Ricardo
Energy & Environment

Ammonia futures: understanding implications for habitats and requirements for uptake of mitigation measures

Stakeholder Feasibility Workshops and supporting review

Report for Defra

ecm_53127

ED 11554 | Issue Number 1 | Date 08/07/2019

Customer:

Defra

Customer reference:

ecm_53127

Confidentiality, copyright & reproduction:

Contact:

Dr Jeremy Wiltshire
Ricardo Energy & Environment
Gemini Building, Harwell, Didcot, OX11 0QR, United Kingdom

t: +44 (0) 1235 75 3593

e: Jeremy.Wiltshire@ricardo.com

Ricardo is certificated to ISO9001, ISO14001 and OHSAS18001

Author:

Jeremy Wiltshire

Approved By:

Hugh Martineau

Date:

08 July 2019

Ricardo Energy & Environment reference:

Ref: ED11554- Issue Number 1

Executive summary

Based on thirteen regional stakeholder workshops across England, this project has provided an insight into the views of the farming industry about the ability of farming businesses to implement actions to mitigate ammonia emissions.

Projections of UK ammonia emissions, under a business as usual scenario, suggest action is required for the UK to meet 2020 and 2030 targets for ammonia emissions, as agreed under the revised Gothenburg Protocol and National Emissions Ceiling Directive. Of the ammonia emissions from agriculture in England (199 kt in 2016[1]), 85% were from agriculture.

In May 2018 the draft Clean Air Strategy was published for consultation, and the Clean Air Strategy 2019 was published on 14 January 2019. This Strategy document sets out plans to introduce rules on specific emissions-reducing practices including actions related to fertiliser use, livestock housing design, slurry storage, and spreading of slurry and solid manures to land. Plans to regulate to reduce pollution from organic and inorganic fertiliser use are also given, alongside plans for an extension of environmental permitting to dairy and intensive beef farms.

A list of mitigation actions was compiled for discussion at the stakeholder workshops, which included the measures consulted on in the draft Clean Air Strategy alongside other potential mitigation options. The co-benefits/potential trade-offs with other environmental areas were considered, providing an update to the evidence base on ecosystem impacts from current and potential ammonia reduction. Farmscoper was used to model the secondary impacts of ammonia mitigation measures on emissions of climate change gases and of nutrients to water. The results demonstrate that generally, those measures that have the greatest impact on ammonia emission produce the greatest change in emission of other pollutants.

The locations for the 13 regional workshops across England were based, approximately, on the areas of responsibility for the 13 Natural England Area Teams. We registered a total of 186 attendees across the 13 events.

The stakeholder workshops were well attended and well received by attendees with good engagement during the meetings. In general, there was much consistency between regions, with similar points and comments on the mitigation actions being raised across the country despite the differences in farming systems, soil types and climate. Where there were regional differences, the variation mainly related to differences in farming systems, soil types and rainfall.

The points made were often made strongly, and the active discussions brought out much knowledge that the farming industry has, to contribute to the formulation and implementation of policy to mitigate ammonia emissions. The willingness to contribute and the quality of the discussions can be harnessed by government as the policies outlined in the Clean Air Strategy 2019 are developed further.

The project reported here included a work package reported separately, on the assessment of scientific tools for interpretation of data.

[1] Air Pollutant Inventories for England, Scotland, Wales, and Northern Ireland: 1990-2016. http://naei.beis.gov.uk/reports/reports?report_id=970

Table of contents

1 Introduction

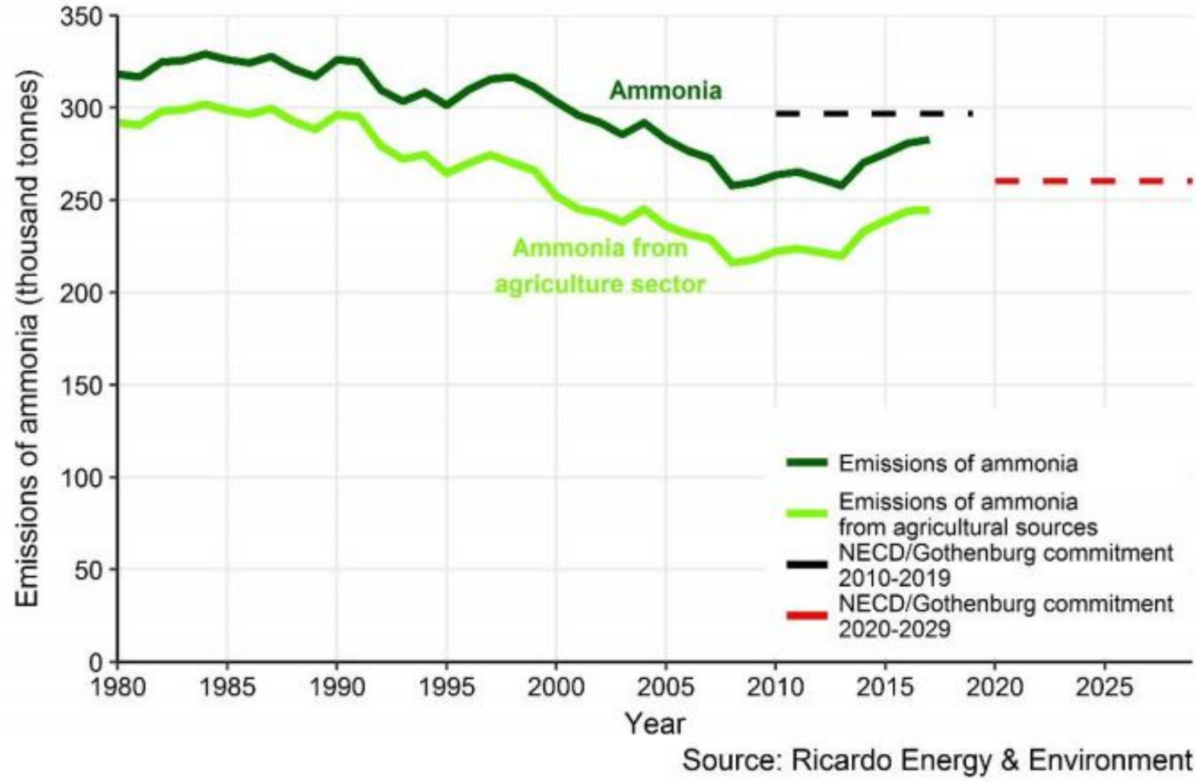
1.1 Background and policy context

Ammonia (NH_3) is an air pollutant that reacts with other pollutants to form aerosols (fine particulate matter, $PM_{2.5}$), which are harmful to human health. Ammonia and associated, secondary $PM_{2.5}$ is alsodeposited to sensitive ecosystems, increasing available nitrogen and influencing species composition. Ammonia is also toxic to aquatic organisms following deposition to water.

Agricultural sources emit 87% of UK ammonia emissions[2]. The main sources of ammonia emissions from agriculture in the UK are livestock excreta (particularly from housed livestock and spreading of manures to land) and nitrogen fertilisers that contain urea. The emission of ammonia is a loss of reactive N from the farming system, where it has value as a nutrient.

The Gothenburg Protocol sets ceilings for ammonia emissions as decreases from 2005 levels of 8% by 2020 and 16% by 2030, and these ceilings are adopted by the National Emission Ceilings Directive (2016/2284/EU). The targets are set at a national (UK) level, so are not spatially targeted to protect sensitive sites. The UK is not on target to meet the 2020 and 2030 targets, unless further action is taken as outlined in the Clean Air Strategy 2019; the trend in emissions is shown in Figure 1.

Figure 1. Emissions of ammonia in the UK, from 1980 to 2017[3].



[2] Emissions of air pollutants in the UK, 1990 to 2017, by pollutant and by major emissions source https://www.gov.uk/government/statistical-data-sets/env01-emissions-of-air-pollutants Accessed 13 March 2019.

[3] Defra National Statistics Release: Emissions of air pollutants in the UK, 1970 to 2017. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/778483/Emissions_of_air_pollutants_1990_2017.pdf Accessed 25 April 2019.

Annual changes in UK ammonia emissions from agriculture are related to changes in numbers of livestock, especially housed livestock, and changes in the amount of inorganic fertiliser use, particularly urea-based fertilisers.

In May 2018 the draft Clean Air Strategy was published for consultation, and the Clean Air Strategy 2019 was published on 14 January 2019. This Strategy document sets out plans to introduce rules on specific emissions-reducing practices including:

- action to reduce emissions from urea-based fertilisers
- a requirement for all solid manure and solid digestate applied to bare land (other than no-till land) to be incorporated within 12 hours;
- a requirement to spread slurries and digestate using low-emission spreading equipment by 2025 – perhaps earlier for digestate or large volumes of slurry;
- a requirement for slurry and digestate stores to be covered by 2027 – perhaps earlier for digestate or large volumes of slurry;
- design standards for new intensive poultry, pig and beef livestock housing and for dairy housing.

Plans to regulate pollution from organic and inorganic fertiliser use are also given:

- put in place a robust framework to limit inputs of nitrogen-rich fertilisers such as manures, slurries and chemicals to economically efficient levels backed up by clear rules, advice and, where appropriate, financial support;
- task an expert group including agricultural policy experts, agronomists, scientists and economists to make recommendations on the optimal form of regulation to minimise pollution from fertiliser use. The recommendations should prioritise the use of organic fertilisers, limiting ammonia emissions, greenhouse gas (GHG) emissions and water pollution and protecting sensitive habitats at least in line with government commitments.

The Clean Air Strategy 2019 also sets out plans for an extension of environmental permitting to dairy and intensive beef farms by 2025, including the development of Best Available Technique (BAT) documents for the sector.

Mitigation of ammonia emissions from agriculture is encouraged by a Government pilot scheme, launched on 18 September 2018 and backed with £3m of funding, to help farmers reduce ammonia emissions from agriculture. The Catchment Sensitive Farming partnership between Defra, the Environment Agency and Natural England[4] is supporting farmers in high priority water catchment areas to mitigate ammonia emissions, through training events, tailored advice, individual farm visits and support with grant applications.

This project has improved the understanding of the farming industry's perceptions of mitigation actions that will make a contribution towards legal obligations on emissions reduction. The improved understanding will help inform policy development.

1.2 Objectives

The four objectives were:

1. To develop an understanding of the feasibility and likely obstacles to the implementation of proven ammonia mitigation measures.
2. To provide a horizon scan for the implications of adopting potential measures in consideration and consider links and co-benefits/potential trade-offs with other environmental areas (e.g. water quality).
3. To compare effectiveness of a national versus local approach to ammonia mitigation.

[4] https://www.gov.uk/government/news/3m-support-scheme-launched-to-reduce-air-pollution-from-farming

4. To update the current evidence base on ecosystem impacts from current and potential ammonia reduction:
    - to consider the future policy changes;
    - to include technological advances in agriculture, emission reduction techniques and new ammonia sources (e.g. anaerobic digestion);
    - to evaluate benefits for the wider environment.

1.3 Project structure and links to objectives

The project was based around review activities supported and informed by stakeholder input and academic expertise.

The work reported here was structured into two technical work packages, Work Package 0 and Work Package 1.

Work Package 0 is reported in Section 2 and focusses on the co-benefits and potential trade-offs, and addresses project objectives 2 and 4.

Work package 1 provided a summary of potential mitigation measures and their effectiveness, and then gained information from stakeholders on co-benefits, trade-offs, local factors, and barriers to implementation and incentives to overcome barriers. This was done through a series of 13 regional (England) stakeholder workshops. It is reported in Section 3, and it addresses project objectives 1 (from the perspective of stakeholders) and 3 (through regional differences in stakeholder views).

There was also another work package (Work Package 2) that focussed on modelling approaches to represent the effects of ammonia mitigation; this is reported in a separate report, and contributes to project objectives 2, 3 (modelling the effects of local targeting of mitigation actions) and 4.

2 Implications of adopting mitigation measures

2.1 Purpose

The work reported in this section considered co-benefits/potential trade-offs with other environmental areas, providing an update to the evidence base on ecosystem impacts from current and potential ammonia reduction.

The aim of the Farmscoper modelling was to identify the national and farm scale cost and reductions in nutrient (nitrate and phosphorus) and greenhouse gas (nitrous oxide and methane) emissions from agricultural land associated with the implementation of select ammonia mitigation measures.

2.2 Recent literature

A focused literature search was carried out to identify updates to the evidence base around the impacts of ammonia, both in terms of the impact pathways and quantification and monetisation of effects. This was done using internet search tools such as Science Direct and Google Scholar. Research reports from governments and agencies were also searched. This was a focused literature review to identify updates more recent than the evidence used in the damage costs estimates (see 2.3). The search focused on likely future changes in ecosystem impacts.

In 2018, Guthrie et al. (in collaboration with The Royal Society) published *The impact of ammonia emissions from agriculture on biodiversity – an evidence synthesis*[5], a summary of the existing evidence on the impacts on ammonia on biodiversity in the UK and the costs of various modes of intervention.

[5] Guthrie, S., S. Giles, F. Dunkerley, H. Tabaqchali, A. Harshfield, B. Ioppolo, C. Manville. 2018. 'The impact of ammonia emissions from agriculture on biodiversity – an evidence synthesis'. RAND Corporation, available at: https://royalsociety.org/~/media/policy/projects/evidence-synthesis/Ammonia/Ammonia-report.pdf

The report describes the four main ways ammonia can impact biodiversity:

- **Eutrophication** as a result of excess deposition of nitrogen in topsoil leading to nitrogen leaching in groundwater.
- **Acidification** through direct deposition of nitrogen compounds.
- **Direct toxicity** of ammonia on plant leaves and surfaces.
- **Indirect effects** resulting from changes in species composition and susceptibility of plant species to frost, drought and pathogens through air soil and water.

The report states that exceedances of the critical level (broadly the level below which significant harmful effects do not occur) can occur at levels far below the 8µg m^{-3} level established by the United Nations Economic Commission for Europe (UNECE) in 1992. Only the direct toxic effect had been used to establish the UNECE critical level, but subsequent evidence suggested that much of the impact occurs through changes species composition as a result of variation in the competitive ability of plant groups. In addition, other evidence subsequently emerged indicating impacts of ammonia on species composition and lichens at very low concentrations. Based on this evidence, critical levels were revised by UNECE in 2011 to be 1 and 3µg m^{-3} for lower plants and higher plants respectively.

The report highlights and discusses the challenges of monetising the impacts of ammonia emissions on biodiversity loss specifically. Various methods exist through which impacts can be estimated, which often produce varying estimations (and indeed different studies applying the same technique can generate very different results), and there is little consensus around which is the most preferable approach. . A list of these various methods, and examples of studies that have applied these methods to value impacts on biodiversity are presented in table 4 of Guthrie et al. (2018), replicated here in Table 1. This clearly demonstrates the uncertainty that exists around the quantification and monetisation of biodiversity impacts (which is one of a number of impacts of ammonia emissions). Where valuation is undertaken in practice, it is good practice to reflect this uncertainty in any analysis, for example through the use of ranges for the valuation of impacts.

Table 1. Estimated costs of biodiversity loss due to ammonia pollution (Extracted from Table 4 of TRS report - Guthrie et al. (2018).

Method	Estimate (£ per kg of NH_3 2018 prices)	Caveats	Source
Willingness To Pay (WTP)	£0.42	Includes breakdown by habitat type and notes differential dose response depending on existing nitrogen deposition; UK-specific.	Jones et al (2018)[6]
Ecosystem Restoration	£0.24	Assumes society willing to bear the costs of restoration and provide a lower bound estimate of those costs.	Ott et al (2006)[7]

[6] Jones, L., A. Milne, J. Hall, G. Mills, A. Provins, and M. Christie. 2018. 'Valuing Improvements in Biodiversity Due to Controls on Atmospheric Nitrogen Pollution'. Ecological Economics, 152: 358–66.

[7] Ott, W., M. Baur, Y. Kaufmann, R. Frishknecht, R. Steiner. 2006. 'Assessment of Biodiversity Losses'. Deliverable D4.2.-RS1b/WP4- July 06. NEEDS (New Energy Externalities Developments and Sustainability). Project number 502678. Switzerland

Method	Estimate (£ per kg of NH_3 2018 prices)	Caveats	Source
Ecosystem damage	£3.40-£16.80	For all of Europe, not UK-specific. Based on estimates for nitrogen rather than ammonia specifically.	Brink et al. (2011)[8]
Costs of eutrophication	£0.60	No distinction made between effect of nitrogen and phosphorous, and costs are quite heterogeneous. Values extrapolated by Brink et al. (2011) for N only. Freshwater costs only.	Brink et al (2011)
Stated preference	£3.70	Based on comparing current legislation to the costs associated with alternative legislative approaches and the reductions in emissions they would produce.	Eclaire (2015)[9]

Summarising the evidence presented in the table, Guthrie et al. (2018) conservatively conclude that for the UK biodiversity impacts are likely to be in the range of £0.2–£4 per kg of ammonia.

