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Project Title: AIM-HEALTH: Effectiveness of agricultural interventions to minimise the health impacts of air pollution

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Chief Investigator: Hilary Cowie

Sponsor: Institute of Occupational Medicine, Edinburgh, UK

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Version Control Table

Date	Version number	Editor	Comments
15/05/2020	1.0	HC	First version of study protocol
20/11/2020	1.1	HC	Revision to name of ethics committee (section 4.1)

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1. Aims and Objectives

The overall aim of the project is to investigate whether interventions included in the national Clean Air Strategy[1] are effective and cost-effective in minimising the adverse health impacts and inequalities of outdoor air pollution from agricultural sources.

The specific objectives are to:

i. Assess the long- and short-term health impact of air pollution (secondary $PM_{2.5}$, microbial aerosols, and ozone) from intensive agriculture and farming on the general population, and susceptible sub-groups, for different levels of adoption of the interventions;
ii. Evaluate the effectiveness and cost-effectiveness of the specific interventions at local-to-regional level, and then scaled up to national level;
iii. Gain insight into the potential for further uptake and implementation of the proposed agricultural interventions in the UK;
iv. Assess the impact of the interventions on health equity, particularly for populations (including susceptible groups) living near intensive farming and agriculture units;
v. Assess the environmental co-benefits and trade-offs of the interventions, including impacts on ecosystems and climate.

2. Background

Air pollution emissions from other sectors in the UK are declining, but those from agriculture are not [1] and are attracting public health attention. This consortium carried out a rapid evidence assessment of agricultural interventions to improve ambient air quality, commissioned by Public Health England (PHE) [2], which aimed to assess the evidence for effective and cost-effective interventions to identify actions that will significantly reduce harm from air pollution, mainly focusing on local interventions but including relevant national interventions supported by evidence. This assessment did not find sufficient evidence for effectiveness of interventions in affecting public health outcomes, and very little evidence on the cost-effectiveness and distributional effects of interventions. New research is urgently needed to fill this knowledge gap.

Important emissions from agriculture, which affect air quality, are ammonia (NH_3), particulate matter (PM), volatile organic compounds (VOCs), oxides of nitrogen (NOx), hydrogen sulphide (H_2S), odours, and bioaerosols. The main sources of NH_3 are livestock manures exposed to the atmosphere in livestock housing, in storage, during and following application to land, and from manures deposited to pasture during grazing. Ammonia is also emitted following application to land of some manufactured fertilisers, and from crop residues and silage. Estimates of NH_3 emissions at a UK level show that around 82% of agricultural emissions are from livestock manures, with over half from cattle farming. Poultry and pig farming also make important contributions to the emissions total. Particulate matter emissions from agriculture occur directly from farming activities, and from reaction of NH_3 with acidic pollutants to form fine particles ($PM_{2.5}$, i.e. particles with diameter of 2.5 µm or less). Direct emissions of PM_{10} (i.e. particles with diameter of 10 µm or less) are predominantly from poultry and pig farming, with a smaller contribution from arable farming. Emissions of PM from livestock buildings are influenced by the type of bedding, factors that influence animal activity (e.g. age), feeding systems, manure management systems, and building design [3].

The evidence found in our rapid assessment [2] was primarily made up of studies reporting emissions data for alternative farm practices, or effects of farm practices on air quality. There was no substantial

[1] https://www.gov.uk/government/publications/clean-air-strategy-2019

information on effects of interventions on health, equality or economic impacts. Much of the available evidence was concentrated on a few major sources of air pollution, which were:

- Emissions from housed livestock and their excreta, including effects of feed inputs;
- Emissions from manure management, storage and spreading to land;
- Emissions from soils after application of nitrogen fertilisers.

The results focused attention on opportunities to make or extend interventions that can decrease emissions by large percentages of what are often large emissions. This potential includes: (i) acid scrubbers to filter exhaust air from livestock buildings; (ii) cattle diet changes (reduced crude protein intake for housed cattle); (iii) covered slurry and solid manure storage; (iv) improved land spreading methods for manures; and (v) use of ammonium nitrate as a nitrogen fertiliser in place of urea. Another key conclusion of our rapid evidence assessment was that not just mitigation potential but also current implementation and practicality of further implementation of interventions needs to be considered, requiring further research into barriers, enablers, costs, and unintended consequences of the interventions, as well as assessment of the public health benefits.

Socially and economically disadvantaged people are likely to be exposed to higher levels of air pollution, particularly in urban areas [4,5]. There is no clear evidence of differential exposure of socioeconomically disadvantaged people to pollutants related to agriculture, such as secondary inorganic $PM_{2.5}$. However, it is important to ensure that agricultural interventions aiming to improve ambient air quality do not inadvertently exacerbate existing health inequalities in the UK, particularly for communities living near large agricultural units.

3. Methods

3.1. Design overview

The study is a mixed methods design incorporating both qualitative and quantitative methods. Emissions will be measured at 6 farming units, selected to represent dairy, poultry and pig farms with and without adoption of the interventions set out as government policy. Supplemented by exposure modelling, these emissions will be used to estimate changes in population exposure to $PM_{2.5}$, O_3 and bioaerosols associated with future implementation of interventions. A health impact assessment will be carried out to assess the effects on mortality and morbidity of these changes in population exposure, and an economic assessment will estimate the costs and benefits of the interventions.

Literature reviews will be carried out to identify the health effects associated with agricultural emissions, the effectiveness of agricultural interventions and the costs, lifetime and wider environmental, social and economic co-benefits and impacts of the interventions.

Surveys and focus groups will be carried out with residents near the selected farming units and with farmers across the UK. These will identify barriers and enablers to the implementation of interventions, and potential environmental health and annoyance issues, as well as perceived benefits, of living near to farms. Finally, interviews will be held with a range of stakeholders including regulators and policy makers.

3.2. Outcome measures

3.2.1. Primary outcomes

The primary health outcomes are mortality attributable to long-term exposure to secondary $PM_{2.5}$, mortality/morbidity associated with microbial aerosols, and mortality and hospital admissions attributable to short-term exposure to ozone.

3.2.2. Secondary outcomes

The secondary outcomes are increased knowledge of the uptake of these interventions, including barriers and enablers, and distribution of uptake across the UK; information on potential health or annoyance issues affecting those who live near farming units; and measured and modelled exposure concentrations around farming units and the impact on these of the implementation of the interventions.

3.3. Literature reviews on health and intervention effectiveness

This literature review will comprise two linked rapid evidence reviews – one review will consider the health effects of the environmental exposures ($PM_{2.5}$, ammonia, microbial aerosols, ozone) including the potentially differential toxicity of secondary $PM_{2.5}$ from ammonia, and the second will consider the effectiveness and cost-effectiveness of agricultural inventions to improve air quality. The review will expand on our recent evidence assessment [2] to identify additional publications on the effectiveness and cost-effectiveness of agricultural/farming interventions to improve air quality.

