Ammonia emissions from UK non-agricultural sources in 2017: contribution to the National Atmospheric Emission Inventory

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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 2017 (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 average emission factor for land spreading of non-manure digestates from anaerobic digestion (AD) has increased to 1.19 kg NH_3-N t^{-1} digestate (range 1.07 – 1.3 kg) in 2017, from 1.14 kg NH_3-N t^{-1} digestate, due to a higher proportion of inputs as food wastes (higher N content) in 2017 (48%) than 2016 (45%).

5. There was a decrease in the emission factor for smoking by young people, from 4 g NH_3-N $smoker^{-1}$ yr^{-1} to 2.6 g NH_3-N $smoker^{-1}$ yr^{-1} (range 1.3 – 4.8), due to an increased amount of people smoking less cigarettes per day.

Emission source populations

6. Anaerobic digestion (AD) plants in the UK are estimated to have had inputs of approx. 11,426 kt in 2017 (increased from 9,442 kt compared with the reported inventory data for 2016) at 472 sites (excluding brewery/distillery AD sites), compared to 394 in 2016. Approx. 83% of materials are estimated to originate from non-farm sources (84% in the 2016 dataset). The emissions for 2017 were estimated at 0.64 kt NH_3-N yr^{-1} for fugitive and storage emissions at AD plants, and 9.4 kt NH_3-N yr^{-1} for landspreading of non-manure-based materials. Together these represent an increase of 2 kt NH_3-N yr^{-1} from 2016. Emissions from landspreading of manure-based feedstock are reported separately as part of Defra project SCF0107 (agricultural emission inventory).

7. The latest estimates of waste being land-filled, based on Local Authority landfill statistics for the four countries of the UK, show another large decrease of 1,230 kt to 5,843 kt (approx. 18.5%) (following a decrease of 2,163 kt last year), while the amount of sewage sludge going to landfill remained at 9.3 kt. Overall there has been a substantial relative decrease (17.2%) in NH_3 emissions from this source, down from 0.99 kt NH_3-N in 2016 to 0.82 kt NH_3-N in 2017. This decrease is due to reduced amounts of waste to landfill.

8. Since the 2016 inventory, sewage sludge applied to agricultural land is counted under the agricultural section of the UK Greenhouse Gas Inventory (Defra project SCF0107) and is removed from this report series. Emissions from sewage sludge used in land reclamation is still reported here and are currently 0 kt NH_3-N yr^{-1}.

9. The equine population estimate for the UK (including horses, donkeys, mules, etc.) has again been divided into three categories, for improved transparency, in the same way as for 2016; 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. 10,000 in the total number of agricultural equines (i.e. horses counted as present on agricultural holdings in the annual June Census/Survey), or about 4%. The best emission estimate for 2017 is 4.80 kt NH_3-N for all horses, a decrease of 0.04 kt NH_3-N from 2016.

10. Inputs to permitted composting facilities increased by approximately 2% to 2,499 kt dry matter. This was reflected by an increase of 2% in the emission estimate, to 5.56 kt NH_3-N yr^{-1} (compared with 5.43 kt NH_3-N yr^{-1} in 2016). The increased proportion of inputs in the form of food wastes (from 5.1% in 2015 to 8.5% in 2016), is retained in the 2017 inventory. The amount of waste input to household-based composting in 2017 in the UK was approximately 236 kt (an increase from 226 kt in 2016). This resulted in an emissions estimate of 0.11 kt NH_3-N yr^{-1} for 2017.

11. New population figures for domestic pets (dogs increased by 500,000 from 2016 to 2017) resulted in increased emissions by 0.32 kt NH_3-N yr^{-1} for dogs between 2016 and 2017. Population estimates and emissions from cats remain unchanged.

12. The source populations for other categories (e.g., human subcategories, household appliances, wild geese, wild deer and wild seals) were also updated, most changes were very small in absolute terms and have not resulted in substantial changes in emissions. The largest of these changes is for emissions from wild deer where new population estimates have resulted in increased emissions by 0.034 kt NH_3-N yr^{-1}. No new activity data were found/available for sea birds, game birds, domestic chickens, other wild animals, parks and gardens, golf courses, biomass burning and sewage works.