In addition, ammonia also has important effects for human health (presented in table 5 of Guthrie et al., 2018), estimated to be in the range of £2–£52 per kg NH_3. Combining estimates of the quantitative impacts of ammonia on biodiversity and human health, the report estimates a conservative total cost from ammonia pollution of £2.50 per kg ammonia (with a range of £2-£56/kg). This equates to an impact cost of £700M per year in 2020 if no action is taken to reduce ammonia emissions, with a range of £580Mm to £16.5B.

2.3 Damage Costs from the Interdepartmental Group on Costs and Benefits

The Interdepartmental Group on Costs and Benefits (IGCB) has published guidance on how to monetise the impacts associated with the emission of air pollutants. As part of this guidance, the Defra-led IGCB have developed 'damage costs' which aggregate and monetise the impacts associated with air pollutant emissions in the UK into a single impact value for each pollutant, expressed in terms of a '£' impact per tonne of emission. The existing evidence base around the

[8] Brink, C., H. van Grinsven, B. H. Jacobsen, A. Rabl, I. M. Gren, M. Holland, Z. Klimont, et al. 2011. 'Costs and Benefits of Nitrogen in the Environment'. In M. A. Sutton, C. M. Howard, J. W. Erisman, G. Billen, A. Bleeker, P. Grennfelt, H. van Grinsven, and B. Grizzetti, 'The European Nitrogen Assessment', 513–40. Cambridge: Cambridge University Press.

[9] ÉCLAIRE. 2015. 'Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems. Seventh Framework Programme. Theme: Environment'. Project Number 282910. As of 8 August 2018: http://www.eclaire-fp7.eu/sites/eclaire-fp7.eu/ files/eclaire-files/documents/Dissemination/ D24.2_final.pdf

environmental impacts of ammonia emissions was summarised, based on our experience of the IGCB damage costs.

Air pollutants, such as ammonia, have a range of associated detrimental impacts, including on human health and on the natural and built environments. Monetising these impacts is one way to facilitate direct comparison to abatement costs to understand if abatement measures present value-for-money from a social perspective. In addition, Social benefit is also linked to the inherent value of habitat[10]. However, inherent value of semi-natural habitat needs to be considered within any decision about cost-benefit and should not solely be based on monetisation. These values represent an average impact for an average unit of ammonia emission across the UK – by design they are simple to apply, but in achieving this they inherently overlook factors specific to any local context (e.g. unique local sensitive receptors) in which they are applied which may influence the size of impacts.

IGCB's damage costs include a £/tonne value for the emission of ammonia to air. The most recent damage cost published in January 2019 is £6,046 per tonne (2017 prices) of ammonia emission (with a low-high sensitivity range of £1,133 to £18,867 per tonne ammonia).The human health impacts captured by this damage cost focus on the contribution of ammonia as a precursor to the formation of Particulate Matter (PM), which in turn is strongly associated with a range of negative health impacts. The key impact pathways (i.e. those which present the greatest contribution to the overall damage cost) are the effects on long-term mortality rates, chronic heart disease and asthma in children. Exposure to secondary particulates is also associated with respiratory and cardiovascular hospital admissions, work and school days lost, stroke, lung cancer, diabetes and chronic bronchitis (however the evidence supporting the link to school days lost, diabetes and chronic bronchitis is considered less robust hence these impacts are only included in the high damage cost sensitivity). The existing ammonia damage costs do not capture any human health impact from direct exposure. The IGCB damage cost also includes the contribution of ammonia to impacts on ecosystems. Emissions of ammonia to air are also strongly linked to impacts on ecosystem services through eutrophication and acidification, as well as direct toxicity. However, ecosystem impacts are harder to quantify as they require the resolution of willingness to pay *vs* the actual cost of habitat restoration (see Table 1).

Defra commissioned several studies to explore ecosystem impacts in 2014, the key output of which was a study by Jones et al. 2014[11], which defined several pathways through which ammonia emissions impact on provisioning, regulating and cultural services. There were varying levels of confidence around the different pathways from ammonia emission to ecosystem impact – the following were ranked most highly as 'robust' or 'acceptable' by Jones et al. 2014:

- Negative impact on biodiversity: Increasing N deposition contributes to **aquatic** eutrophication and leads to reduced abundance and diversity of aquatic life (fish, invertebrates, birds) in rivers and lakes (cost associated with emission);
- Negative impact through prevalence of GHGs: increased N deposition leads to higher N_2O emissions, which themselves are a GHG (cost associated with emission);
- Positive impact through carbon sequestration: increasing N deposition leads to changes in plant growth and therefore carbon sequestration in biomass and soils. Responses are habitat specific but overall effect is higher growth and sequestration (benefit associated with emission).

Other pathways considered by Jones et al. 2014 (those labelled 'improvement desirable') include: :

- Positive impact on timber production: increasing N deposition leads to increased tree growth, and sale value (benefit associated with emission);

[10] See Natural Capital Indicators: http://publications.naturalengland.org.uk/publication/6742480364240896

[11] Jones, L., Mills, G., Milne, A., 2014. Assessment of the Impacts of Air Pollution on Ecosystem Services – Gap Filling and Research Recommendations. Defra Project AQ0827, Final Report, July 2014.https://uk-air.defra.gov.uk/assets/documents/reports/cat10/1511251140_AQ0827_Asessment_of_the_impacts_of_air_pollution_on_Ecosystem_Services_Final_report.pdf

- Positive impact on livestock production: increasing N deposition leads to increased pasture yield, leading to higher livestock growth and value (benefit associated with emission);
- Negative impact on recreational fishing: increasing N deposition contributes to aquatic eutrophication and leads to reduced fish abundance and diversity in rivers and lakes (cost associated with emission).

Only those pathways ranked as 'robust' or 'acceptable' by Jones et al. (2014) are included in the damage costs (across all sensitivities). As such, the damage costs present a conservative estimate of the damages associated with emissions and several associated effects are not captured. In addition, the damage costs represent the damage from an average unit of emission in the UK. When applied at a local scale or in specific contexts (e.g. semi-natural habitats), they may not reflect any specific parameters of the local environment which may affect the size of impacts. When applying the damage costs, it is critical to consider uncertainties around the estimates, and at least qualitatively consider any other impacts or local parameters which would influence the size of impacts assessed (as discussed further in the next section).

The relative size and direction of impacts explored by Jones et al. (2014) is presented in Table 2.

Table 2. Impact per tonne of ammonia emission at 2014 prices, from Jones et al, 2014.

Impact category	Impact per tonne ammonia emission (2014 prices)	
Timber production	-93.10	(#)
Livestock production	-294.10	(#)
CO_2 GHG	-1,267.10	#
N_2O GHG	338.40	#
Recreational fishing	2.20	(#)
Appreciation of Biodiversity (across habitats: acid grassland, heath, dunes and bogs)	413.80	##

Note: +ve value represents damage (cost) associated with additional unit of emission; -ve value represents benefit associated with additional unit of emission; each pathway is ranked based on the strength of underlying evidence - ## = robust, # = acceptable, (#) = improvement desirable

It is important to note that there are uncertainties around the estimation of these impacts, and around the strength of the link from emission to impact itself. There are wide uncertainty bounds around the estimation of each individual pathway, and around the overall ammonia damage cost: IGCB's guidance recommends a low and high damage cost per tonne for ammonia of £1,133 and £18,867 respectively.

Although there are benefits associated with increased nitrogen, they do not outweigh the negative impacts on human health. Additionally, there are a wide range of negative impacts on ecosystems including reduction of species richness and diversity, soil acidification, and local extinction of some plant species with effects on habitat microclimates and pollinators that are difficult to monetise.

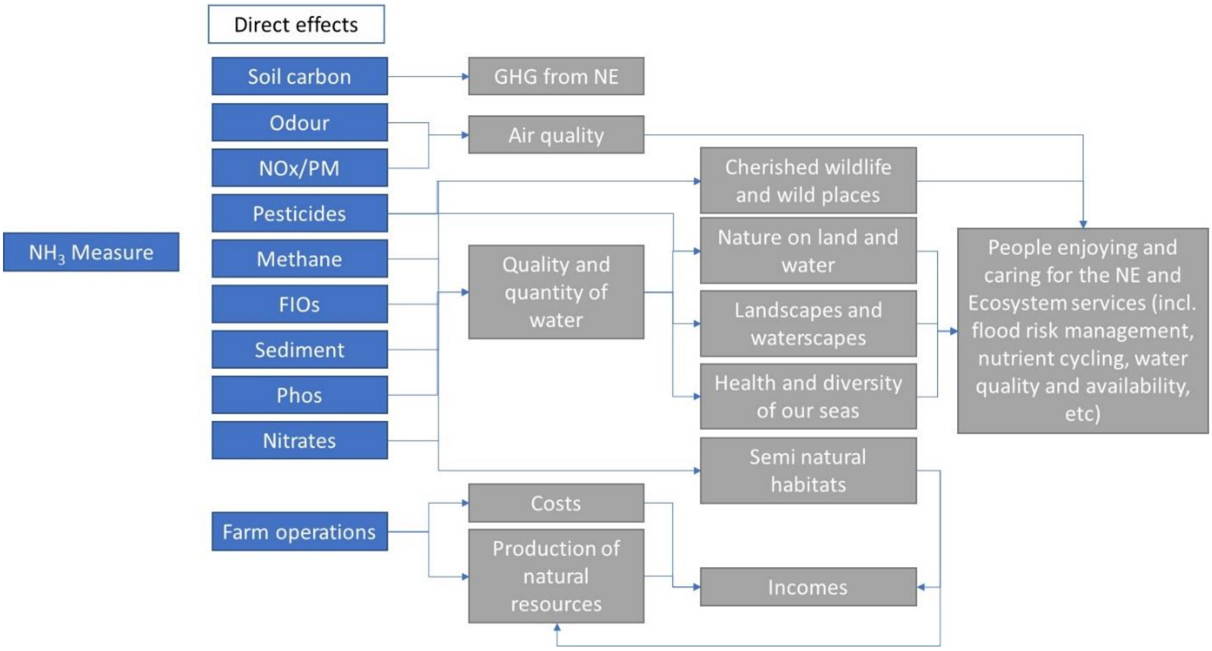
2.4 Qualitative framework

A measure to reduce ammonia pollution will have impacts beyond the immediate effect on emissions. The measure could affect farm operations (inputs and outputs) and have other environmental impacts.

Figure 2 sets out an illustrative framework of how a measure designed to reduce ammonia emissions can have positive and negative impacts on a wide range of issues and stakeholders. The headings used (edited) are based on from the list of draft headline indicators, with editing (being consulted on at the time of writing) for the 25 Year Environment Plan[12] with cost and incomes added to take into account co-benefits (or costs) for the land manager.

Using this framework, we can deduce expected co-benefits by identifying the direct effects of a measure beyond just a reduction in ammonia emissions.

Figure 2. A co-benefit framework for NH_3 measures.



Notes: NE = natural environment; FIO = faecal indicator organism; NOx = Nitrogen oxides released as air pollutants; PM = Particulate Matter; Phos = Phosporous emission to water; GHG = Greenhouse Gas; production of natural resources relates to farming productivity and soil health (indicators H28 and H29 from the 25 year Environment Plan)

2.5 Farmscoper modelling

2.5.1 Aims of the Farmscoper modelling

The aim of the Farmscoper modelling was to identify the national and farm scale cost and reductions in nutrient (nitrate and phosphorus) and greenhouse gas (nitrous oxide and methane) emissions from agricultural land associated with the implementation of select ammonia mitigation measures.

The modelling work applies only considers the changes in emissions from agricultural land and makes no assessment of the impact of these changes on e.g. water quality or habitat function.

2.5.2 Farmscoper modelling methodology

Farmscoper (Gooday et al., 2014[13]) was initially developed as a farm-scale decision support tool able to predict the emissions of nine different pollutants, to quantify the effect of implementation of one or more mitigation measures on those pollutant emissions and to estimate the cost of measure implementation. The tool contains a library of over 100 mitigation methods, based around those in the

[12] Defra, 2018, Measuring Environmental Change - Measuring environmental change – draft indicators framework for the 25 Year Environment Plan - Draft for discussion, Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766207/indicator-framework-consult-document.pdf

[13] Gooday, R., Anthony, S., Chadwick, D., Newell-Price, P., Harris, D., Duethmann, D., Fish, R., Collins, A. & Winter, M. (2014). Modelling the cost-effectiveness of mitigation methods for multiple pollutants at farm scale. Science of the Total Environment, 468-469, 1198-1209.

Mitigation Method User Guide (Newell-Price et al., 2011[14]) and certain Environmental Stewardship options. Farmscoper now includes the functionality and input data required in order for it to be applied at Water Framework Directive operational catchment scale, through the automated creation of multiple farms representative of the farming within an operational catchment.

The catchment-scale version of Farmscoper requires knowledge of the number of livestock and area of cropping within a catchment for a range of different categories, along with the count of the different farm types within the catchment. It then uses assumptions on typical farm management and stocking density constraints to apportion the livestock and cropping between these different farms. The tool also requires the fertiliser rates to be specified by crop type for each farm type, along with the proportion of each livestock type managed on solid manure or slurry systems and a preference table for which crops receive which manure type. The majority of the other assumptions on farm management that are used to model pollutant losses are set by default within Farmscoper, as they are contained within the existing database of modelled loss coefficients (this database is a synthesis of a large number of model runs for England and Wales). These other assumptions include timing of fertiliser and manure applications, duration of grazing and soil phosphorus status. They are based upon national survey data (such as the British Survey of Fertiliser Practice (BSFP) and the Defra Farm Practice Surveys) and are therefore representative of the average management across a catchment rather than the management on any one particular farm.

Farmscoper recognises three different soil types, which are designed to reflect the different dominant flow pathways. These soils are (i) free draining soils, where nearly all water travels vertically through the soil profile, and impermeable soils, which are subdivided into ii) those requiring artificial drainage for productive arable use and iii) those requiring artificial drainage for productive arable or grassland use - where artificial drainage leads to substantial lateral flow though drains. The modelling used to calculate the pollutant loss coefficients in Farmscoper was done nationally at 1 km^2, and then the results area weighted to produce outputs for the different climate and soil types in Farmscoper. Thus, the results for a particular climate and soil type reflect all land in England and Wales that has that particular climate and soil.

2.5.2.1 Agricultural survey data

The latest version of Farmscoper (v4) includes catchment input data at a range of spatial scales, from River Basin Districts down to Water Framework Directive waterbodies. The catchment data were derived from the 2015 Defra June Agricultural Survey (JAS), with the locations of farms and disaggregation of census data between catchments achieved by joining the JAS data to 2015 farm boundary data. Fertiliser usage data in v4 was updated to the 2015 BSFP data, but other farm management data were based on recent data up to 2015.

When calculating pollutant emissions, Farmscoper disaggregates the total agricultural survey data for a catchment between the different farm types according to the count of each farm type within a catchment and the relative likelihood of each crop or livestock type being found in that catchment, with the default likelihoods included in Farmscoper derived from the national data.

The majority of pig and poultry holdings are relatively small in terms of the land area farmed and they export the majority of the manure they produce to neighbouring farms. However, rather than attempt to calculate this export of manure, the catchment version of Farmscoper effectively imports land from other farm types within the catchment until it has sufficient land to spread all of the manure it produces at an appropriate rate. Thus, the results for the pig and poultry farms produced by Farmscoper are the effective results for the pig and poultry farm itself and the land that receives the manure by that farm, although that land may actually be managed by a neighbouring farm.

[14] Newell Price, J.P., Harris, D., Taylor, M., Williams, J.R., Anthony, S.G.,Duethmann, D., Gooday, R.D., Lord, E.I. and Chambers, B.J., Chadwick, D.R. and Misselbrook, T.H. (2015) An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture – User Guide. Defra Project WQ`06(5). Final Report.

2.5.2.2 Costs of mitigation method implementation

Farmscoper estimates the costs to the farmer of implementing mitigation methods (i.e. it does not consider potential scheme administration costs). Both capital and operational costs are calculated, with capital costs amortised over the lifetime of the investment in order to allow an overall annual cost of implementation to be determined. The results in this project have used implementation costs based upon 2013 data, which are the most up-to-date data contained within Farmscoper. A workbook within Farmscoper lays out all of the assumptions used in the derivation of the cost calculations for each mitigation method.

