Ammonia emissions from UK non-agricultural sources in 2016: contribution to the National Atmospheric Emission Inventory

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

Estimation of total UK ammonia emissions from nature, waste disposal and other miscellaneous sources

1. Ammonia emission estimates were reviewed for natural sources, waste disposal and other miscellaneous sources, regarding both source strength estimates ("emission factors") and source populations for the UK, and brought up to date to 2016 (or the latest available data).

2. The emission sources listed above were assigned to the classification system used by the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP) and the EMEP/EEA Air Pollutant Emission Inventory Guidebook (2016). The relevant categories ("Sectors") in the guidebook are "solvent and product use" (Sector 2D), "waste" (Sector 5), "other sources" (Sector 6) and "natural sources" (Sector 11 or unclassified).

3. Ammonia emissions estimates from the land spreading of sewage sludge to farmland were removed from this inventory and are now estimated as part of the agricultural inventory (Defra SCF0107), using the same methodology as applied in this report series during previous years. Therefore emissions from this source are no longer reported here. However, emission estimates from the application of sewage sludge for land reclamation purposes are still included in this report series.

Emission source strength estimates

4. The emission factor for the land spreading of food-based digestates from anaerobic digestion (AD) has been updated in the 2016 inventory, with new information. The new best estimate is 1.75 kg NH_3-N t^{-1} digestate (range 1.5 – 2 kg) for the whole time series and replaces the 2015 version of 2.06 kg NH_3-N t^{-1} digestate.

5. For emissions from AD facilities, an adjustment was made to the historic time series as follows: sites are assumed to have storage coverings throughout the time series, and this replaces the 2015 method of incrementally increasing the fraction of sites that cover storage facilities from 2001 (0 sites) to 2010 (all sites). The abatement factor used for covering of storage facilities is unchanged at 95%.

6. There was an increase in the emission factor for composting at permitted sites from 2.04 kg NH_3-N t^{-1} dry matter to 2.23 kg NH_3-N t-1 dry matter (range 0.57 – 2.98), due to an increase in the proportion of composted food wastes.

7. Emission factors for horses kept by professionals were updated with new information from Misselbrook *et al.* (2017), from 27.3 kg NH_3-N $horse^{-1}$ yr^{-1} to 16.1 kg NH_3-N $horse^{-1}$ yr^{-1} (range 14.5 – 17.8), and also in the emission factor for all other horses, from 10.5 kg NH_3-N $horse^{-1}$ yr^{-1} to 3.9 kg NH_3-N $horse^{-1}$ yr^{-1} (range 3.5 – 4.3), due to

Emission source populations

8. Anaerobic digestion (AD) plants in the UK are estimated to have had inputs of approx. 9,442 kt in 2016 (increased from 8,580 kt compared with the reported inventory data for 2015) at 374 sites (excluding brewery/distillery AD sites), compared to 345 in 2015, with approx. 84% of materials originating from non-farm sources (increased from 75% in the 2015 dataset). The emissions for 2016 were estimated at 0.53 kt NH_3-N yr^{-1} for fugitive and storage emissions at AD plants, and 7.5 kt NH_3-N yr^{-1} for landspreading of non-farm-based materials. Together these represent an increase of 0.1 kt NH_3-N yr^{-1} from 2015.

9. The latest estimates of waste being land-filled, based on local authority landfill statistics for the four countries of the UK, show a large decrease of 2,163 kt to 7,073 kt (approx. 23.5%), while the amount of sewage sludge going to landfill increased from 6.9 kt to 9.3

kt. Overall there has been a substantial decrease in NH_3 emissions from this source, down from 1.28 kt NH_3-N in 2015 to 0.99 kt NH_3-N in 2016. This decrease is due to reduced amounts of waste to landfill and is offset slightly by the increased amounts of nitrogen-rich sewage sludge going to landfill.

10. Sewage sludge applied to agricultural land is now counted under the agricultural section of the UK Greenhouse Gas Inventory (Defra project SCF0107) and is removed from this report series from here on. Emissions from sewage sludge used in land reclamation is still reported here and is currently 0 kt NH_3-N yr^{-1}.

11. The equine population estimate for the UK (including horses, donkeys, mules, etc.) has again been divided into three categories (previously two), for improved transparency, in the same way as for 2015; professional horses (i.e. horses on a higher protein diet), 'normal' horses located on agricultural holdings (and counted in the agricultural census) and 'normal' privately owned horses (not counted in the agricultural census). No new estimates were found for professional or 'normal' privately owned horses but there has been a reduction of approx. 14,000 in the total number of agricultural equines (i.e. horses counted as present on agricultural holdings in the annual June Census/Survey), or about 5%. The best estimate for 2016 is 4.84 kt NH_3-N for all horses, a decrease of 6.94 kt NH_3-N from 2015 (see Section 3.3.1).

12. Inputs to permitted composting facilities decreased by approximately 4% to 2,439 kt dry matter. The increased proportion of inputs in the form of food wastes (from 5.1% in 2015 to 8.5% in 2016), however, resulted in an increased emission estimate of 5.43 kt NH_3-N yr^{-1} (compared with from 5.18 kt NH_3-N yr^{-1} in 2015), due to food waste containing more nitrogen than green waste. The decreased amount of input was due to improved data sources, compared to 2015. The amount of waste input to household-based composting in 2016 in the UK was approximately 226 kt (an increase from 219 kt in 2015). This resulted in an emissions estimate of 0.1 kt NH_3-N yr^{-1} for 2016.

13. New population figures for domestic pets (cats increased by 500,000 from 2015 to 2016) resulted in increased emissions by 0.06 kt NH_3-N yr^{-1} for cats between 2015 and 2016. Population estimates and emissions from dogs remains unchanged.

14. The source populations for other categories (e.g., human subcategories, wild geese, wild deer and wild seals) were also updated, most of which were very small in absolute terms and have not resulted in substantial changes in emissions. The largest of these changes is for emissions from seabirds where new population estimates have resulted in increased emissions by 0.16 kt NH_3-N yr^{-1}. No new data were found for game birds, domestic chickens, other wild animals, parks and gardens, golf courses, biomass burning, sewage works and household appliances.