3.3.1. Search strategy

The scope criteria for the review are detailed in Table 1. Other details may be subsequently identified and included before being translated in to search strings. Relevant websites will be identified for grey literature and searched for relevant documents. The search strategy has been designed to identify publications relevant to both rapid reviews, with allocation across the review topics determined at the screening stage.

Table 1 Scope criteria

Criteria	**Description**
Source/ Pollutant	Agricultural emissions of ammonia (NH_3), PM_{10}, $PM_{2.5,}$ Particulate Matter (PM), Secondary Inorganic Aerosols (SIA), Ammonium nitrate, Total Suspended Particulates (TSP), Nitrogen oxides (NO_x) (from agricultural Non-Road Mobile Machinery), Nitrogen dioxide (NO_2), Volatile Organic Compounds (VOCs) (including NMVOCs), Bio-aerosols
Pathway	Outdoor exposure, Indoor exposure, Inhalation exposure
Receptor	Human including vulnerable groups, individuals and populations
Intervention types	Animal excreta (manure) management: Livestock housing, Slurry/manure storage, Slurry/manure application to land, Manure deposition, Manure spreading, Slurry spreading; Livestock housing (including litter/bedding management) particularly for Chickens (broilers/layers), Poultry, Cattle (dairy/beef), Pigs; Intensive livestock systems; Fertiliser use (urea); Crop production (including crop residues/silage);
Health outcomes	Respiratory mortality; Respiratory morbidity; Inflammatory response; Asthma; Chronic Obstructive Pulmonary Disease (COPD); Cardiovascular mortality; Cardiovascular morbidity; Cardiac symptoms; Cardiac parameters; Cancer; Cognition; Dementia; Diabetes; Prenatal effects; Hospital admissions; Primary care visits; GP visits; Medication use; Inflammation; Oxidative stress (Reactive Oxygen

	species (ROS) production, antioxidant levels/activity, oxidant damage to proteins/lipids); DNA damage; Disability-adjusted life-years; Quality-adjusted life-years
Types of studies	Randomised or non-randomised controlled trials; Cohort studies; Before and after studies; Natural experiments; Cross-sectional; Observational and modelling studies; Accountability studies; Economic evaluations; Cost-utility (cost per QALY); Cost-benefit (i.e. net benefit); Cost-effectiveness (cost per unit of effect); Cost-minimisation; Cost-consequence; Studies looking at wider economic benefits and impacts
Inclusion criteria	Published 1995-2020; English language only; UK and international evidence; Scientific literature; Grey literature
Exclusion criteria	Air pollution interventions relating to the following: Occupational health
Databases	Web of Science; ABI/INFORM® Professional Advanced; AGRICOLA; Aquatic Science & Fisheries Abstracts (ASFA); Bacteriology Abstracts (Microbiology B); CAB ABSTRACTS; Ecology Abstracts; Embase®; Health & Safety Science Abstracts; Industrial and Applied Microbiology Abstracts (Microbiology A); MEDLINE®; Oceanic Abstracts; ProQuest Biological & Health Science Professional; ProQuest Dissertations and Theses Professional; SciSearch®; Toxicology Abstracts; TOXLINE

3.3.2. Search strategy for databases and websites

A detailed search strategy will be developed and reviewed by the study steering group, and some additions and modifications may be made at this stage. The search terms will then be translated into search strings covering both of the reviews. Following the development of the search strings, these will be trialled before being entered into the databases identified in the table above.

Various reports from government or non-governmental sources may not be available via the database searches so additional website searches will be conducted for grey literature. The websites will be identified in discussion with the project team and the study steering group.

3.3.3. Data screening

Following the searches, the bibliographic information including abstracts of relevant references will be saved in the reference management software RefWorks.

Titles of all publications identified in the searches will be extracted into an Excel spreadsheet including author names, publication date and journal. At this stage the titles and abstracts will be screened for relevance based on the potential for inclusion with those being identified as not relevant being excluded at this stage. This initial screening will be done separately for each review, with any publications of relevance for the other review being highlighted.

Publications retained after the screening will be taken forward into the data extraction phase of the review. For these papers taken forward full texts will be obtained. These may be sourced and obtained from freely available texts online, direct requests to corresponding authors, or purchased from the British Library.

At both screening and data extraction stages, a 10% sample of publications will be re-assessed by a second reviewer for quality assurance purposes. Where discrepancies occur, a conservative approach will be taken.

3.3.4. Data extraction

Data extraction will be carried out using a spreadsheet to ensure consistency. Examples of the fields to be assessed and populated are presented in Table 2.

Table 2 Screening and data extraction criteria to be populated

Data extraction assessment criteria	**Example fields to be populated**
Screening of paper	RefWorks ID number Reference Reviewer name Include or Exclude Reason for exclusion
Study details	What research question(s) does the study address? Research design
Intervention	Name of intervention Aim of the intervention How does it work? Target pollutants (primary/secondary) Target receptors (individual/population level) Has the intervention been implemented? Where was the intervention planned/ implemented? What were the costs associated with the intervention and the funder?
Intervention effects	What was the effect on concentrations/exposures (direct/implied impacts) What was the effect on short and long term health outcomes
Implementation	What was the feasibility and timescales (time required to implement and to benefit) Were there any Incentives/disincentives used during implementation Limitations and barriers to implementation Were there any existing levers to make the intervention more effective? Was there a package of interventions i.e any relationships and combinations with other interventions
Evaluation	How was the intervention evaluated? What were the results of the evaluation? (e.g. success/failure, generalisability, effect of contextual issues)
Health (yes/no)	Were there any identified health outcomes presented as a result of the intervention? Were these directly related to the intervention and if so over what time period
Economic impact (yes/no)	Were there any economic impact assessment including e.g. implementation cost, willingness to pay, cost effectiveness – industry, society, NHS/social care
Equality/inequalities (yes/no)	Was there information on inequalities impact assessment including e.g. geographic distribution, population exposure, population subsets, measures of deprivation
Additional information	Any evidence gaps identified or any additional notes and comments

3.3.5. Quality assessment

The quality assessment of the individual papers will be based on the National Institute for Health and Care Excellence (NICE) public health guidance Quality Appraisal Checklist for quantitative intervention studies [6] which is used to record a quality score for a range of aspects of the paper, e.g. study population, relevance of outcome variables, appropriateness of analytical methods, using the following scoring scheme:

++ For that aspect of study design, the study has been designed or conducted to minimise the risk of bias.

+ Either the answer to the checklist question is not clear from the way the study is reported, or the study may not have addressed all potential sources of bias for that particular aspect of study design.

− For aspects of the study design in which significant sources of bias may persist.

An overall quality score will then be allocated to each paper, consisting of two rankings (e.g. ++/+) representing:

- Are study results internally valid?
- Are findings generalizable to the source population?

These composite scores will be based on the data extractor's summary of the quality assessments. Responses to each checklist aspect for each paper will be recorded in the data extraction spreadsheet, and the overall ranking assigned by the data extractor.