UK Emission estimates for 2017

Overall emissions from the sources reviewed for Sectors 2D, 5, 6 and 11 amount to 38.4 kt NH_3-N $year^{-1}$ for 2017, with an uncertainty range of 22.2 – 67.8 kt NH_3-N $year^{-1}$. This constitutes a decrease of 2.3 kt NH_3-N yr^{-1}, compared with the 2016 estimate (36.2 kt NH_3-N yr^{-1}). The main changes between 2016 and 2017 are the increase in emissions from the landspreading of digestates from anaerobic digestion (by 1.9 kt NH_3-N yr^{-1}, 26%), pet dogs (by 0.32 kt NH_3-N yr^{-1}, 6%) and composting (by 0.13 kt NH_3-N yr^{-1}, 2.5%). Other notable changes are decreased emissions from landfill by 0.2 kt NH_3-N yr^{-1} (17%) and the increase in emissions from fugitive releases from anaerobic digestion plants sites by 0.11 kt NH_3-N yr^{-1} (21%). The largest relative changes were for emissions from landspreading of digestates from anaerobic digestion (increased 26%) and fugitive releases from anaerobic digestion plants (increased 21%).

N.B. Due to structural changes in the 2016 inventory, emissions from sewage spreading onto agricultural land (2015: 3.44 kt NH_3-N yr^{-1}), are reported as part of the 2017 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 2017, 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 2018.

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 2017 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 2017 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 2017), a 10% increase from the figure of 0.5% used in inventory years prior to 2013.

The input of 9.3 kt of sewage sludge to the landfill process in 2017 (reintroduced to the inventory estimates in 2013 following the availability of new data) is the same as the previous estimate in 2016, due to availability of data (the best estimate of N content for sewage sludge remained at 3.6% as per previous years). The 2017 best estimate emission factor is unchanged at 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 2017 inventory. The best estimate emission factor for fugitive and storage emissions at UK AD plants is 0.056 kg NH_3-N t^{-1} fresh weight feedstocks (range 0.004 – 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 emission 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 of 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). This represents 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.). This emission factor is carried forward for 2017. The emission factor for land spreading digestates from non-manure, non-food waste materials was not updated from 2015

onwards 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, 2016) was combined with an analysis of inputs to all AD sites in the UK (NNFCC, 2018) to produce an average emission factor of 1.19 kg NH_3-N t^{-1} feedstocks (range 1.07 – 1.31 kg).

NB: Emissions from landspreading of manure-based digestate are now (from 2017) included explicitly in the agricultural inventory and are not presented here.

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 2017 based on waste data reports and Local Authority waste streams (see Section 3.2.2). The 2016 best estimate emission source strength of 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, is carried forward into the 2017 estimations.

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 2017 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 have 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, however the activity data are currently reported as zero.

3.2.2. New source data

Landfill

Source numbers were updated with 2017 landfill statistics (local authority (LA) collected waste) for England (Defra, 2017), Scotland (SEPA, 2018), Wales (StatsWales, 2017) and Northern Ireland (NIEA, 2018). Data for England and Wales covered the financial reporting year 2016/17 while Scotland and Northern Ireland report the 2017 calendar year. 9.3 kt of sewage sludge, at 3.6% N content, was included in the total amount of landfilled materials (same as 2016, via Sarah Gilhespy, Rothamsted Research, pers. comm.). UK landfill totals for 2017 from LA wastes amount to 5,843 kt of materials – a reduction of 1,230 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 2017 is 0.82 kt NH_3-N $year^{-1}$ (range 0.73 - 0.9 kt), compared with 0.99 kt NH_3-N $year^{-1}$ in 2016.