2.5.2.3 Mitigation methods to be examined

A set of mitigation practices, agreed with Defra, was selected for examination using the modelling work. These mitigation practices were mapped to existing Farmscoper mitigation methods, as shown in **Table 3.** Of the 23 mitigation practices supplied, it was possible to map nineteen of them to mitigation methods in Farmscoper. For some practices, multiple methods (targeting different land uses (e.g. arable or grassland) or different livestock types) were mapped to a single mitigation practice. There are some methods where Farmscoper is only parameterised for application to certain farm systems, despite those methods potentially being applicable to other systems(**Table 3**). For methods 42 to 44 inclusive (straw bedding, scraping of cubicles and washing of yards), Farmscoper only applies these methods to Dairy systems and not to Pig systems. Farmscoper method 48 (air scrubbers and filtering) is parameterised specifically for Pig systems.

To allow scaling of the results with uptake, the modelling was done assuming 100% uptake of each method, with the reduction expressed relative to a baseline emissions with no uptake of any mitigation methods. Therefore, if a reduction of 10% in a pollutant is achieved with 100% uptake then a reduction of 5% would be achieved with 50% uptake of the method. Although Farmscoper can include current uptake of measures based on data from farm surveys and farm agri-environment schemes, it was felt that providing a scalable estimate of the potential reduction in pollutant emissions for each method was more appropriate for this work, and so these estimates of current uptake were not used in the modelling work.
It should be recognised that this approach, which examines each method individually, will not account for interactions between methods if they are applied in combination and that the overall reduction when using multiple methods will not necessarily be equivalent to the sum of the reductions of the individual methods.

2.5.2.4 Environmental benefit

Because Farmscoper predicts the impacts of mitigation implementation on multiple pollutants, it can be hard to discern the ‘best’ overall methods. One way to achieve this is to use an environmental benefit calculation, which attempts to place a monetary value on the level of pollutant emission reductions, combining both the potential reduction in damage costs and the benefits for ecosystem services for each pollutant considered. The units of each pollutant saved under a mitigation scenario are multiplied by the unit environmental benefit (as £ per unit), and then totalled across all pollutants to produce an overall value at a national level. The reductions in methane and nitrous oxide emissions are converted to carbon dioxide equivalents (using global warming potentials of 21 and 310 respectively). These values, and the reductions in energy use are then multiplied by the non-traded value for carbon, which represents the costs of mitigating emissions (in line with the current UK Government approach to valuing carbon). The reductions in ammonia are multiplied by a value representing the damage costs to society reflecting the impact of exposure to air pollution on human Health (Defra 2011) (see 2.3). The reductions in nitrate, phosphorus and sediment are multiplied by values taken from Defra Project WT0706, which represent the impacts of water pollution from agriculture on drinking water quality, fishing, bathing water quality and other ecosystem goods and services relating to aquatic systems. These benefits account for any costs savings associated with reduced treatment of drinking water, although the report also points out that groundwater and surface water sources would continue to remain contaminated with nitrate for significant periods of time after a reduction in agricultural inputs had occurred. The environmental benefit values used in Farmscoper are provided in **Table 4**.

The environmental benefit takes account of all pollutants and therefore it is possible for a negative environmental benefit to occur where there is a decrease in ammonia emissions combined with increases in the other pollutants (GHG emissions, nitrate, phosphorus and sediment)

Table 3. Mapping of ammonia mitigation actions to Farmscoper methods (N/A indicates mapping to Farmscoper methods was not possible).

Mitigation action	Mitigation action applicable to: Cattle	Pigs	Poultry	Crops	Farmscoper Method ID	Farmscoper Method Name
1. Extended season grazing	Y				36	Extend the grazing season for cattle[15]
2. Slurry bags for storage	Y	Y			N/A	
3. Cover stores	Y	Y			54	Install covers to slurry stores[16]
4. Housing: additional straw bedding to provide a barrier between urine and air, encouraging microbial immobilisation of ammonium-N	Y	Y			43	Additional targeted bedding for straw-bedded cattle housing (not applied to pigs)
5. Regularly wash and scrape floors and collecting yards	Y	Y			42/44	Increase scraping frequency in dairy cow cubicle housing / Washing down of cow collecting yards (not applied to pigs)
6. Improve floor and slurry pit design for effective transfer to store with reduced emissions	Y	Y			N/A	
7. Amend livestock diet for good feed efficiency; match nitrogen content to expected level of production and stock growth stage	Y	Y	Y		331/332/333	Reduce dietary N and P intakes (Dairy/Pigs/Poultry)
8. Sheeting solid manure stores (like clamp silage)	Y	Y	Y		62	Cover solid manure stores with sheeting
9. Strategic planting of vegetative buffers near livestock houses	Y	Y	Y		83	Establish tree shelter belts around livestock housing
10. Acidification of slurry	Y	Y		Y	N/A	

[15] Farmscoper assumes cattle are outdoors for approximately 6 months (depending on type and age), with the extension in grazing being a further 1 month.

[16] Slurry tanks only, not lagoons and not floating covers.

Mitigation action	Mitigation action applicable to:					
	Cattle	Pigs	Poultry	Crops	Farmscoper Method ID	Farmscoper Method Name
11. Reduced emission slurry spreading (trailing hose)	Y	Y		Y	70	Use slurry band spreading application techniques
12. Reduced emission slurry spreading (trailing shoe)	Y	Y		Y	70	Use slurry band spreading application techniques
13. Reduced emission slurry spreading (injection)	Y	Y		Y	71	Use slurry injection techniques
14. Incorporate manures into soil soon after spreading	Y	Y	Y	Y	73	Incorporate manure into the soil
15. Housing: improve animal behaviour and design of pens to keep solid parts of the floor as clean as possible		Y			N/A	
16. Housing: air scrubbers to filter pollutants		Y	Y		48	Install air-scrubbers or biotrickling filters in mechanically ventilated pig housing (not applied to poultry)
17. Housing: regularly check structure and water drinkers to reduce leaks and keep litter dry			Y		N/A	
18. In-house poultry manure drying			Y		51	In-house poultry manure drying
19. Housing: increase frequency of litter removal to two or three times per week (belt removal, layers only)			Y		50	More frequent manure removal from laying hen housing with manure belt systems
20. Transport poultry litter for energy recovery			Y		N/A	
21. Introduction of nitrogen (fertiliser) limits; efficient use of N fertiliser, nutrient management plans, etc.				Y	22	Use a fertiliser recommendation system

Mitigation action	Mitigation action applicable to:					
	Cattle	Pigs	Poultry	Crops	Farmscoper Method ID	Farmscoper Method Name
22. Use of ammonium nitrate fertilisers instead of urea based, or use urease inhibitor with urea				**Y**	290/291	Replace urea fertiliser to grassland/arable land with another form
23. Put land/buildings out of production; reduce stocking densities on land near sensitive sites	**Y**	**Y**	**Y**	**Y**	N/A	

Table 4. Environmental Benefit unit values used in Farmscoper.

Variable	Unit	Value (£)
Nitrate	£ kg^{-1} NO_3-N	0.97
Phosphorus	£ kg^{-1} P	33.16
Sediment	£ kg^{-1} S	0.39
Ammonia	£ kg^{-1} NH_3-N	2.79
Methane	£ kg^{-1} CO_2-e	0.06
Nitrous Oxide	£ kg^{-1} CO_2-e	0.06
Pesticides	£ dose $unit^{-1}$	0.00
FIOs	£ 10^9 cfu^{-1}	0.00
Energy Use	£ kg^{-1} CO_2-e	0.06

2.5.3 Farmscoper pollutant load estimates

The Farmscoper Upscale tool was used to generate a set of pollutant load estimates, at operational catchment scale, for ammonia, nitrate, total phosphorus and sediment along with faecal indicator organisms (FIOs), pesticides and greenhouse gas emissions. Loads were then generated 100% uptake of each of the nineteen selected mitigation methods, with each method considered individually. The loads at operational catchment scale were then summed to give national scale loads by farm type and an overall national load. From these loads, the percentage reduction in the pollutant loads were then calculated. These national loads, along with a pollutant footprint (kg/ha), are shown in **Table 5**.

Table 5. The total national load (kt) and footprint (kg/ha) of pollutants, predicted by Farmscoper as the baseline, using 2015 June Agricultural Survey data.

Pollutant	National Load (kt)	Footprint (kg/ha)
Ammonia	160.57	18.46
Nitrate	229.79	26.42
Phosphorus	4.86	0.56
Sediment	1956.24	224.91
Methane	441.64	50.78
Nitrous Oxide	67.34	7.74

At a national scale, the percentage reductions in ammonia emissions and emissions of other pollutants (nutrients, greenhouse gases, etc.) are shown in **Table 6**. The table shows that for ten out of the nineteen ammonia mitigation measures, there is little or no impact on the loss of nutrients or emissions of greenhouse gases from agricultural land. For the measure that is most effective in reducing ammonia emissions, Extending the grazing season of cattle, there is a trade off in implementation as it increases the loss of nutrients and emission of nitrous oxide (soils are likely to be wetter, so more prone to compaction and excreta is being deposited in the field at times of higher risk for pollutant mobilisation), but does reduce methane emissions. Use of slurry injection and slurry band spreading application techniques both result in an increase in nitrate leaching (because the nitrogen not lost as ammonia is now available for leaching), but this increase could be offset if adjustments are made to inorganic fertiliser application rates to account for the additional available manure nitrogen.

2.5.4 Costs and benefits of Farmscoper mitigation methods

Table 7 shows both the national scale, costs to the farmer of implementing the mitigation methods and the environmental benefit value arising. These values assume 100% uptake of the mitigation methods where applicable to a farm type.

From the table it can be seen that for the five most effective methods, only two (extending the grazing season and using a fertiliser recommendation system) result in a cost saving for the farmer. However, all of these top five methods have a positive impact on the environment (indicated by the environmental benefit value), except replacing urea fertiliser on arable land. The negative environmental impact for this method is due to an increase in embedded emissions from the manufacture of alternatives to urea (this also applies to the replacement of urea in grassland). In addition to the methods mentioned above, there are only two methods where the environmental benefit value exceeds the costs of implementation, such that there is an overall positive impact:

1) Covering solid manure stores with sheeting, and
2) More frequent manure removal from laying hen housing with manure belt systems.

These two methods have limited impact on ammonia emissions, with reductions of less than 1%.

2.5.5 Additional outputs and information

A full summary of the outputs at national scale (total and by farm type) is provided in the Excel workbook that accompanies this report. In addition to the pollutant load emissions, the total costs and environmental benefit value associated with the application of each mitigation method, the workbook includes the impacts on production, faecal indicator organisms (FIOs), pesticides, soil carbon and energy use. The workbook also includes the unit costs of implementation for each of the mitigation methods that are used to calculate the total cost of implementation of a method.

Table 6. Percentage reduction in ammonia, nutrient and greenhouse gas emissions at national scale resulting from 100% implementation of the mitigation methods targeting ammonia being implemented individually, expressed relative to the baseline pollutant load calculated by Farmscoper for 2015 (Table 5).

Method	Ammonia	Nitrate	Phosphorus	Sediment	Methane	Nitrous oxide
Extend the grazing season for cattle	**8.8**	-0.1	-1.0	-0.9	3.5	-3.67
Replace urea fertiliser to arable land with another form	**7.5**	-	-	-	-	-
Use slurry injection application techniques	**6.4**	-0.3	3.5	-	-	-0.1
Use slurry band spreading application techniques	**4.2**	-0.3	-	-	-	-0.1
Use a fertiliser recommendation system	**3.6**	3.2	0.3	-	-	2.8
Increase scraping frequency in dairy cow cubicle housing	**2.7**	-	-	-	-	-
Additional targeted bedding for straw-bedded cattle housing	**2.1**	-	-	-	-	-
Incorporate manure into soil	**1.9**	0.3	0.4	-	-	0.0
Washing down of dairy cow collecting yards	**1.6**	-	-	-	-	-
Reduce dietary N and P intakes: Poultry	**1.2**	0.9	0.2	-	0.0	0.2
Install air-scrubbers or biotrickling filters in mechanically ventilated pig housing	**1.1**	-	-	-	-	-
Install covers to slurry stores	**0.9**	-	-	-	-	-
Reduce dietary N and P intakes: Pigs	**0.8**	0.4	0.1	-	0.1	0.1
Cover solid manure stores with sheeting	**0.8**	0.0	0.2	-	-	0.0
Reduce dietary N and P intakes: Dairy	**0.5**	0.2	0.2	-	0.8	0.1
In-house poultry manure drying	**0.3**	-	-	-	-	-
Replace urea fertiliser to grassland with another form	**0.3**	-	-	-	-	-
Establish tree shelter belts around livestock housing	**0.1**	-	-	-	-	-
More frequent manure removal from laying hen housing with manure belt systems	**0.1**	-	-	-	-	-

Table 7. Annual costs (£ million), environmental benefit value (£ million) and net cost (£ million), defined as cost minus environmental benefit value, for the national implementation of the Farmscoper methods on all farms.

Method	Annualised Capital Cost (Capex)	Operational Cost (Opex)	Total Cost (Capex + Opex)	Environmental Benefit	Net Cost (Total Cost – Env. Ben)
Extend the grazing season for cattle	-	-97.47	-97.47	5.80	-103.27
Replace urea fertiliser to arable land with another form	-	47.58	47.58	-45.37	92.95
Use slurry injection application techniques	-	75.37	75.37	30.93	44.44
Use slurry band spreading application techniques	-	28.82	28.82	16.58	12.24
Use a fertiliser recommendation system	-	-68.36	-68.36	61.11	-129.46
Increase scraping frequency in dairy cow cubicle housing	-	65.38	65.38	10.48	54.90
Additional targeted bedding for straw-bedded cattle housing	-	81.38	81.38	9.34	72.03
Incorporate manure into soil	-	122.31	122.31	8.68	113.64
Washing down of dairy cow collecting yards	-	65.88	65.88	6.80	59.08
Reduce dietary N and P intakes: Poultry	-	22.03	22.03	10.31	11.72
Install air-scrubbers or biotrickling filters in mechanically ventilated pig housing	44.61	28.22	72.83	4.67	68.16
Install covers to slurry stores	92.73	-13.96	78.77	4.50	74.26
Reduce dietary N and P intakes: Pigs	-	13.72	13.72	6.16	7.56
Cover solid manure stores with sheeting	2.98	0.25	3.23	3.98	-0.75
Reduce dietary N and P intakes: Dairy	-	21.94	21.94	9.47	12.47
In-house poultry manure drying	0.05	3.46	3.51	0.87	2.64
Replace urea fertiliser to grassland with another form	-	-4.52	-4.52	-6.26	1.73

Method	Annualised Capital Cost (Capex)	Operational Cost (Opex)	Total Cost (Capex + Opex)	Environmental Benefit	Net Cost (Total Cost – Env. Ben)
Establish tree shelter belts around livestock housing	0.84	2.94	3.79	0.47	3.31
More frequent manure removal from laying hen housing with manure belt systems	-	0.02	0.02	0.38	-0.36

3 Stakeholder feasibility workshops

3.1 Purpose

The purpose of the 'workshop' meetings was to improve understanding of the barriers and opportunities for farmers in implementing measures to reduce ammonia emissions. This understanding can help Defra in designing new policies and in planning policy changes. Furthermore, the understanding of barriers and opportunities for farmers is valuable in planning the detail around ammonia mitigation policy implementation. This is important as, following the publication of the Clean Air Strategy 2019 during the workshops, the detail of many policies is yet to be developed and the workshops form an important part of this policy development process.

3.2 Methods

3.2.1 Locations and attendance

The locations for the 13 regional workshops across England were based, approximately, on the areas of responsibility for the 13 Natural England Area Teams (Figure 3). A list of the locations, with workshop dates, is given in Table 8.

The workshops were publicised, and invitations were made, through stakeholder organisations that contacted farmers and other interested parties through their own communications channels. Natural England Catchment Sensitive Farming Officers (CSFOs) helped to recruit attendees through their direct contacts with farmers. We liaised with the CSFOs to ensure representation of an appropriate cross-section of farming systems in each region. Attendees were not given any financial or other incentives to attend, except for the prospect of a gain in knowledge and the opportunity to have their views conveyed to Defra.

The numbers of attendees at each stakeholder workshop are given in Table 9, with a breakdown to show representation of farming enterprises and organisations representing farmers. We registered a total of 186 attendees across the 13 events.

The workshops were held during a period that was not expected to coincide with workload peaks for most farmers. For the first 12 workshops the draft Clean Air Strategy 2018 was available, and the draft proposals were referred to in these meetings. For the last workshop, at Shepton Mallet on 16 January 2019, the final version of the Clean Air Strategy 2019 was available (published on 14 January 2019). This influenced the discussion at that workshop because there were some changes in the plans for mitigation actions, between that draft Clean Air Strategy 2018 and the Clean Air Strategy 2019 (see 3.2.2).

Figure 3. Map of Natural England Area Teams, October 2017, showing numbered locations of stakeholder workshops (see Table 8 for location names and numbers used on the map).

