The spatial distribution of ammonia, methane and nitrous oxide emissions from agriculture in the UK 2016

Annual Report to Defra (Project SCF0107)

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EXECUTIVE SUMMARY

Modelling and mapping UK ammonia and greenhouse gas emissions from agriculture

Defra project SCF0107

- Agricultural emissions of ammonia, methane and nitrous oxide for 2016 were spatially distributed across the UK, and maps produced.
- Emission estimates produced for the 2016 inventory are based on a new emissions model developed by ADAS, Rothamsted Research and Cranfield University. The new emissions model replaces the previous NARSES and GHGI spreadsheets used to estimate emissions in the 2015 inventory and has been written in C#.
- In parallel with the development of the new emission inventory model under Defra project SCF0102, the AENEID model, used to produce high-resolution maps of UK agricultural emissions, has also been updated. The new model version builds on techniques previously implemented in the AENEID model (e.g. Dragosits et al. 1998, Hellsten et al. 2008) and has been developed in the R statistical environment. It produces non-disclosive agricultural emission maps at a grid resolution of 1 km, compared with a 5 km grid resolution previously. The model incorporates detailed agricultural census data, landcover data (Rowland *et al.*, 2017), agricultural practice information (e.g. fertiliser application rates, stocking densities) and emission source strength data from the UK emissions inventories for agriculture 2016 (Wakeling *et al.* 2018 and Brown *et al.* 2018).
- All emission maps correspond to the totals reported by Rothamsted Research North Wyke (RResNW) for 2016.

1. INTRODUCTION

1.1. Background

Emission estimates of ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O) for the 2016 inventory are based on a new agricultural emission model jointly developed by, Rothamsted Research, ADAS, CEH and Cranfield University. The new model replaces the NARSES Excel spreadsheet (Misselbrook *et al.* 2016) used to estimate NH_3 emissions and GHGI Excel spreadsheet (Cardenas *et al.* 2016) used to estimate CH_4 and N_2O emissions from agricultural sources. The model has been implemented in the C# programming language and is capable of generating UK agricultural emission estimates at a 10 km grid resolution.

The estimates produced using the new model have been spatially resolved to produce high-resolution 1 km emission maps. In previous years the NARSES and GHGI spreadsheets produced emission estimates for the UK's four devolved authorities (i.e. England, Wales, Scotland and Northern Ireland), which were then spatially distributed to a grid resolution of 5 km by the AENEID model (e.g. Dragosits *et al.* 1998, Hellsten *et al.* 2008).

The AENEID model has been redeveloped to be compatible with the spatially variable emissions output produced by the new inventory model. The AENEID model was originally written in FORTRAN but has been re-developed in the R statistical environment and includes some modifications that enable non-disclosive 1 km grid output. Previously, 1 km grid resolution agricultural emission estimates produced by the long-established AENEID model had to be summarised to a 5 km grid resolution due to data licensing restrictions for the underlying disclosive livestock and crop/grass datasets. The new model dynamically summarises these confidential holding-level data to ensure that the emissions represented by each 1 km grid square include data from ≥ 5 holdings with relevant emission sources present to comply with the licensing conditions. This report briefly describes the methodology used for the sources listed above, including any changes in the methodology and the consequences of these changes for the inventory.

The agricultural emission estimates for ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O) are derived annually under Defra project SCF0107 and reported to Ricardo-AEA as part of the UK national inventory submissions (inventories by Wakeling *et al.* 2018 and Brown *et al.* 2018; see Table 1). This report summarises CEH's contribution of high-resolution spatial distribution of emissions from agricultural sources to the UK NAEI, and complements the expertise of the wider project consortium in producing UK emission estimates from experimental data, peer-reviewed literature and agricultural management practices, including mitigation options.

Due to data licensing restrictions in relation with the Data Protection Act, the detailed 1 km model output can currently only be shown as "emissions from livestock" and "emissions from fertiliser application to crops and grassland", rather than for individual livestock sectors or crop types.

Table 1: UK emissions of ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O) for 2016, as submitted by RResNW and mapped by CEH (in kt yr^{-1}).