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 2017 inventory, along with updates for existing sources. The comprehensive database for AD sites now contains 472 plants operational during 2017 (NNFCC, 2018), an increase from 394 in the 2016 methodology (356 in 2015). These plants are estimated to process 12,238 kt of materials (fresh weight) during 2017, an increase of approx. 20% on the 2016 methodology. Approximately 83% of input materials to AD were from non-manure sources, such as crops and food wastes, similar to the 84% in 2016. As per 2016, large volumes of materials (approx. 813 kt at 24 sites) were 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 2017 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 emissions inventory (Defra project SCF0107). 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 (2018) data differs from the previous data collections in 2015 (Biogas, 2016; WRAP, 2016b). This is because the reported inputs to each site in NNFCC reflect the actual tonnes inputted by feedstock category, compared with previously available datasets, which utilised the capacity of the site as the presumed input (in the absence of quantitative input data). Furthermore, input materials to each site are now reported as quantities for 'manures', 'crops', 'food' and 'other' for each site, thereby reducing the uncertainty when estimating category proportions. In the NNFCC dataset, multiple manure types may still be listed in the inputs, with an aggregate 'manure' input total. This allows input materials, and therefore resulting digestates, to be characterised with more detail, and also enables more accurate estimation 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 2017 was 0.64 kt NH_3-N yr^{-1} (range 0.05 – 2.34 kt) for fugitive and storage emissions at AD plants, and 9.4 kt NH_3-N yr^{-1} (range 8.4 – 10- kt) for landspreading of non-manure-based materials. The 21% increase in fugitive and storage emissions is due to the increase of materials sent to AD processing plants. Regarding emissions from landspreading of digestate, there was a 26% increase (1.9 kt yr^{-1}) in estimated emissions due to the increase of materials input to AD plants and therefore an increase in digestates being spread on land. There was also a slight increase in the proportion of food-based inputs to AD (48% from 45%), which have a high N content.

This results in a total estimated emission of 10.1 kt NH_3-N (8.4 – 13.1 kt) from anaerobic digestion for 2017, compared with 8 kt NH_3-N in 2016, an increase of 2.1 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 2017 (EA, 2018; WDF, 2018). 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. Such data were not available for Northern Ireland and so LA summary data were used, as in 2015 (NIEA, 2018). 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 2017 inventory. Overall, 6,289 kt of materials were estimated to have been composted in 2017 - producing 2,499 kt of dry matter and amounting to emissions of 5.56 kt NH_3-N $year^{-1}$ (range 1.4 – 7.4 kt), a slight increase from the 2016 estimate of 5.43 kt NH_3-N $year^{-1}$. As in the previous inventory year, input materials have an increased proportion of food wastes (that have a higher N content), from 5.1% in 2015 (Horne *et al.*, 2013) 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 first 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, 2018) and totalled 237 kt for 2017 (up from 226 kt in 2016). The best NH_3 emission estimate for 2017 is 0.11 kt NH_3-N $year^{-1}$ (range 0.05 – 0.16 kt).

Landspreading of sewage sludge

This source was removed to the agricultural inventory (see Section 3.2.1 for details) in the 2016 inventory update.

Emissions from sewage used for land reclamation are in the remit of this report series, but are currently estimated to be zero, as zero tonnage for this purpose is reported in the official statistics for 2017. However, there is a residual time line for this source in the backcast time series, 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 2016 submission of the agricultural inventory, used in the 2016 calculations, and brought forward for the 2017 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 16.1 kg NH_3-N $horse^{-1}$ (range 14.5 – 17.8), a decrease of 41% from the 2015 inventory, introduced in the 2016 inventory. 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% from the 2015 inventory, also introduced in the 2016 inventory.

3.3.2. New source data

Horses

The UK population estimate for horses was updated for the 2017 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 953,813 equines (range 0.86 – 1.05 million), down from 963,423 in 2016, representing a continual decrease from the 2005 estimate. Numbers of horses kept by professionals (as a proxy for higher protein diets) are estimated at 87,112. Combined with the new (for the 2016 inventory) source strength data outlined in Section 3.3.1, estimated emissions from horses for 2017 are 4.8 kt NH_3-N (range 4.3 – 5.3 kt), a decrease of 1% compared with 2016.

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 2016) and 258,459 equines kept by private owners elsewhere (a decrease of ~10,000 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 when 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 2017 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 2017.

Other sources – cigarette smoking

The latest smoking statistics available for the UK are from the Adult Smoking Habits in the UK 2017 bulletin (ONS 2018). The percentage of male adults who smoke decreased in 2017 from 18% to 17% while the percentage of women decreased from 14% to 13%. There were no new data available for 2017 on the number of cigarettes smoked by adults so the numbers from 2016 are carried forward. Therefore, the emissions per smoker of NH_3-N yr^{-1} are unchanged. The emission factor per cigarette smoked is unchanged from previous estimates, with no relevant new data found in the literature.

