UK Centre for Ecology & Hydrology

Ammonia Reduction by Trees (ART)

Priority targeting of treebelts for ammonia mitigation in the landscape

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Title	Ammonia Reduction by Trees (ART) : Priority targeting of treebelts for ammonia mitigation in the landscape
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1 Executive Summary

- Three datasets were combined to provide a combined scoring index of suitability for planting trees for ammonia mitigation. These were based on distance to a protective site, ammonia emissions at 1km and prevailing wind direction derived of 5 years of data from the Numerical Weather Prediction (NWP) model.
- Combined scoring of emissions and wind direction provide a suitable method for targeting sources around protected sites;
- A scoring index was devised from: 1 – ‘least suitable’ to 5 – ‘most suitable’ and ammonia sources within 5 km from protected sites were included in the final spatial map. are seen as an optimal distance for site impact;
- Single site assessment provides a quick way to define target areas for that site only while multi-site assessment in the landscape can start to pinpoint the optimal areas for tree planting;
- Planting treebelts at any emission source > 5 km from a site (or at an emission source that has a low combined score within a 5 km zone) should use the prevailing wind statistics to plant on the most frequent downwind side of a source.
- For any ammonia source and for non-designated semi-natural habitats, the prevailing wind direction dataset gives a guide to where to plant ‘downwind’ treebelts.
- The datasets produced by in this work package are available and have been integrated into the NH_3 calculator tree tool to give provide further guidance and knowledge around designing treebelts for ammonia mitigation.

2 Background

Atmospheric nitrogen (N) deposition represents a significant threat to sensitive habitats and species In the United Kingdom, with excessive N supply leading to declines in many important species of high conservation value, at the expense of fast growing species that can exploit the additional nitrogen supply (e.g. Dise et al. 2011, RoTAP 2012). Trees are very effective at capturing both gaseous and particulate pollutants from the atmosphere. But while studies have often focussed on PM and NOx in the urban environment, little research has been carried out on the tree effect of capturing gaseous ammonia (NH_3) in the rural landscape. In the UK, 59.1% (363) of SACs and 68.7% (4,696) of Sites of Special Scientific Interest (SSSIs) currently receive NH_3 concentrations above 1 µg m^{-3} anywhere across the site.

In this study we look at the potential of developing a framework to model targeted areas that are suitable for planting trees in order to recapture NH_3 emissions close to source (and typically on agricultural land) and lower N concentration and depositions received by Special Areas of Conservation (SACs) and SSSIs.

The most suitable locations for planting treebelts are:

- Areas upwind of a sensitive receptor (i.e. SAC/SSSI)
- Areas downwind of NH_3 emission hotspots
- Close to large NH_3 emission hotspots

The relative location of an emission source to prevailing wind sectors substantially impacts the amount of NH_3 received by a site. Therefore, to assess suitable areas for tree planting trees it is important to understand whether emission sources are typically upwind/downwind of the receptor which requires protection.

This study also assesses NH_3 hotspots that do not impact a protected site but can potentially still be used to mitigate NH_3 emissions to the atmosphere by planting trees. There has been interest from livestock farmers to use treebelts for capturing NH_3 from their housing and reduce the overall atmospheric nitrogen footprint.

3 Methodology

Three key datasets were used for the building the targeting as set out in Table 1. The wind dataset contains UK atmospheric high resolution data (2 x 2 km grid resolution) from the UK Met Office operational NWP (Numerical Weather Prediction) Unified Model (UM). This dataset was used to extract hourly data wind statistics for the UK of wind speed and wind direction. High resolution (1 x 1 km grid resolution) UK agricultural ammonia emission maps (Figure 1) were used to identify likely emission hotspots surrounding SAC/SSSI site boundaries. NH_3 disperses and dilutes rapidly downwind of sources and therefore emission sources >5 km from SACs and SSSIs were not considered to be suitable for tree planting for this purpose. Although emissions are likely to vary substantially at a sub-grid resolution, for this national analysis we assume that each 1 x 1 km grid estimate is representative of the sources within each cell and associated suitability for tree planting.

Table 1: Database table of inputs

Dataset Name	**Downloaded from:**	**Licence**
Wind data from NWP-UKV dataset (2016 to 2020) with 2 km resolution in the CEDA catalogue	Extracted from Jasmin super cluster. Available here	Licence available here
SAC and SSSI designated sites shapefiles	Downloaded from countries datasets and merged	Open access
UK agricultural ammonia emissions for the year 2018 at 1 km resolution	https://naei.beis.gov.uk/	

