

Modelling and mapping UK emissions of  
ammonia, methane and nitrous oxide  
from agriculture, nature, waste disposal and  
other miscellaneous sources for 2013

Tomlinson S.J, Carnell E.J., Tang Y.S., Sutton M.A. and Dragosits U.

*Centre for Ecology & Hydrology (Edinburgh Research Station)  
Bush Estate, Penicuik, Midlothian, EH26 0QB, UK.*

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Main authors: Tomlinson S.J, Carnell E.J, Tang Y.S., Sutton M.A. and Dragosits U.	
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## EXECUTIVE SUMMARY

### Modelling and mapping UK ammonia emissions from agriculture, nature, waste disposal and other miscellaneous sources for 2013

1. Ammonia emission estimates for 2013 were spatially distributed for agriculture (SNAP Codes 10.1, 10.2 and 10.5), natural sources (SNAP Codes 11.3, 11.7), waste disposal (SNAP Code 9.4), sewage works and sewage sludge spreading (SNAP Code 9.10), solvents (SNAP Code 6.4) and other miscellaneous sources for the UK.
2. Emissions from non-agricultural sources such as waste disposal, sewage, solvents, pets, composting, anaerobic digestion, biomass burning, wild animals and seabirds as well as humans were spatially distributed through a combination of population census data, landcover data, data on waste disposal and recycling facilities, mammal distribution data from the Biological Records Centre (BRC), seabird census data and subsequent population trend updates (Seabird2000 survey and JNCC 2014), locations of composting plants, golf courses, public parks & gardens, etc.
3. Overall, non-agricultural NH<sub>3</sub> emissions from sources estimated by CEH under the current contract (covered by SNAP codes 6, 9, 10, 11) amount to 51.1 kt NH<sub>3</sub> year<sup>-1</sup> for 2013, with an uncertainty range of 24.1-99.8 kt NH<sub>3</sub> year<sup>-1</sup>. (N.B. This includes all equines, i.e. those on agricultural holdings and those present elsewhere). This constitutes a decrease of 1.2 kt NH<sub>3</sub> yr<sup>-1</sup>, compared with the estimate for 2012 (52.3 kt NH<sub>3</sub> yr<sup>-1</sup>).
4. The main changes in the non-agricultural emission sources covered in this report between 2012 and 2013 are decreased emissions from anaerobic digestion (mainly fugitive emissions), sewage spreading and seabirds, and increases in emissions from pet dogs. . The largest change is a reduction of emissions from anaerobic digestion (fugitive emissions), down 1.7 kt NH<sub>3</sub>, due to the calculation methodology now taking account of policy requirements that 100% of sites must cover inputs and outputs (previously 50% was used) and the removal of some input materials from the calculations that were found to be vegetable washing water (not used in the digestion process).
5. The estimate of NH<sub>3</sub> emissions from UK agriculture decreased by 1.9 kt NH<sub>3</sub> between 2012 and 2013, from 235.0 to 233.1 kt NH<sub>3</sub> yr<sup>-1</sup>. This includes decreases in fertiliser emissions by 3.2 kt NH<sub>3</sub>. The change is mainly due to a small decrease in total N fertiliser use and in the proportion of fertiliser applied as urea.
6. Emission source strength data for non-agricultural NH<sub>3</sub> sources matching the final inventory version as submitted to Defra by Ricardo-AEA were used throughout this report.
7. Emission source strength data for CH<sub>4</sub> and N<sub>2</sub>O were used as reported to Defra under the NAEI/GHGI project for 2013 for all agricultural and non-agricultural sources, and all maps correspond to the totals reported.

8. Agricultural NH<sub>3</sub>, CH<sub>4</sub> and N<sub>2</sub>O maps (livestock manures, enteric fermentation, soils, fertilisers) were submitted to the NAEI/GHGI under Defra contract AC0112 (Carnell *et al.* 2015), but are included in this report for completeness. These maps were derived from output of the CEH/University of Edinburgh AENEID model, which incorporates agricultural census data, landcover data, agricultural practice information (e.g., fertiliser application rates, stocking densities) and emission source strength data. The latter are closely coordinated with the UK agricultural emissions inventories for NH<sub>3</sub>, CH<sub>4</sub> and N<sub>2</sub>O in 2013 calculated annually at North Wyke Research (Misselbrook *et al.* 2014, Cardenas *et al.* 2014).

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# 1. INTRODUCTION

## 1.1. Background NH<sub>3</sub>

Emissions of ammonia for 2013 were spatially distributed using the AENEID model (Dragosits *et al.* 1998, Hellsten *et al.* 2008) and mapped for the UK for SNAP codes 6 (use of solvents), 9 (waste disposal, excluding incineration), and 11 (other sources and sinks, including natural sources) under this contract. This report briefly describes the methodology used for the sources listed above, including any changes in the methodology and the consequences of these changes.

The spatial distribution of emissions from agriculture is not part of the current contract between CEH and Ricardo-AEA, but is being carried out under Defra Project SCF0102 in collaboration with Rothamsted Research North Wyke. As part of SCF0102, the final emission maps for ammonia (NH<sub>3</sub>) from agricultural sources (livestock, fertilisers) are submitted for inclusion in the National Atmospheric Emissions Inventory (NAEI) annually (Carnell *et al.* 2015). A short summary on the methods and results for the agricultural sources is included in this report.

The spatially distributed NH<sub>3</sub> emissions for non-agricultural sources are coordinated with the best estimates produced by CEH and Ricardo-AEA and submitted to Defra (by Ricardo-AEA) under this project in late 2014 (see Table 1). Emission source strength data for non-agricultural NH<sub>3</sub> sources matching the final inventory version as submitted to Defra by Ricardo-AEA were used throughout this report. The agricultural emission estimates from fertilisers and livestock are coordinated with results from Defra project SCF0102 (NH<sub>3</sub> inventory by Misselbrook *et al.* (2014); see also Table 1).

The current contract exploits the expertise of CEH in spatially distributing emissions from agricultural sources, nature and other miscellaneous sources (e.g., Sutton *et al.* 2000), and complements the expertise of Ricardo-AEA on combustion, industry and transport sources.

**Table 1:** UK ammonia emissions (SNAP Codes 6, 9, 10, 11) as collated by Ricardo-AEA from Rothamsted Research North Wyke (Misselbrook *et al.*, 2014) and CEH data for 2013 (Tomlinson *et al.*, 2014), submitted to Defra.

Source	SNAP Code	Best estimate (kt NH <sub>3</sub> )
Appliances & household products (solvents)	6.4	1.2
Landfill	9.4	1.64
Sewage works and sewage spreading	9.10	5.4
Composting	9.10	5.9
Anaerobic digestion	9.10	3.9
Agricultural fertilizers	10.1	34.5
Livestock manures (including all horses)	10.5	198.6
Biomass burning	11.3	0.4
Pets	11.7.2	8.1
Nature (wild mammals, seabirds, pheasants)	11.7.3	7.4
Human breath & sweat, babies' nappies and smoking	0	1.2
Public parks, gardens and golf courses	0	0.4

## 1.2. Background CH<sub>4</sub> and N<sub>2</sub>O

Emissions of methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) for 2013 were spatially distributed using the greenhouse gas version of the AENEID model (Dragosits *et al.* 1998, Sutton *et al.* 2004 and 2006) and mapped for the UK for SNAP Codes 9 (waste disposal, excluding incineration), 10 (agriculture) and 11 (other sources and sinks, including natural sources).

As for NH<sub>3</sub>, emissions from agricultural CH<sub>4</sub> and N<sub>2</sub>O sources were modelled under Defra Project SCF0102 in collaboration with Rothamsted Research, North Wyke (i.e., not as part of the current project with Ricardo-AEA), but were submitted to Ricardo-AEA for inclusion in the Greenhouse Gas Inventory (GHGI) and are therefore discussed briefly here. This report describes the methodology used for the sources listed above, presents the results and discusses uncertainties.