To review the overall evidence for health effects and the effectiveness of interventions, papers will be grouped by health outcome for the first REA and type of intervention for the second REA. Scores given will then summarise the ++/+/- scores of the papers contributing to each group. For uncertainty, a high, medium and low rating will be given based on the number and quality of studies within each group and the consistency of the study results.

All of the above ratings will be allocated by expert judgement taking account of the assessment of multiple papers and other evidence sources (including original scientific papers, technical guidelines and reviews).

3.4. Data collection

3.4.1. Selection of farming units

We will identify and recruit six farms for the monitoring programme, based on the following criteria:

- Farms will include dairy cattle farms, poultry farms and pig farms (one pair of each);
- Pairs of farms will comprise one farm with adoption of interventions set out as government policy in Defra's Clean Air Strategy, and one farm with no (or lower) adoption of these interventions;
- Livestock farms will be chosen that have good and local links to the locations where the manures they produce are spread to land;
- Farm locations will be chosen based on identification of farming systems, intervention adoption, and practicality for taking measurements (e.g. local topography will be taken into account to avoid unusual complexities for dispersion); it is anticipated that farms will be selected from the representative areas for the specific sectors (e.g. dairy in SW England, pigs and poultry in East Anglia);
- Farms will be chosen with interested and committed managers, using the existing Ricardo network of farmers (e.g. the project team has recently completed a set of 13 stakeholder workshops for Defra to gain views of farmers on practicalities of intervention implementation, with around 200 farmers attending, and we are able to maintain contact with this group).

3.4.2. Surveys and focus groups

Residents near farming units

We will carry out a survey with residents living near (< 1,000 m) the farms selected to participate in the wider study to identify potential environmental annoyance issues (e.g. air pollution, odour, noise) and record self-reported health symptoms (e.g. respiratory, gastrointestinal, neurological, and stress-related symptoms) [7]. Perceived benefits from living near to farm units will also be recorded. The survey will be co-designed with local residents living near the farms through up to 6 focus groups (each with maximum 10 participants). The aim of the focus groups will be to discuss the content, format and distribution of the questionnaires to ensure they are relevant and applicable to the intended respondents and their concerns around potential health and environmental annoyance issues. Recruitment to the focus groups will involve contacting a sample of local residents directly by letter to invite them to participate. The focus group schedules will be developed by the project team with input from the study steering group.

The finalised questionnaire will be distributed by post to all residents living within the designated areas around the farms. Using the data processed earlier, Geographic Information System tools will be used to assist in the selection of residential properties within 1000m of the six selected farms. Depending on available data, the geographic locations of the farms and the addresses of the properties will either be directly selected from a suitable address dataset such as Ordnance Survey (OS) Address base (subject to licensing terms). If no suitable address data is available or a higher aggregation is required to protect the identity of individuals, this can be based on postcodes. Google maps may also be used to aid determination of the main likely emission sources in the areas to be included in the survey. The mailing will include an information leaflet to inform participants about the project, a copy of the questionnaire and a consent form; their completion of the consent form and survey and posting this to the project team will indicate their consent. The survey will take place at the start of the project and will be repeated towards the end to identify changes in perceptions and awareness levels. Participation in the survey will be maximised, and selection bias minimised, by employing local engagement methods (community researchers, focus groups, survey co-design) that we used in a similar successful project in the past [8]. Teedon et al [8] reported that using community researchers enhanced the rigour of the work due to improvements in quantity and quality of the data received.

The two surveys will be conducted within the same 3-month calendar period at the start and end of the project to take account of the seasonality of agricultural practices. We will aim to conduct the surveys during the times of the year when manure spreading is likely to be taking place (e.g. between March and September, although this may vary depending on the types of farm selected i.e. soil types and whether the land is grassland or cropland). The survey material will include questions about annoyance issues and health symptoms, and will ask about symptoms in the last month and the previous 12 months, as well as chronic symptoms. Most of the questions will be formulated on the basis of already well validated health questionnaires such as the ones used within the European Community Respiratory Health Surveys (http://www.ecrhs.org/). In this framework we will also include questions which will address seasonality and perception regarding sources of symptom exacerbation when relevant.

Farmers

This survey aims to estimate the current level of implementation of interventions, and related barriers and enablers, to facilitate the development of scenarios for alternative future levels of implementation. Current implementation of interventions is uncertain and will affect the extent to which future implementation is possible. To minimise this uncertainty we will survey livestock farmers with housed dairy cattle, pigs or poultry, and farmers that spread livestock manures, to identify the extent of current intervention uptake. We will include questions about barriers and enablers, and the economic costs and benefits of interventions, which will inform the cost-effectiveness analysis.

This will be an online survey, co-designed with our study steering group including key stakeholders (e.g. the National Farmers Union (NFU)) and will use the outreach capacity of the stakeholders (newsletters, websites, twitter accounts) to maximise participation. From previous experience, we expect the sample size to be between 200 and 300 responses. Although this will be a self-selected population, we will minimise selection bias by recruiting participants using a wide range of methods and media channels, engaging with potential participants through trusted, well-known stakeholders including industry representatives e.g. the NFU, NFUS, Ulster Farmers Union, CLA, and QMS and Government (Defra, Deara NI and EA). The distribution of respondents by geographical location, type and size of farm will be assessed to ensure representation from all relevant groups (e.g. dairy/beef farms, poultry/pig farmers, UK-wide participation) and, compared with available national statistics, to determine general representativeness of the UK farming community. In the survey we will also ask farmers about their interest in participating in a focus group for the purpose of the project. We plan to conduct focus groups with farmers in three different geographical locations where farming emissions and related population exposures are a particularly important issue. A further way that we could gain information on intervention uptake will be to work with Defra to include questions in Defra surveys that are conducted annually. We will explore this with our study steering group, which includes Defra representation.

Stakeholders

As part of the engagement work we will carry out semi-structured interviews (up to 12) with key stakeholders. These stakeholders will represent policy makers, regulators, agricultural and health sectors. Individuals will be recruited from and by the study steering group to represent the different stakeholder groups and different geographical locations. We already have representation in the study steering group from the agricultural sector (e.g. NFU) and environmental health (e.g. CIEH).

Using semi-structured interviews will enable us to gather focused information, comparable between interviews, to gain a broader understanding of barriers and enablers for increased adoption of the agricultural interventions from the stakeholders' perspective. The interview schedule will be informed by the results of the survey with farmers. In exploring the barriers and obstacles to intervention implementation the questions are likely to ask about issues such as the costs involved, time to implement, and practicalities of implementation. In exploring the enablers and facilitators we will ask questions on the effectiveness of the interventions, success factors in implementation and main reasons for their implementation. The interviews will be conducted face-to-face or via telephone.