Gas	Source	UK emission (kt) 2015
NH_3	Livestock manure	183.6 kt NH_3
	Fertiliser application	60.3 kt NH_3
	Total agriculture	**243.9 kt NH_3**
CH_4	Enteric fermentation	877.4 kt CH_4
	Livestock manure	172.9 kt CH_4
	Total agriculture*	**1,050.3 kt CH_4**
N_2O	Crops & soils	39.2 kt N_2O
	Livestock manure	8.3 kt N_2O
	Total agriculture *	**47.5 kt N_2O**

* includes non-agricultural horses (i.e. all horses present in the UK, rather than only those present on farms that are counted as part of the annual agricultural statistics)

1.2. Annual work schedule/deliverables

- Task 1: To acquire source data (agricultural census) from the devolved authorities for spatially distributing agricultural ammonia emissions from livestock manures and fertiliser application. This included acquiring data from the cattle tracing system for Great Britain (CTS, via Cranfield University).
- Task 2: To model NH_3, CH_4 and N_2O emissions from agricultural sources at a 1 km grid resolution using the new version of the agricultural emission distribution model for the UK (AENEID).
- Task 3: To provide a short report describing the methodology and results, highlighting any changes and their consequences.
- Task 4: To streamline the inventory process jointly between CEH and the consortium partners (Rothamsted Research North Wyke, ADAS, Cranfield University). This included developing a new agricultural emission distribution model, which is compatible with the livestock/crop categories used in the new agricultural emission inventory model.
- Task 5: To submit the spatial datasets to Ricardo Energy & Environment for inclusion in the National Atmospheric Emission Inventory (NAEI) and Greenhouse Gas Inventory (GHGI).

2. METHODS - SPATIAL DISTRIBUTION OF NH_3, CH_4 AND N_2O EMISSIONS FROM AGRICULTURAL SOURCES

Agricultural census/survey data for 2016 were acquired at the holding level from the devolved authorities in the UK, i.e. Defra (England), the Scottish Government (Scotland), Welsh Assembly (Wales) and Daera (Northern Ireland). Aggregated cattle population data were supplied by Cranfield University from cattle tracing system (CTS) data. The holding level data for the different countries were aggregated to a common set of emission source categories used by the new agricultural emission inventory model (see Appendix A), to ensure compatibility between the different countries' systems and consistency over the period 1990-2016. Emissions from 'non-agricultural' horses (i.e.

horses that are not kept on agricultural holdings) are **not included** in the ammonia emissions maps shown in this report and are mapped and reported separately. Emission from these horses are however, **included** in the CH_4 and N_2O emission maps, for reasons of compliance with the different sets of emission inventory guidelines for air pollutants and GHGs.

Agricultural emissions were estimated using the new inventory model, separately for each emission source specified in Appendix A and for each Robust Farm Type, at a 10 km grid resolution. 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 individual emission source categories. Average fertiliser N application rates to different crops and types of grassland were taken from the British Survey of Fertiliser Practice for 2016 (BSFP 2017).

The spatially variable emission factors (per farm type) at the 10 km grid resolution were then applied to the original holding level data to derive the high resolution (1 km grid) maps submitted for inclusion in the NAEI. The area-based non-disclosive distribution methodology works by identifying and merging parishes which contain fewer than 5 holdings. Within the areas emissions were then distributed to suitable land cover types using the AENEID methodology by Dragosits *et al.* (1998). (e.g. arable land, improved grass, part-improved grass, rough grazing etc.), using the CEH landcover map (LCM2015, Rowland *et al.*, 2017). Methane and nitrous oxide emissions were distributed in the same way.

3. Results

3.1. Spatially distributed emissions of NH_3, CH_4 and N_2O for 2016

All UK maps were produced on the Ordnance Survey GB Grid at a resolution of 1 km x 1 km. The units for all GIS datasets submitted are kg ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O), respectively, per grid square. All spatial datasets were submitted to RResNW (Defra Contract SCF0107) and to Ricardo (for use in the National Atmospheric Emission Inventory (NAEI, see http://naei.beis.gov.uk/). Figures 1, 2 and 3 show the 2016 maps resulting from the spatial modelling of agricultural emissions (excluding non-agricultural horses) for NH_3, CH_4 and N_2O, respectively (units: kg ha^{-1} $year^{-1}$).