Non-agricultural emission estimates are coordinated with the values submitted to Defra under this project for 2013 (see Table 2). The agricultural emission estimates (enteric fermentation, livestock manures and soils) are coordinated with detailed results from the CH<sub>4</sub> and N<sub>2</sub>O inventories calculated by Rothamsted Research, North Wyke (Cardenas *et al.* 2014; see Table 2), derived following IPCC methodology.

**Table 2:** CH<sub>4</sub> and N<sub>2</sub>O emission sources as reported to Defra, for 2013.

Source	kt CH <sub>4</sub>	kt N <sub>2</sub> O
Waste disposal to land (landfill)	659.9	-
Sewage sludge decomposition	18.8	3.5
Agriculture-soils (including sewage sludge applied to agricultural land)	-	64.8*
Agriculture-livestock manures	136.8*	6.1
Agriculture-enteric fermentation	923.5*	-
Peat & wetlands	126.3	-

\*Estimate differs from Cardenas *et al.* 2014, due to the omission of non-agricultural horses, which have been mapped/distributed separately

## 1.3. Summary of work schedule/deliverables

- Task 1: To model, map and submit spatially distributed emissions of NH<sub>3</sub>, CH<sub>4</sub> and N<sub>2</sub>O from selected non-agricultural sources at a 1/5 km grid resolution and SNAP level 2, and to convert results for Northern Ireland to the Ordnance Survey GB grid.
- Task 2: To provide a description of the methodology, highlighting changes and their consequences.
- Spatially distributed emissions from agricultural sources of NH<sub>3</sub>, CH<sub>4</sub> and N<sub>2</sub>O are produced outside of this contract (by Defra project SCF0102), but are submitted to Ricardo-AEA for inclusion into the NAEI/GHGI.

## 2. METHODS

### 2.1. Spatial distribution of emissions from agricultural sources - SNAP Code 10

Agricultural census/survey data for 2013 were acquired at the finest available spatial resolution from the devolved authorities in the UK and aggregated to a common set of categories, to ensure compatibility between the different countries' systems.

The agricultural emission inventory for NH<sub>3</sub>, was mapped using output from the NARSES model at Rothamsted Research, North Wyke (Misselbrook *et al.* 2014, Defra project SCF0102). As in previous years, detailed emission source strength estimates were derived for the main livestock emission components (housing, manure storage, landspreading of manures, grazing) for each NARSES category. Average fertiliser N application rates to different crops were taken from the British Survey of Fertiliser Practice for 2013 (BSFP 2014). For mapping the CH<sub>4</sub> and N<sub>2</sub>O inventory (Cardenas *et al.* 2014, Defra project SCF0102), the greenhouse gas version of AENEID was used, which builds on the same input datasets but takes account of the spatial location of CH<sub>4</sub> and N<sub>2</sub>O sources.

These detailed data were applied in the AENEID model, and livestock and fertiliser emissions were distributed to different land cover types (e.g. arable land, improved grass, part-improved grass, rough grazing, etc.) derived from the CEH landcover map, using LCM2007.

The resulting spatially distributed emission estimates were then aggregated as follows:

- NH<sub>3</sub>: emissions from **livestock manures** and **fertilisers**,
- CH<sub>4</sub>: emissions from **enteric fermentation** and **livestock manures**
- N<sub>2</sub>O: emissions from **livestock manures** and **soils**

All output data were re-checked for consistency with the NARSES inventory and then aggregated to the categories listed in Tables 1 and 2 (above). It should be noted that N<sub>2</sub>O emissions from the application of livestock manures are included in the “soils” category, rather than with livestock manure emissions, as is usual for NH<sub>3</sub>.

## **2.2. Spatial distribution of emissions from non-agricultural sources (SNAP Codes 6, 9 and 11)**

### **2.2.1. EMISSIONS OF NH<sub>3</sub> FROM HOUSEHOLD PRODUCTS (SOLVENTS) – SNAP CODE 6.4**

The most suitable spatial distribution for these sources is to scale by population (UK Population Census 2001, adjusted to account for mid-2013 population estimates, considering that emissions occur from normal household activities such as cleaning with products containing ammonia, hair perming, levelling floors using latex screed, refrigerants, etc.

### **2.2.2. EMISSIONS OF NH<sub>3</sub> AND CH<sub>4</sub> FROM LANDFILL – SNAP CODE 9.4**

For the spatial distribution of ammonia emissions from landfill sites in Scotland, locations and size of landfill sites were available from the Scottish Environmental Protection Agency for 2013 (SEPA 2014). For Northern Ireland, no locations of landfill sites were available, thus emissions were mapped using population density data, but excluding areas with a population density greater than 1000 people per square kilometre, as an approximation. For England and Wales, data from the Environment Agency (EA) website (<http://www.environment-agency.gov.uk>) were used. Emissions of CH<sub>4</sub> were calculated by scaling the 2013 NH<sub>3</sub> emission map to the CH<sub>4</sub> emission total reported by Ricardo-AEA for 2013.

### **2.2.3. EMISSIONS OF NH<sub>3</sub>, CH<sub>4</sub> AND N<sub>2</sub>O FROM SEWAGE – SNAP CODE 9.10**

For the spatial distribution of emissions from **sewage works**, locations and population served by sewage treatment works for England and Wales were made available from the Lowflows2000 database (Williams *et al.* 2009). The database was collected during 2005/06 and covers a population of 31.4 M, equivalent to 55.1% of the current 57 M residents in England and Wales in 2013. A large proportion of the remaining population is assumed to be using septic tanks instead of being connected to sewage treatment works. Currently, there are no estimates of NH<sub>3</sub> emissions from septic tanks, which is an area needing further investigation in the future. For Scotland and Northern Ireland, emissions from sewage works were spatially distributed by population, excluding densely populated inner-city areas and areas with very low population density.

**Landspreading of sewage sludge** has increased since the ban on dumping of sewage sludge in the sea in 1999. Only treated sewage is permitted to be spread, and is used on grass, forage crops (excluding crops grown for human consumption such as vegetables), for land reclamation and nutrient supply in areas of afforestation. However, only a small part of the agricultural area of the UK receives sewage sludge at present. It is not possible to spatially-distribute emissions from the landspreading of sewage sludge to exactly where they occur, due to the lack of data. Thus, as an approximation, emissions were distributed over all grassland, arable land and areas of coniferous woodland, using a combination of agricultural census and landcover data. Emissions of CH<sub>4</sub> and N<sub>2</sub>O from landspreading of sewage sludge were spatially distributed by scaling with NH<sub>3</sub> emissions.

#### 2.2.4. EMISSIONS OF NH<sub>3</sub> FROM COMPOSTING – SNAP CODE 9.10.

The latest available comprehensive survey of organics recycling facilities in the UK was carried out by WRAP for 2012 (Horne *et al.* 2013), and data from a large number of composting sites in the UK, including amounts and types of materials composted, processes used, etc are available on their website for 2013, for compost producers under different certification schemes. The WRAP survey data was updated with the latest municipal waste figures for composted materials for 2013 for all of the UK. Postcodes for all sites were converted to OS grid coordinates for the 2013 inventory, and the UK total of 5.8 kt NH<sub>3</sub> for 2013 was distributed among the sites, depending on amounts and types of materials processed and processes used. Furthermore, household composting, totalling 0.1 kt NH<sub>3</sub> for 2013, was spatially distributed for the first time in 2013 by population (except for densely populated urban areas) and added to the main composting emissions for a total of 5.9 kt NH<sub>3</sub> for 2013.