UK Emission estimates for 2016

Overall emissions from the sources reviewed for Sectors 2D, 5, 6 and 11 amount to 36.2 kt NH_3-N $year^{-1}$ for 2016, with an uncertainty range of 20.6 – 64.5 kt NH_3-N $year^{-1}$. This constitutes a decrease of 10.04 kt NH_3-N yr^{-1}, compared with the 2015 estimate (46.2 kt NH_3-N yr^{-1}). The main changes between 2015 and 2016 are the decrease in emissions from 'normal' privately owned horses (by 4.03 kt NH_3-N yr^{-1}, 63%), horses on agricultural premises (by 1.94 kt NH_3-N yr^{-1}, 65%) and professional horses (by 0.97 kt NH_3-N yr^{-1}, 41%).Other notable changes are decreased emissions from landfill by 0.3 kt NH_3-N yr^{-1} (23%), the increase in emissions from permitted composting sites by 0.25 kt NH_3-N yr^{-1} (5%), and increased emissions from seabirds (by 0.16 kt NH_3-N yr^{-1}). The largest relative changes were for emissions from 'normal' privately owned horses (increased 63%) and horses on agricultural premises (increased 65%).

N.B. Due to structural changes in the inventory, emissions from sewage spreading onto agricultural land (2015: 3.44 kt NH_3-N yr^{-1}), are now reported as part of the agricultural emission inventory (Defra project SCF0107), using the same methodology.

CONTENTS

1. INTRODUCTION

Ammonia (NH_3) emissions are recognized as a major component in the assessment of transboundary air pollution fluxes for acidification and eutrophication. While most attention has been and is being given to agricultural sources, non-agricultural sources of ammonia represent around 15-20% of the total, but had received very little attention until the late 1990s in the UK, when Defra funded a review of the different sources by CEH (Sutton *et al*. 2000), and an assessment of the potential for reducing emissions from these sources, conducted by AEAT (Handley *et al*. 2001). Since 2003 (inventory year 2002), CEH has been providing annual updates on the following non-agricultural emission source categories for inclusion in the National Atmospheric Emission Inventory (NAEI):

- Sector 2D (solvent and product use): household cleaning materials, perming solutions, refrigeration, etc.
- Sector 5 (waste): landfill, sewage works and sewage spreading, composting (excluding incineration)
- Sector 6 (other sources): professional and privately owned horses (i.e. all equines not recorded on agricultural premises)
- Sector 11 (natural sources): pets, wild mammals, seabirds, humans, biomass burning

The current contract (Oct-2016 to Mar-2020) for the inventory years 2015-2017 exploits the expertise of CEH in non-agricultural sources of NH_3, focusing on emissions from nature, waste disposal and other miscellaneous sources, which complements the expertise of Ricardo on combustion, industry and transport sources.

2. METHODOLOGY AND WORK SCHEDULE

An extensive literature search is conducted annually for new scientific publications on the sources under investigation, to improve existing estimates of source strength, as well as to scan the literature for new sources. In addition, a wide-ranging search for new source activity statistics is carried out for the annual inventory update. Any new information found is used in the inventory calculations, which result in "best estimates" for each source type. Low and high estimates are also calculated to provide a range/indication of the uncertainty. Emission sources are referenced to the Sector system recommended by the EMEP/EEA Air Pollutant Emission Inventory Guidebook (2016) since the 2015 update.

The current report focuses on updating non-agricultural ammonia emissions for the inventory year 2016, both regarding new scientific information and assembling of data on source activities and calculation of annual UK emissions. The annual reports contain a short description of methodology, highlighting changes in source strength and source populations and their consequences on NH_3 emissions. This report incorporates the latest information available by mid-October 2017.

3. RESULTS

3.1. SOLVENT AND PRODUCT USE (SECTOR 2D)

3.1.1. New emission source strength data

No new scientific literature was found that would merit changing the current approach.

3.1.2. New source data

Source numbers for hair products were updated using UK 2016 population numbers (see Section on Humans below for details), resulting in a very small, non-significant increase in emissions from solvent and product use (Sector 2D) for the year. The current best estimate is 1.0 kt NH_3-N yr^{-1}.

3.2. WASTE TREATMENT AND DISPOSAL, EXCLUDING INCINERATION (SECTOR 5)

3.2.1. New emission source strength data

Landfill

The detailed research undertaken to update the estimated N content of land-filled materials from local authority waste streams since the 2013 inventory, to replace the old value derived from Burton and Watson-Craik (1998), was repeated for the 2016 inventory. Various waste composition reports (Defra 2014; Resource Futures 2013; SEPA 2012; The University of Warwick 2005; WRAP Cymru 2010 & Zero Waste Scotland 2010) were used to analyse the tonnage of different materials going to landfill to produce a new N content estimate of 0.55% for 2013 (still the most up to date information, unchanged for 2016), a 10% increase from the figure of 0.5% used in inventory years prior to 2013.

Also, the input of 9.3 kt of sewage sludge to the landfill process in 2016 (reintroduced to the inventory estimates in 2013 following the availability of new data) meant more high-nitrogen materials were going to landfill in 2016 (the best estimate of N content for sewage sludge remained at 3.6% as per previous years). The 2016 best estimate emission factor is 0.14 kg NH_3-N t^{-1} of landfilled materials.

Anaerobic digestion

Emission factors calculated for fugitive and storage emissions at AD plants were modified in the 2015 inventory following a thorough review of relevant literature and remain the same for the 2016 inventory. The best estimate emission factor for fugitive and storage emissions at UK AD plants is 0.056 kg NH_3-N t^{-1} feedstocks (range 0.053 – 0.205 kg), with this EF derived by careful re-analysis of existing data and new data from the UK and elsewhere to provide an emission factor for the three main stages of emissions at the site: pre-AD storage (0.004 kg NH_3-N t^{-1} feedstocks), process emissions (0.003 kg NH_3-N t^{-1} feedstocks) and post-AD storage (0.048 kg NH_3-N t^{-1} feedstocks) (Bell *et al.*, 2016; Cuhls *et al.*, 2010; Cumby *et al.*, 2005). Post-AD storage incorporates an emissions reduction factor of 95% (Cumby *et al.*, 2005) from sealed covers on digestate materials on site (previously 80%). For the 2015 inventory and earlier versions, the proportion of sites using the covering was estimated to be 100% from 2010 onwards, with incremental steps back to 0% of sites using coverings in 2000, to account for legislation that requires all AD plants to cover input and output storage areas (WRAP/EA 2009). However, in the 2016 inventory, all sites throughout the time series are assumed to have had a storage covering, due to a reassessment of the AD sector's practices with new information. This has reduced estimated fugitive and storage emissions at AD plants by over 90% pre-2005.