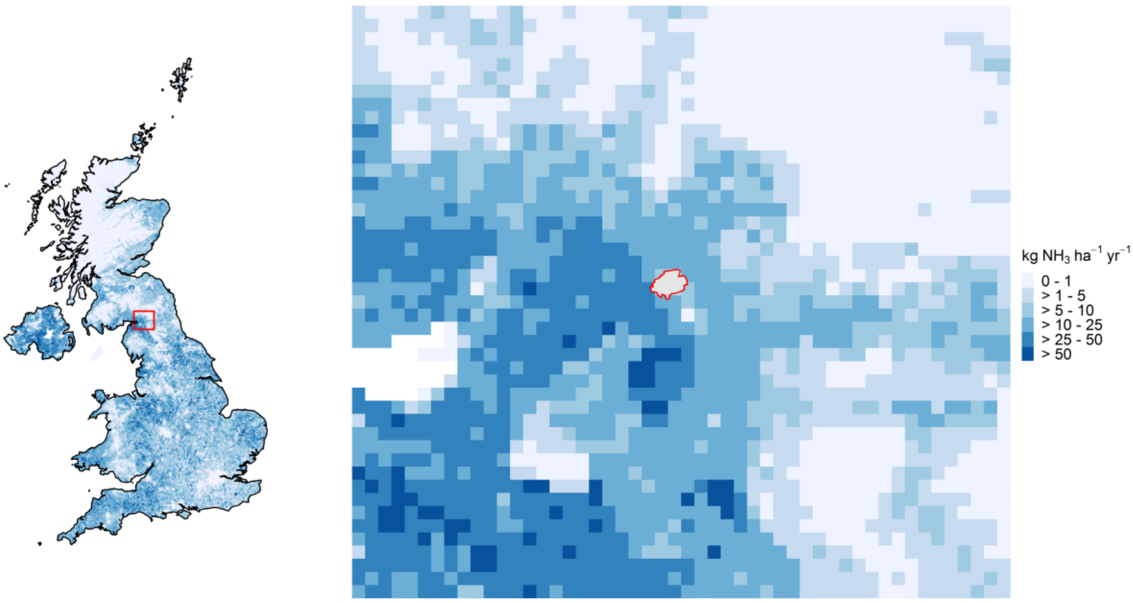

Figure 1: 2018 UK agricultural NH_3 emissions and zoomed in to study region

The probability of an emission source T (represented by a 1 x 1 km grid-square) being upwind of a designated site was estimated by calculating the direction each grid-square to (the nearest point) of each designated site. This relationship was then compared to hourly wind data to determine how often an emission source is upwind of a designated site. Hourly wind data for the period 2016 – 2020 was downloaded from CEDA at a 2 x 2 km grid resolution and was disaggregated to a nominal grid-resolution of 1 x 1 km for comparison to NH_3 emission estimates. A full flow diagram of the processes is set out in Figure 2 and follow 4 main phases:

