely to change rapidly.
	4.6 Area of protected sites (reported separately for SACs, SPAs and SSSIs/ASSIs) where Critical Load (CL) for nutrient N is exceeded for at least one sensitive feature	30	An important statistic for legislative requirements. Overlaps among site designations mean it is not simple to provide overall statistics for protected sites.

To quantify the effectiveness of the modelled mitigation scenarios on designated sites, two main types of indicators were used for the proportion of designated sites exceeding critical levels and loads (following the approach of Hallsworth *et al.* 2010, see also Figure 1-2). This approach was applied in the preceding Defra AC0109 project, assessing both the number and area of designated sites as follows:

- **Designation weighted indicator (DWI)** - shows the proportion of sites with exceedance over at least part of the site, giving the same weight to each designated site, regardless of size. The rationale is that the designation of each site is of equal importance, and that it is equally relevant to protect smaller nature areas in the UK countryside. The approach recognises the fact that larger sites tend to be located in more remote (cleaner) locations.

- **Area weighted indicator (AWI-1)** - shows the overall area of sites with exceedance across all or part of their area, i.e. exceedance is estimated to occur in at least part of the site. The AWI implicitly assumes that the value associated with nature conservation is directly proportional to site area, while making the link to whether the integrity of each site is compromised by exceedance in any part of the site. However, for very large sites, the risk to designated features may be relatively small if only a small corner exceeds the Critical Load (CL) / Critical Level (CLe), and in these cases the AWI-2 may be a more suitable indicator.
- **Area weighted indicator 2 (AWI-2)** - shows the actual exceeded areas within protected sites. The AWI-2 needs to be considered in combination with AWI, as the designated habitats and species in any protected site may or may not be located in the areas exceeded within sites. This indicator cannot quantify whether the designated features of a site would be protected or not, but shows of the % area of sites that are predicted to be below the CLe/CL. The DWI and the AWI, on the other hand, are more precautionary, in that they assume a site may be considered at risk when exceedance occurs in part of its area. Potential improvements from the tested mitigation scenarios can be seen by comparing both AWI and AWI-2 between scenarios, rather than looking at them in isolation.

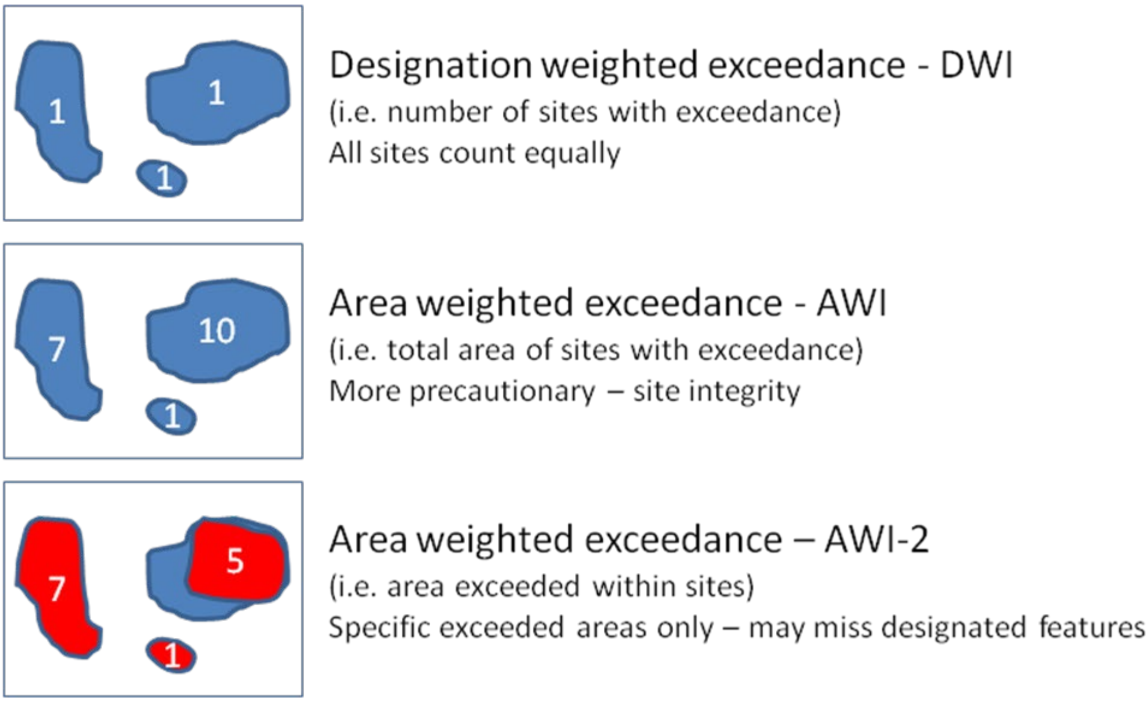

Figure 1-2. Graphical representation of indicators for quantifying the % of SACs/SSSIs exceeding a Critical Level (following the approach of Hallsworth *et al.* 2010, as applied in Defra AC0109).

2 Emissions

Emissions of ammonia (NH_3) and oxides of nitrogen (NO_x) were estimated for all scenarios, building on the detailed analysis and assessment of the most recent available UK emission inventory datasets (2017), the 2030 baselines and mitigation scenarios established under Work Package 1 (WP1) of the Nitrogen Futures project. Additionally, sulphur dioxide (SO_2) emission baselines were established, as SO_2 concentrations play a major part in atmospheric chemistry, reacting with NH_3 and influencing its atmospheric lifetime and chemical transformation.

The following sections show the results the high-resolution emission modelling (1 km by 1 km grid resolution) for all scenarios and quantify the reduction in emissions for the UK as a whole and the four constituent countries (England, Scotland, Wales and Northern Ireland), as well as associated costs. Cost estimates were only made for NH_3 emission reductions, where detailed information on measures and associated costs were available.

2.1 UK and country summaries

For spatial targeting of NH_3 mitigation close to designated sites, Emission Reduction Zones (ERZ) and Emission Displacement Zones (EDZ) were modelled around the site boundaries, using 1 km, 2 km and 5 km distances in the study. In the EDZ scenario, emissions are not actually reduced overall across the country, but manure and slurry spreading is excluded from 1 km zones around designated sites, with the related emissions “displaced” to beyond 2 km from the site boundaries (thereby resulting in increased emissions further away). The focus of these scenarios was on Sites of Special Scientific Interest (SSSIs) in Great Britain, and the equivalent Areas of Special Scientific Interest (ASSIs) in Northern Ireland. An additional scenario with ERZ (2 km zone) was carried out for Special Areas of Conservation (SACs), to determine any differences in effectiveness due to the geographical distribution of the two types of designated sites, differences in size, sensitivity of designated features, *etc.* The area of the UK taken up by N-sensitive designated sites and the different widths of ERZ/EDZ are quantified in Table 2-1, with the same data shown for the UK countries in Table 2-1.

Table 2-1. Comparison of Emission Reduction Zones (ERZ) and designated site areas with comparisons to UK land area (units: ‘000 ha, % of UK land area).

Designation	ERZ	Site Area	ERZ (inc. site)	ERZ (exc. site)	Site area	ERZ (inc. site)	ERZ (exc. site)
		‘000 ha			% of UK land area		
SAC	2 km	1,291	5,962	4,672	5%	25%	19%
SSSI	1 km	1,867	6,311	4,444	8%	26%	18%
SSSI	2 km		10,605	8,738	8%	44%	36%
SSSI	5 km		19,559	17,692	8%	81%	73%

Table 2-2. Comparison of Emission Reduction Zones (ERZ) and designated site areas by country (units: '000 ha, % of land area within each country).

Country	ERZ	Site Area	ERZ (inc. site)	ERZ (exc. site)	Site area	ERZ (inc. site)	ERZ (exc. site)
		'000 ha			% of total land within each country		
England	SAC-2km	523	2,547	2,024	4%	19%	15%
Wales		127	919	792	6%	44%	38%
Scotland		580	2,253	1,674	7%	28%	21%
Northern Ireland		35	299	264	2%	20%	18%
England	SSSI-1km	783	3,329	2,546	6%	25%	19%
Wales		193	789	596	9%	38%	29%
Scotland		809	1,938	1,130	10%	24%	14%
Northern Ireland		56	340	284	4%	23%	19%
England	SSSI-2km	783	5,791	5,008	6%	44%	38%
Wales		193	1,290	1,097	9%	62%	53%
Scotland		809	3,062	2,253	10%	39%	28%
Northern Ireland		56	575	519	4%	38%	35%
England	SSSI-5km	783	10,784	10,001	6%	83%	77%
Wales		193	1,993	1,800	9%	96%	86%
Scotland		809	5,822	5,013	10%	73%	63%
Northern Ireland		56	1,119	1,063	4%	75%	71%

Figure 2-1 below illustrates, for the different zone sizes, the area of the country where spatially targeted NH_3 measures were tested in the modelling study. The leftmost map shows the location of zones where spatially targeted measures were modelled in 1 km ERZ, with the second and fourth map contrasting 2 km zones for the SSSI and SAC network, respectively, and the third map outlining 5 km zones around all SSSIs. It is evident from these maps and Table 2-1 and 2-2 that the larger zones take up a considerable area of the UK's and countries' land mass. However, there are still substantial unaffected areas that are at least 2 or 5 km away from a designated site. For example, 19% of the UK land area is further than 5 km from the nearest SSSI (and not within an SSSI), a proportion that rises to 54% and 75% if the distance is reduced to 2 km from the nearest SSSI or SAC, respectively (and not within sites). Scotland has the largest proportion of land designated as SAC or SSSI, closely followed by Wales, due to the spatial distribution of sites more of Wales's land area is close to a designated site for all sizes of ERZ/EDZ. It is further evident that SSSIs are much more numerous (4,853 nitrogen sensitive SSSIs vs 538 SACs) and more widely dispersed than SACs, with the associated modelled mitigation zones being much larger for SSSIs, and more frequently overlapping. The effects of these patterns are evaluated in the following sections of this report and key points summarised in the main report.

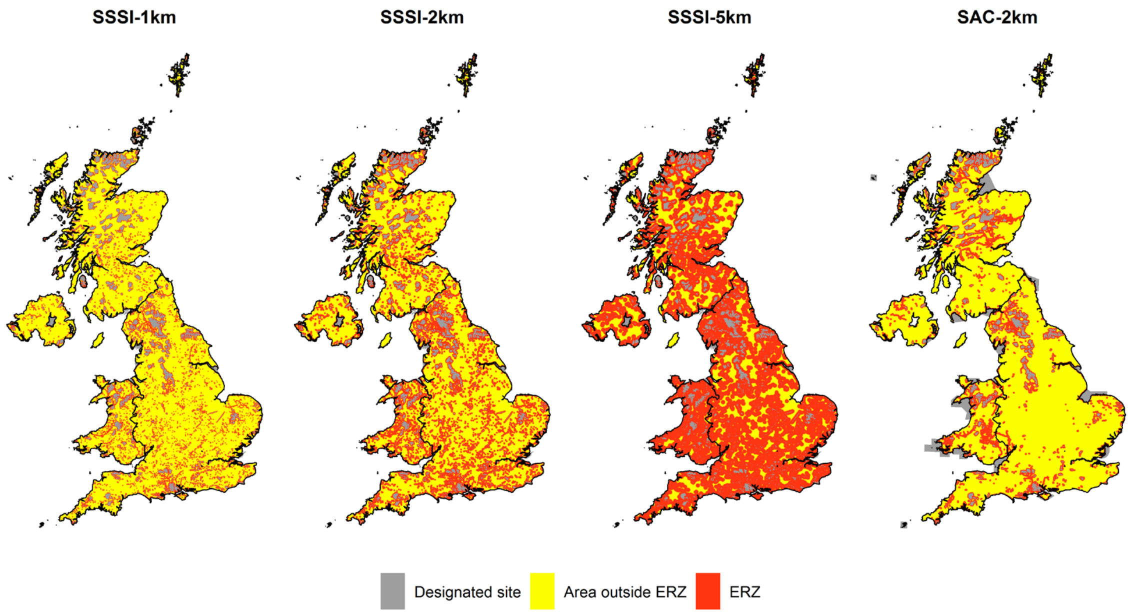

Figure 2-1. Emission Reduction Zones (ERZ) and Emission Displacement Zones (EDZ) used for the spatially targeted mitigation scenarios.

2.2 Ammonia

Ammonia emissions from UK agriculture are estimated on an annual basis (currently under Defra project SCF0107; Misselbrook & Gilhespy 2019) for UK inventory compilation and international reporting purposes using a bespoke model with detailed representation of the UK (and DA) agricultural sector, soils, climate and management practices and country- and practice-specific NH_3 emission factors. This model has been significantly developed in recent years following UK government funding under the Greenhouse Gas Platform (Defra projects AC0114, AC0115 and AC0116) with greater sectoral, spatial and temporal resolution, improved emission factors and other model parameters and improved representation of current management practices (see the UK Informative Inventory Report; Richmond *et al.* 2019[4]). Emission projections are also made annually (currently to 2030) based on the model version used for the most recent inventory submission and using agricultural activity data projections provided by the FAPRI project (Food and Agricultural Policy Research Institute (FAPRI-UK data, provided by Defra – pers. comm.)). For the 'With Measures' (WM) projections presented here for the agriculture sector we have used FAPRI activity data forecasts as provided in April 2019. These are more recent data than those underlying the officially submitted projections (as listed in the appendix to Annex 1, which used FAPRI forecasts from 2017) and therefore regarded as the best available data for the purposes of this project.

Table 2-3 presents a comparison between the 2017 baseline and future emission projections. Generally, the projected emission trends are related directly to trends in projected livestock numbers, as under the 'With Measures' scenario there are no changes to the current (2017 values) implementation of mitigation measures. The exception to this is for dairy cows, where projected increase in milk yield per cow results in an increase in the implied emission factor per cow (because of higher N excretion per animal associated with the higher productivity). Emissions from fertiliser use are associated with overall quantity of N use but also the proportion of different fertiliser types; urea in particular is associated with a higher emission factor than other N fertiliser types. We have used the FAPRI data to estimate future total N use but lacking any detail we have assumed the proportional use of

[4] https://uk-air.defra.gov.uk/library/reports?report_id=978

different fertiliser types to remain at 2017 values. This is an important assumption to which emission estimates will be sensitive, as the emission factor for urea fertiliser is much greater than for other fertiliser types. However, we have no justification for assuming either an increase or decrease in proportional use of different fertiliser types under current policies. Table 2-4 presents the totals for each UK country for the 2017 and 2030 baselines.

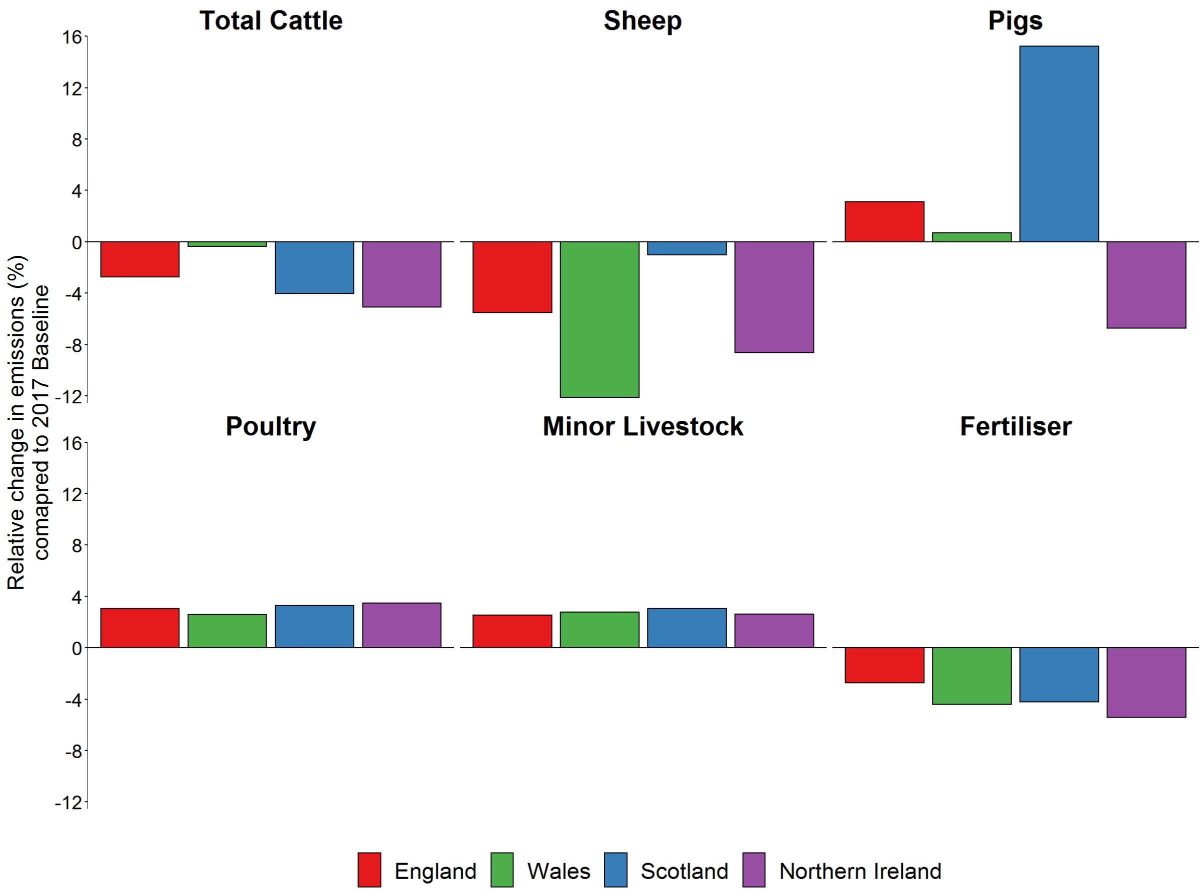

Figure 2-2. Relative change in agricultural emissions between 2030 BAU (WM) and 2017 baseline, emissions are separated by sector and presented individually for the UK countries (i.e. England, Wales, Scotland and Northern Ireland).

Emissions from cattle, sheep and N fertilisers are projected to decline by -3.0, -6.3 and -3.1 %, respectively, compared with 2017 values, while those from poultry and pigs are projected to increase by +3.1 and +2.5 %, respectively, for the UK. As noted above, the emission estimate from fertiliser use assumes the same proportional make-up of fertiliser type for 2030 as for 2017. Decreasing the proportion of urea fertiliser used (e.g. by replacing with ammonium nitrate) would give greater reductions in emissions from fertiliser use. There are some differences between the DAs, with trends for England being much the same as for the UK, whereas Wales shows less of a decrease in emissions from cattle (-0.4 %) but a much larger decrease in emissions from sheep (-12.1 %), Scotland has larger decreases for cattle (-4.0 %) and N fertilisers (-4.2 %) but larger increases for poultry (+3.3%) and pigs (+15.2%). Northern Ireland also shows a larger decrease for cattle (-5.1%) and N fertilisers (-5.4%), a decrease for pigs (-6.7%) and an increase for poultry (3.5%). Total emissions from agriculture are projected to decrease by -1.7% for the UK and -1.1, -1.8, -2.3 and -3.9% for England, Wales, Scotland and Northern Ireland, respectively. It should be noted that these totals do not include emissions from sewage sludge or digestate applications to land.

Agricultural NH_3 emission reductions for all scenarios are summarised in Table 2-3 and further illustrated in Figure 2-3, which shows sector details. The largest step changes in emissions are from 2017 to the 2030 NAPCP+DA baseline (ca 36 kt NH_3) and from the 2030 NAPCP+DA baseline to the 2040+ UK-wide high ambitions with additional regulatory measures for large cattle farms (ca. 17 kt NH_3), with the spatially targeted scenarios providing reductions to areas surrounding designated sites. The difference of 4.9 kt NH_3 between the UK-wide higher ambition scenarios (2030 High Amb. exc. cattle; 2040 High Amb. inc. cattle) are solely due to additional measures for larger dairy and beef farms (see Annex 2 for details).

The biggest obstacle to more detailed future agricultural emission scenarios is forecasting the size/make-up of the agricultural sector for 2040+, when predictions for 2030 are already very uncertain, For example, if there were large changes in consumer behaviour, such as reduction in red meat/dairy in diets, the associated changes to agriculture may have larger effects than the introduction of more ambitious specific mitigation measures.

Emission totals for 2017 include emissions from all sources that have been quantified, i.e. all sources that are relevant for an as complete as possible picture to explain concentration and deposition patterns. This includes “memo items” from the NAEI, i.e. emission sources that are not included in the official national totals, which are used for comparing against targets. For NH_3, this includes emissions from wild mammals and seabirds, as well as small amount from international shipping.

Table 2-3. UK ammonia emission totals for all scenarios, by major sectors. Spatial targeting scenarios were modelled using Emission Reduction Zones (ERZ) and Emission Displacement Zones (EDZ). “HGD” refers to horses on agricultural holdings, goats and farmed deer (minor livestock categories). “Other” refers to non-agricultural emission sources, which includes the waste, transport, nature, industrial, *etc*. sectors. Units: kt NH_3. 2017 emission totals include emissions from all sources that have been quantified, i.e. all sources that are relevant for an as complete as possible picture to explain concentration and deposition patterns. This includes “memo items” from the NAEI, i.e. emission sources that are not included in the official national totals, which are used for comparing against targets. For NH_3, this includes emissions from wild mammals and seabirds, as well as small amount from international shipping (units: kt NH_3).

Scenario	Cattle	Mineral fertiliser	HGD / minor	Pigs	Poultry	Sheep	Other	Total
2017 Baseline	115.8	44.9	1.4	18.6	37.7	9.6	61.4	289.3
2030 BAU (WM)	112.3	43.5	1.4	19.1	38.8	9.0	67.9	292.0
2030 NAPCP+DA (NECR NO_x)	94.9	28.7	1.4	17.1	34.6	9.0	67.9	253.6
2030 NAPCP+DA	94.9	28.7	1.4	17.1	34.6	9.0	67.9	253.6
2030 ERZ SAC 2km	93.9	28.7	1.4	16.8	34.1	9.0	67.9	251.8
2030 ERZ SSSI 1km	94.0	28.7	1.4	16.7	34.0	9.0	67.9	251.7
2030 ERZ SSSI 2km	93.0	28.7	1.4	16.3	33.3	9.0	67.9	249.6
2030 ERZ SSSI 5km	90.9	28.7	1.4	15.3	31.4	9.0	67.9	244.6
2030 High Amb. exc. cattle	89.8	28.7	1.4	14.7	30.3	9.0	67.9	241.8
2030 EDZ SSSI 1km	94.9	28.7	1.4	17.1	34.6	9.0	67.9	253.6
2040+ High Amb. inc. cattle	84.8	28.7	1.4	14.7	30.3	9.0	67.9	236.9
2040+ ERZ SSSI 2km inc cattle	91.2	28.7	1.4	16.3	33.3	9.0	67.9	247.7
2040+ Trees SSSI 2km	91.8	28.7	1.4	16.6	34.0	9.0	67.9	249.4

Table 2-4. UK ammonia emission totals (in kt NH_3 yr^{-1}) for 2017 and 203 baseline scenarios, separated by devolved authority.

Scenario	Source	England	Wales	Scotland	Northern Ireland
2017 Baseline	Cattle	64.4	13.8	17.3	19.8
2030 BAU (WM)	Cattle	62.7	13.7	16.6	18.8
2030 NAPCP+DA (NECR NOx)	Cattle	52.2	11.5	14.6	16.2
2017 Baseline	Sheep	4.4	2.3	2.2	0.7
2030 BAU (WM)	Sheep	4.1	2.1	2.1	0.6
2030 NAPCP+DA (NECR NOx)	Sheep	4.1	2.1	2.1	0.6
2017 Baseline	Pigs	14.8	0.1	1.2	2.5
2030 BAU (WM)	Pigs	15.2	0.1	1.3	2.3
2030 NAPCP+DA (NECR NOx)	Pigs	13.6	0.1	1.2	2.1
2017 Baseline	Poultry	27.9	2.0	2.5	5.2
2030 BAU (WM)	Poultry	28.8	2.0	2.6	5.4
2030 NAPCP+DA (NECR NOx)	Poultry	25.7	1.7	2.3	4.9
2017 Baseline	Minor Livestock	0.9	0.2	0.2	0.1
2030 BAU (WM)	Minor Livestock	1.0	0.2	0.2	0.1
2030 NAPCP+DA (NECR NOx)	Minor Livestock	1.0	0.2	0.2	0.1
2017 Baseline	Mineral fertiliser	39.5	2.4	4.5	2.5
2030 BAU (WM)	Mineral fertiliser	34.8	2.0	4.2	2.4
2030 NAPCP+DA (NECR NOx)	Mineral fertiliser	22.3	1.7	3.1	1.6
2017 Baseline	Non-agricultural	42.1	3.2	7.6	2.6
2030 BAU (WM)	Non-agricultural	51.2	3.8	8.5	3.0
2030 NAPCP+DA (NECR NOx)	Non-agricultural	51.2	3.8	8.5	3.0

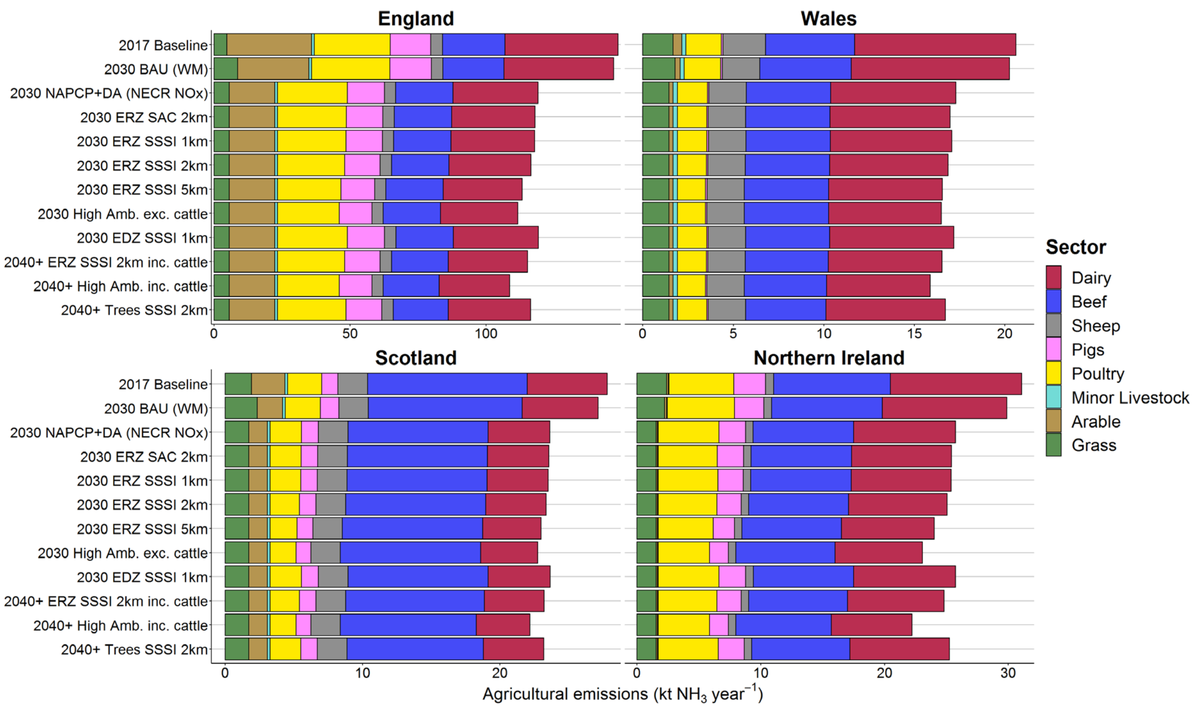

Figure 2-3. Comparison of scenarios: agricultural NH_3 emissions totals for each UK devolved authority, separated by agricultural emission sector.

For NH_3 emission sectors other than agriculture (i.e. waste, transport, industry, nature, *etc.*), no further mitigation measures were implemented beyond those already included in the 2030 NAPCP baseline assumptions (see Annex 1). Therefore, any changes in overall emissions in the modelling beyond the baseline scenarios can be attributed to agricultural mitigation. Figures 2-4 and 2-5 show the increasing relative importance of these other, non-agricultural, emission sources in the UK overall and the devolved administrations.

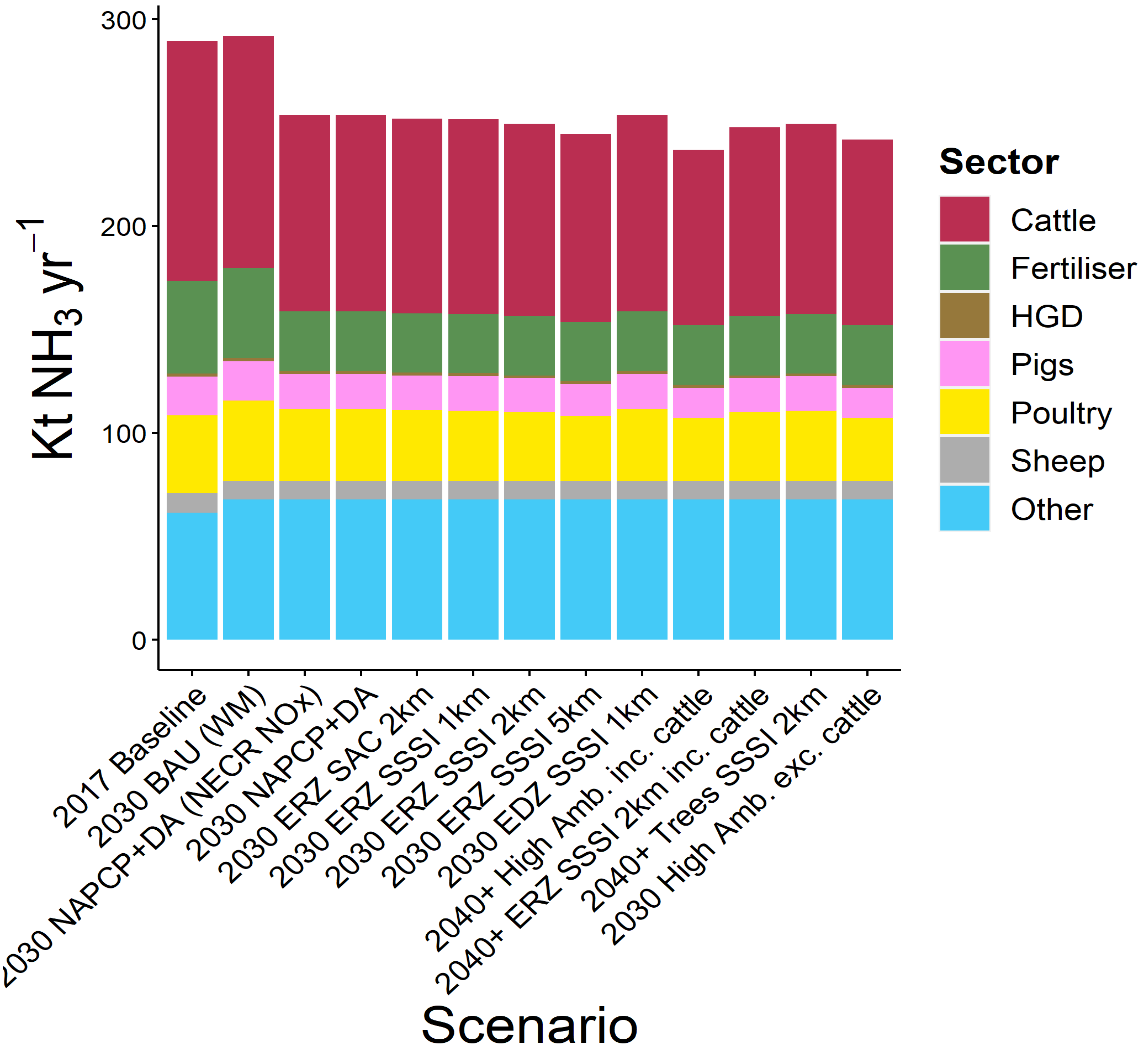

Figure 2-4. Comparison of scenarios: UK NH_3 emissions totals, separated by main emission sectors (kt $NH_{3}2$).

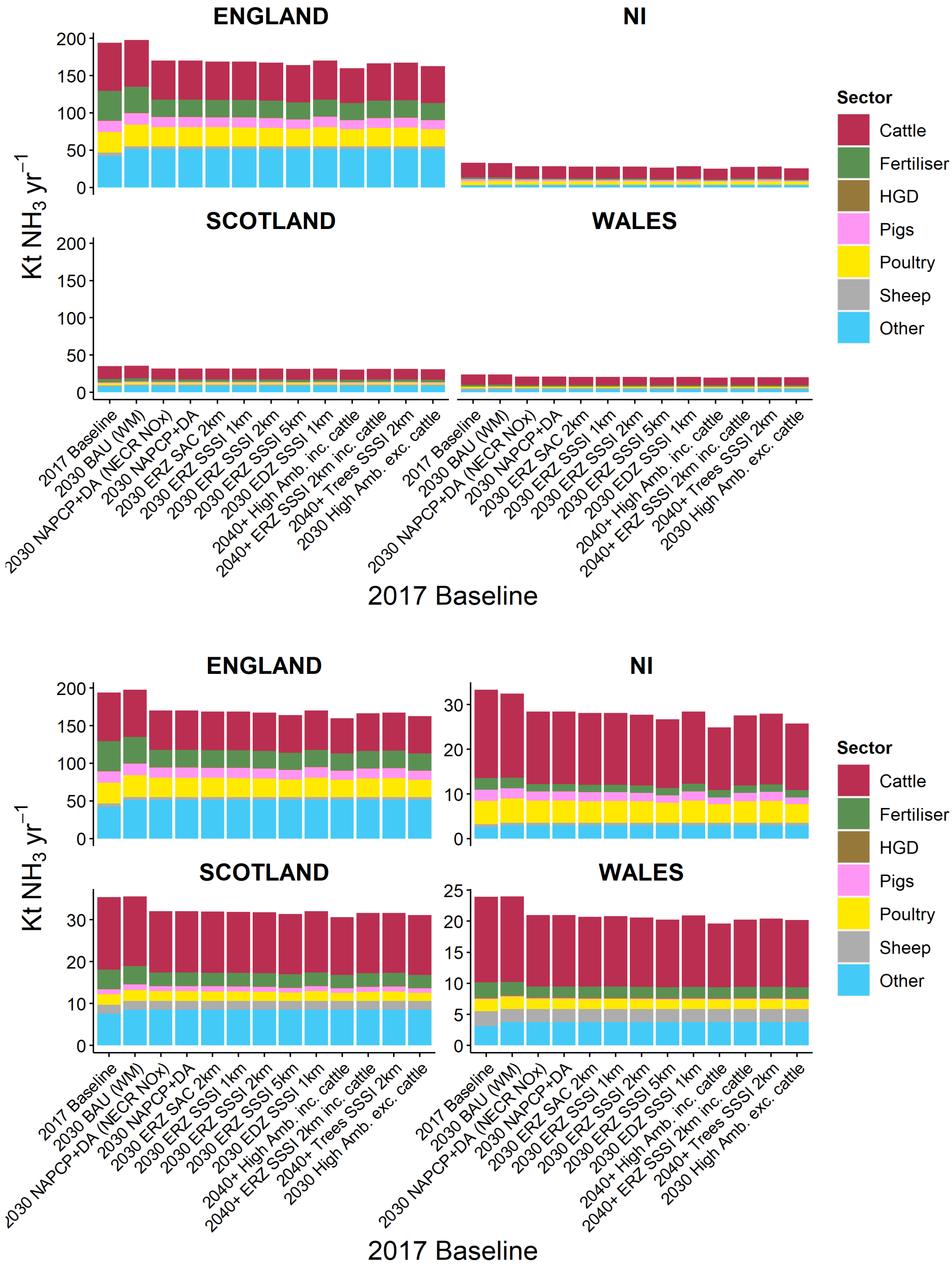

Figure 2-5. Comparison of scenarios: NH_3 emissions totals, separated by main emission sectors and UK country (kt NH_3). Upper figure shows UK countries on same y-axis scale, to enable comparison of emission magnitudes between countries. Lower figure uses country-specific y-axis scales, to enable comparison of the relative importance of sectors within and between countries.

2.3 Nitrogen Oxides

Emissions of nitrogen oxides (NO_x) were estimated for 2017 and the 2030 baselines using mainly existing data from the UK NAEI for 2017 and UK projections and policy targets, respectively (see Annex 1 for details). For illustrating potential additional mitigation ambitions and their effects on emissions and concentrations of NO_x, as well as on total N deposition, two further scenarios were modelled. For all 2030 mitigation scenarios, an additional reduction of NO_x emissions in urban agglomerations by 10% (all sectors) was modelled and compared with the NAPCP+DA baseline (i.e. the baseline meeting NECR targets). For all 2040+ scenarios, a further reduction by 15% across the UK was modelled, i.e. on top of the 10% in agglomerations by 2030. The underlying assumptions of these emission reductions are described in more detail in Annex 2. Figure 2-6 and Table 2-5 illustrate the details for all scenarios, with the emission sector breakdown by UK country illustrated in Figure 2-7. Table 2-6 presents the totals for each UK country for the 2017 and 2030 baselines.

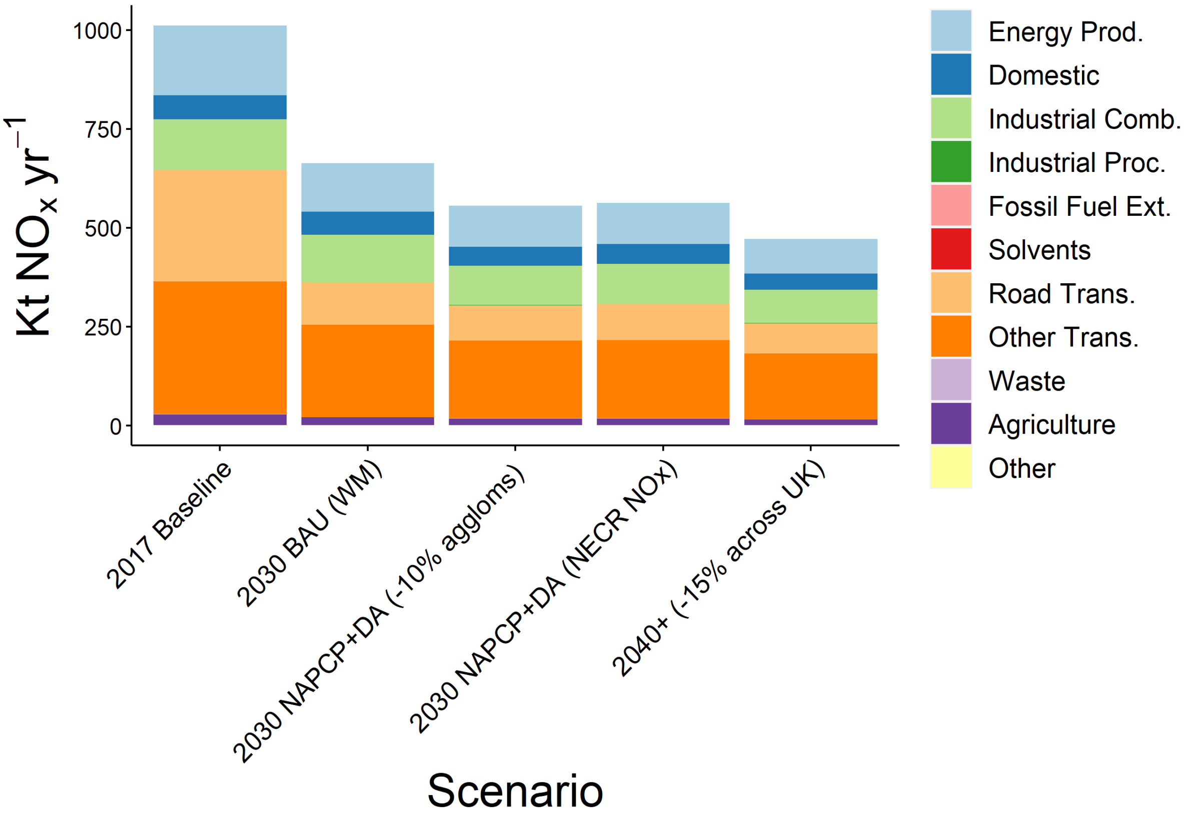

Figure 2-6. Comparison of UK scenarios: NO_x emissions totals, separated by main emission sectors (kt NO_2). Some sector totals are very small and not visible in the graphics, but the full legend has been retained to clarify that all sectors are included in the totals.

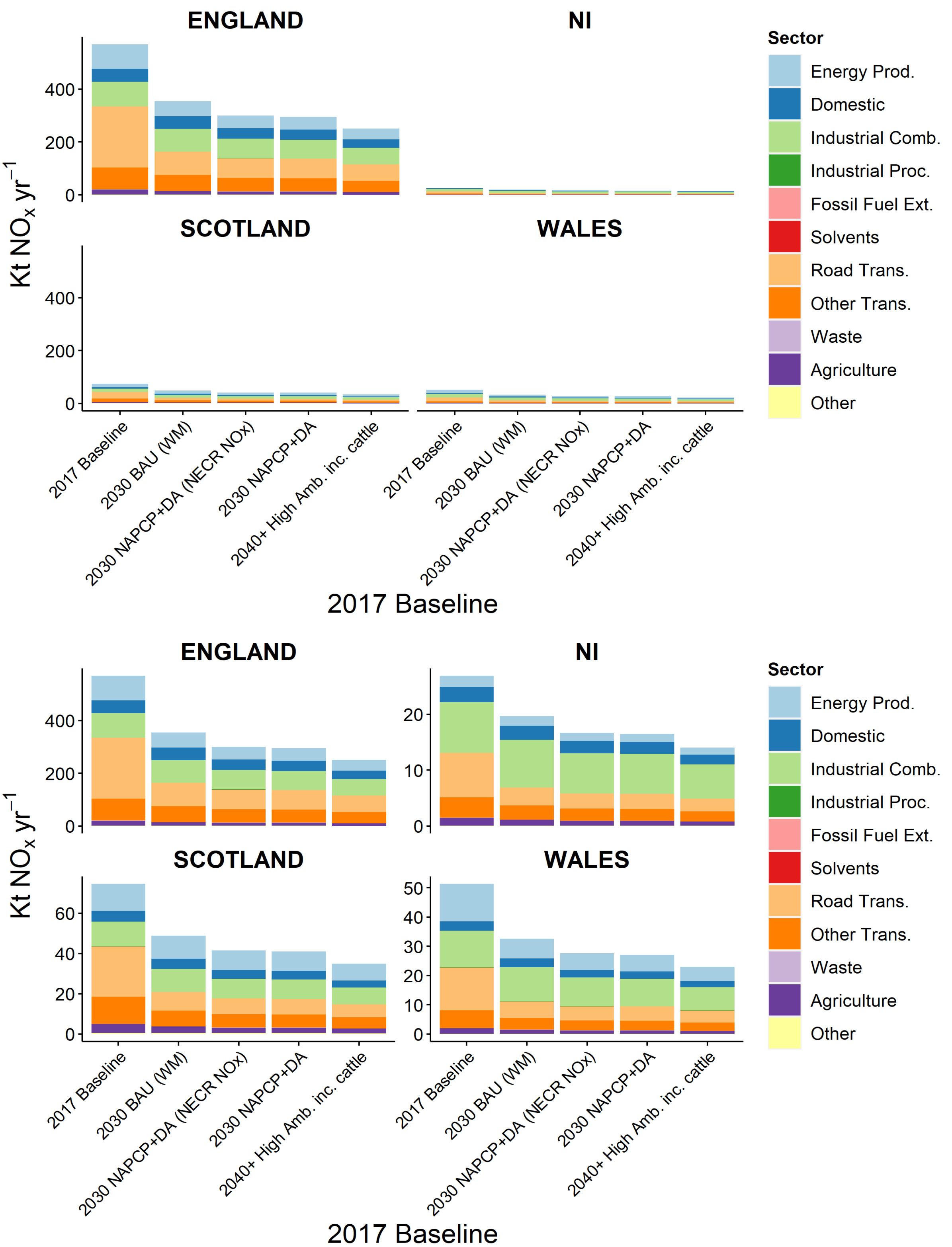

Figure 2-7. Comparison of scenarios: NO_x emissions totals, separated by main emission sectors and UK country (kt NO_2). Upper figure shows UK countries on same y-axis scale, to enable comparison of emission magnitudes between countries. Lower figure uses country-specific y-axis scales, to enable comparison of the relative importance of sectors within and between countries. Some sector totals are very small and not visible in the graphics, but the full legend has been retained to clarify that all sectors are included in the totals.

Table 2-5. UK NO_x emission totals for all main scenarios, by sectors (in kt NO_2). N.B. 2017 emission totals include emissions from all sources that have been quantified, i.e. all sources that are relevant for an as complete as possible picture for concentration and deposition patterns. This includes “memo items” from the NAEI, i.e. emission sources that are not included in the official national totals, which are used for comparing against targets. For NO_x, this includes international shipping, cropped to the model domain making up the difference to the total reported in the NAEI (as reported in 2019, 873 kt NO_2).

Scenario	2017 Baseline	2030 BAU (WM)	2030 NAPCP+DA (NECR NOx)	2030 NAPCP+DA (-10% aggloms)	2040+ (-15% across UK)
Energy Production	176.4	123	104.4	103.3	87.8
Domestic combustion	60.5	58.6	49.8	47.9	40.7
Industry Combustion	128.5	119.8	101.6	100.1	85.1
Industry Proc.	0.3	0.3	0.3	0.3	0.2
Fossil Fuel Extraction	0.1	0.1	0.1	0.1	0
Solvents	0.1	0	0	0	0
Road Transport	281.5	107.2	91	89.8	76.3
Other Transport	334.9	232.8	197.5	196	166.6
Waste	0.9	0.8	0.7	0.7	0.6
Agriculture	26.9	19.3	16.4	16.4	13.9
Other	1.5	1.5	1.3	1.3	1.1
Total	1,011.70	663.5	562.9	555.8	472.4

Table 2-6. UK NO_x emission (in kt NO_2) totals for 2017 and 203 baseline scenarios, separated by UK country.