The emission factor for land spreading digestates from food waste sources was updated for 2016 to reflect better knowledge surrounding N losses from the volatilisation of NH_3 once digestate had been applied to land, giving an emission factor of 1.75 kg NH_3-N t^{-1} food digestate (range 1.5 – 2 kg), a 15% decrease from the previous emission factor of 2.06 kg NH_3-N t^{-1} food digestate (WRAP, 2016a; Nicholson et al., 2017; Fiona Nicholson, ADAS, pers. comm.). The emission factor for land spreading digestates from non-manure, non-food waste materials was not updated from 2015 and remains at 0.68 kg NH_3-N t^{-1} digestate. For non-manure, non-food digestates, the latest evidence of spreading emissions (Cumby *et al.*, 2005; WRAP, 2016a) was combined with an analysis of inputs to all AD sites in the UK (Biogas, 2016; WRAP, 2014; WRAP, 2016b) to produce an average emission factor of 1.39 kg NH_3-N t^{-1} feedstocks (range 1.39 – 1.59 kg).

NB: Manure sources are assumed to be mostly included in the agricultural inventory already in terms of landspreading emissions, and were omitted here, to avoid potential double-counting, as for the previous years.

Permitted Composting

Data from Burns *et al.* (2017), regarding the composition of materials composted at permitted facilities, were used to apportion the amount of tonnes sent to composting facilities in 2016 based on waste data reports and Local Authority waste streams (see Section 3.2.2). The 2016 best estimate emission source strength is 2.23 kg NH_3-N t^{-1} dry matter composted (range 0.57 – 2.98 kg), an increase from 2.04 kg NH_3-N t^{-1} dry matter composted in 2015, due to the increased fraction of food wastes going to compost facilities, thereby increasing the quantity of nitrogen rich materials (8.5% in 2016, an increase from 5.1% in 2015).

Household Composting

Domestic composting (i.e. at private dwellings) was included in this report series for the first time in 2014 after being introduced in the 2013 inventory by Ricardo. Due to scant scientific information regarding emissions or emission factors from home-based composting techniques, it was decided to use the dry matter fraction and N-content of garden waste that goes to composting facilities (40% and 1.11% respectively). Furthermore, a scaling factor of 0.78 was applied to account for the lack of any regular turning of the composting materials, a reflection of the ratio between EFs of turned and non-turned materials cited in Cuhls *et al.* (2015). This resulted in a 2016 best estimate emission source strength of 0.45 kg NH_3-N t^{-1} of dry matter composted (range 0.23 – 0.68 kg) which remains unchanged from 2014.

Land spreading and land reclamation of sewage sludge and sewage works

Emissions from the land spreading of sewage sludge to farmland has been removed from this inventory and are now estimated as part of the agricultural inventory (Defra SCF0107), using the same methodology as applied in this report series during previous years. Therefore emissions from this source are no longer reported here. However, emission estimates from the application of sewage sludge for land reclamation purposes are still included in this report series. The N content of sewage used in land reclamation matches that used in the UK Greenhouse Gas Inventory for emissions from spreading of sewage to agricultural land (Cardenas *et al.* 2016) during the previous inventory year (Tomlinson *et al.* 2016). As the N content of 3.6% has not been updated by Cardenas *et al.* (2016), the emission factor of 2.4 kg (range 0.9-4.5) NH_3-N t^{-1} (dry solids) is still the best estimate.

3.2.2. New source data

Landfill

Source numbers were updated with 2016 landfill statistics (local authority (LA) collected waste) for England (Defra, 2016), Scotland (SEPA, 2017), Wales (StatsWales, 2017) and Northern Ireland (NIEA, 2017). Data for England and Wales covered the financial reporting year 2015/16 while Scotland and Northern Ireland the 2016 calendar year. 9.3 kt of sewage sludge, at 3.6% N content, was included in the total amount of landfilled materials (via Sarah

Gilhespy, Rothamsted Research, pers. comm.). UK landfill totals for 2016 from LA wastes amount to 7,073 kt of materials – a reduction of 2,163 kt from the previous year. Overall, emissions from landfill have decreased as less waste went to landfill (and was diverted to other processes and treatments). The current best NH_3 emission estimate for 2016 is 0.99 kt NH_3-N year^{-1} (range 0.89 - 1.09 kt), compared with 1.28 kt NH_3-N year^{-1} in 2015.

Anaerobic digestion

The amounts of materials treated in UK AD plants are considerable, and this source has been growing rapidly. New NH_3 emission sources from anaerobic digestion were identified for the 2016 inventory, along with updates for existing sources. The comprehensive database for AD sites now contains 394 plants operational during 2016 (NNFCC, 2017), an increase from 356 in the 2015 methodology (265 in 2014). These plants are estimated to process 10,167 kt of materials (fresh weight) during 2016, an increase of approx. 8% on the 2015 methodology. Approximately 84% of input materials to AD were from non-manure sources, such as crops and food wastes, an increase from 75% in 2015. As per 2015, large volumes of materials (approx. 725 kt at 20 sites) were then removed from the non-farm based input stream after it was established they did not enter the AD process as characterised in this inventory. These materials were predominantly distillery and brewery wastes (and some vegetable washings) and were not included in the emissions estimate for 2016 as they are likely to be processed in other ways; these distillery and brewery wastes have also been removed from the historic timeline for AD as was done with the previous database. For estimating fugitive and storage emissions, all materials that are processed by AD were included in the calculations, whereas for estimating landspreading emissions for digestate, farm-based products (i.e., mainly manure/slurry) were excluded, to avoid double-counting with the agricultural inventory by Misselbrook *et al.* (2016). A reduction factor of 0.84 (WRAP, 2014) was also used to reflect the fact that the amount of digestate produced in comparison to the amount of inputs used at the site is usually lower (due to the recycling of digestate to catalyse the process in the digester etc.).