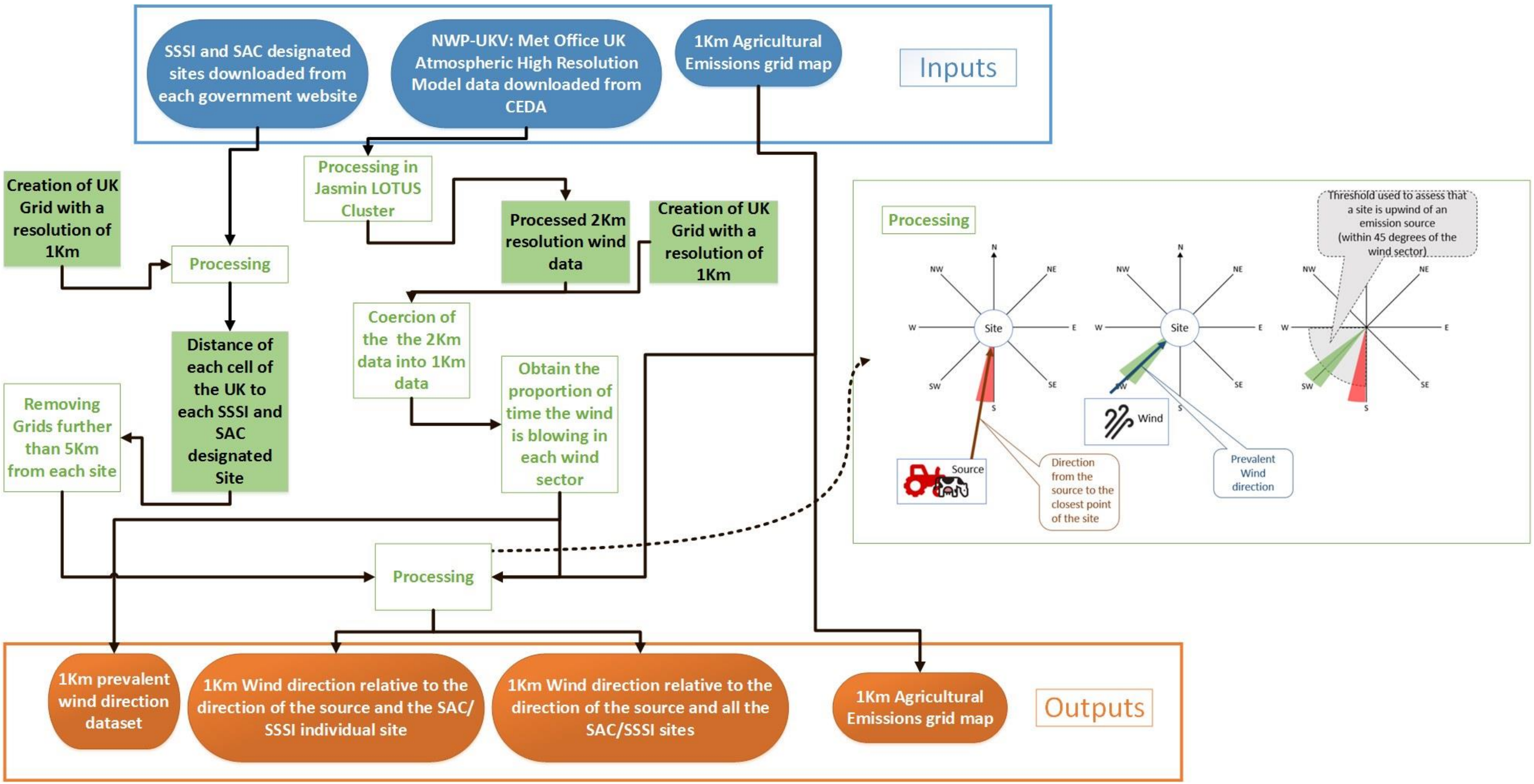

Figure 2: Inputs and Outputs for applying targeted approaches.

Phase1: Input Datasets

High resolution (1 x 1 km grid resolution) UK agricultural NH_3 emission maps (https://naei.beis.gov.uk/) were used to identify likely emission hotspots surrounding SAC/SSSI site boundaries. NH_3 disperses rapidly and emission sources >5 km from SACs and SSSIs were not considered to be suitable for tree planting as they would not affect NH_3 concentrations on site. This is shown with an example of Bolton Fen Moss and local SACs (Figure 2), each grid pixel is shaded with proximity distance to the site. Although it is known that emissions are likely to vary substantially at a sub-grid resolution, for this national mapping analysis we assume that each 1 x 1 km grid estimate is representative of the sources within each cell and associated suitability for tree planting.

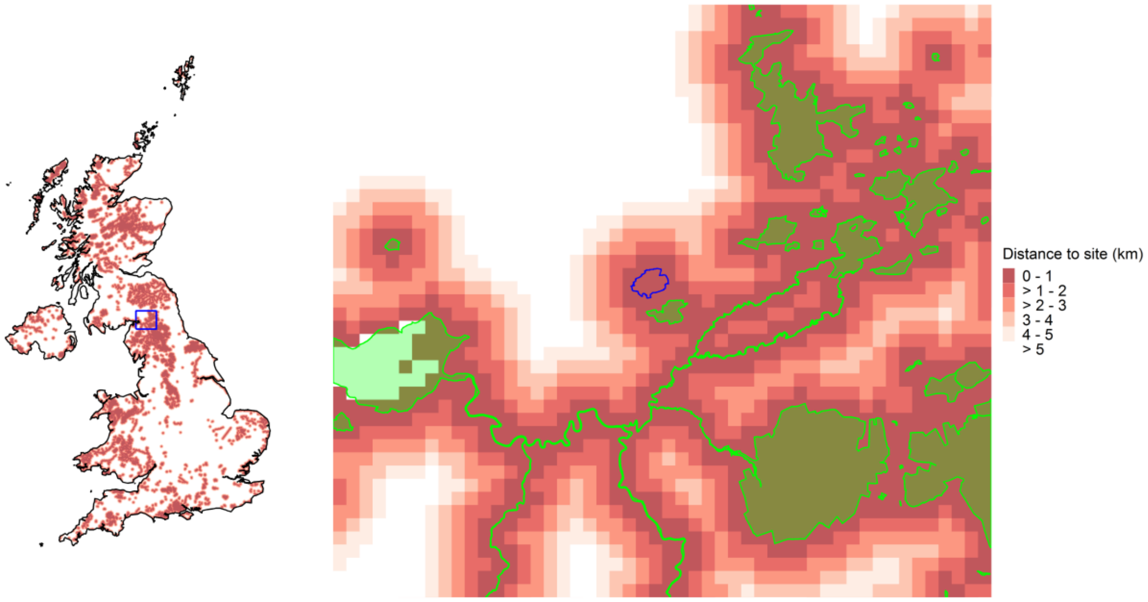

Figure 3: Distance criteria of 5 km radius was applied to protected sites and Bolton Fen Moss (blue) and surrounding SACs (green) zoomed up close.