For young smokers, new statistics (NHS Digital, 2016) show that the proportion of regular smokers remained at 3% and the proportion of occasional smokers rose from 2% to 4%. The number of cigarettes smoked by regular smokers decreased from 31.1 to 26.1 cigarettes per week and the number of cigarettes smoked by occasional smokers decreased from 5 to 4 cigarettes per week. These changes result in a decrease in the average emission factor per young smoker from 4 to 2.6 g NH_3-N yr^{-1} (range 1.3 to 4.8).

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. For parks and gardens, an average of all fertiliser types was used rather than just ammonium sulphate and di-ammonium phosphate. 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 2017 is 3.07%. 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. 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), and resulting in 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 2017 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 2017. 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 2016 to 2017. 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-2017 estimate of 66,040,229 (ONS 2018). This constitutes an increase of approx. 392,000 people or 0.6%, compared with 2016. 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

The decrease in UK emissions from adult cigarette smoking (by ~4%) is due to the decrease in the proportion of adults smoking. Cigarette smoking emissions from young people decreased by 8% to 0.9 t NH_3-N yr^{-1} for 2017, due to the lower number of cigarettes smoked by both regular and occasional smokers.-

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 2017, with a very small increase of ~5 t NH_3-N yr^{-1} from 2016, due to the overall increase in the UK population.

Pets

New survey data from the Pet Food Manufacturers Association (PFMA 2018) for 2017 show that the UK population estimate for dogs has increased by approx. 500,000 to 9 million from 2016 figures, while cats have remained unchanged at 8 million. With the same emission estimate per animal as used for previous inventory years, emissions for 2017 are estimated to have increased from 5.43 kt NH_3-N yr^{-1} to 5.75 kt NH_3-N yr^{-1} for dogs (range 2.4 – 10.02 kt), and remained 0.89 kt NH_3-N yr^{-1} for cats (range 0.38 – 1.43 kt).

Seabirds

No new estimates of population trends for seabirds were made in 2017, so last year's 2000 to 2015 time series (JNCC 2016) was carried over from the 2016 inventory for 2017. 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 in 2017 remain at 2.51 kt NH_3-N yr^{-1} (range 1.68 – 5.02 kt), the same as 2016.

Wild animals

For the 2017 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 1,812,000 deer in the UK in 2017, an increase of 2.6% from the 2016 inventory. Overall the emission estimate for 2017 was 1.65 kt NH_3-N (range 0.62 – 4.19 kt), an increase of ~2% from 2016.

SCOS (2018) estimates grey seal population numbers of 141,000 (117,500 – 168,500) for 2016 (most recent best estimate). This is an increase (~1 %) on the previous population estimates from 2015, with an emission estimate of 62 t NH_3-N. Furthermore, SCOS estimates the harbour seal population in the UK to be 43,500 (35,600 - 58,000). This is a minor increase of 0.5% on previous population estimates from 2015, with an emission estimate of 19 t NH_3-N. In total, emissions from seals are estimated to be 81 t NH_3-N.

The 2017 estimate of wild geese populations in the inventory was updated with the best estimates of various species types from different sources (Brides et al. 2018; Musgrove *et al.*, 2011; WWT, 2018). Overall, approx. 223,000 geese are estimated to be resident in the UK all year round (a decrease of ~1% from last year's estimate), with a further approx. 1,020,000 (previously 1,038,000) 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 125 t NH_3-N (range 94 - 157 t) for 2017, compared with 127 t for 2016. 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 2017, 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 2017; The Ranger 2011), including the National Farmers Union chairman, estimate the population at 0.5 to 3 million. A best estimate of 1.75 million chickens was used for the 2017 inventory. Estimated emissions are 0.42kt NH_3-N yr^{-1} (range 0.12 – 0.74 kt) for 2016, a decrease of 12.5% on previous estimates due to a decrease in the lowest estimate of domestic chicken population. It is currently not possible to develop a complete timeline for this new source.