Scenario	Source	England	Wales	Scotland	Northern Ireland
2017 Baseline	Energy Production	93.2	12.8	13.3	2.0
2030 BAU (WM)	Energy Production	56.8	6.7	11.4	1.7
2030 NAPCP+DA (NECR NOx)	Energy Production	48.2	5.7	9.7	1.5
2017 Baseline	Domestic combustion	48.5	3.2	5.4	2.7
2030 BAU (WM)	Domestic combustion	47.4	3.0	5.2	2.6
2030 NAPCP+DA (NECR NOx)	Domestic combustion	40.2	2.5	4.4	2.2
2017 Baseline	Industry Combustion	92.6	12.4	12.2	9.1
2030 BAU (WM)	Industry Combustion	86.3	11.6	11.4	8.5
2030 NAPCP+DA (NECR NOx)	Industry Combustion	73.2	9.8	9.7	7.2
2017 Baseline	Industry Proc.	0.2	0.1	0.0	0.0
2030 BAU (WM)	Industry Proc.	0.2	0.1	0.0	0.0
2030 NAPCP+DA (NECR NOx)	Industry Proc.	0.1	0.1	0.0	0.0
2017 Baseline	Fossil Fuel Extraction	0.0	0.0	0.0	0.0
2030 BAU (WM)	Fossil Fuel Extraction	0.0	0.0	0.0	0.0
2030 NAPCP+DA (NECR NOx)	Fossil Fuel Extraction	0.0	0.0	0.0	0.0
2017 Baseline	Solvents	0.0	0.0	0.0	0.0
2030 BAU (WM)	Solvents	0.0	0.0	0.0	0.0
2030 NAPCP+DA (NECR NOx)	Solvents	0.0	0.0	0.0	0.0
2017 Baseline	Road Transport	231.9	14.6	24.9	7.9
2030 BAU (WM)	Road Transport	88.2	5.7	9.3	3.2

2030 NAPCP+DA (NECR NOx)	Road Transport	74.9	4.8	7.9	2.7
2017 Baseline	Other Transport	82.6	6.1	13.6	3.7
2030 BAU (WM)	Other Transport	60.1	3.9	7.7	2.6
2030 NAPCP+DA (NECR NOx)	Other Transport	51.0	3.3	6.6	2.2
2017 Baseline	Waste	0.8	0.0	0.1	0.0
2030 BAU (WM)	Waste	0.7	0.0	0.1	0.0
2030 NAPCP+DA (NECR NOx)	Waste	0.6	0.0	0.1	0.0
2017 Baseline	Agriculture	19.1	1.8	4.5	1.4
2030 BAU (WM)	Agriculture	13.7	1.3	3.2	1.0
2030 NAPCP+DA (NECR NOx)	Agriculture	11.6	1.1	2.7	0.9
2017 Baseline	Other	0.8	0.1	0.5	0.1
2030 BAU (WM)	Other	0.8	0.1	0.5	0.1
2030 NAPCP+DA (NECR NOx)	Other	0.6	0.1	0.4	0.1

2.4 Sulphur dioxide

Emissions of sulphur dioxide (SO_2) were estimated for 2017 and the 2030 baselines using mainly existing data from the UK NAEI for 2017 and UK projections and policy targets, respectively (Table 2-7, Figure 2-8, see Annex 1 for details). SO_2 emissions, markedly decreased in the UK since 1970 (>90%) already, are due to decrease further by 2030. SO_2 emissions are important for atmospheric chemistry transport models due to the creation, for example, of ammonium sulphate and the subsequent non-linear effects on NH_3 concentrations, especially at local scales. For all 2030 mitigation scenarios, SO_2 emissions were kept at the same level as in the NAPCP+DA baseline (i.e. the baseline meeting NECR targets).

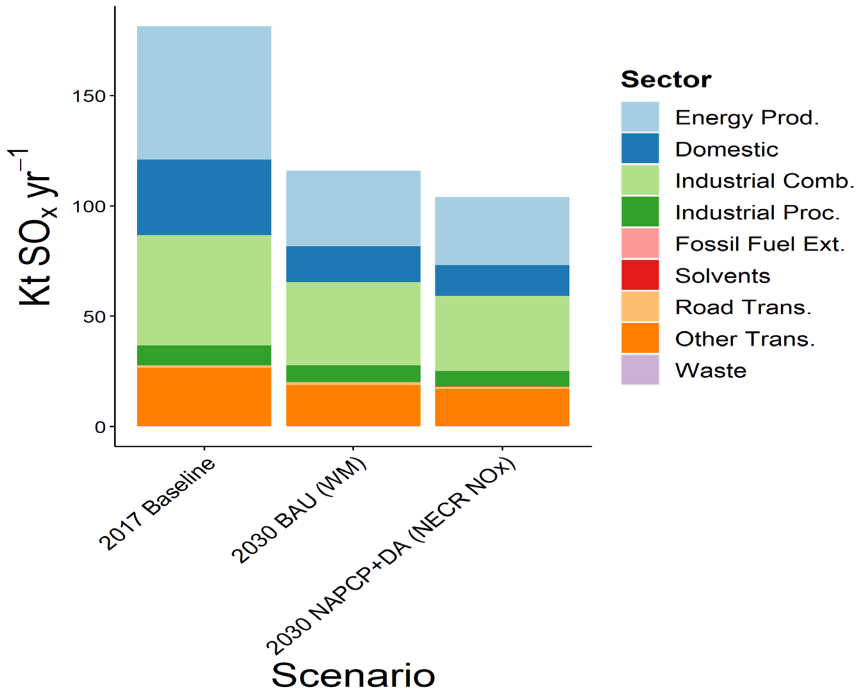

Figure 2-8. Comparison of UK baseline scenarios: SO_2 emissions totals, separated by main emission sectors (in kt SO_2). Some sector totals are very small and not visible in the graphics, but the full legend has been retained to clarify that all sectors are included in the totals.

Table 2-7. UK SO_2 emission totals for all main scenarios, by sectors (kt SO_2). N.B. 2017 emission totals include emissions from all sources that have been quantified, i.e. all sources that are relevant for an as complete as possible picture for concentration and deposition patterns. This includes "memo items" from the NAEI, i.e. emission sources that are not included in the official national totals, which are used for comparing against targets. For SO_2, this includes international shipping, cropped to the model domain making up the difference to the total reported in the NAEI (as reported in 2019).

Scenario	2017 Baseline	2030 BAU (WM)	2030 NAPCP+DA (NECR NOx)
Energy Production	60.4	34.2	30.9
Domestic combustion	34.3	16.2	13.8
Industry Combustion	50.0	37.8	34.2
Industry Proc.	8.9	7.7	7
Fossil Fuel Extraction	<0.1	<0.1	<0.1
Solvents	<0.1	<0.1	<0.1
Road Transport	1.3	1.3	1.2
Other Transport	26.4	18.6	16.8
Waste	0.2	0.2	0.1
Total	181.5	116.0	104.0

2.5 High-resolution maps of emissions

All emission scenarios were modelled at a 1 km by 1 km grid resolution. A selection of maps is shown below in Figure 2-9, to illustrate the spatial distribution and magnitude of change. The comparison between scenarios is shown here in two stages:

- 2017 vs 2030 baselines; and
- 2030 NAPCP+DA baseline vs mitigation scenarios

The comparison with optimised scenarios is shown separately in Section 10.

2.5.1 Ammonia

Ammonia emissions are expected to change substantially between the most recent UK emission inventory data available (2017) and 2030, with UK NAPCP measures (based on England data by Defra, and modified with adaptations by the devolved administrations, see Annex 1 for details) implemented to meet NECR targets (Figure 2-9). The intermediate 2030 baseline, BAU (WM), differs only very slightly (ca 3 kt) from the 2017 emission total (Table 2-3 above).

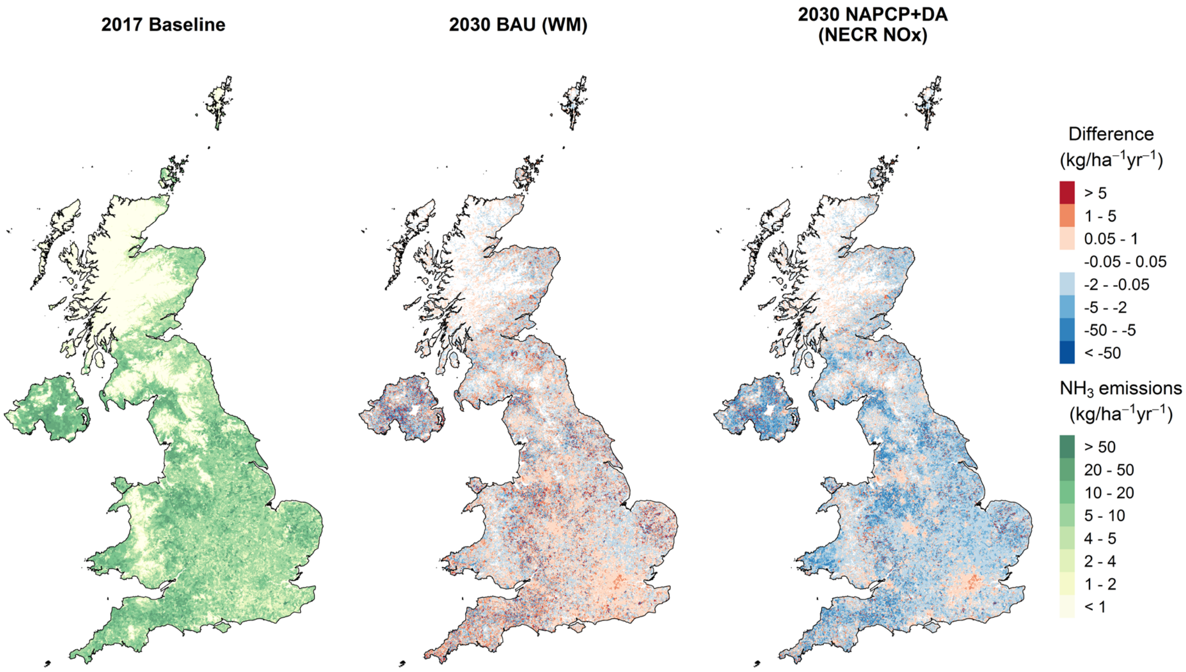

Figure 2-9. Comparison of NH_3 emission baselines: 2017, 2030 BAU (WM), 2030 NAPCP+DA.

The local and regional spatial differences within each of the UK countries between the 2017 and 2030 BAU (WM) baselines are due to the assumptions that had to be made about the different agricultural livestock sectors and their spatial distribution. For example, despite mitigation measures, emissions from the pig and poultry sector are estimated to increase between these two scenarios UK-wide, as these sectors are predicted to grow between 2017 and 2030. While overall spatial patterns of activity are expected to remain similar to the present over the next decade, individual farming enterprises, landfill or anaerobic digestion sites (or other sources) are likely to change dynamically over time, with some closing/reducing activities, and others newly opening or expanding. As it is not possible to predict the exact locations where such additional sector activities are likely to emerge, the assumption had to be made that emissions within each sector (by country rather than UK-wide) would increase/decrease proportionally. This results in a patchwork of small increases and decreases across the difference map. By contrast, the much more ambitious measures modelled under the 2030 NAPCP+DA baseline results in emission reductions throughout the agricultural sectors, with very few exceptions.

Emission estimates (emission factors) for most emission sources are typically lower under 2030 High Ambition. exc. cattle (and the ERZ scenarios) than NAPCP+DA (NECR NO_x). These additional emission reductions are mainly associated with livestock housing (especially for pigs & poultry), as most of the potential mitigation measures for manure storage and low emission land-spreading are already included in the 2030 NAPCP+DA baseline scenario (see Table 10 in Annex 1 and Table 3 in Annex 2). This is illustrated in Figures 2-10 and 2-11 below. Improving housing systems to reduce emissions is likely to retain more N in the manure and therefore result in proportional increases to the N content of manure/slurry. This leads to an increase in associated emission potential further down the manure management chain, i.e. emissions associated with storage and land spreading emissions. Similarly, increasing the grazing period for dairy cows (extended grazing) as is the case with the higher ambition measures may increase emissions for grid squares where grazing is a prominent source (while emissions from housing and associated manure storage and spreading emissions decrease, due to the shorter housing period).

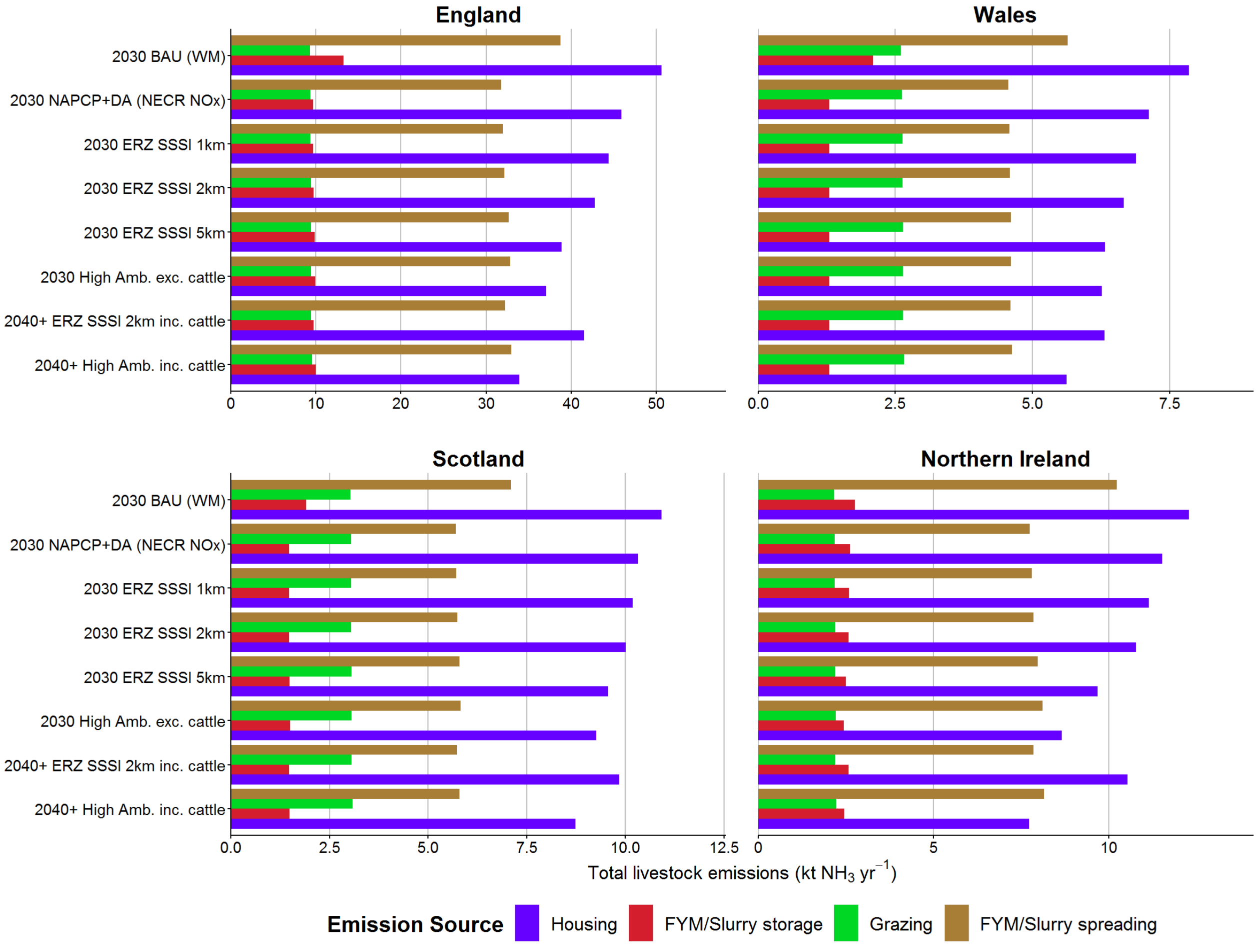

Figure 2-10. Agricultural livestock NH_3 emission estimated for each UK country for emission scenarios implemented with spatial targeting, separated by manure management activity.

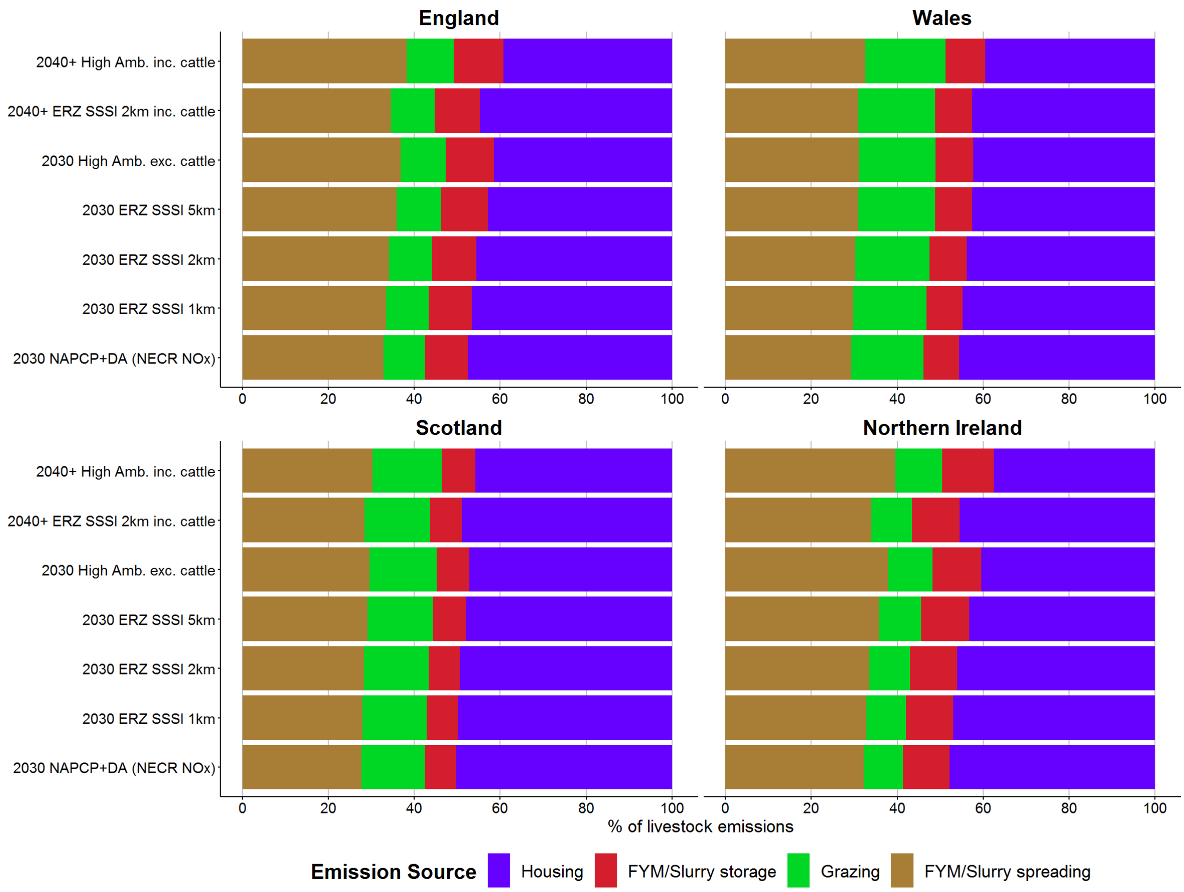

Figure 2-11. Proportion of NH_3 emission from livestock by manure management activity, for each UK country.

There are some emission increases (relative to NAPCP+DA NECR NO_x), especially in large parishes, particularly in Scotland, where livestock housing is associated with different land use/land covers to storage/grazing/spreading emissions. This is a reflection of the statistical methodology used in the AENEID model (i.e. the high-resolution model used in the UK NAEI) to distribute emissions based on suitable land use. The location of individual holdings in the underlying data is uncertain, is typically based on postcodes and can be associated to registered addresses away from farm location rather than the location of emission sources. To improve the spatial distribution of NH_3 emissions, land use/land cover data are used to distribute farming emission within agricultural parishes. The model is described in detail in Dragosits *et al.* (1998) and Hellsten *et al.* (2008).

An example of locations where increased storage/land-spreading emissions are estimated for mitigation scenarios, due to increased housing emissions, is the area surrounding Whim Bog (see Figure 2-12). The area is known for intensive poultry farming (IED farms), embedded in extensive upland beef and sheep grazing. This area contains land cover types more suitable to grazing and land spreading emissions rather than livestock housing (as per the model's statistical approach). Therefore, by applying emission factors (EFs) by manure management component, emissions can be seen to be increasing in some grid squares (despite overall emission reductions from the scenario modelling for the area).

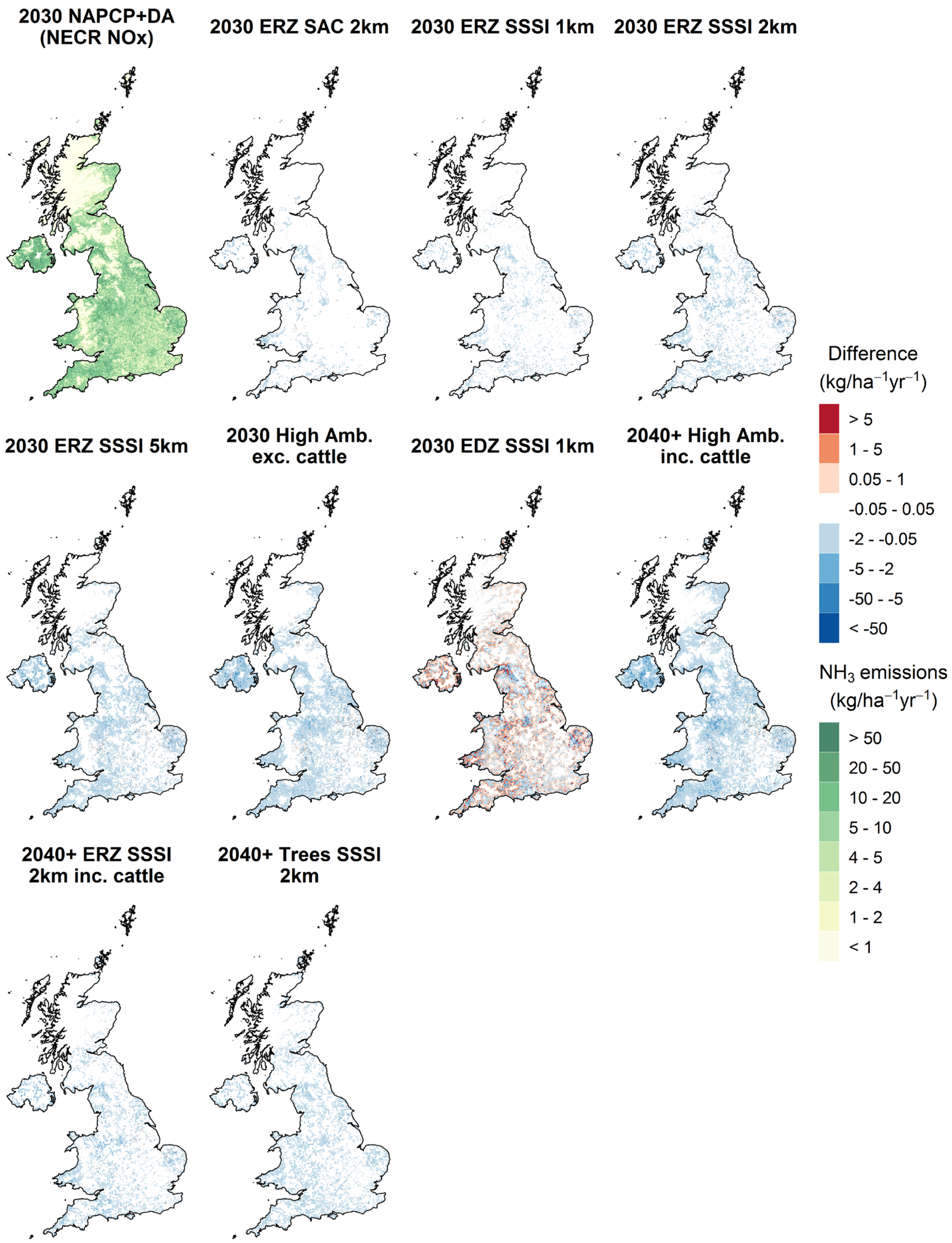

Figure 2-12. NH_3 mitigation scenarios (UK-wide higher ambitions and spatial targeting): comparison with the 2030 NAPCP+DA (NECR NOx) baseline.

For the more ambitious UK-wide and spatially targeted mitigation scenarios, the comparison with the NAPCP+DA baseline confirms that the key drivers for the spatial location and extent of emission reductions are

- the zone width/size of the areas covered by spatially targeted measures (vs. UK-wide);
- the ambition level of the mitigation measures;

- the geographical distribution of the designated sites (N.B. the differences between the 2 km scenarios for SACs vs SSSIs, see also Figure 2-1); and
- the presence/absence of emission sources for applying mitigation measures.

The latter is particularly notable in the more remote parts of the UK with relatively low agricultural activity, especially in upland areas with only extensive sheep and beef farming at very low densities. Designated sites located in such areas are already relatively less affected by local emission sources, compared with sites located in areas with much higher emission densities. This is further illustrated in the local case studies presented in Annex 5, with key messages summarised in the main report.

2.5.2 Nitrogen Oxides

For NO_x, emissions are expected to change substantially between the most recent UK emission inventory data available (2017) and the 2030 BAU (WM) scenario, with 2030 UK NAPCP baseline (i.e. meeting NECR targets) providing further emission reductions (Figure 2-13). The local and regional spatial differences are due to the assumptions that had to be made about the different sectors and their spatial distribution. While it was possible to take account of specific geographic differences (such as projected individual airport growth rates, power station data – see Annex 1 for further details), other sectors had to be scaled using the overall predicted change across the UK. For example, industrial production or power generation sites are likely to change dynamically over time, with some sites closing, others newly opening or expanding. It was not possible to take account of such highly uncertain factors, in the same way as for ammonia.

For the spatially targeted mitigation scenario (-10% NO_x emissions across agglomerations, Figure 2-14), emission reductions were limited to the more densely populated areas of the UK (Section 2.3, with further details in Annex 2). This results in 2030 NO_x concentrations reductions (and for other related pollutants such as PM) where they will benefit future human health rather than sensitive vegetation, with the exception of designated sites located close to busy urban/suburban roads and emission sources. Relevant measures include Clean Air Zones or changes to vehicle fleets.

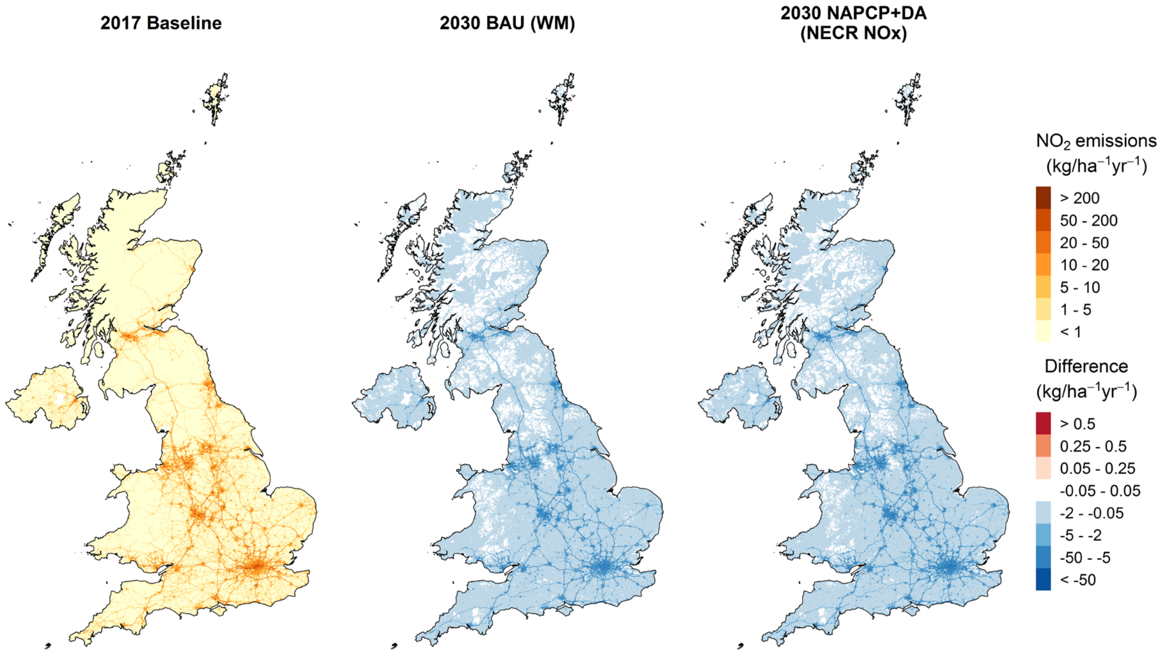

Figure 2-13. Comparison of NO_x emission baselines: 2017, 2030 BAU (WM), 2030 NAPCP+DA (kg ha NO_2 yr^{-1}).

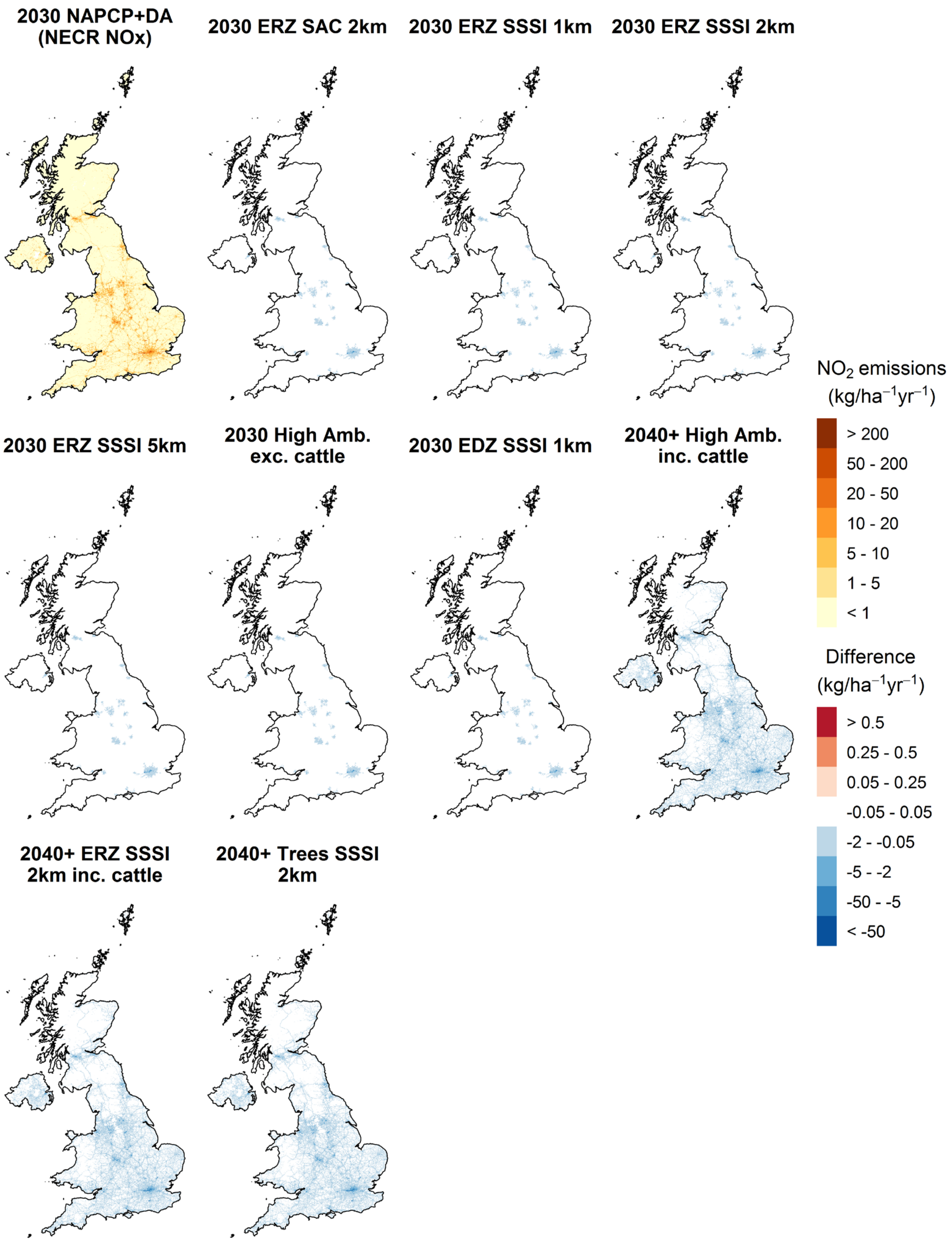

Figure 2-14. NO_2 emissions under 2030 NAPCP+DA NECR NOx (top left, shown in orange) compared to the modelled NO_2 emissions under each mitigation scenario (UK-wide higher ambitions and spatial targeting). Increases (relative to NAPCP+DA NECR NOx) in concentrations are shown in red and decreases are shown in blue.

2.6 Estimating the economic costs of NH_3 emission reductions

2.6.1 Costs for UK-wide 2030 scenarios

Costs associated with the implementation of mitigation measures will vary greatly, depending on farm size, structure and operating conditions, market forces, interest and exchange rates and assumed depreciation lifetimes and rates. As such, the costs presented here should be considered as indicative and to enable relative comparisons between scenarios.

Costs for the different mitigation methods were taken from estimates made in Defra project AQ0947 (Misselbrook 2017), derived mostly from previous estimates either from the FarmScoper3 Cost Tool or from those provided by ApSimon *et al.* (2012). Those from FarmScoper3 were year 2015 specific. Those derived from ApSimon *et al.* (2012) were inflated by 6%, representing an approximate 2% per year increase from 2012 to 2015. An amortisation rate of 3.5% has been used throughout for capital costs and where this differed from previous cost estimates this has been revised. Within the Nitrogen Futures project no further inflation of costs has been applied, therefore costs remain at the assumed 2015 values. Exceptions to this were the following measures, where costs have been revised as part of DAERA-funded project 17/4/02 (Review of Northern Ireland's agricultural ammonia emissions, atmospheric ammonia deposition monitoring and modelling, and assessment of potential ammonia mitigation measures), based on more recent assumptions and values:

- dairy cattle low protein diet;
- acid scrubbers for mechanically-ventilated pig and poultry housing;
- fixed slurry tank covers;
- slurry application by trailing hose, trailing shoe and shallow injection; and
- use of a urease inhibitor with urea fertiliser.

Mitigation measures applied to the agricultural sector were each associated with an NH_3 emission reduction efficiency and an annualised cost (Table 2-8). Reduction efficiency values are largely based on UK-based measurements (summarised in Misselbrook & Gilhespy 2019) or, where appropriate, using values from the UNECE TFRN Ammonia Abatement Guidance Document (Bittman *et al.* 2014). Implementation rates for the different measures at UK country level for each scenario were agreed in consultation with the relevant policy groups in each UK country (e.g. see Table 10 of Annex 1 for implementation rates for the 2030 NAPCP+DA scenarios).

Costs were all expressed on a per-animal place basis (for housing measures), per tonne of manure (for manure storage and application measures) or per kg N (for mineral fertiliser measures). Total costs per UK country for the assumed measure implementation for a given scenario were therefore derived as the measure cost multiplied by the implementation rate, expressed in the same units (i.e. animal places, tonnes of manure or kg fertiliser). The most expensive measures are related to cattle housing, with grooved flooring having high capital costs, spread over a 20-year depreciation, whereas frequent washing down of yards is associated with high labour costs.

Table 2-8. Ammonia mitigation measures, reduction efficiency and costs as applied in the agricultural sector scenarios.

Emission source	Mitigation measure	Emission reduction efficiency# (%)	Annualised cost## (£)	Cost unit
Dairy cattle	Low protein diet	20% reduction in Total Ammonia Nitrogen (TAN) excretion over housed period	0.00	per animal place
Cattle housing	Grooved flooring for dairy housing	35	20.00	per animal place
Cattle yards	Washing dairy collecting yards	70	30.11	per animal place
Pig housing	Acid air scrubbers	80	12.94	per animal place
Poultry housing	Acid air scrubbers	80	0.45–0.55	per animal place
Slurry storage	Rigid covers applied to tanks	80	2.44	per tonne manure
Slurry storage	Floating covers applied to lagoons	60	0.96	per tonne manure
Field manure heaps	Sheeting cover	60	0.64	per tonne manure
Slurry application	Trailing hose	30	0.61	per tonne manure
Slurry application	Trailing shoe	60	0.73	per tonne manure
Slurry application	Shallow injection	70	1.28	per tonne manure
Cattle slurry application	Rapid incorporation (12h) by plough	35	0.15	per tonne manure
Cattle slurry application	Rapid incorporation (12h) by disc	31	0.08	per tonne manure
Cattle slurry application	Rapid incorporation (12h) by tine	27	0.08	per tonne manure
Pig slurry application	Rapid incorporation (12h) by plough	44	0.25	per tonne manure
Pig slurry application	Rapid incorporation (12h) by disc	39	0.13	per tonne manure
Pig slurry application	Rapid incorporation (12h) by tine	34	0.13	per tonne manure
Cattle, pig and duck FYM application	Rapid incorporation (12h) by plough	50	0.30	per tonne manure
Cattle, pig and duck FYM application	Rapid incorporation (12h) by disc	39	0.16	per tonne manure
Cattle, pig and duck FYM application	Rapid incorporation (12h) by tine	17	0.16	per tonne manure
Poultry manure application	Rapid incorporation (12h) by plough	73	0.79-1.48	per tonne manure
Poultry manure application	Rapid incorporation (12h) by disc	62	0.43-0.80	per tonne manure
Poultry manure application	Rapid incorporation (12h) by tine	54	0.43-0.80	per tonne manure
Urea fertiliser	Urease inhibitor	70	0.08	per kg N applied
Urea fertiliser	Replace with ammonium nitrate	85	0.15	per kg N applied

Emission reductions are as measured against the unmitigated reference case. For housing, this is the conventional housing system for that livestock type; for manure storage, this is uncovered manure stores; for

slurry application, this is surface broadcast application; for manure incorporation, this is manure left on the surface for 5 days
Ranges indicate varying costs by poultry type (broiler, layer, turkey, *etc*.) which have been factored into the calculations.

2.6.2 Costs for emission displacement scenario

Costs of manure application can vary considerably depending on the specific circumstances of a given farm, e.g. slurry or solid manure, own equipment or contractor, specific method, volume to be applied in any year, distance to travel, field working rate. However, a large proportion of the overall cost and/or time involved in the operation, is associated with the transport of the manure from the store to the field where it is to be applied – this is a key assumption underpinning current cost estimates. We can also assume that, within reason, a farm will generally apply manure to closer lying land, while bearing in mind NVZ limits and good agricultural practice regarding loading rates. Therefore, prohibiting spreading in a 1 km zone around designated sites and relocating to within a 2-5 km zone will almost certainly involve some additional travelling in many cases, although with a large uncertainty as to how much.

For the purposes of this project we can estimate a range in potential additional costs, from zero, assuming no additional transport costs involved, to a maximum reflecting the amount of total applied manure that is displaced and assumed additional transport distance. At the UK scale, the scenario involves displacing 31% of total manure applied, as a direct ratio with the emissions displaced, but this varies across the UK countries with 32, 42, 23 and 22% for England, Wales, Scotland and Northern Ireland, respectively. For our *maximum cost assumption*, we assumed that there is a mean additional transport cost of 25% for each tonne of displaced manure. This assumption is *highly uncertain* and may be reviewed and revised as appropriate. The *mean cost assumption* is therefore 50% of the maximum cost, assuming a minimum cost assumption of zero. The latter is the case when farms can spread the displaced manure elsewhere on the farm at no additional cost. It is important to note that the additional transport costs apply to the total cost of manure application and not just the marginal additional cost of the low emission application methods. Base costs for slurry applications have been used for the calculations and then applied uniformly across all manure types and for all livestock types.

Based on these assumptions, additional costs associated with displacing manure applications from EDZs around all N-sensitive SSSIs are between £0 and £7.5 million across the UK, with a mean estimate of £3.7M (mean costs of 2.32, 0.58, 0.46 and 0.38 £M for England, Wales, Scotland and Northern Ireland, respectively).

2.6.3 Costs for additional cattle measures for 2040+ scenarios

This 2040 high ambition scenario assumed additional measures and efficiency improvements to be implemented on large dairy and beef farms by 2040. Based on current statistics (2018 June Agricultural Survey data), 62 and 22% of dairy and beef cows, respectively, are on large farms (>150 and >100 dairy and beef cows, respectively). The proportion of cattle present on large farms will almost certainly increase by 2040, following current trends. Taking a conservative approach, the additional measures are attributed to 65 and 25% of the dairy and beef cattle numbers for this scenario. The specific measures are not described in detail, but include an assumption of improvements to genetic merit and feed conversion efficiencies in the beef sector and additional housing measures (unspecified) for the dairy cows:

- **Dairy cows**: In addition to the assumptions in used for the 2030 High Ambition scenario (High Amb. exc. Cattle, i.e. high ambition NAPCP+DA measures), 65% of dairy cows were associated with 'improved housing measures' giving a 75% reduction in housing emissions. This can be taken to represent feeding, genetic and housing improvements beyond those associated with 2030 High Amb. Exc. Cattle. As the measure has no specific detail, costs are ***highly uncertain***. Those associated with housing infrastructure changes are likely to be large with a broad estimate in the region of £25 - £50 per cow (based on estimates for fitting of comfort slat mats and automated scrapers to cattle housing in Northern Ireland – Aurelia Samuels, AFBI, 2019). At the country-scale this gives additional annual costs of for the UK (£M 33.9-68.0, 7.3-14.5, 4.4-8.8 and 10.0-20.0 for England, Wales, Scotland and Northern Ireland, respectively). Of course, depending on the actual technologies and associated costs giving the assumed emission reduction, costs could vary widely from these figures.

- **Beef cattle**: the assumed genetic improvement and improved feeding/feed conversion efficiency are estimated to be cost neutral.

2.6.4 Estimated cost of planting trees to recapture ammonia emissions

In order to accurately estimate the cost of planting tree belts to recapture ammonia, detailed local information would need to be known about the amount of woodland required to shelter agricultural sources. The area of trees needed to recapture emissions from each source will vary between agricultural sectors and the configuration of individual farms and the wider agricultural landscape surrounding a site. As this information is not available at a national level, costs cannot be provided for this scenario. However, following work carried out by Bealey *et al.* in 2014, Table 2-9 illustrates estimated costs (for 2014) to plant a hectare of woodland. The cost of this measure to farmers may be offset, however, if woodland grant schemes were available in 2030.

Table 2-9. Example costs of measures for creating and maintaining woodland structures (£ per ha per year at 2014 prices, from Bealey *et al*. 2014); costs are likely to vary considerably depending on circumstances.

Costs	Option 1 (housing/lagoon shelterbelt)	Option 2 (e.g. livestock under trees)
Agricultural Opportunity Cost (p.a.)	£ 655*	£ 655*
Establishment (year 0)	£ 9,076	£6,801
Management (year 1 onwards)	£24	£24
Fertiliser and spraying (years 1-4)	£102	£102
Fencing (year 4 onwards)	£92	£92
Thinning (year 25, 30, 35 & 40)	£716	£1526
Backstop Maintenance (year 5 onwards)	£11	£11

* arable farm on medium soil with an annual rainfall of 600 mm.

2.6.5 Estimating the cost of spatially targeted mitigation

The agricultural emission scenarios developed for this study are based on underlying high-resolution data from the June Agricultural Survey (JAS) and average agricultural management practice data for each of the UK countries (i.e. England, Wales, Scotland and Northern Ireland). The emissions released by an individual source can vary substantially depending on the management practices adopted by individual holdings (e.g. proportion of slurry spread with low-emission techniques, proportion of slurry stores that are covered). In the UK, information on management practice is not available for individual holdings and assumptions must be made based on overall agricultural practice.

In order to accurately estimate the cost of the spatially targeted emission scenarios, detailed management practice information would need to be known at the local level. As this information if not available, the cost of the spatially targeted mitigation scenarios has been estimated based on total emission reductions achieved, compared to UK-wide implementation. It is assumed that the additional cost of the spatially targeted (higher ambition) measures (for each DA) is equivalent to the proportion of the additional emission reductions achieved by the UK wide higher-ambition scenario.

It is therefore assumed that, if targeting a 1 km zone around SSSIs achieves an additional (nominal) 10 % reduction in emissions compared with NAPCP+DA, the cost would be the cost of NAPCP+DA plus the extra 10 % of the additional cost (i.e. minus the cost of NAPCP+DA) of the scenario.

2.6.6 Potential costs associated with replacing the use of urea

One potential measure for reducing fertiliser emissions would be to replace the use of urea for other fertilisers with lower volatilisation losses. This option was not included with the initial scenarios but was explored in the optimised scenarios. Urea is generally less expensive per kg N than ammonium nitrate fertiliser but is also associated with a lower agronomic efficiency on average because of greater losses through ammonia volatilisation. Urea products including a urease inhibitor (e.g. Agrotain) will improve the agronomic efficiency of the urea through lowering volatilisation losses (and possibly through a more gradual release of plant-available N), making it comparable to ammonium nitrate (with some variability around that). The inhibited product is therefore generally marketed at a price per kg N comparable to ammonium nitrate (but prices vary considerably over time). Therefore, our best assumption is that replacement of inhibited urea with ammonium nitrate fertiliser would be *cost neutral*.

2.6.7 Estimated economic costs of NH_3 mitigation

The estimated costs for implementing the mitigation scenarios for 2030 and 2040+ is summarised in Figure 2-15 and Tables 2-10 and 2-11, showing totals for the UK and the split across the four countries. Costs increase with increasing ambition of measures as well as with increasing widths of ERZ. Given the larger number and wider geographic spread of SSSIs compared with SACs, it follows that implementing the same ambition of measures in 2 km zones around SACs would cost less than for SSSIs.

Table 2-10. Total estimated cost £ million of each agricultural NH_3 emission scenario. Costs of spatially targeted scenarios have been estimated based on the UK-wide implementation (see Section 2.6.5). Costs are highly variable and should be considered as indicative.