#### 2.2.5. EMISSIONS OF NH<sub>3</sub> FROM ANAEROBIC DIGESTION (AD) – SNAP CODE 9.10.

This source was identified for the first time for the 2010 inventory of non-agricultural ammonia sources (Dragosits *et al.* 2012). Locations and capacities for 142 plants were identified in a comprehensive search (Tomlinson *et al.* 2014) – an increase of 28 plants from 2012 - and these were used to map emissions from storage and processing at AD plants (1.1 kt NH<sub>3</sub>) across the UK. Emissions from landspreading of AD sludge (2.8 kt NH<sub>3</sub>) were distributed across agricultural land in areas close to AD sites. This approach was taken in consultation with John Williams (ADAS) and Tom Misselbrook (Rothamsted Research), who are currently working on a WRAP project on AD. Due to the relatively low value of AD digestate, it is in most cases not transported further than 20-30 km from AD sites, for reasons of limited economic viability and practicality. This is the case even in areas with substantial availability of locally produced livestock manures. The areas where landspreading of AD sludge is likely to occur were adapted to the capacity of local AD plants, with materials from smaller plants assumed to be spread closer to the plants than for larger plants.

#### 2.2.6. EMISSIONS OF NH<sub>3</sub> FROM DOMESTIC ANIMALS AND NATURE – SNAP CODE 11.7

Separate emission maps were produced for non-agricultural horses and pets (cats & dogs) and nature (wild mammals, seabirds and game birds).

Emissions from **non-agricultural horses** (i.e., horses that are not already counted with the annual agricultural census) were distributed using a combination of landcover data (LCM2000) and population census data. Emissions from **pets (cats and dogs)** were scaled by population, assuming an even distribution of pets over the UK population, except for densely populated urban areas, where it was assumed that fewer pets were present per human population. It should be noted that populations of wild or semi-wild horses and ponies in areas such as Dartmoor, Exmoor or the New Forest are not mapped specifically, and that the methodology used is a statistical approximation from secondary proxy data (human populations and landcover) at a UK scale.

Emissions from **wild animals** (deer, seals, rabbits and hares, foxes, badgers and feral cats) were distributed for Great Britain using 10 km presence/absence maps from the Biological

Records Centre (BRC) based at CEH Wallingford, landcover data (LCM2000) and data for Scottish populations of wild deer (Hunt 2003).

Emissions from **game birds** (broadened from the category pheasants to include the UK population of red-legged partridge) were included in the “nature” category. The spatial distribution was derived from a combination of landcover data (feeding of pheasants occurring in woodlands) and a county map of numbers of pheasants shot, provided by the Game Conservancy Trust.

Emissions from **seabirds** were spatially distributed according to the approach of Wilson *et al.* (2004a, 2004b). There was no change to these data, compared with the 2007-2009 inventories, so the 2007 map was carried forward unchanged.

Emissions from **wild geese** were distributed over suitable landcover categories from the CEH Landcover Map (LCM2000), representing suitable geese habitats, such as “fen, marsh, swamp”, some grassland categories etc.

Emissions from the sources described above were aggregated to a) non-agricultural horses and pets and b) natural sources for inclusion in the NAEI.

#### 2.2.7. EMISSIONS OF NH<sub>3</sub> FROM BIOMASS BURNING (MUIRBURN) – SNAP CODE 11.3

Emissions from biomass burning were revised completely for the 2007 inventory, focusing on controlled burning of patches of heather (“muirburn”), a practice used in upland areas to encourage heather growth. In the UK, approximately 3,000 km<sup>2</sup> of heather are estimated to be managed by controlled burning on a rotational basis (“muirburn”). The practice of muirburn involves controlled burning of heather in the uplands, approx. every 10-15 years, in patches, to encourage fresh growth on grouse moors and for sheep grazing. For 2010, estimates of muirburn emissions were revised with newly available data (Dragosits *et al.*, 2012). Emissions of NH<sub>3</sub> from muirburn were spatially distributed over suitable landcover categories from the CEH Landcover Map (LCM 2000), i.e., dwarf shrub heaths. It is anticipated that these maps will be revised with LCM2007 in the next inventory year. As the spatial distribution of these emissions is not based on actual year-to-year spatial data of exact locations where muirburn occurred, but on the statistical likelihood of present moorland potentially being burned.

#### 2.2.8. EMISSIONS OF CH<sub>4</sub> FROM PEAT AND WETLANDS – SNAP CODE 11.4

The most suitable simple spatial distribution for this source is to scale by the distribution of relevant landcover categories according to the CEH landcover map (LCM2000), and to assume an equal distribution of emissions per unit area of peatland and wetland. Emissions from this source were aggregated to a 5 km grid resolution for inclusion in the GHGI, and checked against the total derived using calculations derived from Hargreaves and Fowler (1998).

#### 2.2.9. EMISSIONS OF NH<sub>3</sub> FROM PUBLIC PARKS, GARDENS AND GOLFCOURSES – SNAP CODE 0.0

Emissions from nitrogen fertilisers applied to public parks, gardens and golf courses were included in the NAEI for the first time in 2008 (Dragosits *et al.* 2010). Revised emission factors and updated fertiliser application practices from Tomlinson *et al.* (2014) were applied to 2012 information regarding the location of parks, gardens and golf courses. Data from Kearns and Prior (2013), on the average size for golf course components (e.g. greens, roughs etc) and related N fertiliser application rates, were used.

#### 2.2.10. EMISSIONS OF NH<sub>3</sub> FROM OTHER SOURCES (HUMANS) – SNAP CODE 0.0

Emissions from humans (breath and sweat, cigarette smoking, babies’ nappies) were scaled by population, assuming an equal distribution of these sources within the UK population. Emissions from these sources are provided at a 1 km grid resolution for inclusion in the NAEI.

### 3. RESULTS –EMISSION MAPS OF NH<sub>3</sub>, CH<sub>4</sub> AND N<sub>2</sub>O FOR 2013

#### 3.1. Spatial resolution of the inventory maps

An additional task under this project during the inventory year 2009 was to investigate the possibility to improve the spatial resolution from a 5 km by 5 km grid resolution to a 1 km by 1 km grid resolution, where feasible. There were several issues to consider, with the three main constraints being:

- resolution of input data used for spatial distribution of emissions
- data licensing and permissions/disclosivity of underlying data sources
- uncertainty due to methodology of spatial distribution and input data quality

This approach has been followed again for the 2013 inventory submission. For sources where detailed spatial data are freely available and no major uncertainties need to be considered, emissions were mapped at a 1 km grid resolution for 2013.

Emission sources that are mapped by scaling with the 1 km population census map, such as human breath, sweat, pets, or household products, were mapped at a 1 km grid resolution, as there are no restrictions on use of the data or concerns about significant uncertainties associated with the spatially distributed emissions. Domestic composting, a new sub-source that was spatially distributed in 2013 for the first time, was mapped by the 1 km population census map modified for densely built-up areas.

The combined dataset from the sources under the heading “Nature” (wild mammals, seabirds, etc) is provided at a nominal 1 km resolution, with the different contributing components combined at their respective best possible spatial resolution. Some datasets are provided at a coarse resolution, e.g., mammal distributions from the Biological Record Centre, where a 10 km by 10 km grid is the best available resolution. By contrast, for other sources mapped with auxiliary landcover data, an improved resolution of the NH<sub>3</sub> emission map to a 1 km grid resolution was feasible.

Other sources, such as biomass burning (muirburn), or land spreading of sewage sludge, are mapped by using landcover data as a proxy, with muirburn practice (a very small source of emissions in the UK context) being evenly distributed over suitable landcover types. However, this is not representative of real year-on-year burning events, as individual patches are, on average, only managed by controlled burning periodically, every 10-20 years. Land spreading of sewage sludge is limited to certain types of land cover/land use (see Section 2.2.3 above), but as there are no UK-wide data on precise locations, the emissions had to be apportioned over all potentially suitable land. The resulting maps provide the best possible distribution, without expending substantial additional effort that would be disproportionate to the amount of NH<sub>3</sub> emitted from these sources. Due to the uncertainty associated with the maps, any increase in spatial resolution would provide a merely cosmetic improvement, without any scientific justification. Instead, it could potentially be counter productive, as users of the data may take the spatial resolution at face value.

Emissions from landfill and composting are currently distributed using incomplete sets of spatially located sources. For instance, detailed landfill site locations with amounts of materials land-filled per site are available routinely from SEPA, with data for the other parts of the UK of different quality/completeness and age. At present, the spatial distribution is considered too uncertain to increase the spatial resolution beyond the current 5 km by 5 km grid, as this may create unrealistic hot spots. However, the aim is to improve data access and subsequently to decrease the uncertainty in this map.