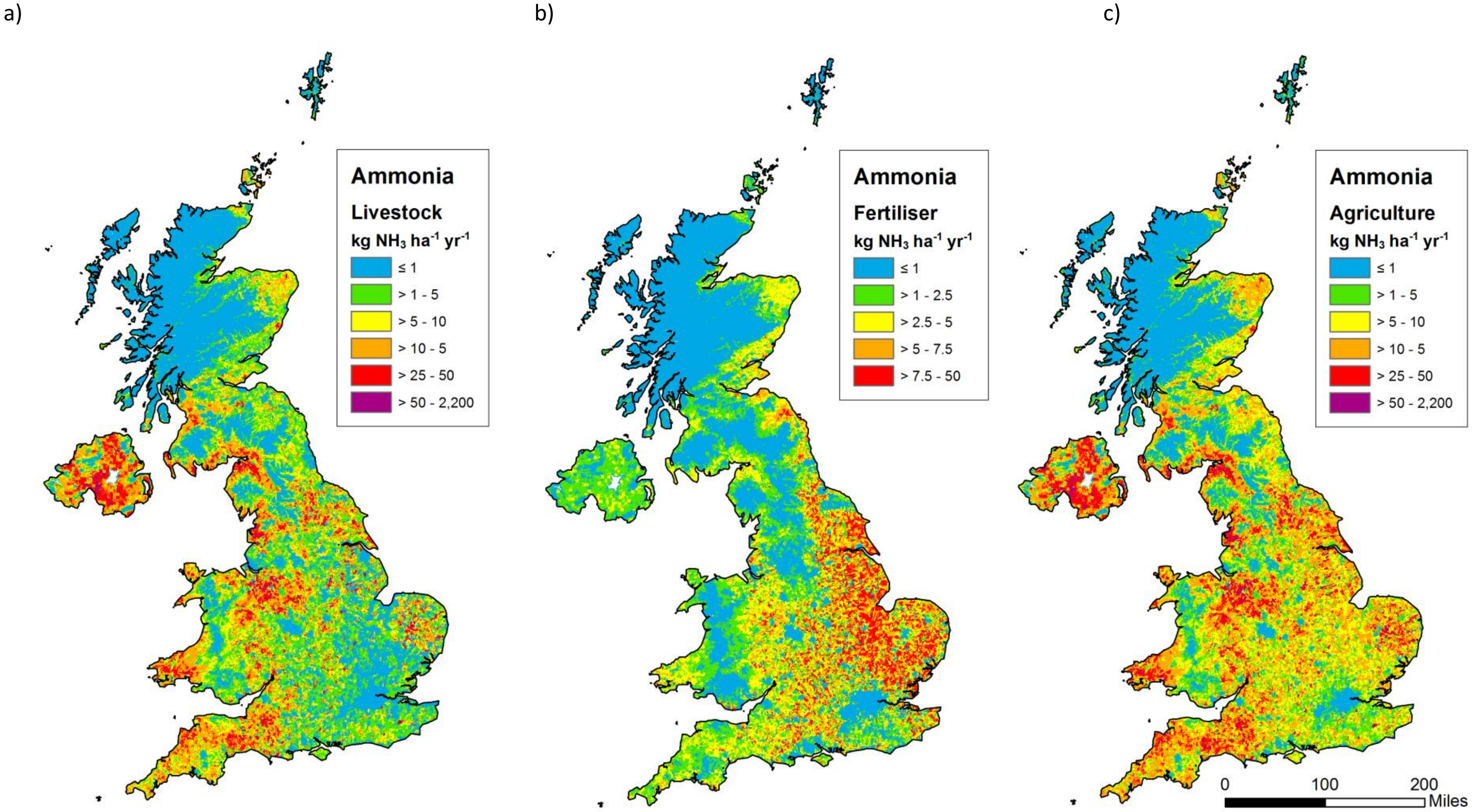

Figure 1: UK ammonia emissions from a) livestock manures, b) fertilisers and c) total agriculture (c = a + b) for 2016 (Units: kg NH_3 ha^{-1} $year^{-1}$).