It should be noted that the new site information database recorded in the NNFCC (2017) data differs from the previous data collections in 2015 (Biogas, 2016; WRAP, 2016b), as the reported inputs to each site in NNFCC reflect the actual tonnes inputted by feedstock category, as opposed to previously available datasets which utilised the capacity of the site as the presumed input. AD sites generally do not operate at 100% capacity so the increase in inputs from 2015 to 2016 was not as large as expected. Furthermore, input materials to each site are now reported with less uncertainty: each site has quantities listed for manures, crops, food and 'other', as opposed to material types only, thereby superseding the previously necessary approach of having to estimate proportions. This allows input materials, and therefore digestates, to be characterised with more detail and for more accurate removal of manure-based digestates In summary, the newly available NNFCC dataset provides a substantial improvement to the inventory, due to a large reduction in uncertainty on the quantities of different materials.

By combining the new site data with the emission factors reported in Section 3.2.1, the estimate of UK NH_3 emissions from AD for 2016 was 0.53 kt NH_3-N yr^{-1} (range 0.04 – 1.93 kt) for fugitive and storage emissions at AD plants, and 7.52 kt NH_3-N yr^{-1} (range 6.68 – 8.55 kt) for landspreading of non-farm-based materials. The 10% increase in fugitive and storage emissions is due to the increase of materials sent to AD processing plants. Regarding emissions from landspreading of digestate, the small 0.7% increase (0.05 kt yr^{-1}) occurred due to the increase of digestates being spread on land, offset by a reduction in the emission factor for food-based digestates (Section 3.2.1) and the reduction in the uncertainty of food waste quantities in the AD sector. This resulted in the food-based proportion of total digestate being lower in 2016 (42%) than in 2015 (52%, using older data methods).

This results in a total estimated emission of 8.04 kt NH_3-N (6.72 – 10.48 kt) from anaerobic digestion for 2016, compared with 7.94 kt NH_3-N in 2015, an increase of 0.1 kt NH_3-N.

Permitted Composting

Datasets of increased detail (England – Waste Data Interrogator, Scotland and Wales – WasteDataFlow) were used to estimate the tonnages of inputs to permitted composting sites in Great Britain (GB) for 2016 (EA, 2017; WDF, 2017). These data allow for greater insight into how waste products are transferred and processed in GB and decrease uncertainty in the amount of materials being composted. Data were not available for Northern Ireland and so LA summary data were used as in 2015 (NIEA, 2017). The 2012 data on ratios of types of waste composted from Horne *et al.* (2013) were updated with new data from Burns *et al*. (2017) to calculate the different compost streams for the 2016 inventory. Overall, 6,136 kt of materials were estimated to be composted in 2016 - producing 2,439 kt of dry matter and amounting to emissions of 5.43 kt NH_3-N year^{-1} (range 1.4 – 7.3 kt), an increase from the 2015 estimate of 5.18 kt NH_3-N year^{-1}. Total input materials decreased by 3.5% from 2015 but this is most likely due to previous data containing an overestimation of c. 5%, as previously estimated totals used only the reported organic fraction of MSW (which may not all go to compost). This decrease in materials in the estimate was offset by a higher proportion of composted materials assumed to be food wastes (that have a higher N content) from 5.1% in 2015 (Horne *et al.*, 2012) to 8.5% in 2016 (Burns *et al*., 2017). It should be noted that a number of unlicensed composting sites exists in the UK, from which it is not possible to estimate inputs and/or emissions – i.e. the current best estimate is likely an underestimate.

Household Composting

Inputs to household composting were calculated for the 2013 inventory by using population statistics (ONS, 2012) and district level analysis for home composting in the UK (Parfitt, 2009). Inputs for household composting are scaled with the latest UK population estimates (ONS, 2017) and totalled 226 kt for 2016 (up from 219 kt in 2015, previous number provided by Ricardo). The best NH_3 emission estimate for 2016 is 0.10 kt NH_3-N year^{-1} (range 0.05 – 0.15 kt).

Landspreading of sewage sludge

The total amount of sewage sludge applied to farmland, for emissions from spreading of sewage to agricultural land (Cardenas *et al*. 2016), was removed from this inventory and placed in the agricultural inventory (see Section 3.2.1 for details). This resulted in a removal of the previous emission estimate of 3.4 kt NH_3-N yr^{-1} (range 1.3 – 6.5 kt) for 2015 from this report. Emissions from sewage used for land reclamation are currently estimated to be zero, as zero tonnage of sludge being used for this purpose is reported in the official statistics for 2015 and 2016. However, there is a residual time line for this source, for 1990-2014

3.3. OTHER SOURCES (SECTOR 6)

3.3.1. New emission source strength data

Horses

New information regarding the emission source strength for professional horses, ‘normal’ privately owned horses and all horses kept on agricultural premises was taken from the latest submission of the agricultural inventory (Misselbrook *et al.*, 2017) and used in the 2016 calculations. These new data reflect the new N-flow methodology used for horse emission estimates and are substantially lower than previous emission factors used in 2015 and previous years.

For horses kept by professionals, the best estimate emission factor is now 16.1 kg NH_3-N horse^{-1} (range 14.5 – 17.8), a decrease of 41%. For 'normal' privately owned horses and horses on agricultural premises, the best estimate emission factor is now 3.9 kg NH_3-N horse^{-1} (range 3.5 – 4.3), a decrease of 63%.