Phase 2: Calculation of relative wind to emissions

To estimate the probability of an emission source (represented by a 1 x 1 km grid-square) being upwind of a designated site, we calculated the direction each grid-square was from (the nearest point) of each designated site. This relationship was then compared to hourly wind data to determine how often an emission source is upwind of a designated site. Hourly wind data for the period 2016 – 2020 was downloaded from CEDA at a 2 x 2 km grid resolution and was disaggregated to a nominal grid-resolution of 1 x 1 km for comparison to NH_3 emission estimates.

Over the 5 year period of 2016 - 2020, the relative wind direction of each 1 x 1 km grid cell (potential emission source) was compared to the direction of each sensitive receptor (in turn). A grid-square was considered to be upwind of a site if it was within 45 degrees of the average wind condition for that hour.

Phase 3: Scores of emission strength and source location relative to wind direction

NH_3 emissions and relative wind direction were then categorised into scores of 1 – 5, and a combined score calculated (assuming equal weighting). For each 1 x 1 km grid cell, a score was assigned based on estimated agricultural emission estimate and also based on the location of each cell relative to wind direction. These criteria used to assign scores is shown in Table 2.

Table 2: Combined Indicator scores based on emissions and relative location of source and wind statistics.

Score	Agricultural NH_3 emission criteria (kg NH_3 ha^{-1} $year^{-1}$)	Relative location of source criteria (% of time upwind/within 45 degrees of wind)
1	≤ 5	≤ 20
2	> 5 – 10	> 20 - 40
3	> 10 – 25	> 40 - 60
4	> 25 – 50	> 60 - 80
5	> 50	> 80

The output results are shown both for UK-scale maps and with maps zoomed into to a particular protected site, for example Bolton Fen Moss SAC (highlighted yellow in Figure 4).

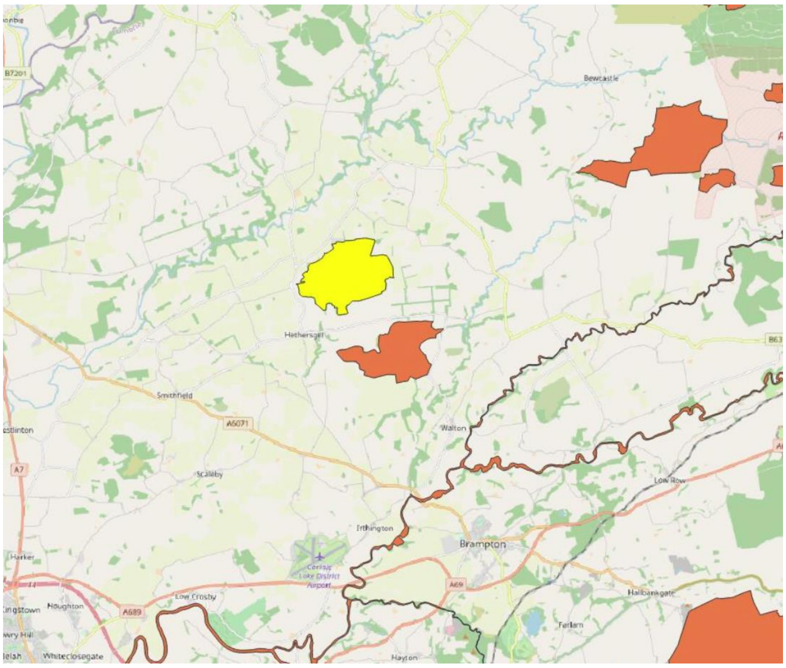

Figure 4: Bolton Fen Moss SAC (in yellow) *© OpenStreetMap contributors*

4 Results

Wind statistics for the UK were averaged using the 2016-2020 meteorological dataset (Table 1, Figure 5). Figure 5 (LHS) which shows the predominant wind directions across the whole of the UK and Figure (RHS) Cumbria area (red square) which includes Bolton Fens Moss SAC (shown with red outline). It can be seen that the prevailing wind is predominantly from the south west but there are local variations, as would be expected in an area with significant amounts of complex terrain.