Country	England	Wales	Scotland	NI	UK	Difference to NAPCP+DA (UK)
2030 BAU (WM)	27.0	2.0	3.2	6.5	38.7	n/a
2030 NAPCP+DA (NECR NOx)	109.8	13.8	17.0	18.5	159.1	-
2030 ERZ SAC 2km	120.8	16.4	17.9	22.1	177.6	18.5
2030 ERZ SSSI 1km	123.2	15.6	18.2	22.2	179.5	20.4
2030 ERZ SSSI 2km	137.5	17.3	19.7	26.1	201.1	42.0
2030 ERZ SSSI 5km	171.5	19.9	23.4	37.6	252.9	93.8
2030 High Amb. exc. cattle	187.9	20.3	25.9	48.2	282.4	123.3
2030 EDZ SSSI 1km	112.1	14.2	17.5	19.0	162.8	3.7
2040+ ERZ SSSI 2km inc. cattle	157.0	23.2	21.7	29.9	231.8	72.7
2040+ High Amb. inc. cattle	238.9	31.2	32.5	63.2	365.8	206.7

Table 2-11. Relative cost of each agricultural NH_3 emission scenario compared to NAPCP+DA (NERC NOx). Costs of spatially targeted scenarios have been estimated based on the UK-wide implementation (see Section 2.6.5).

Country	England	Wales	Scotland	Northern Ireland	UK
2030 NAPCP+DA (NECR NOx) (£ million)	109.8	13.8	17.0	18.5	159.1
2030 ERZ SAC 2km	10%	18%	5%	20%	12%
2030 ERZ SSSI 1km	12%	13%	7%	20%	13%
2030 ERZ SSSI 2km	25%	25%	16%	41%	26%
2030 ERZ SSSI 5km	56%	44%	38%	103%	59%
2030 High Amb. exc. cattle	71%	47%	52%	161%	77%
2030 EDZ SSSI 1km	2%	3%	3%	3%	2%
2040+ ERZ SSSI 2km inc. cattle	43%	68%	28%	62%	46%
2040+ High Amb. inc. cattle	118%	126%	91%	243%	130%

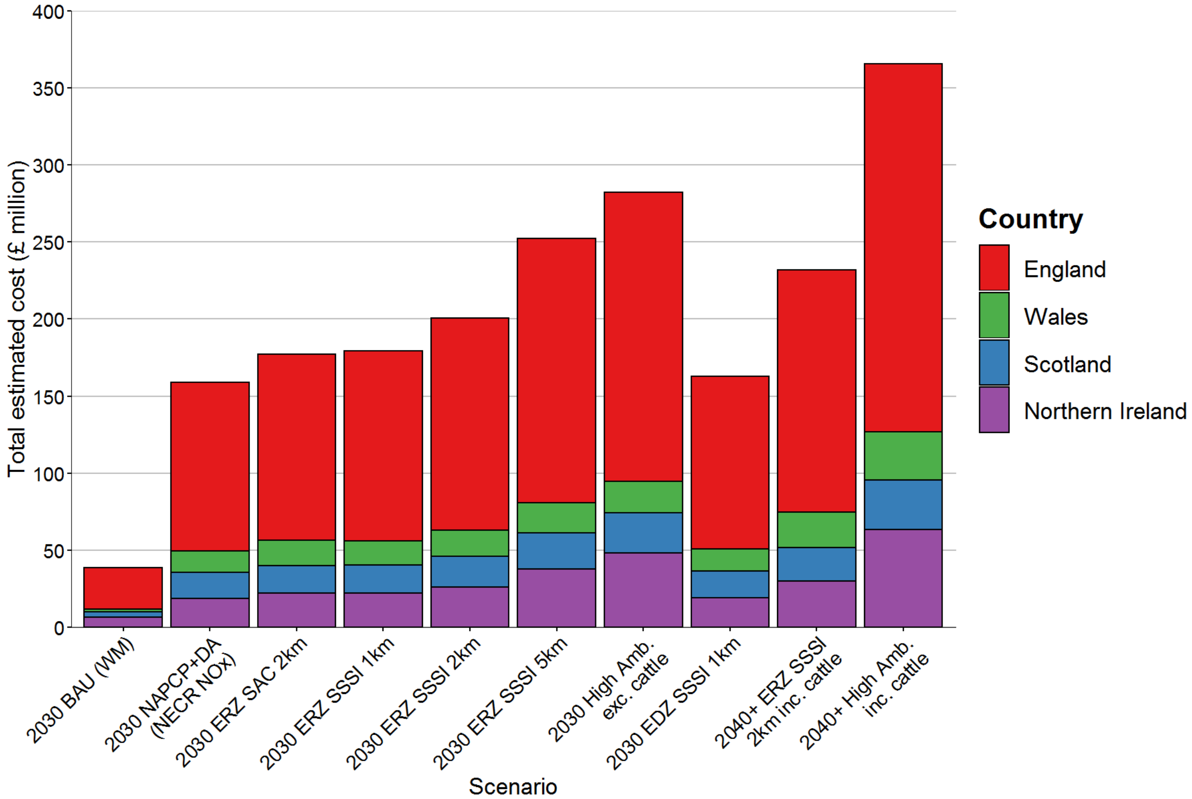

Figure 2-15. Total estimated cost (£ million) of agricultural mitigation measures. Costs have been estimated separately for each UK country.

3. Atmospheric concentrations

Atmospheric concentration of ammonia (NH_3) and oxides of nitrogen (NO_x) were estimated for all scenarios, by running the FRAME model with the emission maps described in the previous section, followed by calibration with measurement data (and including the PCM model baseline for NO_x). The methodology is described in more detail in Section 1.3. The following sections show the results of the high-resolution modelling for all scenarios and quantify the reduction in concentrations across the UK.

3.1 High-resolution concentration maps

All scenarios were modelled at a 1 km by 1 km grid resolution. A selection of maps is shown below, to illustrate the spatial distribution and magnitude of change. The comparison between scenarios is shown here in two stages:

- 2017 vs 2030 baselines
- 2030 NAPCP+DA baseline vs mitigation scenarios

The comparison with optimised scenarios is shown separately in Section 10.

3.1.1 Ammonia

A comparison between baseline concentrations of ammonia between 2017 and 2030 BAU (WM) shows relatively small differences, as expected from the underlying emission maps (Figure 3-1). Similarly, larger NH_3 concentration differences (with mostly decreases) were estimated between the most recent present-day estimate (2017) and the 2030 NAPCP+DA baseline, which represents likely patterns for the UK meeting its NECR targets.

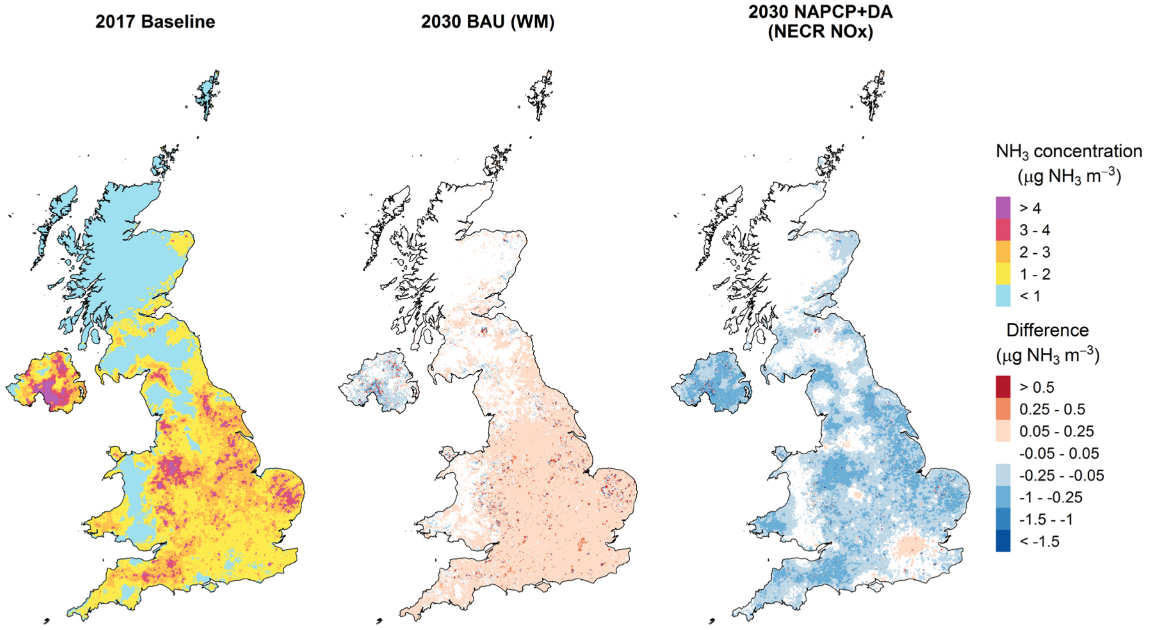

Figure 3-1. Ammonia concentration baselines: 2017 (left), difference to 2030 BAU (WM) (middle), difference to 2030 NAPCP+DA.

For the spatially targeted and UK-wide mitigation scenarios, a comparison with the NAPCP+DA baseline confirms that the key drivers for the spatial location and extent of concentration reductions are

- the zone width/size of the mitigation zones (vs. UK-wide);
- the ambition of the mitigation scenarios;
- the geographical distribution of the designated sites (N.B. the differences between the 2km scenarios for SACs vs SSSIs, see also Figure 2-1); and
- the presence/absence of emission sources for applying mitigation measures.

The following comparison (Figure 3-2) shows differences in concentrations on top of the 2030 NAPCP+DA baseline, i.e. additional concentration reductions to those shown from 2017 to 2030 in Figure 3-1 above. For the UK-wide mitigation scenarios (2030 and 2040+ High Amb. exc./inc. cattle, respectively), the largest concentration decreases are mostly in the areas with the highest emission densities and therefore highest absolute emission reductions. In the spatially targeted scenarios, the concentration decreases are predicted to be much less widespread and limited to areas that have designated sites present. One scenario standing out from the rest with particularly different concentration patterns is the EDZ scenario, where concentration increases are shown in some areas of the country, due to additional manure/slurry application that was displaced from 1 km zones around all N-sensitive SSSIs. The 5 km ERZ scenario for SSSIs (middle row, leftmost map) in Figure 3-2 is not dissimilar to the same measures applied UK-wide (middle row, 2nd map from the left), showing that much of the relatively intensive agricultural land contains a large number of widely distributed SSSIs.

Regionally, the largest effects of more ambitious measures, whether modelled UK-wide or as spatially targeted scenarios, are found in Northern Ireland and the more intensive agricultural landscapes of England and SW Wales, with dairy, pig and poultry dominated areas most prominent in terms of concentration reductions. These patterns are not surprising, as they reflect the areas with highest emission densities and therefore highest mitigation potential. At a finer scale, the same patterns can be seen more locally, e.g. in Ayrshire and other more intensive areas of agricultural activities in Scotland.

As expected, there are only minor NH_3 concentration reductions in the more remote parts of the UK, with relatively low agricultural activity, such as upland areas with only very extensive sheep and beef cattle farming at very low densities. Designated sites located in such areas are already relatively less affected by local emission sources, compared with sites in areas with much higher emission densities. The relatively localised effects of targeted emission mitigation on NH_3 concentrations (or lack thereof in areas far away from sources) is further illustrated in the local case studies presented in Annex 5, with key messages summarised in the main report.

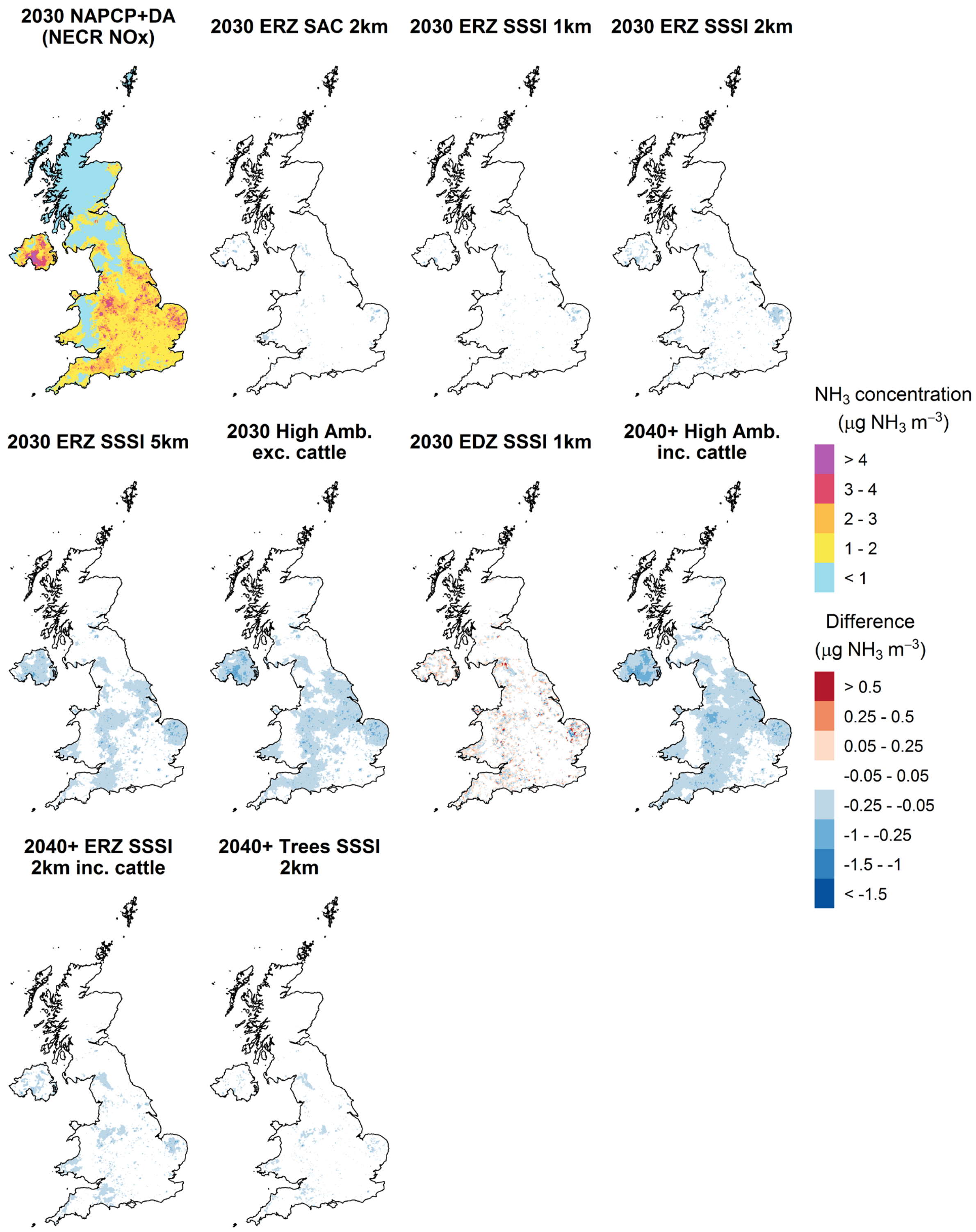

Figure 3-2. Comparison of more ambitious UK-wide and spatially targeted mitigation scenarios to 2030 NAPCP+DA (i.e. meeting NECR targets).

3.1.2 NO_x

A comparison of baseline concentrations of NO_2 between 2017 and 2030 BAU (WM) show substantial differences from the underlying emission maps (Figure 3-3). Similarly, further NO_2 concentration differences were estimated between the 2017 and the 2030 NAPCP+DA

(NECR NO_x) baselines, which represents likely patterns for the UK meeting its NECR targets.

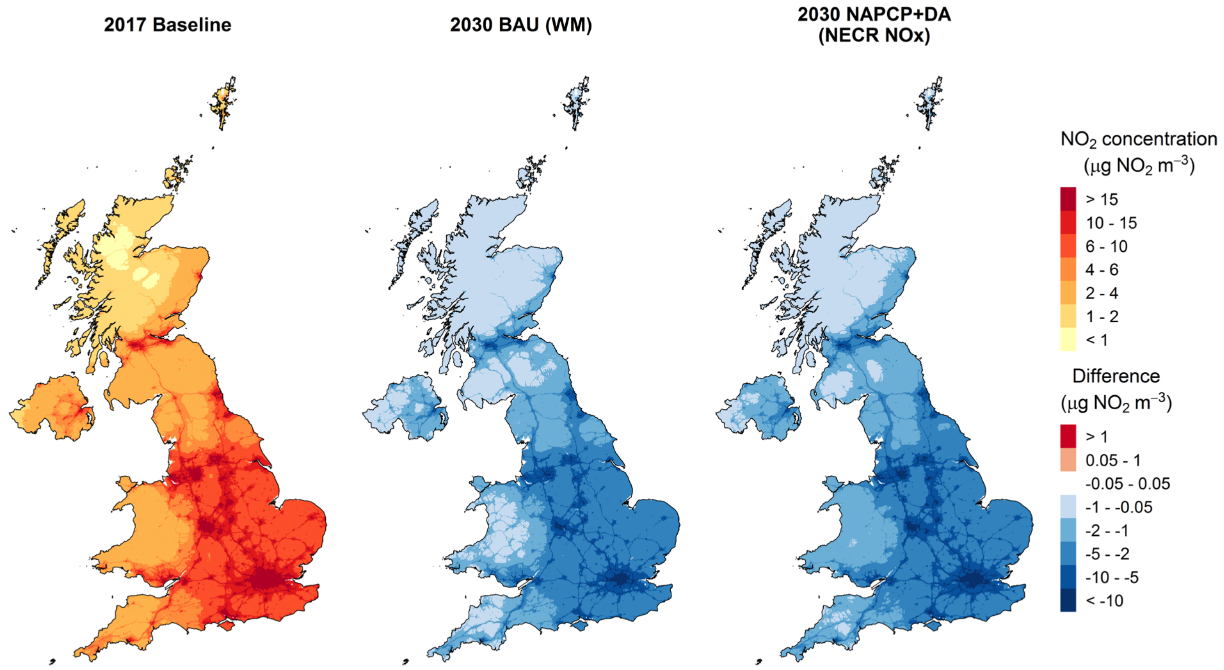

Figure 3-3. NO_2 concentration baselines: 2017 (left), difference to 2030 BAU (WM) (middle), difference to 2030 NAPCP+DA (NECR NO_x).

Further emission reductions on top of the 2030 NO_x baseline, which has been modelled to meet the UK's NECR emission reduction targets, are estimated to achieve further decreases in NO_2 concentrations across the UK and are presented in Figure 3-4. The highest decreases are expected in areas with combustion activities, i.e. the most densely populated and trafficked areas parts of the country.

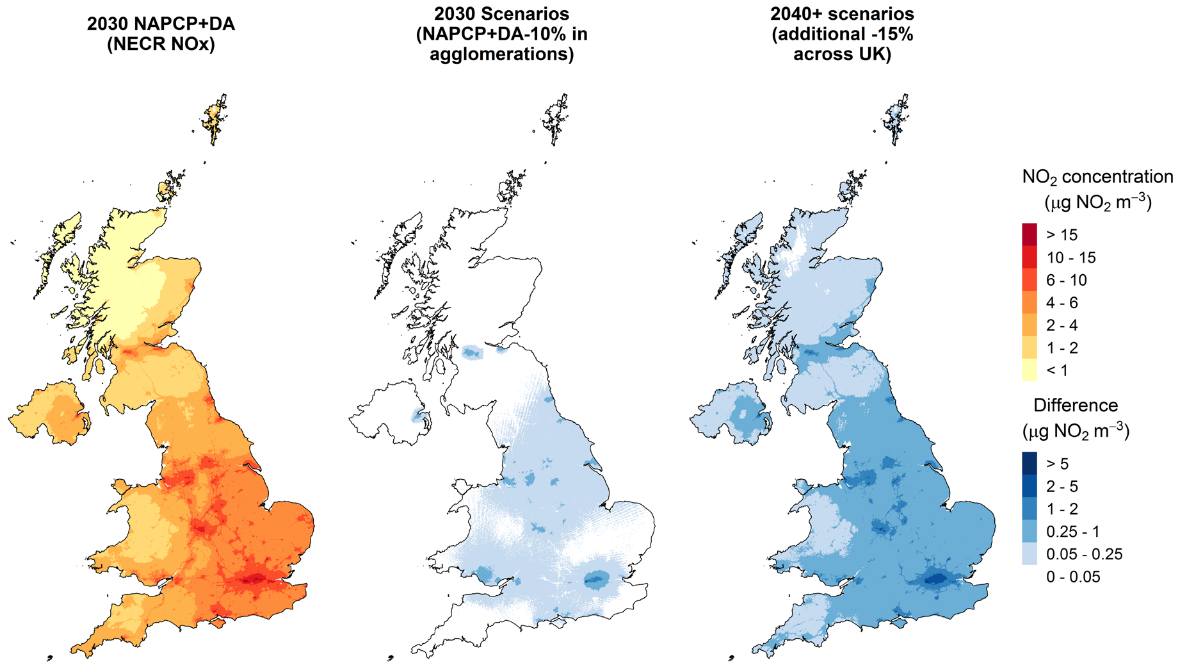

Figure 3-4. NO_2 concentrations - comparison of emission reduction scenarios.

4. Atmospheric nitrogen deposition

Atmospheric nitrogen deposition was estimated for all scenarios, by running the FRAME model with the spatially resolved emission estimates described in the previous section, followed by calibration with measurement data, using the CBED approach. The following sections show the results the high-resolution modelling for all scenarios and quantify the reduction in deposition across the UK.

4.1 UK and country summaries

Table 4-1 and Figure 4-1 summarise the estimated total N deposition to the UK land area, i.e. onto both N-sensitive and insensitive habitats, using grid-average data to account for land-use dependent deposition rates within each grid square.

The model outputs for the baseline scenarios show that substantial decreases in N deposition are expected to occur between 2017 and 2030, under existing emission reduction commitments. The BAU (WM) and NAPCP+DA (NECR NO_x) baselines are estimated to result in ca. 38 and 58 kt N less N deposited overall across the UK, respectively. The larger part of the decrease in N deposition by 2030 (meeting NECR targets) is estimated to be from NO_y (35.6 kt N), with NH_x contributing 22.2 kt N. In terms of wet/dry deposition contributions, the split in the reduction from 2017 to 2030 (NECR) is estimated at 36.0 vs 21.8 kt N, respectively across the UK. It should be noted that these reductions are in part due to reductions in transboundary air pollution, with lower imported N deposition from Europe and beyond (c.12% lower NH_x-N imports and c.20% lower NO_y-N imports in 2030 NECR than 2017), due to the wide ranging international efforts under the NECD and Gothenburg Protocol.

Further, but less substantial, reductions in N deposition (compared with meeting the NECR targets) could be achieved with meeting the UK-wide high ambition NAPCP scenario (2030 High Amb. exc. cattle), at 5.4 kt N, and 11.4 kt N with a 2040+ High Amb. inc. cattle scenario. As expected, N deposition decreases are more moderate for the spatially targeted scenarios than the UK-wide versions of the same scenarios, with overall N deposition decreasing in line with increased ERZ widths. The EDZ scenario does not result in significant differences in total N deposition to the UK (compared with the mitigation scenario NAPCP+DA, to which it is identical in terms of overall NH_3 and NO_x emissions). However, differences in the spatial patterns of atmospheric (NH_3 concentrations and) N deposition are clearly demonstrated in the following sections of this report and in the local case studies in Annex 5.

The tree planting scenario (around SSSIs) shows a, perhaps counter-intuitive, decrease in N deposition rather than an increase in deposition, which would be expected due to higher deposition velocity associated with woodland. This is due to the way this scenario has had to be implemented: the limitations of the spatial resolution of the modelling (1 km x 1 km grid) do not allow the representation of localised processes of recapture in small optimised tree belts very close to livestock houses and manure stores. Instead, the recapture process had to be implemented as average emission reductions, thereby not capturing the actual emission from the local sources followed by the recapture within each affected model grid cell (see Annex 2 for further details).

Table 4-1. Summary of N deposition to the UK land area for all baseline and mitigation scenarios, split into the main components of wet, dry, reduced and oxidised nitrogen (kt N yr^{-1}). The data represent grid square average N deposition, i.e. the land cover within each model grid square is taken into account to provide land cover dependent total deposition.

Scenario (all values kt N)	NHx-N dry	NHx-N wet	NOy-N dry	NOy-N wet	Total N
2017 Baseline	75.3	93.8	34.6	73.3	277.1
2030 Baseline BAU (WM)	76.1	86.5	22.8	54.1	239.5
2030 Baseline NAPCP+DA (NECR NOx)	67.2	79.7	20.9	51.4	219.1
2030 NAPCP+DA	67.2	79.6	20.5	51.0	218.4
2030 ERZ SAC 2km	66.8	79.3	20.5	51.0	217.6
2030 ERZ SSSI 1km	66.8	79.3	20.5	51.0	217.6
2030 ERZ SSSI 2km	66.3	79.0	20.5	50.9	216.8
2030 ERZ SSSI 5km	65.3	78.1	20.6	50.9	214.8
2030 High Amb. exc. cattle	64.6	77.6	20.6	50.9	213.7
2030 EDZ SSSI 1km	67.2	79.7	20.5	50.9	218.3
2040+ High Amb. inc. cattle	63.5	76.4	18.8	48.9	207.7
2040+ ERZ SSSI 2km inc cattle	66.0	78.4	18.8	49.0	212.1
2040+ Trees SSSI 2km	66.3	78.7	18.8	49.0	212.8

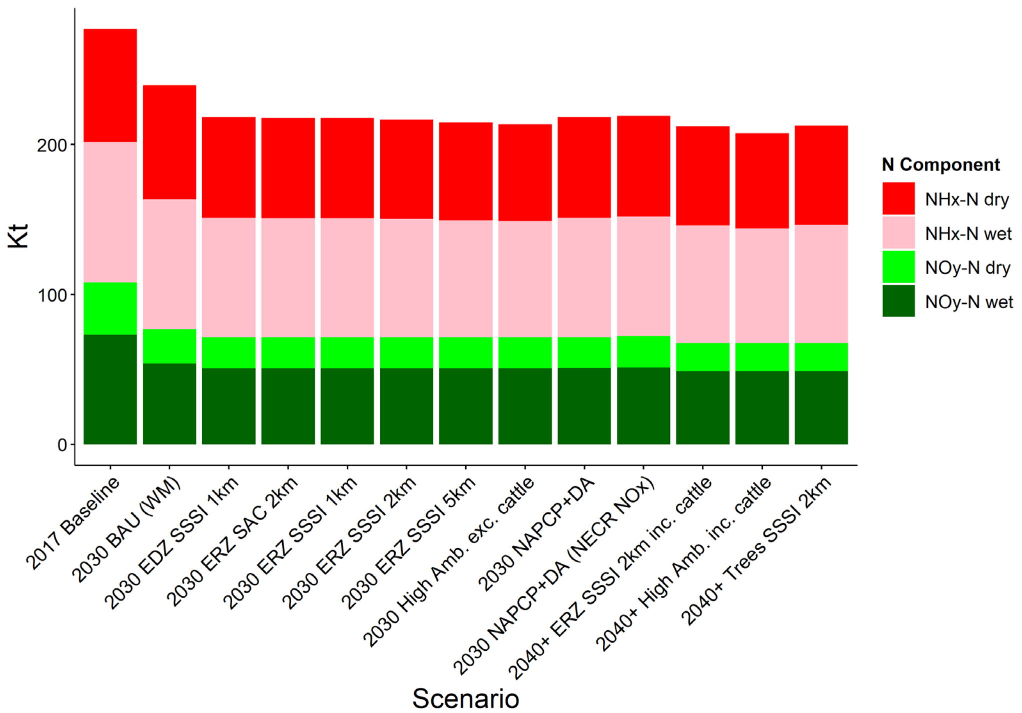

Figure 4-1. Summary of N deposition to the UK land area for all baseline and mitigation scenarios, split into the main components of wet, dry, reduced and oxidised nitrogen (kt N). The data represent grid square average N deposition, i.e. take into account the land cover within each model grid square to provide land cover dependent total deposition.

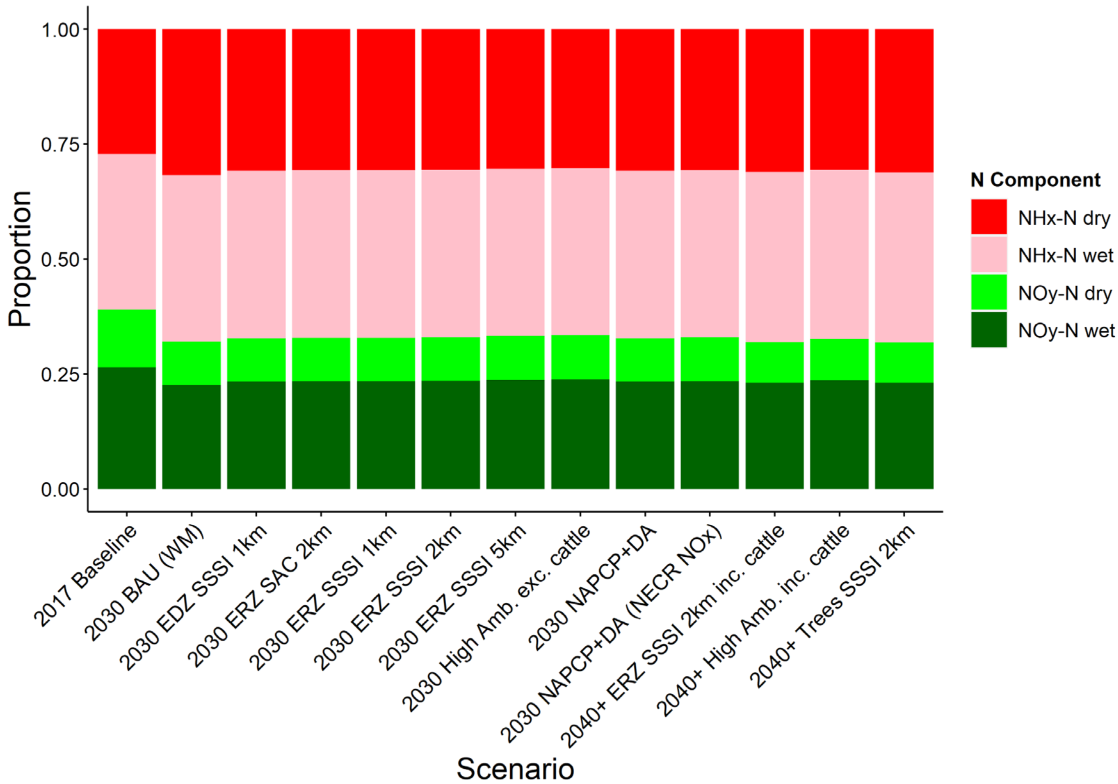

Figure 4-2. Summary of N deposition to the UK land area for all baseline and mitigation scenarios, split into the main components of wet, dry, reduced and oxidised nitrogen and expressed as relative proportions of total deposition (%).

The partitioning of the different components of N deposition varies across the UK, most obviously with more wet deposition in areas with higher precipitation, often originating from further afield and arriving through regional/long-distance atmospheric transport, and more locally originating dry deposition. Table 4-2 and Figure 4-3 summarise the different N deposition components by country. It is notable that the reduced N fraction (NH_x), originating from NH_3 emissions, is much more prominent in Northern Ireland at 38%, compared with, for example, Scotland at 21% (Table 4-2). By contrast, oxidised N (NO_y) is relatively less important in Northern Ireland than across other parts of the UK, at 25%. In terms of wet deposition (implying more long-range transport), Scotland has much higher fractions than the other countries. These differences which play out regionally/more locally within each country are important to consider when analysing the results of the mitigation scenarios as they determine how effective local measures can be in reducing deposition.

Table 4-2. Country-specific N deposition to the UK land area for all baseline and mitigation scenarios, split into the main components of wet, dry, reduced and oxidised nitrogen (kt N). The data represent grid square average N deposition, i.e. the land cover within each model grid square is taken into account to provide land cover dependent total deposition.

	DA (all kt)	2017 Baseline	2030 Baseline BAU (WM)	2030 Baseline NAPCP+DA (NECR NOx)	2030 NAPCP+DA	2030 ERZ SAC 2km	2030 ERZ SSSI 1km	2030 ERZ SSSI 2km	2030 ERZ SSSI 5km	2030 High Amb. exc. cattle	2030 EDZ SSSI 1km	2040+ High Amb. inc. cattle	2040+ ERZ SSSI 2km inc cattle	2040+ Trees SSSI 2km	2030 CLe opt. ERZ SSSI (no urea)	2030 CL opt. ERZ SSSI (no urea)
NHx-N dry	**E**	44.8	45.4	39.4	39.4	39.2	39.2	38.9	38.2	37.9	39.4	37.3	38.6	38.9	36.4	36.5
	NI	5.8	5.7	5.1	5.1	5.1	5.1	5.0	4.9	4.7	5.1	4.6	5.0	5.0	4.8	4.8
	S	14.2	14.6	13.3	13.4	13.3	13.3	13.2	13.1	13.0	13.4	12.8	13.2	13.2	12.9	12.9
	W	10.3	10.4	9.2	9.2	9.2	9.2	9.1	9.0	8.9	9.2	8.7	9.0	9.1	8.8	8.8
NHx-N wet	**E**	52.9	48.4	44.4	44.4	44.3	44.2	44.0	43.6	43.4	44.4	42.8	43.7	43.9	42.7	42.7
	NI	5.6	5.3	4.9	4.9	4.9	4.9	4.8	4.7	4.7	4.9	4.6	4.8	4.8	4.7	4.7
	S	25.7	24.1	22.3	22.3	22.2	22.2	22.1	21.9	21.7	22.3	21.4	22.0	22.1	21.7	21.7
	W	9.3	8.5	7.8	7.8	7.8	7.8	7.7	7.7	7.6	7.8	7.5	7.7	7.7	7.6	7.6
NOy-N dry	**E**	25.5	16.6	15.1	14.9	14.9	14.9	14.9	14.9	14.9	14.9	13.6	13.6	13.6	15.0	15.0
	NI	1.1	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.7	0.7
	S	4.8	3.2	3.0	2.9	2.9	2.9	3.0	3.0	3.0	2.9	2.7	2.7	2.7	3.0	3.0
	W	3.1	2.2	2.0	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.8	1.9	1.9
NOy-N wet	**E**	40.8	29.8	28.4	28.2	28.2	28.2	28.2	28.2	28.2	28.2	27.2	27.2	27.2	28.1	28.1
	NI	2.7	2.0	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.8	1.9	1.9
	S	22.4	16.7	15.8	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.0	15.0	15.0	15.7	15.7
	W	7.3	5.4	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	4.9	4.9	4.9	5.1	5.1
Total N	**E**	164.1	140.2	127.4	127.0	126.6	126.5	126.0	124.9	124.4	126.9	120.8	123.2	123.5	122.3	122.3
	NI	15.2	13.7	12.6	12.5	12.5	12.5	12.4	12.2	11.9	12.5	11.6	12.2	12.3	12.1	12.1
	S	67.1	58.7	54.5	54.3	54.2	54.2	54.0	53.6	53.3	54.3	51.9	52.9	53.0	53.2	53.2
	W	30.0	26.4	24.2	24.1	23.9	24.0	23.9	23.6	23.6	24.1	22.9	23.3	23.4	23.4	23.4

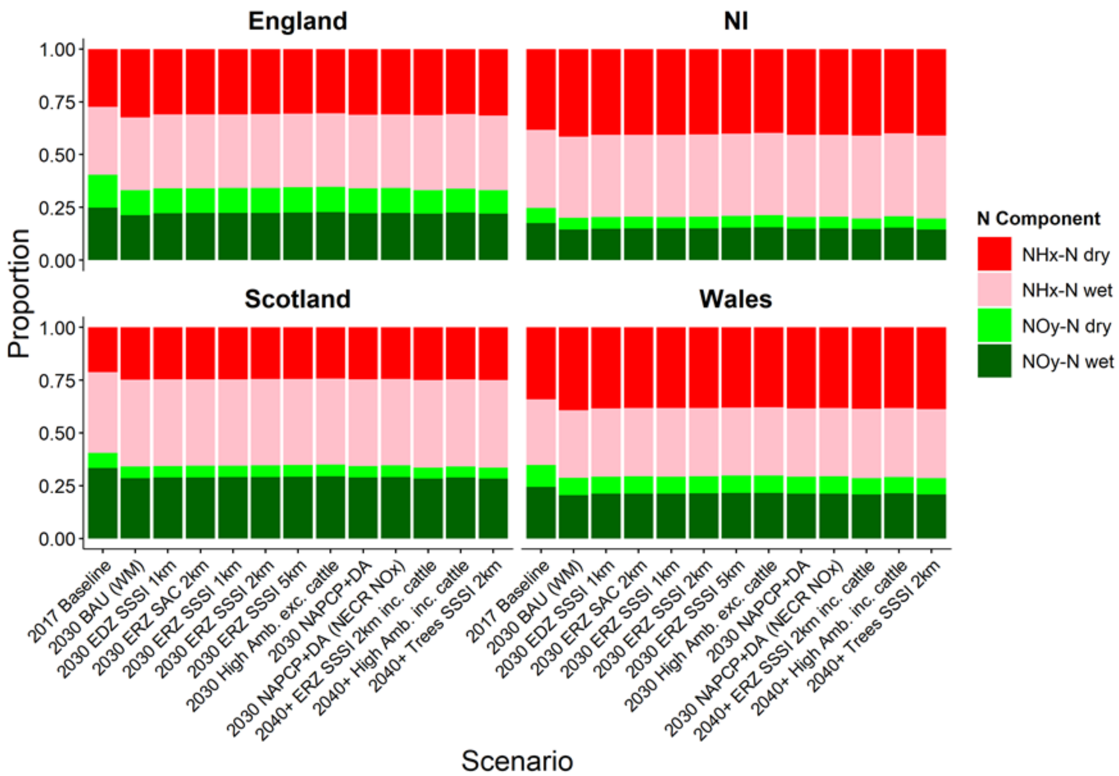

Figure 4-3. Summary of N deposition to the UK countries' land area for all baseline and mitigation scenarios, split into the main components of wet, dry, reduced and oxidised nitrogen (kt N). The data represent grid square average N deposition, i.e. the land cover within each model grid square is taken into account to provide land cover dependent total deposition.

4.2 Clean Air Strategy target: deposition onto protected sensitive habitats

For all scenarios, a metric has been calculated that can be related to the UK Government's Clean Air Strategy (CAS) target. The target is "*to reduce damaging deposition of reactive forms of nitrogen by 17% over England's protected priority sensitive habitats by 2030*".

The definition of "*protected priority sensitive habitats*" remains under discussion [at the time of finalising this report], so this study has used as an operational definition the set of priority habitats that are currently reported in the annual Trends Report (Rowe *et al.* 2019). These are: Calcareous grassland; Dwarf shrub heath (wet & dry); Montane; Bog; Beech woodland (unmanaged); Acidophilous oak woodland (unmanaged); Scots Pine woodland (unmanaged); Dune grassland; and Saltmarsh. Deposition of reactive N onto these habitats (Table 4.3) follows a similar geographical pattern to overall deposition, with similar mean deposition in England, Wales and Northern Ireland, but considerably less overall deposition in Scotland.

The CAS target for England is expressed as a 17 % decrease in N deposition onto N-sensitive priority habitats by 2030, so the scenarios are most easily compared by looking at percentage decrease (Table 4-4). However, the numbers in this table are percentage decrease since 2017. It has recently been decided that a 2016 baseline will be used to assess progress towards the CAS target, as explained in Rowe *et al*. (2020). This means that percentage decreases will be larger than shown in Table 4-4. For example, the *NAPCP+DA (NECR NOx)* scenario was projected to decrease N deposition onto N-sensitive priority habitats in England by 16.5 % over the period 2017-2030. Allowing for the observed decrease between 2016 and 2017 (Rowe *et al*. 2020), this corresponds to a decrease of

18.9 % between 2016 and 2030. Similarly, the estimated decrease from a 2016 baseline was more than 17 % for all countries of the UK under *NAPCP+DA (NECR NOx)* and all more stringent scenarios. The BAU (WM) scenario was not projected to meet the target, however, with a 7.1 % decrease 2017-2030 and only an estimated 9.7 % decrease 2016-2030. The most effective scenario, *CLe opt. ERZ SSSI with EDZ (no urea)*, resulted in a 21.0 % decrease in N deposition onto N-sensitive priority habitats in England 2017-2030 and an estimated 23.3 % decrease 2016-2030.

Updates to the maps of protected sensitive habitats are expected, so numbers presented here should be considered preliminary. Relative changes in deposition to any set of habitats are expected to be similar, so the projected percentage decreases (Table 4-4) are likely to be representative of results obtained using the final definition. However, if "protected sensitive habitats" are defined as areas within designated sites and/or give greater weight to areas within designated sites, the effects will be larger for the scenarios that include spatial targeting measures.

Table 4-3. Mean deposition of total reactive N onto nutrient-N sensitive priority habitat in kg ha^{-1} $year^{-1}$, by UK country.

	Average area weighted N deposition onto nutrient-N sensitive priority habitats, by UK country				
Scenario	**England**	**Wales**	**Scotland**	**Northern Ireland**	**UK**
2017 Baseline	20.9	18.3	8.2	19.1	12.2
2030 BAU (WM)	19.4	16.5	7.3	17.9	11.1
2030 NAPCP+DA (NECR NOx)	17.4	15.2	6.8	16.3	10.1
2030 NAPCP+DA	17.4	15.1	6.8	16.3	10.1
2030 ERZ SAC 2km	17.3	15.1	6.8	16.1	10.1
2030 ERZ SSSI 1km	17.3	15.1	6.8	16.2	10.1
2030 ERZ SSSI 2km	17.2	15.0	6.8	16.1	10.0
2030 ERZ SSSI 5km	17.0	14.9	6.7	15.7	9.9
2030 High Amb. exc. cattle	17.0	14.8	6.7	15.4	9.9
2030 EDZ SSSI 1km	17.3	15.1	6.8	16.3	10.1
2040+ ERZ SSSI 2km inc. cattle	16.9	14.8	6.6	15.9	9.9
2040+ High Amb. inc. cattle	16.6	14.5	6.5	15.0	9.6
2040+ Trees SSSI 2km	17.0	14.8	6.6	16.0	9.9
2030 CLe opt. ERZ SSSI (no urea)	16.5	14.7	6.7	15.5	9.8
2030 CL opt. ERZ SSSI (no urea)	16.5	14.7	6.7	15.5	9.8

Table 4-4. Percentage change (from 2017 baseline) in mean deposition of total reactive N onto nutrient-N sensitive priority habitat in kg ha^{-1} $year^{-1}$, by UK country.

	Percentage change in area-weighted mean deposition of total reactive N onto nutrient-N sensitive priority habitat, by UK country				
Scenario	**England**	**Wales**	**Scotland**	**Northern Ireland**	**UK**
2030 BAU (WM)	-7.1	-9.7	-11.5	-6.5	-9.4
2030 NAPCP+DA (NECR NOx)	-16.5	-17.1	-17.4	-14.9	-16.9
2030 NAPCP+DA	-16.6	-17.3	-17.6	-15.0	-17.0
2030 ERZ SAC 2km	-17.0	-17.7	-17.8	-15.7	-17.4
2030 ERZ SSSI 1km	-17.1	-17.7	-17.8	-15.5	-17.4
2030 ERZ SSSI 2km	-17.5	-18.0	-18.1	-16.1	-17.7
2030 ERZ SSSI 5km	-18.3	-18.7	-18.7	-18.0	-18.5
2030 High Amb. exc. cattle	-18.7	-19.0	-19.1	-19.6	-19.0
2030 EDZ SSSI 1km	-17.0	-17.4	-17.6	-15.0	-17.2
2040+ ERZ SSSI 2km inc. cattle	-18.8	-19.5	-19.6	-16.9	-19.1
2040+ High Amb. inc. cattle	-20.6	-21.0	-21.1	-21.5	-20.9
2040+ Trees SSSI 2km	-18.4	-19.2	-19.5	-16.3	-18.8
2030 CLe opt. ERZ SSSI (no urea)	-21.0	-19.7	-19.2	-19.0	-19.9
2030 CL opt. ERZ SSSI (no urea)	-21.0	-19.7	-19.3	-19.0	-19.9

4.3 High-resolution maps of nitrogen deposition

All scenarios were modelled at a 1 km by 1 km grid resolution. A selection of maps is shown below, to illustrate the spatial distribution and magnitude of change. The comparison between scenarios is shown here in two stages:

- 2017 vs 2030 baselines
- 2030 NAPCP+DA baseline vs mitigation scenarios

The comparison with optimised scenarios is covered separately in Section 7 of this document.

For assessing impacts of N deposition to sensitive habitats and designated sites, vegetation specific deposition estimates need to be used, i.e. model outputs that quantify the amount of N deposited to a habitat if it is present in a 1 km grid square. Such maps are calculated separately for low-growing semi-natural vegetation (e.g. bogs, heathlands, grassland) and woodlands, using appropriate deposition velocities.

4.3.1 Grid average deposition

For assessing overall N deposition to the UK land mass, deposition estimates to different surfaces (e.g. vegetation specific values for woodland, low-growing semi-natural vegetation, agricultural land, built-up areas) are combined with land cover information, to calculate the total N deposition for each grid square. Grid average N deposition data are useful for calculating N input to catchments, or country budgets of atmospheric deposition. However, for assessing atmospheric N input to specific habitat types, the vegetation specific deposition estimates are used (Sections 3.3.2, 3.3.3).

Figures 4-4 and 4-5 below show differences in N grid average deposition compared to the baselines (i.e. 2017 to 2030) and for the more ambitious spatially targeted and UK-wide scenarios.