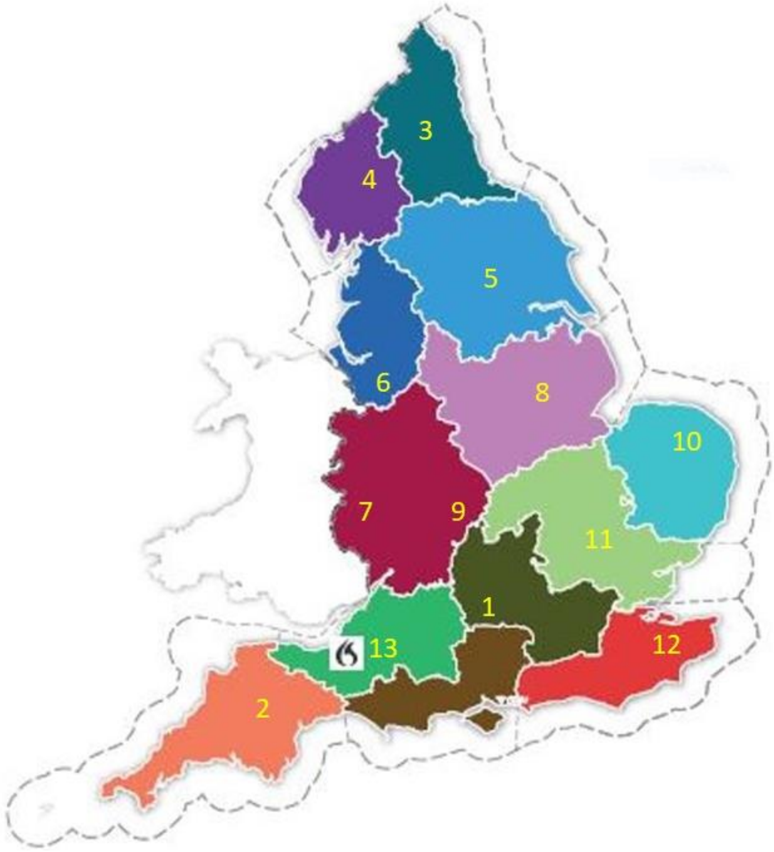


Table 8. Dates and locations of stakeholder workshops.

Workshop dates	Locations	Number on Map (Figure 3)
21 November 2018	Harwell (Oxfordshire)	1
22 November 2018	Okehampton (Devon)	2
27 November 2018	Hexham (Northumberland)	3
28 November 2018	Penrith (Cumbria)	4
29 November 2018	York (Yorkshire)	5
05 December 2018	Crewe (Cheshire East)	6
06 December 2018	Leominster (Herefordshire)	7
11 December 2018	Newark (Nottinghamshire)	8
12 December 2018	Stoneleigh (Warwickshire)	9
08 January 2019	Norwich (Norfolk)	10
09 January 2019	Manuden (Essex)	11
10 January 2019	Ashford (Kent)	12
16 January 2019	Shepton Mallet (Somerset)	13

Table 9. Numbers of attendees at each stakeholder workshop: total attendees and numbers by farming enterprises, or from an organisation representing farmers. In each row, the sum of the numbers for enterprises and organisations representing farmers is greater than the total attendees because farming attendees often had more than one enterprise on their farms.

Location	Total attendees	Cereals	General Cropping	Dairy	Grazing Livestock (Lowland)	Grazing Livestock (LFA)	Specialist pigs	Specialist Poultry	Mixed	Horticulture	Organisation representing farmers
Harwell	17	9	4	4	4	0	2	1	1	1	3
Okehampton	19	2	4	11	11	3	1	1	1	2	3
Hexham	8	3	1	3	3	1	2	0	0	0	1
Penrith	12	2	1	7	3	2	0	0	1	0	2
York	13	3	2	3	1	0	4	0	2	0	0
Crewe	10	2	4	6	4	2	2	2	2	0	2
Leominster	9	5	2	4	6	1	0	3	2	0	1
Newark	19	10	9	7	7	3	3	1	3	4	3
Stoneleigh	15	1	1	4	4	3	1	2	3	0	6
Norwich	13	8	8	3	3	0	2	0	3	1	3
Manuden	16	11	4	4	8	0	4	4	2	1	3
Ashford	17	7	4	6	5	0	0	2	3	3	6
Shepton Mallet	18	11	6	9	8	1	0	2	3	0	4

3.2.2 Workshop structure

Before the workshops were held, a list of mitigation actions for presentation and discussion was agreed with Defra. This is given in section 3.3.1.

The workshop agenda was the same for all workshops and had five main elements, as follows.

1. Purpose of workshop, policy context
2. Implementation of mitigation actions, principles and practicalities
3. Overview of mitigation actions in livestock housing, manure storage, manure application to soil, inorganic fertilisers, with group discussion
4. Complete scoring sheet
5. Facilitated discussion

In an introduction, attendees were assured that all views will be conveyed to Defra anonymously. Questions from the attendees and discussion points were encouraged throughout the day.

Item 1 explained the purpose (see 3.1) and gave some policy context. Ammonia emission limits under the 1999 Gothenburg Protocol were given, together with the trend from 1980 to 2016 (Figure 1).

The draft Clean Air Strategy 2018 was referred to in the first 12 workshops and the following list of draft proposals was presented:

- Limit N fertiliser applications.
- Extend environmental permitting to large dairy farms (currently pig and poultry).
- Requirement to spread urea-based fertilisers with urease inhibitors, unless injected on appropriate land.
- Design standards for new livestock housing.
- Requirement to incorporate solid manures within 12 hours of spreading.
- Requirement to use reduced-emission spreading equipment for slurry.
- Requirement for all slurry and digestate stores and manure heaps to be covered.

For the last meeting on 16th January 2019, the Clean Air Strategy 2019 was referred to and the following list of proposals was presented:

1. Introduce rules on specific emissions-reducing practices including:
    - action to reduce emissions from urea-based fertilisers: consult in 2019, legislate as soon as possible;
    - a requirement for all solid manure and solid digestate spread to bare land (other than no-till) to be incorporated within 12 hours;
    - a requirement to spread slurries and digestate using low-emission spreading equipment (trailing shoe, trailing hose or injection) by 2025 – perhaps earlier for digestate or large volumes of slurry;
    - a requirement for slurry and digestate stores to be covered by 2027 – perhaps earlier for digestate or large volumes of slurry;
    - design standards for new intensive poultry, pig and beef livestock housing and for dairy housing.
2. Regulate to minimise pollution from organic and inorganic fertiliser use:
    - target for reduction of damaging deposition of reactive forms of nitrogen by 17% over England's protected, priority, sensitive habitats by 2030;
    - review what longer term targets should be;
    - work with farmers to improve fertiliser use efficiency: "limit inputs of nitrogen-rich fertilisers such as manures, slurries and chemicals to economically efficient levels".
3. Extension of environmental permitting to dairy and intensive beef farms by 2025:
    - agree appropriate emission limits and Best Available Technique (BAT) documents.

Prominent changes between the draft Clean Air Strategy 2018 and the final Clean Air Strategy 2019 (following a 12 week public consultation) were extension of environmental permitting to the dairy and intensive beef sectors (rather than just large dairy), and the commitment to establish an expert group to advise on the best regulatory options for reducing pollution from fertiliser use (rather than necessarily setting fertiliser limits)..A A further change following consultation was the removal of a proposed requirement to cover heaps of solid manure in response to concerns regarding practicality, health and safety and recycling of waste plastic expressed during the consultation.

Item 2 of the agenda (see above) provided some information on the principles and practicalities associated with the implementation of mitigation actions. The main sources of emissions were identified. The principle was explained that ammonia conserved (i.e. not emitted) early in the manure handling chain (in livestock housing) can be lost at a later stage of the manure handling chain (at spreading to land), with the consequence that a whole-system approach is needed to maximise benefits.

Item 3 of the agenda explained each of the mitigation actions under consideration (see 3.3.1) and gave opportunity for questions and some discussion.

Item 4 of the agenda was an exercise for each attendee, to score mitigation actions for costs, benefits and practicality, to gain information on perceptions. Attendees were asked to provide scores from 1 to 5 for each mitigation action for which they had some interest or knowledge.

Item 5 of the agenda was a facilitated discussion that filled the afternoon session of each workshop. For some workshops the attendees were divided into smaller groups, whereas in other workshops this discussion took place with a single group; this depended on the number of attendees, and the mix of farm types represented. This discussion was facilitated by one of the three presenters and focussed on the mitigation actions of most interest to the group. Notes were taken, with a focus on four areas:

1. co-benefits
2. trade-offs
3. local factors
4. barriers to implementation

3.2.3 Post workshop engagement

Following each workshop an email was sent to attendees; attached to the email was a shortened version of the presentation slides given on the day, a summary of the group discussions noted during the afternoon session and a feedback form to be completed and returned. Of the approximately 190 emails sent out, 20 completed feedback forms were returned.

The feedback form gave the opportunity to rate the event 1 (poor) to 5 (excellent) on the following areas: usefulness of the workshop, usefulness of the presentations, how well the workshop allowed their views to be expressed and suitability of the venue. Each question received a score of 4.5 or greater.

The second part of the feedback form asked the recipients to read the summary notes and indicate whether they felt the notes reflected the discussions of the meetings and the views of the attendees. There were more answers than the number of feedback forms received because some selected more than one response; 10 answered yes, 11 answered mostly yes and 5 answered yes with some omissions. The form allowed attendees to add in any further views or comments. Those who answered ‘mostly yes’ or ‘yes with some omissions’ tended to complete this section. Any additional comments not already in the overall summary for each mitigation measure were added into the summaries of stakeholders’ views in this report (see 3.3.2).

3.3 Results

3.3.1 Mitigation actions

A list of mitigation actions for presentation and discussion was agreed with Defra before the first workshop and is given in Table 10. The list is based on the following documents:

- Ammonia emissions from agriculture, Ricardo E&E, 2017 (report for Defra).
- Code of Good Agricultural Practice (COGAP) for Reducing Ammonia Emissions, Defra, 2018. https://www.gov.uk/government/publications/code-of-good-agricultural-practice-for-reducing-ammonia-emissions/code-of-good-agricultural-practice-cogap-for-reducing-ammonia-emissions#contents
- Draft Clean Air Strategy, Defra, 2018. https://consult.defra.gov.uk/environmental-quality/clean-air-strategy-consultation/user_uploads/clean-air-strategy-2018-consultation.pdf
- Rapid Evidence Assessment of Interventions to Improve Ambient Air Quality, IOM, 2018.
- How to comply with your environmental permit for intensive farming, Environment Agency, 2010 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/297091/geho0110brsg-e-e.pdf
- Case Studies for delivering Ammonia measures, Natural England, 2015.
- BITTMAN, S., DEDINA, M., HOWARD C.M., OENEMA, O. AND SUTTON, M.A. (ED.), 2014. Options for ammonia mitigation. Guidance from the UNECE Task Force on Reactive Nitrogen. Edinburgh: Centre for Ecology and Hydrology.
- United Nations Economic Commission for Europe, 2015. Framework Code for Good Agricultural Practice for Reducing Ammonia Emissions. Published by the European Commission, Directorate-General Environment on behalf of the Task Force on Reactive Nitrogen of the UNECE Convention on Long-range Transboundary Air Pollution. http://www.unece.org/index.php?id=41358
- Misselbrook T.H., Chadwick D.R., Chambers B.J., Smith K.A., Sutton M.A., Dore C.A. 2007. An Inventory of Methods to Control Ammonia Emissions from Agriculture Ammonia: Mitigation User Manual. https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwjPudzirL3eAhWRHsAKHSNRC1IQFjAAegQIABAC&url=https%3A%2F%2Fwww.feedadviserregister.org.uk%2Flatest-documents%2Fammonia-mitigation-user-manual%2Fammonia-mitigation-user-manual-final-v2.pdf&usg=AOvVaw2395I-IMpW4sO621pa8CFd
- Newell Price, J.P., Harris, D., Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D., Gooday, R.D., Lord, E.I., Chambers, B.J., Chadwick, D.R. and Misselbrook, T.H. (2011). An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture. Prepared as part of Defra Project WQ0106.

Table 10. Mitigation actions and their applicability to major farm types, for presentation and discussion at stakeholder workshops.

Mitigation action	Applicable to:			
	Cattle	Pigs	Poultry	Crops
1. Extended season grazing	✓			
2. Slurry bags for storage	✓	✓		
3. Cover slurry stores	✓	✓		
4. Housing: additional straw bedding to provide a barrier between urine and air, encouraging microbial immobilisation of ammonium-N	✓	✓		
5. Regularly wash and scrape floors and collecting yards	✓	✓		
6. Improve floor and slurry pit design for effective transfer to store with reduced emissions	✓	✓		
7. Amend livestock diet for good feed efficiency; match nitrogen content to expected level of production and stock growth stage	✓	✓	✓	
8. Sheeting solid manure stores (like clamp silage)	✓	✓	✓	
9. Strategic planting of vegetative buffers near livestock houses	✓	✓	✓	
10. Acidification of slurry	✓	✓		✓
11. Reduced emission slurry spreading (trailing hose)	✓	✓		✓
12. Reduced emission slurry spreading (trailing shoe)	✓	✓		✓
13. Reduced emission slurry spreading (injection)	✓	✓		✓
14. Incorporate manures into soil soon after spreading	✓	✓	✓	✓
15. Housing: improve animal behaviour and design of pens to keep solid parts of the floor as clean as possible		✓		
16. Housing: air scrubbers to filter pollutants		✓	✓	
17. Housing: regularly check structure and water drinkers to reduce leaks and keep litter dry			✓	
18. In-house poultry manure drying			✓	
19. Housing: increase frequency of litter removal to two or three times per week (belt removal, layers only)			✓	
20. Transport poultry litter for energy recovery			✓	
21. Introduction of nitrogen (fertiliser) limits; efficient use of N fertiliser, nutrient management plans, etc.				✓
22. Use of ammonium nitrate fertilisers instead of urea based, or use urease inhibitor with urea				✓
23. Put land/buildings out of production; reduce stocking densities on land near sensitive sites	✓	✓	✓	✓

3.3.2 Summaries of stakeholders' views

The views presented in this section are stakeholder views, drawn together from the 13 stakeholder workshops. The points made here do not represent the views of the authors of this report. There were many views, often contradicting one another.

All comments were recorded with anonymity, allowing us to gain the confidence of attendees and encouraging open discussion.

3.3.2.1 Mitigation action 1: Extended grazing season

Co-benefits

- Considered a cheaper option due to less bedding, forage, concentrates and labour, so overall less capital cost for production. Because of this, it was considered relatively easy to implement.
- Health benefits for livestock to being outside for longer periods of time.
- Potential improvement in public perception if cattle seen outside, countering the view of intensive farms.

Trade offs

- Pollution swapping - nitrate leaching, phosphate losses and a risk of cross pollution.
- Counteracts efforts to reduce GHG emissions if animals are outside for longer periods of time. If housed animals are reducing their ammonia emissions through better housing design and spreading, it is possible that their ammonia emissions will be less than, or equivalent to, grazed cows. This view was related to the perception that productivity is higher and more efficient for housed cattle, compared with unhoused. It was acknowledged that more research is needed.

Local factors

- Soil type and weather will determine if this measure is suitable. Other local requirements may be in place hindering suitability, for example Higher Level Stewardship Scheme (HLS) which requires cattle to be kept off pastures for migratory birds.
- The UK weather isn't reliable enough for a long season of grazing.

Barriers to implementation

Impact on land/environment

- 6 – 7 months is workable - but longer periods are more difficult and risk soil and nutrient losses due to increased pressure on the fields.
- Risk of permanent sward damage which will potentially have an impact on spring growth.
- Ammonia emissions per litre of milk should be assessed and may make this measure seem less attractive.
- Greater run off and water pollution.

Animal health

- Some farms have found welfare has been improved by increased housing, such gains could be lost by additional grazing.

Suitability to farm system

- Could potentially require a change in farming system completely if extended grazing is to increase, e.g. different stock, infrastructure and production aims.

Knowledge

- Difficult to regulate due to specifics on how long to keep livestock grazed for and if there should be fixed dates – the measure would require flexibility.
- Need more evidence of the benefits.

3.3.2.2 Mitigation action 2: Slurry bags for storage

Co-benefits

- Relatively quick solution, less restrictive planning required and can be used as a satellite storage facility.

Economics

- Low cost compared to above ground metal store.
- Higher amount of ammonia and N available from pig slurry compared with cattle slurry, so this is more financially beneficial for pig production.

Trade offs

- Better suited for temporary storage rather than a permanent solution.
- Limited access to the inside of the storage system raised concerns, as it would cause problems for stirring and removal of debris.

Local factors

- None proposed

Barriers to implementation

- Vandalism – concerns that these bags are easy to puncture and can only be stored in isolated areas.
- Concerns regarding the lifespan.
- Requires a large area of land, something not all farms can provide.