3.5. New UK total emissions for 2017

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 38.4 kt NH_3-N $year^{-1}$ for 2017, with a range of 22.2 – 67.8 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 2017 UK population.

Waste treatment and disposal, excluding incineration (Sector 5)

Landfill

Landfill emissions are estimated to have decreased by ~17% from the 2016 emission estimate (0.99 kt NH_3-N) to 0.82 kt NH_3-N in 2017, due to the reduction of inputs to landfill, largely driven by reductions in England and Wales.

Composting

Emissions from permitted composting sites for 2017 are ~2.5% higher than the 2016 estimate, at 5.56 kt NH_3-N, compared with 5.43 kt NH_3-N previously. This is due to an increase in materials sent to compost. Furthermore, household based composting emissions are 4% higher than 2016, 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 2017 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 2017 with updated detailed data on AD sites and their inputs (NNFCC, 2018). The methodology update in 2016, 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), was carried forward to 2017.

Land spreading emissions from digestate of non-manure origin were estimated at 9.4 kt NH_3-N yr^{-1} (range 8.3 – 10.8 kt), an increase of 1.9 kt due to increased inputs to AD. Fugitive and storage emissions at AD plants were estimated at 0.6 kt NH_3-N yr^{-1} (range 0.05 – 2.3 kt), a 21% increase from 2016, due to the increases in inputs to AD facilities. This results in a total estimated emission of 10.1 kt NH_3-N yr^{-1} (range 8.4 – 13.1 kt) from AD for 2017, compared with a total of 8 kt NH_3-N yr^{-1} in 2016.

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 2017 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 ~1% from the 2016 emission estimate (4.84 kt NH_3-N) to 4.8 kt NH_3-N in 2017. This was due to a decrease in numbers of horses kept on agricultural holdings by ~10,000 (~4%) in 2017, while populations of professional and 'normal' privately owned horses remained unchanged, with no new data available.

Natural sources (Sector 11)

Forest and other vegetation fires

No changes were made to area burnt under muirburn schemes for the 2017 inventory.

Mammals

There were small changes in NH_3 emissions from (domestic) mammals for 2017: there was an increase in emissions from dogs by 0.32 kt NH_3-N yr^{-1} to 5.75kt NH_3-N yr^{-1}, due to new population estimates.

Other animals

The largest change in NH_3 emissions from other animals was wild deer, which increased from 1.61 kt NH_3-N yr^{-1} to 1.65 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, other major wild animals or wild seals) or no changes at all (seabirds, gamebirds).

Humans

There were marginal decreases (<0.5%) in emissions from humans between 2016 and 2017, mainly due to the changes in the emissions from smokers, despite the continuing increase in the UK population (by 392,000 persons or 0.6%) 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 2016, due to no availability of updated data.