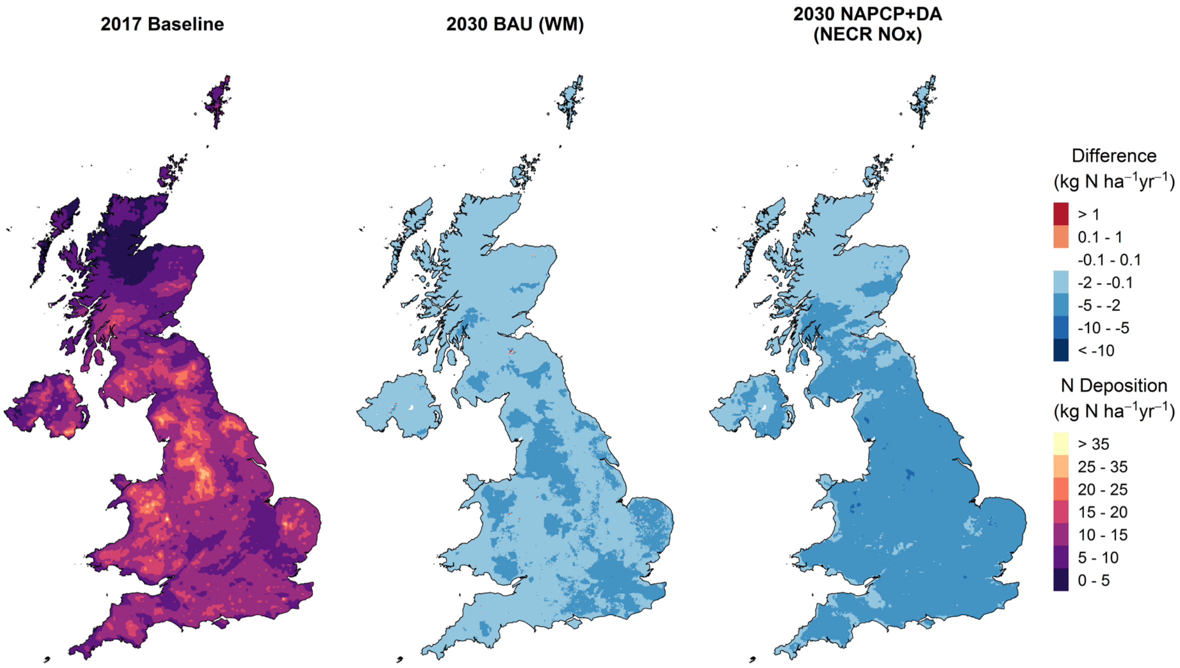

Figure 4-4. N deposition (kg N ha^{-1} yr^{-1}) grid average - baselines: 2017 (left), difference to 2030 BAU (WM) (middle), difference to 2030 NAPCP+DA.

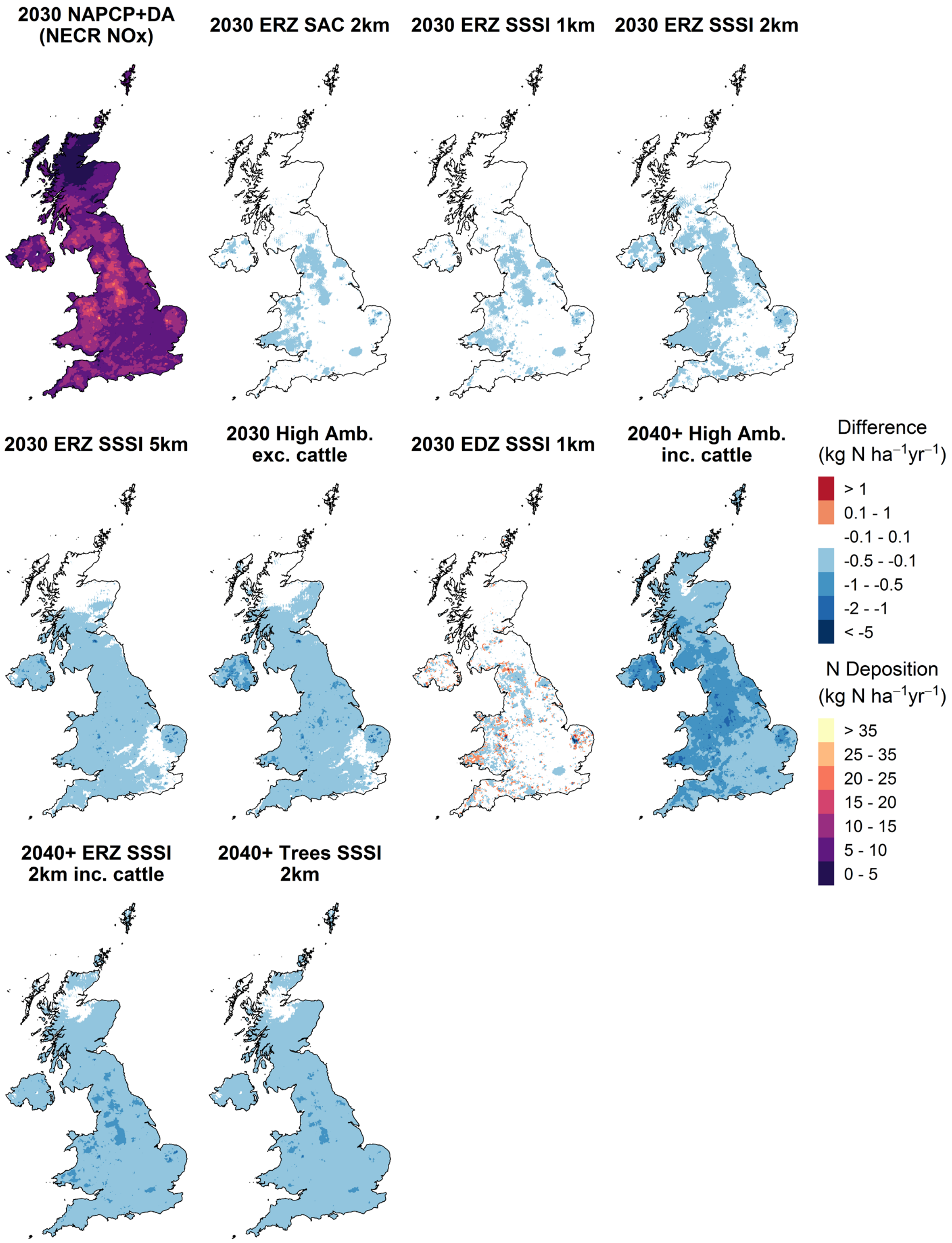

Figure 4-5. Grid average N deposition (kg N ha^{-1} yr^{-1}): comparison of more ambitious UK-wide and spatially targeted mitigation scenarios to 2030 NAPCP+DA (i.e. meeting NECR targets).

4.3.2 Deposition to low-growing semi-natural vegetation

Figures 4-6 and 4-7 below show differences in N deposition to low-growing semi-natural vegetation for the baselines (i.e. 2017 to 2030) and for the more ambitious spatially targeted and UK-wide scenarios. For the baseline comparison, substantial differences in N deposition can be seen, with decreases by up to 5 kg N ha^{-1} yr^{-1} from 2017 to 2030, under the NAPCP+DA baseline, i.e. meeting NECR targets. Decreases in deposition are estimated across all parts of the UK, both in source areas and more remote parts of the country, through both dry and wet deposition pathways (Figure 4-6). There are some small areas where increased deposition is estimated. This is mainly due to projected changes in livestock populations for 2030, where the increased numbers of animals present counteract estimated emission reductions on a per-animal basis.

For the more ambitious UK-wide mitigation scenarios for 2030 and 2040+ (Figure 4-7, 2nd and 4th map from the left, middle row), additional N deposition reductions of >1 kg N ha^{-1} yr^{-1} are estimated for large parts of Northern Ireland, and for the areas in GB with the highest emission densities. For the spatially targeted scenarios, decreases in N deposition are, as expected, more limited and focused on where designated sites are located. The EDZ scenario stands out from the scenarios focused on emission reduction – with increases in deposition further away from designated sites (in red) contrasting with deposition reductions at the sites. Impacts of these scenarios on deposition at individual case study sites are illustrated in more detail in Annex 5, and statistics on exceedance of critical loads for priority habitats and designated sites are covered in Section 6 below.

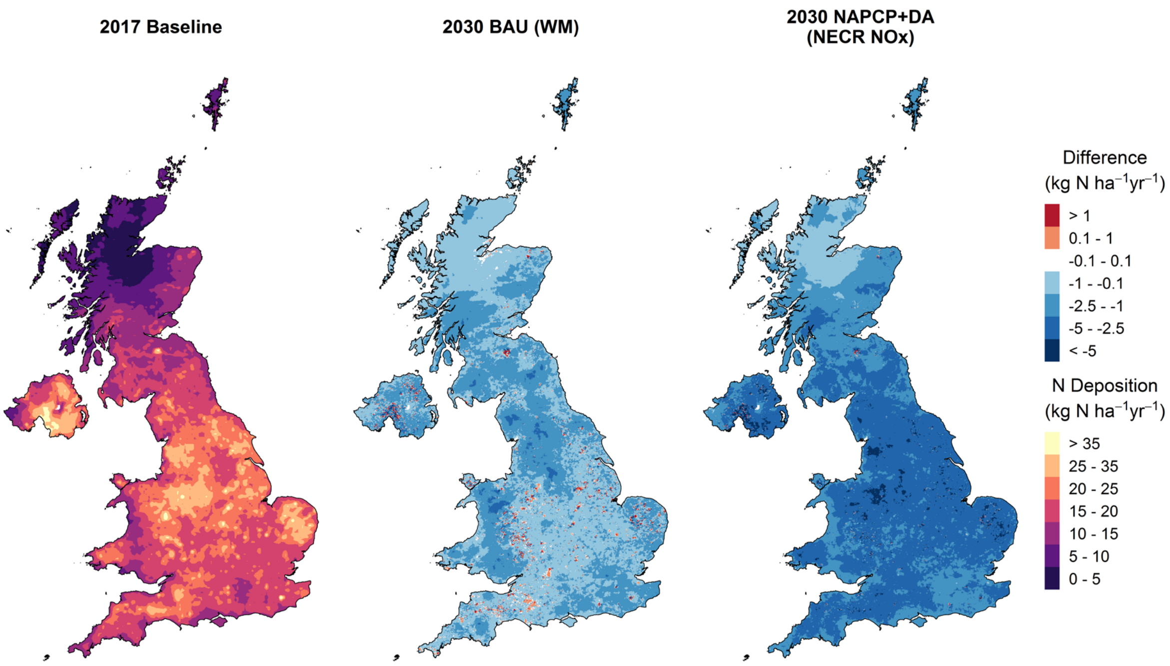

Figure 4-6. N deposition (kg N ha^{-1} yr^{-1}) to low-growing semi-natural vegetation - baselines: 2017 (left), difference to 2030 BAU (WM) (middle), difference to 2030 NAPCP+DA.

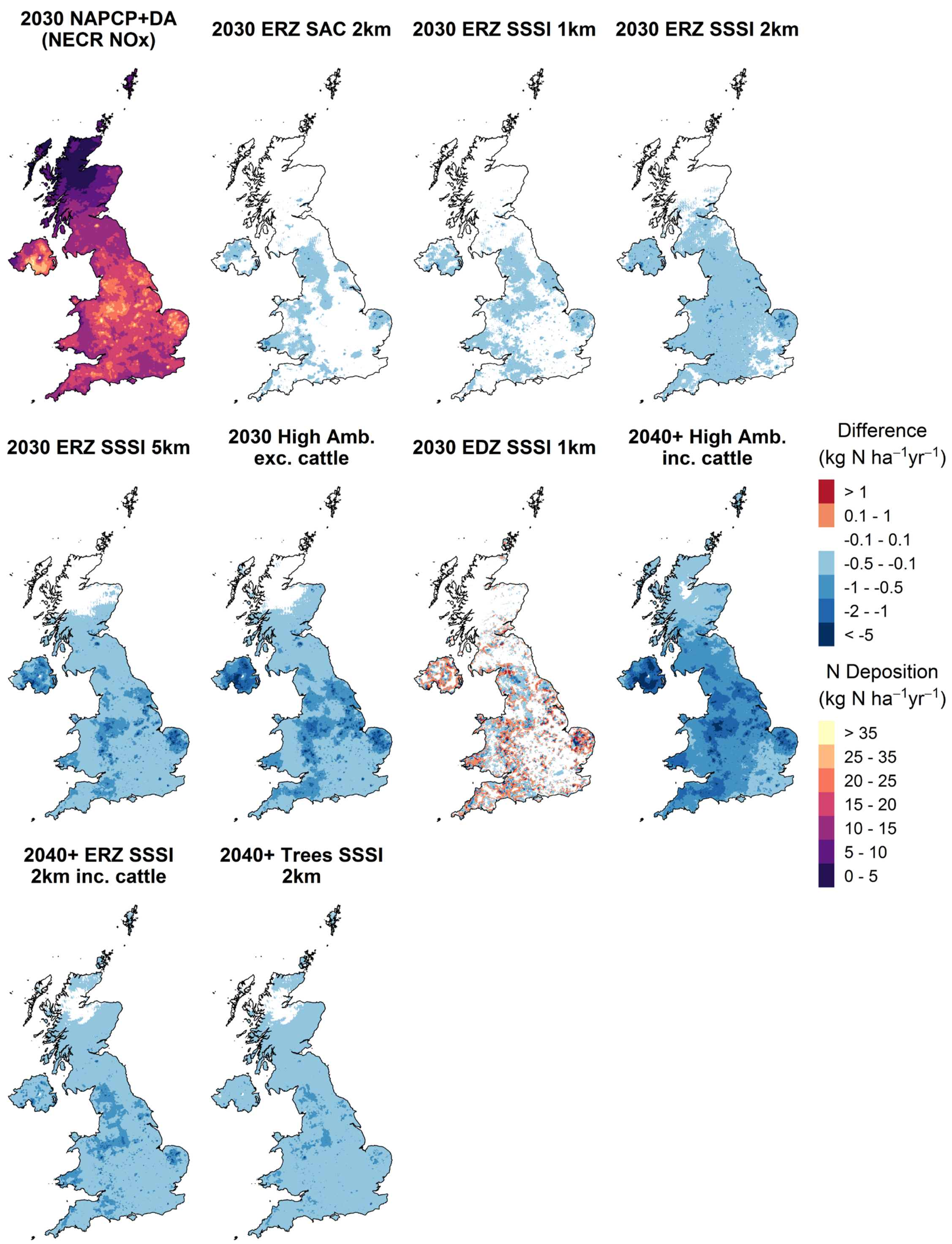

Figure 4-7. N deposition (kg N ha^{-1} yr^{-1}) to low-growing semi-natural vegetation features - comparison of more ambitious UK-wide and spatially targeted mitigation scenarios to 2030 NAPCP+DA (i.e. meeting NECR targets).

4.3.3 Deposition to woodland

Figures 4-8 and 4-9 below show differences in N deposition to woodland features for the baselines (i.e. 2017 to 2030) and for the more ambitious spatially targeted and UK-wide scenarios. For the baseline comparison, substantial differences in N deposition can be seen, with decreases by up to 5 kg N ha^{-1} yr^{-1} for large parts of the UK, from 2017 to 2030, under the NAPCP+DA baseline (i.e. meeting NECR targets). For N-sensitive woodland habitats located across large parts of lowland England, Wales and Northern Ireland, decreases in N deposition are expected to exceed 5 kg N ha^{-1} yr^{-1}. Decreases in deposition are estimated across all parts of the UK, both in source areas and more remote parts of the country, through both dry and wet deposition pathways (Figure 4-8). The impact of decreasing NOx emissions by 10% in agglomeration areas (Figure 4-9, centre map of top row) on N deposition to any woodland habitats present in the blue grid cells is clearly visible. While the deposition reduction (mostly as dry deposition near sources) estimated is relatively small on average, the 1 km grid square resolution is diluting the likely effects close to sources such as busy roads. This is quantified for some case studies (e.g. Epping Forest, Ashdown Forest) in Annex 5. The more ambitious UK-wide NH_3 mitigation scenarios for 2030 and 2040+ (2nd and 4th map from the left, middle row), additional N deposition reductions of >2 kg N ha^{-1} yr^{-1} are estimated for large parts of Northern Ireland, and for the areas in GB with the highest emission densities. For the spatially targeted scenarios, decreases in N deposition are, as expected, more limited and focused on where designated sites are located. The EDZ scenario stands out from the scenarios focused on emission reduction – with increases in deposition further away from designated sites (in red) contrasting with deposition reductions at the sites. Impacts of these scenarios on deposition at individual case study sites are illustrated in more detail in Annex 5, and statistics on exceedance of critical loads for priority habitats and designated sites are covered in Section 6 below.

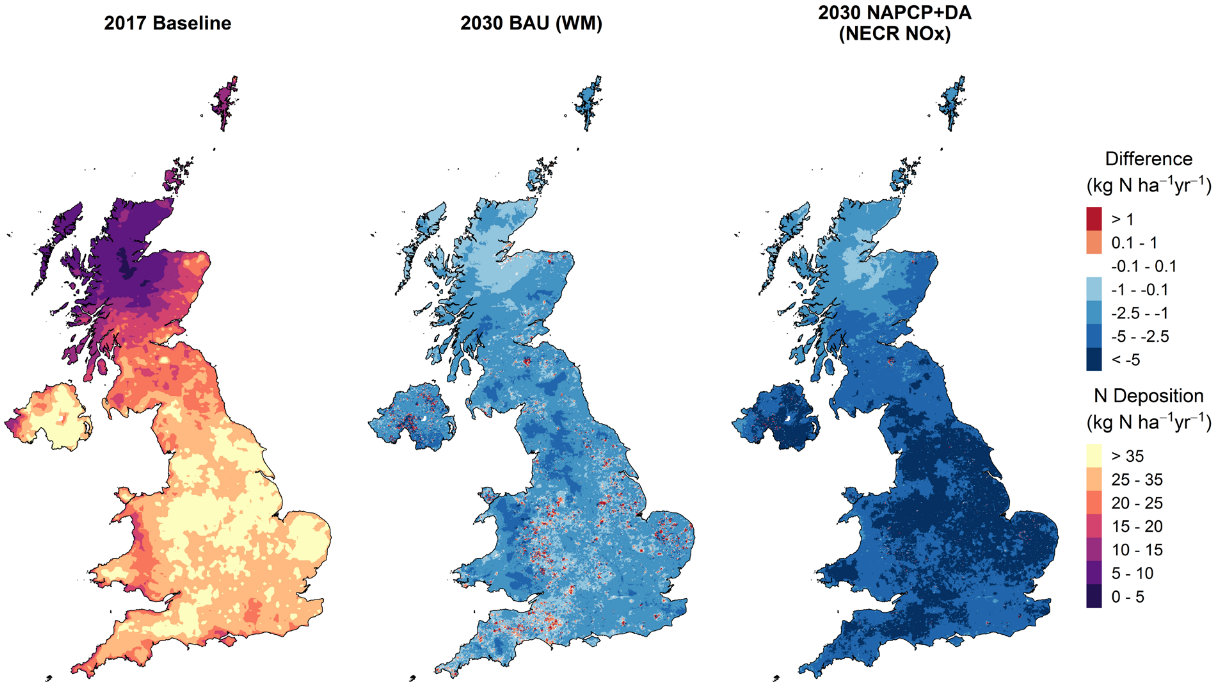

Figure 4-8. N deposition (kg N ha^{-1} yr^{-1}) to woodland features - baselines: 2017 (left), difference to 2030 BAU (WM) (middle), difference to 2030 NAPCP+DA.

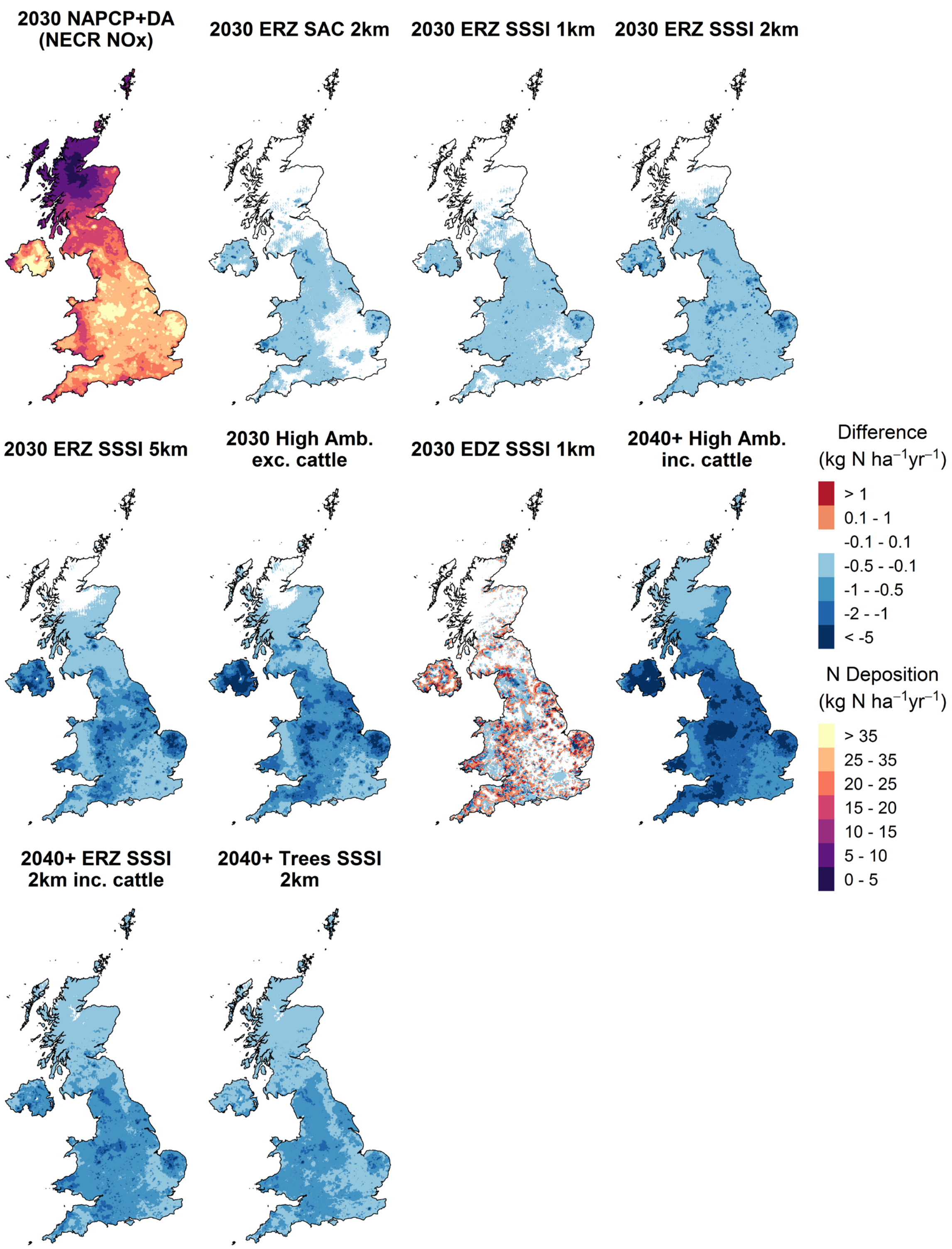

Figure 4-9. N deposition (kg N ha^{-1} yr^{-1}) to woodland features: comparison of more ambitious UK-wide and spatially targeted mitigation scenarios to 2030 NAPCP+DA (i.e. meeting NECR targets).

5 Ammonia critical level exceedance

5.1 UK and country summaries

From the NH_3 concentration and N deposition maps presented so far, it is evident that there are distinct spatial patterns across the regions of the UK, with designated sites in some areas much more at risk from critical level (and critical loads) exceedance than others. The NH_3 Critical Level statistics were also analysed at a country basis, separately for England, Wales, Scotland and Northern Ireland. In the following paragraphs, the results are discussed for both UK-wide mitigation scenarios and spatially targets scenarios in turn, for the 1 and 3 µg m^{-3} critical levels.

Exceedance of both the 1 and 3 µg m^{-3} critical levels at SSSIs is estimated to increase between 2017 and the 2030 BAU (WM) scenario, i.e. a first tranche of measures that are already in the process of being implemented towards the NECR targets (Figure 5-1). This is likely due to the small overall increase in NH_3 emissions predicted, by ca. 3 kt NH_3, and the spatial patterns of the increase of different emission sectors close to designated sites (Section 5.2). Similarly, this net increase is masking a number of sites that no longer exceed vs. those that newly exceed the critical levels, due to the spatial distribution of the emission sectors increasing/decreasing locally (Section 5.2 maps). For the 3 µg m^{-3} critical level, the proportion of exceeded sites drops substantially with any of the more ambitious scenarios. In meeting NECR targets through the NAPCP+DA measures, the proportion of sites exceeding the 3 µg m^{-3} critical level across the UK drops from ~8% to < 5%, with the more ambitious scenarios bringing this figure down to 3%. Interestingly, the EDZ scenario (i.e. removing all manure and slurry spreading from a 1 km zone around SSSIs) appears to be the most effective, on average. The 1 µg m^{-3} critical level is harder to tackle, as a much larger number (and proportion) of sites are currently in exceedance, and many sites are located in areas with substantial regional emission sources, providing for higher background concentrations (see Section 8.1 for further analysis). The proportion of nitrogen sensitive sites exceeding the 1 µg m^{-3} critical level (at least over part of their area, i.e. DWI) across the UK drops from ~76% under 2030 BAU (WM) to ~71% under 2030 NAPCP+DA (NECR NOx). The proportion of land area within sites in exceedance of the 1 µg m^{-3} critical level (i.e. AW-2) decreases from ~28% under 2030 BAU (WM) to ~22% under 2030 NAPCP+DA (NECR NOx).

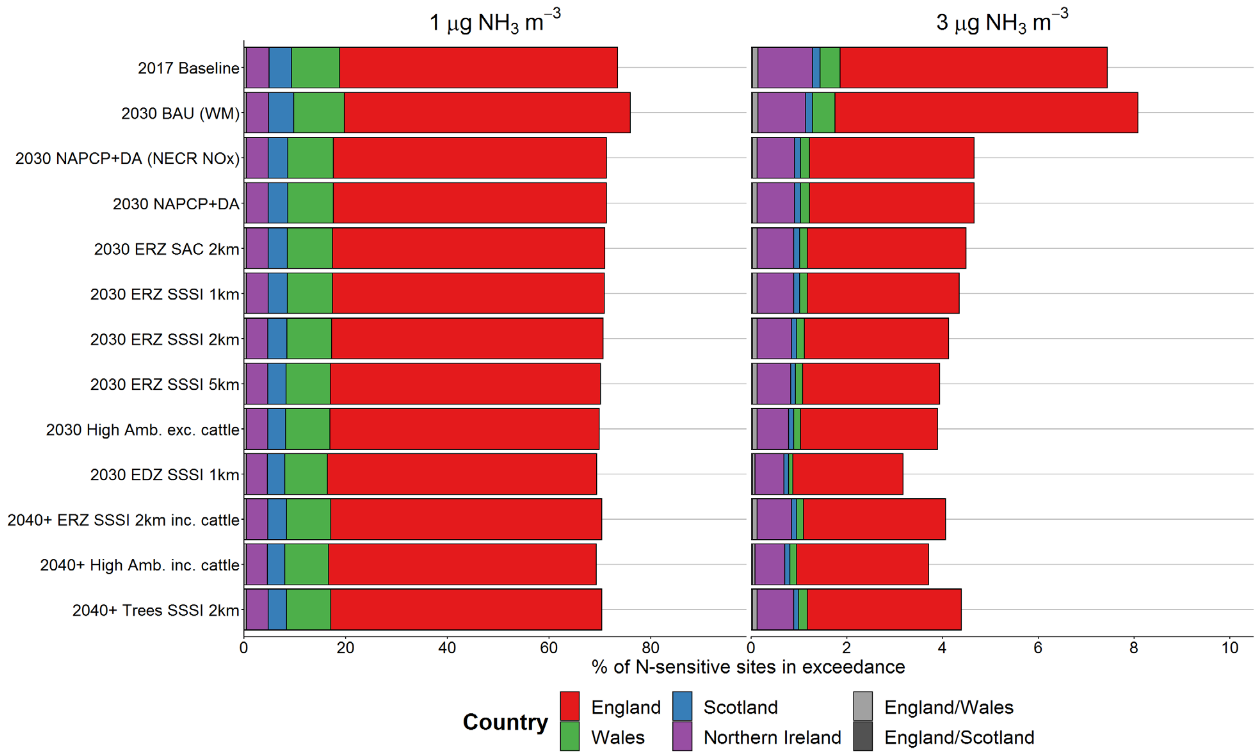

Figure 5-1. A comparison of the proportion of nitrogen-sensitive UK SSSIs (n = 4,853) in exceedance of critical levels (1 µg m^{-3} and 3 µg m^{-3}) under each scenario. The 1 NH_3 µg m^{-3} is relevant for assessing lichens, mosses and bryophytes and 3 NH_3 µg m^{-3} for higher plants.

Tables 5-1 and 5-2 summarise the exceedance indicators for the 1 and 3 µg NH_3 m^{-3} critical levels across the four UK countries. The Designated Weighted Indicator (DWI) shows the number of sites with exceedance, the Area Weighted Indicator (AWI-1) shows total area of sites with exceedance, and AWI-2 shows the total area exceeded across sites (full description in Section 1.4). For example, in England 89.0% of nitrogen sensitive SSSIs exceed the 1 µg NH_3 m^{-3} CLe (DWI) under the 2017 baseline, which is equivalent to 90.5% of the total area of SSSIs in England (i.e. AWI-1). Across all SSSIs in England, 42.3% of the area exceeds the 1 µg CLe (AWI-2).

For the 2017 baseline scenario, the majority of SSSIs in England and Northern Ireland exceed, at least in part, the 1 µg m^{-3} critical level set for the most sensitive species (Table 5-1) across the more precautionary indicators, i.e. the DWI and AWI-1. For Wales, levels are lower, at around 2/3 of sites. By contrast, many SSSIs in Scotland benefit from being located in relatively remote and cleaner areas, away from substantial NH_3 emission sources (23% of sites for the DWI, i.e. number of sites, and 10% for the AWI-1, i.e. the proportion of SSSI area for all sites with exceedance of 1 µg m^{-3} anywhere on site). As expected, the AWI-2 indicator, which refers to the overall area exceeded across all sites (i.e. counts specific exceeded areas within sites only), is substantially lower for much of the UK, with the exception of Northern Ireland, where NH_3 concentrations are high throughout most of the country (>80%).

The 2030 NAPCP+DA scenario appears to be more effective across Wales, Scotland and Northern Ireland than for England, in terms of the number of sites coming out of 1 and 3 µg NH_3 m^{-3} CLe exceedance (DWI), with decreases in exceedance of around 3-5%. This is due to the much higher baseline concentrations across Northern Ireland, with relatively larger efforts needed to achieve decreases below the CLe thresholds. For the two area weighted indicators, there is a pattern of higher % decreases for the countries with higher proportions of sites exceeded, i.e. from >7% AWI-2 in Northern Ireland to <1% in Scotland. More ambitious UK-wide mitigation scenarios decrease the indicators further, by up to 3% for the DWI. For the AWI-1, no large differences are expected across, England (up to 1%) and for Scotland/Northern Ireland (<1%), the latter due to different reasons – with diminishing returns for the remaining smaller number of sites in Scotland vs. the remaining relatively high emission density across Northern Ireland making this indicator much harder to meet for the 1 µg m^{-3} CLe. For Wales, the higher-level UK-wide scenarios result in a nearly 10% drop in AWI-1, likely due to a number of sites being relatively close to maximum NH_3 concentrations of just >1 µg m^{-3}. For the AWI-2 indicator, decreases are more modest for England (~4%), Wales (<2%) and Scotland (<1%), but relatively high in Northern Ireland at >12%. Table 5-1 shows that it is possible to decrease NH_3 concentrations across considerable parts of the currently exceeded SSSI area (i.e. AW-2) to below 1 µg m^{-3}.

The spatially targeted scenarios achieve, as expected, proportionally smaller decreases than the UK-wide versions of the same measures (effectiveness is further evaluated in Section 8). The EDZ scenario (i.e. land spreading emissions displaced from a 1 km zone around SSSIs to 2-5 km away) does not include actual emission reduction measures compared with NAPCP+DA, but appears to be relatively successful at decreasing exceedance of the 1 µg m^{-3} CLe across all countries and indicators, compared with the emission reduction scenarios, with the lowest AWI-1 of all scenarios predicted by up to >2%.

For the 3 µg m^{-3} critical level (Table 5-2), 2017 baseline exceedances across all indicators are largest for Northern Ireland, at 23% for DWI and 48% for AWI-1, followed by England (9% and 21%, respectively), Wales (4 and 5%, respectively), with Scotland at 1% and 2.6%, respectively. Substantial improvements are expected for the 2030 NAPCP+DA scenario, with the largest decreases in Northern Ireland (DWI 7 % lower, AWI-1 5% lower) and England (reductions of >3 and 5%, respectively). In Wales, where exceedances for all indicators are already lower, substantial relative change is still estimated compared to 2017.

In Scotland, the area of SSSIs exceeding 3 µg m^{-3} (using the AWI-2) is already very small (below 0.1%). The UK-wide and spatially targeted mitigation scenarios are expected to result in further decreases in the three indicators. The largest difference in the DWI (number of sites) and AWI-1 (area based) is again (as for the 1 µg m^{-3} CLE) achieved by the EDZ scenario across England, Wales and Northern Ireland. For Scotland, the differences are relatively small between the scenarios that achieve the highest benefit for SSSIs, with all but the smallest ERZ scenarios achieving similar gains in the country-average indicators.

Another way to look at the scenario results is the number of sites coming out of exceedance, compared with the 2017 baseline, i.e. current best estimate. Overall, atmospheric NH_3 concentrations across 138 UK SSSIs currently exceeding 1 µg m^{-3} CLe are expected to drop below this threshold with the implementation of the 2030 NAPCP+DA measures. Approximately 46% of these SSSIs are located in England, 22% in Wales, 20% in Scotland and 11% in Northern Ireland. The higher ambition UK-wide mitigation scenarios are estimated to bring a further 65 and 92 SSSIs, respectively, out of exceedance, with the spatially targeted ERZ scenarios providing increasing benefits with the width of the mitigation zones, as expected. In terms of the maximum number of sites coming out of exceedance, for the UK as a whole, the 2040+ UK-wide highest ambition scenario (including regulation of large cattle farms) is estimated to achieve similar success as the EDZ scenario. The same two scenarios also achieve the highest numbers for Scotland and Northern Ireland, whereas in Wales the EDZ scenario appears most successful, and in England the 2040+ UK-wide highest ambition scenario.

Figure 5-2 shows the average area-weighted exceedance above the 1 µg NH_3 CLe at N-sensitive SSSIs under each mitigation scenario. This quantification of the average area weighted concentration above the CLe, shows the wider benefits of increasingly ambitious mitigation across designated sites. While the number of sites achieving non-exceedance increases with ambition levels, those that remain in exceedance also benefit from decreased concentrations. For a large proportion of sites in Scotland and Wales the area-weighted concentration is estimated to be only marginally above the 1 µg CLe, by up to 0.2 µg NH_3 m^{-3} (yellow bars in Figure 5-2).

The average area-weighted exceedance above the 3 µg NH_3 CLe at N-sensitive SSSIs under each mitigation scenario are presented in Figure 5-3. The proportion of sites in exceedance of the 3 µg NH_3 CLe are much lower than for the 1 µg CLe. This is especially the case in Scotland where only 7 sites (with areas in Scotland) are in exceedance of the 3 µg CLe under NAPCP+DA (NECR NO_x). While the number of sites achieving non-exceedance increases with ambition levels, those that remain in exceedance also benefit from decreased concentrations. In the same way as for the 3 µg NH_3 CLe, sites that are coming out of exceedance with mitigation efforts are those with the lowest levels of excess NH_3 concentrations.

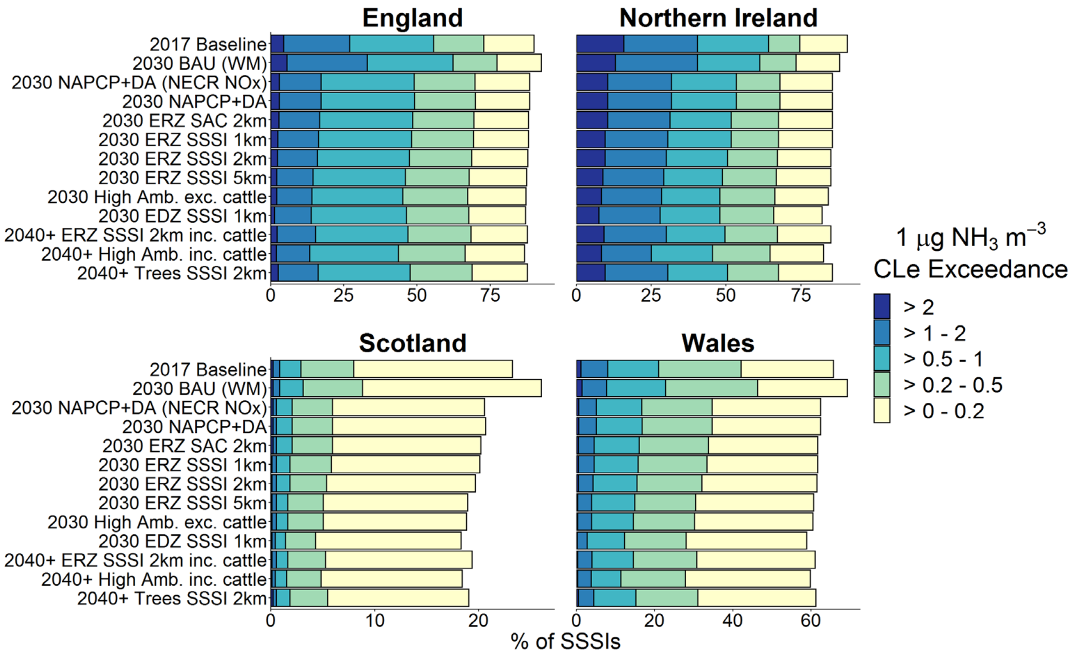

Figure 5-2. Average-area weighted exceedance above the 1 ug critical level at UK nitrogen sensitive SSSI sites (in exceedance of critical level).

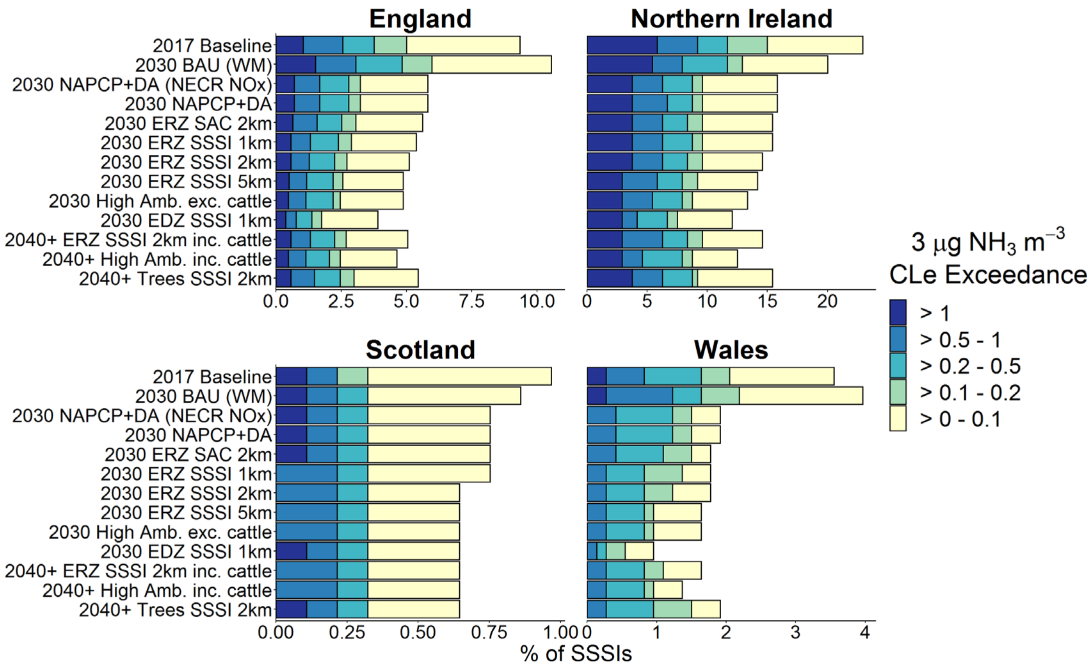

Figure 5-3. Average-area weighted exceedance above the 3 ug critical level at UK nitrogen sensitive SSSI sites (in exceedance of critical level).

Table 5-1. UK-wide and spatially target mitigation scenarios: Percentage of ammonia critical level exceedance (>1 μg m^{-3}) in nitrogen sensitive SSSIs by UK country (England, Wales, Scotland, Northern Ireland). Indicators shown are the DWI (Designation Weighted Indicator) and AWI (Area Weighted Indicators).

	England			Wales			Scotland			Northern Ireland		
Scenario	DWI	AWI-1	AWI-2	DWI	AWI-1	AWI-2	DWI	AWI-1	AWI-2	DWI	AWI-1	AWI-2
2017 Baseline	89.9	90.5	42.3	65.7	70.8	13.9	23.2	10.2	2.4	90.4	97.1	84.3
2030 BAU (WM)	92.5	93.2	49.6	69.3	69.8	15.4	26.0	11.0	2.6	87.9	95.4	83.1
2030 NAPCP+DA (NECR NOx)	88.4	88.5	37.7	62.4	66.5	10.8	20.5	9.8	1.7	85.4	94.1	77.2
2030 ERZ SAC 2km	88.1	88.4	36.9	61.7	66.4	10.3	20.2	9.8	1.6	85.4	94.1	76.4
2030 ERZ SSSI 1km	88.0	88.4	36.9	61.7	66.4	10.5	20.1	9.8	1.6	85.4	94.1	76.7
2030 ERZ SSSI 2km	87.8	88.3	36.4	61.5	66.3	10.2	19.7	9.6	1.5	85.0	94.1	76.2
2030 ERZ SSSI 5km	87.5	88.3	35.2	60.7	55.9	9.7	18.9	9.5	1.4	85.0	94.1	74.0
2030 High Amb. exc. cattle	87.2	88.0	34.6	60.5	55.9	9.5	18.8	9.5	1.4	84.2	94.0	69.8
2030 EDZ SSSI 1km	87.1	85.4	35.9	58.9	53.6	9.6	18.3	9.3	1.3	82.1	91.5	76.1
2040+ ERZ SSSI 2km inc. cattle	87.6	88.3	36.1	61.1	56.0	9.8	19.4	9.6	1.5	85.0	94.1	75.9
2040+ High Amb. inc. cattle	86.7	87.5	33.4	59.8	55.9	8.9	18.4	9.4	1.3	82.5	94.0	64.6
2040+ Trees SSSI 2km	87.7	88.3	36.5	61.2	66.3	10.1	19.0	9.5	1.5	85.4	94.1	76.4

Table 5-2. UK-wide and spatially target mitigation scenarios: Percentage of ammonia critical level exceedance (> 3 µg m^{-3}) in nitrogen sensitive SSSIs by UK country (England, Wales, Scotland, Northern Ireland). Indicators shown are the DWI (Designation Weighted Indicator) and AWI (Area Weighted Indicators).

	England			Wales			Scotland			Northern Ireland		
Scenario	DWI	AWI-1	AWI-2	DWI	AWI-1	AWI-2	DWI	AWI-1	AWI-2	DWI	AWI-1	AWI-2
2017 Baseline	9.3	20.9	1.0	3.6	4.8	0.4	1.0	2.6	0.0	22.9	48.0	1.3
2030 BAU (WM)	10.5	19.5	1.1	4.0	4.8	0.5	0.9	2.6	0.0	20.0	43.3	1.2
2030 NAPCP+DA (NECR NOx)	5.8	14.9	0.6	1.9	4.2	0.3	0.8	2.6	0.0	15.8	41.8	0.9
2030 ERZ SAC 2km	5.6	14.7	0.6	1.8	3.9	0.3	0.8	2.6	0.0	15.4	41.8	0.9
2030 ERZ SSSI 1km	5.4	14.7	0.6	1.8	3.9	0.3	0.8	2.6	0.0	15.4	41.8	0.8
2030 ERZ SSSI 2km	5.1	14.7	0.5	1.8	3.9	0.3	0.6	2.6	0.0	14.6	41.7	0.8
2030 ERZ SSSI 5km	4.9	14.7	0.5	1.6	3.9	0.2	0.6	2.6	0.0	14.2	41.6	0.8
2030 High Amb. exc. cattle	4.9	14.7	0.5	1.6	3.9	0.2	0.6	2.6	0.0	13.3	41.6	0.8
2030 EDZ SSSI 1km	3.9	12.9	0.3	1.0	3.7	0.1	0.6	2.6	0.0	12.1	41.3	0.7
2040+ ERZ SSSI 2km inc. cattle	5.0	14.7	0.5	1.6	3.9	0.2	0.6	2.6	0.0	14.6	41.7	0.8
2040+ High Amb. inc. cattle	4.6	14.6	0.5	1.4	3.8	0.2	0.6	2.6	0.0	12.5	41.5	0.7
2040+ Trees SSSI 2km	5.4	14.7	0.6	1.9	4.2	0.3	0.6	2.6	0.0	15.4	41.8	0.8

Table 5-3. Additional number of nitrogen sensitive UK SSSIs (compared with the 2017 baseline) that are no longer in exceedance of the 1 μg m^{-3} critical level under each of the emission scenarios. The 1 μg m^{-3} critical level is relevant for assessing lichens, mosses and bryophytes. Exceedance of critical levels has been assessed based on the maximum estimated concentrations at sites.

Scenario	England	Wales	Scotland	NI	UK
2030 BAU (WM)	0	5	6	8	19
2030 NAPCP+DA (NECR NOx)	64	31	28	15	138
2030 ERZ SAC 2km	73	36	32	15	156
2030 ERZ SSSI 1km	74	36	33	15	158
2030 ERZ SSSI 2km	81	37	38	16	172
2030 ERZ SSSI 5km	86	43	46	16	191
2030 High Amb. exc. cattle	93	44	47	19	203
2030 EDZ SSSI 1km	98	59	51	24	232
2040+ ERZ SSSI 2km inc. cattle	82	39	42	16	179
2040+ High Amb. inc. cattle	107	50	50	23	230
2040+ Trees SSSI 2km	81	39	45	15	180

For the 3 μg m^{-3} CLe, atmospheric NH_3 concentrations across 157 UK SSSIs currently exceeding this threshold are expected to drop below this threshold with the implementation of the 2030 NAPCP+DA measures. The majority (76%) of these SSSIs are located in England, with 14% in Northern Ireland, 9% in Wales, 2% in Scotland. The higher ambition UK-wide mitigation scenarios are estimated to bring a further 40 and 51 SSSIs, respectively, out of exceedance, with the spatially targeted ERZ scenarios providing increasing benefits with the width of the mitigation zones, as expected. It is notable that the 5 km ERZ is almost as successful as the same scenario implemented UK-wide. This is in part due to the 5 km ERZ covering large parts of the country, 73% UK-wide (Tables 1-4, 1-5). However, due to the highly reactive nature of NH_3 as a local pollutant, emission decreases within the nearest 5 km to designated sites are expected to have more impact than those further away. This is the central premise of the spatial targeting concept. In terms of the maximum number of sites coming out of exceedance, for the UK as a whole the EDZ scenario is estimated to bring 21 more sites out of exceedance than the 2040+ UK-wide highest ambition scenario (including regulation of large cattle farms). This scenario is estimated to achieve the highest numbers across England, by a relatively large margin, and to a lesser extent for Wales and Northern Ireland. For Scotland, where relatively few SSSIs exceed the 3 μg m^{-3} CLe), all scenarios achieve only relatively modest further gains for this indicator, as would be expected. The same two scenarios, EDZ and 2040+ High Amb. inc cattle are similarly successful for Scotland and Northern Ireland. For Wales, the EDZ scenario is estimated to be the most successful option, whereas for England the 2040+ UK-wide highest ambition scenario had the highest rating. The main reason for the EDZ being more successful than the ERZ is that more emissions are removed from the immediate area surrounding the sites with these measures.