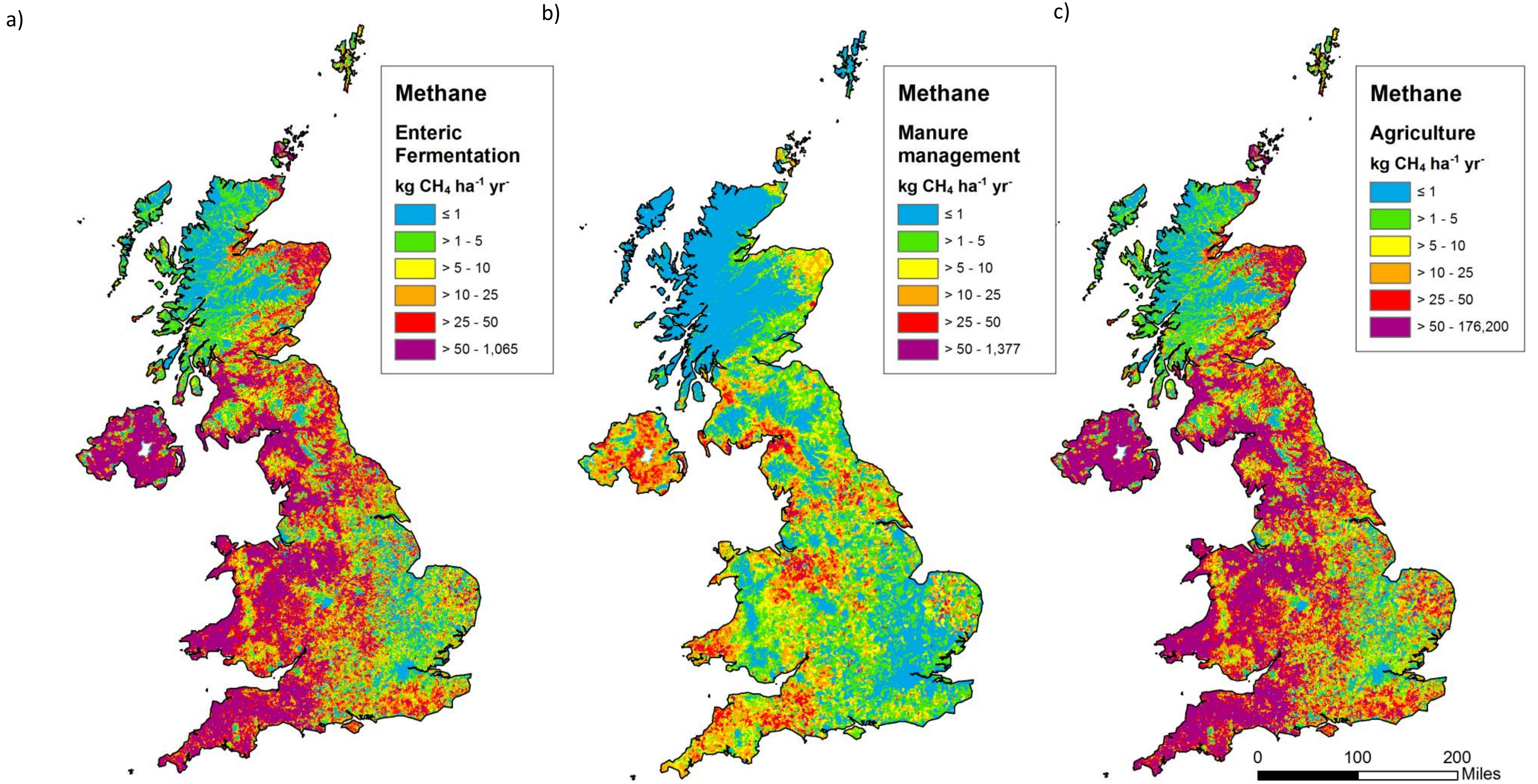

Figure 2: UK methane emissions from a) enteric fermentation, b) livestock manure management and c) total livestock (c = a + b) for 2016 (Units: kg CH_4 ha^{-1} $year^{-1}$).