3.4.3. Emissions measurements

The interventions that will be prioritised in the selection of farms will focus on livestock housing and manure spreading to land. Interventions that can be implemented in livestock housing include ensuring that levels of protein in livestock diets are well matched to nutritional needs (especially applicable to dairy farms where there is more potential for improvement than in pig or poultry farms), modern buildings with design features to improve animal health and welfare and minimise environmental pollution to air, and frequent manure removal (e.g. scraping of floors) or removal and drying of poultry litter. Interventions that can be implemented for manure spreading to land include using low emissions techniques (for example, manure spreading by injection, trailing shoe or trailing hose), and incorporating manures into bare soils within 12 hours of spreading. Effects of interventions on air quality will be assessed over a period of up to two years. This will be assessed by undertaking measurement campaigns during winter and summer periods. The duration of each site visit measurement campaign will be defined once the production cycles for each selected location are understood. The monitoring will include measurements of ammonia, particulate matter ($PM_{2.5}$ and PM_{10}), and bioaerosols emissions.

We will determine ammonia emissions at source using appropriate measurement approaches to determine emissions from livestock buildings and manure spreading activities. Operators will also be asked to record activities undertaken on site during the period of measurement. This will enable emissions to be correlated with activities and mitigation processes used.

Measurement of emissions from farm buildings: The monitoring approach proposed involves the determination of emission factors for ammonia from the buildings. Emission factors are derived from measurements of pollutant concentration and emission flow rates. How these parameters are measured is influenced by the type of building and the type of emission points present.

There are typically two general building configurations used each presenting different challenges to achieve quality representative measurements. These configurations are

- managed/controlled ventilation using fans and ducts (includes heat exchange units);
- natural draft ventilation which includes open buildings as used for dairy cattle and buildings with continuous ridge vents as adopted for poultry rearing.

For buildings that have managed/controlled ventilation systems measurements will be made at selected outlet duct emission points. There are usually several emission points from these buildings. However, it is proposed that measurements from these buildings/systems will be undertaken at a single emission point. The operation of fan and associated ductwork within a ventilation system will be used to select the emission point measured. Primarily the emission point most likely to be in operation will be used. Measurement of ammonia concentration, flow and temperature will be undertaken at the selected emission point, either a fan duct or flue depending on the type of facility and technology being employed. Where possible sample lines, flow and temperature sensors will be installed and remain in place for the duration of the project. This will enable repeat visits to be undertaken relatively easily, which will enable data to be collected at various times of the year. Other emission points from a building will be monitored by measuring flow data. It is proposed to use site logged data, current loop sensors, vane anemometers or a combination of these. Ammonia and moisture measurement at emission points will be undertaken using analysers such as LOS GATOS Research (LGR) Ammonia analyser (EAA-EP) .

Flow measurement at emission points: There are different fan configurations used to provide ventilation for the livestock buildings. The type of flow measurement method used will be determined by the location and type of the fan enclosure. Methods to be used will include averaging pitot tubes and differential pressure measurement and vane anemometers fixed to the outside of the vent so that the exit velocity can be measured (when it is not possible to install a pitot tube). Temperature will be measured at the emission point as well as a measurement of ambient temperature made close to the enclosure where the monitoring system was placed, using thermocouples. It should be pointed out that the emissions points installed in typical buildings are not usually configured such that they meet recognised standards for the measurement of flow. This will introduce a level of uncertainty to the measurements. An estimate of this uncertainty will be made.

For the work on open buildings such as used to house dairy cattle continuously, we propose to deploy Ferm tube passive samplers [9]. The use of an open path measurement approach will be investigated as a possible option to collect representative data. Total emission will be reported as g of ammonia-N per livestock unit per day to enable ready comparison with other reported emissions. This enables comparison of data from published literature. Emissions will also be reported as % of N and TAN excretion so they can be used in the NARSES (National Ammonia Reduction Strategy Evaluation System) model of national emissions of ammonia. Previous published work suggest that the study buildings require between 250 and 350 Ferm tube samplers in the sides and roofs of the building. The actual numbers of tubes to be deployed will be defined after assessment of the selected buildings.

Farms will be visited for sampling on a minimum of 6 occasions over a year, with timings scheduled to ensure representation of seasonal weather and livestock management variation. Some sampler measurements can carry a large influence on the overall emission value, especially those in large open spaces where flux values are multiplied by a large area. To offset against this (in the absence of enough samplers in any one area) the method of grouping will be applied. This means that samplers in a similar position (e.g. part of the building and similar opening type) are grouped together and the average applied to all related openings. Hence the impact of a spurious value is reduced. Analysis of Ferm tubes will be undertaken by an analytical laboratory such as SOCOTEC Analytical Services Ltd. These influences on the data collected by Ferm tubes is the reason for investigating the use of open path measurement methods.

Spreading Activities: It is proposed to determine the emission from spreading activities by adopting a methodology described as a “whole site” measurement approach. This approach uses the site boundary to provide upwind and downwind measurement locations. This approach captures ammonia emissions from all the areas on the site as there is not a defined emission release point. The method involves monitoring ammonia concentrations at up and downwind locations around the field on which the spreading has taken place. Concentration data is combined with measurement of wind speed and direction to provide estimates of emission rates. The emission rate is determined using a simplified ‘box’ model approach. The data collected can be further assessed using reverse modelling (i.e. using a dispersion model such as ADMS) based on concentrations measured at the line of measurement along with wind speed and direction.

It is proposed that the location of downwind monitoring stations will be close enough to assure a measurable uplift in concentration but far enough that discrete sources merge into a common plume. In practice, this may present a challenge in that the ideal monitoring locations may be outside the field boundary so presenting possible issues with access. In most instances, the most practical monitoring location will be on the field fence-line inside or close to the field boundary.

We propose to monitor the effect of spreading of manures (slurry and/or solid manure) to land by monitoring each study location 3 times during the project for up to a week to obtain measurements for different times of the year, using an appropriate micrometeorological technique. These measurements will be closely co-ordinated with the farmer or operative undertaking the spreading on behalf of the study site to ensure that the measurements are made at the most appropriate time to reflect the emission profile from the slurry/manure.

Fine particulate matter measurements ($PM_{2.5}$) as well as coarser fractions (PM_{10}) through filtration sampling will be carried out simultaneously upwind and downwind of the main buildings and at the same locations, where practicable, as the ammonia measurements, to quantify PM as well as endotoxin content [10,11] used as a marker for bioaerosol concentrations around farms [12-14]. These measurements, in conjunction with the box/reverse modelling approaches described above, will allow us to estimate or confirm PM/bioaerosol emission factors available in the scientific literature. Filtration sampling will be carried out using SKC IMPACT samplers (Part nub. 225-392 and 225-390; SKC Ltd, Blandford forum, Dorset, UK) on Teflon and glass-fibre filters (for endotoxin analysis) and with a flow rate of 10 l/min to collect fine ($PM_{2.5}$) and coarse particles (PM_{10}). Measurement height will be approximately within the human breathing zone with the pumps adjusted to sample for 10-15 min every hour to avoid overloading of the filters.