Table 5-4. Additional number of nitrogen sensitive UK SSSIs (compared with the 2017 baseline) that are no longer in exceedance of the 3 µg m^{-3} critical level under each of the emission scenarios. The 3 µg m^{-3} critical level is relevant for assessing higher plants. Exceedance of critical levels has been assessed based on the maximum estimated concentrations at sites.

Scenario	England	Wales	Scotland	Northern Ireland	UK
2030 BAU (WM)	23	1	2	12	38
2030 NAPCP+DA (NECR NOx)	119	14	3	22	157
2030 ERZ SAC 2km	127	16	3	23	168
2030 ERZ SSSI 1km	133	16	3	23	174
2030 ERZ SSSI 2km	142	16	4	25	186
2030 ERZ SSSI 5km	149	17	4	26	195
2030 High Amb. exc. cattle	149	17	4	28	197
2030 EDZ SSSI 1km	175	22	4	32	229
2040+ ERZ SSSI 2km inc. cattle	144	17	4	25	189
2040+ High Amb. inc. cattle	158	20	4	30	208
2040+ Trees SSSI 2km	132	14	4	23	172

5.2 Maps

SSSIs expected to no longer exceed the 1 and 3 µg m^{-3} critical levels, respectively, by 2030, due to NAPCP+DA measures, compared with 2017, are shown in Figure 5-4 and 5-5 (blue dots). The spatial distribution of sites no longer in exceedance reflects the gradients across the UK concentration maps. There is a contrast between the generally cleaner sites away from major emission source areas vs sites situated in mainly agricultural landscapes with relatively higher emission densities. The generally cleaner sites are mainly located in the uplands and closer to coasts, across Northern England, Wales, western NI and southern Scotland. The agricultural areas with the highest emission densities are in English lowland areas and large parts of Northern Ireland. However, with NH_3 emissions expected to increase slightly under the BAU (WM) scenario, and SO_2 concentrations expected to decrease further (thereby increasing the atmospheric lifetime of NH_3), a number of sites are expected to be pushed into exceedance (red dots), both for the 1 and 3 µg m^{-3} critical levels, with some exceptions.

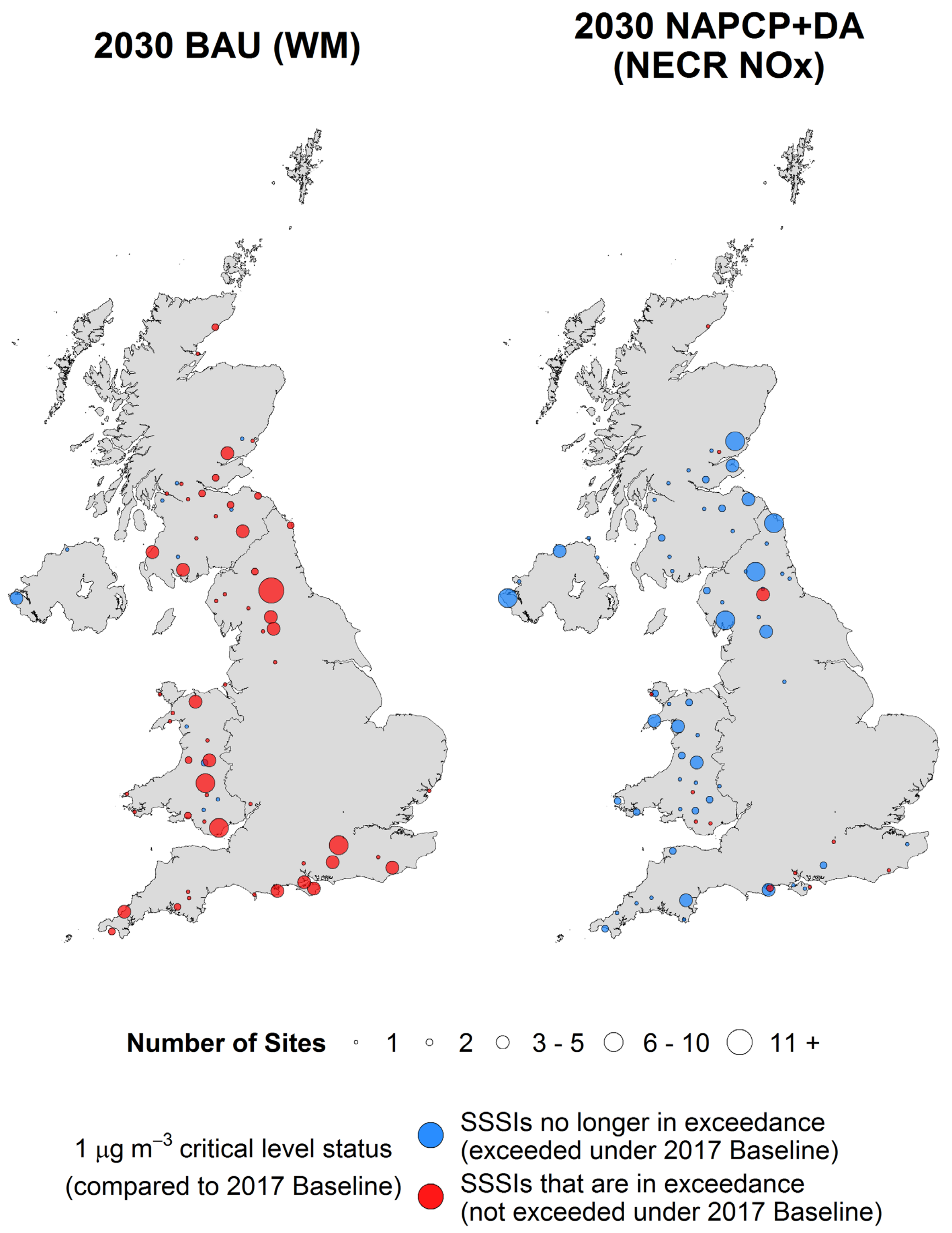

Figure 5-4. Maps showing the additional number of nitrogen sensitive UK SSSIs (compared with the 2017 baseline) that are no longer in exceedance of the 1 µg m^{-3} critical level under each of the emission scenarios. The 1 µg m^{-3} critical level is relevant for assessing lichens, mosses and bryophytes. Exceedance of critical levels has been assessed based on the maximum estimated concentrations at sites. Sites clustered together with nearby site up to a distance of 50 km for visualisation. Sites that are in exceedance in 2030 but not in the 2017 baseline are shown in red.

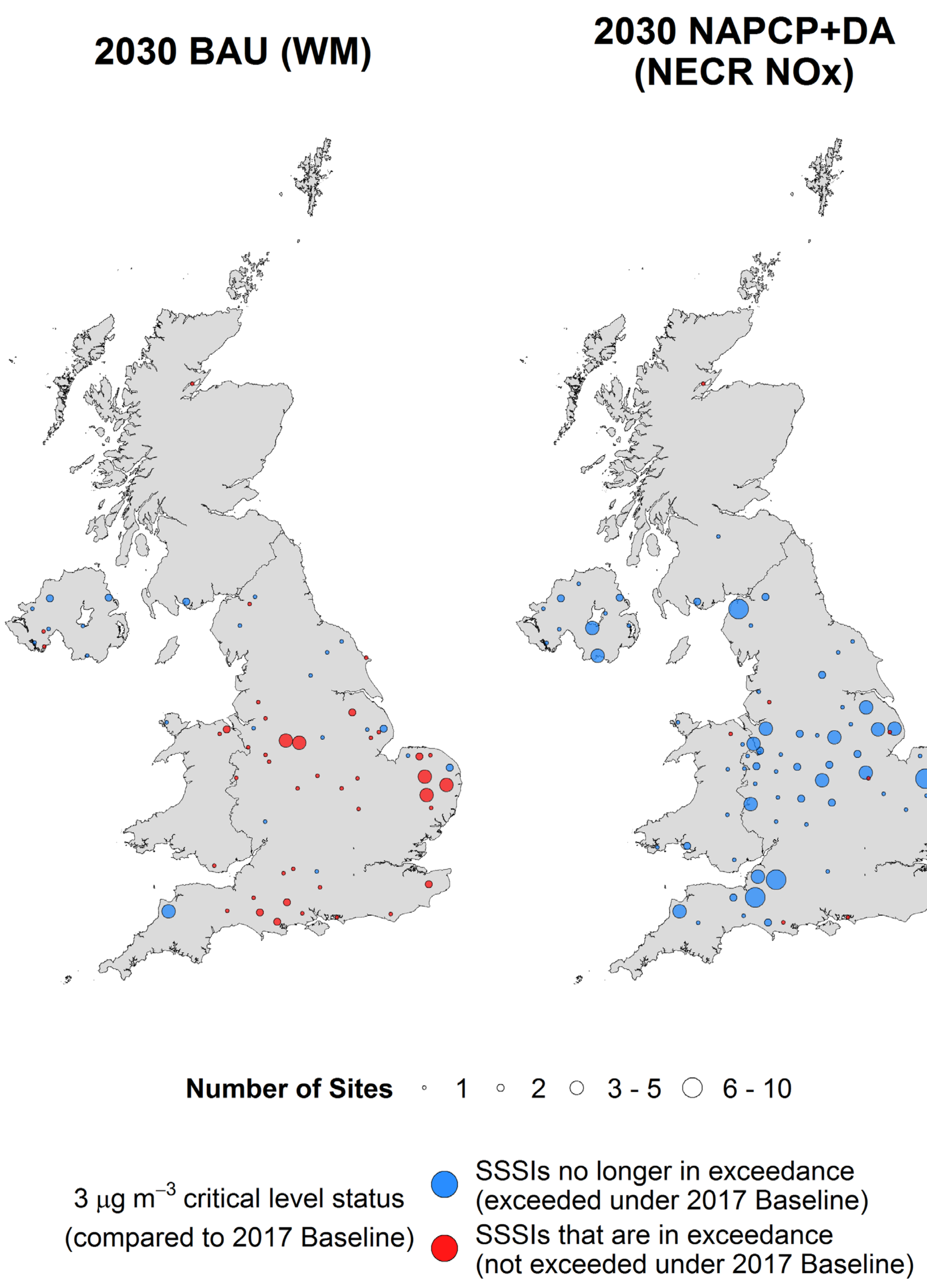

Figure 5-5. Maps showing the additional number of nitrogen sensitive UK SSSI sites (compared with the 2017 baseline) that are no longer in exceedance of the 3 µg m^{-3} critical level relevant for assessing higher plants. Exceedance of critical levels has been assessed based on the maximum estimated concentrations at sites. Sites clustered together with nearby site up to a distance of 50 km for visualisation.

For the more ambitious UK-wide and the spatially targeted scenarios, additional sites are estimated to be no longer in exceedance of the 1 µg m^{-3} critical level, compared with the NAPCP+DA (NECR NO_x) scenario (Figure 5-6). These sites are mostly located in already relatively clean areas away from major emission source areas.

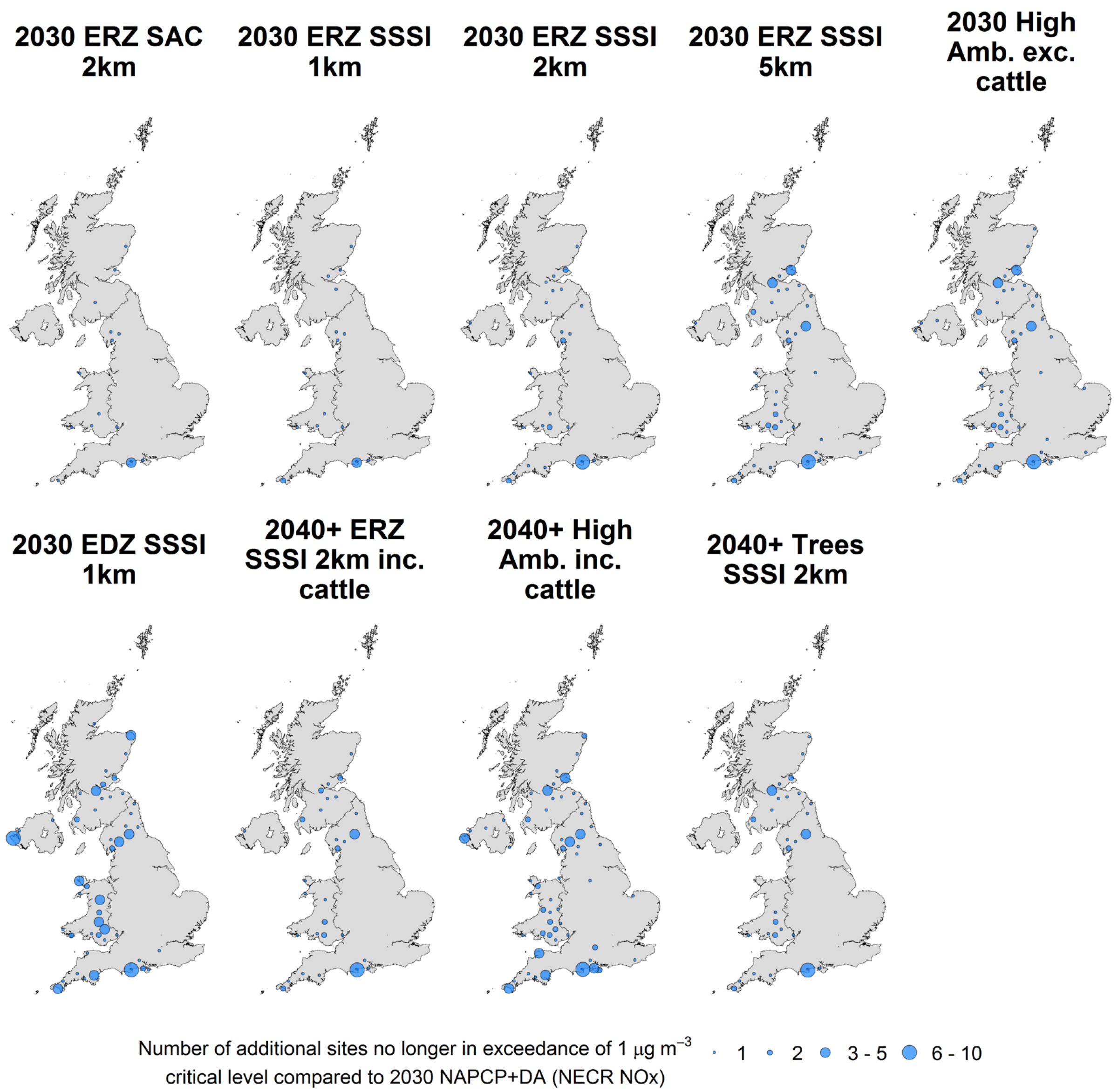

Figure 5-6. Maps showing the additional number of nitrogen sensitive UK SSSIs (compared with the NAPCP+DA NECR NO_x scenario) that are no longer in exceedance of the 1 µg m^{-3} critical level under each of the emission scenarios. The 1 µg m^{-3} critical level is relevant for assessing lichens, mosses and bryophytes. Exceedance of critical levels has been assessed based on the maximum estimated concentrations at sites. Sites clustered together with nearby site up to a distance of 50 km for visualisation.

For the more ambitious UK-wide and the spatially targeted scenarios, additional sites are estimated to be no longer in exceedance of the 3 µg m^{-3} critical level, compared with the NAPCP+DA (NECR NO_x) scenario (Figure 5-7). These sites are mostly located in areas with higher emission densities, e.g. those associated with cattle farming in Northern Ireland, dairy and poultry farming in Shropshire/Cheshire and pig/poultry farming in eastern England.

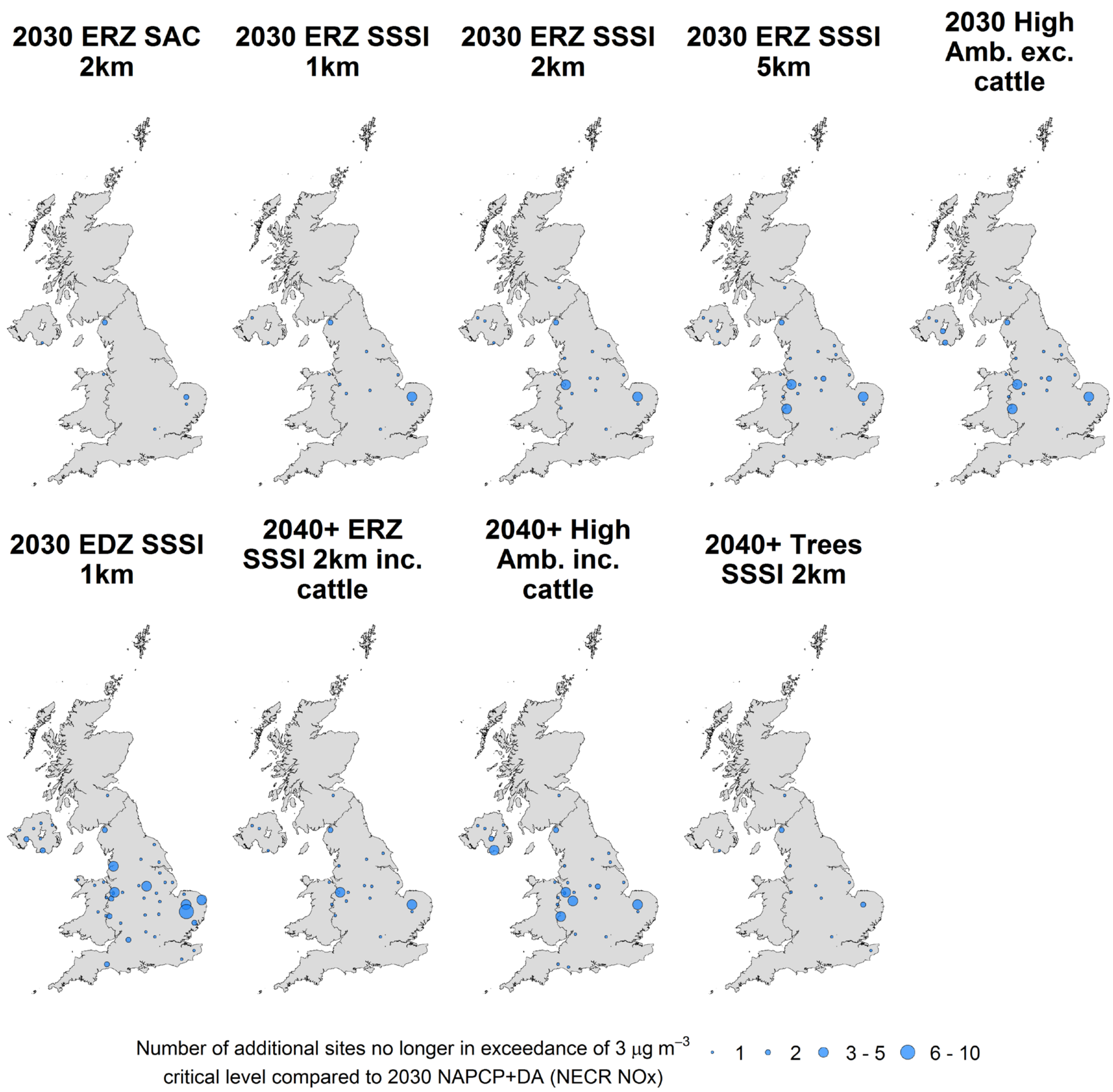

Figure 5-7. Maps showing the additional number of nitrogen sensitive UK SSSI sites (compared with the NAPCP+DA NECR NO_x scenario) that are no longer in exceedance of the 3 µg m^{-3} critical level relevant for assessing higher plants. Exceedance of critical levels has been assessed based on the maximum estimated concentrations at sites. Sites clustered together with nearby site up to a distance of 50 km for visualisation.

6 Nutrient nitrogen critical loads exceedance

Critical loads exceedances for nutrient nitrogen were estimated for all scenarios using the NFC methodology applied annually for the UK Trends reports (Rowe *et al.* 2019). Under this project, an updated dataset of designated sites (2019) was used for implementing the spatially targeted mitigation scenarios, and all metrics related to emissions, concentrations deposition and critical levels exceedance. Compared with the 2011 dataset currently still used as part of the NFC Trends reports, this new dataset contains additional SSSIs and SACs, and uses updated site boundaries, with some sites having e.g. increased in size, merged with neighbouring sites or newly designated. While the new boundary dataset could be used for the modelling of emissions, concentrations, deposition and critical levels exceedance, it was not possible to use it for assessing critical loads exceedance, as any changes to designated features for modified sites and newly designated features for new sites have not yet been incorporated into the national NFC database yet. This work has started but is complex and requires further detailed communications with the relevant nature conservation agencies across the UK to be finalised, and this was not possible within the time frame of this project. Therefore, any site-based critical loads statistics in this section refer to the 2011 site database used by the NFC. All SACs in the latest (2019) dataset could be linked to the designated features list from 2011, however for SSSIs, there were 127 sites (of 4,853 SSSIs in the latest dataset) that did not have critical load information in the 2011 dataset. These sites have been excluded from some of the critical load statistics as it is not possible to estimate exceedances without accurate critical load information for designated features. In addition, although it has been possible to link the 2019 dataset to the 2011 features list, in this study it was necessary to assume that sites have no new additional features and that all designated features are the same as in 2011. This was due to the tight project timeline and resources.

6.1 UK habitat and country summaries

Tables 6-1 to 6-4 below relate to total habitat area per country, whether or not this habitat is within protected sites.

Table 6-1 shows the percentage of the total areas of UK habitats that are sensitive to nitrogen deposition, which exceed their relevant critical loads for nitrogen deposition. Exceeded areas in all scenarios are reduced although, the reduction seen in grassland habitats is much more than seen in wooded habitats. The *2040+ High Amb. inc. cattle* scenario performs generally best across the board with the largest reductions in exceedance across all habitats except for calcareous grassland, dune grassland, salt marsh and beech woodland, where the *2030 CLe opt. ERZ SSSI* scenario performs slightly better. A large proportion of these habitats occurs on protected sites, for which the latter scenario is targeted.

Table 6-2 shows excess nitrogen for the UK as a whole broken down by habitat. The scenarios reduce excess nitrogen across all habitats, but reductions in woodland habitats are similar to, or even greater, than more open habitats. Similar reduction optima can be seen in excess nitrogen than in areas exceeded (see Section 1.1.1), except that scenario *2030 CLe opt. ERZ SSSI* performs better at reducing excess nitrogen for deciduous and mixed woodland too in addition to the habitats mentioned in Section 1.1.1. The *2040+ High Amb. inc. Cattle scenario* still performs better over the majority of assessed habitats.

Table 6-1. Percentage area of nitrogen sensitive habitat in the UK that exceeds nitrogen critical load.

Scenario	Percentage habitat where critical load is exceeded (%)												
	Acid grassland *5234 km²*	**Calcareous grassland** *3578 km²*	**Dune grassland** *323 km²*	**Bog** *5524 km²*	**Salt marsh** *427 km²*	**Dwarf shrub heath** *24826 km²*	**Montane** *3130 km²*	**Coniferous woodland** *8323 km²*	**Deciduous woodland** *7482 km²*	**Beech woodland** *719 km²*	**Oak woodland** *1434 km²*	**Scots pine woodland** *204 km²*	**Mixed woodland** *1761 km²*
2017 Baseline	56.1	91.6	36.0	43.1	1.9	37.1	52.3	82.2	95.7	100.0	83.0	14.3	93.4
2030 BAU (WM)	46.1	86.4	27.8	39.8	1.7	33.2	39.7	79.4	95.1	99.9	80.5	8.4	92.7
2030 NAPCP+DA (NECR NOx)	37.9	69.2	21.4	39.2	0.7	30.6	34.6	76.9	94.6	99.8	78.3	6.7	92.3
2030 NAPCP+DA	37.6	68.9	21.3	39.2	0.7	30.5	34.4	76.9	94.5	99.8	78.3	6.5	92.3
2030 ERZ SAC 2km	37.2	67.8	21.0	39.2	0.6	30.4	34.2	76.8	94.5	99.8	78.3	6.4	92.2
2030 ERZ SSSI 1km	37.3	67.7	21.0	39.2	0.7	30.4	34.2	76.8	94.5	99.8	78.3	6.4	92.2
2030 ERZ SSSI 2km	36.8	66.3	20.7	39.1	0.7	30.2	33.9	76.7	94.5	99.7	78.1	6.4	92.2
2030 ERZ SSSI 5km	36.0	63.8	19.8	39.1	0.6	29.8	33.5	76.5	94.4	99.7	77.9	6.2	92.1
2030 High Amb. exc. cattle	35.5	62.9	19.4	39.0	0.5	29.6	33.3	76.3	94.4	99.7	77.8	6.1	92.1
2030 EDZ SSSI 1km	37.6	67.4	20.3	39.2	0.3	30.5	34.4	76.9	94.5	99.7	78.3	6.5	92.2
2040+ ERZ SSSI 2km inc. cattle	35.1	62.9	19.7	39.0	0.6	29.3	32.8	76.1	94.3	99.7	77.7	5.9	92.1
2040+ High Amb. inc. cattle	33.0	57.8	17.9	38.8	0.4	28.4	32.0	75.4	94.2	99.7	77.1	5.4	92.0
2040+ Trees SSSI 2km	35.4	63.9	19.9	39.0	0.6	29.4	32.8	76.2	94.3	99.7	77.7	5.9	92.1
2030 CLe opt. ERZ SSSI‡	34.4	50.8	16.7	39.0	0.2	29.4	33.2	76.2	94.3	99.6	77.7	6.0	92.1
2030 CL opt. ERZ SSSI‡	34.4	51.1	16.8	39.0	0.2	29.3	33.2	76.2	94.3	99.6	77.7	5.9	92.0

‡ Includes emission displacement of FYM and slurries and measures to replace the use of urea fertilisers ‡ Includes emission displacement of FYM and slurries and measures to replace the use of urea fertilisers

Table 6.2. Excess nitrogen (Average accumulated exceedance) for UK nitrogen sensitive habitats.

Scenario	Average accumulated exceedance (kg N ha^{-1} yr^{-1})												
	Acid grassland	**Calcareous grassland**	**Dune grassland**	**Bog**	**Salt marsh**	**Dwarf shrub heath**	**Montane**	**Coniferous woodland**	**Deciduous woodland**	**Beech woodland**	**Oak woodland**	**Scots pine woodland**	**Mixed woodland**
2017 Baseline	3.10	4.74	1.19	3.47	0.06	2.37	1.96	10.18	17.53	14.07	12.67	0.51	18.70
2030 BAU (WM)	2.24	3.88	0.95	2.74	0.05	1.80	1.27	8.58	16.23	12.46	11.34	0.32	17.44
2030 NAPCP+DA (NECR NOx)	1.58	2.10	0.62	2.17	0.01	1.37	1.02	7.02	13.16	9.77	9.50	0.22	14.28
2030 NAPCP+DA	1.56	2.08	0.61	2.15	0.01	1.36	1.01	6.98	13.12	9.73	9.47	0.22	14.25
2030 ERZ SAC 2km	1.53	2.02	0.59	2.12	0.01	1.34	1.00	6.90	13.00	9.64	9.39	0.22	14.14
2030 ERZ SSSI 1km	1.53	2.01	0.59	2.12	0.01	1.34	1.00	6.90	12.99	9.61	9.38	0.22	14.10
2030 ERZ SSSI 2km	1.50	1.94	0.58	2.09	0.01	1.32	0.99	6.82	12.85	9.50	9.30	0.21	13.96
2030 ERZ SSSI 5km	1.43	1.79	0.55	2.02	0.01	1.27	0.97	6.65	12.53	9.26	9.12	0.20	13.59
2030 High Amb. exc. cattle	1.38	1.74	0.53	1.97	0.01	1.24	0.95	6.54	12.40	9.18	9.04	0.20	13.37
2030 EDZ SSSI 1km	1.55	2.08	0.56	2.13	0.01	1.35	1.01	6.92	13.10	9.65	9.39	0.22	14.18
2040+ ERZ SSSI 2km inc. cattle	1.41	1.79	0.55	2.00	0.01	1.25	0.92	6.57	12.51	9.15	9.02	0.20	13.65
2040+ High Amb. inc. cattle	1.25	1.52	0.49	1.83	0.01	1.14	0.86	6.17	11.87	8.68	8.64	0.18	12.85
2040+ Trees SSSI 2km	1.43	1.85	0.56	2.02	0.01	1.26	0.92	6.63	12.63	9.23	9.08	0.20	13.78
2030 CLe opt. ERZ SSSI‡	1.33	1.41	0.43	1.92	0.00	1.20	0.95	6.36	11.73	8.43	8.69	0.19	12.70
2030 CL opt. ERZ SSSI‡	1.33	1.42	0.43	1.92	0.00	1.20	0.94	6.35	11.74	8.45	8.69	0.19	12.71

‡ Includes emission displacement of FYM and slurries and measures to replace the use of urea fertilisers

Table 6-3 shows, for the countries of the UK, the percentage of the total areas of all nitrogen-sensitive habitats where their critical load for nutrient-N is exceeded. In most countries the *2040+ High Amb. inc. Cattle scenario* achieves the greatest reductions in exceeded area, but in England the more targeted optimised scenarios (*2030 CLe opt. ERZ SSSI* and *2030 CL opt. ERZ SSSI*) achieve greater reductions, even within the shorter timeframe to 2030. The same pattern is seen for Excess Nitrogen (Table 6-4). Targeted measures are thus particularly effective for reducing N pressure on sensitive habitats in England.

Table 6-3. Percentage of nitrogen sensitive habitat exceeding critical load for nitrogen by UK country.

Scenario	Percentage area of sensitive habitat exceeded (%)				
	England	Wales	Scotland	NI	UK
2017 Baseline	97.1	89.7	33.7	90.1	58.6
2030 BAU (WM)	95.7	84.7	27.1	86.4	53.7
2030 NAPCP+DA (NECR NOx)	90.3	80.2	23.8	79.8	49.5
2030 NAPCP+DA	90.2	80.0	23.7	79.7	49.4
2030 ERZ SAC 2km	89.8	79.6	23.6	79.1	49.2
2030 ERZ SSSI 1km	89.8	79.7	23.6	79.3	49.2
2030 ERZ SSSI 2km	89.5	79.4	23.4	78.9	49.0
2030 ERZ SSSI 5km	88.7	79.0	23.1	78.0	48.5
2030 High Amb. exc. cattle	88.4	78.7	22.8	77.4	48.2
2030 EDZ SSSI 1km	89.8	79.9	23.7	79.6	49.3
2040+ ERZ SSSI 2km inc. cattle	88.2	78.1	22.6	78.5	48.0
2040+ High Amb. inc. cattle	86.6	76.8	21.7	76.2	46.8
2040+ Trees SSSI 2km	88.5	78.3	22.6	78.9	48.1
2030 CLe opt. ERZ SSSI‡	85.4	77.9	22.8	77.3	47.3
2030 CL opt. ERZ SSSI‡	85.4	77.9	22.7	77.3	47.2

‡ Includes emission displacement of FYM and slurries and measures to replace the use of urea fertilisers

Table 6-4. Excess nitrogen (Average Accumulated Exceedance for nutrient N) for all nitrogen sensitive habitats by country under each emission scenario, values are given for the UK overall and for each of the devolved administrations.

Scenario	Excess Nitrogen (Average Accumulated Exceedance) (kg N ha^{-1} yr^{-1})				
	England	Wales	Scotland	Northern Ireland	UK
2017 Baseline	13.3	8.9	1.7	10.2	5.8
2030 BAU (WM)	11.8	7.2	1.2	8.9	5.0
2030 NAPCP+DA (NECR NOx)	9.3	5.7	0.9	7.2	3.9
2030 NAPCP+DA	9.3	5.7	0.9	7.2	3.9
2030 ERZ SAC 2km	9.2	5.6	0.9	7.1	3.8
2030 ERZ SSSI 1km	9.2	5.6	0.9	7.1	3.8
2030 ERZ SSSI 2km	9.1	5.6	0.8	7.0	3.8
2030 ERZ SSSI 5km	8.8	5.4	0.8	6.6	3.7
2030 High Amb. exc. cattle	8.7	5.4	0.8	6.3	3.6
2030 EDZ SSSI 1km	9.2	5.7	0.9	7.2	3.9
2040+ ERZ SSSI 2km inc. cattle	8.8	5.3	0.8	6.8	3.6
2040+ High Amb. inc. cattle	8.3	5.0	0.7	5.9	3.4
2040+ Trees SSSI 2km	8.9	5.3	0.8	7.0	3.7
2030 CLe opt. ERZ SSSI‡	8.1	5.3	0.8	6.4	3.4
2030 CL opt. ERZ SSSI‡	8.2	5.3	0.8	6.4	3.4

‡ Includes emission displacement of FYM and slurries and measures to replace the use of urea fertilisers

The proportion of N-sensitive SSSIs that exceed critical loads under all scenarios decreases with increasing ambition of mitigation measures (Figure 6-1, Table 6-4). N.B. for Northern Ireland and also for Wales there is a substantial proportion of sites designated after 2011 (20% and 5%, respectively) that could not be assessed due to a lack of critical loads assigned to designated features at the time of this project's model runs being carried out. The largest change in exceedance is due to the substantial reductions in emissions and subsequently deposition expected in meeting the NECR targets. Further reductions at sites exceeding their critical loads are estimated in line with levels of ambition in further emission reductions.

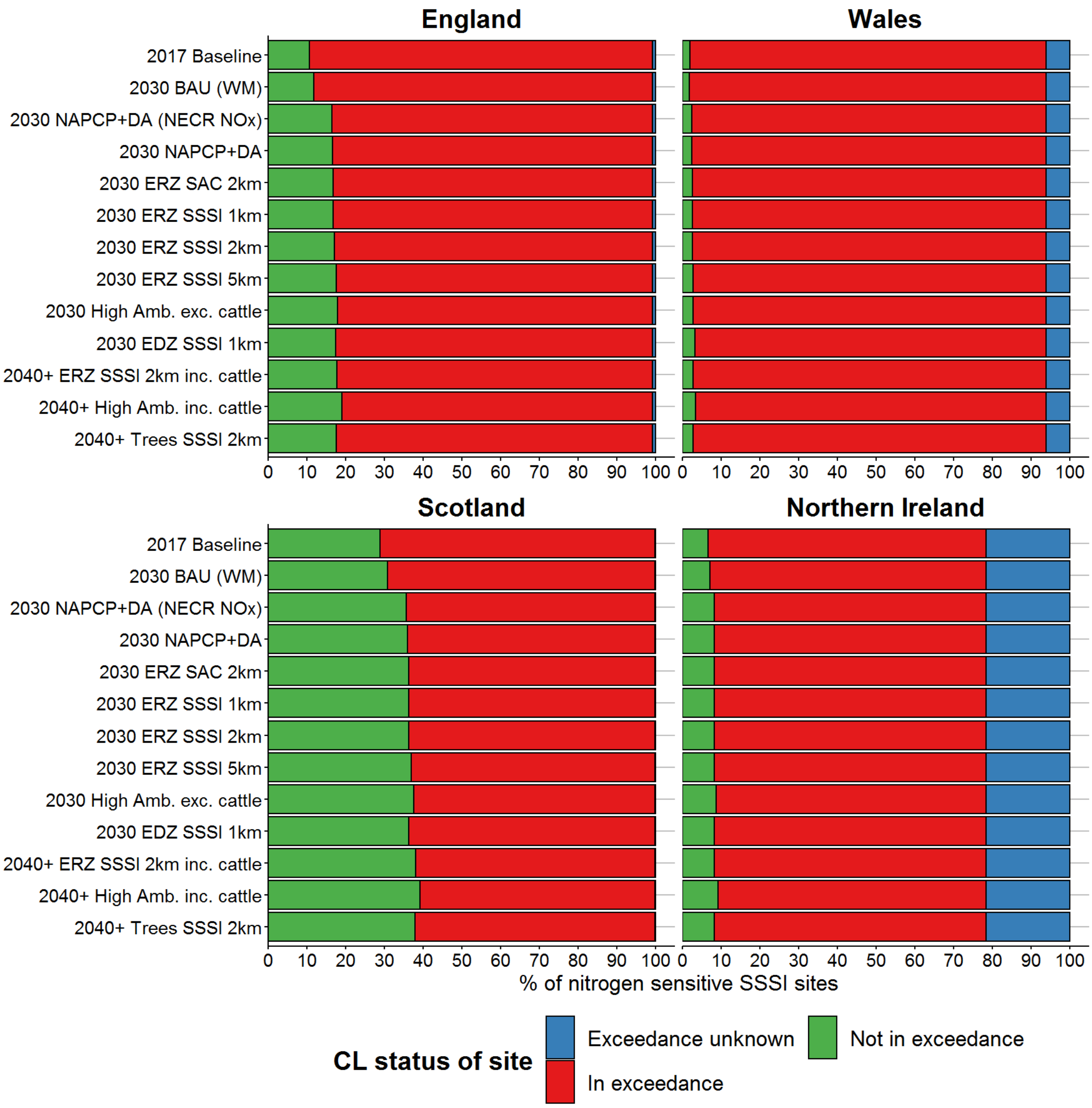

Figure 6-1. A comparison of the proportion of nitrogen-sensitive UK SSSIs (n = 4,853) brought out of exceedance of critical loads under each emission scenario. N.B. new sites where critical load information is not available are shown in blue. The list of sensitive features was collated in ~2011 and therefore does not have information about sites that were designated more recently.

Figure 6-2 shows the proportion of designated sites (based on area rather than number of sites), however excluding sites where critical loads data are not present in the NFC database. The largest relative decrease in exceeded site area is estimated for Scotland, from 2017 to 2030 (baselines).

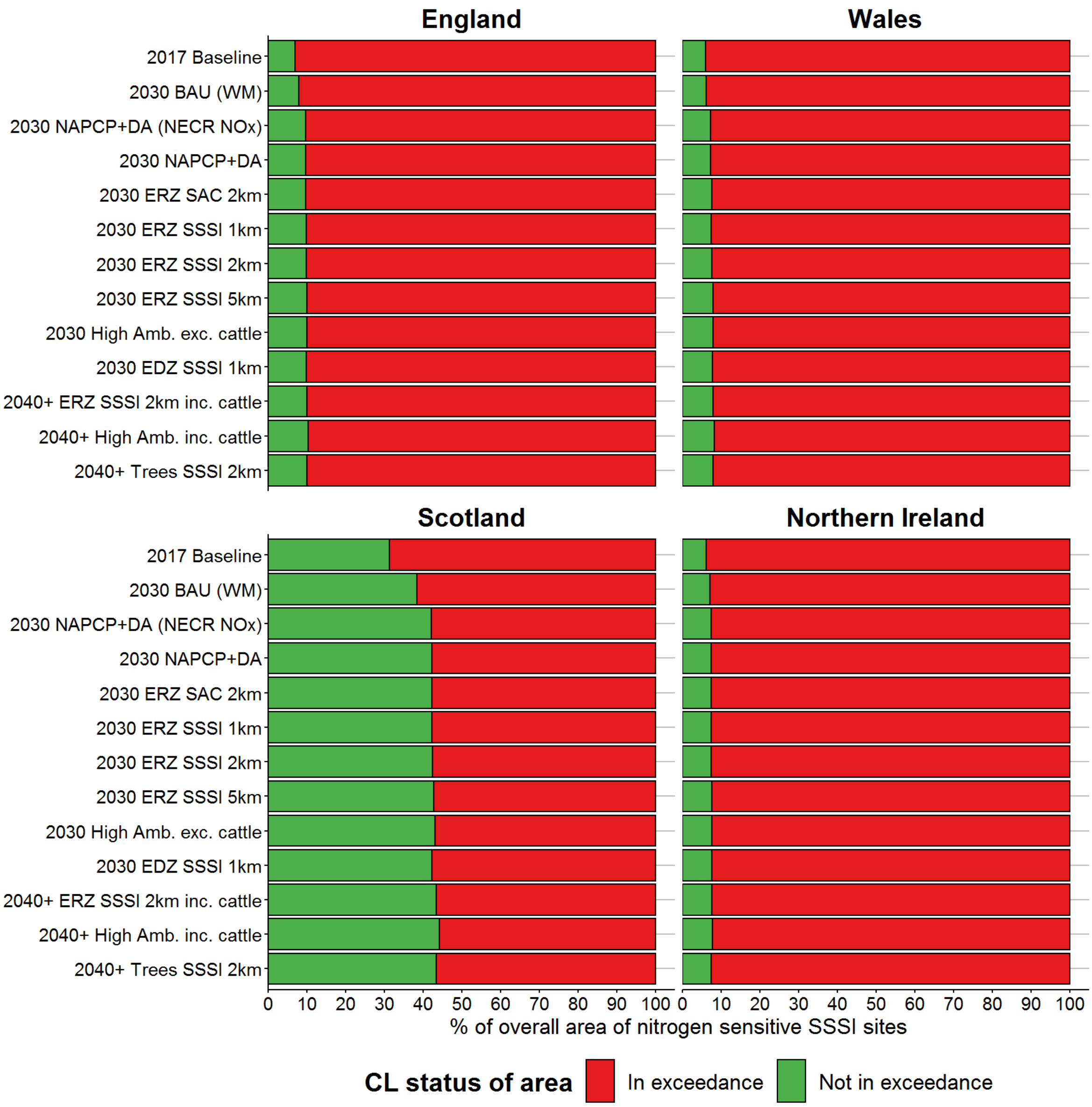

Figure 6-2. A comparison between critical loads exceedance of nitrogen-sensitive UK SSSIs with critical loads information (n = 4,727) under each emission scenario. N.B. new sites where critical load information is not available are not included in this plot. The list of sensitive features was collated in ~2011 and therefore does not have information about all sites.

In terms of excess nitrogen above the relevant critical load received by SSSIs across the UK, the largest step change in the exceedance statistics is estimated to occur due to measures needed to meet the 2030 NECR targets. Scenarios with higher ambitions, modelled UK-wide or with spatial targeting around SSSIs achieve further decreases in excess N.

Overall, the amount of excess N deposition (AAE) is largest in Northern Ireland, across all scenarios, and smallest in Scotland, much smaller than across the rest of the UK (Figure 6-3).

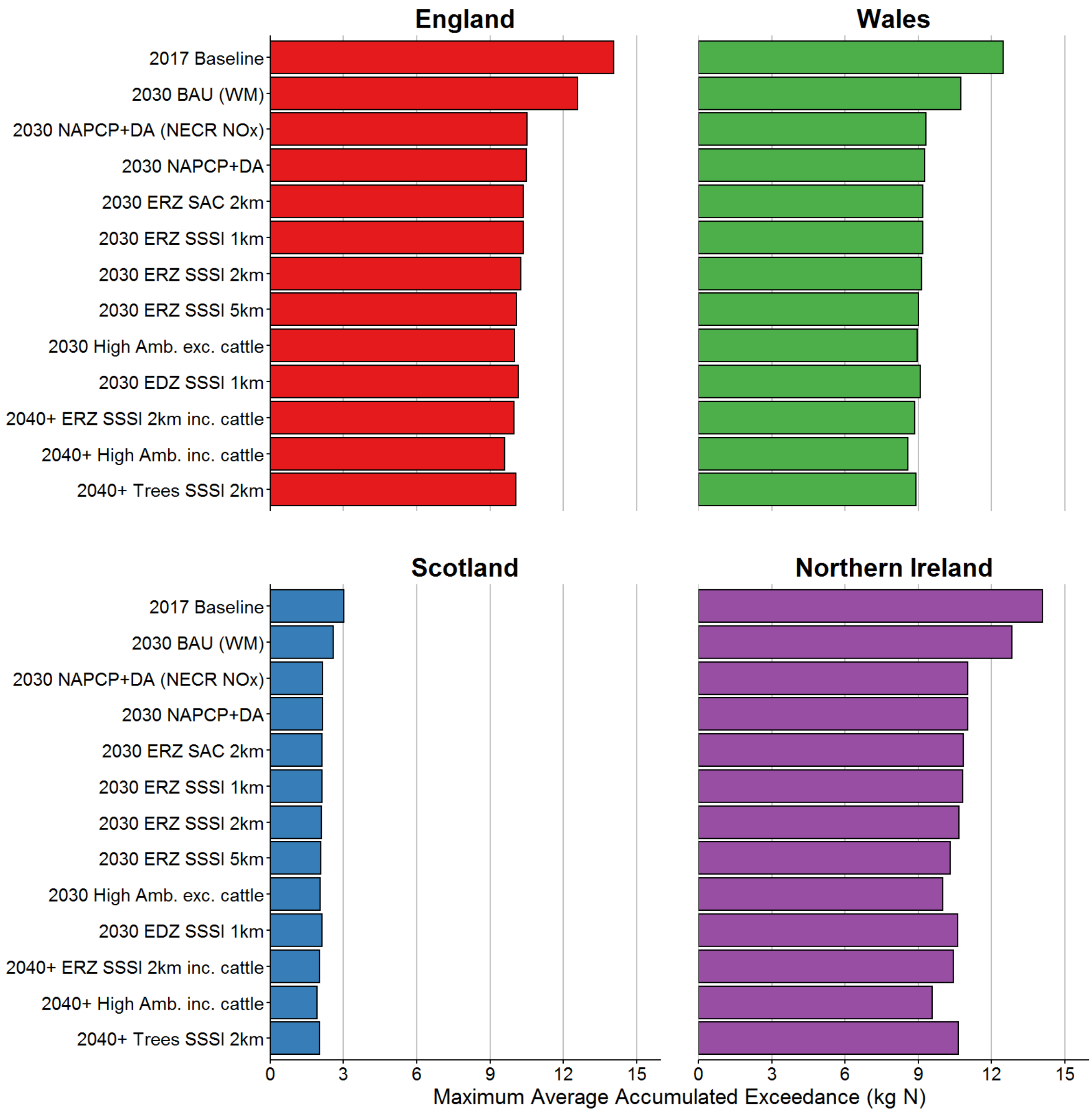

Figure 6-3. A comparison of excess nitrogen (maximum average accumulated exceedance, kg N) for nitrogen-sensitive UK SSSIs with critical loads information (n = 4,727) under each emission scenario. N.B. more recently designated sites where critical load information is not available are not included in this plot. The database of sensitive features used by the NFC was collated in ~2011 and therefore does not have information about all sites.