3.3.2. New source data

Horses

The UK population estimate for horses was updated for the 2016 inventory with new figures on agricultural equines in the UK, but no new data for professional horses or 'normal' privately owned horses were found. The current best population estimate is 963,423 equines (range 0.87 – 1.06 million), down from 978,029 in 2015. Numbers of horses kept by professionals (as a proxy for higher protein diets) are estimated at 87,112. Combined with the new (substantially lower) source strength data outlined in Section 3.3.1, estimated emissions from horses for 2016 are 4.84 kt NH_3-N (range 4.35 – 5.32 kt), a decrease of 6.94 kt NH_3-N compared with 2015, a decrease of 59%.

The non-professional horses were previously re-categorised as 'non-agricultural "normal" horses' (summarised from agricultural census/survey data from the UK Devolved Administrations) and 'agricultural "normal" horses', to differentiate between those on and not on agricultural holdings. The split is 608,242 equines on non-agricultural holdings (the same as 2015) and 268,069 equines kept by private owners elsewhere (a decrease of 15,000 equines).

3.4. NATURAL SOURCES (SECTOR 11)

3.4.1. New emission source strength data

Biomass burning

No new information was found on emission source strength for biomass burning (muirburn), and the current best estimates and uncertainty range remain at 1.1 g (range 0.3-2.4) NH_3-N m^{-2}.

N.B. It should be noted that biomass burning of agricultural residues (stubble burning), which only occurred in the UK up to 1992 before it was banned, is now reported as part of the agricultural emission inventory.

Domestic Chickens

The category of domestic chickens was introduced to the 2013 inventory to account for the growing popularity of 'backyard' poultry in the UK (The Ranger 2011). Each animal has been attributed an emission factor of 0.25 kg NH_3-N chicken^{-1}. This is a slightly modified estimate for non-agricultural layers as derived from the agricultural inventory for 2013 (Misselbrook *et al*. 2014), accounting for the birds spending more time outdoors than estimated for commercial flocks in larger free-range units. There is no update of the emission factor for the 2016 inventory, and it has not been possible to develop a timeline back to the 1990 base year, due to lack of suitable data.

Other animals

The category of 'pheasants' was revised for the inventory year 2012 to 'game birds', incorporating the large population of red-legged partridges in the UK (Bicknell et al., 2010; Defra, 2013), which are reared in the same way as pheasants. The emission source strength was weighted to allow for the smaller mass (on average) of a partridge compared to a pheasant (BTO, 2013), creating an average emission factor for game birds of 0.017 kg NH_3-N $bird^{-1}$ yr^{-1} (range 0.01 – 0.05 kg), a slight decrease from 0.02 kg NH_3-N $bird^{-1}$ yr^{-1} for pheasants.

No new information was found on emission source strength for wild animals, wild geese or seabirds for 2016.

Other sources – cigarette smoking

The latest smoking statistics available for the UK are from the Adult Smoking Habits in the UK 2016 bulletin (ONS 2017). The percentage of male adults who smoke decreased in 2016 from 20% to 18% while the percentage of women decreased from 17% to 14%. The number of cigarettes smoked by adults decreased slightly for men (12.2 to 12) and increased slightly for women (10.5 to 11) . This resulted in slightly increased emissions per smoker of 15.8 g NH_3-N yr^{-1} (range 7.9 – 28.7 g) from 15.6 g NH_3-N yr^{-1} for 2016. The emission factor per cigarette smoked is unchanged from previous estimates, with no relevant new data found in the literature.

For young smokers, there are no new statistics for 2016 so the proportion of regular smokers and number of cigarettes smoked from 2014 are carried forward (Fuller *et al.* 2015). The average emission factor per young smoker remains 4 g NH_3-N yr^{-1} (range 2 – 7.3 g).

Other human sources

No new scientific literature was found that would merit changing the current approach.

Golf courses, parks and gardens

The average NH_3 volatilisation rate for fertiliser application was kept in line with the emission factors for fertiliser application to agricultural grassland from the UK inventory for 2015 (Misselbrook *et al.*, 2016) due to the unavailability of updated figures in time for this report. For parks and gardens, an average of all fertiliser types was used rather than just ammonium sulphate and di-ammonium phosphate, which slightly increased the emission factor from 2.24% to 2.33% in 2015. Similarly for golf courses, the average of all fertiliser types was used (instead of only ammonium nitrate), including the usage of some N-rich urea, and the best estimated emission factor for 2015 is 3.07%, a slight increase from 2.99% in 2014. Finally, the average area of an 18-hole golf course, which increased slightly from 0.51 km^2 to 0.53 km^2 due to new information in 2013 (de Castella 2013), has been carried forward unchanged. Using these adjustments to the emission factors in the 2015 inventory for the 2016 inventory, the best estimate emission factor for parks and gardens remains 0.7 kg NH_3-N ha^{-1} (range 0.23 – 1.4 kg). For golf courses, the best estimate emission factor remains 0.72 kg NH_3-N ha^{-1} (range 0.42 – 1.18 kg).

Detailed information regarding golf-course composition and fertiliser application practice was ascertained for the 2012 inventory (Bartlett and James, 2011; Kearns and Prior, 2013) and has remained for this years' inventory. In principle, golf courses do not receive a uniform rate of fertiliser application over the areas of green, tee, rough and fairway, and so these course composition studies allow more detailed estimates to be made.

3.4.2. New source data

Biomass burning (muirburn)

The area of biomass burnt annually in the UK through muirburn was updated for the 2014 inventory, based on a recent remote sensing study. Douglas *et al.* (2015) suggest that burning occurred across 8,551 1-km squares in the UK. Based on typical vegetation regeneration rates, they assume that burning in these squares took place within the last 25 years. The area detected as burnt is estimated to be 1,428 km^2 with, on average, 16.7 % of the area of each grid square burnt. The area burned varies from year to year, depending on weather conditions and burning frequency, and is estimated between 57 km^2 – 142 km^2 for an average burning frequency of 15 years (uncertainty range 10-20 years). Previous equivalent biomass burning estimates of between 205 – 411 km^2 yr^{-1} were based on data from the Moorland Working Group (2002) and Yallop *et al.* (2006). An average of these two estimates was used, giving an estimated 131 – 276 km^2 yr^{-1} (assuming a burning frequency of 10 – 20 years), giving an emission estimate of 0.19 kt NH_3-N (range 0.04 – 0.66 kt) for biomass burning. The area statistics were carried forward for the 2016 inventory.