The amount of collected PM on the filters will be estimated gravimetrically and its endotoxin content assessed with methods described by Spaan et al. [10,11]. Briefly, samples will be extracted in 5 ml of pyrogen-free water (PFW) with 0.05% (v/v) Tween-20, shaken mechanically for 60 minutes and then centrifuged for 15 minutes at 1000g. Subsequently, 1 ml of the supernatant will be removed, aliquoted in four 0.1 ml portions, and analysed for endotoxin in PFW (1 : 200 dilution) using a quantitative kinetic chromogenic Limulus Amebocyte Lysate (LAL) test (Kinetic-QCL 50-650U kit, Lonza, Walkersville, Maryland, USA).

Quality control including for preparation, collection, transport, storage and analysis of samples will be provided by duplicate samples, field blanks (i.e. filters/tubes brought to the field but not subjected to air sampling), and laboratory blanks (i.e. filters/tubes kept in the laboratory and not subjected to air sampling) included in every round to provide quality control. All instruments will be regularly calibrated and deployed following standard operating procedures. A Portable Remote Weather Station measuring wind speed, direction and temperature, will be used to provide local meteorological data at each farm during monitoring.

3.5. Data analysis

3.5.1. Survey and focus group data

Analyses will be conducted on each symptom separately, as well as for clusters of respiratory, gastrointestinal, neurological, and stress-related symptoms. In addition, participants will be asked to rate their general health using a 5 point Likert scale (bad to very good), following the methods described by Hooiveld et al., 2015 [7]. Health data will be analysed in relation to metrics for exposure to agricultural emissions, these metrics will include, at a minimum, distance from emissions and geographic location, supplemented where practicable, with other farm characteristics such as farm size and type and number of animals (e.g. categorised into quartiles plus a 'no animal' category).

The association between the exposure metrics and environmental annoyance (dependent variable) will be analysed with mutually adjusted multiple logistic regression analysis. It is anticipated that the association will be adjusted for years living in the current home, hours per day around/in house, smoking status, growing up on a farm, age, gender, nationality, marital status, and presence of other animals. Multiple ordinal logistic (general health), logistic and Poisson (health symptoms) regression analyses will be used to assess the association between environmental annoyance and health. Spearman's correlation coefficients between all environmental stressors will be calculated to evaluate whether participants report multiple environmental stressors more often.

The results from the focus groups (with residents and farmers) and interviews (with stakeholders) will be analysed by following the six recursive phases recommended by Braun and Clarke [15] for thematic analysis; familiarisation, coding, 'searching' for themes, reviewing themes, defining and naming themes, and writing the report. This will be an iterative process to identify any distinct and interlinked themes. The thematic analysis will be conducted separately for each of the tasks (e.g. focus groups with residents, focus groups with farmers and interviews with stakeholders). The themes created as a result of this process inform the following:

- Findings from the focus groups with residents will inform the development of the resident survey.
- Findings from focus groups with farmers will provide more detailed understanding on the current and future levels of implementation of interventions; this will inform the project conclusions and recommendations.
- Findings from the stakeholder interviews will provide more detailed understanding of barriers and enablers for increased adoption of the agricultural interventions from the stakeholders' perspective; this will inform the project conclusions and recommendations.

3.5.2. Emissions data

We will estimate changes in population exposure to $PM_{2.5}$, O_3 and bioaerosols associated with future implementation of interventions using air quality (chemical transport, and dispersion) modelling approaches, including estimates of change in exposure through realistic scenarios for the extent of implementation, and the degree of mitigation that these interventions lead to. The population exposure modelling is underpinned by CMAQ air quality 10-km^2 grid predictions of annual mean concentrations. The model would be configured to output grid square mean values for $PM_{2.5}$ and O_3. The underlying population in each 10-km^2 is used to derive a population-weighted exposure for the whole of the UK. Scenario outputs generating different surface predictions of $PM_{2.5}$ and O_3 will be similarly treated. From these outputs the total population-weighted exposure to $PM_{2.5}$ and O_3 will be calculated. It will be further possible to disaggregate exposure estimates e.g. by urban / rural areas or region of the UK.

Regional scale chemical transport modelling

This task will develop a base case scenario for UK-wide modelling using Community Multiscale Air Quality Modelling System (CMAQ, version 5.2) and the evaluation of concentration predictions against national monitoring network data. The national measurement data used for evaluation will include $PM_{2.5}$, PM_{10}, NH_3 and O_3 (Defra's Automatic Urban & Rural Network (AURN) and UK Eutrophying & Acidifying Network (UKEAP)). Given the importance of NH_3 in contributing to $PM_{2.5}$ specific evaluation of model ammonium nitrate predictions will be made against surface measurements. The $PM_{2.5}$ and O_3 model predictions will be used to generate UK surface concentration predictions that can be combined with population data to derive population-weighted exposures.

CMAQ (version 5.2) has been developed by the US Environmental Protection Agency to model urban/regional impacts of air pollution. The project team has long experience in the use of CMAQ, and the National Atmospheric Emissions Inventory (NAEI) as the principal emissions input to the model [16], for a wide range of applications [17]. CMAQ is designed for applications ranging from regulatory and policy analysis to understanding the complex interactions of atmospheric chemistry and physics. It is a three-dimensional Eulerian atmospheric chemistry and transport modelling system that simulates ozone, particulate matter (PM), toxic airborne pollutants, visibility, and acidic and nutrient pollutant species throughout the troposphere. Designed as a 'one-atmosphere' model, CMAQ can address the complex couplings among several air quality issues simultaneously across spatial scales ranging from local to hemispheric. The focus of the modelling will be UK impacts, but the model domain will extend to cover much of continental Europe to ensure transboundary contributions are explicitly accounted for. The model will be driven by the Weather Research Forecasting (WRF) model, developed by NCAR/NOAA and widely used in conjunction with CMAQ [18]. The modelling of NH_3, O_3 exposure and secondary $PM_{2.5}$ requires a chemical transport model that explicitly treats the main physical and chemical processes of atmospheric dispersion, deposition and chemistry. Our modelling system will use the most recent version of the Carbon Bond Mechanism chemical scheme (CB05TUCL), which is frequently used in CMAQ modelling and was the basis of earlier CMAQ inter-comparisons conducted by Defra.

Farming is also a source of NMVOC but the emission rates and species involved are highly uncertain, although total VOC estimates have now been made for agricultural activities in the NAEI. We will therefore review the available literature on NMVOC from farming and recent NAEI estimates to develop a speciated emissions profile and emissions estimate for use in the regional scale modelling of ozone and subsequent health impact assessments. Sensitivity tests related to the magnitude and composition of NMVOC emissions will also be conducted to understand the potential contribution to UK surface ozone concentrations.