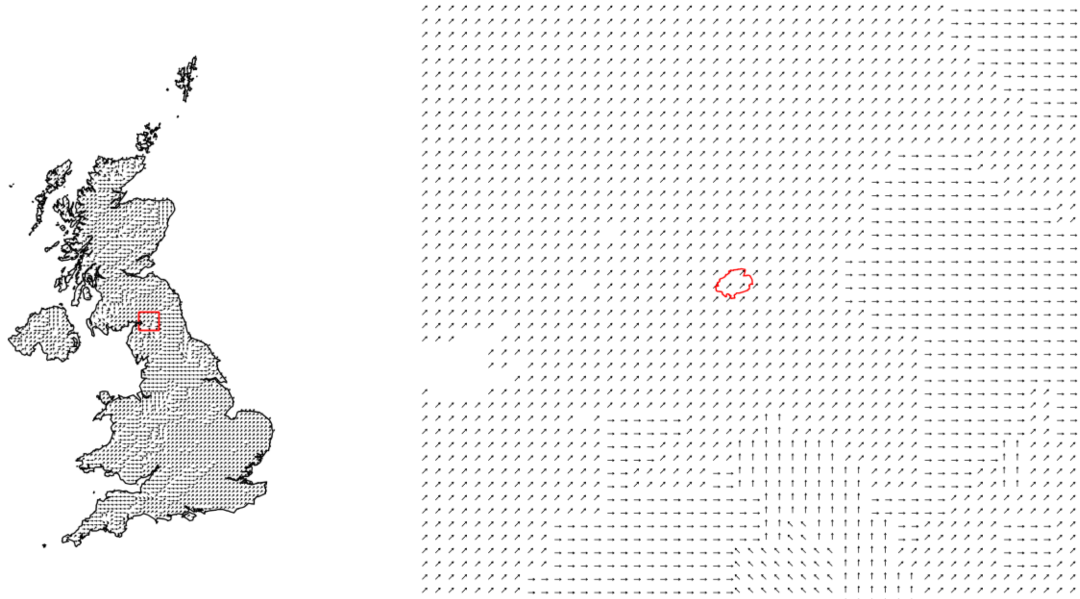

Figure 5: Prevailing wind direction across the UK and inset of study area. Data is available for every 2 x 2 km grid but is shown for the UK on a 10 km grid and at 2 x 2 km for the Bolton Fells Moss study area (in red right hand image).

The number of hours an emission source site was upwind (within 45 degrees) was summarised on an annual basis and is illustrated for Bolton Fens Moss SAC in Figure 6. Cells on the SW of the site are most likely to be upwind of the site, which corresponds to the prevailing wind direction shown by arrows. In areas where multiple SACs/SSSIs are within 5 km of potential emission sources, the highest probability of a site being upwind of any SACs can also be considered as shown in Figure 7, for the same region surrounding Bolton Fens Moss SAC. Figure 7 shows the annual proportion of time that potential emission sources are upwind (with 45 degrees of the prevailing wind) of all SACs surrounding Bolton Fens Moss SAC.

In Phase 3 which is the calculation of scores, the scores were combined for individual sites. Again Bolton Fens Moss SAC is used as an example (Figure 8), where it can be seen that one of the cells adjacent to the SAC scores highest. This is also the case when all SACs as used to calculate the maximum score (Figure 9) however the pattern of scores is different. The equivalent combined scores for all SACs in the UK are presented in Figure 10. On a national level that the wind scores broadly reflect prevailing wind conditions in the UK with areas south west of designated sites being more suitable for tree planting than other areas surrounding sites.

Figure 6 shows the wind arrows around Bolton Fen Moss and the coloured areas showing the percentage of time over the year the protected site is upwind of a grid square. The darker squares indicate the best areas to plant treebelts. When more sites are included in the routine, Figure 7, the situation becomes quite complex as nearby sites have overlapping influences but the rule still applies.