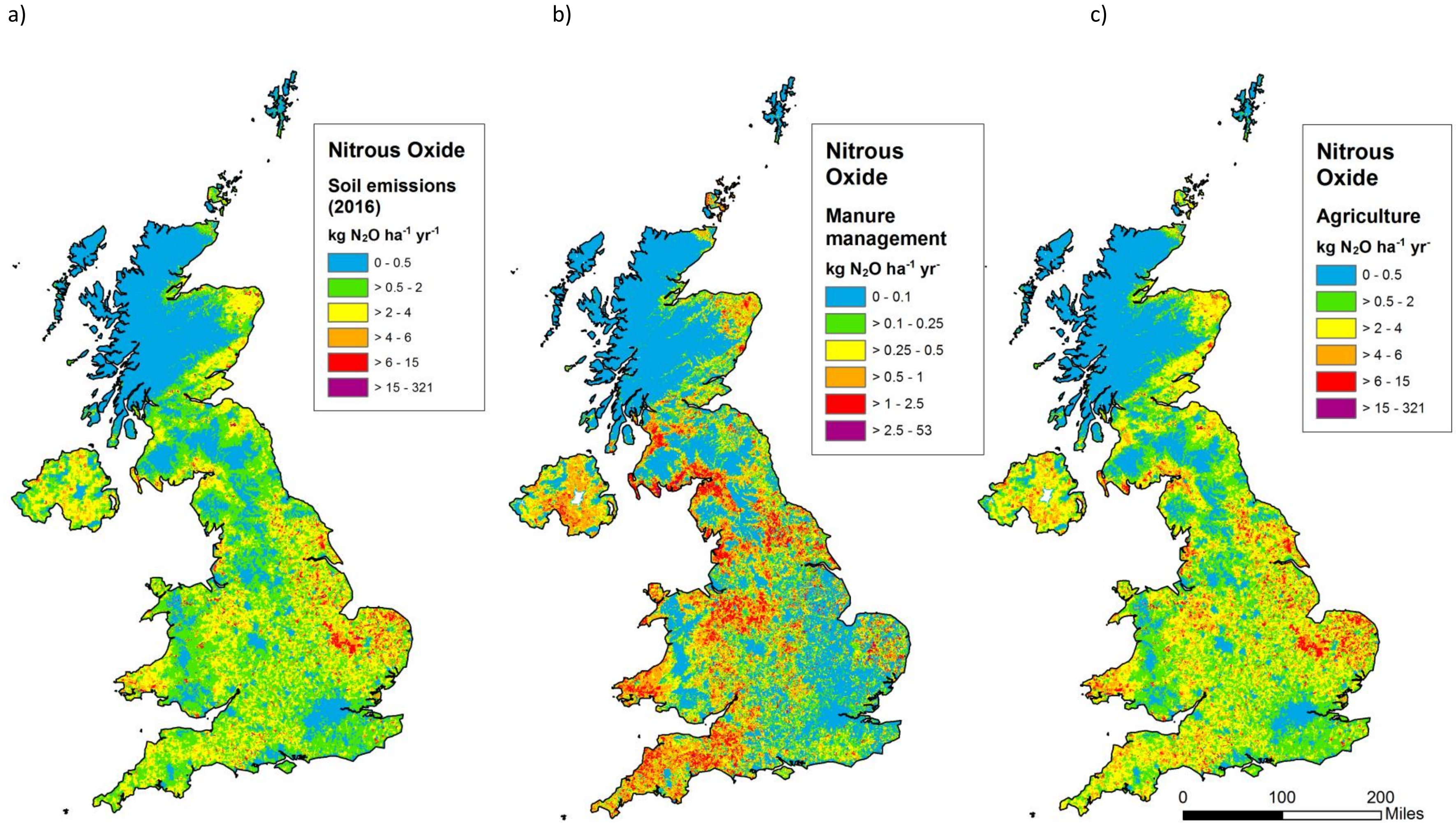

Figure 3: UK nitrous oxide emissions from a) soils, b) livestock manure management and c) total agriculture (c = a + b) for 2016 (Units: kg N_2O ha^{-1} $year^{-1}$).

3.2. Major changes and Consequences

3.2.1. Changes in emissions from agricultural NH_3 sources

Overall, estimated NH_3 emissions from UK agricultural sources have increased by 6.3 kt NH_3 between the 2015 and 2016 inventories, with 237.6 kt NH_3 and 243.9 kt NH_3 emitted, respectively. These changes are primarily due to methodological changes between the NARSES Excel spreadsheet (Misselbrook *et al.* 2016) used to produce the 2015 estimates and the new 'C# emissions model' used to generate the 2016 estimates.

To compare these methodological differences, the 2015 emission estimates produced using the NARSES spreadsheet and the new 'C# emissions model' are compared (Table 2). Overall, the new emission estimates are 6 % lower for livestock sources and 14 % higher for fertiliser sources. The new model also includes emissions from sewage sludge, which had previously been included in the non-agricultural emissions inventory (e.g. Tomlinson *et al.* 2016).