Local scale dispersion modelling

CMAQ is ideal for modelling at scales from about 2 km and above but cannot treat the sub-grid scale processes important for emissions and deposition of ammonia or bioaerosols. To better-quantify these sub-grid scale processes we will use ADMS 5.0 (Atmospheric Dispersion Modelling System), an advanced Gaussian local scale dispersion model [19]. The ADMS model allows for complex source configurations (including volume, area and line sources), source characteristics (such diurnal and seasonal variations in source strength) and deposition processes (dry and wet) to be modelled. A specific focus of the local-scale modelling will be to understand the fine-scale distribution of ammonia and bioaerosol concentrations. In particular, the high deposition velocity of ammonia means that it will be important to understand the extent to which ammonia deposition occurs in the near-field (i.e. the grid scale resolution of the CMAQ model).

The ADMS modelling domain will consider a range of up to ~10 km, consistent with the minimum domain of the CMAQ model proposed for UK modelling and sufficient to understand sub-grid scale processes. The model meteorological input will be driven by the WRF model to ensure consistency with regional CMAQ modelling and also local surface meteorological measurements to better-understand the uncertainties in meteorological input data.

The local and regional modelling and exposure assessment are subject to many uncertainties. One of the principal uncertainties is related to the emission of ammonia (magnitude, temporal and spatial characteristics). The measurements of ammonia emissions as part of this project will help better understand the limitations of the current emission inventory (NAEI) and act as new data to run sensitivity tests to evaluate the impact of uncertainties in ammonia emissions. To address the wider modelling uncertainties, including those associated with the deposition of ammonia, sensitivity tests will be conducted to understand their influence on population-weighted exposure to $PM_{2.5}$. We will also extensively evaluate the regional model predictions of $PM_{2.5}$ against national and regional air quality network measurements and specifically consider the evaluation of particulate ammonium nitrate and sulphate against measured concentrations.

Impact evaluation using scenario modelling

In this task, a range of mitigation scenarios will be developed and evaluated. The scenarios we propose will be three levels of intervention implementation, in addition to the base case scenario. The choice of implementation levels for multiple interventions will be made based on the findings of the farmer survey and advice from the study steering group of stakeholders regarding realistic levels of future intervention. The study steering group will include experts involved in policy development (e.g. from Defra), and farmers' representatives (e.g. NFU), allowing multiple perspectives to be considered. The scenarios will be evaluated at the local scale using ADMS and regional scale using CMAQ. The principal output will be UK surface predictions of $PM_{2.5}$, ozone and bioaerosol concentrations that will be coupled with population density data to derive a weighted population exposure for each scenario.

3.6. Health impact assessment

We will undertake a comprehensive population exposure and Health Impact Assessment (HIA) to estimate the extent of change in health impacts (attributable mortality, hospital admissions, years of life lost) in relation to the interventions and their implementation/adoption at local, regional and national scale. The HIA will rely on concentration-response functions (CRF) from the scientific literature for short- and long-term exposure to key pollutants ($PM_{2.5}$, PM_{10}, ozone, bioaerosols) and related health outcomes, including respiratory and cardiovascular effects [20-23].

3.6.1. Population exposure assessment

We will use Geographic Information System (GIS) methods to estimate population weighted exposure to $PM_{2.5}$, ozone, and bioaerosols. In preparation for GIS analysis, a data scoping study will be carried out to determine what data is needed; what data exists or has to be sourced; what resolution and projection of boundaries is required; and identify any data protection and licensing considerations. This phase will ensure that the format of survey responses can be integrated with the geospatial data and determine the required mapping and geostatistical output formats. The scoping study will be followed by a data loading and processing phase to prepare all required geospatial data for analysis, and to join census data, farm animal statistics, population numbers and survey results at a common spatial projection. All data will be loaded into an ArcGIS geodatabase and be made available as ESRI shapefiles where required.

The modelled concentrations will be made up of cells at a larger scale than ward boundaries i.e. several cells will cover an individual ward area. We will calculate the average modelled $PM_{2.5}$ concentration for each ward in the UK using the zonal statistics function in GIS. The ward average $PM_{2.5}$ concentration will be recalculated to a population-weighted concentration for use in the HIA and health equity analysis. The population for each ward is freely available and published annually as part of government statistics by the Office of National Statistics (ONS).

3.6.2. Health impact analysis

We will carry out a comprehensive heath impact analysis of the base case and different mitigation scenarios. As part of our core health impact analysis we will model: (a) attributable all-cause and cause-specific (respiratory, cardiovascular and lung cancer) mortality, (b) respiratory and cardiovascular emergency hospitalisations, and (c) years of life lost due to long- and/or short-term exposure to $PM_{2.5}$, PM_{10}, O_3 and bioaerosols. We will carry out separate calculations for short- and long-term exposure where possible (e.g. $PM_{2.5}$), using concentration-response functions (CRF) from COMEAP and WHO. For some pollutants, such as O_3, only short-term exposure response coefficients are recommended by COMEAP. In addition to the core health impact analysis, we will carry out sensitivity analyses using CRFs for pollutant-health outcome pairs which are less firmly established using emerging evidence from the scientific literature. For example, Pimpin et al.,2018 have reported associations (and corresponding CRFs) of chronic bronchitis and diabetes with long-term exposure to $PM_{2.5}$ [24]. CRFs of associations between PM_{10} and chronic bronchitis will be used for sensitivity analysis only, as recommended by COMEAP [25]. Required baseline mortality (all-cause and cause-specific deaths) and morbidity data (e.g. emergency respiratory and cardiovascular hospital admissions) will be obtained at appropriate spatial scales from the ONS and Hospital Episode Statistics (HES).

Health impacts (e.g. attributable mortality or hospital admissions) will be calculated by multiplying the attributable fraction of the health outcome with the baseline rate of this outcome in the region of interest. The attributable fraction will be calculated for each 10-km^2 grid cell from the relative risk coefficient and the population-weighted exposure to the pollutant in this cell. Years of life lost will be calculated using IOMLIFET, a system of spreadsheets organising age- and year-specific data for life-table calculations. This approach allows flexibility in the many assumptions that can be made in terms of the sizes of future birth cohorts, the mortality rates that will affect them at various ages, and the factors by which changes in air pollution will alter cause-specific hazard rates. In addition to this standard life-table approach, we will attempt to incorporate transition into and between morbid states for childhood asthma associated with $PM_{2.5}$ exposure, including recovery to disease-free status and relapse, with transition rates informed by age- and asthma prevalence, incidence and mortality data, as described by Milner et al. (2015) [26]. Incorporation of disease recovery in the HIA model is important for conditions such as childhood asthma which have high incidence in early life but likelihood of recovery in adulthood.

Sensitivity analyses will be also carried out with additional CRFs for PM from agriculture/farming that may be available in the scientific literature. For ozone, we will additionally carry out a sensitivity analysis for long-term exposure effects on COPD mortality (see method in the Global Burden of Disease study, Cohen et al. [27]). Threshold effects and counterfactuals will be examined as we did in our previous studies [22] and/or recommended elsewhere [20, 10].