Emissions from processing and storage of materials at anaerobic digestion (AD) plants were mapped at a 1 km grid resolution, due to the availability of accessible data for the majority of AD sites allowing mapping at this resolution with relatively high confidence. Similarly,

information on emission sources from landspreading of AD sludge to agricultural land was deemed to be sufficiently well documented to provide the data at a 1 km grid resolution.

In conclusion, there were no scientific or data permission obstacles for emissions from humans, solvents, parks & golf courses, anaerobic digestion and nature to be provided at a true 1 km grid resolution (depending on resolution of available input data for individual sub-sources). For other datasets, such as landfill emissions ( $\text{CH}_4$  and  $\text{NH}_3$ ), work is underway to improve the underlying datasets. Once this is completed satisfactorily, it should be possible to provide these maps at a 1 km grid resolution. For sources such as biomass burning or land spreading of sewage sludge, the spatial location of sources is very difficult to derive, even indirectly by using proxy datasets, and for these an increase in resolution is not recommended, due to the inherent uncertainty.

The datasets of agricultural emissions of  $\text{NH}_3$ ,  $\text{CH}_4$  and  $\text{N}_2\text{O}$  are modelled independently under a separate project (Defra SCF0102), but are submitted for inclusion in the NAEI & GHGI here. These data are reliant upon access to detailed disclosive agricultural census/survey data from the devolved authorities of the UK, with strict rules agreed for the level of detail of any output under the Data Protection Act. For this reason, the current 5 km by 5 km grid resolution is the best resolution possible for the foreseeable future.

### 3.2. Ammonia emission maps for 2013

All datasets were produced at a 1 km grid resolution for 2013 (in the same way as for 2012). It should be noted that this is a nominal 1 km resolution for some sources, as detailed in Section 3.1 above. The following maps are shown below (units: kg NH<sub>3</sub> ha<sup>-1</sup> year<sup>-1</sup>):

- Figure 1. livestock manures – SNAP Code 10.5
- Figure 2. agricultural and non-agricultural fertilisers – SNAP Code 10.1
- Figure 3. biomass burning – SNAP Code 11.3
- Figure 4. household products (solvents) – SNAP Code 6.4
- Figure 5. landfill – SNAP Code 9.4
- Figure 6. sewage works and landspreading of sewage sludge – SNAP Code 9.10
- Figure 7. composting – SNAP Code 9.10
- Figure 8. anaerobic digestion – SNAP Code 9.10
- Figure 9. human breath and sweat, smoking and babies' nappies – SNAP Code 0.0
- Figure 10. nature (wild mammals, seabirds, pheasants) – SNAP Code 11.7
- Figure 11. non-agricultural horses and pets (cats, dogs)
- Figure 12. parks, gardens and golf courses