Presence of solids

- Getting Straw, sand and other bedding material out will be difficult. Taking greater care to prevent debris getting into slurry bags was considered a barrier.
- Need to separate slurry in advance before putting in to bag, to get to 3-4% dry matter.
- Cannot be used if there is grit or other material in the slurry.

3.3.2.3 Mitigation action 3: Cover stores

Co-benefits

- Having a cover would increase nutrient retention in the slurry.
- Lower surface water pollution risk.
- Straw covers are easy to implement/use (providing a straw chopper is available) using a straw cover will reduce issues arising with retro fitting. Also useful for digestate which doesn't form a natural crust.
- A cover will reduce the amount of rainfall entering the store, so is a low-cost way to improve storage capacity. This will also reduce costs and overall carbon footprint due to less removal/transportation/spreading of additional rainwater.

Trade offs

- Using a plastic sheet as a cover creates additional environmental problems.
- Some slurries are too thick for reduced emission spreading if they are not being diluted with rainwater in an open store. Diluted slurry is also seen as beneficial for liquid fertiliser in drier periods.
- Straw covers gave concern about the ability to spread without clogging equipment, although it was recognised that modern band spreaders can have a macerator, avoiding this problem.
- Slurry crusts more quickly if exposed to air, so a cover put in place to reduce rainwater capture (e.g. a roof that allows natural ventilation) could inhibit crust formation and therefore increase ammonia emissions.
- Given that slurry stores are only responsible for about 5% of emissions nationally, some didn't see the point and would rather focus efforts on techniques that reduce emissions from bigger sources.

Local factors

Rainfall

- For several regions, the main incentive is to stop the capture of rainwater, so permeable covers such as clay balls would be useless.
- In York – stopping rainwater entry would not be cost effective.
- Large range of pay back dependent on rainfall in the region.
- Big variation in annual rainfall in Penrith, annual rainfall ranging from 38” in Penrith to 150” in the hills.

Wind

- Wind speeds may be too high for certain types of cover.

Barriers to implementation

Practicality

- A cover would make stirring slurry very difficult and limits access to the store to clear out accumulated sediment or solids
- Corrosion on tanks known to increase with the addition of a roof.

Health and safety

- Gas accumulation is a health and safety risk, specialist breathing apparatus may be required if entering a covered store.

Suitability

- Retro fitting can be difficult, many structures are not suitable, for example covering large lagoons can be very difficult and, in some instances, dangerous.
- Surface to volume ratio should be considered, and perhaps only a requirement for larger stores to be covered.
- Pre-1991 stores do not need to be Silage Slurry and Agricultural Fuel Oil (SSAFO) compliant and should not be touched because this might change the exempt status of such stores.

Knowledge

- More information required to prove the financial justification and the effectiveness of options for different circumstances.
- Clear definition of cover required, if slurry is being stored under slats within a building, is a cover really needed?

Schemes/grants

- Need a financial incentive for retro and new fits.
- During recent Farming Ammonia Reduction Grant (FARG) scheme, suppliers were not able to meet the increased demand, any future schemes will need a wider window, this will also allow covering of a store at a suitable time in the farming cycle. The scheme had a poor up take because it was not practical, not because of lack of interest.
- Some farmers are holding back on slurry store options waiting for Defra to clarify what can be done via a grant scheme.
- Planning authorities need to be more prepared for initiatives to support store covers.

Economics

- Capital cost and maintenance cost are a barrier.
- In one case, a farmer had a floating cover fitted, but as a result required an additional £16k investment in slurry mixing equipment.

3.3.2.4 Mitigation action 4: Housing: additional straw bedding to provide a barrier between urine and air, encouraging microbial immobilisation of ammonium-N

Co-benefits

- Increased nutrient content in manure, resulting in higher organic matter of soil once spread to land.

Trade offs

- An abundance of straw slows down the rotting process of manure, creating difficulties in the spreading process. Slurry becomes difficult to spread with a higher solid content.
- Negative impact on soil organic matter if arable farmers choose to bale and sell straw to meet increased demand as opposed to chopping and incorporating.

Local factors

- After the summer of 2018 straw was hard to come by in parts of the country.

Barriers to implementation

Economics

- Additional cost.
- Some farming systems set up solely for sawdust and sand, so the use of straw may require significant capital spend.
- Increased price of straw if demand is increased.
- Need to identify any financial benefit to farmer to encourage uptake. Possible potential for use of auto scrapers or robotic scrapers to keep yards cleaner.

Animal welfare

- Many have already moved away from straw bedding for good reasons such as animal welfare and less mastitis, reducing the potential for uptake.

Knowledge

- Lack of scientific evidence of the benefits so farmers not convinced about the effectiveness of the method.
- Different farms have different priorities, so a 'blanket' solution is not a good approach.
- How can this method be monitored for compliance?

3.3.2.5 Mitigation action 5: Regularly wash and scrape floors and collecting yards

Co-benefits

- Clean yards will result in less foot related health issues and provide general disease benefits.
- Opportunity to extract heat from slurry to cool slurry and reduce ammonia emissions.

Trade offs

Water use

- Requires too much water to be easily implemented, however using recycled water would have both environmental and cost saving benefits.
- Volumes of water produced and subsequently to be disposed of, rolls into NVZ issues.
- Too much water needed to regularly wash, however increased scraping may be more easily achievable.

Animal welfare

- Increased scraping may result in welfare issues for cattle due to increased skidding.

Local factors

- The feasibility of implementing depends on the slope and system.

Barriers to implementation

Economics

- Additional costs incurred due to increased need for water for washing purposes.
- Huge capital costs of robotic scraper may only be achievable with grants, even with a full grant, reluctancy was shown due to the management costs and high break down rate.

Knowledge

- Needs to be a clear definition of increased scraping frequency.
- Point raised that inventory assumptions currently assumes no abatement (because of a lack of on farm knowledge, survey data) so a lot of clean yard abatement may already be in place and is not being accounted for.

Suitability

- Retro-fitting to existing systems is not always easy.
- Currently farmers are scraping twice a day, which fits in with cattle movements so would be difficult to increase this.

3.3.2.6 Mitigation action 6: Improve floor and slurry pit design for effective transfer to store with reduced emissions

Co-benefits

- Standard of animal welfare and health is better with better floor design and disease control is also improved.

Trade-offs

- Difficult to retro fit new components into existing systems, often milking parlours, housing and slurry storage have been cobbled together over the years.
- Grooved floors can retain urine if the slope is inadequate. Retro grooving of concrete yards can be used to reduce emissions, but only if yards are built on a slope.
- Good welfare systems need solid floor areas which conflicts with ammonia mitigation.

Local factors

- Need to provide guidance to planning services to encourage positive support for well-designed agricultural buildings.

Barriers to implementation

Retro fitting

- Retro fitting is not practical and can be difficult and expensive, new builds are likely to be more suitable for more frequent flushing of slurry.
- Changes in building design should be recommendations, not legal requirements.

Tenant farmers

- Tenant farmers would face challenges with investment and buildings that are not fit for purpose if landlords lack motivation to implement changes. Because of this there should be separate rules and regulations for tenant farmers.
- Landlord/tenant issues if not perceived value increase in the property, why should the landlord invest in the farm if there is no financial return?

Economics

- There are more cost-effective ways to cut emissions which should be prioritised before building design.
- Access to finance via private and government grant can be difficult.

3.3.2.7 Mitigation action 7: Amend livestock diet for good feed efficiency; match nitrogen content to expected level of production and stock growth stage

Co-benefits

- Implementing this would be a good opportunity to educate farmers.
- Low capital cost and less protein in the diet will reduce feed costs.
- Fairly easy to implement, aside from the need to measure protein content of the feed, it was considered a relatively easy action to take on.
- Fine tuning rations has led to more productive animals and fewer replacements. Considered to be an industry-wide improvement.
- Diets best matched to livestock requirements will improve farm efficiency and cost control.

Trade-offs

- Introducing extended grazing season will make this harder to implement, difficult to control if animals are grazing on high protein grass.
- More suited to large dairy farms, little scope for small suckler herd of 30 cattle to take on diet plans.
- Some will still tend to use high protein ration for finishing cattle.
- Reduced costs have driven reductions in protein in pig and poultry rations rather than a drive to cut ammonia levels.

Local factors

- Regions such as the North West are not suitable for increased maize growth due to short harvest window and implications for run-off and water quality.

Barriers to implementation

Knowledge

- Lack of knowledge on the percentage of protein amendments to make, some tend to be safe and feed a little more than is required.
- More scientific evidence is needed before implementation due to farmer experience in sending samples to different labs and receiving different results, which limits confidence in the evidence.
- Difficult to implement as a strategy and requires a knowledge transfer led approach.

Economics

- Farmers not always prepared to pay for independent nutrition advice.
- Cost benefit is better for dairy than for beef.

Time limitations

- Some farmers may not have the time to regularly undertake analysis and implement ration changes. Such time limitations may inevitably lead to ‘one size fits all’ mentality.

Productivity

- Concerns regarding reduced production, there is the potential for fertility issues and/or reduction in milk or protein output if feeding the incorrect level of protein.
- Utilisable energy balance is key to ruminant feeding to avoid bypass protein.

3.3.2.8 Mitigation action 8: Sheeting solid manure stores

Co-benefits

- Acceptance that N would be retained, and the process would reduce leaching to the ground and water.

Trade offs

- Stores are a small source and ammonia is likely to be lost after spreading (unless incorporated), this seems like a very low priority action and seems that the effort could be better spent elsewhere.
- If more straw bedding is used as a mitigation measure the heaps will be larger and more difficult to cover.

Local factors

- Would reduce localised emissions, odour and number of flies.
- If the plastic sheet blows away during windy conditions, there's a risk it could end up on a road and cause serious problems.

Barriers to implementation

Issues for farmer

- Sheeting and un-sheeting on a regular basis would be impractical, even more so for farmers working on their own who would need to bring in extra help.
- To be effective it would require concrete pads, that can be drained, to be introduced to yard layouts.

Health & safety

- Strong negative response in relation to the additional burden on farmers as well as health and safety.
- Farmers and staff being made to walk on a manure pile is dangerous, high risk they may fall into a wet patch or pocket of slurry in a heap – particularly dangerous for lone farmers.

Knowledge

- The benefits of the mitigation measure are not well understood, practical on-farm examples of how it can work are required.
- Farmers need to know the economics, it is difficult to be clear and get a single answer as it will depend on the price of N and volume of manure.
- Clarification is needed to understand logistics; how quickly should the heaps be covered? Whether it needs to be covered every day or just when it is complete; whether heaps of a low pH or low N content (e.g. composts) should be covered.

Type of cover

- It was suggested that heaps could be covered with straw, however this would only be suitable for farms with straw already in place for bedding. Using straw also brings a risk of black grass contamination.
- Potential to use loose material, for example potato waste and gypsum. Such materials will not all be impermeable and so could lose effluent even if ammonia is significantly reduced.
- Retro fitting roofs on existing manure stores would be difficult as many are not designed for that purpose.

Plastic sheets

- When not in use, where is the plastic sheet to be stored? Need to consider the impacts after one or two years of use, the sheet will be soiled and just add to the single use plastic issues.
- Public perceptions may be impacted if single use plastic seen to be used on farms.
- Covering with plastic sheet not practical due to several reasons; different sizes, different sites, large heaps, will need to take the sheet on and off and will be tricky to manage in high winds.

3.3.2.9 Mitigation action 9: Strategic planting of vegetative buffers near livestock houses

Co-benefits

- A visually appealing mitigation measure, which may improve public perceptions.
- Once planted this is a long-term solution, with little maintenance cost when established.
- Would also be useful to reduce dust movement and odour.

Trade offs

- Many may not have sufficient land available to implement the measure, could be particularly difficult for tenant farmers.

Local factors

- Worth considering existing woodlands and how they can be utilised to benefit ammonia emissions.

Barriers to implementation

Knowledge

- More information needed on how effective it is as a measure before it will be considered as an option.
- Information required on the correct tree species to use for method to be most effective.

Animal welfare

- Impact on ventilation should be taken into consideration, reduced ventilation near animal housing such as dairy units can result in health implications.

3.3.2.10 Mitigation action 10: Acidification of slurry

Co-benefits

- Welfare for livestock and people improved due to air quality improvements.
- Increases the N available to crops without other intervention.

Trade offs

- Acidification should exempt a farmer from needing to cover the store and from applying slurry by reduced emission techniques.
- This will not be suitable for all farms; type of buildings and stores will influence applicability.

Local factors

- Concerns were raised about PR issues associated with farmers spreading acid infused slurry onto soils. Method should be referred to as ‘reducing pH’ rather than ‘acidification’.
- By applying acid slurry, will there be negative impacts on the wider environment?

Barriers to implementation

Applicability

- Only suitable for new-build, not retro-fit.
- Needs incentivisation; must be a reward.
- Only suitable for liquid manures, is there something that can be used to acidify solid manure?

Economics

- Perceived as expensive. Varying views on the cost effectiveness – relates to value of saved N, the possible avoidance of other measures such as covering tanks, and the ability to expand livestock buildings or build a new site, which otherwise might not get planning consent.
- No overall cost benefit from acidification, the cost of acid is likely to be more than the value of the increased levels of nitrogen in the slurry.
- Will it be incentivised in the future? Early adopters of measures are often penalised.

Health & safety

- Health and safety risks associated with handling acid: is there a waste or natural product that can be used instead? A study at Aarhus University has found adding sugar to slurry is as effective as acid.
- What is the possibility of using weaker/alternative acids to avoid accident risk?
- Potential foaming of slurry.

Knowledge

- Lack of farmer knowledge, as well as a lack of UK based studies showing the benefits.
- Uncertainty on the effect on soil pH, this needs to be understood before action implemented.

Challenges

- Acidified slurry will deteriorate concrete and stores.
- Very few English dairy farms are on slats which is the most suited building type for acidification
- Need for more lime.
- Will restrictions be introduced on the sale of acid?
- Where can the acid be stored?

3.3.2.11 Mitigation action 11, 12, 13: Reduced emission spreading (trailing hose, trailing shoe, injection)

Co-benefits

- Better utilisation of N and reduced odour.
- Earlier field re-entry for grazing or silage cut earlier than with splash plate, therefore spreading opportunities are increased.
- Improves accuracy of spreading and can be applied to growing crops.

Trade offs

- Agronomists do not recommend slurry application to growing crops
- Reliance on contractors to undertake work is not an ideal situation for many farmers that are already set up with their own machinery, and may not have the resources to pay contractors.
- Pollution swapping is a concern, e.g. reducing ammonia but increasing CO_2 by more soil incorporation or reduce ammonia but increase leaching by more efficient spreading in autumn.

Local factors

- Not practical on stony land and uneven, sloping fields make these techniques difficult.
- Existing contractor network may not be able to meet the huge increase in demand. Limited machinery availability may result in contractors over-applying while they are on site.

Barriers to implementation

Economic

- Large capital cost for additional technology/machinery required. Many farmers already using their own tankers and have little incentive to invest in new equipment without grants. If capital costs could be brought down, it would be a very attractive option.
- Concerns that if a trailing hose is purchased, the following year the government might require injection, incurring additional capital cost.
- Grants would be required, but there is a risk that cost of kit may inflate with the introduction of grants.

Additional work

- Slows down the rate of work as opportunities for incorporation are weather dependent.

- Generally aging population of farmers may not be able to undertake additional labour.
- Creates additional work due to the need to separate solids before spreading if using sand/straw bedding, may also require more frequent testing of slurry.
- Inconsistency of slurry makes spreading impractical.

Impact to land

- Injection can cause cracking on heavier soils and damage to the sward.
- More wheel compaction due to heavier vehicle use, some soils are too heavy for the machinery.

Challenges

- Significant logistical issues associated with low emission equipment due to weight, size and limited number of machines. As well as putting pressure on soils and the interaction with the general public (knocking car wing mirrors off).
- There was a call for guidelines on appropriate field conditions. Spreading window is too tight, would prefer 'little and often' as perceived to be more efficient.

3.3.2.12 Mitigation action 14: Incorporate manures into soil soon after spreading

Co-benefits

- Greater N available to the crop and reduced run-off.
- Considered one of the easier mitigation measures to implement.

Trade offs

Practicality

- Need ensure effort is not wasted, i.e. autumn application and incorporation for a spring sown crop will exchange one loss (ammonia) for another (nitrate).
- 24h is more practical – spread one day, cultivate the next, but it was acknowledged this is too late.
- This is practical sometimes – farmers should attempt to achieve this, but not always possible due to weather conditions; so, it should be an aspiration, not a requirement.

Impact on land

- Increased risk of nitrate leaching.
- Runs counter to gains obtained from minimal tillage.
- Speed of application can increase overall pollution risk.
- The need to have right conditions for spreading and incorporating will inevitably reduce the operating window. It may be OK to spread but soil conditions not good for incorporation?