We will assess the impact of the interventions on respiratory health effects associated with exposure to bioaerosols (i.e. low levels of airborne endotoxin) for populations living near intensive agriculture units using CRFs from Farokhi et al. [28]. This will be initially carried out for the six selected farms based on modelled concentrations maps and local population data and then be scaled up to national level based on information on farm size/type and local population density/proximity from available registers (e.g. Defra, EA, SEPA, NIEA), and the farmers' survey and stakeholders' interviews. As this will involve a number of simplifying assumptions about population exposure, we will carry out sensitivity analyses to estimate related uncertainties in the health effects.

3.6.3. Health equity analysis

We will carry out a health equity analysis investigating distributional effects of the interventions on $PM_{2.5}$, secondary inorganic aerosols (i.e. nitrates), and ozone exposure for the UK population. This will be based on the quantitative method described by Williams et al. [29], which involves the use of the Carstairs index as the ward-level socioeconomic indicator. The Carstairs index [30] is a composite measure of socioeconomic deprivation commonly used in health studies to assess distributional effects (e.g. Hansell et al. [31]) and will be calculated by summing four standardised variables (unemployment, car ownership, overcrowding, and social class). Carstairs socioeconomic index data are available at LSOA/DZ/UKDS level under license from the UK Data Service . These data can be aggregated to ward level and linked to the modelled $PM_{2.5}$, secondary inorganic aerosol, and ozone population-weighted concentrations to assess distributional effects (i.e. health inequalities).

Potential health inequalities related to bioaerosol exposure of local population living in the proximity of large farms will be assessed qualitatively for different interventions based on information collected in the residents' survey, the farmers' survey and stakeholders' interviews, and the local scale dispersion modelling.

3.7. Economic analysis

An economic appraisal of mitigation measures will be performed, drawing on the outputs of the preceding work packages and complementing these with additional research and analysis, in particular around the costs of mitigation measures. A societal cost-benefit analysis (CBA) will be performed by an assessment module built in MS Excel which will link to the calculations performed under the preceding work packages. The analysis will compare the monetised costs and benefits of the mitigation measures to test the cost-effectiveness and value-for-money of individual measures and of the levels of ambition defined in the Clean Air Strategy. The evaluation will be performed relative to a base case of no action (or 'do nothing').

3.7.1. Economic literature review

The first step will be to gather data to facilitate the economic appraisal. The analysis will draw on the existing evidence and analysis collated under the other work packages, such as: mitigation potential of measures, wider impacts and feasibility of uptake and their health impacts. To complement this, additional data gathering will focus on costs, lifetime and wider environmental, social and economic co-benefits and impacts of measures. We will seek data regarding the different costs (e.g. investment capex and associated financing costs, operating costs, administrative or planning costs) across the different stages of implementation (e.g. research, planning, implementation, operation, renewal / end-of-life). We will co-ordinate and align with the data gathering under other work-packages to maximise efficiency.

Many of the literature sources reviewed in the health effect and intervention effectiveness rapid reviews may contain relevant information on costs of measures. In this case we will widen the literature review, both in terms of what evidence we are looking for and the sources reviewed. For ammonia emission reduction techniques in agriculture, a key reference will be the UNECE Framework Code for Good Agricultural Practice for Reducing Ammonia Emissions [32]. This was defined in the Defra's Clean Air Strategy as being a key reference document for the development of a national advisory code of good agricultural practice to control ammonia emissions. There are also a range of other references which offer guidance on best practice (or in the case of the Intensive Rearing of Poultry or Pigs (IRPP) Best Available Techniques document [33] they are mandatory requirements for farms above relevant thresholds). Furthermore, some of the sources also include estimates of the regulatory costs associated with bringing additional farms under permitting regimes. These will be useful for estimating administrative burdens of mitigation scenarios. Additional sources to be reviewed for technique cost data in industry include the Multi Pollutant Measures Database (MPMD) published by Defra .

In addition, the farmers' survey and focus groups and stakeholder interviews could offer valuable 'real-world' sources of cost data, in particular of the often hidden administrative costs of planning and implementing measures. Where appropriate we will seek to include topics and questions as part of these data gathering exercises to collect information on costs which can be used to stress test generic figures gathered from the literature. In doing so we will keep a close eye on the length of the survey, the clarity of questions in each format and information that farmers will have to hand so-as to minimise impact on the completion rate of the survey.

The output of this task will be a set of cost ranges and central values for different techniques and different cost types which can be used in the Economic Appraisal module. Where possible, this will differentiate costs by critical variables such a geographic location, farm type (e.g. poultry, cattle) and farm size, where these influence cost.

3.7.2. Monetising health benefits, analysis of costs and benefits to public health and NHS

Reductions in exposure to ammonia and other air pollutants through the mitigation measures will deliver a range of health benefits. These will be quantified in the health impact assessment and expressed as a change in health outcome (e.g. change in hospital admissions). To include these in the economic appraisal, the Economic Appraisal Module will apply established techniques to monetise these impacts so they can be readily compared to costs.

In the first instance, we will deploy the approaches and assumptions which underpin the UK's Interdepartmental Group on Costs and Benefits (IGCB) air pollutant damage costs . These in turn are based on guidance issued by the Committee on the Medical Effects of Air Pollutants (COMEAP) . Under this guidance, mortality and hospital admission impacts are monetised using willingness-to-pay estimates per year of life lost or hospital admission. Other morbidity pathways are assessed with a standard value per Quality Adjusted Life Year (QALY). There is varying opinion regarding the most appropriate method to monetise health impacts and different institutions adopt different approaches. In particular, the EEA apply both a value for year of life lost and value of statistical life (VSL) lost per death to capture mortality impacts. As a sensitivity, we will also apply VSL's applied in EU studies (e.g. EEA Industrial Costs of Pollution) to numbers of deaths to illustrate the impact of this sensitivity on the analysis .

A further alternative to monetise the impacts of air pollution is to focus on the change in costs to the NHS and social care, as implemented by PHE in their recently developed tool . This considers the burden on the health service for treating each condition (assessing four categories of costs: primary care, prescription, secondary care, and social care) [24]. In theory, these costs are captured by the WTP approach adopted by Defra which are considered to comprehensively capture all impacts associated with the change in health outcome. We will also explore this methodology for valuing health impacts again to illustrate the variance based on method adopted. This will offer an alternative and potentially more understandable (and therefore powerful) output of the work (i.e. by expressing the benefits in terms of NHS costs rather than overall societal value).