Taking into account methodological differences, livestock emissions are estimated to have increased marginally by 2.9kt NH_3 (2 % increase), with fertiliser emissions increasing substantially by 5.0 kt NH_3 (9 % increase). This substantial increase in emissions associated with fertiliser application is attributed to an increase in total fertiliser N use (by 0.6%) and predominantly to an increase in the use of urea-based N fertilisers (by 3.6%), associated with higher emission factors.

The minor estimated increase in livestock emissions between 2015 and 2016 is associated with increases in total cattle, sheep, pig and poultry populations, by 1.0, 1.8, 2.7 and 3.0%, respectively.

Table 2: Differences between reported emissions from UK agriculture in 2015 (adapted from Misselbrook *et al*. 2016) and the revised 2015 and 2016 inventory estimates. Totals may not add up exactly due to rounding.

	Reported 2015 emissions (kt NH_3)	Revised 2015 emissions (kt NH_3)	Methodological differences	Reported 2016 emissions (kt NH_3)	Annual difference
All cattle	*129.6*	*116.8*	*- 10 %*	*119.0*	*+ 2%*
All sheep	*9.9*	*9.5*	*- 3 %*	*9.3*	*- 2 %*
All pigs	*18.2*	*18.0*	*- 1 %*	*18.3*	*+ 2 %*
All poultry	*31.8*	*35.0*	*+ 10 %*	*35.6*	*+ 2 %*
Horses, Goats and Deer	*3.6*	*1.5*	*- 59 %*	*1.4*	*- 4 %*
Application of fertilisers	*44.3*	*51.2*	*+ 14 %*	*56.1*	*+ 10 %*
Sewage sludge	*-*	*4.2*		*4.2*	*+ 1 %*
Livestock total	**193.3**	**180.8**	**- 6 %**	**183.6**	**+ 2 %**
N fertiliser total	**44.3**	**55.4**	**+ 23 %**	**60.3***	**+ 9 %**
Total agriculture	**237.6**	**236.2**	**- 1 %**	**243.9**	**+ 3 %**

*Includes emissions from sewage sludge, which was previously included with non-agricultural emissions in the inventory.

3.2.2. Changes in emissions from agricultural CH_4 sources

Total agricultural CH_4 emissions from UK agricultural sources have decreased by 53.3 kt CH_4 between the published 2015 and 2016 inventories, with 1,103.6 kt CH_4 and 1,050.3 kt CH_4 emitted, respectively. As with the NH_3 emissions (Section 3.2.1), the differences are primarily due to methodological changes between the old and new agricultural emission inventory models.

To compare these methodological differences, the 2015 emission estimates produced using the GHGI spreadsheet (Cardenas *et al.* 2016) and the new agricultural emission inventory model are compared (Table 3). Overall, the new consistent time series derived using the new model estimates 2016 emissions to be 9 % lower for enteric emissions and 22 % higher for emissions associated with livestock manures than in 2015.

Taking into account methodological differences, enteric emissions are estimated to have increased marginally by 0.6 kt CH_4 (0.1 % increase) and emissions associated with livestock manures by 0.7 kt CH4 (0.4 % increase), attributed to the increases in livestock numbers.

Table 3: Differences between reported CH_4 emissions from UK agriculture in 2015 (adapted from Cardenas *et al.* 2016) and the revised 2015 and 2016 inventory estimates. Totals may not add up exactly due to rounding.