6.2 Maps

SSSIs expected to no longer exceed their critical loads by 2030, due to measures to meet BAU (WM) and the NECR targets (NAPCP+DA measures), compared with 2017, are shown in Figure 6-4. Decreases in N deposition in the BAU (WM) scenario are mainly due to NOx emission decreases, however some effect of decreasing agricultural NH_3 are also likely to contribute (Figure 6-4, left map), as are decreases in long-range import from the continental Europe and the Republic of Ireland. The more substantial decreases (blue dots) in N deposition under the NAPCP+DA to meet the NECR targets are much more wide spread across the UK and include sites in source areas as well as more remote parts of the UK, illustrating that different deposition pathways are likely contributing across the UK. There are some sites (red dots) where slight increases in N deposition cause critical loads to be exceeded, for the 2030 baseline scenarios, due to a combination of increases in local or regional emissions and changes in the partitioning of the N deposition (proportion of wet and dry and/or reduced and oxidised nitrogen).

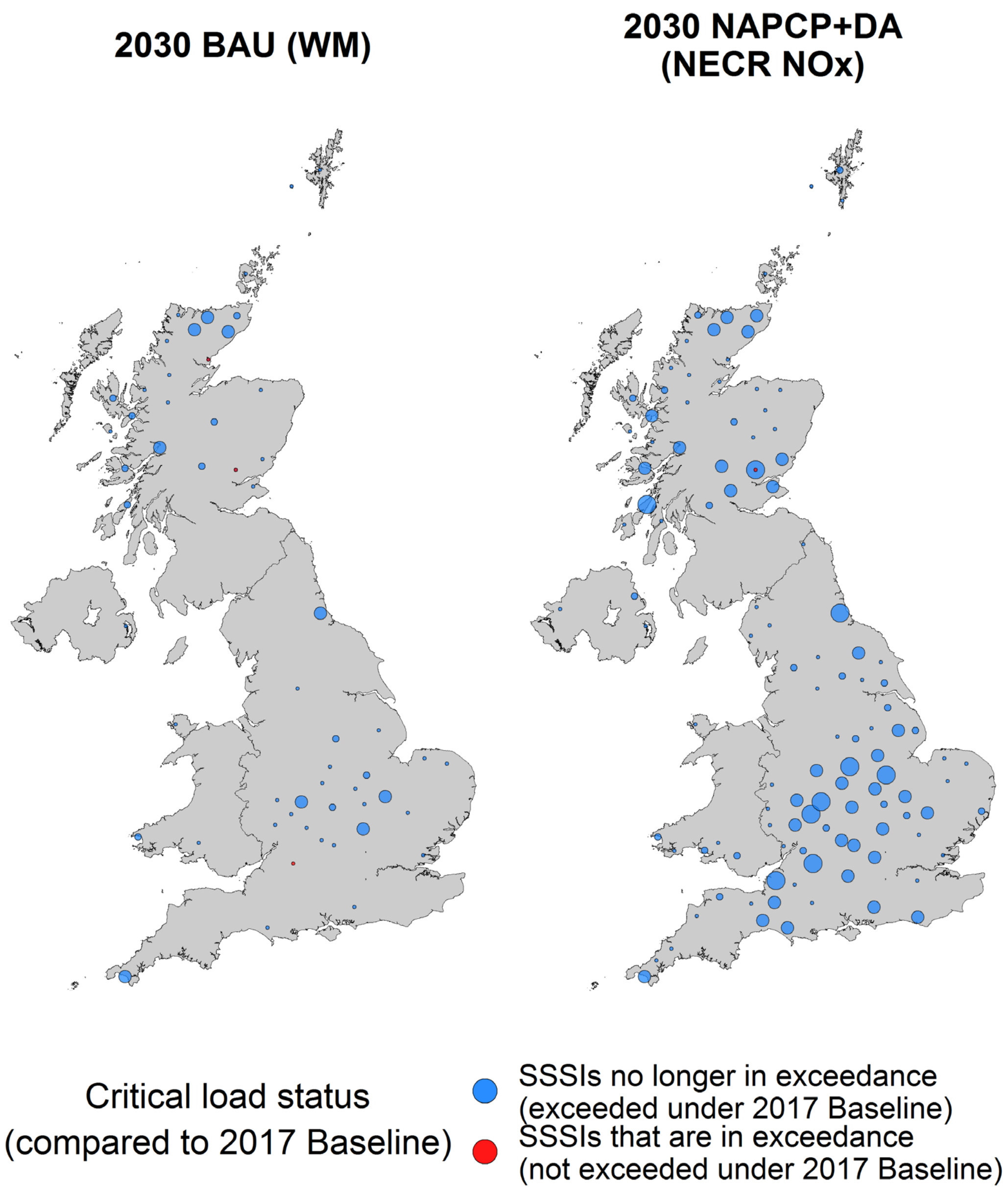

Figure 6-4. Maps showing the additional number of nitrogen sensitive UK SSSIs (compared with 2017 baseline) that are no longer in exceedance of critical loads under each mitigation scenario. This figure excludes the 127 SSSIs where critical load information is unknown. Sites clustered together with nearby site up to a distance of 50 km for visualisation.

For the more ambitious UK-wide and the spatially targeted scenarios, additional sites are estimated to be no longer in exceedance of their critical loads, compared with the NAPCP+DA (NECR NO_x) scenario (Figure 6-5). These sites are located across the UK, in areas of higher and lower emission density, showing that the impact of emission reductions can have wide ranging effects due to medium and long-range transport and wet deposition as well as more localised dry deposition reductions.

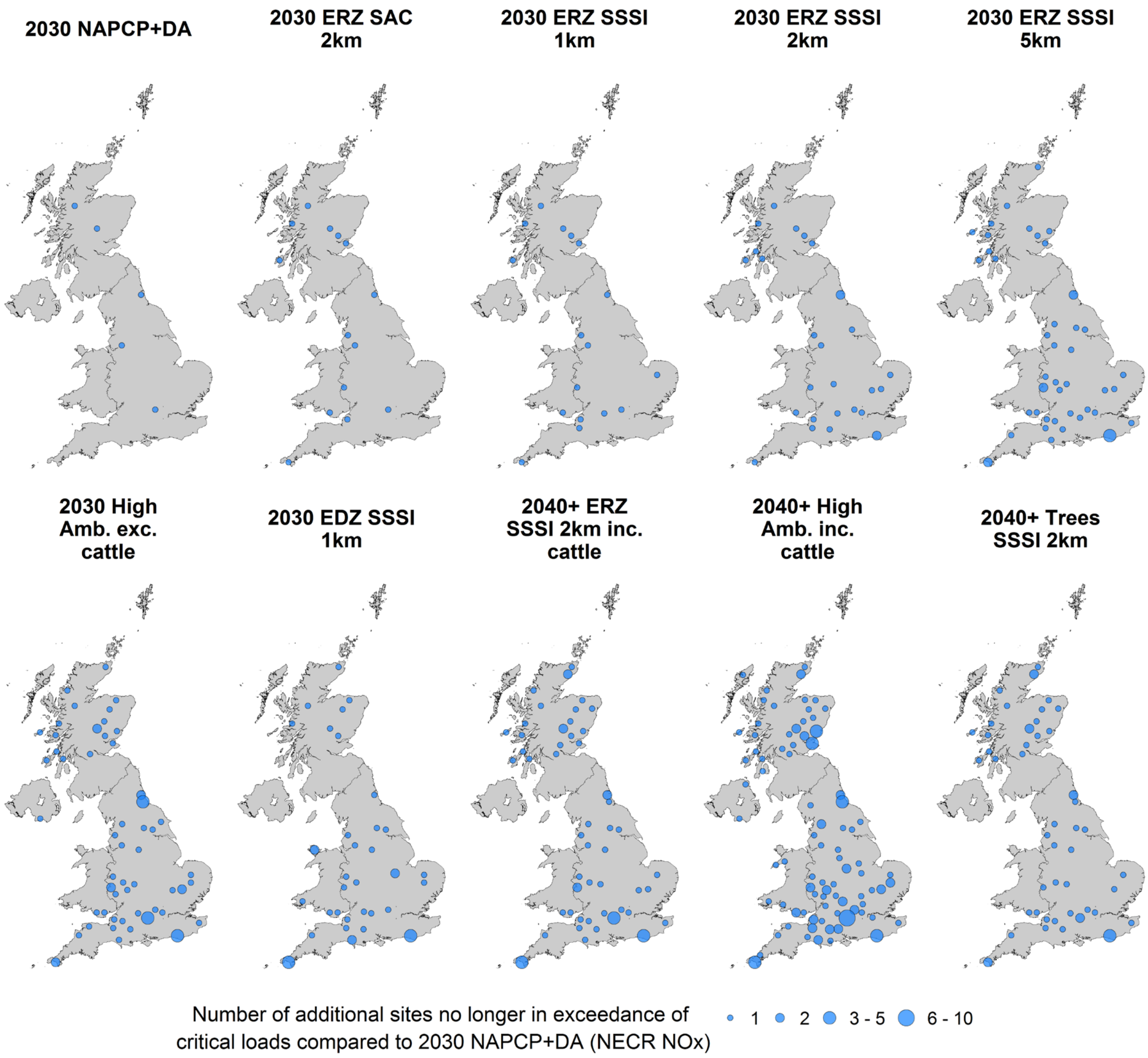

Figure 6-5. Maps showing the additional number of nitrogen sensitive UK SSSIs (compared with the NAPCP+DA NECR NO_x scenario) that are no longer in exceedance of critical loads under each mitigation scenario. This figure excludes the 127 SSSIs where critical load information is unknown. Sites clustered together with nearby site up to a distance of 50 km for visualisation.

Overall, an additional 276 SSSIs are estimated to no longer exceed their critical loads (for all designated features present) in the 2030 NAPCP+DA (NECR NO_x) baseline scenario, compared with 2017, with 64% of these sites located in England, 31% in Scotland, 3% in Wales and >1% in Northern Ireland. In this comparison, it is important to note that decreases in N deposition are due to both local effects of mitigation (e.g. dry deposition of reduced N) and medium/long-range input of both oxidised and reduced nitrogen, with the effects of mitigation showing a different spatial distribution, depending on the deposition component(s) dominating locally. The relatively large proportion of sites in Scotland coming out of exceedance (compared with the critical levels assessment in Section 5) can largely be attributed to the impact of decreased medium/long-range atmospheric transport and deposition of nitrogen, likely due to a combination of Scottish SSSIs already having less excess nitrogen deposition above their respective CL and the relative importance of medium/long-range components of atmospheric N input, compared with other parts of the UK. By comparison, Northern Ireland's N deposition has higher proportions of ammonia emissions than NOx emissions contributing to local/regional deposition.

The higher ambition 2030 NO_x emission reduction scenario (2030 NAPCP+DA, -10% emission reduction in agglomerations; also included in all other 2030 scenarios) is estimated to bring a further 6 SSSIs out of CL exceedance, four in England and two in Scotland. Figure 6-5 (top left map) illustrates that the Scottish sites were likely close to their CL and benefited from further reductions in long-range transport, whereas the sites in England are located close to agglomerations and likely benefit from regional NO_2 emission reductions. The UK-wide 2030 scenario with higher NH_3 emission reductions (High Amb. exc. cattle) also includes the same NO_x emission reductions, and overall achieves an additional 60 SSSIs no longer exceeding their critical loads, compared with NAPCP+DA, or 343 compared with the 2017 baseline. Of these additional 66 sites, 70% are in England, 25% in Scotland, 3% in Wales and <1% in Northern Ireland. The location of these sites (Figure 6-5 bottom left map) shows that there is a combined effect of the different components of N deposition at play, with local, regional and more long-range impacts of the combined NH_3 and NO_x emission reductions. The UK-wide 2040+ scenario with the highest NO_x and NH_3 emission reductions (High Amb. inc. cattle) brings an additional 54 sites out of exceedance, compared with the 2030 UK-wide high-ambition scenario (High Amb. exc. cattle), or 397 sites compared with the 2017 baseline. Of these 54 sites, 60% are in England, 27% in Scotland, 9% in Wales and 2% in Northern Ireland. The spatial patterns (Figure 6-5, bottom row, 4th map) again imply a complex pattern of local decreases in both NH_3 and NO_x emissions and related short and long-range N deposition. The spatially targeted ERZ scenarios for NH_3 emissions are, as expected, more effective with larger ERZ widths in England (and to some degree in Scotland), as the impact of local NH_3 emission reductions on the dry deposition component is combined with more regional and long-range N input from wet NH_x deposition and oxidised N deposition. For the same reasons, the EDZ scenario is less effective for decreasing N deposition across sites more generally than for critical level exceedance. Additionally, this scenario does not actually decrease emissions, but places them further away from SSSIs, with the resulting atmospheric N still subject to chemical transformation to less reactive NH_4^+ and subsequent transport and wet NH_x deposition.

Table 6-5. Additional number of nitrogen sensitive UK SSSIs (compared with the 2017 baseline) that are no longer in exceedance of nutrient critical loads under each mitigation scenario (DWI). This figure excludes the 127 SSSIs where critical load information is unknown.

Country	England	Wales	Scotland	Northern Ireland	UK
2030 BAU (WM)	39	1	39	4	83
2030 NAPCP+DA (NECR NOx)	179	4	84	9	276
2030 NAPCP+DA	183	4	86	9	282
2030 ERZ SAC 2km	187	4	89	10	290
2030 ERZ SSSI 1km	189	4	89	10	292
2030 ERZ SSSI 2km	199	4	90	10	303
2030 ERZ SSSI 5km	211	4	96	11	322
2030 High Amb. exc. cattle	225	5	101	11	342
2030 EDZ SSSI 1km	208	4	90	14	316
2040+ ERZ SSSI 2km inc. cattle	218	4	106	11	339
2040+ High Amb. inc. cattle	257	6	117	16	396
2040+ Trees SSSI 2km	211	4	105	11	331

6.3 Maximum area of SSSI under exceedance of Nutrient N critical loads

Table 6-6. Maximum exceeded area (km^2) values for SSSIs. Values are maximum as all features are assumed to cover the entire area of site.

	Maximum area exceeded (km^2)				
	England	Wales	Scotland	NI	UK
*Total area of SSSIs with CL (km^2)**	9,336	2,290	8,829	788	21,244
2030 BAU (WM)	8,637	2,150	5,301	732	16,820
2030 NAPCP+DA (NECR NO_x)	8,470	2,123	4,968	729	16,291
2030 NAPCP+DA	8,468	2,122	4,956	729	16,276
2030 ERZ SAC 2km	8,462	2,117	4,947	729	16,255
2030 ERZ SSSI 1km	8,458	2,120	4,949	729	16,257
2030 ERZ SSSI 2km	8,453	2,115	4,939	729	16,235
2030 ERZ SSSI 5km	8,441	2,110	4,907	728	16,187
2030 High Amb. exc. cattle	8,437	2,109	4,877	728	16,151
2030 EDZ SSSI 1km	8,447	2,113	4,943	728	16,231
2040+ ERZ SSSI 2km inc. cattle	8,433	2,108	4,840	728	16,110
2040+ High Amb. inc. cattle	8,399	2,102	4,770	727	15,997
2040+ Trees SSSI 2km	8,442	2,109	4,844	729	16,124
2030 CLe opt. ERZ SSSI‡	8,367	2,098	4,858	726	16,050
2030 CL opt. ERZ SSSI‡	8,371	2,098	4,855	726	16,050

* Not all SSSIs could be considered for this assessment due to critical load information being unknown at 127 sites. These areas are therefore missing from the table above.
‡ Includes emission displacement of FYM and slurries and measures to replace the use of urea fertilisers

Table 6-7. Proportion of overall area designated as SSSI in exceedance (%) of nutrient N critical loads. Values are maximum as all features are assumed to cover the entire area of site.

	Maximum area exceeded (%)*				
Scenario	England	Wales	Scotland	NI	UK
2030 BAU (WM)	92.5	93.9	60.0	92.9	79.2
2030 NAPCP+DA (NECR NOx)	90.7	92.7	56.3	92.6	76.7
2030 NAPCP+DA	90.7	92.7	56.1	92.6	76.6
2030 ERZ SAC 2km	90.6	92.4	56.0	92.5	76.5
2030 ERZ SSSI 1km	90.6	92.6	56.1	92.5	76.5
2030 ERZ SSSI 2km	90.5	92.3	55.9	92.5	76.4
2030 ERZ SSSI 5km	90.4	92.1	55.6	92.4	76.2
2030 High Amb. exc. cattle	90.4	92.1	55.2	92.4	76.0
2030 EDZ SSSI 1km	90.5	92.3	56.0	92.4	76.4
2040+ ERZ SSSI 2km inc. cattle	90.3	92.1	54.8	92.4	75.8
2040+ High Amb. inc. cattle	90.0	91.8	54.0	92.2	75.3
2040+ Trees SSSI 2km	90.4	92.1	54.9	92.5	75.9
2030 CLe opt. ERZ SSSI‡	89.6	91.6	55.0	92.2	75.6
2030 CL opt. ERZ SSSI‡	89.7	91.6	55.0	92.2	75.6

* Not all SSSIs could be considered for this assessment due to critical load information being unknown at 127 sites. These areas are therefore missing from the table above.
‡ Includes emission displacement of FYM and slurries and measures to replace the use of urea fertilisers

6.4 Maximum areas of SACs where nitrogen critical load is exceeded

Table 6-8. Area where the critical load for nutrient nitrogen is exceeded (km²) values for SACs. Values are maximum as all features are assumed to cover the entire area of site.

	Maximum area exceeded (km²)				
	England	Wales	Scotland	NI	UK
*Total area of SACs with CL (km²)**	*7,782*	*2,840*	*7,435*	*605*	*18,661*
2030 BAU (WM)	6,682	1,783	6,004	569	15,038
2030 NAPCP+DA (NECR NOx)	6,571	1,745	5,879	568	14,763
2030 NAPCP+DA	6,569	1,744	5,874	568	14,755
2030 ERZ SAC 2km	6,561	1,736	5,871	567	14,736
2030 ERZ SSSI 1km	6,564	1,739	5,871	567	14,741
2030 ERZ SSSI 2km	6,557	1,736	5,866	567	14,727
2030 ERZ SSSI 5km	6,529	1,732	5,851	567	14,679
2030 High Amb. exc. cattle	6,510	1,724	5,837	567	14,639
2030 EDZ SSSI 1km	6,563	1,733	5,865	567	14,727
2040+ ERZ SSSI 2km inc. cattle	6,525	1,721	5,812	567	14,625
2040+ High Amb. inc. cattle	6,470	1,689	5,770	567	14,496
2040+ Trees SSSI 2km	6,538	1,725	5,813	567	14,642
2030 CLe opt. ERZ SSSI‡	6,472	1,711	5,830	567	14,579
2030 CL opt. ERZ SSSI‡	6,476	1,711	5,828	567	14,582

* Not all SACs could be considered for this assessment due to critical load information being unknown at 2 sites in England. These areas are therefore missing from the table above

‡ Includes emission displacement of FYM and slurries and measures to replace the use of urea fertilisers

Table 6-9. Proportion of overall area designated as SACs under exceedance (%) of nutrient N critical loads. Values are maximum as all features are assumed to cover the entire area of site**.**

	Maximum area exceeded (%)*				
Scenario	England	Wales	Scotland	NI	UK
2030 BAU (WM)	85.9	62.8	80.8	94.0	80.6
2030 NAPCP+DA (NECR NOx)	84.4	61.4	79.1	93.9	79.1
2030 NAPCP+DA	84.4	61.4	79.0	93.9	79.1
2030 ERZ SAC 2km	84.3	61.1	79.0	93.8	79.0
2030 ERZ SSSI 1km	84.3	61.2	79.0	93.8	79.0
2030 ERZ SSSI 2km	84.3	61.1	78.9	93.8	78.9
2030 ERZ SSSI 5km	83.9	61.0	78.7	93.8	78.7
2030 High Amb. exc. cattle	83.7	60.7	78.5	93.8	78.4
2030 EDZ SSSI 1km	84.3	61.0	78.9	93.8	78.9
2040+ ERZ SSSI 2km inc. cattle	83.8	60.6	78.2	93.8	78.4
2040+ High Amb. inc. cattle	83.1	59.5	77.6	93.7	77.7
2040+ Trees SSSI 2km	84.0	60.7	78.2	93.8	78.5
2030 CLe opt. ERZ SSSI‡	83.2	60.2	78.4	93.7	78.1
2030 CL opt. ERZ SSSI‡	83.2	60.2	78.4	93.7	78.1

* Not all SACs could be considered for this assessment due to critical load information being unknown at 2 sites in England. These areas are therefore missing from the table above

‡ Includes emission displacement of FYM and slurries and measures to replace the use of urea fertilisers

7 Optimised scenarios

7.1 Definition of optimised scenarios for SSSIs

The spatially targeted mitigation scenarios described in this report so far were analysed for effectiveness, to inform the design of the two optimised scenarios. As agreed with the Steering Group, two further scenarios were designed, one for optimising ERZ widths at SSSIs for critical loads exceedance, the other for NH_3 critical levels exceedance (1 ug m^{-3}).

The optimisation approach was carried out in two steps, with the three fixed width ERZ datasets (1, 2, 5 km) being analysed for the minimum ERZ width to bring each site out of exceedance (if possible), followed by additional application of ERZ measures which further reduce landspreading emissions, and an additional measure for mineral fertilisers. An overview for the optimising approach is shown in Figure 7-1, with further details following below.

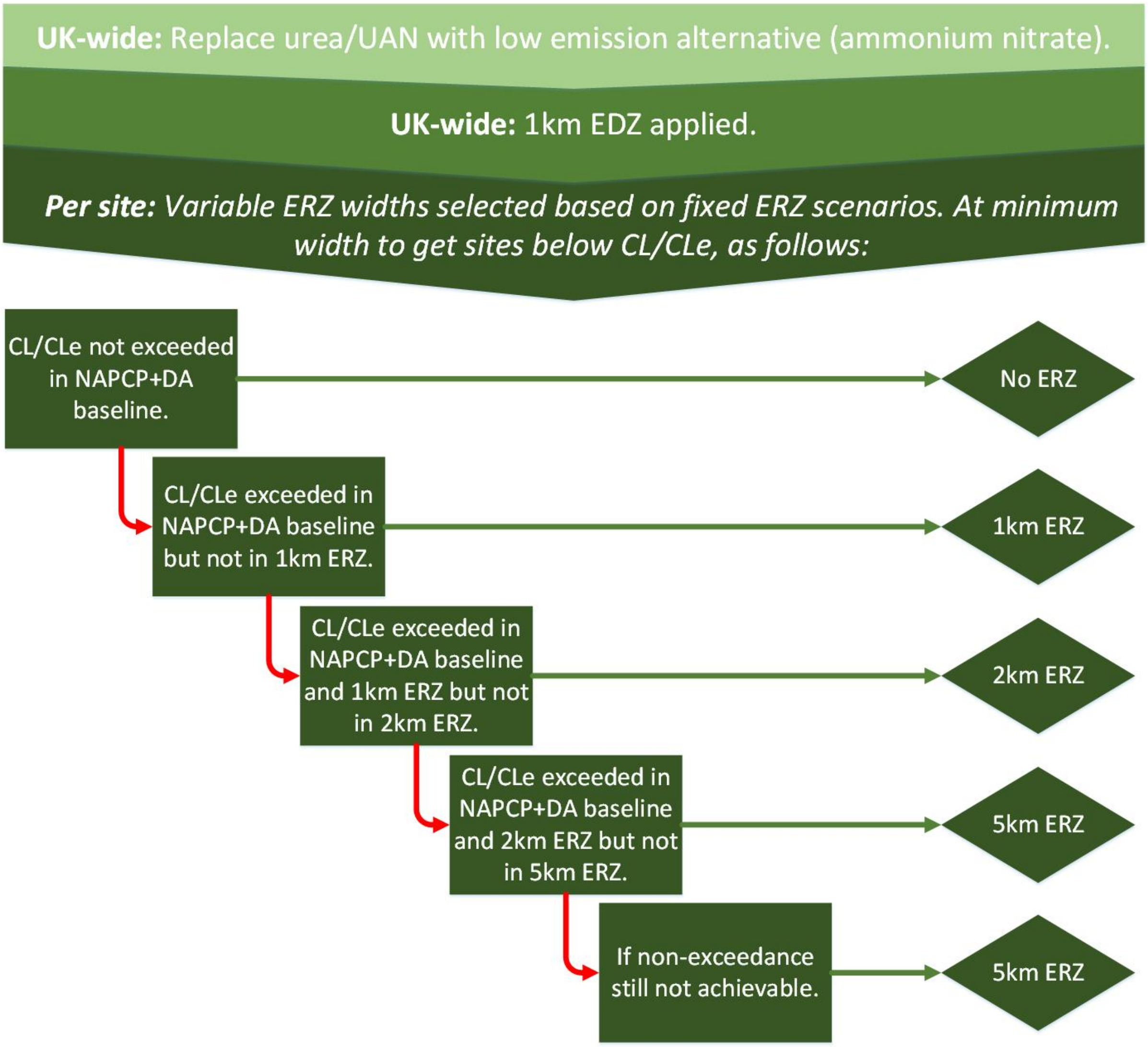

Figure 7-1. Flow chart showing assumptions made for designing optimised scenarios. This includes the targeted use of ERZ only where they move sites out of exceedance (2 scenarios, one each for site-relevant critical loads (CL) and for the 1 ug m^{-3} critical levels (CLe), respectively), EDZ for all sites and replacement of urea and UAN fertiliser with ammonium nitrate.

The number of sites requiring more ambitious mitigation to come out of exceedance is larger for critical loads than for critical levels and includes many more remote sites (Figure 7-2). This illustrates the more localised nature of ammonia concentration impacts, compared with N deposition, where a variable component is due to medium/longer range atmospheric transport, mainly related to wet deposition.

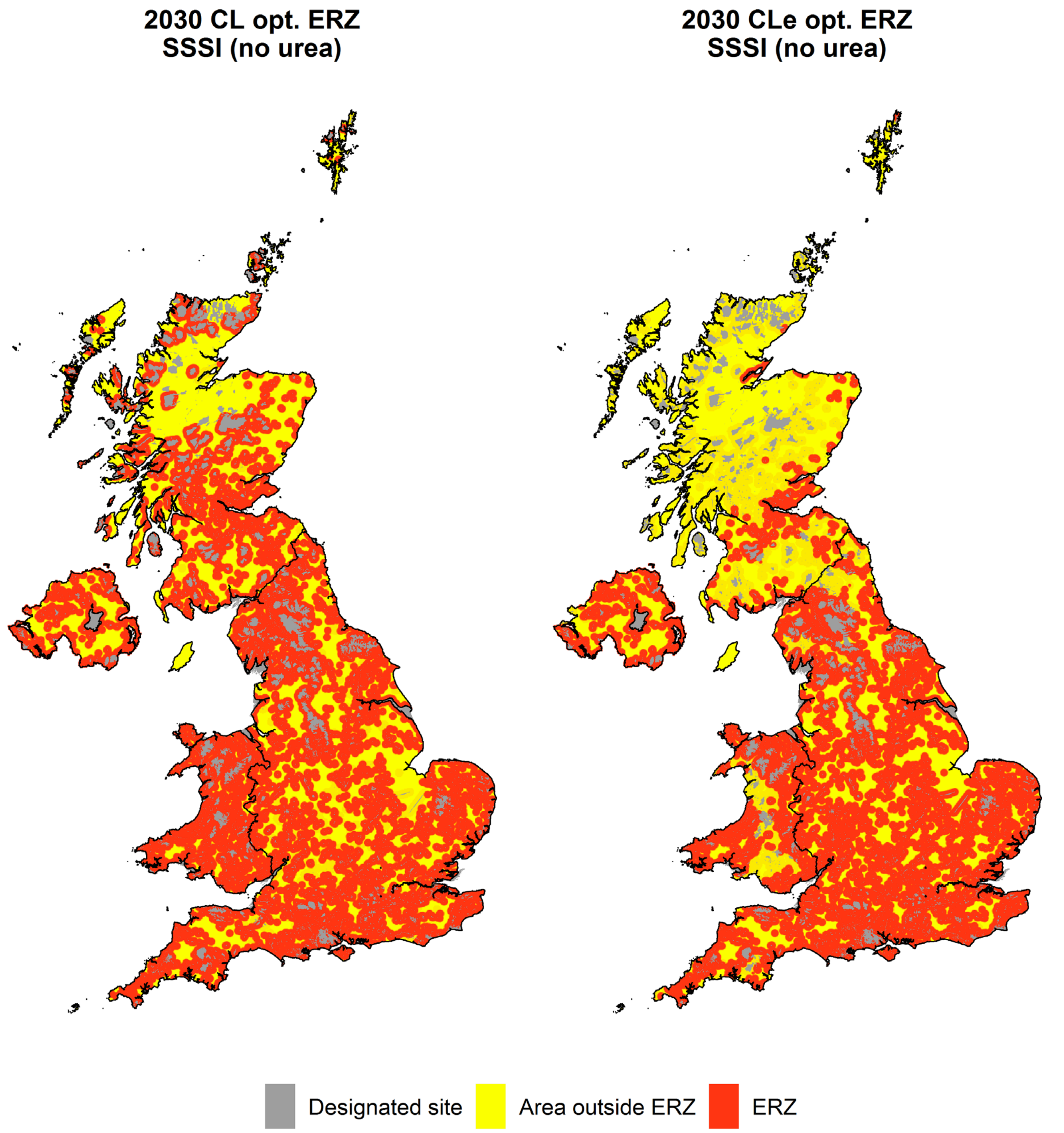

Figure 7-2. Emission Reduction Zones (ERZ) surrounding nitrogen sensitive SSSIs in the UK for the two emission scenarios optimised for minimising critical level exceedance (CLe) and nutrient N critical load exceedance (CL).

7.2 Sites brought out of 1 µg NH_3 m^{-3} critical level exceedance

The following tables illustrate the optimising approach and show details of sites where smaller widths of ERZ were sufficient to reduce the maximum concentration at the SSSI (represented as 1 km grid data). Table 7-1 presents SSSIs that were brought out of 1 µg NH_3 m^{-3} critical level exceedance with a 1 km ERZ with higher ambition measures. For these sites, a 1 km ERZ was then used in the 2030 CLe Opt ERZ SSSI scenario. Table 7-2 presents the sites that were taken out of exceedance with a 2 km ERZ and Table 7-3 the sites brought out of exceedance with a 5 km ERZ. These sites' maximum NH_3 concentrations were already very close to the critical level under the 2030 NAPCP+DA (NECR NO_x) scenario (i.e. meeting NECR targets), and the additional spatially targeted measures provide sufficient further emission reductions for the site no longer to exceed the critical level. Some of these reductions are at the 3rd decimal place, and it is clear that the uncertainty in modelled emissions and concentrations for such sites are larger than can be conveyed with the average 1 km grid modelling approach using best available national data. However, these data provide a good indication of which sites are already relatively clean but may still have local sources within a 1 km zone where mitigation may be helpful to ensure protection of the designated features. At a local/landscape scale, the likely NH_3 concentrations across a site will be dependent on the relative spatial configuration of any sources in relation to the site. For example, a large livestock house or manure storage facility within 1 km from the site boundary can be located within 100 m of the site boundary or 900m away and can be upwind or downwind in relation to local prevailing winds. This issue of scale and resolution of the model input and output data is discussed further in Annex 5 (local case study assessments).

Table 7-1. SSSI sites brought out of exceedance of the 1 µg NH_3 m^{-3} critical level under 2030 ERZ SSSI 1 km.

Country	Site Code	Site Name
England	1001327	Blackdike Bog
England	1001068	Calbourne Down
England	1003819	Corfe Meadows
England	1006569	Coverack To Porthoustock
England	2000419	Ewefell Mire
England	1002993	Hartland Moor
England	1004213	Porthgwarra To Pordenack Point
England	1002313	Rempstone Heaths
England	1000944	Thrasher's Heath
England	2000216	Underlaid Wood
Scotland	111	Back Burn Wood And Meadows
Scotland	644	Flisk Wood
Scotland	674	Garron Point
Scotland	8183	Peeswit Moss
Wales	33WGV	Barbadoes Hill Meadows
Wales	32WUS	Freshwater East Cliffs To Skrinkle Haven
Wales	33WSK	Pen-y-graig-goch
Wales	32WQ2	The Wern, Rhosgoch
Wales	31WCC	Tre Wilmot

Table 7-2. SSSI sites brought out of exceedance of the 1 µg NH_3 m^{-3} critical level under 2030 ERZ SSSI 2 km.

Country	Site Code	Site Name
England	1004323	Bavington Crags
England	1002937	Carrine Common & Penwethers
England	1000726	Dozmary Pool
England	2000439	Hurn Common
England	1000901	Lady's Wood And Viaduct Meadow
England	2000086	Luscombe Valley
England	1002490	Shaw Meadow & Sea Pasture
England	1003268	Studland & Godlingston Heaths
Northern Ireland	ASSI274	Dunaree Hill
Scotland	112	Back Wood
Scotland	563	Dunbog Bog
Scotland	796	Howierig Muir
Scotland	1540	Tinto Hills
Wales	33WLM	Blackmill Woodlands
Wales	33WVB	Monknash Coast

Table 7-3. SSSI sites brought out of exceedance of the 1 µg NH_3 m^{-3} critical level under 2030 ERZ SSSI 5 km.

Country	Site Code	Site Name
England	1000568	Ebblake Bog
England	1005537	Highclere Park
England	1005814	Landford Heath
England	1002995	Maplehurst Wood
England	1006127	Middle Crossthwaite
England	1006125	Middle Side & Stonygill Meadows
England	1000482	Park End Wood
England	1001836	Spindlestone Heughs
England	1003953	Yarncliff Wood, Padley
Scotland	4	Abbey St Bathans Woodlands
Scotland	126	Ballantrae Shingle Beach
Scotland	213	Black Loch (abdie)
Scotland	498	Darnrig Moss
Scotland	1690	Hassockrigg And North Shotts Mosses
Scotland	877	Knockdolian Hill
Scotland	937	Linhouse Valley
Wales	31WBY	Berwyn
Wales	32WGV	Caeau Bronydd-mawr
Wales	33WJC	Coed Nant Menascin
Wales	32WFN	Coedydd Llawr-y-glyn
Wales	32WKM	Llynoedd Tal-y-llechau, (talley Lakes)
Wales	31WEW	Porth Dinllaen I Borth Pistyll

7.3 Sites brought out of critical load exceedance

The following tables illustrate the optimising approach and show details of sites where smaller widths of ERZ were sufficient to reduce the maximum Excess Nitrogen (Average Accumulated Exceedance). Table 7-4 presents SSSIs that were brought out of critical load exceedance with a 1 km ERZ with higher ambition measures. For these sites, a 1 km ERZ was then used in the 2030 CL Opt ERZ SSSI scenario. Table 7-5 presents the sites that were taken out of exceedance with a 2 km ERZ and Table 7-6 the sites brought out of exceedance with a 5 km ERZ. Excess N at these sites was already very close to the critical level under the 2030 NAPCP+DA (NECR NOx) scenario (i.e. meeting NECR targets), and the additional spatially targeted measures provide sufficient further emission reductions for the site no longer to exceed the critical load. Some of these reductions are at the 3rd decimal place, and it is clear that the uncertainty in modelled emissions and deposition for such sites are larger than can be conveyed with the average 1 km grid modelling approach using best available national data. These data do however provide a good indication of which sites are already relatively clean but may still have local sources within a 1 km zone where mitigation may be helpful to ensure protection of the designated features.

Table 7-4. SSSI sites brought out of exceedance of the critical loads under 2030 ERZ SSSI 1 km.

Country	Site Code	Site Name
England	2000205	The Sturts
England	1001940	Cockerham Marsh
England	1005965	Castle Acre Common
England	2000345	Haydon Meadow
England	1005812	Axbridge Hill And Fry's Hill
England	1000670	West Lizard
Wales	33WPS	Waun-fawr, Cefn Cribwr
Scotland	765	Hare Myre, Monk Myre And Stormont Loch
Scotland	435	Craighouse Ravine, Jura
Scotland	809	Inner Tay Estuary

Table 7-5. SSSI sites brought out of exceedance of the critical loads under 2030 ERZ SSSI 2 km.

Country	Site Code	Site Name
England	1000191	Holland Hall (melbourn) Railway Cutting
England	1003321	Newton Mask
England	1003911	Yarnbury Castle
England	1005494	Aller Hill
England	1000683	Gomm Valley
England	1006660	Tuthill Quarry
England	1002742	Folkington Reservoir
England	1001069	Fleam Dyke
England	1002847	Bickenhill Meadows
England	1003237	Wilmington Downs
Scotland	8158	Knapdale Woods

Table 7-6. SSSI sites brought out of exceedance of the critical loads under 2030 ERZ SSSI 5 km.

Country	Site Code	Site Name
England	2000271	Prince's Rough
England	1004459	Bradwell Meadows
England	1002719	North Brewham Meadows
England	1001101	Bishop Monkton Ings
England	1007257	Highclere
England	1001647	Burgh Hill Farm Meadow
England	1002904	Moulsford Downs
England	1006000	Hill Houses & Crumpsbrook Meadows
England	1005749	Down Bank
England	1003030	Thorne And Doves Moors
England	1004035	Marazion Marsh
England	1006344	Queestmoor Meadow
Wales	33WAL	Cog Moors
Scotland	334	Carrot Hill Meadow
Scotland	1284	Phillips Mains Mire
Scotland	1349	Rhunahaorine Point
Scotland	962	Loch Ba Woodland
Scotland	1230	North East Coll Lochs and Moors
Scotland	358	Claish Moss

7.4 Optimised scenarios - emissions

Following the assessment of the minimum width of ERZ required for each SSSI, as described in the previous section, for most sites, with the exception of sites not exceeded under 2030 NAPCP+DA NECR NOx and those listed in Section 7.2 and 7.3 above, 5 km ERZ were established in the optimised scenario, i.e. the higher ambition measures included in the NAPCP+DA policy documents available for this study. In addition, ERZ measures were implemented across the UK, with no manure or slurry applied within a 1 km zone of the site boundaries but displaced to at least 2 km from the SSSIs. For most of the already cleaner and more remote and upland sites such measures are not relevant and likely to have minimum effects. However, it should be immediately obvious to site managers whether manure or slurry spreading is occurring locally near a site, due to associated odours. This measure is not expected to influence the overall magnitude of emissions, as the land spreading is displaced rather than an overall emission reduction measure. The addition of the urea/UAN replacement measure UK-wide, as described in the definition of the optimised scenarios, provides the largest single source of emission reduction, at ca. 8.9 kt NH_3, and substantially helps to decrease NH_3 concentrations and N deposition as a consequence (Figure 7-3, Tables 7-7 and 7-8), especially in arable areas of England. For Wales and Northern Ireland, the largest decreases in emissions are from manure management measures in the dairy sector, whereas for Scotland the urea replacement (mineral fertiliser application to arable and grass combined) is also the most prominent measure in the emission reductions.

Table 7-7. Agricultural NH_3 emission reductions made under the 2030 scenario optimised for minimising critical level exceedance CLe opt. ERZ SSSI (no urea) vs NAPCP+DA (NECR NOx) for each UK devolved administration. Scenarios and separated by agricultural emission sector. Emission Reduction Zones (ERZ) in this scenario are optimised to the minimum width necessary to bring sites out of CLe exceedance, where possible, i.e. 0, 1, 2 or 5 km width. Units: kt NH_3 yr^{-1}

Sector	England	Wales	Scotland	Northern Ireland	**UK**
Dairy	2.26	0.62	0.21	0.73	**3.82**
Beef	0.00	0.00	0.00	0.08	**0.08**
Sheep	0.00	0.00	0.00	0.00	**0.00**
Pigs	1.27	0.01	0.04	0.44	**1.77**
Poultry	2.30	0.10	0.29	0.46	**3.14**
Minor Livestock	0.00	0.00	0.00	0.00	**0.00**
Arable	6.01	0.02	0.17	0.02	**6.23**
Grass	2.01	0.14	0.21	0.30	**2.66**
Total	**13.85**	**0.89**	**0.92**	**2.04**	**17.70**

Table 7-8. Agricultural NH_3 emission reductions made under the scenario optimised for minimising critical loads exceedance 2030 CL opt. ERZ SSSI (no urea) vs NAPCP+DA (NECR NOx) for each UK devolved administrations. Scenarios and separated by agricultural emission sector. Emission Reduction Zones (ERZ) in this scenario are optimised to the minimum width necessary to bring sites out of CL exceedance, where possible, i.e. 0, 1, 2 or 5 km width. Units: kt NH_3 yr^{-1}

Sector	England	Wales	Scotland	Northern Ireland	**UK**
Dairy	2.19	0.63	0.24	0.72	**3.78**
Beef	0.00	0.00	0.00	0.08	**0.08**
Sheep	0.00	0.00	0.00	0.00	**0.00**
Pigs	1.23	0.01	0.07	0.44	**1.74**
Poultry	2.21	0.10	0.30	0.45	**3.06**
Minor Livestock	0.00	0.00	0.00	0.00	**0.00**
Arable	6.01	0.02	0.17	0.02	**6.23**
Grass	2.01	0.14	0.21	0.30	**2.66**
Total	13.64	0.90	0.99	2.02	**17.54**

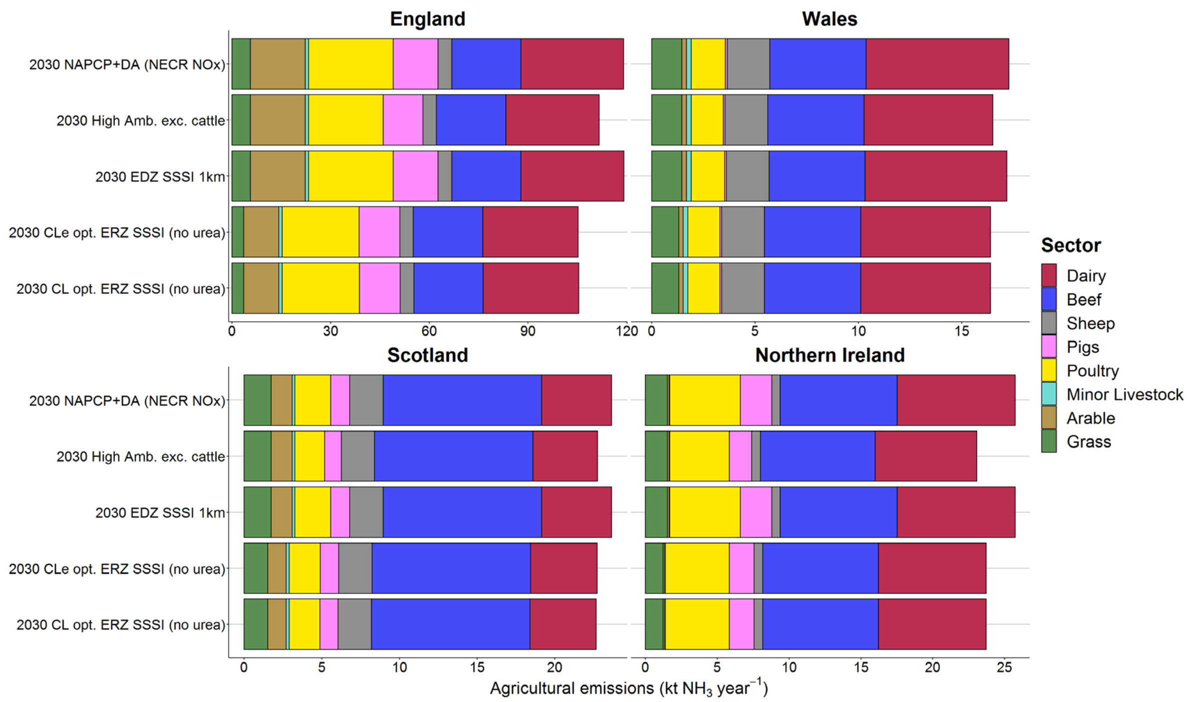

Figure 7-3. Comparison between agricultural NH_3 emissions totals for each UK country, under NAPCP+DA and the optimised emission scenarios and separated by agricultural emission sector.

Table 7-9 compares emissions (by sector) across the relevant baseline and mitigation scenarios that are closely related with the optimised scenarios, i.e. the ERZ and EDZ scenarios, which were used to design the combined sets of measures.

Table 7-9. Comparison of UK ammonia emission totals for optimised scenarios, by major sectors, with other relevant scenarios. Spatial targeting scenarios were modelled using Emission Reduction Zones (ERZ) and Emission Displacement Zones (EDZ). “HGD” refers to horses on agricultural holdings, goats and farmed deer (minor livestock categories). “Other” refers to non-agricultural emission sources, which includes the waste, transport, nature, industrial, *etc*. sectors. CLe refers to critical levels and CL to critical loads. Units: kt NH_3

Scenario	Cattle	Mineral fertiliser	HGD/ minor	Pigs	Poultry	Sheep	Other	Total
2017 Baseline	115.8	44.9	1.4	18.6	37.7	9.6	61.4	289.3
2030 NAPCP+DA (NECR NO_x)	94.9	28.7	1.4	17.1	34.6	9.0	67.9	253.6
2030 ERZ SSSI 1km	94.0	28.7	1.4	16.7	34.0	9.0	67.9	251.7
2030 ERZ SSSI 2km	93.0	28.7	1.4	16.3	33.3	9.0	67.9	249.6
2030 ERZ SSSI 5km	90.9	28.7	1.4	15.3	31.4	9.0	67.9	244.6
2030 High Amb. exc. cattle	89.8	28.7	1.4	14.7	30.3	9.0	67.9	241.8
2030 EDZ SSSI 1km	94.9	28.7	1.4	17.1	34.6	9.0	67.9	253.6
2030 CLe opt. ERZ SSSI (no urea)	91.0	19.8	1.4	15.4	31.4	9.0	67.9	235.9
2030 CL opt. ERZ SSSI (no urea)	91.0	19.8	1.4	15.4	31.5	9.0	67.9	236.0

7.5 Economic Costs of optimised mitigation

The cost of the optimised scenarios was calculated by piecing together the costs of the measures that were combined, i.e. the higher ambition measures implemented in the variable sized ERZ and the EDZ, with the urea/UAN replacement being deemed, on average, cost-neutral, compared with the inhibitor cost (Figure 7-4, Table 7-10). Overall, the UK costs associated with optimising for the smallest number of sites exceeding the 1 μg m^{-3} critical level is slightly higher than for critical loads, by £1.8M or 0.7% of the cost of the CLe optimised scenario of £253M. This difference is dominated by estimates for England (£2.2M), with much smaller differences for Scotland (£0.6M), Northern Ireland (£0.2M), and Wales (£0.1M). However, while the CLe scenario is marginally more expensive for England and Northern Ireland, it is expected to be slightly less so for Wales and Scotland). Overall, the optimised scenarios are costed at >£90M more than the 2030 NAPCP+DA baseline, with most of the additional cost (>£60M) associated with England, nearly £20M with Northern Ireland, £7M with Wales and nearly £5M with Scotland. The relatively higher costs associated with Northern Ireland are due to the higher agricultural NH_3 emission sector than in Wales or Scotland.