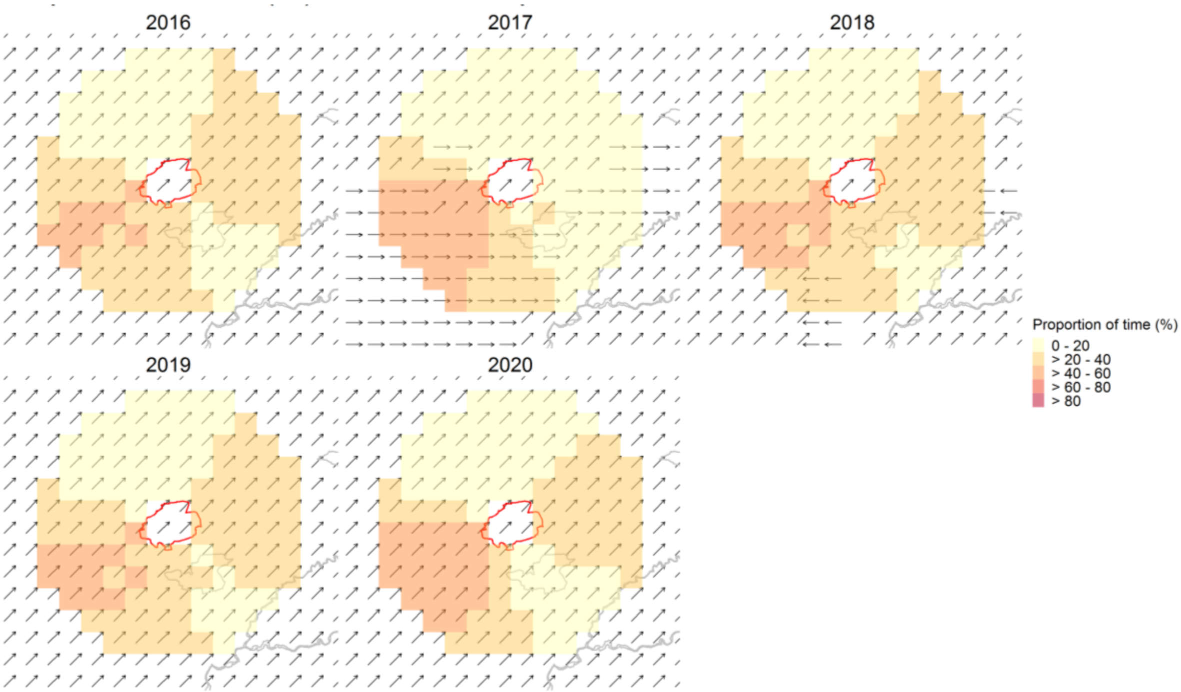

Figure 6: Annual proportion of time, using meteorological years 2016 to 2020, that potential emission sources are upwind (with 45 degrees of the prevailing wind) of Bolton Fens Moss SAC.

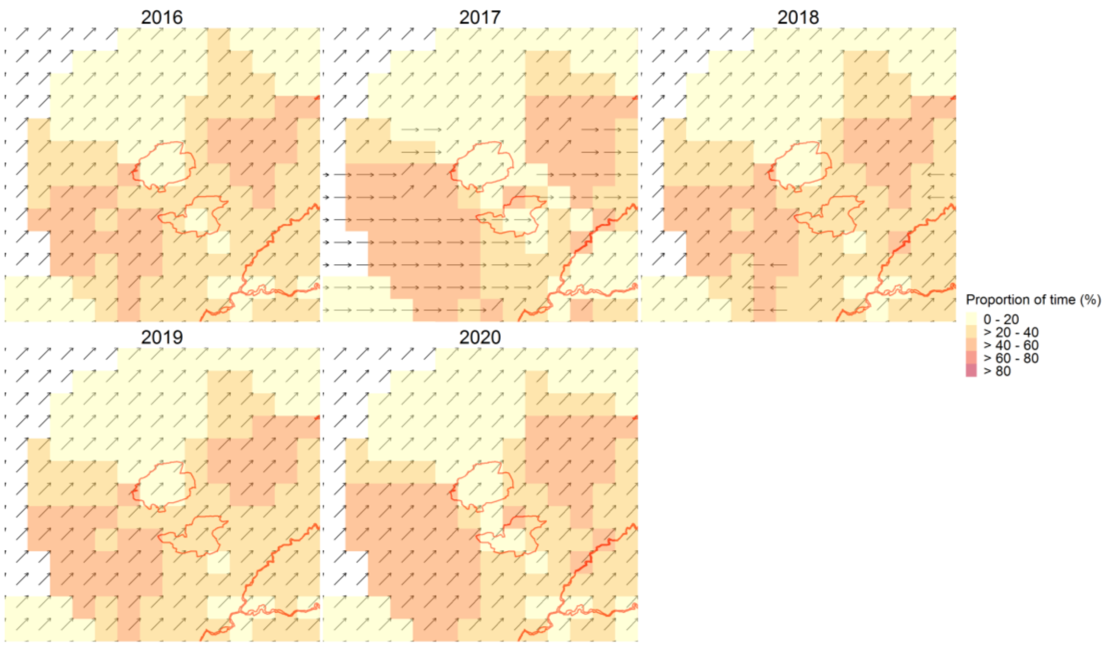

Figure 7: Annual proportion of time that potential emission sources are upwind (with 45 degrees of the prevailing wind) of all SACs surrounding Bolton Fens Moss SAC.

When scores of emissions and wind direction are combined in Figure 8 the influence of emission strength is evident as areas to the south score highly. Figure 9 includes all protected sites and clearly shows a matrix of areas that are suitable for targeted tree planting. It should be noted that protected sites close to large sources, but not in the prevailing wind sector, could still be buffered by treebelts as the wind may still come from a suitable wind sector. Determination of the outputs from e.g. Figure 9 would provide these important decisions.Figure 7

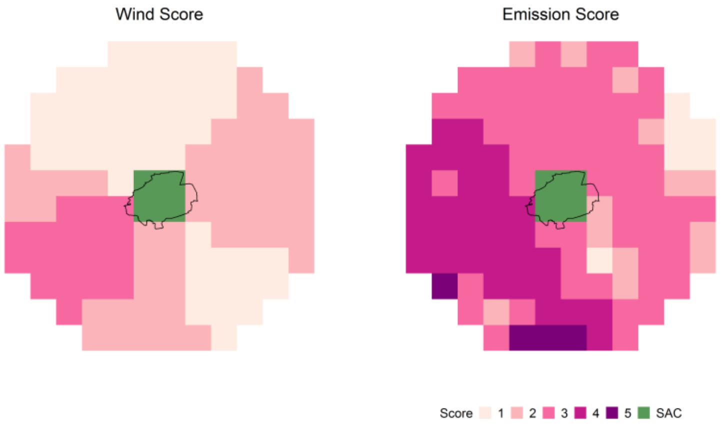

Figure 8: Upwind source scoring for Bolton Fens Moss SAC; LHS: Wind score associated with time that potential emission sources are upwind (with 45 degrees of the prevailing wind); Middle: annual emission estimates score; and RHS combined score. Green area indicates the protected site.