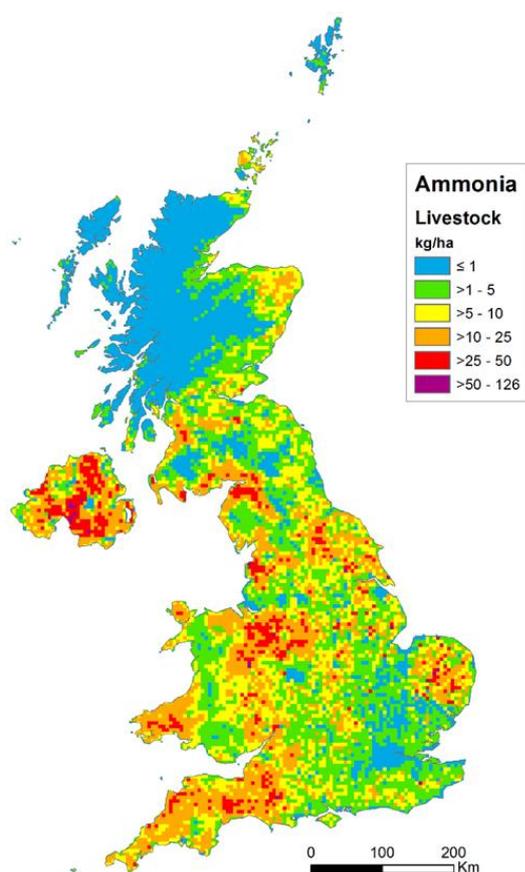


Figure 1. Ammonia emissions from livestock manure

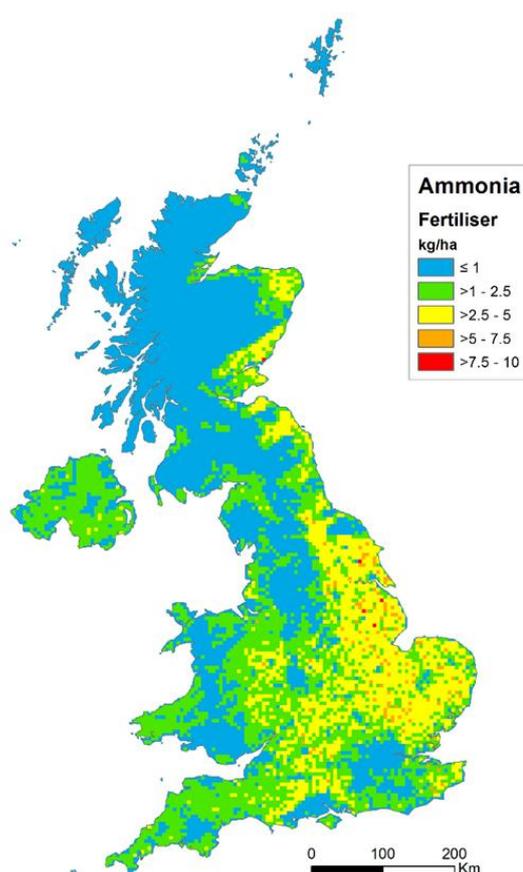


Figure 2. Ammonia emissions from fertilisers

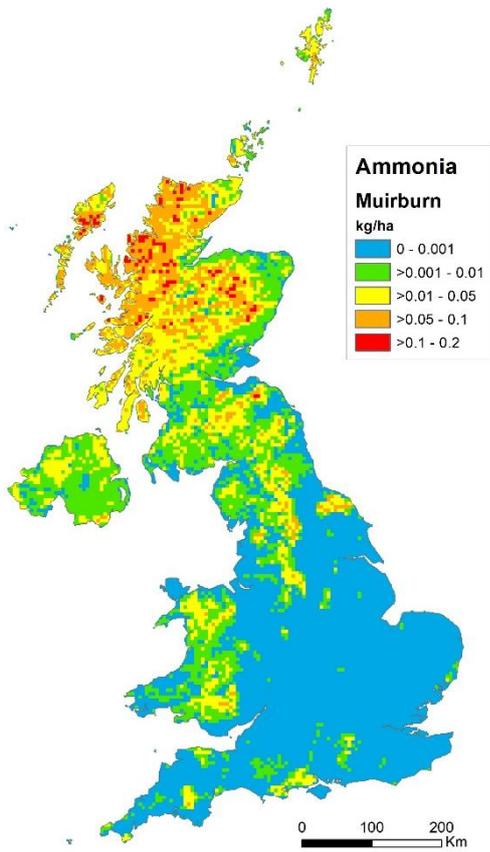


Figure 3. Ammonia emissions from biomass burning

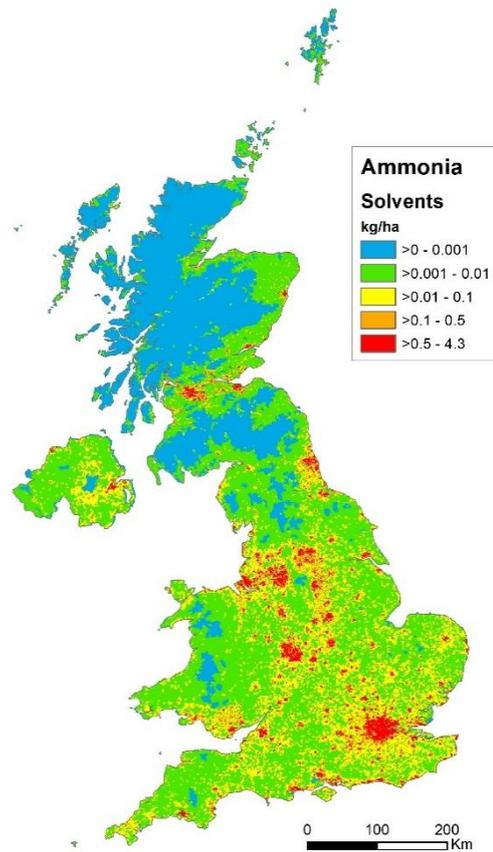


Figure 4. Ammonia emissions from solvents

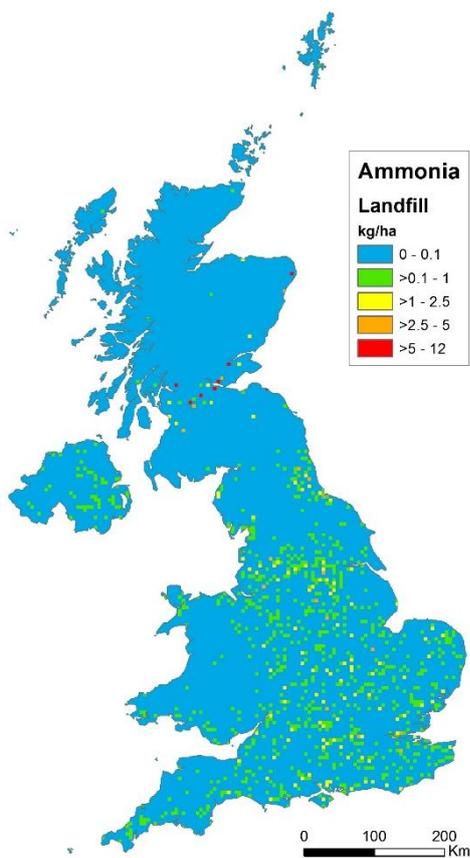


Figure 5. Ammonia emissions from landfill

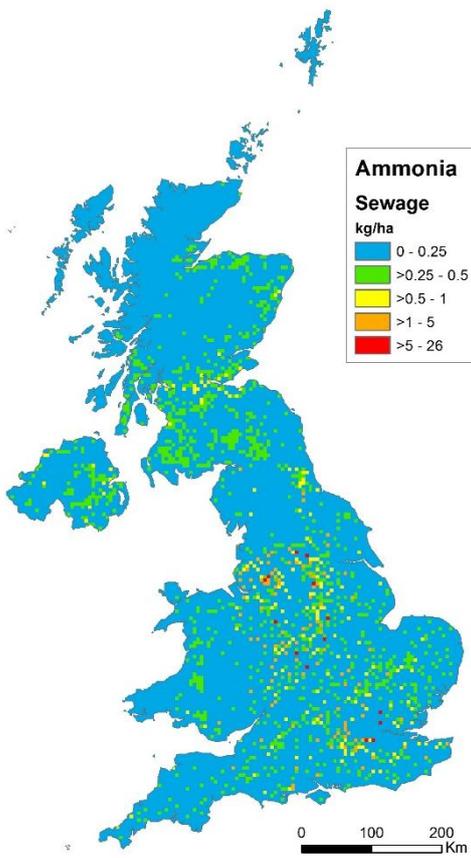


Figure 6. Ammonia emissions from sewage

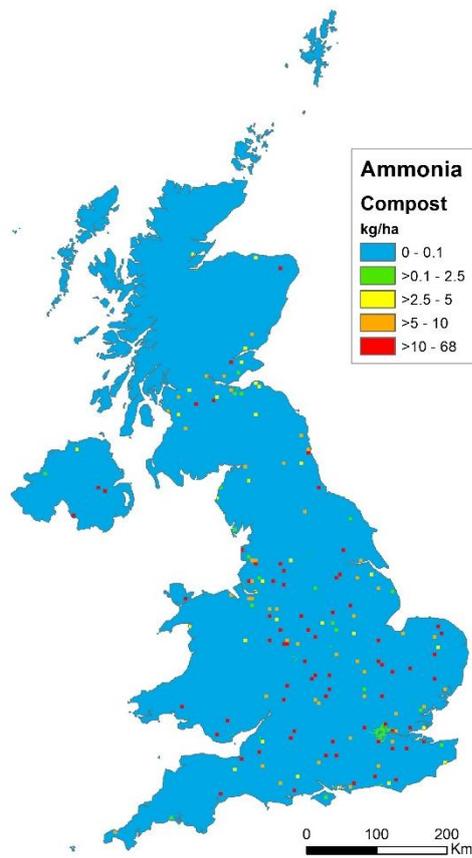


Figure 7. Ammonia emissions composting

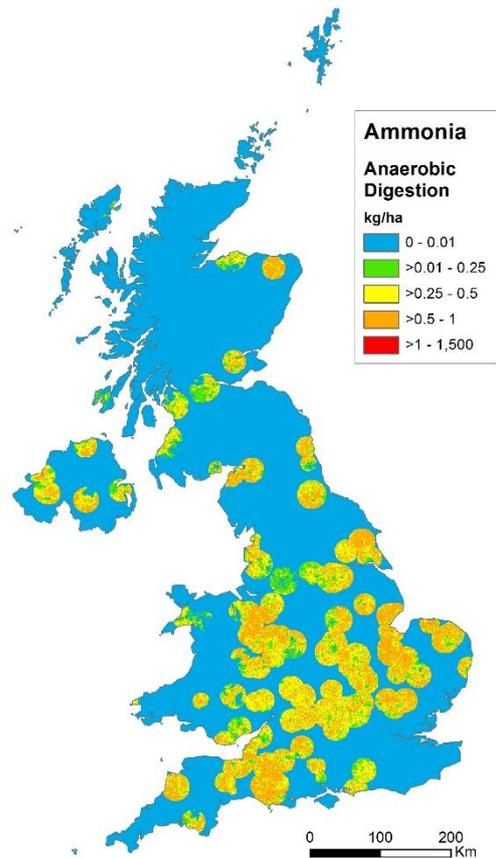


Figure 8. Ammonia emissions anaerobic digestion

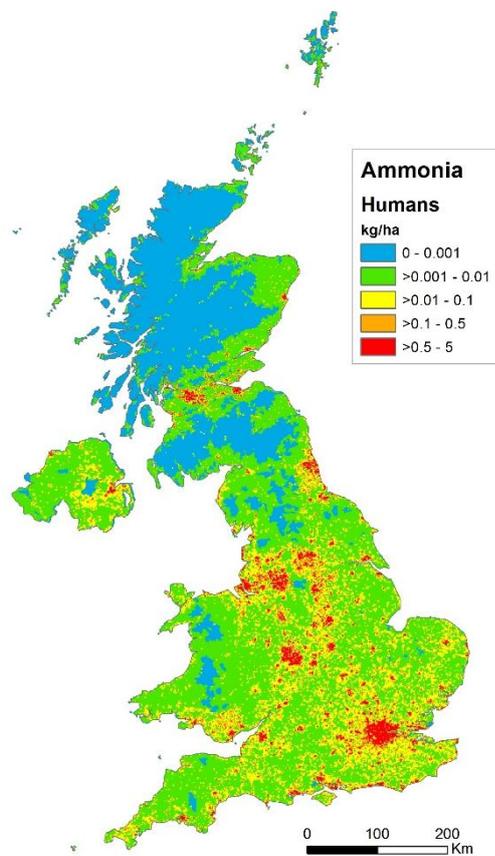


Figure 9. Ammonia emissions from humans

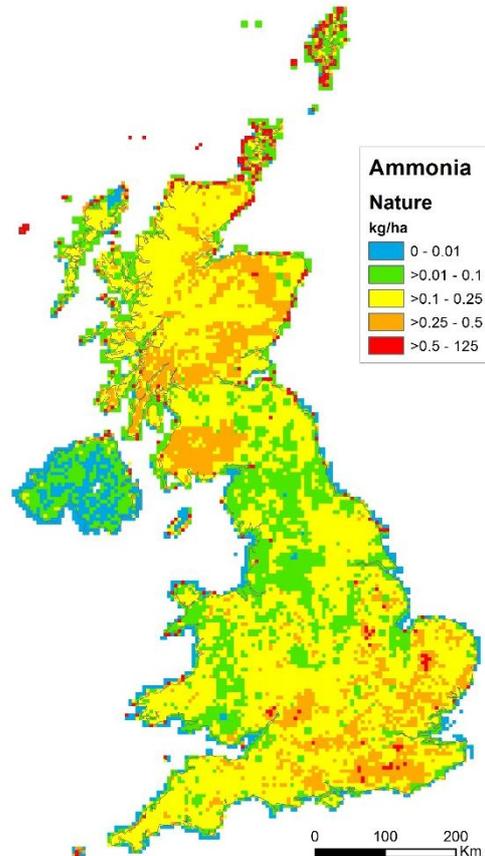