Table 7-10. Total estimated cost (£ million) of the optimised mitigation scenarios and the associated /related scenarios from which they were constructed. Costs have been estimated separately for each UK country. N.B. Costs only refer to agricultural NH_3 measures.

Scenario	England	Wales	Scotland	Northern Ireland	UK
2030 NAPCP+DA (NECR NOx)	109.8	13.8	17.0	18.5	159.1
2030 High Amb. exc. cattle	187.9	20.3	25.9	48.2	282.4
2030 EDZ SSSI 1km	112.1	14.2	17.5	19.0	162.8
2030 CLe opt. ERZ SSSI‡	172.6	20.7	22.2	37.9	253.4
2030 CL opt. ERZ SSSI‡	170.4	20.8	22.8	37.7	251.6

‡ Includes emission displacement of FYM and slurries and measures to replace the use of urea fertiliser.

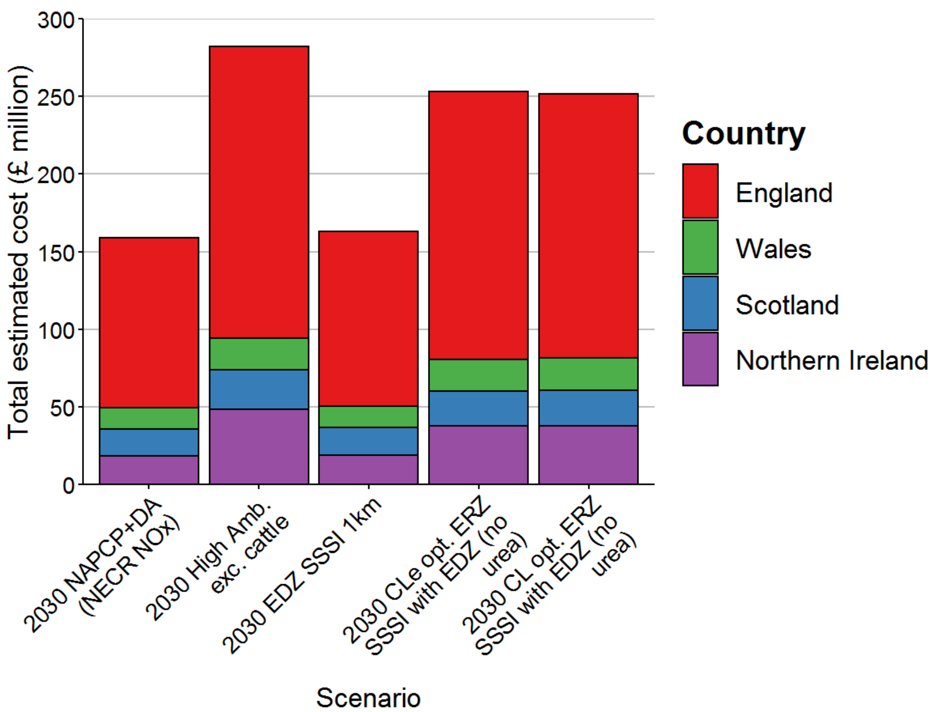

Figure 7-4. Total estimated cost (£ million) of the optimised mitigation scenarios and the associated scenarios from which they were constructed. Costs have been estimated separately for each devolved administration.

7.6 Ammonia concentrations

Ammonia concentrations for the two optimised scenarios are relatively similar, as a) both the EDZ and urea/UAN replacement measures are identical, and b) many of the ERZ also requiring similar widths for the majority of sites to bring them out of the 1 µg CLe and the respective CL exceedance, or at least minimise atmospheric N input if non-exceedance could not be achieved (for details see Sections 7.1-7.3 above). Compared with the 2017 baseline, large agriculturally dominated lowland areas of England and most of Northern Ireland are expected to see decreases in NH_3 concentrations of up to 1 µg NH_3, and a substantial improvement compared with the 2030 NAPCP+DA baseline (Figure 7-5).

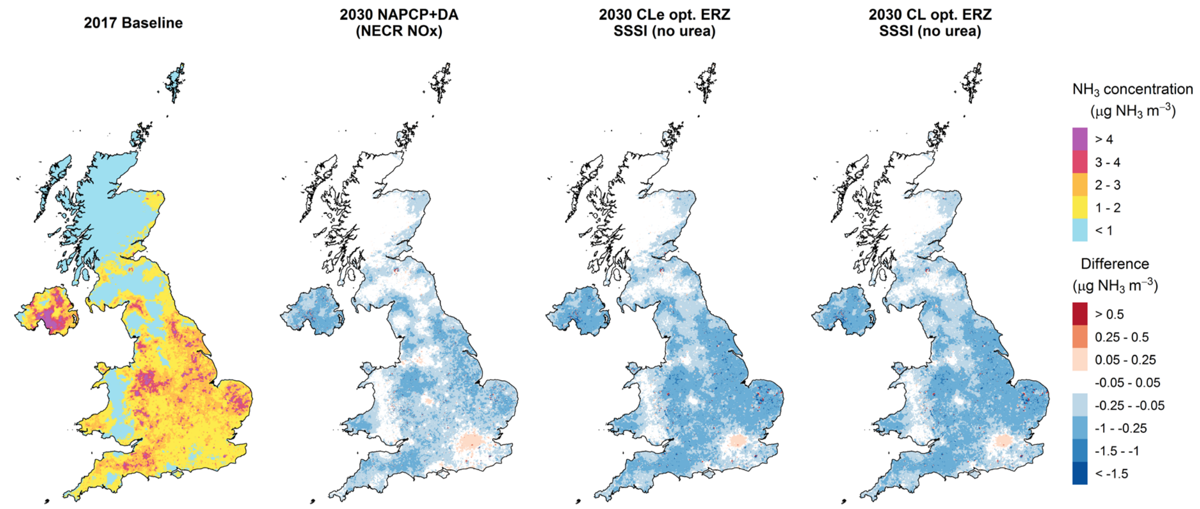

Figure 7-5. NH_3 optimised mitigation scenarios: comparison with 2017 baseline.

7.7 Deposition

In the same way as for NH_3 concentrations, the two optimised scenarios are very similar to each other, but represent substantially increased deposition savings compared with both the 2017 and 2030 baselines. Table 7-11 summarises the estimated total N deposition to the UK land area, using grid-average data to account for land-use dependent deposition rates within each grid square.

Table 7-11. Summary of N deposition to the UK land area for all baseline and mitigation scenarios, split into the main components of wet, dry, reduced and oxidised nitrogen (kt N). The data represent grid square average N deposition, i.e. the land cover within each model grid square is taken into account to provide land cover dependent total deposition.

Scenario (all values kt N)	NHx-N dry	NHx-N wet	NOy-N dry	NOy-N wet	Total N
2030 Baseline NAPCP+DA (NECR NOx)	67.2	79.7	20.9	51.4	219.1
2030 High Amb. exc. cattle	64.6	77.6	20.6	50.9	213.7
2030 EDZ SSSI 1km	67.2	79.7	20.5	50.9	218.3
2030 CLe opt. ERZ SSSI (no urea)	63.1	76.9	20.6	50.8	211.5
2030 CL opt. ERZ SSSI (no urea)	63.1	76.9	20.7	50.8	211.5

As discussed in Annex 3, a metric has been calculated for all scenarios, which can be related to the UK Government's 2019 Clean Air Strategy target. Table 7-12 summarises total reactive N deposition onto protected sensitive habitats.

Table 7-12. Mean deposition of total reactive N onto nutrient-N sensitive priority habitat in kg N ha^{-1} $year^{-1}$, by country and at the UK level.

	Average area weighted deposition to all "priority" habitats by country				
Scenario	England	Wales	Scotland	NI	UK
2030 Baseline NAPCP+DA (NECR NOx)	17.4	15.2	6.8	16.3	10.1
2030 High Amb. exc. cattle	17	14.8	6.7	15.4	9.9
2030 EDZ SSSI 1km	17.3	15.1	6.8	16.3	10.1
2030 CLe opt. ERZ SSSI with EDZ (no urea)	16.5	14.7	6.7	15.5	9.8
2030 CL opt. ERZ SSSI with EDZ (no urea)	16.5	14.7	6.7	15.5	9.8

For low-growing semi-natural vegetation, N deposition rates are estimated to decrease by >5 kg N ha^{-1} yr^{-1} across much of lowland agricultural land in England and large parts of Northern Ireland. The spatial patterns presented in Figure 7-6 show increased benefits in emission source areas, due to the NH_3 focus of the measures, but also wider effects in more remote areas, due to decreased medium/longer range transport of NH_4^+. The additional benefits of optimising emission reductions are least evident across the cleanest areas of northern and western Scotland.

For woodland features (Figure 7-7) across most of England and Northern Ireland, N deposition is expected to decrease by at least 5 kg N ha^{-1} yr^{-1}, with the spatial patterns of N deposition being similar to those for low-growing semi-natural vegetation.

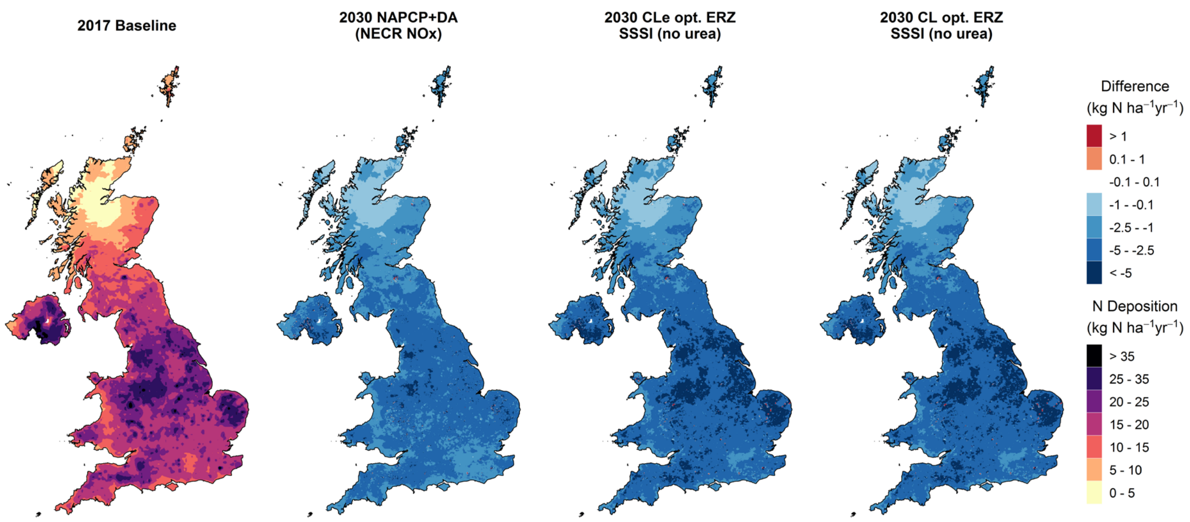

Figure 7-6. N deposition to low-growing semi-natural vegetation optimised scenarios: comparison with 2017 baseline.

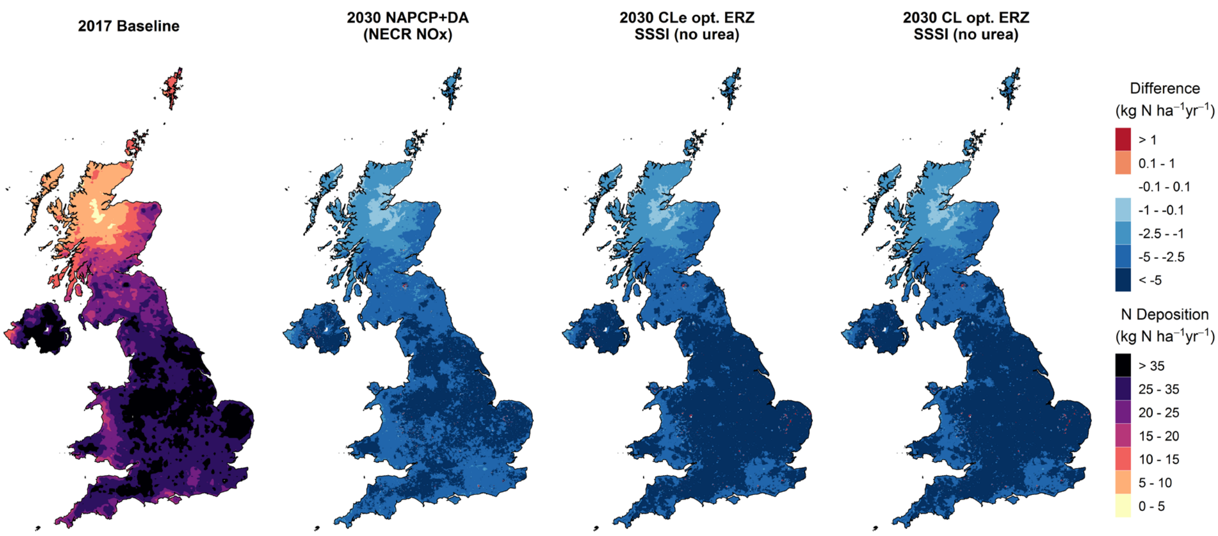

Figure 7-7. N deposition to woodland features optimised scenarios: comparison with 2017 baseline.

7.8 Ammonia critical Levels exceedance

Both optimised scenarios (for critical loads and levels) were assessed for their impact on critical level exceedance at SSSIs. For the optimisation tailored with ERZ widths chosen to minimise critical level exceedance, 419 SSSIs across the UK no longer exceed the1 µg m^{-3} threshold (Figure 7-8, left map), compared with the 2017 baseline, and for optimisation to minimise critical load exceedance, 417 SSSIs are no longer in exceedance (Table 7-13, Figure 7-8, right map). The parts of the UK benefitting most from these scenarios are Scotland, Wales and NW England as well as the south coast of England and the west of Northern Ireland, with the three types of measures (higher ambition ERZ, EDZ and urea/UAN replacement) combining to achieve the additional benefits. Compared with the 2030 baseline, approx. 280 additional SSSIs no longer exceed the 1 µg m^{-3} CLe.

Table 7-13. Additional number of nitrogen sensitive UK SSSIs (compared with the 2017 baseline) that are no longer in exceedance of the 1 µg m^{-3} critical level under each of the optimised mitigation (and associated) emission scenarios. The 1 µg m^{-3} critical level is relevant for assessing lichens, mosses and bryophytes. Exceedance of critical levels has been assessed based on the maximum estimated concentrations at sites. Sites that are located across UK country boundaries have been included in each UK country summary, so the UK summary may not equal the UK total (where sites have been counted once).

Scenario	England	Wales	Scotland	Northern Ireland	UK
2030 BAU (WM)	0	5	6	8	19
2030 NAPCP+DA (NECR NOx)	64	31	28	15	138
2030 High Amb. exc. cattle	93	44	47	19	203
2030 EDZ SSSI 1km	98	59	51	24	232
2030 CLe opt. ERZ SSSI with EDZ (no urea)	223	84	86	26	419
2030 CL opt. ERZ SSSI with EDZ (no urea)	223	84	84	26	417

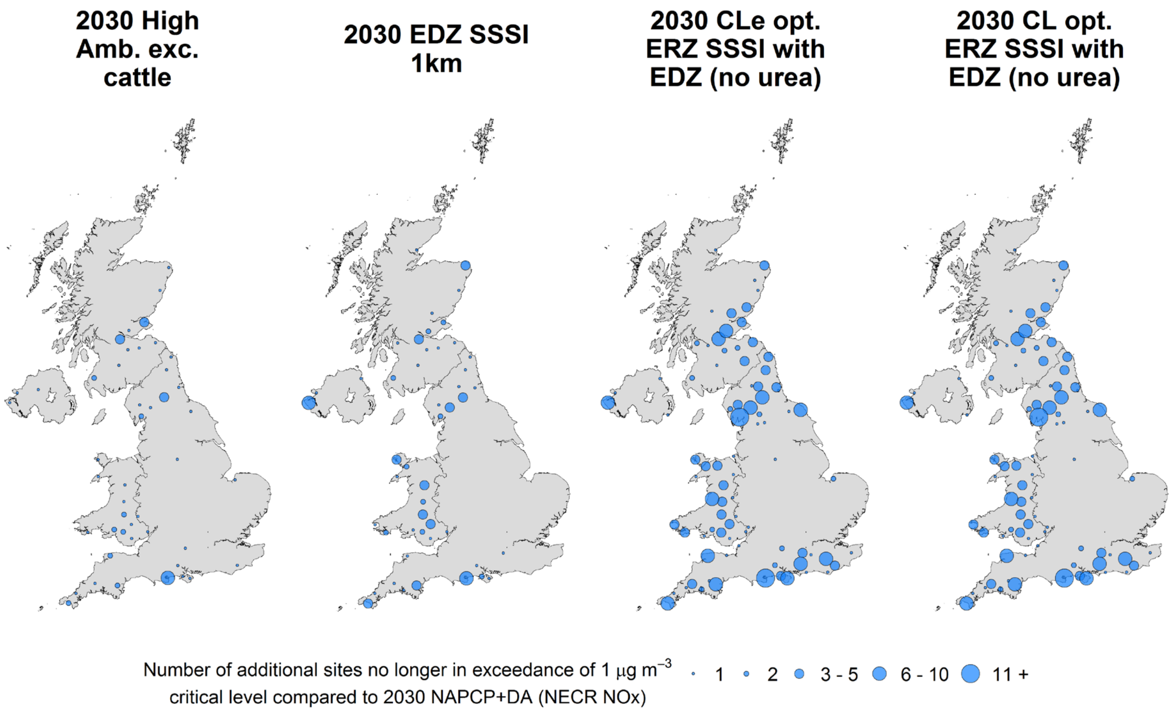

Figure 7-8. Maps showing the additional number of nitrogen sensitive UK SSSI sites (compared with the NAPCP+DA NECR NO_x scenario) that are no longer in exceedance of the 1 µg m^{-3} critical level under each of the optimised mitigation scenarios. The 1 µg m^{-3} critical level is relevant for assessing lichens, mosses and bryophytes. Exceedance of critical levels has been assessed based on the maximum estimated concentrations at sites. Sites clustered together with nearby site up to a distance of 50 km for visualisation.

The same scenarios are estimated to bring 280 SSSIs across the UK out of exceedance for the 3 µg m^{-3} CLe compared with the 2017 baseline, or 123 additional sites compared with the 2030 baseline (Figure 7-9). The main areas to benefit spanning the lowland areas with higher emission densities in England and Northern Ireland, where the majority of sites exceeding the 3 1 µg m^{-3} CLe are located.

Table 7-14. Additional number of nitrogen sensitive UK SSSIs (compared with the 2017 baseline) that are no longer in exceedance of the 3 µg m^{-3} critical level under each of the optimised mitigation (and associated) emission scenarios. The 3 µg m^{-3} critical level is relevant for assessing higher plants. Exceedance of critical levels has been assessed based on the maximum estimated concentrations at sites. Sites that are located in multiple countries have been included in each UK country summary, so the UK summary may not equal the UK total (where sites have been counted once).

Scenario	England	Wales	Scotland	Northern Ireland	UK
2030 BAU (WM)	23	1	2	12	38
2030 NAPCP+DA (NECR NOx)	119	14	3	22	157
2030 High Amb. exc. cattle	149	17	4	28	197
2030 EDZ SSSI 1km	175	22	4	32	229
2030 CLe opt. ERZ SSSI with EDZ (no urea)	215	25	4	41	280
2030 CL opt. ERZ SSSI with EDZ (no urea)	215	25	4	41	280

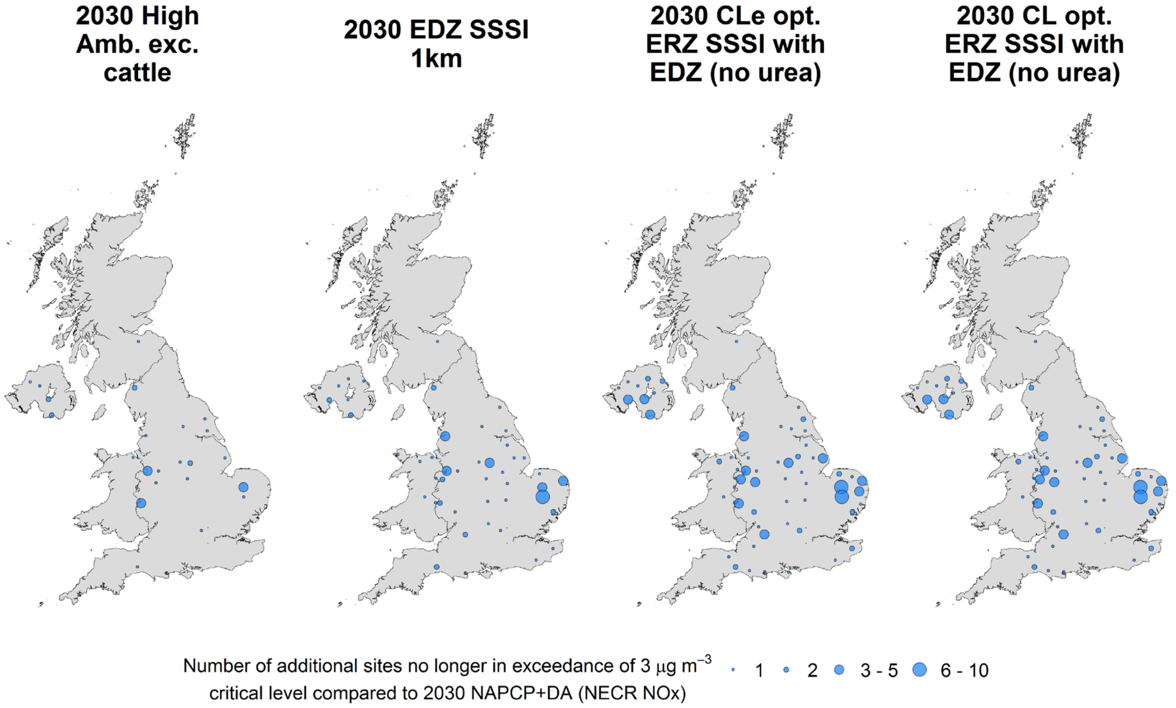

Figure 7-9. Maps showing the additional number of nitrogen sensitive UK SSSI sites (compared with the NAPCP+DA NECR NO_x scenario) that are no longer in exceedance of the 3 µg m^{-3} critical level under each of the optimised mitigation scenarios. The 3 µg NH_3 m^{-3} critical level is relevant for higher plants. Exceedance of critical levels has been assessed based on the maximum estimated concentrations at sites. Sites clustered together with nearby site up to a distance of 50 km for visualisation.

Figure 7-10 shows the average area-weighted exceedance above the 1 µg NH_3 CLe at N-sensitive SSSIs under each optimised mitigation scenario and the associated mitigation scenarios which were combined to develop the optimised scenarios. Although the overall number of sites coming out of exceedance does not decrease steeply with increasing ambition, concentrations above the critical level are substantially reduced with increased mitigation effort. While the proportion of sites in exceedance of the 1 µg NH_3 CLe in England and Northern Ireland remains high, even with optimised mitigation, the level of exceedance is substantially reduced across sites that are in exceedance.

The average area-weighted exceedance above the 3 µg NH_3 CLe at N-sensitive SSSIs under optimised mitigation and associated emission scenarios are presented in Figure 7-11. The proportion of sites in exceedance of the 3 µg NH_3 CLe is much lower than for the 1 µg NH_3 CLe,and is substantially reduced under both optimised scenarios. Only a small proportion of sites have area weighted concentrations above the 3 µg NH_3 CLe.

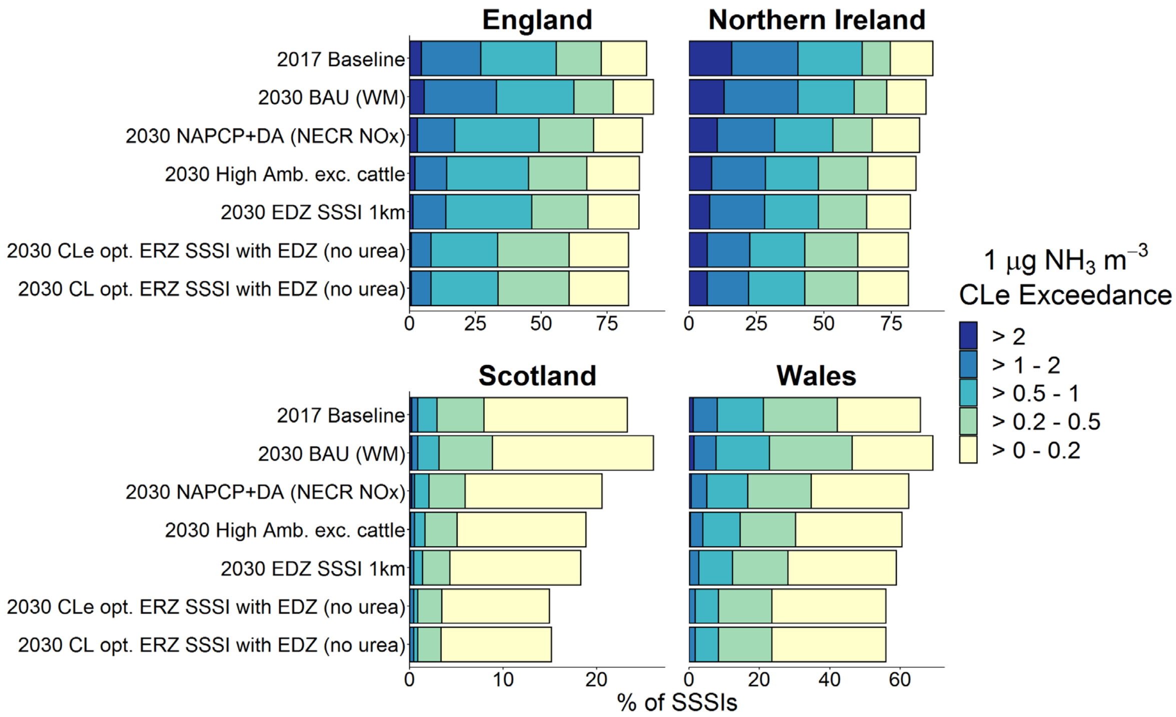

Figure 7-10. Average-area weighted exceedance above the 1 ug NH_3 critical level at UK nitrogen sensitive SSSI sites (in exceedance of critical level) under each optimised mitigation (and associated) emission scenarios.

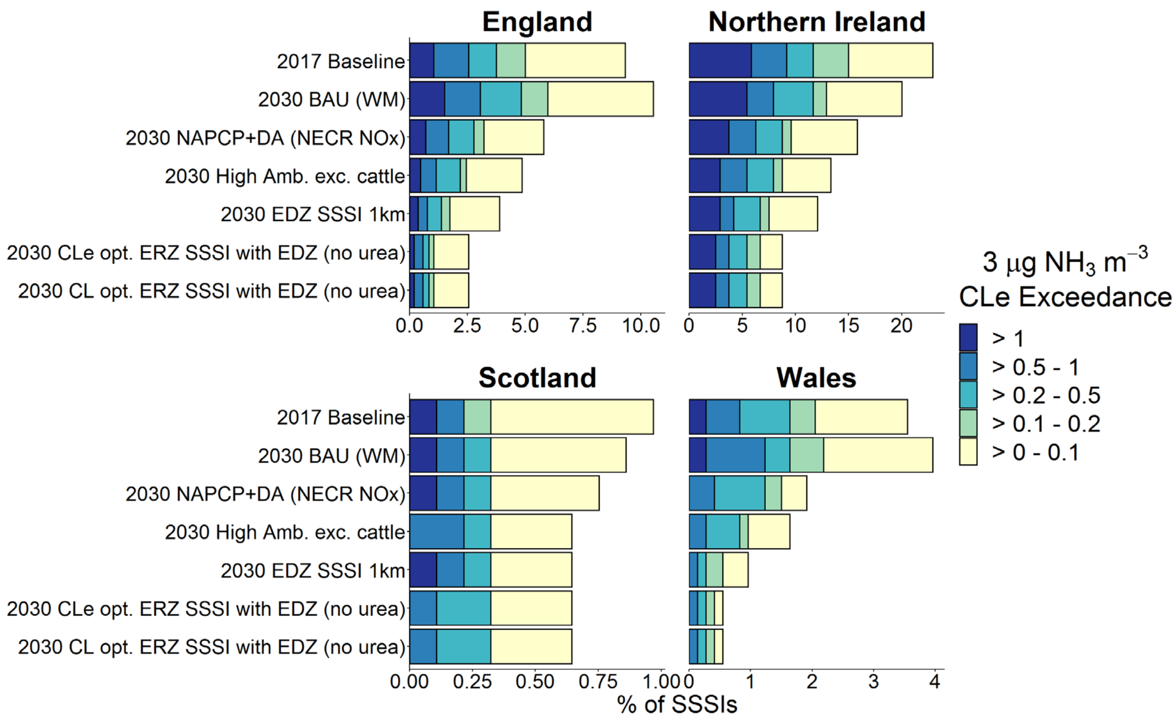

Figure 7-11. Average-area weighted exceedance above the 3 ug NH_3critical level at UK nitrogen sensitive SSSI sites (in exceedance of critical level) under each optimised mitigation (and associated) emission scenarios.

Table 7-15 presents the designation and area weighted indicators (DWI, AWI) for critical level exceedance (>1 µg NH_3 m^{-3}) at nitrogen sensitive SSSIs by UK country. The optimised scenarios provide a substantial decrease in the number of sites in exceedance, compared with the 2030 baseline NAPCP+DA (NECR NO_x). This ranges from an additional 4.1 % of sites coming out of exceedance in Northern Ireland to 6.5 % in Wales. In terms of additional areas within sites coming out of exceedance, i.e. AWI-2, the decreases are more substantial in England (~8.1 %) and Northern Ireland (~7.9 %) than they are in Scotland (0.6 %), where only a small proportion of area within Scottish N-sensitive SSSIs (1.7 %) was exceeded under NAPCP+DA (NECR NO_x). Table 7-16 presents the same indicators for the 3 µg m^{-3} critical level. The number of sites in exceedance of the 3 µg NH_3 m^{-3} CLe under the optimised mitigation scenarios is approximately half the number under NAPCP+DA (NECR NO_x) for England and NI and a third for Wales. For all DAs the area within sites above the 3 µg NH_3 m^{-3} CLe is relatively small under all scenarios.

Table 7.15. UK-wide and optimised (and associated) spatially target mitigation scenarios: Percentage of ammonia critical level exceedance (>1 µg m^{-3}) in nitrogen sensitive SSSIs by UK country (England, Wales, Scotland, Northern Ireland). Indicators shown are the DWI (Designation Weighted Indicator) and AWI (Area Weighted Indicators).

	England			Wales			Scotland			Northern Ireland		
Scenario	DWI	AWI-1	AWI-2	DWI	AWI-1	AWI-2	DWI	AWI-1	AWI-2	DWI	AWI-1	AWI-2
2030 NAPCP+DA (NECR NOx)	88.4	88.5	37.7	62.4	66.5	10.8	20.5	9.8	1.7	85.4	94.1	77.2
2030 High Amb. exc. cattle	87.2	88.0	34.6	60.5	55.9	9.5	18.8	9.5	1.4	84.2	94.0	69.8
2030 EDZ SSSI 1km	87.1	85.4	35.9	58.9	53.6	9.6	18.3	9.3	1.3	82.1	91.5	76.1
2030 CLe opt. ERZ SSSI	83.1	80.7	29.5	55.9	53.0	7.7	14.9	9.2	1.1	81.3	91.5	69.3
2030 CL opt. ERZ SSSI	83.1	80.7	29.6	55.9	53.0	7.7	15.2	9.2	1.1	81.3	91.5	69.3

Table 7-16. UK-wide and spatially target mitigation scenarios: Percentage of ammonia critical level exceedance (> 3 µg m^{-3}) in nitrogen sensitive SSSIs by UK country (England, Wales, Scotland, Northern Ireland). Indicators shown are the DWI (Designation Weighted Indicator) and AWI (Area Weighted Indicators).

	England			Wales			Scotland			Northern Ireland		
Scenario	DWI	AWI-1	AWI-2	DWI	AWI-1	AWI-2	DWI	AWI-1	AWI-2	DWI	AWI-1	AWI-2
2030 NAPCP+DA (NECR NOx)	5.8	14.9	0.6	1.9	4.2	0.3	0.8	2.6	0.0	15.8	41.8	0.9
2030 High Amb. exc. cattle	4.9	14.7	0.5	1.6	3.9	0.2	0.6	2.6	0.0	13.3	41.6	0.8
2030 EDZ SSSI 1km	3.9	12.9	0.3	1.0	3.7	0.1	0.6	2.6	0.0	12.1	41.3	0.7
2030 CLe opt. ERZ SSSI	2.6	12.2	0.2	0.5	3.1	0.1	0.6	2.6	0.0	8.8	41.1	0.7
2030 CL opt. ERZ SSSI	2.6	12.2	0.2	0.5	3.1	0.1	0.6	2.6	0.0	8.8	41.1	0.7

7.9 Nutrient nitrogen critical loads exceedance

Both optimised scenarios show increased numbers of SSSIs no longer exceeding their critical loads compared to NACP+DA (NECR NO_x), with the scenario optimised for critical loads (additional 204 SSSIs) outperforming the scenario optimised for critical levels (additional 202 SSSIs), but only by a small margin of two sites. This is the case for both the number of sites (Figure 7-12) as well as by area (Figure 7-13).

Figure 7-12. A comparison of the proportion of nitrogen-sensitive UK SSSIs (n = 4,853) in exceedance of critical loads under the optimised (and associated) mitigation scenarios. N.B. new sites where critical load information is not available are shown in blue. The list of sensitive features was collated in ~2011 and therefore does not have information about all sites.

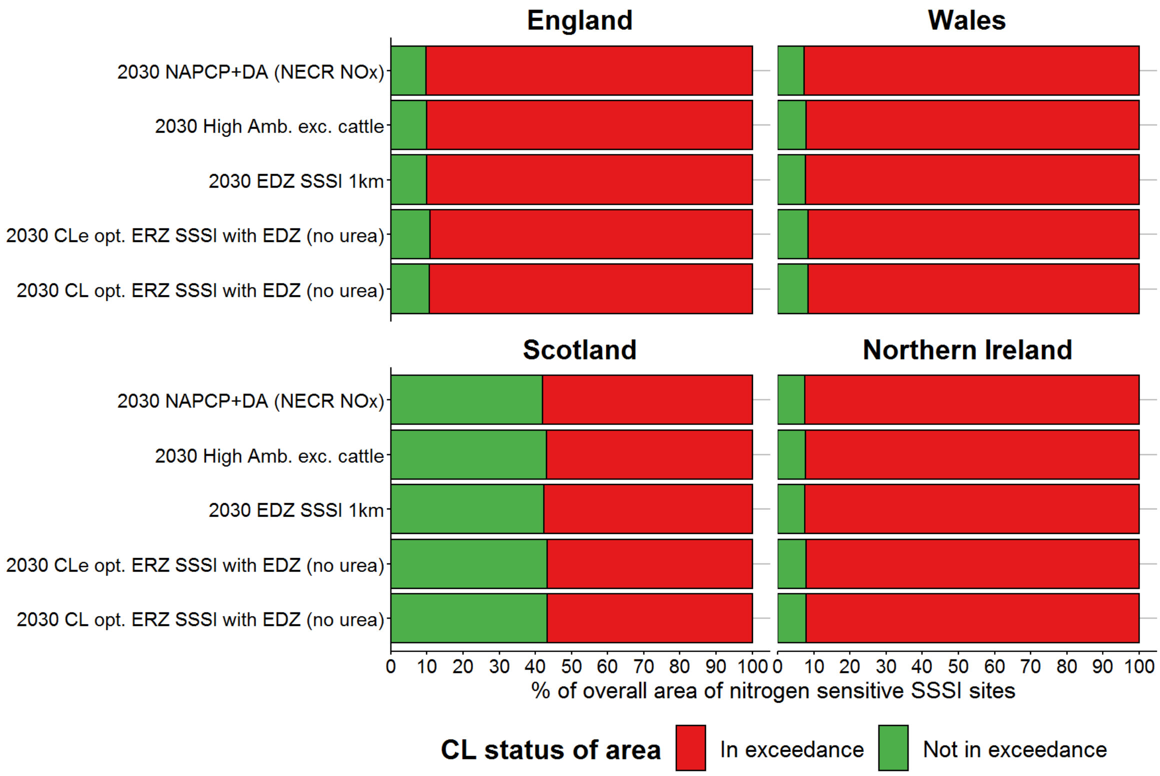

Figure 7-13. A comparison between critical loads exceedance of nitrogen-sensitive UK SSSIs with critical loads information (n = 4,727) under the optimised mitigation scenarios. N.B. new sites where critical load information is not available are not included in this plot. The list of sensitive features was collated in ~2011 and therefore does not have information about all sites.

Compared with the 2017 UK baseline, the optimised scenarios result in approximately 480 SSSIs no longer exceeding their critical loads, or an increase of >200 from the 2030 NAPCP+DA baseline (Table 7-17). For England, the number of sites no longer exceeding their CL nearly doubles from the 2030 NAPCP+DA baseline, with an even larger increase in Wales (>120%), with the number of sites in Scotland and Northern Ireland increasing by ~50% (Table 7-17, Figure 7-14). The spatial distribution of the sites estimated to no longer exceed their CL under the optimised scenarios focuses on central, southern and eastern England, eastern Scotland and coastal areas of Wales and SW England, with the Northern Irish sites being located near Lough Larne (Newlands ASSSI) and near the southern border (Cruninish Island ASSSI).

Table 7-17. Additional number of nitrogen sensitive UK SSSIs (compared with the 2017 baseline) that are no longer in exceedance of nutrient critical loads under each optimised mitigation (and associated) scenario. This figure excludes the 127 SSSIs where critical load information is unknown.

	England	Wales	Scotland	Northern Ireland	UK
2030 NAPCP+DA (NECR NOx)	179	4	84	9	276
2030 High Amb. exc. cattle	225	5	101	11	342
2030 EDZ SSSI 1km	208	4	90	14	316
2030 CLe opt. ERZ SSSI with EDZ (no urea)	338	6	113	21	478
2030 CL opt. ERZ SSSI with EDZ (no urea)	338	6	115	21	480

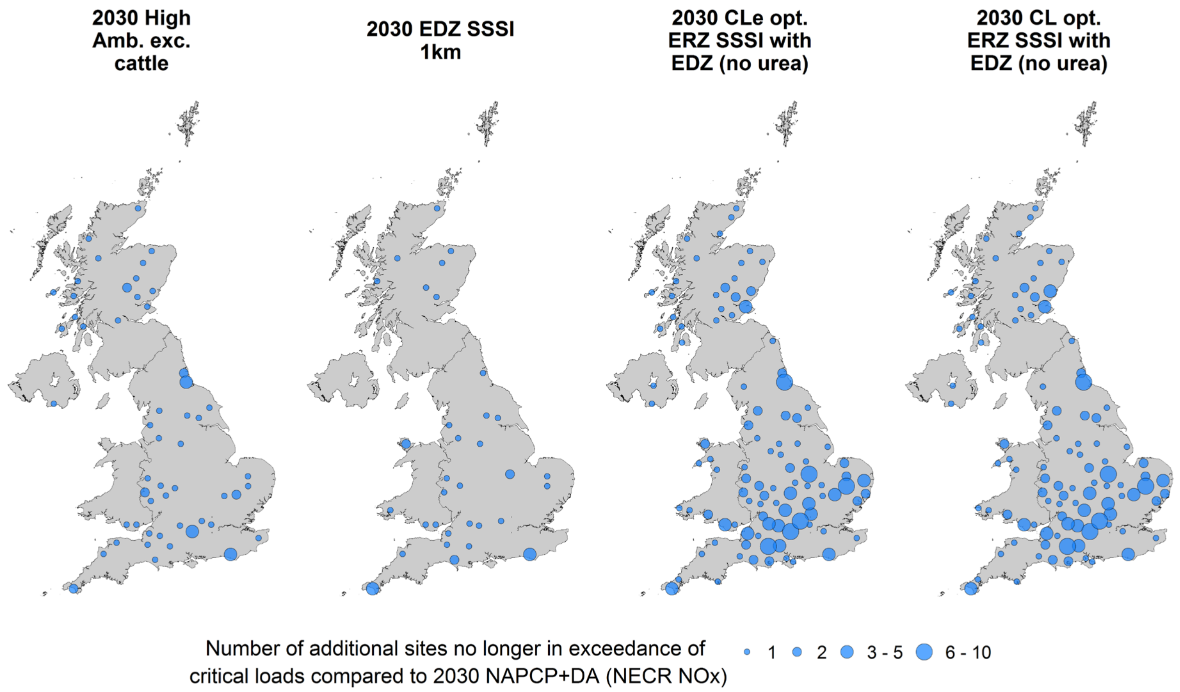

Figure 7-14. Maps showing the additional number of nitrogen sensitive UK SSSIs (compared with the NAPCP+DA NECR NO_x scenario) that are no longer in exceedance of critical loads under the optimised (and associated) mitigation scenarios. This figure excludes the 127 SSSIs where critical load information is unknown. Sites clustered together with nearby site up to a distance of 50 km for visualisation.

8 Effectiveness of agricultural mitigation scenarios

The effectiveness of the all mitigation scenarios was assessed by comparing the additional number of sites (DWI) and additional area (AWI-1, AWI-2) protected in terms of critical levels and critical loads exceedance and excess N (AAE), compared with the 2030 NAPCP+DA. For the agricultural measures, it was also possible to factor in costs, in the same way as under the Defra AC0109 project i.e. costs of NH_3 mitigation. The main difference to the constellation of scenarios in the AC0109 project was that in that project the projected 2020 baseline for agricultural NH_3 was very similar to the 2008 baseline for the most recent available year with detailed emission inventory data. By contrast, the 2030 NAPCP+DA scenario includes a wide range of mitigation measures that decrease emissions by 42 kt NH_3 compared with the 2017 baseline, with the spatially targeted measures having much less scope for improvement, on top of the NAPCP+DA measures. Whereas the spatially targeted measures in ERZ under AC0109 were estimated to achieve between 5-21% further emission reduction compared with the 2020 baseline, the equivalent numbers for the current project amount to 0.7-7% compared to the 2030 NAPCP+DA baseline.

8.1 Effectiveness of mitigation on reducing NH_3 critical levels exceedance

The following sections describe the effectiveness of the different scenarios on decreasing exceedance of the 1 and 3 µg m^{-3} CLe at N-sensitive SSSIs, both for UK-wide and spatially targeted emission scenarios, separately for the UK and the four constituent countries.

At the UK level, the EDZ measures are by far the most cost-effective, across both the 1 and 3 µg m^{-3} CLe, and across all three indicators (DWI, AWI-1, AWI-2). In terms of the largest proportion of sites protected, both by designation and by area, the two optimised spatially targeted scenarios (2030 CLe opt. ERZ SSSI and 2030 CL opt. ERZ SSSI) stand out across both CLe and all indicators, and are the second most cost-effective options overall, but at a much greater cost. They are, however, no more expensive than the 5 km ERZ around all SSSI, with savings from the minimum necessary variable ERZ size balancing out the estimated cost of the EDZ measures.

For the 1 µg m^{-3} CLe, there is no clear difference in the cost effectiveness between the different widths of ERZ and the UK-wide scenario regarding the proportion of additional sites/areas protected (all 3 indicators, Table 8-1). However, for the 3 µg m^{-3} CLe, the % additional sites (DWI) and additional area (AWI) as well as the cost indicators all show clear trends, with the narrower ERZ making the most difference in terms of additional protection and most cost-effectively. The UK-wide version of the same scenario (2030 High Amb. exc. cattle) provides only relatively small additional benefits compared with the 5 km ERZ.

For England (Table 8-2), similar patterns in terms of effectiveness were found as for the UK, for both critical levels, and across all indicators. In Wales (Table 8-3), the optimised scenarios are more effective than in England, and most indicators for % additional sites and area protected are larger than for England. The most cost-effective scenario is again the EDZ measures, with the cost-based indicators all >100%, due to the estimated cost of this scenario being very low, at only £0.4M across all SSSIs in Wales.

In Scotland (Table 8-4), due to the very small number of SSSIs exceeding the 3 µg m^{-3} CLe, the estimates for the different scenarios are less meaningful, with all but the least ambitious ERZ scenarios only achieving a single site to come out of exceedance. For the 1 µg m^{-3} CLe, similar patterns are shown as for Wales, but with much larger gains in terms of % additional sites (DWI) and % additional area (AWI-2) protected. For the AWI-1, values in Scotland are lower. Scotland is the only country with small but notable differences between the two optimised scenarios, with the scenario optimised for CLe being slightly more effective than the scenario optimised for CL, across all indicators.

In Northern Ireland (Table 8-5), the absolute numbers as well as additional (relative) proportions of sites (DWI) and area (AWI) only increase very slowly with increasing ambitions of measures, likely due to the relatively high baseline in NH_3 concentrations across most of the country. At the 3 µg m^{-3} level, the optimised scenarios are most effective, with the largest relative increase in protected sites and areas coming out of exceedance. The EDZ scenario being the best of the rest of the scenarios, but also by far the most cost effective. At the 1 µg m^{-3} level, the optimised scenarios and the EDZ scenario are much closer together in terms of effectiveness for the DWI and the AWI-1 indicators. However, for the AWI-2, i.e. the less precautionary indicator that counts areas not exceeded within sites that may have some exceedance, the most successful option is the 2040+ scenario with regulation for larger cattle farms. Given that the cattle sector is proportionally much more important in Northern Ireland than across the rest of the UK, this shows how measures targeting the most prominent sector(s) may achieve more over larger areas of the country.