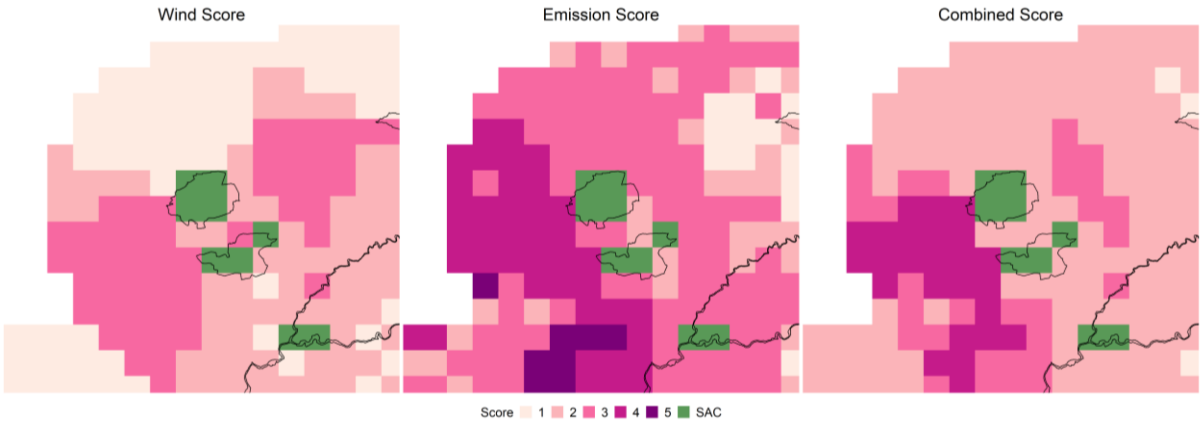

Figure 9: Upwind source scoring for SAC sites surrounding Bolton Fens Moss SAC; LHS: Score associated with time that potential emission sources are upwind (with 45 degrees of the prevailing wind) of all; Middle: annual emission estimates and RHS: combined score.