Figure 10. Ammonia emissions from nature

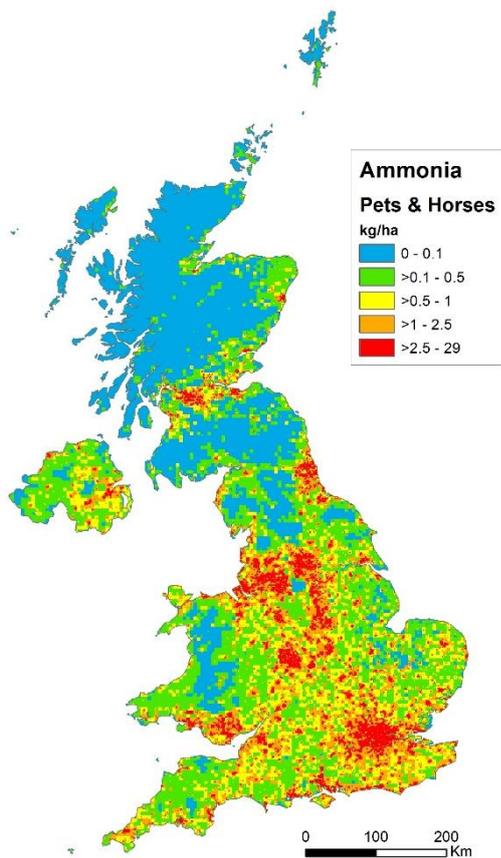


Figure 11. Ammonia emissions from pets (cats and dogs) and non-agricultural horses

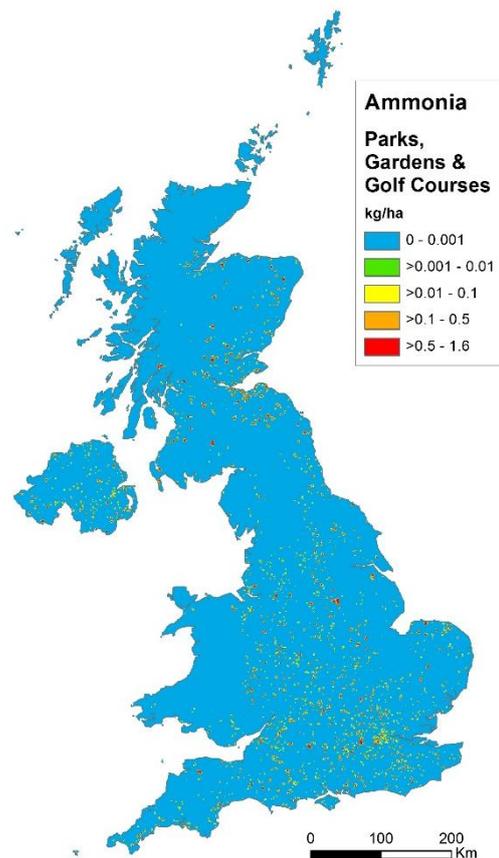


Figure 12. Ammonia emissions from parks, gardens and golf courses

### 3.2. Methane and nitrous oxide emission maps for 2013

The following spatial datasets were produced for the UK for 2013 and are mapped below (Figures 13-20); units: kg CH<sub>4</sub> and N<sub>2</sub>O ha<sup>-1</sup> year<sup>-1</sup>, respectively):

- livestock manures (CH<sub>4</sub>, N<sub>2</sub>O)
- enteric fermentation (CH<sub>4</sub> only)
- agricultural soils (crops/grasslands etc.) (N<sub>2</sub>O)
- nature (peat & wetlands, (CH<sub>4</sub> only))
- landfill (CH<sub>4</sub> only)
- land spreading of sewage sludge (CH<sub>4</sub>, N<sub>2</sub>O)