It should be noted that these estimates are due to improved data rather than real changes over time, compared with any earlier estimates. It is recommended that this estimate is used as a constant for back-casting timelines, as there is insufficient evidence to show any change in the practice of muirburn and resulting NH_3 emissions.

Parks & gardens + golf courses

Emissions from parks, gardens and golf course were unchanged in 2016. There were no new data for volatilisation rates from applied fertilisers. There were no new data available regarding the area or composition of parks and gardens or golf courses, and the current best estimates for parks (England: English Heritage (2013); Scotland: Historic Scotland (2013); Northern Ireland: DOENI (2013)) and golf courses (England: England Golf (2013); Wales: Welsh Golf Courses (2013); Northern Ireland: GUI (2013)) are carried over from 2015 to 2016. This resulted in a total emission of 0.20 kt NH_3-N yr^{-1} (range 0.07 – 0.40 kt) for parks and gardens and 0.10 kt NH_3-N yr^{-1} (range 0.06 – 0.15 kt) for golf courses.

Humans

The UK population figures were updated to the latest available data, the mid-2016 estimate of 65,648,100 (ONS 2017). This constitutes an increase of approx. 538,000 people or 0.8%, compared with 2015. The emission source populations were also updated for the number of infants in the two age groups considered for babies' nappy emissions (0-1 years, >1 – 3 years old). Due to a change in reporting ages for adult smokers and young smokers, the emission source populations for these categories in 2016 were split into 18+ years old (adult smoker) and <18 years old (young smoker). This created a 2% decrease in the adult smoker group and a 13% increase in the young smoker group (including the slight increase in overall population).

The decrease in UK emissions from adult cigarette smoking (by ~15%) is due to the 2% decrease in the 'adult' population group (i.e. 18 years and over) and the proportion of those adult males and females who, in turn, smoke a slightly decreased amount of cigarettes per week, offset slightly by an overall increase in the UK population. Cigarette smoking emissions from young people increased by 43% to 1 t NH_3-N yr^{-1} for 2016, due to the larger population group now included in the available statistics constituting young smokers (<18 years in 2016, previously <16 years) and the slight increase in the overall UK population. No new data were available regarding proportion of smokers among under 18 year olds or data regarding cigarettes consumed.

Emissions from other human sources (breath, sweat and babies' nappies) are estimated at 0.8 kt NH_3-N yr^{-1} for the UK in 2016, with a very small increase of ~7 t NH_3-N yr^{-1} from 2015, due to the overall increase in the UK population of young children.

Pets

New survey data from the Pet Food Manufacturers Association (PFMA 2017) for 2016 show that the UK population estimate for cats has increased by approx. 500,000 to 8 million from 2015 figures, while dogs have remained unchanged at 8.5 million. With the same emission estimate per animal as used for previous inventory years, emissions for 2016 are estimated to have increased from 0.83 kt NH_3-N yr^{-1} to 0.89 kt NH_3-N yr^{-1} for cats (range 0.38 – 1.43 kt), and remained 5.43 kt NH_3-N yr^{-1} for dogs (range 2.26 – 9.47 kt).

Seabirds

A new estimate of population trends for 2000 to 2015 (JNCC 2016) was used to update the 2015 inventory for 2016. The population trends (as a % change) for each species were applied to previously existing population estimates and the emissions were scaled accordingly. The total population estimate for seabirds in the UK in 2016 is 6.39 million, a decrease from 6.65 million in 2015. Estimated emissions have increased to 2.51 kt NH_3-N yr^{-1} (range 1.68 – 5.02 kt) from 2.35 kt NH_3-N yr^{-1}, due to a much higher prevalence of Northern Gannets which are larger birds and therefore have a higher EF associated.

Wild animals

For the 2016 update, some new estimates of wild deer populations were made; previous population estimates for the 2010 inventory were updated using population growth estimations for five species of deer (Munro, 2002; POST Report 325, 2009). This resulted in a new total source estimate of 1,770,000 deer in the UK in 2016, an increase of 2.6% from the 2015 inventory. Overall the emission estimate for 2016 was 1.61 kt NH_3-N (range 0.6 – 4.10 kt), an increase of ~2% from 2015.

SCOS (2017) estimates grey seal population numbers of 139,800 (116,500 - 167,100) for 2015 (most recent best estimate). This is an increase (~20 %) on the previous population estimates from 2014, with an emission estimate of 62 t NH_3-N. Furthermore, SCOS estimates the harbour seal population in the UK to be 43,300 (35,500 - 59,000). This population has not been included in previous inventories and equates to an estimate of 19 t NH_3-N. In total, emissions from seals are estimated to be 81 t NH_3-N.

The 2016 estimate of wild geese populations in the inventory was updated with the best estimates of various species types from different sources (Mitchell and Brides, 2017; Musgrove *et al.*, 2011; WWT, 2017). Overall, approx. 226,000 geese are estimated to be resident in the UK all year round (an increase of ~31% from last year's estimate), with a further approx. 1,038,000 (previously 1,041,000) migratory geese over-wintering in the UK. These winter visitors stay in the UK between September/October/November and March/April, depending on species. An average residence time of six months has been estimated for the purpose of the NH_3 inventory. Emissions from wild geese are estimated at 127 t NH_3-N (range 96 - 159 t) for 2016, compared with 119 t for 2015. While the total emissions from wild geese are relatively small, these are locally important sources in areas where geese congregate in large numbers, e.g., in western Scotland and on some Scottish islands (especially Islay).

In 2012, the pheasant category was broadened to 'game birds' to include the UK population of red-legged partridges. Population numbers in 2013 were 50.3 million for both species combined, of which 73% were pheasants (Bicknell et al., 2010; Defra, 2013). There is no updated information for populations in 2016, so the estimate of UK NH_3 emissions from game birds remains unchanged at 0.84 kt NH_3-N (0.23 – 2.79 kt).