Sector	Grouping	Reported 2015 emissions (kt CH_4)	Revised 2015 emissions (kt CH_4)	Methodological difference	Reported 2016 emissions (kt CH_4)	Annual difference
All cattle	*Enteric emissions*	*768.3*	*692.0*	*- 10 %*	*694.2*	*+ 0.3 %*
All sheep	*Enteric emissions*	*168.8*	*159.0*	*- 6 %*	*157.4*	*- 1 %*
All pigs	*Enteric emissions*	*7.1*	*7.1*	*0.0 %*	*7.3*	*+ 3 %*
Horses, Goats & Deer	*Enteric emissions*	*18.7*	*18.7*	*0.0 %*	*18.5*	*- 1 %*
All cattle	*Livestock manure*	*104.5*	*138.1*	*+ 32 %*	*138.3*	*+ 0.1 %*
All sheep	*Livestock manure*	*6.6*	*4.3*	*- 34 %*	*4.2*	*- 2 %*
All pigs	*Livestock manure*	*24.7*	*24.7*	*0.0 %*	*25.3*	*+ 2 %*
All poultry	*Livestock manure*	*3.4*	*3.6*	*+ 3 %*	*3.6*	*0.0 %*
Horses, Goats & Deer	*Livestock manure*	*1.6*	*1.6*	*- 2 %*	*1.5*	*- 1 %*
Total Enteric emissions		**962.9**	**876.8**	**- 9 %**	**877.4**	**+ 0.1 %**
Total Livestock manure		**140.7**	**172.2**	**+ 22 %**	**172.9**	**+ 0.4 %**
Total Agriculture		**1,103.6**	**1,049.0**	**- 5 %**	**1,050.3**	**+ 0.1 %**

3.2.3. Changes in emissions from agricultural N_2O sources

Total agricultural N_2O emissions from UK agricultural sources have decreased by 5.6 kt N_2O between the published 2015 and 2016 inventories, with 53.1 kt N_2O and 47.5 kt N_2O emitted, respectively. These differences are primarily due to methodological changes and the inclusion of non-agricultural sewage sludge. To compare the methodological differences, the 2015 emission estimates produced using the GHGI spreadsheet (Cardenas et al. 2016) and the new agricultural emission inventory model are compared (Table 4). Overall, the new consistent time series derived using the new model estimates 2016 emissions are 3 % higher for direct emissions from manure management and 12 % lower for soil emissions than in 2015 (including indirect emissions form manure management).

Taking into account methodological differences, total N2O emissions have increased fractionally by 0.09 kt N_2O (0.2 % increases), with the small net increase as a result of increases due to increasing livestock numbers and fertiliser N use being offset by decreases in emissions from crop residues.

Table 4: Differences between reported N_2O emissions from UK agriculture in 2015 (adapted from Cardenas *et al.* 2016) and the revised 2015 and 2016 inventory estimates. Totals may not add up exactly due to rounding.

Sector	Grouping	Reported 2015 emissions (kt N2O)	Revised 2015 emissions (kt N2O)	Methodological differences	Reported 2016 emissions (kt N2O)	Annual difference (%)
All cattle	*Manure management*	3.7	5.8	+ 57 %	5.9	+ 0.8 %
All sheep	*Manure management*	0.5	0.1	- 82 %	0.1	- 2 %
All pigs	*Manure management*	0.6	0.8	+ 51 %	0.9	+ 1 %
All poultry	*Manure management*	0.1	0.8	+ 459 %	0.8	+ 1 %
Horses, Goats & Deer	*Manure management*	0.005	0.6	+ 12052.9 %	0.6	- 1 %
All cattle	*Soil emissions**	6.4	6.3	- 2 %	6.3	0.0 %
All sheep	*Soil emissions**	1.5	1.4	- 7 %	1.4	- 1 %
All pigs	*Soil emissions**	0.5	0.8	+ 51 %	0.8	2 %
All poultry	*Soil emissions**	0.7	1.1	+ 60 %	1.1	2 %
Horses, Goats & Deer	*Soil emissions**	0.4	0.5	+ 20 %	0.5	- 1 %
Application of fertilisers	*Soil emissions**	37.5	22.8	- 39 %	22.8	0.0 %
Sewage sludge	*Soil emissions**	1.1	6.3	+ 452 %	6.3	0.0 %
Total direct manure management emissions		4.9	8.2	66%	8.3	0.8%
Total soil emissions		48.2	39.2	-19%	39.2	0.1%
Total agicultural emissions		**53.1**	**47.4**	**-11%**	**47.5**	**0.2%**

4. Conclusions

New ammonia, methane and nitrous oxide emission maps were derived for the UK (Defra project SCF0107), and submitted for inclusion in the 2016 version of the NAEI and GHGI for agriculture in the UK. Agricultural emissions were estimated using the new agricultural emission inventory model and high-resolution spatial distribution model developed under Defra project AC0102. The 2016 maps have been submitted at a 1 km grid resolution (non-disclosive) for the first time, enabling higher resolution modelling of ammonia impacts on sensitive habitats and designated sites.

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