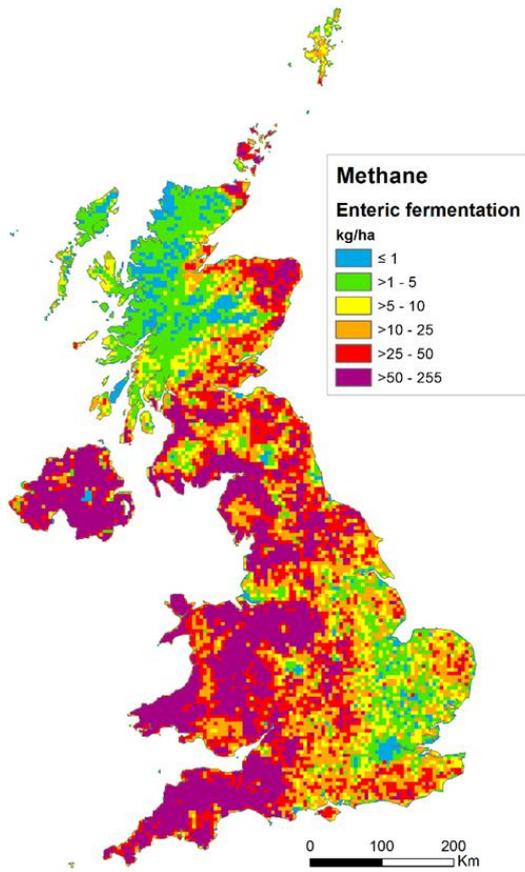


Figure 13. Methane emissions from enteric fermentation

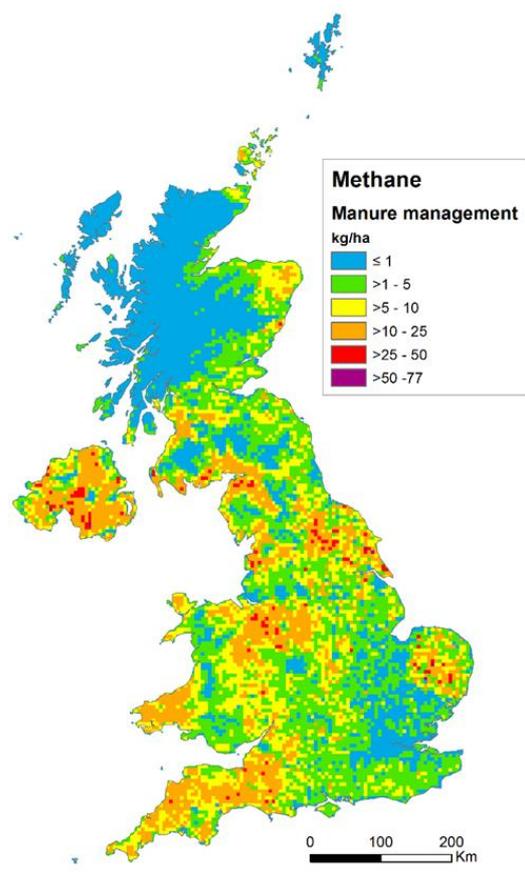


Figure 14. Methane emissions from livestock manure

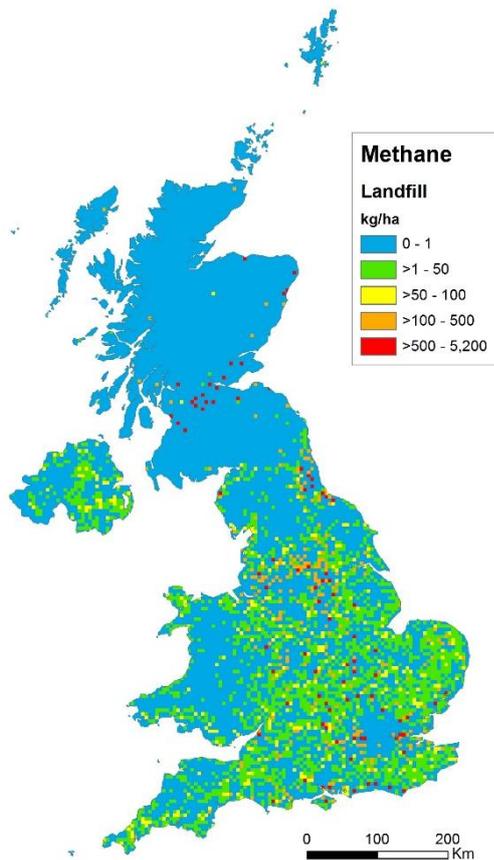


Figure 15. Methane emissions from landfill

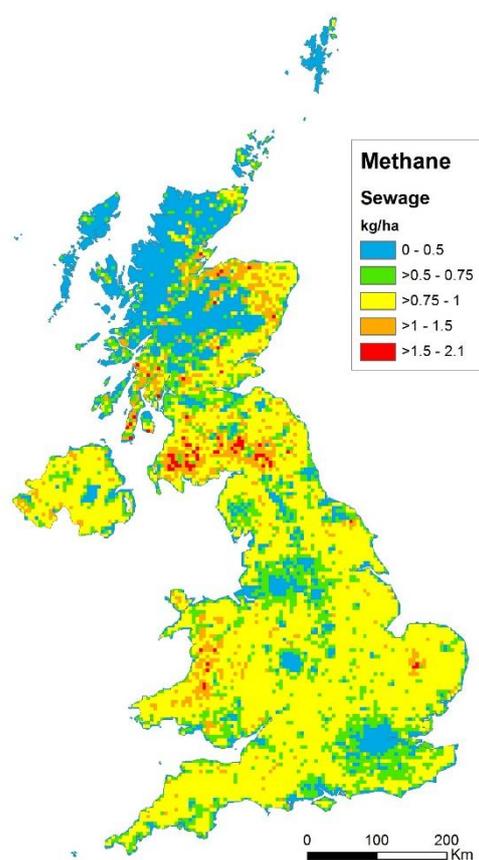


Figure 16. Methane emissions sewage spreading

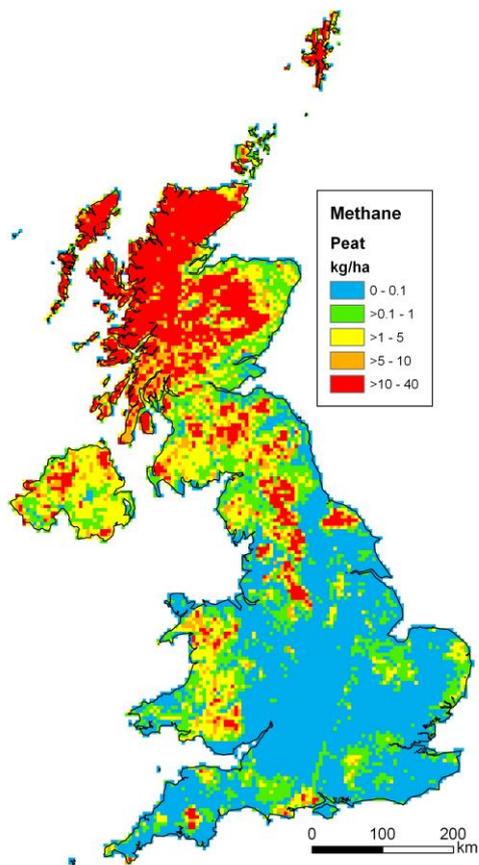


Figure 17. Methane emissions from peatland

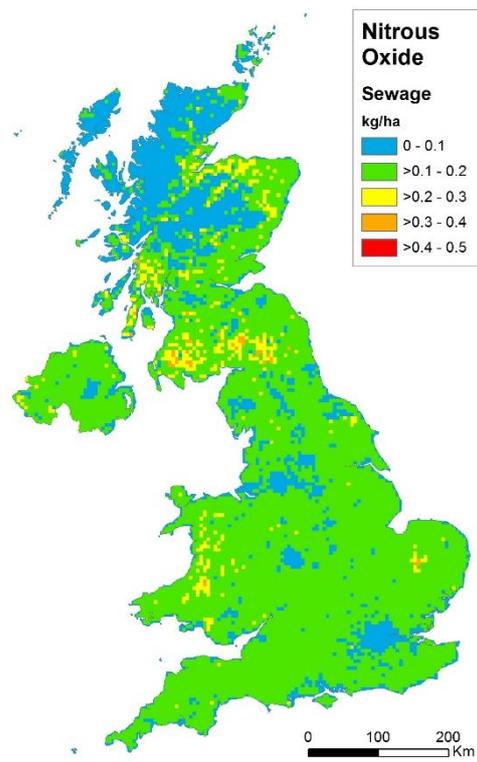


Figure 18. Nitrous oxide emissions sewage spreading

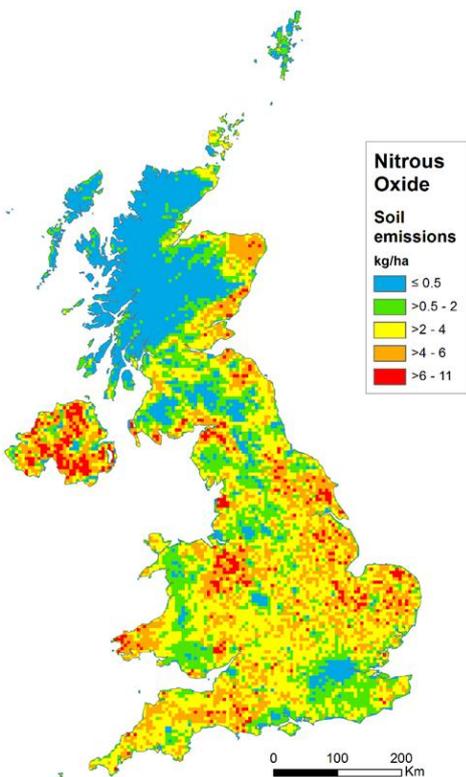


Figure 19. Nitrous oxide emissions from soil

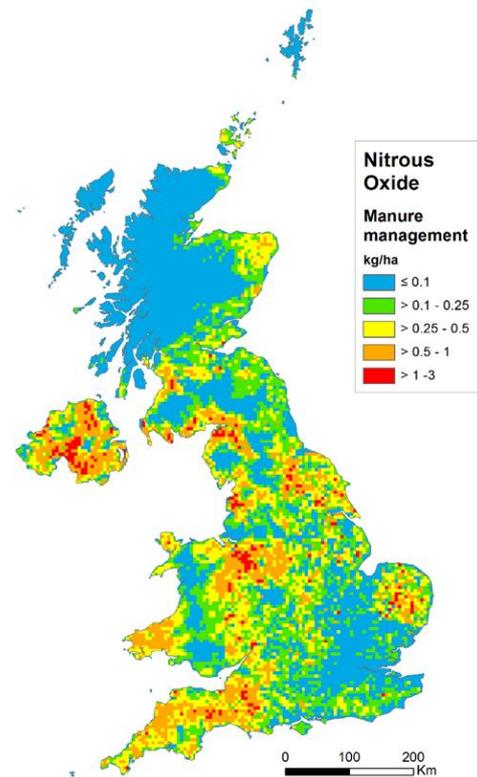


Figure 20. Nitrous oxide emissions manure management

### **3.3. Spatial datasets for submission to the NAEI/GHGI**

The units for all spatial datasets submitted are kg ammonia (NH<sub>3</sub>), methane (CH<sub>4</sub>) or nitrous oxide (N<sub>2</sub>O) per grid square, respectively. The datasets were produced on the Ordnance Survey GB Grid at a resolution of 1 km x 1 km and were delivered to Ricardo-AEA (see Section 3.1. for details on spatial resolution).