Table 8-1. Assessment of effectiveness and cost-effectiveness of UK-wide and spatially targeted mitigation scenarios for NH_3 Critical Levels exceedance (1 and 3 µg m^{-3}) for UK nitrogen sensitive SSSIs. All comparisons are made to NAPCP+DA (NECR NOx) for which:

- 1 µg m^{-3}: DWI 3,361 (of 4,853) SSSIs were exceeded. AWI-1 1,175,449 ha of SSSIs were exceeded. AWI-2 480,060 ha within SSSIs were exceeded.
- 3 µg m^{-3}: DWI 226 (of 4,853) SSSIs were exceeded. AWI-1 201,782 ha of SSSIs were exceeded. AWI-2 7,044 ha within SSSIs were exceeded.

Critical Level	Scenario	Difference in cost (£m)	DWI Additional sites protected	DWI % additional sites protected	DWI % additional sites protected / £5 m	AW-1 Additional area protected (ha)	AWI-1 % additional area protected	AWI-1 % additional area protected / £5 m	AWI-2 Additional area protected (ha)	AWI-2 % additional area protected	AWI-2 % additional area protected / £5 m
1	2030 ERZ SAC 2km	18.1	17	0.5	0.1	1,203	0.1	0.0	9,497	2.0	0.5
1	2030 ERZ SSSI 1km	20.2	19	0.5	0.1	1,409	0.1	0.0	9,360	1.9	0.5
1	2030 ERZ SSSI 2km	41.5	34	1.0	0.1	4,269	0.4	0.0	16,147	3.4	0.4
1	2030 ERZ SSSI 5km	93.3	56	1.6	0.1	29,491	2.5	0.1	31,562	6.6	0.4
1	2030 High Amb. exc. cattle	123.3	68	2.0	0.1	32,295	2.7	0.1	42,829	8.9	0.4
1	2030 EDZ SSSI 1km	3.7	94	2.7	3.6	68,284	5.8	7.8	23,043	4.8	6.4
1	2040+ ERZ SSSI 2km inc. cattle	72.7	44	1.3	0.1	28,943	2.5	0.2	20,872	4.3	0.3
1	2040+ High Amb. inc. cattle	206.7	97	2.8	0.1	38,460	3.3	0.1	61,189	12.7	0.3
1	2030 CLe opt. ERZ SSSI	94.3	268	7.7	0.4	117,192	10.0	0.5	97,688	20.3	1.1
1	2030 CL opt. ERZ SSSI	92.6	266	7.7	0.4	116,965	10.0	0.5	96,655	20.1	1.1
3	2030 ERZ SAC 2km	18.1	8	3.5	1.0	1,828	0.9	0.3	346	4.9	1.4
3	2030 ERZ SSSI 1km	20.2	15	6.6	1.6	1,973	1.0	0.2	515	7.3	1.8
3	2030 ERZ SSSI 2km	41.5	26	11.5	1.4	2,491	1.2	0.1	674	9.6	1.2
3	2030 ERZ SSSI 5km	93.3	35	15.5	0.8	2,774	1.4	0.1	884	12.5	0.7
3	2030 High Amb. exc. cattle	123.3	37	16.4	0.7	2,805	1.4	0.1	910	12.9	0.5
3	2030 EDZ SSSI 1km	3.7	72	31.9	42.6	20,369	10.1	13.5	2,790	39.6	52.9
3	2040+ ERZ SSSI 2km inc. cattle	72.7	29	12.8	0.9	2,529	1.3	0.1	701	10.0	0.7
3	2040+ High Amb. inc. cattle	206.7	46	20.4	0.5	3,429	1.7	0.0	1,155	16.4	0.4
3	2030 CLe opt. ERZ SSSI	94.3	122	54.0	2.9	27,906	13.8	0.7	3,789	53.8	2.9
3	2030 CL opt. ERZ SSSI	92.6	122	54.0	2.9	27,906	13.8	0.7	3,789	53.8	2.9

Table 8-2. Assessment of effectiveness and cost-effectiveness of UK-wide and spatially targeted mitigation scenarios for NH_3 Critical Levels exceedance (1 and 3 µg m^{-3}) nitrogen sensitive SSSIs in England (includes five sites bordering Scotland and 23 sites bordering Wales). All comparisons are made to NAPCP+DA (NECR NOx) for which:

- 1 µg m^{-3}: DWI 2,633 (of 2,979) SSSIs were exceeded. AWI-1 868,772 ha of SSSIs were exceeded. AWI-2 369,935 ha within SSSIs were exceeded.
- 3 µg m^{-3}: DWI 173 (of 2,979) SSSIs were exceeded. AWI-1 145,802 ha of SSSIs were exceeded. AWI-2 5,858 ha within SSSIs were exceeded.

Critical Level (**µg m^{-3}**)	Scenario	Difference in cost (£m)	DWI Additional sites protected	DWI % additional sites protected	DWI % additional sites protected / £5 m	AWI-1 Additional area protected (ha)	AWI-1 % additional area protected	AWI-1 % additional area protected / £5 m	AWI-2 Additional area protected (ha)	AWI-2 % additional area protected	AWI-2 % additional area protected / £5 m
1	2030 ERZ SAC 2km	11.0	9	0.3	0.2	842	0.1	0.0	7,329	2.0	0.9
1	2030 ERZ SSSI 1km	13.4	10	0.4	0.1	1,000	0.1	0.0	7,676	2.1	0.8
1	2030 ERZ SSSI 2km	27.7	18	0.7	0.1	2,068	0.2	0.0	12,984	3.5	0.6
1	2030 ERZ SSSI 5km	61.7	27	1.0	0.1	2,297	0.3	0.0	24,451	6.6	0.5
1	2030 High Amb. exc. cattle	78.1	35	1.3	0.1	4,875	0.6	0.0	30,857	8.3	0.5
1	2030 EDZ SSSI 1km	2.3	39	1.5	3.2	30,995	3.6	7.7	17,212	4.7	10.0
1	2040+ ERZ SSSI 2km inc. cattle	47.2	22	0.8	0.1	2,132	0.2	0.0	16,008	4.3	0.5
1	2040+ High Amb. inc. cattle	129.1	51	1.9	0.1	9,837	1.1	0.0	42,099	11.4	0.4
1	2030 CLe opt. ERZ SSSI	62.8	158	6.0	0.5	76,901	8.9	0.7	80,412	21.7	1.7
1	2030 CL opt. ERZ SSSI	60.6	158	6.0	0.5	76,901	8.9	0.7	79,488	21.5	1.8
3	2030 ERZ SAC 2km	11.0	6	3.5	1.6	1,105	0.8	0.3	337	5.7	2.6
3	2030 ERZ SSSI 1km	13.4	13	7.5	2.8	1,245	0.9	0.3	440	7.5	2.8
3	2030 ERZ SSSI 2km	27.7	21	12.1	2.2	1,643	1.1	0.2	590	10.1	1.8
3	2030 ERZ SSSI 5km	61.7	28	16.2	1.3	1,812	1.2	0.1	745	12.7	1.0
3	2030 High Amb. exc. cattle	78.1	28	16.2	1.0	1,812	1.2	0.1	762	13.0	0.8
3	2030 EDZ SSSI 1km	2.3	57	32.9	71.1	18,910	13.0	28.0	2,575	44.0	94.8
3	2040+ ERZ SSSI 2km inc. cattle	47.2	23	13.3	1.4	1,681	1.2	0.1	615	10.5	1.1
3	2040+ High Amb. inc. cattle	129.1	35	20.2	0.8	2,340	1.6	0.1	955	16.3	0.6
3	2030 CLe opt. ERZ SSSI	62.8	97	56.1	4.5	26,185	18.0	1.4	3,482	59.4	4.7
3	2030 CL opt. ERZ SSSI	60.6	97	56.1	4.6	26,185	18.0	1.5	3,482	59.4	4.9

*Sites that border Wales and Scotland (and have areas outside England) are included here and areas situated outside England are also included in the totals.

Table 8-3. Assessment of effectiveness and cost-effectiveness of UK-wide and spatially targeted mitigation scenarios for NH_3 Critical Levels exceedance (1 and 3 µg m^{-3}) nitrogen sensitive SSSIs in Wales (includes 23 border sites with England). All comparisons are made to NAPCP+DA (NECR NOx) for which:

- 1 µg m^{-3}: DWI 457 (of 732) SSSIs were exceeded. AWI-1 157,575 ha of SSSIs were exceeded. AWI-2 25,616 ha within SSSIs were exceeded.
- 3 µg m^{-3}: DWI 14 (of 732) SSSIs were exceeded. AWI-1 9,954 ha of SSSIs were exceeded. AWI-2 619 ha within SSSIs were exceeded.

Critical Level **(µg m^{-3})**	Scenario	Difference in cost (£m)	DWI Additional sites protected	DWI % additional sites protected	DWI % additional sites protected / £5 m	AWI-1 Additional area protected (ha)	AWI-1 % additional area protected	AWI-1 % additional area protected / £5 m	AWI-2 Additional area protected (ha)	AWI-2 % additional area protected	AWI-2 % additional area protected / £5 m
1	2030 ERZ SAC 2km	2.5	5	1.1	2.1	220	0.1	0.3	1,246	4.9	9.5
1	2030 ERZ SSSI 1km	1.8	5	1.1	3.1	220	0.1	0.4	834	3.3	9.2
1	2030 ERZ SSSI 2km	3.5	7	1.5	2.2	419	0.3	0.4	1,517	5.9	8.5
1	2030 ERZ SSSI 5km	6.1	13	2.8	2.3	25,025	15.9	13.1	2,709	10.6	8.7
1	2030 High Amb. exc. cattle	6.5	14	3.1	2.3	25,036	15.9	12.2	3,150	12.3	9.4
1	2030 EDZ SSSI 1km	0.4	26	5.7	74.7	30,488	19.3	254.1	2,866	11.2	146.9
1	2040+ ERZ SSSI 2km inc. cattle	9.4	10	2.2	1.2	24,828	15.8	8.4	2,388	9.3	5.0
1	2040+ High Amb. inc. cattle	17.4	19	4.2	1.2	25,186	16.0	4.6	4,514	17.6	5.1
1	2030 CLe opt. ERZ SSSI	6.9	48	10.5	7.6	31,972	20.3	14.7	7,392	28.9	20.9
1	2030 CL opt. ERZ SSSI	7.0	48	10.5	7.5	31,972	20.3	14.6	7,416	29.0	20.8
3	2030 ERZ SAC 2km	2.5	1	7.1	14.0	699	7.0	13.8	6	0.9	1.9
3	2030 ERZ SSSI 1km	1.8	1	7.1	20.2	699	7.0	19.8	6	0.9	2.7
3	2030 ERZ SSSI 2km	3.5	1	7.1	10.2	699	7.0	10.0	17	2.8	4.0
3	2030 ERZ SSSI 5km	6.1	2	14.3	11.8	699	7.0	5.8	41	6.7	5.5
3	2030 High Amb. exc. cattle	6.5	2	14.3	10.9	699	7.0	5.4	41	6.7	5.1
3	2030 EDZ SSSI 1km	0.4	7	50.0	656.5	1,144	11.5	150.8	436	70.4	924.0
3	2040+ ERZ SSSI 2km inc. cattle	9.4	2	14.3	7.6	699	7.0	3.7	41	6.7	3.6
3	2040+ High Amb. inc. cattle	17.4	4	28.6	8.2	1,021	10.3	2.9	100	16.2	4.6
3	2030 CLe opt. ERZ SSSI	6.9	10	71.4	51.6	2,657	26.7	19.3	495	79.9	57.7
3	2030 CL opt. ERZ SSSI	7.0	10	71.4	51.3	2,657	26.7	19.2	495	79.9	57.4

*Sites that border England (and have areas within England) are included here and any areas situated in England are also included with the Welsh totals.

Table 8-4. Assessment of effectiveness and cost-effectiveness of UK-wide and spatially targeted mitigation scenarios for NH_3 Critical Levels exceedance (1 and 3 µg m^{-3}) nitrogen sensitive SSSIs in Scotland (includes five border sites with England). All comparisons are made to NAPCP+DA (NECR NOx) for which:

- 1 µg m^{-3}: DWI 191 (of 930) SSSIs were exceeded. AWI-1 88,549 ha of SSSIs were exceeded. AWI-2 15,239 ha within SSSIs were exceeded.
- 3 µg m^{-3}: DWI 7 (of 930) SSSIs were exceeded. AWI-1 23,369 ha of SSSIs were exceeded. AWI-2 192 ha within SSSIs were exceeded.

Critical Leve (**µg m^{-3})l**	Scenario	Difference in cost (£m)	DWI Additional sites protected	DWI % additional sites protected	DWI % additional sites protected / £5 m	AWI-1 Additional area protected (ha)	AWI-1 % additional area protected	AWI-1 % additional area protected / £5 m	AWI-2 Additional area protected (ha)	AWI-2 % additional area protected	AWI-2 % additional area protected / £5 m
1	2030 ERZ SAC 2km	0.9	3	1.6	8.5	141	0.2	0.9	647	4.2	23.1
1	2030 ERZ SSSI 1km	1.2	4	2.1	8.8	188	0.2	0.9	821	5.4	22.6
1	2030 ERZ SSSI 2km	2.7	8	4.2	7.8	1,730	2.0	3.6	1,331	8.7	16.2
1	2030 ERZ SSSI 5km	6.4	15	7.9	6.1	2,117	2.4	1.9	2,263	14.8	11.6
1	2030 High Amb. exc. cattle	8.8	16	8.4	4.7	2,282	2.6	1.5	2,658	17.4	9.9
1	2030 EDZ SSSI 1km	0.5	21	11.0	119.3	4,069	4.6	49.9	3,191	20.9	227.3
1	2040+ ERZ SSSI 2km inc. cattle	4.7	11	5.8	6.2	1,932	2.2	2.3	2,081	13.7	14.6
1	2040+ High Amb. inc. cattle	15.4	20	10.5	3.4	3,288	3.7	1.2	3,650	24.0	7.8
1	2030 CLe opt. ERZ SSSI	5.1	52	27.2	26.5	5,552	6.3	6.1	5,412	35.5	34.5
1	2030 CL opt. ERZ SSSI	5.8	50	26.2	22.5	5,325	6.0	5.2	5,380	35.3	30.4
3	2030 ERZ SAC 2km	0.9	0	0.0	0.0	-	0.0	0.0	-	0.0	0.0
3	2030 ERZ SSSI 1km	1.2	0	0.0	0.0	-	0.0	0.0	17	8.8	36.9
3	2030 ERZ SSSI 2km	2.7	1	14.3	26.5	106	0.5	0.8	20	10.6	19.7
3	2030 ERZ SSSI 5km	6.4	1	14.3	11.1	106	0.5	0.4	20	10.6	8.3
3	2030 High Amb. exc. cattle	8.8	1	14.3	8.1	106	0.5	0.3	20	10.6	6.0
3	2030 EDZ SSSI 1km	0.5	1	14.3	155.1	106	0.5	4.9	18	9.2	99.6
3	2040+ ERZ SSSI 2km inc. cattle	4.7	1	14.3	15.3	106	0.5	0.5	20	10.6	11.3
3	2040+ High Amb. inc. cattle	15.4	1	14.3	4.6	106	0.5	0.1	20	10.6	3.4
3	2030 CLe opt. ERZ SSSI	5.1	1	14.3	13.9	106	0.5	0.4	23	11.9	11.6
3	2030 CL opt. ERZ SSSI	5.8	1	14.3	12.3	106	0.5	0.4	23	11.9	10.3

*Sites that border England (and have areas within England) are included here and any areas situated in England are also included with the Scottish totals.

Table 8-5. Assessment of effectiveness and cost-effectiveness of UK-wide and spatially targeted mitigation scenarios for NH_3 Critical Levels exceedance (1 and 3 µg m^{-3}) nitrogen sensitive SSSIs in Northern Ireland. All comparisons are made to NAPCP+DA (NECR NOx) for which:

- 1 µg m^{-3}: DWI 205 (of 240) ASSIs were exceeded. AWI-1 98,989 ha of SSSIs were exceeded. AWI-2 81,178 ha within SSSIs were exceeded.
- 3 µg m^{-3}: DWI 38 (of 240) ASSIs were exceeded. AWI-1 43,955 ha of SSSIs were exceeded. AWI-2 923 ha within SSSIs were exceeded.

Critical Level (µg m^{-3})	Scenario	Difference in cost (£m)	DWI Additional sites protected	DWI % additional sites protected	DWI % additional sites protected / £5 m	AW1 Additional area protected (ha)	AW1 % additional area protected	AW1 % additional area protected / £5 m	AW2 Additional area protected (ha)	AW2 % additional area protected	AW2 % additional area protected / £5 m
1	2030 ERZ SAC 2km	3.6	0	0.0	0.0	-	0.0	0.0	814	1.0	1.4
1	2030 ERZ SSSI 1km	3.8	0	0.0	0.0	-	0.0	0.0	478	0.6	0.8
1	2030 ERZ SSSI 2km	7.6	1	0.5	0.3	52	0.1	0.0	1,059	1.3	0.9
1	2030 ERZ SSSI 5km	19.1	1	0.5	0.1	52	0.1	0.0	3,298	4.1	1.1
1	2030 High Amb. exc. cattle	29.8	3	1.5	0.2	102	0.1	0.0	7,744	9.5	1.6
1	2030 EDZ SSSI 1km	0.6	8	3.9	33.5	2,733	2.8	23.7	1,164	1.4	12.3
1	2040+ ERZ SSSI 2km inc. cattle	11.4	1	0.5	0.2	52	0.1	0.0	1,366	1.7	0.7
1	2040+ High Amb. inc. cattle	44.8	7	3.4	0.4	149	0.2	0.0	13,202	16.3	1.8
1	2030 CLe opt. ERZ SSSI	19.4	10	4.9	1.3	2,767	2.8	0.7	8,332	10.3	2.6
1	2030 CL opt. ERZ SSSI	19.2	10	4.9	1.3	2,767	2.8	0.7	8,232	10.1	2.6
3	2030 ERZ SAC 2km	3.6	1	2.6	3.6	24	0.1	0.1	8	0.9	1.2
3	2030 ERZ SSSI 1km	3.8	1	2.6	3.5	29	0.1	0.1	56	6.1	8.0
3	2030 ERZ SSSI 2km	7.6	3	7.9	5.2	43	0.1	0.1	62	6.7	4.4
3	2030 ERZ SSSI 5km	19.1	4	10.5	2.8	157	0.4	0.1	116	12.6	3.3
3	2030 High Amb. exc. cattle	29.8	6	15.8	2.7	188	0.4	0.1	126	13.6	2.3
3	2030 EDZ SSSI 1km	0.6	9	23.7	203.2	532	1.2	10.4	157	17.0	145.7
3	2040+ ERZ SSSI 2km inc. cattle	11.4	3	7.9	3.5	43	0.1	0.0	64	6.9	3.0
3	2040+ High Amb. inc. cattle	44.8	8	21.1	2.4	283	0.6	0.1	177	19.2	2.1
3	2030 CLe opt. ERZ SSSI	19.4	17	44.7	11.5	771	1.8	0.5	237	25.7	6.6
3	2030 CL opt. ERZ SSSI	19.2	17	44.7	11.6	771	1.8	0.5	237	25.7	6.7

8.2 Effectiveness of mitigation on reducing nutrient N critical loads exceedance

The effectiveness of the different scenarios for reducing exceedance of critical loads (CL) at UK nitrogen sensitive SSSIs was analysed for both the UK-wide and spatially targeted emission scenarios, for the UK and separately for the UK countries. Unlike the assessment of CLe exceedance (Section 8.1), which is primarily a reflection of local NH_3 emissions, CL exceedance at a site can be substantially affected by long-range and NO_x emission sources, as well as by local NH_3. This also makes assessing the cost effectiveness of scenarios on a UK country level more complicated than for CLe exceedance, as most sites will benefit from emissions reductions made by other DAs. Effects of the scenarios on CL exceedance for the whole habitat area and for protected sites are likely to be similar, except that the measures that are targeted specifically on protected sites are relatively more effective for protected sites than for the whole habitat.

At the UK level (Table 8-6) the EDZ scenario is the most cost-effective measure across all critical load indicators. Similar trends were found for the effectiveness of mitigation on reducing NH_3 CLe exceedance (Section 8.1). The costs of implementing the EDZ scenario are relatively small in comparison to the other mitigation scenarios, and displacing landspreading emissions and related local deposition brings sites that are close to their CL out of exceedance. It should be noted that the overall effectiveness at a UK level will be lower than in the UK country specific tables, due to the inclusion of cross-border sites and associated areas/excess N being included for each country they are situated in. The optimised emission scenarios achieved the highest decreases in the number of sites in exceedance of CLs and (as with CLe exceedance, Section 8.1) and in terms of effectiveness they are the second most cost-effective measures. Replacing the use of urea at no additional cost is likely to provide a significant contribution to effectiveness of the optimised scenarios.

For England (Table 8-7), the cost effectiveness of the optimised emission scenarios is greater than the overall figures presented in Table 8-6 for the UK, for reducing excess N and bringing sites out of exceedance. In Wales (Table 8-8), the optimised scenarios are more effective at reducing excess N than they are for England with a 5 % reduction in excess N per £5M. However, for both England and Wales, the additional areas brought out of exceedance (compared to NAPCP+DA NECR NOx) are very marginal under all the scenarios modelled (< 1.2 % reduction).

For Scotland (Table 8-9), the overall effectiveness of the optimised scenarios is higher than it is for the UK. The scenario optimised for CLe exceedance is the more cost effective than the scenario targeting CLs, as the lower emission reductions needed (and costs) achieve similar reductions in deposition. This is a clear illustration that the CL assessment is more complex than interpreting NH_3 critical levels as emission reductions in other DAs can provide reductions in wet deposition.

For Northern Ireland (Table 8-10), the number of sites being brought out of exceedance is very low. There are a few potential reasons for this: N deposition in Northern Ireland is relatively high compared with the rest of the UK, both at present (2017 baseline) and for the 2030 baseline scenarios. Therefore, bringing substantial numbers of sites below their CLs is likely to require more effort than is tested in the current emission scenarios, both country-wide and spatially targeted. While the number of sites coming out of exceedance is very low, it is worth noting the achievements in reducing excess N above CL across NI sites. The country-wide uptake rates tested in the N Futures 2030 NAPCP+DA scenario are considered to be a realistically achievable baseline with measures that can be readily implemented. There are, however, further opportunities to increase ambition, both country-wide and spatially. Ambitious agricultural emission reductions (relative to 2017 baseline) have been modelled under the Nitrogen Futures project, with 2040+ High Amb. inc. cattle achieving a 28 % reduction in (agricultural) emissions relative to 2017 baseline. This reduction is partly achieved through projected changes in livestock numbers (according to FAPRI data) and comparing the 2040+ High Amb. inc. cattle scenario to the 2030 NAPCP+DA baseline only achieves a 14 % reduction in (agricultural) emissions, i.e. compared with UK-wide achievement of the NECR target. It should be noted that a recent modelling exercise carried out specifically for Northern Ireland (unpublished report, Carnell *et al*. (2020), tested a more ambitious NI-wide mitigation scenario, including non-technical measures such as genetic improvement, longer grazing season. That scenario achieved a 25% reduction in NI agricultural NH_3 emissions relative to the 2017 baseline. A substantial proportion of N deposition to Northern Ireland originates from emissions within the Republic of Ireland which are not mitigated in the spatially targeted scenarios modelled here, but emission reductions based on 2030 NECD targets were incorporated in the baseline. Transboundary contributions from the RoI are most significant in the area closest to the border, in terms of elevated NH_3 concentrations and NH_x dry deposition, with atmospheric N being imported and exported across the border in both directions.

Table 8-6. Assessment of effectiveness and cost-effectiveness of UK-wide and spatially targeted mitigation scenarios for nutrient N critical loads exceedance at UK nitrogen sensitive SSSIs. All comparisons are made to NAPCP+DA (NECR NOx) for which:

- 3,889 (of 4,853) SSSIs were in exceedance
- 1,625,997 ha of SSSI were in exceedance
- 14,485 tonnes of excess N were deposited to SSSIs

Scenario	Difference in cost (£m)	Additional SSSIs protected	% additional SSSIs protected	% additional SSSIs protected / £5 m	Additional area protected (ha)	% additional area protected	% additional area protected / £5 m	Reduction in AE (tonnes N)	% reduction in Excess N	% reduction in Excess N / £5 m
2030 ERZ SAC 2km	18.1	14	0.4	0.1	3,364	0.2	0.1	217	1.5	0.4
2030 ERZ SSSI 1km	20.2	16	0.4	0.1	3,407	0.2	0.1	228	1.6	0.4
2030 ERZ SSSI 2km	41.5	27	0.7	0.1	5,572	0.3	0	354	2.4	0.3
2030 ERZ SSSI 5km	93.3	46	1.2	0.1	10,206	0.6	0	607	4.2	0.2
2030 High Amb. exc. cattle	123.3	66	1.7	0.1	13,766	0.8	0	741	5.1	0.2
2030 EDZ SSSI 1km	3.7	40	1.0	1.4	5,910	0.4	0.5	455	3.1	4.2
2040+ ERZ SSSI 2km inc. cattle	72.7	63	1.6	0.1	17,828	1.1	0.1	792	5.5	0.4
2040+ High Amb. inc. cattle	206.7	120	3.1	0.1	29,121	1.8	0	1345	9.3	0.2
2030 CLe opt. ERZ SSSI	94.3	202	5.2	0.3	23,878	1.5	0.1	1524	10.5	0.6
2030 CL opt. ERZ SSSI with EDZ	92.6	204	5.2	0.3	23,829	1.5	0.1	1519	10.5	0.6

Table 8-7. Assessment of effectiveness and cost-effectiveness of UK-wide and spatially targeted mitigation scenarios for nutrient N critical loads exceedance at nitrogen sensitive SSSIs in England, including border sites. All comparisons are made to NAPCP+DA (NECR NOx) for which:

- 2,482 (of 2,979) SSSIs were in exceedance
- 848,618 ha of SSSI were in exceedance
- 9,887 tonnes of excess N were deposited to SSSIs

Scenario	Difference in cost (£m)	Additional SSSIs protected	% additional SSSIs protected	% additional SSSIs protected / £5 m	Additional area protected (ha)	% additional area protected	% additional area protected / £5 m	Reduction in Excess N (tonnes N)	% reduction in Excess N	% reduction in Excess N / £5 m
2030 ERZ SAC 2km	11.0	8	0.3	0.1	798	0.1	0	149	1.5	0.7
2030 ERZ SSSI 1km	13.4	10	0.4	0.2	1,145	0.1	0.1	157	1.6	0.6
2030 ERZ SSSI 2km	27.7	20	0.8	0.1	1,703	0.2	0	243	2.5	0.4
2030 ERZ SSSI 5km	61.7	32	1.3	0.1	2,831	0.3	0	408	4.1	0.3
2030 High Amb. exc. cattle	78.1	46	1.9	0.1	3,264	0.4	0	486	4.9	0.3
2030 EDZ SSSI 1km	2.3	29	1.2	2.5	2,323	0.3	0.6	341	3.4	7.4
2040+ ERZ SSSI 2km inc. cattle	47.2	39	1.6	0.2	3,649	0.4	0	523	5.3	0.6
2040+ High Amb. inc. cattle	129.1	78	3.1	0.1	7,095	0.8	0	873	8.8	0.3
2030 CLe opt. ERZ SSSI	62.8	159	6.4	0.5	10,242	1.2	0.1	1158	11.7	0.9
2030 CL opt. ERZ SSSI with EDZ	60.6	159	6.4	0.5	9,896	1.2	0.1	1151	11.6	1.0

*Sites that border Wales and Scotland (and have areas outside England) are included here and areas situated outside England are also included in the totals.

Table 8-8. Assessment of effectiveness and cost-effectiveness of UK-wide and spatially targeted mitigation scenarios for nutrient N critical loads exceedance at nitrogen sensitive SSSIs in Wales, including border sites. All comparisons are made to NAPCP+DA (NECR NOx) for which:

- 686 (of 732) SSSIs were in exceedance
- 214,528 ha of SSSI were in exceedance
- 2,157 tonnes of excess N were deposited to SSSIs

Scenario	Difference in cost (£m)	Additional SSSIs protected	% additional SSSIs protected	% additional SSSIs protected / £5 m	Additional area protected (ha)	% additional area protected	% additional area protected / £5 m	Reduction in Excess N (tonnes N)	% reduction in Excess N	% reduction in Excess N / £5m
2030 ERZ SAC 2km	2.5	1	0.1	0.3	579	0.3	0.5	33	1.5	3.0
2030 ERZ SSSI 1km	1.8	1	0.1	0.4	280	0.1	0.4	30	1.4	3.9
2030 ERZ SSSI 2km	3.5	1	0.1	0.2	840	0.4	0.6	45	2.1	3.0
2030 ERZ SSSI 5km	6.1	2	0.3	0.2	1,336	0.6	0.5	73	3.4	2.8
2030 High Amb. exc. cattle	6.5	2	0.3	0.2	1,389	0.6	0.5	84	3.9	3.0
2030 EDZ SSSI 1km	0.4	5	0.7	9.6	1,006	0.5	6.2	57	2.6	34.4
2040+ ERZ SSSI 2km inc. cattle	9.4	2	0.3	0.2	1,464	0.7	0.4	111	5.1	2.7
2040+ High Amb. inc. cattle	17.4	7	1	0.3	2,100	1	0.3	171	7.9	2.3
2030 CLe opt. ERZ SSSI	6.9	12	1.7	1.3	2,528	1.2	0.9	153	7.1	5.1
2030 CL opt. ERZ SSSI with EDZ	7.0	12	1.7	1.3	2,528	1.2	0.8	153	7.1	5.1

*Sites that border England (and have areas within England) are included here and any areas situated in England are also included with the Welsh totals.

Table 8-9. Assessment of effectiveness and cost-effectiveness of UK-wide and spatially targeted mitigation scenarios for nutrient N critical loads exceedance at nitrogen sensitive SSSIs in Scotland, including border sites. All comparisons are made to NAPCP+DA (NECR NOx) for which:

- 600 (of 930) SSSIs were in exceedance
- 533,829 ha of SSSI were in exceedance
- 1,986 tonnes of excess N were deposited to SSSIs

Scenario	Difference in cost (£m)	Additional SSSIs protected	% additional SSSIs protected	% additional SSSIs protected / £5 m	Additional area protected (ha)	% additional area protected	% additional area protected / £5 m	Reduction in Excess N (tonnes N)	% reduction in Excess N	% reduction in Excess N / £5 m
2030 ERZ SAC 2km	0.9	5	0.8	4.5	1,924	0.4	2	29	1.5	8.0
2030 ERZ SSSI 1km	1.2	5	0.8	3.5	1,919	0.4	1.5	31	1.6	6.6
2030 ERZ SSSI 2km	2.7	6	1	1.9	2,954	0.6	1	48	2.4	4.5
2030 ERZ SSSI 5km	6.4	12	2	1.6	5,939	1.1	0.9	87	4.4	3.4
2030 High Amb. exc. cattle	8.8	17	2.8	1.6	8,958	1.7	0.9	111	5.6	3.2
2030 EDZ SSSI 1km	0.5	6	1	10.9	2,478	0.5	5	41	2.1	22.3
2040+ ERZ SSSI 2km inc. cattle	4.7	22	3.7	3.9	12,615	2.4	2.5	135	6.8	7.3
2040+ High Amb. inc. cattle	15.4	33	5.5	1.8	19,660	3.7	1.2	227	11.4	3.7
2030 CLe opt. ERZ SSSI	5.1	29	4.8	4.7	10,806	2	2	154	7.7	7.5
2030 CL opt. ERZ SSSI with EDZ	5.8	31	5.2	4.4	11,103	2.1	1.8	156	7.8	6.8

*Sites that border England (and have areas within England) are included here and any areas situated in England are also included with the Scottish totals.

Table 8-10. Assessment of effectiveness and cost-effectiveness of UK-wide and spatially targeted mitigation scenarios for nutrient N critical loads exceedance at nitrogen sensitive SSSIs in Northern Ireland. All comparisons are made to NAPCP+DA (NECR NOx) for which:

- 168 (of 240) SSSIs were in exceedance
- 722,944 ha of SSSI were in exceedance
- 870 tonnes of excess N were deposited to SSSIs

Scenario	Difference in cost (£m)	Additional SSSIs protected	% additional SSSIs protected	% additional SSSIs protected / £5 m	Additional area protected (ha)	% additional area protected	% additional area protected / £5 m	Reduction in Excess N (tonnes N)	% reduction in Excess N	% reduction in Excess N / £ 5m
2030 ERZ SAC 2km	3.6	0	0	0	63	0.1	0.1	14	1.6	2.2
2030 ERZ SSSI 1km	3.8	0	0	0	63	0.1	0.1	17	2	2.6
2030 ERZ SSSI 2km	7.6	0	0	0	75	0.1	0.1	29	3.4	2.2
2030 ERZ SSSI 5km	19.1	0	0	0	100	0.1	0.0	57	6.6	1.7
2030 High Amb. exc. cattle	29.8	1	0.6	0.1	156	0.2	0.0	81	9.3	1.6
2030 EDZ SSSI 1km	0.6	0	0	0	103	0.1	1.2	34	3.9	33.2
2040+ ERZ SSSI 2km inc. cattle	11.4	0	0	0	100	0.1	0.1	47	5.4	2.3
2040+ High Amb. inc. cattle	44.8	2	1.2	0.1	265	0.4	0.0	115	13.2	1.5
2030 CLe opt. ERZ SSSI	19.4	2	1.2	0.3	302	0.4	0.1	104	12	3.1
2030 CL opt. ERZ SSSI with EDZ	19.2	2	1.2	0.3	302	0.4	0.1	104	12	3.1

9 Comparing spatial targeting of SACs vs SSSIs

One question posed during the development of the scenarios was on the geographical distribution of designated sites and how this might influence the effectiveness of spatial targeting of mitigation. This was tested by applying the same set of measures to both SSSIs and SACs, with 2 km wide ERZ surrounding sites. As shown in Figure 2-1, nitrogen-sensitive SSSIs are more numerous (4,853, 1.87M ha) than nitrogen-sensitive SACs (538, 1.29M ha). The respective 2 km buffer zones take up 36 % and 19 % of the UK land area (Table 1-4). These two scenarios allow a direct comparison between site types, to assess whether effects may differ due to the geographical distribution of the two types of designated sites, differences in size, sensitivity of designated features, *etc*.

To compare the effectiveness of targeting each site type, both scenarios were assessed for the additional number of sites (DWI) and additional area (AWI-1, AWI-2) protected in terms of critical levels and critical loads exceedance, compared with the 2030 NAPCP+DA baseline. This follows the same approach as presented in Section 8 for effects of all mitigation scenarios regarding effects at SSSIs. In this section, however, a direct comparison is presented of effects of SAC measures on SACs and SSSI measures on SSSIs.

At the UK level, the overall cost of a 2 km ERZ for SAC sites is much lower than the same scenario around SSSIs. This is simply due to smaller areas being targeted (see Figure 2-1, Table 2-1) and therefore smaller overall emission decreases. Table 9-1 compares the emission reductions achieved for each UK country. The mitigation scenarios achieved larger percentage improvements in Excess N than in area exceeded, in particular with the EDZ scenario. Since Excess N is relatively responsive, it may provide a better basis for communicating benefits of decreases in air pollution. However, the critical load for nutrient-nitrogen is set to avoid harmful effects, and areas receiving deposition in excess of this critical load remain under threat.

Table 9-1 Comparison of UK agricultural ammonia emission totals (kt NH_3) and estimated costs of mitigation for emission 2km ERZ emission scenarios surrounding SAC and SSSI sites.

	Total agricultural emissions (kt NH_3)		Reduction in agricultural emissions compared to NAPCP+DA (kt NH_3)		Total Cost (£m)		Additional cost compared to NAPCP+DA (£ m)	
Country	SAC	SSSI	SAC	SSSI	SAC	SSSI	SAC	SSSI
England	118.0	116.4	1.0	2.6	120.8	137.5	11.0	27.7
Wales	17.0	16.9	0.3	0.4	16.4	17.3	2.5	3.5
Scotland	23.6	23.4	0.1	0.3	17.9	19.7	0.9	2.7
Northern Ireland	25.5	25.1	0.3	0.7	22.1	26.1	3.6	7.6
UK	**184.0**	**181.7**	**1.8**	**4.0**	**177.6**	**201.1**	**18.5**	**42.0**

Table 9-2 presents the effects of the two scenarios for the 1 µg NH_3 m^{-3} critical level exceedance. Bringing SACs out of exceedance of the 1 NH_3 µg m^{-3} CLe is more difficult to achieve than for SSSIs. There are a few possible explanations for this:

a) There are more SSSIs than SACs, and therefore more opportunities for sites to come out of exceedance; Neighbouring small SSSIs can provide additional buffer zones for each other, thereby creating larger areas with mitigation measures present than more isolated SACs; and/or
b) For a site to come out of exceedance (using the DWI), all areas of the site need to come out of exceedance. As a single SAC can often be composed of many smaller SSSIs, all of these sub-sites need to come out of exceedance for the overarching SAC to come out of exceedance. SACs typically span a much larger area than SSSIs, so a much larger area needs to come out of exceedance.

Comparing the areas within sites (i.e. AWI-2) that are brought out of exceedance (as opposed to total area, AWI-1) shows that progress with mitigation is being made beyond reductions made under NAPCP+DA (NECR NO_x), and that the overall costs of bringing these areas out of exceedance is lower for SACs than for SSSIs across all DAs.

Table 9-3 presents the effects of targeting each site type regarding the 3 μg NH_3 m^{-3} critical level. In terms of sites coming out of exceedance of the 3 μg NH_3 m^{-3} CLe, spatial targeting is similarly effective for SACs and SSSIs at the UK level. Most is achieved in Wales, with some success in England. There are no SACs in Scotland and Northern Ireland that are brought out of exceedance with the 2 km ERZ. For bringing areas within sites out of exceedance (AWI-2), targeting SACs appears to be more cost effective for most countries. The exception is Scotland, where only one SAC is expected to be in exceedance of the 3 μg NH_3 m^{-3} CLe. Spatially targeting SACs for 3 μg NH_3 m^{-3} CLe exceedance may be more effective than targeting SSSIs, for the following reasons:

a) The larger site area of many SACs acts as a natural buffer zone for the central parts of sites, thereby overall reducing average concentrations at sites further than for typically smaller SSSI sites.
b) Areas designated as SSSIs are less clustered than areas of SACs across the UK (see Figure 2-1), therefore SSSIs are less likely to co-benefit from emission reductions in zones surrounding nearby sites.
c) Most SACs – but not all - are underpinned by SSSIs, but not all SSSIs are also SACs, i.e. there are much larger areas of designated sites with only SSSI designation. In many cases, a SAC is made up of several underpinning SSSIs, with the two types of designations often not congruent.

Table 9-4 shows the effectiveness of the both scenarios at reducing exceedance of critical loads (CL) at the different site types. Unlike the assessment of CLe exceedance (Table 9-2, 9-3), which primarily reflect local/regional NH_3 emission reduction potential, CL exceedance at a site can be substantially affected by long-range and NO_x emission sources - as well as by local NH_3. No additional SAC sites are brought out of exceedance by implementing higher-ambition agricultural measures within a 2 km ERZ compared to the 2030 baseline (NAPCP+DA NECR NO_x). However, the model outputs show decreases in excess N and the area under exceedance (right-most columns in Table 9-4) – with % reduction in excess N consistently larger for SSSIs than SAC, across the UK and all individual countries. Both lower excess N and smaller areas exceeded can be achieved more cost-effectively for SACs across all UK countries than for SSSIs. The reasons for this are expected to be the same as those outlined above for CLe exceedance, with site size and distribution being major factors.

Table 9-2. Assessment of effectiveness and cost-effectiveness of a 2km ERZ surrounding SAC and SSSI sites, in terms of 1 μg m^{-3} NH_3 Critical Levels exceedance at each site type. The table compares scenario 2030 ERZ 2km SAC at SACs to 2030 ERZ 2km SSSIs scenario at SSSIs, with all comparisons made to NAPCP+DA (NECR NOx).

Country	Designation	Sites exceeded NAPCP+DA	AWI-1 Area exceeded NAPCP+DA (ha)	AWI-2 Area exceeded NAPCP+DA (ha)	Additional sites protected	% additional sites protected	% additional sites protected / £5 m	AWI-1 Additional area protected (ha)	AWI-1 % additional area protected	AWI-1 % additional area protected / £5 m	AWI-2 Additional area protected (ha)	AWI-2 % additional area protected	AWI-2 % additional area protected / £5 m
UK	SAC	312 (of 538)	1,750,450	245,127	1	0.3	0.1	100	0.0	0.0	9,684	4.0	1.1
UK	SSSI	3,461 (of 4,853)	1,175,449	480,060	34	1.0	0.1	4,269	0.4	0.0	16,147	3.4	0.4
England	SAC	185 (of 208)	995,617	189,638	0	0.0	0.0	-	0.0	0.0	7,079	3.7	1.7
England	SSSI	2,633 (of 2,979)	868,772	369,935	18	0.7	0.1	2,068	0.2	0.0	12,984	3.5	0.6
Wales	SAC	60 (of 86)	557,908	29,885	0	0.0	0.0	-	0.0	0.0	1,306	4.4	8.6
Wales	SSSI	457 (of 732)	157,575	25,616	7	1.5	2.2	419	0.3	0.4	1,517	5.9	8.5
Scotland	SAC	32 (of 204)	349,399	10,813	1	3.1	17	100	0.0	0.2	860	8.0	43.2
Scotland	SSSI	191 (of 930)	88,549	15,239	8	4.2	7.8	1,730	2.0	3.6	1,331	8.7	16.2
Northern Ireland	SAC	45 (of 50)	62,600	40,298	0	0.0	0.0	-	0.0	0.0	1,332	3.3	4.6
Northern Ireland	SSSI	205 (of 240)	98,989	81,178	1	0.5	0.3	52	0.1	0.0	1,059	1.3	0.9

Table 9-3. Assessment of effectiveness and cost-effectiveness of a 2km ERZ surrounding SAC and SSSI sites, in terms of 3 µg m^{-3} NH_3 Critical Levels exceedance at each site type. The table compares scenario 2030 ERZ 2km SAC at SACs to 2030 ERZ 2km SSSIs scenario at SSSIs, with all comparisons made to NAPCP+DA (NECR NOx).

Country	Designation	Sites exceeded NAPCP+DA	AW1 Area exceeded NAPCP+DA (ha)	AW2 Area exceeded NAPCP+DA (ha)	Additional sites protected	% additional sites protected	% additional sites protected / £5 m	AW1 Additional area protected (ha)	AW1 % additional area protected	AW1 % additional area protected / £5 m	AW2 Additional area protected (ha)	AW2 % additional area protected	AW2 % additional area protected / £5 m
UK	SAC	39 (of 538)	415,648	1,923	4	10.3	2.8	3,869	0.9	0.3	281.7	14.6	4.0
UK	SSSI	226 (of 4,853)	201,782	7,044	26	11.5	1.4	2,491	1.2	0.1	673.7	9.6	1.2
England	SAC	28 (of 208)	261,596	1,728	2	7.1	3.2	3,248	1.2	0.6	271.1	15.7	7.1
England	SSSI	173 (of 2,979)	145,802	5,858	21	12.1	2.2	1,643	1.1	0.2	589.8	10.1	1.8
Wales	SAC	9 (of 86)	225,974	312	2	22.2	43.6	622	0.3	0.5	64.5	20.7	40.6
Wales	SSSI	14 (of 732)	9,954	619	1	7.1	10.2	699	7.0	10.0	17.3	2.8	4.0
Scotland	SAC	1 (of 204)	43,687	9	0	0	0	-	-	-	-	-	-
Scotland	SSSI	7 (of 930)	23,369	192	1	14.3	26.5	106	0.5	0.8	20.4	10.6	19.7
Northern Ireland	SAC	6 (of 50)	6,324	159	0	0	0	-	-	-	7.4	4.7	6.5
Northern Ireland	SSSI	38 (of 240)	43,955	923	3	7.9	5.2	43	0.1	0.1	61.9	6.7	4.4

Table 9-4. Assessment of effectiveness and cost-effectiveness of a 2km ERZ surrounding SAC and SSSI sites, in terms of for nutrient N critical loads exceedance at each site type. The table compares scenario 2030 ERZ 2km SAC at SACs to 2030 ERZ 2km SSSIs scenario at SSSIs, with all comparisons made to NAPCP+DA (NECR NOx).

Country	Designation	Sites exceeded NAPCP+DA	Area exceeded NAPCP+DA (ha)	Excess N NAPCP+DA	Additional sites protected	% additional sites protected	% additional sites protected / £5 m	Additional area protected (ha)	% additional area protected	% additional area protected / £5 m	Reduction in Excess N (tonnes N)	% reduction in Excess N	% reduction in Excess N / £5 m
UK	SAC	466 (of 538)	1,476,293	10,941	0	0.0	0.0	2,724	0.2	0.1	194	1.8	0.5
UK	SSSI	3,889 (of 4,853)	1,625,997	14,485	27	0.7	0.1	5,572	0.3	0.0	354	2.4	0.3
England	SAC	191 (of 208)	657,131	7,205	0	0.0	0.0	1,004	0.2	0.1	130	1.8	0.8
England	SSSI	2,468 (of 2,979)	844,644	9,764	20	0.8	0.1	1,703	0.2	0.0	242	2.5	0.4
Wales	SAC	81 (of 86)	174,463	1,615	0	0.0	0.0	837	0.5	0.9	31	1.9	3.8
Wales	SSSI	659 (of 732)	211,986	2,105	1	0.2	0.2	840	0.4	0.6	44	2.1	3.0
Scotland	SAC	145 (of 204)	587,894	1,549	0	0.0	0.0	818	0.1	0.8	21	1.3	7.3
Scotland	SSSI	594 (of 930)	496,424	1,746	6	1.0	1.9	2,954	0.6	1.1	40	2.3	4.2
Northern Ireland	SAC	49 (of 50)	56,805	572	0	0.0	0.0	64	0.1	0.2	12	2.2	3.0
Northern Ireland	SSSI	168 (of 240)	72,944	870	0	0.0	0.0	75	0.1	0.1	29	3.4	2.2

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