Domestic Chickens

The new category of Domestic Chickens was introduced to the 2013 inventory to account for the growing popularity of 'backyard' poultry in the UK (The Ranger 2011). There is some difficulty estimating this unregulated source of poultry but secondary sources (PFMA 2014; The Ranger 2011), including the National Farmers Union chairman, estimate the population at 1 to 3 million. A best estimate of 2 million chickens was used for the 2013 inventory and remains unchanged in 2016. Estimated emissions remain as 0.49 kt NH_3-N yr^{-1} (range 0.25 – 0.74 kt) for 2015. It is currently not possible to develop a timeline for this new source.

3.5. New UK total emissions for 2016

UK NH_3 emission totals for non-agricultural sources were recalculated with the updated source strength and source population data, as described above. Emission source strength and source population data as well as UK emission totals from Sectors 2D, 5, 6 and 11 are summarised in Table 1 below. Overall, emissions from Sectors 2D, 5, 6 and 11 (including unclassified sources) amount to 36.18 kt NH_3-N $year^{-1}$ for 2016, with a range of 20.63 – 64.5 kt NH_3-N $year^{-1}$.

4. SUMMARY OF CHANGES AND CONSEQUENCES

Solvent and product use (Sector 2D)

Only minor changes were made to emissions from household products, by including new data on the 2016 UK population.

Waste treatment and disposal, excluding incineration (Sector 5)

Landfill

Landfill emissions are estimated to have decreased by ~23% from the 2015 emission estimate (1.28 kt NH_3-N) to 0.99 kt NH_3-N in 2016, mainly due to the reduction of inputs to landfill, partly offset by a larger amount of high-N content sewage sludge going into the landfill process.

Composting

Emissions from permitted composting sites for 2016 are ~5% higher than the 2015 estimate, at 5.43 kt NH_3-N, compared with 5.18 kt NH_3-N previously. This is due to an increase in the food waste proportion of materials sent to compost, offset by a decrease in the tonnage of materials sent to compost. Furthermore, household based composting emissions are 3% higher than 2015, at 0.1 kt NH_3-N.

Emissions from household-based composting were included for the first time in the 2013 report by Ricardo-AEA and have been moved to CEH's remit by mutual agreement for the 2014 report and continue in the 2016 report. The best estimate for the emission factor remains as 0.45 kg NH_3-N t^{-1} fresh-weight (range 0.23 – 0.68 kg NH_3-N t^{-1} fresh-weight), a small modification of the previous household composting emission factor

Anaerobic digestion

Emission sources from anaerobic digestion (AD), identified and included in the 2010 inventory estimates by Dragosits et al. (2012) for the first time, were re-calculated for 2016 with one new emission factor and new more detailed data on AD sites and their inputs becoming available (NNFCC, 2017). The methodology was also updated with new information on covering of stored materials at sites, which resulted in a decrease in pre-2005 emissions from fugitive and storage emissions at sites, with the more recent historic period unchanged in this respect.

Land spreading emissions from digestate of non-manure origin were estimated at 7.5 kt NH_3-N yr^{-1} (range 6.7 – 8.5 kt), an increase of 0.05 kt due to revision of the emission factor for food-based digestates (Section 3.3.1) and increased non-farm based inputs. Fugitive and storage emissions at AD plants were estimated at 0.5 kt NH_3-N yr^{-1} (range 0.04 – 1.9 kt), a 10% increase from 2015, due to the increases in inputs to AD facilities. This results in a total estimated emission of 8 kt NH_3-N yr^{-1} (range 6.7 – 10.5 kt) from AD for 2016, compared with a total of 7.9 kt NH_3-N yr^{-1} in 2015.

Landspreading of sewage sludge

Emissions from landspreading of sewage sludge have been removed from this emission inventory and are now reported as part of the agricultural inventory, using the same methodology as in previous versions of this report. The amount in 2015 was 3.4 kt NH_3-N and is now excluded. Emissions from sewage sludge in land reclamation will continue to be estimated in this inventory but emissions in 2016 from this source are 0 kt NH_3-N yr^{-1}.

Other sources (Sector 6)

Horses

Total emissions from equines are estimated to have decreased by ~59% from the 2015 emission estimate (11.77 kt NH_3-N) to 4.84 kt NH_3-N in 2016. This was mainly due to new information regarding emission factors for professional horses (16.1 kg NH_3-N $horse^{-1}$, from 27.3 kg NH_3-N $horse^{-1}$), 'normal' privately owned horses and horses on agricultural holdings (both 3.9 kg NH_3-N $horse^{-1}$, a decrease from 10.5 kg NH_3-N $horse^{-1}$). Numbers of horses kept on agricultural holdings decreased by ~14,000 (~2%) in 2016 while populations of professional and 'normal' privately owned horses remained the same.

Natural sources (Sector 11)

Forest and other vegetation fires

No changes were made to area burnt under muirburn schemes for the 2016 inventory.

Mammals

There were small changes in NH_3 emissions from (domestic) mammals for 2016: there was an increase in emissions from cats by 0.05 kt NH_3-N yr^{-1} to 0.89 kt NH_3-N yr^{-1}, due to new population estimates.

Other animals

The largest change in NH_3 emissions from other animals was seabirds, which increased from 2.34 kt NH_3-N yr^{-1} to 2.51 kt NH_3-N yr^{-1} , due to new population estimates, while emissions from all other wild animal groups have had only very small changes (wild geese, seabirds, other major wild animals or wild seals) or no changes at all (gamebirds).

Humans

Emissions from humans decreased by very small amounts between 2015 and 2016, mainly due to the changes in the emissions from smokers, despite the continuing increase in the UK population (by 538,000 persons or 0.8%) and the associated emissions from breath, sweat and babies' nappies.

Gardens, parks and golf courses

The best estimates for emissions from fertiliser application to parks and gardens are 0.2 kt NH_3-N yr^{-1}, and 0.1 kt NH_3-N yr^{-1} are estimated for golf courses. Overall, there is no change for these sources compared with 2015, due to no availability of updated data.