## **4. MAJOR CHANGES AND CONSEQUENCES IN EMISSIONS**

### **4.1. Changes in emissions from non-agricultural sources**

Overall, non-agricultural NH<sub>3</sub> emissions from sources estimated by CEH under the current contract (covered by SNAP codes 6, 9, 10 and 11) amount to 51.1 kt NH<sub>3</sub> (or 42.1 NH<sub>3</sub>-N) year<sup>-1</sup> for 2013, as reported by Tomlinson *et al.* (2014). This constitutes a decrease of 1.2 kt NH<sub>3</sub> yr<sup>-1</sup>, compared with the estimate for 2012.

The main changes to the inventory for 2013 are increased emissions from pet dogs, and decreased emissions from the storage of anaerobic digestion (AD) materials and products and seabird populations. In terms of changes to the methodology for spatial distribution of non-agricultural emissions, the only improvement for the 2013 inventory was the addition of data on the distribution of domestic composting UK-wide.

The 2013 inventory includes, as per 2012, CH<sub>4</sub> and N<sub>2</sub>O emissions from non-agricultural horses, which had been part of the NH<sub>3</sub> inventory for the last decade already. As of 2012, the emissions from all horses (i.e. agricultural and non-agricultural) are calculated under the agricultural inventory by Rothamsted Research, using the same methodology as previously applied under the non-agricultural NH<sub>3</sub> inventory. However, the total horse emissions are split between agricultural and non-agricultural horses in the detailed NAEI data tables by NFR code, to allow differentiation between horses kept on agricultural holdings and other horses, for the allocation to different emission sectors, as well as for estimating mitigation by sectors. This approach keeps the different components of UK horse emissions separate and avoids the potential allocation of the majority of horses (that are not kept on farms) to agricultural emission ceilings or mitigation targets.

### **4.2. Changes in emissions from agricultural sources**

Spatially distributed emissions from agricultural sources, while submitted for inclusion in the NAEI/GHGI here, are not part of the current contract between AEA and CEH, but are modelled as part of Defra Contract SCF0102. Any changes in emissions between years are described in detail by Misselbrook *et al.* (2013) as part of reporting of that project. The main changes are summarized here:

For NH<sub>3</sub>, the overall decrease in livestock emissions by 1.2 kt NH<sub>3</sub> between 2012 and 2013 is mainly due to the small cattle numbers (0.6%) and changes in manure management practices. Fertiliser emissions decreased by 3.4 kt NH<sub>3</sub> due to a large decrease in the overall rates applied to tillage crops (BSFP, 2013).

Between the calculation of the 2012 and 2013 inventories, the methodology of the CH<sub>4</sub> and N<sub>2</sub>O inventory was revised in order to comply with the 2006 IPCC guidelines. This has resulted in substantial changes in emission estimates and the subsequent spatial distribution. Total agricultural CH<sub>4</sub> emissions are estimated to have increased marginally between the inventories (+2.3%), however changes in the methodology have led to an estimated 27.2% increase in emissions from enteric emissions and a substantial decrease (56.1%) in emissions from manure management. Excluding this change in methodology, total CH<sub>4</sub> emissions from UK livestock have decreased by 4.6 kt between 2012 and 2013 (Cardenas *et al.* 2014), largely due to a small decline in cattle numbers (offset by slight increases in sheep, pig and poultry numbers).

For N<sub>2</sub>O, emissions have decreased substantially between 2012 (96.0kt N<sub>2</sub>O) and 2013 (71.5 kt N<sub>2</sub>O), due to the adoption of the 2006 IPCC guidelines. Taking into account the methodological differences between the inventories, N<sub>2</sub>O emissions are estimated to have increased by 0.4 kt (0.5%). The 2013 inventory also includes, for the first time, N<sub>2</sub>O emissions from mineral soil, as a result of land use and management changes. This source category is estimated to produce 0.9 kt of N<sub>2</sub>O emissions. N<sub>2</sub>O emission estimates from livestock manure are in line with those made for 2012, with only a minor increase of 0.5% overall due to changes in livestock numbers. For example, detailed data for Wales were not made available in for 2012, and the 2011 spatial distribution was re-scaled to the correct totals sub-categories.

## 5. CONCLUSIONS

### 5.1. Ammonia

Ammonia emission maps were derived for the UK, for inclusion in the 2013 version of the NAEI for agriculture (SNAP Codes 10.1, 10.3 and 10.5), natural sources (SNAP Code 11.3 and 11.7), waste disposal (SNAP Code 9.4), sewage works, sewage sludge spreading, composting and anaerobic digestion (SNAP Code 9.10), solvents (SNAP Code 6.4) and other miscellaneous sources for the UK.

The non-agricultural sources listed above were spatially distributed using a combination of population census data, landcover data, information on landfill sites and sewage works from the Environment Agency, SEPA and others, anaerobic digestion sites, mammal distribution data from the Biological Records Centre (BRC) etc.

Agricultural emission sources (livestock manures, fertilisers) were distributed using the CEH/University of Edinburgh AENEID model, which incorporates agricultural census data, landcover data, agricultural practice information (e.g., fertiliser application rates, stocking densities) and emission source strength data from the NARSES UK NH<sub>3</sub> Emissions Inventory (Misselbrook *et al.* 2014).

### 5.2. Methane and nitrous oxide

New CH<sub>4</sub> and N<sub>2</sub>O emission maps were derived for the UK, for inclusion in the GHGI for 2013 for agriculture (SNAP Code 10), natural sources (SNAP Code 11), waste disposal and sewage sludge spreading (SNAP Code 9) for the UK. Emissions from non-agricultural horses (i.e. horses not based on agricultural holdings) were again included in the CH<sub>4</sub> and N<sub>2</sub>O emission inventory as per the methodology used for the 2012 inventory.

Agricultural emission sources (livestock manures and enteric fermentation, soils) were distributed using the greenhouse gas version of the CEH/University of Edinburgh AENEID model, with emission source strength data taken from the detailed CH<sub>4</sub> and N<sub>2</sub>O emission inventories for the UK calculated at Rothamsted Research, North Wyke (Cardenas *et al.* 2014). The non-agricultural sources listed above were spatially distributed using a combination of population census data, landcover data, and data from the Environment Agency, SEPA and others on landfill sites.

### 5.3. Spatial resolution

All 2013 maps were submitted for inclusion into the NAEI and GHGI at a 1 km grid resolution, in the same way as for the 2012 inventory. For emission sources with strict data licensing agreements of input data (i.e., all agricultural emissions) and those with large uncertainties in the input data (e.g., sewage sludge, biomass burning, land fill), the 1 km grid is a nominal resolution (explained in detail in Section 3.1). For all other sources without such restrictions, emission maps were provided at a true 1 km grid resolution.

## ACKNOWLEDGEMENTS

The authors are grateful to Defra, who are funding this work as part of the National Atmospheric Emissions Inventory (NAEI) and Greenhouse Gas Inventory (GHGI) project, and to the Biological Records Centre (CEH Monks Wood) for wild mammal distribution data from records compiled by the Mammal Society, to the JNCC for data from the Seabird 2000 survey, the British Deer Society, the Game Conservancy Trust, and others.

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