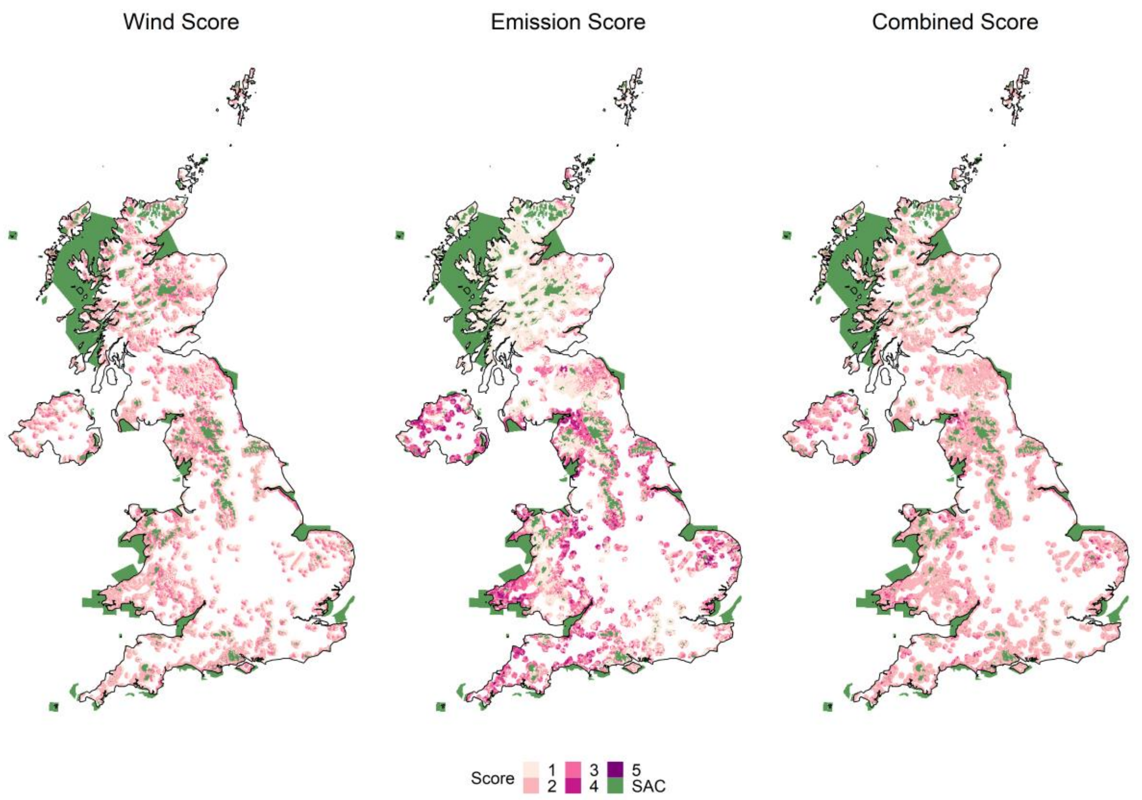

Figure 10: Combined scores for all SACs across the UK based on Wind and Emissions scoring. The higher the number the more suitable to plant trees

5 Discussion

This work package within the Ammonia Reduction by Trees project has collated and analysed the background datasets, and provided combined indicators for planting treebelts based on datasets of NH_3 emissions, prevailing wind direction and distance from a protected site. It is important for policy makers and landscape planners to understand the best location for planting shelterbelts and for what purpose. Trees have the ability to not only capture and retain pollutant emission like ammonia but also have an added ability to disperse a pollutant plume from a nearby source. For a national policy of reducing emissions planting downwind of every source would have a positive effect – field studies and modelling in Work Package 2 made advances in quantifying this although further work is required to capture the full picture of the short and long term nitrogen cycling within a treebelt near ammonia sources. Alternatively, planting treebelts downwind of a source to reduce concentrations and deposition at protected sites is also a beneficial strategy for reducing critical load and level exceedance.

From the analyses undertaken, NH_3 emission strength is a key driver for assessing where tree planting options should be targeted to prevent nitrogen impacts on sensitive habitats on both the national and landscape scales. However, prevailing wind direction is the critical factor as tree planting should be carried out downwind of emission sources such as livestock housing. Distance to the nearest protected site was considered as a suitable criteria as ammonia emissions will deposit onto nearby sites. However, sources with high emissions can have a similar effect on a site at greater distances so a balance of distance and strength were assessed and a 5 km buffer zone around sites was set.

Weightings of each criteria (emissions and prevailing wind) in this exercise were scored the same (1-5), but future users could use different weightings and refine the approach. For example, for a national approach to reduce emissions may put a higher scoring on emission strength while to reduce local impacts to nearby protected habitats may put more emphasis on distance to a protected site.

Figure 10 shows that the prevailing wind direction in the UK are westerlies or south westerlies. Although variation does exit in some areas of the UK and in the study area of Cumbria with some northerlies and north westerlies. In these case, protected sites to the north east of a source would be suitable sites to protect with treebelts. Therefore, prevailing wind direction is a key dataset for land managers to use as a general 'rule of thumb' where to plant their treebelt, and with the ability to plot a wind rose for every 2 km grid square in the UK this dataset could be used as an underlying resource for guiding land managers on locating and establishing the most effect treebelt.

6 Conclusions

- Prevailing wind direction and emission strength are the two key criteria for targeting suitable areas for tree planting;
- Including sources within 5 km from protected sites are seen as an optimal distance for site impact;
- Single site assessment provides a quick way to define target areas for that site only while multi-site assessment in the landscape can start to pinpoint the optimal areas for tree planting;
- Combined scoring of emissions and wind direction provide a suitable method for targeting sources around protected sites;
- Planting treebelts at any emission source > 5 km from a site (or at an emission source that has a low combined score within a 5 km zone) should use the prevailing wind statistics to plant on the most frequent downwind side of a source.
- For any ammonia source and for non-designated semi-natural habitats, the prevailing wind direction dataset gives a guide to where to plant 'downwind' treebelts.

7 Future Developments

The datasets produced by in this work package are available integrated into the NH_3 calculator tree tool to give provide further guidance and knowledge around designing treebelts for ammonia mitigation. Protected site boundaries can be added within a mapped interface to show the correlation of a source in the landscape with sensitive habitats. The combined score dataset and the prevailing wind dataset can provide the data to guide the orientation of any treebelt to a source (or a site) based on spatial inputs from the user.

8 Dataset delivery

The following dataset outputs from this work package are:

- Prevailing wind for the UK (2 x 2 km Ordnance Survey National Grid)
- Relative wind direction to sites (as % of time a site is within 45 degrees of an SAC/SSSI) - this will be available per site and an aggregated version showing the max value per cell for all sites (2 x 2 km Ordnance Survey National Grid)
- Combined score of cells within 5 km of sites, with high scores indicating high NH_3 emissions and likelihood of being upwind (2 x 2 km Ordnance Survey National Grid).

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