3.7.3. Analysis of the costs and benefits to ecosystems

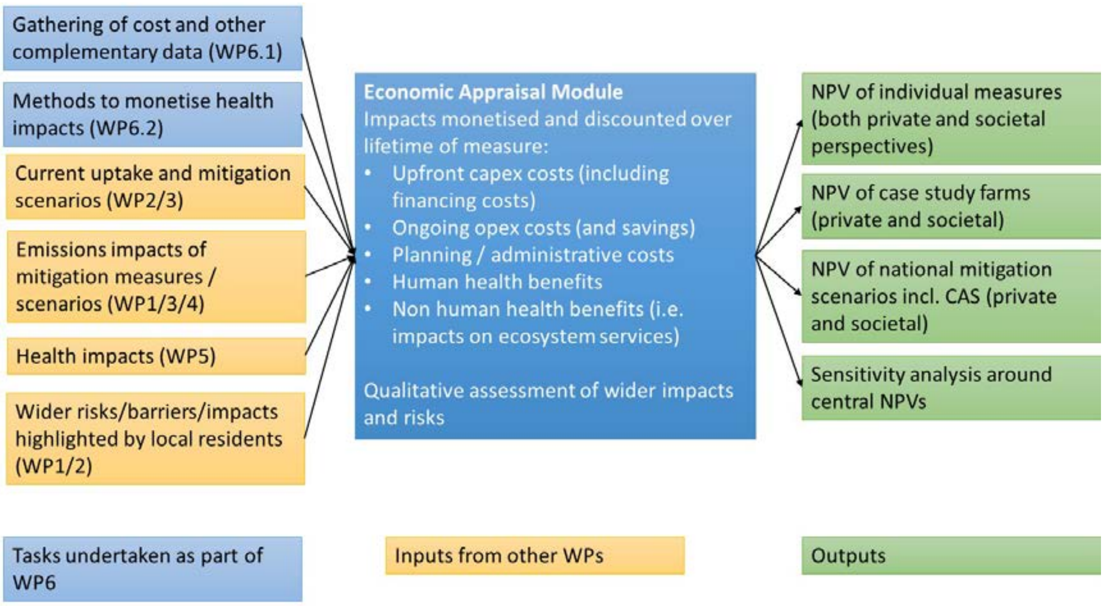
Human health impacts are typically the most significant impacts associated with changes in exposure to air pollution (and the focus of this research programme). That said, to fully assess the cost-effectiveness of mitigation measures, it is pertinent to consider wider impacts and co-benefits of reducing emission of air pollutants. In particular, recent research has advanced methods to monetise non-human health impacts of changes in emissions, in particular on ecosystems. This task will draw on recent research by Jones et al. [34] which has been incorporated into Defra's most recent set of damage costs to monetise the impacts per tonne of emission change. This reflects the impacts of ammonia on: timber and livestock production, greenhouse gases (GHG) regulating services, recreational fishing and appreciation of biodiversity [34,35].

3.7.4. Development of an economic evaluation

To perform the economic evaluation (i.e. cost-effectiveness), we will construct a bespoke assessment module in MS Excel. This module will sit alongside and draw on the analyses performed and modules developed under the other WPs.

The assessment module will draw through the estimates of the impacts on emissions and health impacts and monetise the health benefits of the mitigation measures. Through the damage costs, it will also monetise co-benefits for ecosystem services. These benefits will be compared to cost estimates derived combining the number of measures deployed under the scenarios, with estimates of the capex, opex and other costs per measure based on the data gathered through the literature review and stakeholder engagement. Where impacts occur in the future, these will be discounted. The module will present the outputs of the analysis as a net impact presented as a consolidated Net Present Value (NPV) of the mitigation scenario relative to the baseline 'do nothing' scenario. The analysis will present quantitative outputs alongside a qualitative assessment of the impacts not captured quantitatively, e.g. changes in odour or costs of fertiliser. This will consider wider co-benefits, but also wider risks and unintended consequences. An overview of the functionality of the module is and how this links to the tasks performed under this and other WPs is presented in the Figure below.

Figure – Schematic of the Economics Assessment Module



The assessment module will be used to explore two perspectives:

- 'Private' CBA – this focuses on the private costs and benefits to farmers specifically of implementing the interventions. We will estimate implementation costs and benefits which accrue to the farmer and the business entity to understand the economic trade-off facing the farmer and how long it takes for (and if) measures payback. This will help us to understand the affordability and return on investment of the interventions, which provides useful insight into how likely farmers are to take up these measures in the absence of policy and with policy, what level of incentive is required (or alternatively what burden will be placed on farmers). We will consider wider potential impacts on farmers, such as on crop and livestock production.

- Societal CBA – as more commonly used in policy appraisal, we will look at the costs and benefits for all actors in society. This will compare costs (and potential financial benefits) for farmers, against the environmental and health benefits for wider society.

The analysis will be performed for individual mitigation measures to provide insight into the net effects of measures individually and how these can vary, e.g. by farm type, location or size. CBA will also be performed on the farm case studies and on the national mitigation scenarios defined and assessed under the other WPs. This will provide detailed insight of the potential trade-offs and variability at farm level, and also test the overall cost-effectiveness and value for money of deployment nationally and the ambition set out in the Clean Air Strategy.

We will also perform sensitivity analysis to understand the uncertainty around the central results. Key areas of uncertainty which could be explored are: mitigation impact of measures, the methodologies to assess health impacts (in particular the CRFs adopted), methodologies to monetise the health impacts and the cost of interventions.

4. Project management

4.1. Ethical review

Ethical approval will be sought from the Reading Independent Ethics Committee.

4.2. Study steering group

A study steering group will be set up comprising independent experts, key stakeholders and PPI representatives (local residents, patient associations) to advise on study design, scientific quality, practical relevance and scalability. Confirmed advisory group members: Chartered Institute of Environmental Health, Country Land and Business Association, Northern Ireland Environment Agency, Defra Air Quality Team, Environment Agency, National Farmers' Union, National Farmers' Union Scotland, Scottish Environment Protection Agency, Ulster Farmers' Union. This group will meet twice a year. The study steering group will advise the project in research and engagement with the public, government, and business.

4.3. Study timetable

This will be a 3 year study starting on 1 April 2020. Year 1 will comprise the literature review, surveys/focus groups with local residents and farmers; selection of farms; data gathering of emission and health data; and start of air quality monitoring and modelling. Year 2 will comprise monitoring and modelling of emissions/air quality, and start of the HIA and economic analyses, which will be completed in Year 3, along with the Dissemination and Knowledge transfer activities and development of guidance.

5. Public involvement

This project builds on a series of recent Defra-funded regional workshops with farmers and other stakeholders run by the project team (Defra project code ecm_53127), to gather information and identify knowledge gaps. We have worked closely with Defra and PHE to review the evidence, and identify gaps and priorities for research [2], informing the development of this proposal. Key stakeholders for this project are the NFU, Country Land and Business Association, Defra, Environmental Agency (EA), Scottish Environmental Protection Agency (SEPA), NI Environment Agency (NIEA), Natural England, PHE, and Association of Directors of Public Health (ADPH), representing the farmers, public health community, and general public. The project team was recently in contract to Defra to engage with these stakeholders to gain their views on the practicality of implementing ammonia mitigation actions on farms. The proposed survey of farmers will involve this important pubic sub-group with influence over the implementation of interventions, and with concerns about their own exposure to pollution. We will involve in our study steering group local representatives from communities affected by the interventions (e.g. living near farms), and patient groups through engagement with local communities living around intensive farming units and the BLF. This engagement will adhere to the INVOLVE National Standards for Public Involvement; inclusive opportunities, working together, support and learning, communications, impact and governance.

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