Table 1: Ammonia emissions from UK non-agricultural sources for 2017

2017 (Ammonia as NH3-N)	emission estimates source-1				number of sources				UK emissions 2017 (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	2.04	0.69	6.21	g person-1 yr-1	66040229.00	-	-	persons	0.13	0.05	0.41
human sweat	10.17	1.56	42.08	g person-1 yr-1	63697063.00	-	-	persons	0.65	0.10	2.69
infants emissions < 1yr	11.70	2.38	54.20	g infant-1 yr-1	763201.00	-	-	children <1 yr	0.01	0.00	0.04
infants emissions 1-3 yrs	14.63	2.98	67.75	g infant-1 yr-1	1579965.00	-	-	children 1-3 yr	0.02	0.00	0.11
cigarette smoking (adults)	15.84	7.92	28.68	g smoker-1 yr-1	7867227.25	-	-	smokers	0.12	0.06	0.23
cigarette smoking (young people)	2.63	1.32	4.77	g smoker-1 yr-1	357079.59	-	-	smokers	0.00	0.00	0.00
horses kept by professionals	16.15	16.15	16.15	kg animal-1 yr-1	87112.00	78400.80	95823.20	animals	1.41	1.27	1.55
Non-agricultural 'normal' horses	3.91	3.91	3.91	kg animal-1 yr-1	608242.38	547418.14	669066.62	animals	2.38	2.14	2.62
Agricultural 'normal' horses	3.91	3.91	3.91	kg animal-1 yr-1	258458.90	232613.01	284304.79	animals	1.01	0.91	1.11
dogs	0.64	0.30	1.01	kg animal-1 yr-1	9000000.00	8100000.00	9900000.00	animals	5.75	2.39	10.02
cats	0.11	0.05	0.16	kg animal-1 yr-1	8000000.00	7200000.00	8800000.00	animals	0.89	0.38	1.43
domestic chickens	0.25	0.00	0.00	kg animal-1 yr-1	1750000.00	500000.00	3000000.00	birds	0.43	0.12	0.74
wild deer (large)	1.45	0.73	2.90	kg animal-1 yr-1	679128.49	509346.37	848910.61	animals	0.98	0.37	2.46
wild deer (small)	0.58	0.29	1.16	kg animal-1 yr-1	1137722.65	853291.99	1487259.47	animals	0.66	0.25	1.73
other major wild animals (mammals inc. seals)	-	-	-	-	-	-	-	-	1.03	0.28	2.76
wild geese	-	-	-	kg bird-1 yr-1	1243943.00	-	-	birds	0.13	0.09	0.16
seabirds	-	-	-	-	6385158.39	-	-	birds	2.51	1.68	5.02
biomass burning (heather burning, "muirburn")	1.05	0.30	2.39	g m-2 yr-1	184600566.67	131310340.00	276900850.00	burnt area in m2	0.19	0.04	0.66
ecosystems	0.00	0.00	0.00	-	0.00	0.00	0.00	-	0.00	0.00	0.00
sewage works	-	-	-	-	-	-	-	-	1.20	0.70	4.90
sewage spreading to farmland	NA	NA	NA	0	NA	NA	NA	0	NA	NA	NA
sewage sludge used in land reclamation	0.00	0.00	0.00	EF kg t-1 (dry solids	0.00	0.00	0.00	kt total dry solids yr-1	0.00	0.00	0.00
landfill	0.14	0.13	0.15	kg t-1 landfilled	5852467.21	-	-	t landfilled (MSW + slud	0.82	0.73	0.90
appliances &household products	-	-	-	-	-	-	-	-	1.00	0.30	3.68
non-agricultural fertilizers (households)	-	-	-	-	-	-	-	-	0.23	0.08	0.48
composting	2.23	0.57	2.98	kg NH3-N t-1 dry ma	6286716.92	-	-	t of dry matter compost	5.56	1.43	7.45
household composting	0.45	0.23	0.68	kg NH3-N t-1 fresh v	236602.96	-	-	t of fresh matter compo	0.11	0.05	0.16
game birds (pheasants and red-legged partridge)	0.02	0.01	0.05	kg bird-1 yr-1	50287533.00	45258779.70	55316286.30	birds	0.84	0.23	2.79
parks and gardens	0.70	0.23	1.40	kg ha-1 yr-1	285997.16	278383.00	285997.16	hectares	0.20	0.07	0.40
golf courses	0.72	0.42	1.18	kg ha-1 yr-1	130703.02	0.00	0.00	hectares	0.09	0.06	0.15
Anaerobic digestion (fugitive emissions + storage of	0.06	0.00	0.20	kg t-1 (fresh weight	11425858.00	-	-	tonnes (fresh weight)	0.64	0.05	2.34
Anaerobic digestion (landspreading of non-agricultur	1.19	1.07	1.31	kg t-1 (fresh weight	7943528.17	7785287.46	8260000.11	tonnes (fresh weight)	9.44	8.33	10.79
TOTAL	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**38.43**	**22.16**	**67.8**

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 2017 (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 38.4 kt NH_3-N $year^{-1}$ for 2017, with a range of 22.2 – 67.8 kt NH_3-N $year^{-1}$. This constitutes an increase of ~2 kt NH_3-N overall, compared with 2016 (36.2 - 46.2 kt NH_3-N). These changes are mainly due to the increases in emissions from landspreading of digestates from anaerobic digestion (by 1.9 kt NH_3-N), emissions from pet dogs (by 0.3 kt NH_3-N) and from composting (by 0.14 kt NH_3-N), offset by decreases in emissions from landfill (by 0.2 kt NH_3-N).

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