Local factors

- When the soil is wet ploughing would damage soil structure. Light tillage would allow more rapid incorporation due to greater work rate and do less soil damage.
- Topography of land could possibly make incorporation difficult.
- Fields near the urban fringe would benefit due to reduced odour.

Barriers to implementation

Time

- Not practical – cannot physically cover the ground in time. There is a very small time-window during which manure can be spread and incorporated.
- There was disagreement about the practicality, suggesting that this depends on individual circumstances, such as availability of staff, specialist equipment and soil type.

Challenges

- For logistical reasons may want spreader to 'run ahead' of the incorporation machine by a few hours.
- Capacity of equipment will lead to dependence on contractors meaning additional costs.

Knowledge

- Need to clearly define what is meant by incorporation.
- Limited understanding of the benefits – many think it is not worth the additional trouble.

3.3.2.13 Mitigation action 15: Housing: improve animal behaviour and design of pens to keep solid parts of the floor as clean as possible

Co-benefits

- None proposed

Trade offs

- None proposed

Local factors

- Planning officers need to be familiarised with requirements for ammonia abatement.
- Standardised planning for new buildings would avoid issues with local councils making poor decisions.

Barriers to implementation

- Difficult to introduce a flushing system to an existing building but may be achievable for a new building.
- It has been a long time since funding has been available for new buildings and stores, this is required for many to make appropriate changes.

3.3.2.14 Mitigation action 16: Housing: air scrubbers to filter pollutants

Co-benefits

- Reports of increased bird performance with heat exchangers.
- Ammonia removed from the air passing through the exchanger can be stored as liquor and applied to land.
- Improved air quality in the building.

Trade offs

- The UK uses a lot of natural ventilation, an advantage which could be lost by using air scrubbers.
- Effluent is toxic and difficult to dispose of.

Local factors

- Applicable in key locations where there are sensitive sites to protect.

Barriers to implementation

- Retro-fitting is expensive and impractical.
- High maintenance.
- Not appropriate for cattle where buildings are naturally ventilated.

3.3.2.15 Mitigation action 17: Housing: regularly check structure and water drinkers to reduce leaks and keep litter dry

Co-benefits

- Wet manure is more difficult to handle, dry manure is more desirable in the poultry industry as value increases with dry matter.

Trade offs

- None proposed

Local factors

- Permitted (Integrated pollution prevention and control, IPPC) farms have to have a policy to reduce leaks and report water use as a check.

Barriers to implementation

- None proposed

3.3.2.16 Mitigation action 18: In-house poultry manure drying

Co-benefits

- Relatively inexpensive, approximate cost at £0.23 per bird.

Trade offs

- None proposed

Local factors

- None proposed

Barriers to implementation

- Retro-fitting is not easy, difficult to dry on a belt in an existing system.
- For new buildings, planning requirements are a problem limiting progress in building design.

3.3.2.17 Mitigation action 19: Housing: increase frequency of litter removal to two or three times per week (belt removal, layers only)

Co-benefits

- AD plants have the ability to take manure (if water is added) being cleaned out of buildings two or three times per week.

Trade offs

- None proposed

Local factors

- Ease of implementation depends on where the litter is taken after removal.

Barriers to implementation

- Increases energy usage on site and therefore a potential overall cost increase.

3.3.2.18 Mitigation action 20: Transport poultry litter for energy recovery

Co-benefits

- Implementing this measure gives the opportunity to install on-farm biomass boilers to make use of litter.
- Will save the producer time due to less of a requirement to apply the manure to the land.
- Incineration requires dry matter, so there will be an incentive to keep litter dry which will reduce overall emissions in buildings.

Trade offs

- Not sustainable if sites are having to send broiler litter hundreds of miles away for power generation.
- It would be more beneficial if poultry manure was used to improve soil quality rather than incinerated, being a benefit to the soil and supporting the government's soil policy.

Local factors

- Proximity to energy generation facilities.

Barriers to implementation

- The P and K produced from the ash has been known to have low uptake from crops.

3.3.2.19 Mitigation action 21: Introduction of nitrogen (fertiliser) limits; efficient use of N fertiliser, nutrient management plans, etc.

Co-benefits

Nutrient management plan

- Associated with improved soil health and saves money if implemented effectively.
- Key to the process of selecting appropriate mitigation actions.

N-fertiliser limits

- A benefit to water quality.
- Will minimise the use of bagged fertiliser, so potential for cost savings.
- Introduction of precision farming and other approaches to apply N exactly where and when it is needed.

Trade-offs

N-fertiliser limits

- Potential impact on overall yields and profitability, is it worth risking agricultural production for no direct reduction in ammonia emissions?
- Some have already reduced N fertiliser, so would see little gain from further limits.
- Legislation must not be too rigid; farmers must have scope to use common sense; they know their land, so must be given flexibility.

Local Factors

- Current Catchment Sensitive Farming system tends to focus on farms in vulnerable zones/sensitive areas and nutrient management plans (NMPs) are not promulgated. Plans must be tailored to suit the catchment. A blanket solution is not possible.
- Demonstration farms would be a very good means of increasing awareness, there is an Innovation Fund that might be available for such work.
- Flexibility is needed so that allowance can be made for variation in seasonal weather, i.e. less adherence to dates of application.

Barriers to implementation

- Nitrogen limits would not be popular - and may well encourage breaking the rules. It must be a voluntary activity, regulation will not help as it will just sit on the shelf and not be used.
- This will penalise those who are already efficient. It must be targeted at inefficient farmers

Challenges to farmers

- Need better planning software – PLANET is not good enough, almost unusable, farmers need a more effective computer-based guide to making best use of manure nutrients.
- Lack of available, affordable advice. This is a scientific measure and many farmers need guidance to implement a useful plan.

Knowledge

- Potential lack of knowledge, understanding and motivation of farmers to take on board measures. Many would benefit from knowledge transfer from Defra to educate farmers.
- Perception of the need for record keeping; it was expressed that any option requiring record keeping and auditing imposes unnecessary burden.
- Not clear on where the cap would be, nor how this would be determined.

Economics

- Costs incurred purchasing GPS kit, variable-rate sensor, N-sensor etc.
- Additional money needed to undertake regular soil testing, something the government could provide?

3.3.2.20 Mitigation action 22: Use of ammonium nitrate fertilisers instead of urea based, or use urease inhibitor with urea

Co-benefits

Ammonium nitrate

- No issues with restrictions on urea, reports have found urea does not work as well as AN. This was said to be the least contentious regulation to introduce, taking the pressure off the need for more challenging mitigation actions.
- Very few barriers at a farm scale as long as it does not restrict access to N fertiliser.
- In ammonium nitrate production the CO_2 goes to the market (fizzy drinks) but in urea production CO_2 goes to the urea and is later lost on application, leading to increased GHG emissions.

Urease with inhibitor

- Provides competition in the fertiliser market, providing an alternative to AN.
- Lower cost per unit of N for urea with urease inhibitor compared with ammonium nitrate.
- Time saved at spreading compared with ammonium nitrate - urea has a higher N content so less material to spread, also more likely to release nutrient closer to the time of crop demand.
- Urea with urease inhibitor cannot be used to make explosive devices.

Trade-offs

- Choice is important and the option of having urea with inhibitor is more attractive than not having urea.
- Increased leaching of ammonium nitrate; Defra should ensure any ammonia mitigation options do not conflict with other environmental actions.
- Urea has benefits for water quality, as well as a cost advantage.
- Urea can be used responsibly at the right times and right conditions.
- It is more energy intensive to produce ammonium nitrate than urea, so most fertiliser manufacturers are now producing urea (globally).
- Removing urea gives a monopoly to ammonium nitrate producers, giving them the opportunity to increase costs once competition has been eliminated.
- Amount of N saved through mitigating ammonia emissions is often small.

Local Factors

- Time of year will impact whether to choose urea (spring) or ammonium nitrate (summer). In some parts, urea is currently being used tactically to reduce leaching losses.
- The appropriate fertiliser needs to be chosen for ground conditions.
- A group in Okehampton supported this mitigation measure but noted there may be different views in areas with more arable farming and field horticulture.
- Suggestion – is it possible to add urease inhibitor, or other similar products to manures (slurry) to cut ammonia emissions?

Barriers to Implementation

- Time needs to be given to ensure there is enough supply to meet increased demand.
- Not keen on banning urea. Not just price, but impact on gross margin since agriculture is an industry running on marginal profits. In general, better to leave options open rather than being prescriptive about which actions need to be taken. Give back some freedom to choose options that can reduce emissions but are well suited to the way a particular farm is run.
- The addition of the inhibitor makes N fertilizer a hazardous substance with health and Safety implications for handling.
- Availability of ammonium nitrate post-Brexit?

Economics

- Cost of building an ammonium nitrate plant is significantly more than building a urea plant.
- There is likely to be an additional cost for ammonium nitrate, quoted ammonium nitrate would result in a 30% increase.

Knowledge

- Education as to the science of losses from both ammonium nitrate and urea is needed to encourage careful use of urea.
- Farming industry knowledge of urease inhibitors needs improvement.
- Preferable to have restrictions on urea (when, where, how) rather than addition of an inhibitor.
- Farmers need more information about the emissions.
- The effectiveness of urease inhibitors is not fully proven or understood. There are also unknowns on the persistence of inhibitors in the environment, as well as their shelf life.

3.3.2.21 Mitigation action 23: Put land/buildings out of production; reduce stocking densities on land near sensitive sites

Co-benefits

- None proposed

Trade-offs

- Dependent on the composition of the land and farm, must not be a blanket recommendation, but tailored to specific sites.
- Who decides on the habitat and where the buffer is to be? Restricting activity on buffer zones may be difficult to monitor and creates difficulties within the industry, with restrictions on some producers and not others.

Local factors

- Worrying implications for those farming in any sort of protected areas such as a national park, and many farms in Shropshire are close to SSSIs.
- Will impact on the local economy and could well reduce the desirability of the local area to visitors.

Barriers to implementation

- Difficult to implement.
- Would require incentives/compensations, what time frame would these be decided?
- Significant impact on land value.
- Action must not be based on modelling, but on measurements, hard evidence is needed to justify this as a measure.
- Potentially kills a business, putting major economic impact on farms, risking their financial viability.

3.3.2.22 The need for support

The need for support was frequently expressed by the attendees of the regional workshops and the key points raised are summarised below.

Each mitigation measure involves additional cost, and several require large capital investment, therefore financial benefits to the farmer need to be attractive to encourage uptake. It was stated that livestock farming is not profitable enough to invest properly in new slurry stores, improved building design and reduced emission spreading equipment, so these options would only become feasible with financial support in place. Many attendees explained that 100% capital grants would be required for most mitigation actions, particularly for those requiring retro-fitting, which can incur considerable costs to a farming business. Previous grants and incentives were perceived to be one-off payments, but having ongoing implications, so the grants were not always valuable in the long-term.

The application window for previous grants, such as the Farming Ammonia Reduction Grant (FARG) scheme was perceived to be too short, not allowing enough time for planning and full investment appraisal.

Some participants in the workshops agreed that, because of the financial constraints within the farming industry, measures taking more than four years to begin paying back may not be implemented, and it would beneficial for Defra to undertake a study to investigate the pay back periods.

3.3.3 Stakeholder scores

This scoring exercise was intended primarily to engage workshop attendees individually and provide information to help divide the attendees into groups for a facilitated discussion. An added benefit was to gain information on perceptions. Attendees were asked to score mitigation actions for costs, benefits and practicality for their business, from 1 to 5, for each mitigation action for which they had some interest or knowledge. Despite verbal instructions immediately before this exercise, some attendees scored high costs as 5 and low costs as 1, and some scored high costs as 1 and low costs as 5[17]. This can be seen in the raw data, where some obviously expensive options were scored differently by different attendees. We have decided, therefore, not to use the data on costs in this report because the aggregation of scores can give a misleading view of perceptions. Furthermore, it was apparent in the meetings that many attendees had limited knowledge of costs.

The data for practicality are the most useful data in this set, as the attendees generally were well placed to make judgments about the practical farming considerations. The mean scores across all 13 workshops are shown in Figure 4.

For benefits, the intention was that the attendees scored for benefits to a farming business, but this may be judged in different ways. Attendees may have taken into account, for example: financial performance, improvements in animal welfare, and/or environmental performance. Nonetheless, we present the mean scores across all 13 workshops in Figure 5.

In Appendix 1, the mean practicality scores for each location are shown in a series of bar charts, one for each mitigation action. These are useful to allow visual checking for differences between sites in mean scores. Examination of these charts did not reveal any patterns in the data related to known characteristics of the regions. Four examples follow.

Mitigation action 1. Extended season grazing.

> It was expected that this would be perceived as having low practicality in the west (the grazing period is constrained more by rainfall than the east), and where soils are heavy (soils

[17] This was picked up at the second of 13 workshops and the instructions were clarified for use at subsequent workshops and the workshop leaders were made aware of the issue. However, inspection of the data suggests that incorrect scoring by a minority of attendees continued.

slower to drain, constraining the grazing period). In line with this, practicality scores were low in Shepton Mallet (south-west) and Bishops Stortford (east but with heavy soil type). However, practicality scores were low in Newark and York, both in the east, and with many farms not on heavy soils.

Mitigation action 3. Cover slurry stores.

It was expected that this would be perceived as having low practicality in low rainfall areas (less benefit of minimising volume of stored slurry, more benefit from dilution), and high practicality in high rainfall areas. High mean scores were given in some low rainfall areas (York, Newark, Bishops Stortford), but also in a high rainfall area (Okehampton). Norwich and Leominster are in the east and west respectively and both had both low mean scores.

Mitigation action 4. Housing: additional straw bedding to provide a barrier between urine and air, encouraging microbial immobilisation of ammonium-N.

It was expected that this would be perceived as having high practicality in regions with good availability of straw (regions with large arable areas). High mean scores were given in some of these regions (Newark, Norwich), but low mean scores in another (York).

Mitigation action 22. Use of ammonium nitrate fertilisers instead of urea-based fertilisers, or use urease inhibitor with urea.

There was no clear expectation for how mean scores would vary by region. Scores were generally high (see Figure 4 for the overall mean; this mitigation action was second-highest), but were lowest in Stoneleigh, where there was the greatest representation of stakeholder organisations, influencing the discussions. This effect was related to the convenience of the location for attendees, not to regional differences in farming, climate, or land characteristics.

Figure 4. Practicality scores given by workshop attendees: mean for 13 workshops, ranked from high to low.