Table 1: Ammonia emissions from UK non-agricultural sources for 2016

2016 (Ammonia as NH3-N)	emission estimates source-1				number of sources				UK emissions 2016 (kt NH3-N yr-1)		
source	**best estimate**	**low**	**high**	**units as NH3-N**	**best estimate**	**low**	**high**	**units**	**best estimate**	**low**	**high**
human breath	2.0	0.7	6.2	g person-1 yr-1	65,648,100	-	-	persons	0.13	0.05	0.41
human sweat	10.2	1.6	42.1	g person-1 yr-1	63,287,297	-	-	persons	0.64	0.10	2.67
infants emissions < 1yr	11.7	2.4	54.2	g infant-1 yr-1	782,450	-	-	children <1 yr	0.01	0.00	0.04
infants emissions 1-3 yrs	14.6	3.0	67.8	g infant-1 yr-1	1,578,353	-	-	children 1-3 yr	0.02	0.00	0.11
cigarette smoking (adults)	15.8	7.9	28.7	g smoker-1 yr-1	8,208,786	-	-	smokers	0.13	0.06	0.24
cigarette smoking (young people)	4.0	2.0	7.3	g smoker-1 yr-1	253,116	-	-	smokers	0.00	0.00	0.00
horses kept by professionals	16.1	14.5	17.8	kg animal-1 yr-1	87,112	78,401	95,823	animals	1.41	1.27	1.55
Non-agricultural 'normal' horses	3.9	3.5	4.3	kg animal-1 yr-1	608,242	547,418	669,066	animals	2.38	2.14	2.62
Agricultural 'normal' horses	3.9	3.5	4.3	kg animal-1 yr-1	268,069	241,262	294,876	animals	1.05	0.94	1.15
dogs	0.6	0.3	1.0	kg animal-1 yr-1	8,500,000	7,650,000	9,350,000	animals	5.43	2.26	9.47
cats	0.1	0.1	0.2	kg animal-1 yr-1	8,000,000	7,200,000	8,800,000	animals	0.89	0.38	1.43
domestic chickens	0.2			kg animal-1 yr-1	2,000,000	1,000,000	3,000,000	birds	0.49	0.25	0.74
wild deer (large)	1.5	0.7	2.9	kg animal-1 yr-1	671,501			animals	0.97	0.37	2.43
wild deer (small)	0.6	0.3	1.2	kg animal-1 yr-1	1,098,262			animals	0.64	0.24	1.66
other major wild animals (mammals inc. seals)	-	-	-	-	-	-	-	-	1.03	0.28	2.76
wild geese	-	-	-	kg bird-1 yr-1	1,264,052	-	-	birds	0.13	0.10	0.16
seabirds	-	-	-	-	6385158.391	-	-	birds	2.51	1.68	5.02
biomass burning (heather burning, "muirburn")	1.1	0.3	2.4	g m-2 yr-1	184600566.7	131310340	276,900,850	burnt area in m2	0.19	0.04	0.66
ecosystems	0.0	0.0	0.0	-	0	0	0	-	0.00	0.00	0.00
sewage works	-	-	-	-	-	-	-	-	1.20	0.70	4.90
sewage spreading to farmland	2.4	0.9	4.5	kg t-1 (dry solids) yr-1	1433.79135	1433.79135	1,434	kt total dry solids yr-1	0.00	0.00	0.00
sewage sludge used in land reclamation	2.4	0.9	4.5		0			kt total dry solids yr-1	0.00	0.00	0.00
landfill	0.1	0.1	0.2	kg t-1 landfilled	7,082,251	-	-	t landfilled (MSW + sludge)	0.99	0.89	1.09
appliances &household products	-	-	-	-	-	-	-	-	0.99	0.30	3.67
non-agricultural fertilizers (households)	-	-	-	-	-	-	-	-	0.23	0.08	0.48
composting	2.2	0.6	3.0	kg NH3-N t-1 dry matter	2,439,373			t of dry matter composted	5.43	1.40	7.27
household composting	0.452	0.226	0.678	kg NH3-N t-1 fresh weight	226,564			t of fresh matter composted	0.10	0.05	0.15
game birds (pheasants and red-legged partridge)	0.0	0.0	0.1	kg bird-1 yr-1	50,287,533	45,258,780	55,316,286	birds	0.84	0.23	2.79
parks and gardens	0.7	0.2	1.4	kg ha-1 yr-1	285,997	278,383	285,997	hectares	0.20	0.07	0.40
golf courses	0.7	0.4	1.2	kg ha-1 yr-1	130,703			hectares	0.09	0.06	0.15
Anaerobic digestion (fugitive emissions + storage of digestate)	0.1	0.0	0.2	kg t-1 (fresh weight input) y	9,442,221	9,442,221	9,442,221	tonnes (fresh weight)	0.53	0.04	1.93
Anaerobic digestion (landspreading of non-agricultural materials only)	1.1	1.0	1.2	kg t-1 (fresh weight digesta	6,619,804	6,487,930	6,883,536	tonnes (fresh weight)	7.51	6.68	8.54
TOTAL	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**36.18**	**20.63**	**64.50**

Note: The estimate of emissions from horses has been split into three categories for transparency and includes ALL horses, including horses counted in the agricultural census (and included with the agricultural emission sector in the inventory).

5. CONCLUSIONS

New UK estimates of non-agricultural NH_3 emissions were calculated and brought up to date to 2016 (or the latest available data), for a range of sources (solvent use, waste disposal, nature and other miscellaneous sources), using the latest updates available for source strength estimates ("emission factors") as well as source activity statistics/source populations.

Overall, emissions from sources reviewed for Sectors 2D, 5, 6 and 11 amount to 36.2 kt NH_3-N $year^{-1}$ for 2016, with a range of 20.6 – 64.5 kt NH_3-N $year^{-1}$. This constitutes a decrease of ~10 kt NH_3-N overall, compared with 2015 (46.2 kt NH_3-N). These changes are mainly due to the new emission factors for equines, causing a decrease in emissions by 6.9 kt NH_3-N, the removal of emissions from the spreading of sewage sludge to farmland (3.4 kt NH_3-N yr^{-1}) which is now counted in the agricultural inventory and decreases in emissions from landfill (by 0.3 kt NH_3-N), offset by increases in emissions from composting (by 0.25 kt NH_3-N), and seabirds (by 0.2 kt NH_3-N).

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