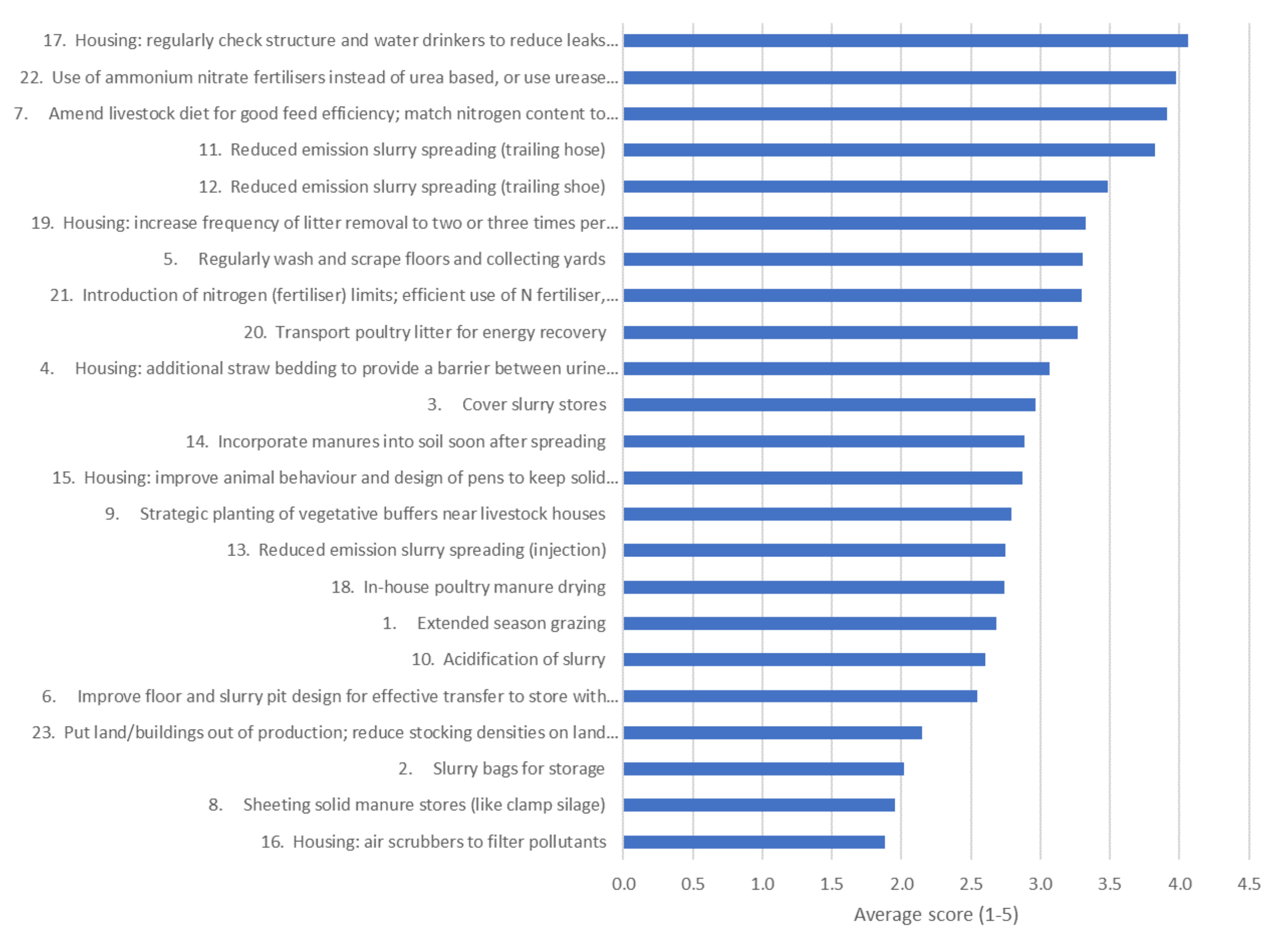
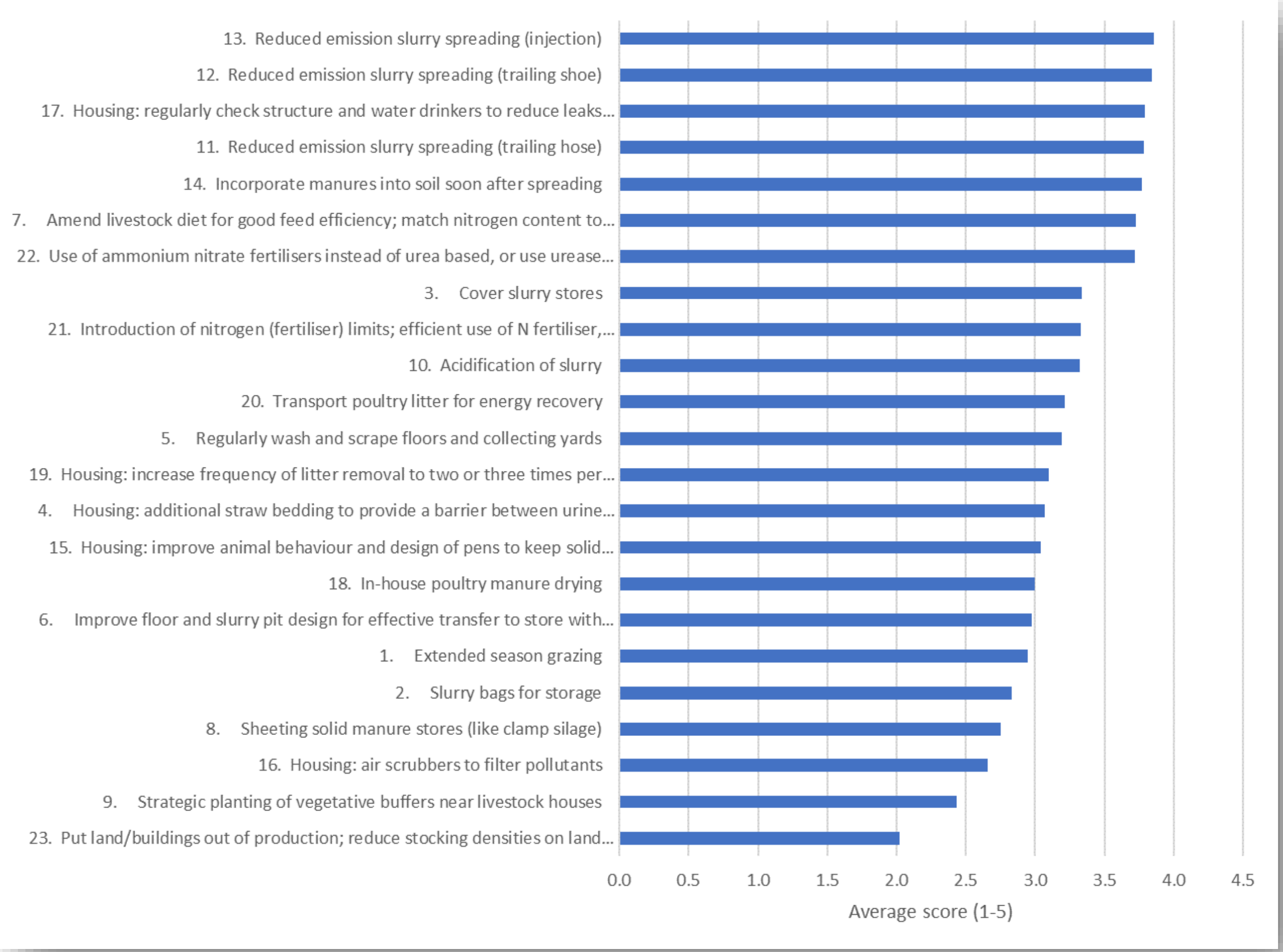


Figure 5. Benefits scores given by workshop attendees: mean for 13 workshops, ranked from high to low.



3.3.4 Regional differences

In general, there was much consistency between regions, with similar points and comments on the mitigation actions being raised across the country despite the differences in farming systems, soil types and climate. However, there were exceptions to this generality that were identified by the discussion facilitators in the stakeholder workshops.

There were differences, due to regional rainfall variation, in the attitude to covering slurry stores. For example, the groups in York felt it was not practical or cost effective to cover stores and reduce the capture of rainfall by stores, which can have the benefit of diluting the slurry to make it easier to pump. However, other groups, such as at Penrith, commented on how reducing the rainfall entering stores is beneficial in high rainfall areas because the volume of slurry to be stored and spread is reduced. It was also noted at Penrith that there are large differences in rainfall within regions, ranging from 38 inches in Penrith to 150 inches in the hills. In summary, the benefit compared with cost is better where rainfall is higher.

There were also different views on extended grazing both on a regional and local scale depending on the soil type, with concern that extended grazing is not practical on heavy clay soils, or where rainfall is high. It was also mentioned that where Higher Level Stewardship Schemes (HLS) are in place, these may hinder increased grazing due to the HLS rules. Extended grazing systems in dairy enterprises often require a complete change in system such as smaller cows

Low emission spreading techniques were perceived to be dependent on both soil type and topography, being difficult to implement in areas with more stony soils and uneven ground. Some questioned whether this action could be implemented across the country because of these factors.

Regarding the use of additional straw bedding, points were raised about availability of straw, with reference to the summer weather of 2018 and how several farmers found it difficult to source enough straw. The availability of straw differs regionally and within the regions. There were concerns about the cost of using additional straw, but it was perceived as an easier option for those with good access to straw, i.e. with their own arable enterprise.

For changes in livestock diet, groups in the North West advised this would not be feasible if this is linked to increased growth of forage maize, because of short harvest windows and the implications for soil run-off and water quality. Some commented they had already tried to grow maize but have reverted to grass.

The action to put land/buildings out of production near sensitive sites had worrying implications for those farming near protected areas, particularly for the group in Crewe where farms were represented that were close to protected sites in Shropshire.

These regional differences were differences in the points made, and the degree of emphasis on these points, in facilitated discussion groups during the stakeholder meetings. Further comment on regional differences in views of stakeholders is made in section 3.3.3, based on the written scoring exercise (see also 3.2.2, agenda item 4).

3.4 Key messages

There were some points made by stakeholders that were universal, or almost universal, across all regional meetings.

- Covering manure heaps was perceived to be impractical and dangerous. This generated more heated discussion than any other mitigation action. Concerns included:
    - Labour requirement to cover and uncover heaps that had manure added to them frequently, sometimes daily;
    - The safety of people covering the heaps, often working alone, and who could fall into a wet patch and drown;
    - The safety considerations for nearby road traffic that could be affected when a gale blows a plastic cover away;
    - The environmental impact of the plastic covers (manufacture and waste); it was asserted that plastic covers would need to be replaced annually;
    - The lack of benefit for ammonia emissions if solid manure is spread to grass after a heap has been covered, because the ammoniacal N that is retained during covered storage will be lost after spreading to grass, where it is not incorporated.
- Covering slurry stores is not practical for many existing stores, but is more practical on new stores;
- There was interest in acidification and the benefits of retaining N were recognised; however, there were concerns about costs, health and safety, and practicality of retro-fitting. There was also a perceived benefit through avoiding the need for other mitigation actions (such as covering slurry stores, or injecting slurry when applying to land) because acidification is effective throughout the manure management chain.
- A flexible approach is needed to regulate ammonia emissions, such as an approach that would require the assessment of a farm baseline ammonia emissions level, followed by choice of mitigation actions to achieve an agreed mitigation target.

There were also other strong themes that emerged across many workshops.

- There was support for use of urease inhibitors:
  - to ensure that urea continues to be available;
  - because urea was perceived to have a lower leaching risk than ammonium nitrate, and therefore farmers wished to continue using it;
  - because it was perceived that urea availability helps to avoid a near-monopoly situation for the supply of ammonium nitrate, that (it was perceived) may develop if urea use is banned.
- Implementation of mitigation actions must not lead to a production decrease, or lower competitiveness internationally. This was especially a concern related to the potential introduction of nitrogen (fertiliser) limits.
- There was a dislike of slurry bags because of concerns about the lack of? ability to remove any sludge or foreign objects.
- Most housing options were perceived to be either too expensive or impractical, unless implemented at the construction of new livestock buildings.
- Extended grazing systems in dairy enterprises often require a complete change in system such as a change to a smaller breed of cows.
- The need for incentivisation was frequently discussed, and it was asserted in some discussions that farmers are struggling financially and do not have the resources to implement the mitigation actions. Many measures require significant capital expenditure without sufficient return, so bank financing is difficult to access – a 40% grant still requires 60% input from the farmer. Options for interest free/low interest loans, as well as grants, should be considered.
- The benefits of reduced emission spreading (trailing hose, trailing shoe, injection) were recognised (more N retention, lower odour nuisance), but there was concern about costs and availability of equipment. A barrier to implementation was a perception that any grants that become available may not be available to contractors and this will limit the availability of the equipment.
- Rapid incorporation would require a complete change in system for some but would be relatively easy to adopt for others. This was usually dependent on cultivation system (plough *vs* minimum tillage) but sometimes it was relating to availability of labour and machinery.

There were other strong messages that were raised at fewer meetings.

- It was perceived that there is little benefit in covering a manure heap if it is on a concrete base because the run-off water can be collected, and it was perceived that most of the N loss occurs through the pathway to water.
- There was surprise that the following mitigation action was on the list for discussion: to regularly check building structure and water drinkers to reduce leaks and keep litter dry. The surprise was because farmers already do this, as it is in their interests to avoid water loss.
- There was a perception that the farmers that have the most opportunity to mitigate ammonia emissions, but the least inclination to do so, have not attended the workshops.

The acceptance of mitigation measures was sometimes dependent on geography or farming system (see 3.3.4).

- For covering slurry stores, where this is practical (depending on the type of store), the cost-benefit is better in high rainfall areas.
- Low emission spreading techniques were perceived to be dependent on both soil type and topography.
- The availability of straw differs regionally and within the regions. The use of additional straw bedding was perceived as an easier option for those with their own arable enterprise.
- The action to put land/buildings out of production near sensitive sites had worrying implications for those farming near protected areas.
- The ability to extend grazing in dairy enterprises can be influenced by soil type and rainfall.

4 Discussion and conclusions

Based on thirteen regional stakeholder workshops across England, this project has provided an insight into the views of the farming industry about the ammonia mitigation, and the ability of farming businesses to implement actions to mitigate ammonia emissions.

Background research before the stakeholder workshops included a brief review of the damage costs associated with ammonia pollution. Damage costs estimates from the Interdepartmental Group on Costs and Benefits (IGCB) suggest a cost in England only, of between £192M and £3.191B, relating to a damage cost range from £1,133 to £18,867 per tonne ammonia, with a central value of £6,046 per tonne (2017 prices). This provides some context to the farming industry, and to policy makers. The damage costs are a policy driver for action to mitigate ammonia pollution, and are reflected in the targets set under the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol, revised 2012), which was ratified by the UK, and the National Emissions Ceiling Directive. Without further mitigation actions on farms, the UK may exceed the agreed Gothenburg Protocol ceilings for ammonia emissions (see 1.1).

Of the ammonia emissions from agriculture in England (199 kt in 2016[18]), 85% were from agriculture. Of the agricultural emissions, 28% were emitted from application of inorganic fertilisers and the rest were from livestock manures. Some of the inorganic fertiliser is applied to grassland or other forage crops for livestock production. There is, therefore, a particular focus on the livestock industry, with regard to ammonia emissions. This was reflected in the prominent representation of mitigation actions that are applicable to livestock systems in the list of mitigation actions that were discussed in the stakeholder workshops. Of the 23 mitigation actions (see 3.3.1), 16 related specifically to livestock systems, four related to the application of manures to land, two related to nutrient applications to crops (including grass), and one is applicable to any agricultural system. Of the farmers that attended the stakeholder workshops, a majority of them were livestock farmers (Table 9), with a high proportion of cattle farmers (dairy and beef).

The trend in ammonia emissions is largely driven by changes in cattle numbers and fertiliser use; the balance between use of the nitrogen fertilisers ammonium nitrate and urea is especially important as urea-based fertilisers have higher ammonia emission factors. There has been an increased usage of urea-based fertilisers in recent years, which has increased overall emissions from agriculture (Figure 1). Mitigation actions relating to fertiliser use were, therefore, also included in the stakeholder workshop discussions, and there was significant representation of arable farmers.

Farmscoper was used to model the secondary impacts of ammonia mitigation measures on emissions of climate change gases and of nutrients to water. Primary effects of ammonia concentrations and deposition on habitat have not been included in the cost-benefit analysis and must be established to

[18] Air Pollutant Inventories for England, Scotland, Wales, and Northern Ireland: 1990-2016. http://naei.beis.gov.uk/reports/reports?report_id=970

provide estimates for policy evaluation. The Farmscoper results were limited by the use of outdated and incomplete damage costs and the assumption of zero existing uptake of mitigation measures. As a national average, the results do not reflect the localised benefits that can also be achieved. To establish the cost-benefit of ammonia reduction related policy for ecosystems, further work is required. However, the results demonstrate that generally, those measures that have the greatest impact on ammonia emission produce the greatest change in emission of other pollutants. The Farmscoper model showed that only two measures (extending the grazing season and using a fertiliser recommendation system) result in a cost saving for the farmer. There were also only two methods for which the environmental benefit value exceeded the costs of implementation, such that there was an overall positive impact:

1) Covering solid manure stores with sheeting, and
2) More frequent manure removal from laying hen housing with manure belt systems.

These two methods had a limited impact on ammonia emissions, with reductions of less than 1%. Farmscoper also showed that replacing urea fertilisers with another form on arable crops has a GHG impact (because of an increase in embedded emissions from the manufacture of alternatives to urea) and a financial cost of implementation. To give context to these results, a life cycle assessment study by Fertilizers Europe[19] has shown that across several potential impact indicators (global warming, non-renewable primary energy consumption, acidification, drinking water eutrophication, marine eutrophication, human toxicity and ecotoxicity in the air, ground and water), ammonium nitrate performed better than urea. In this study ammonium nitrate production, compared with urea, had lower energy consumption, lower GHG emissions, lower N losses in the field, and greater agronomic efficiency.

Of the other mitigation actions that were modelled with Farmscoper, there were two for which the environmental benefit exceeded the implementation costs. These were:

- Sheeting solid manure stores
- Increase the frequency of litter removal from laying hen housing with manure belt systems

Sheeting solid manure stores is not included in plans set out in the Clean Air Strategy 2019, and this mitigation action was strongly opposed by farmers and other stakeholders in the stakeholder workshops (see 3.4), principally on grounds of practicality and safety. A further reason given in the workshops was that the benefits are often over-estimated; for example, if solid manure is spread to grass after a heap has been covered, the ammoniacal N that is retained during covered storage will be lost after spreading to grass, where the manure is not is not incorporated.

A full cost-benefit assessment exercise, which takes into account context-specific factors, would be useful to confirm whether a measure provides a net positive or negative impact on society, after considering the co-benefits and risks. For example, extending the grazing season for cattle has a positive environmental benefit and a cost saving (from our Farmscoper results), but gives an increase in N_2O emissions and faecal indicator organism (FIO) concentrations. Whether this is a worthwhile trade-off is dependent, in part, on N_2O and FIO concentrations in the locality and whether the additional pollutants breach safe levels.

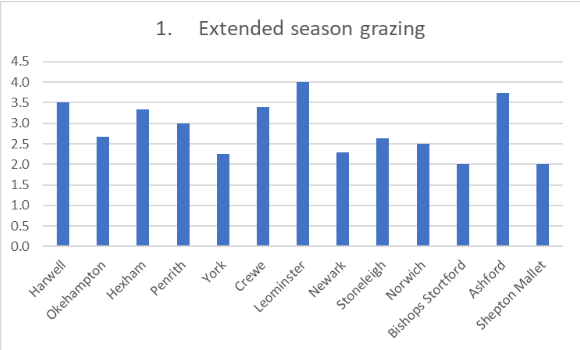
The stakeholder workshops were well attended and well received by attendees (see feedback scores given in 3.2.3); there was good engagement during the meetings, with lively discussions. In general, there was much consistency between regions, with similar points and comments on the mitigation actions being raised across the country despite the differences in farming systems, soil types and climate. Where there were regional differences, the variation mainly related to differences in farming systems, soil types and rainfall.

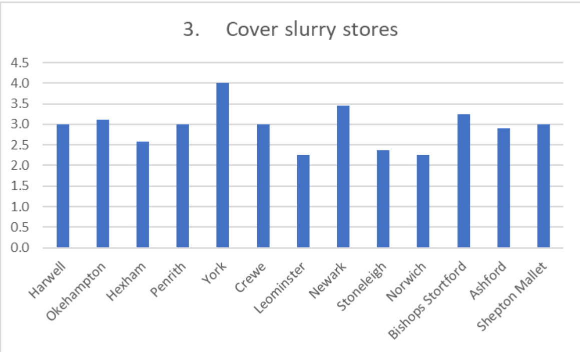
[19] Comparison of the environmental impact of three forms of nitrogen fertilizer (Amandine Berthoud , Aurélie Buet Thierry Genter , Sophie Marquis, 2012). https://www.fertilizerseurope.com/fileadmin/user_upload/publications/agriculture_publications/Enviro_Impact-V9.pdf

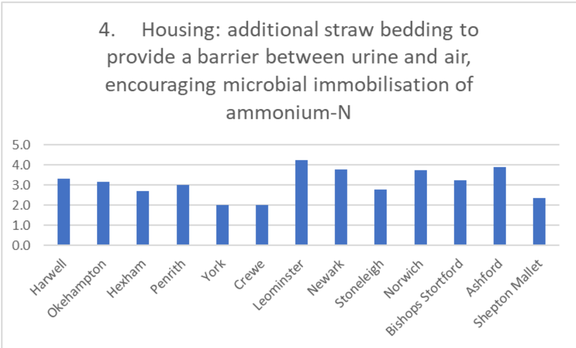
The points made were often made strongly, and the active discussions brought out much knowledge that the farming industry has, to contribute to the formulation and implementation of policy to mitigate ammonia emissions. The willingness to contribute and the quality of the discussions can be harnessed by government as the plans in the Clean Air Strategy 2019 are developed further.

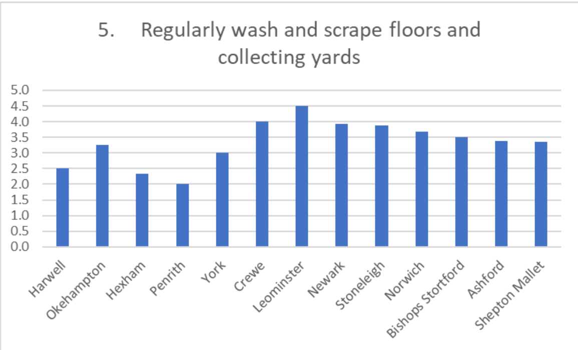
Appendix 1

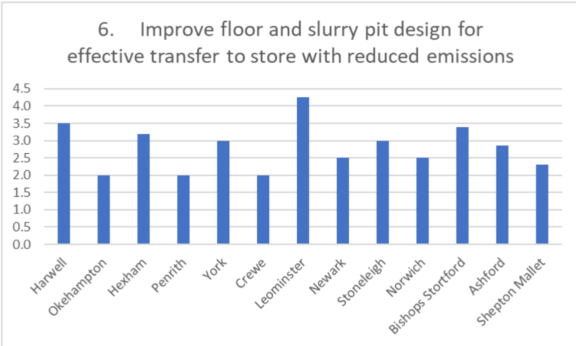
Practicality of ammonia mitigation actions: mean scores for each location

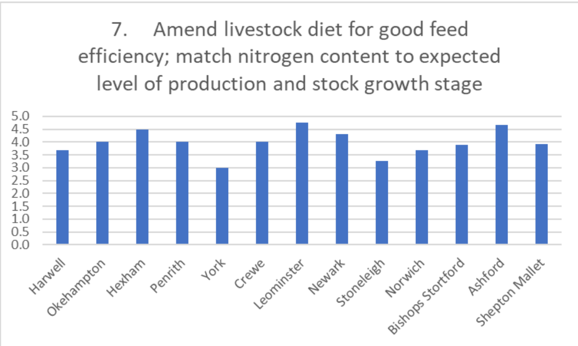


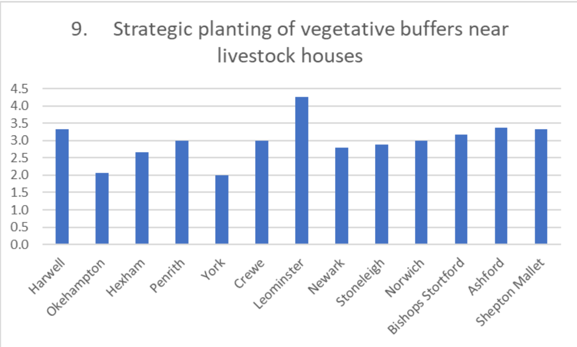


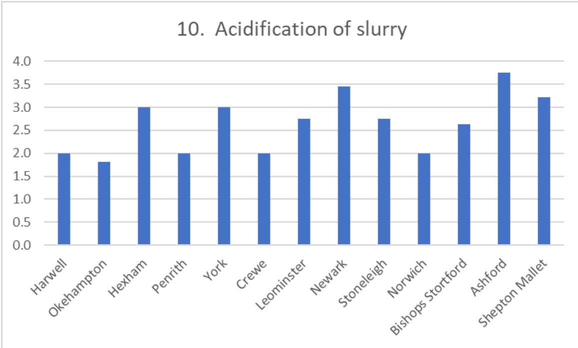


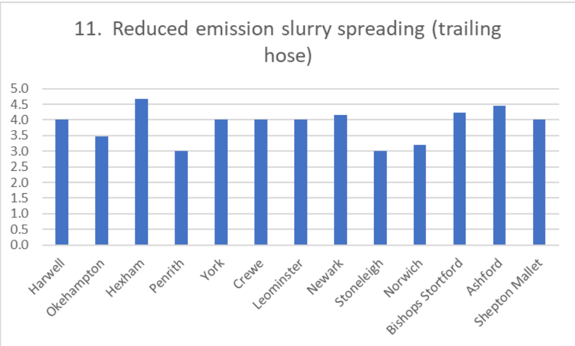


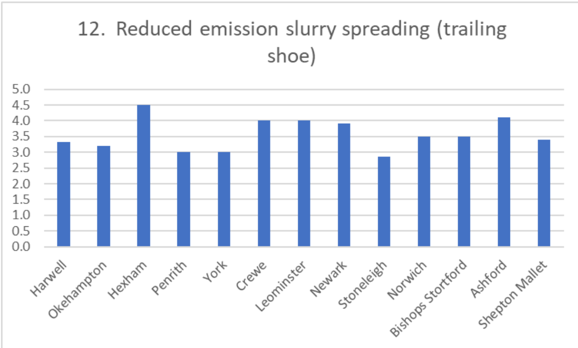


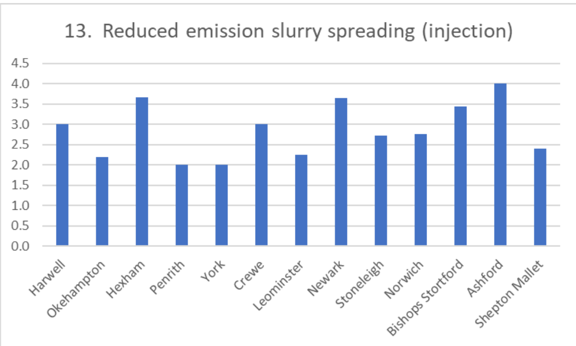


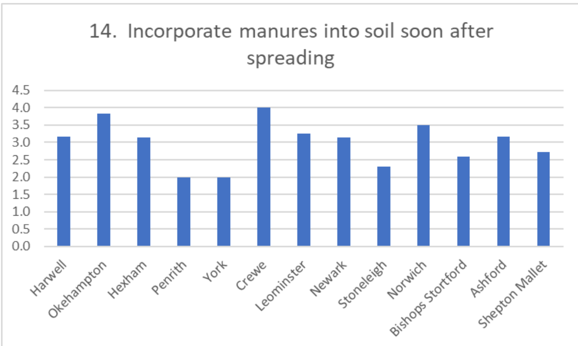

9. Strategic planting of vegetative buffers near livestock houses
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet

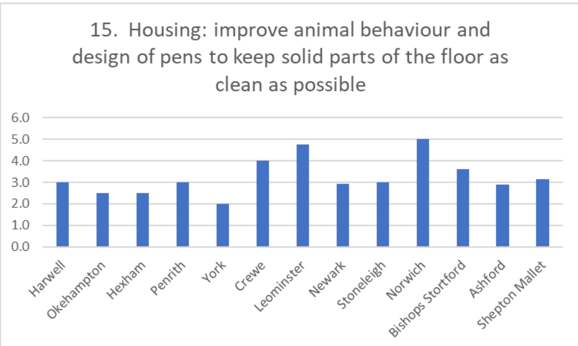

10. Acidification of slurry
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet

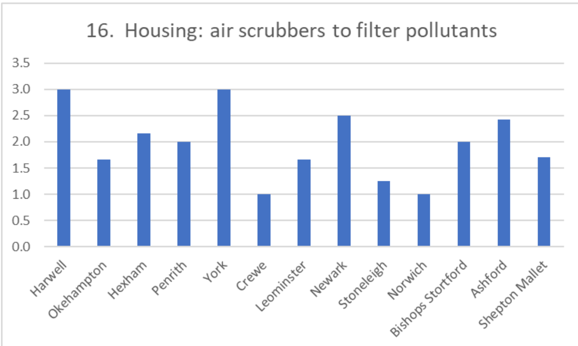

11. Reduced emission slurry spreading (trailing hose)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet

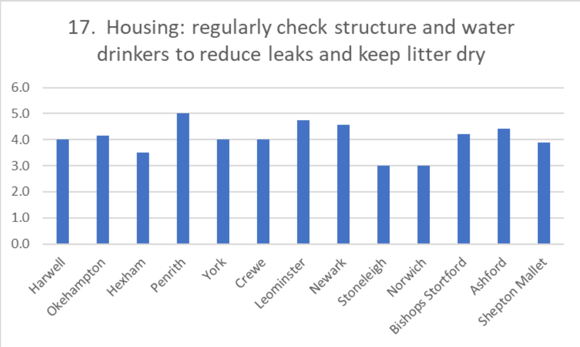

12. Reduced emission slurry spreading (trailing shoe)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet

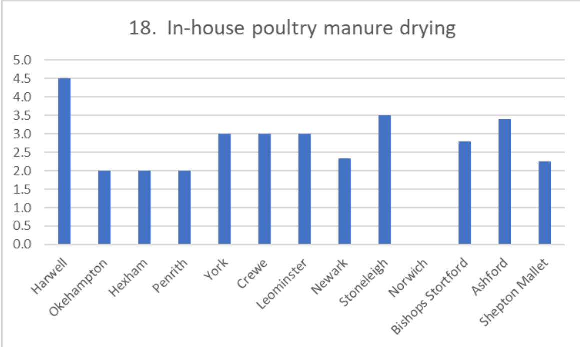

13. Reduced emission slurry spreading (injection)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet

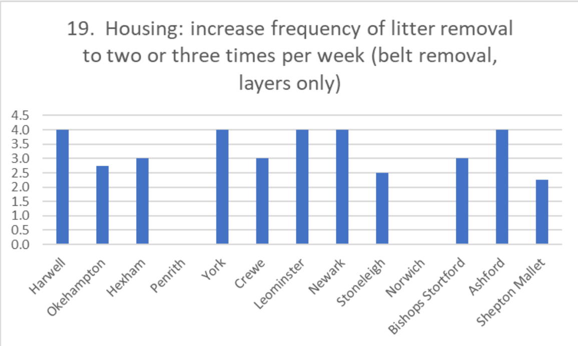

14. Incorporate manures into soil soon after spreading
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet

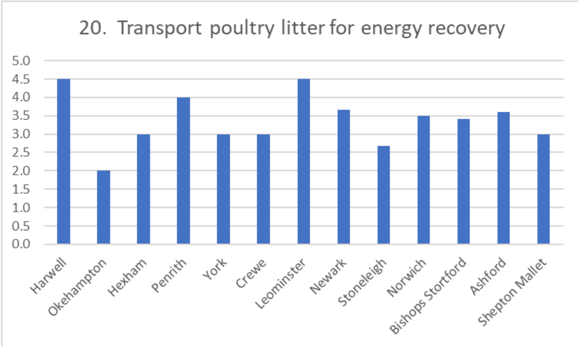

15. Housing: improve animal behaviour and design of pens to keep solid parts of the floor as clean as possible
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet

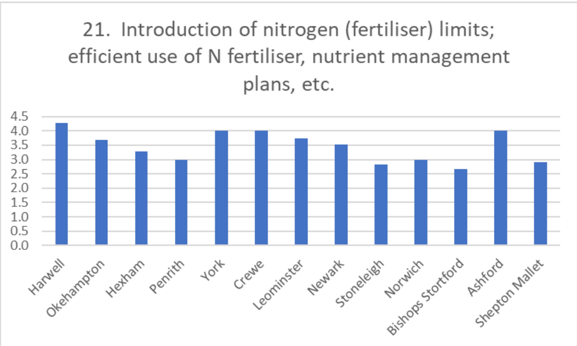

16. Housing: air scrubbers to filter pollutants
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet

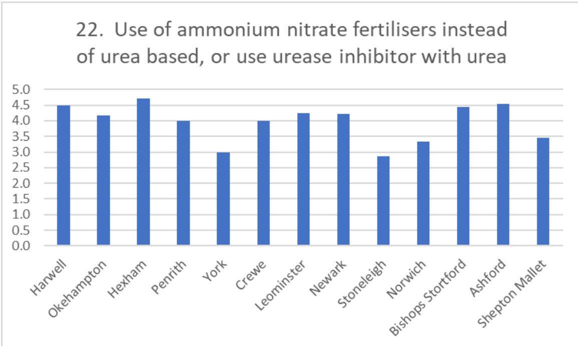

17. Housing: regularly check structure and water drinkers to reduce leaks and keep litter dry
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet

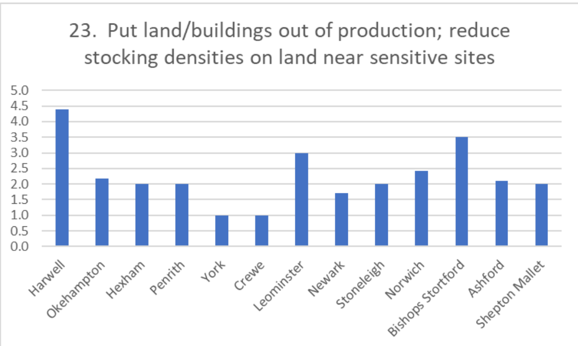

18. In-house poultry manure drying
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet


19. Housing: increase frequency of litter removal to two or three times per week (belt removal, layers only)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet


20. Transport poultry litter for energy recovery
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet


21. Introduction of nitrogen (fertiliser) limits; efficient use of N fertiliser, nutrient management plans, etc.
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet


22. Use of ammonium nitrate fertilisers instead of urea based, or use urease inhibitor with urea
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet


23. Put land/buildings out of production; reduce stocking densities on land near sensitive sites
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Harwell
Okehampton
Hexham
Penrith
York
Crewe
Leominster
Newark
Stoneleigh
Norwich
Bishops Stortford
Ashford
Shepton Mallet

The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR
United Kingdom
t: +44 (0)1235 753000
e: enquiry@ricardo.com

ee.ricardo.com