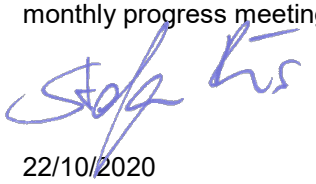
AMPHoRA Protocol

Administrative information

Title	Assessing Mitigation Pathways to Realise Public Health Benefits of Air Pollutant Emission Reductions from Agriculture (AMPHoRA)
Registration	Research Registry: researchregistry5436 PROSPERO: CRD42020172116
Protocol version	22/10/2020 v2.0
Changes to previous version	Updated section 7.2 to reflect the ethics approval having been sought and obtained from Reading Independent Ethics Committee (RIEC).
Funding	National Institute for Health Research, Grant Number NIHR129440
Roles and responsibilities	**Principal Investigator:** Prof. Stefan Reis, UK Centre for Ecology & Hydrology **Co-Investigators:** Prof. Paul Wilkinson (LSHTM), Prof. Alan Dangour (LSHTM), Prof. John Cairns (LSHTM), Dr. Ai Milojevic (LSHTM), Dr. Rosemary Green (LSHTM), Dr. James Milner (LSHTM), Dr. Massimo Vieno (UKCEH), Dr. Ulrike Dragosits (UKCEH), Dr. Mark Miller (UED), Dr. Anoop Shah (UED), Dr. Tom Misselbrook (RRes), Dr. Mike Holland (EMRC), Dr. Scott Jones (MtG) **Lead Centre:** UK Centre for Ecology and Hydrology (UKCEH) **Funder:** NIHR Public Health Research Programme AMPHoRA will be **coordinated** by Stefan Reis, Science Area Head – Atmospheric Chemistry and Effects at UKCEH. He will be supported by experienced scientific staff, and finance and project support experts in the delivery of project management, reporting and communication with the funding agencies. All work package leads and co-leads have ample experience in project management in a research environment. The project executive management will be overseen by the **coordinator** and a **project executive board** (PEB), comprising one representative of each of the 6 work packages. The PEB will safeguard representation of all research organisations participating in AMPHoRA at the same time. In addition, three members of the Core Stakeholder Group will be consulted by the PEB on all project-related matters affecting the direction of research and the review of key project outcomes and outputs. They will be invited as non-executive members of the PEB to all meetings. The PEB will meet at least every 3 months by tele- or videoconference and have a closed meeting at the end of each of the Project Progress Meetings scheduled every 6 months. Ad hoc PEB meetings will be convened as the need arises. All PEB meetings will be chaired by the coordinator. As the proposed research draws on existing data, the generation of model outputs is based on these datasets and is classed as a secondary study of a scale and duration which does not present substantive data management and study design challenges. Therefore, it is not foreseen that an SSC or DMEC are required. However, UKCEH has designated data management staff, which will advise on and review a Data Management Plan for AMPHoRA which will be developed in the first 3 months of the project and reviewed/updated at 6 the 6 monthly progress meetings
Signature	
Date	22/10/2020

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1 Aims and Objectives

Research Question: *"What contribution can emission reductions from agricultural production make to improving public health in the UK?"*

Aims: To evaluate the health impact of food and agriculture strategies in the UK aimed at improving outdoor air pollution, and how to align them with strategies for reducing chronic disease and improving environmental sustainability, including reductions of GHG emissions, and to understand barriers and opportunities for rapid implementation of policies at scale.

Specific objectives:

1) To convene a multi-stakeholder group - comprising government departments/agencies, food and agriculture industry experts, the public, 3rd sector organizations and academics - to delineate existing and potential future policies with potential to reduce emissions of air pollutants and GHGs through changes to (i) agricultural technology and land-use management, and (ii) factors influencing dietary patterns [WP1];
2) To quantify the impact in terms of key nutritional constituents and fulfilment of nutritional needs of interventions aimed at altering patterns of food consumption and UK production that both help to reduce air pollutant emissions and improve diets for health and sustainability [WP2];
3) To quantify the impact of such policies on air pollutants (AP), GHG emissions, and on population-weighted ambient concentrations of PM, NO_2, and ozone, now and in future, under policy scenarios defined in (1) [WP3];
4) To develop and apply models of health impact capturing the mortality and morbidity benefits/harms of changes in air quality of food/agriculture interventions (including both existing and potential future policies), and of the associated dietary changes and environmental impacts where relevant [WP4];
5) To compare policies over time horizons up to 2050 using a multi-criteria assessment framework with assessment criteria developed with the multi-stakeholder group (and to include the fulfilment of AP goals, health, health differentials, GHG emissions targets, economic costs) [WP5];
6) To assess the implications of these analyses for policy development and implementation, patients and the wider public, taking account of real-world constraints and opportunities, including with the aid of an iterative cycle of stakeholder engagements [WP6].

2 Background

Agricultural emissions of ammonia (NH_3), in particular, contribute substantially to the formation of secondary inorganic aerosols (SIA), resulting in widespread population exposure to ammonium nitrate/sulphate components of fine particulate matter ($PM_{2.5}$). Exposure to $PM_{2.5}$ affects much wider areas and populations far away from emission hotspots (compared to e.g. NO_2 exposure) due to the mid- and long-range transport of SIA. Emissions of NH_3, and the formation of SIA with SO_2 and NO_x emissions, are more challenging to address by policy interventions, as emissions stem from a variety of sources and are notably affected by meteorological conditions. Hence, interventions may have both local and long-range effects, and local interventions may not necessarily be effective in reducing local ambient concentrations. At the same time, human diets and the relationships between food production and both human and environmental health are subject to extensive research. We propose to address the key research question of the call *"Which interventions are effective in minimising the negative health impacts of outdoor air pollution from non-road-traffic-related sources?"* with a specific focus on how changes in agricultural production and patterns of food consumption can influence agricultural emissions, their negative health effects and health inequalities. Key topics we will address:

- Contribution of agricultural emissions of NH_3 and other air pollutants to the exposure of UK population to harmful levels of $PM_{2.5}$
- Effectiveness of existing and planned policy interventions to mitigate emissions and reduce exposure.

- Public health benefits in terms of cost savings and improving well-being of vulnerable population groups, patients and the general public.
- Impacts of interventions in terms of socio-economic and environmental aspects, accounting for co-benefits and unintended consequences, with a focus on regional and distributional effects.
- Potential co-benefits of emission and dietary changes for greenhouse gas (GHG) emissions, biodiversity and non-communicable disease prevention.

The UK Clean Air Strategy[1], as well as the Code of Good Agricultural Practice (COGAP) for reducing NH_3 emissions[2], identify a range of policy interventions to reduce NH_3 emissions from agriculture in the UK by 2030. The EAT–Lancet Commission on healthy diets from sustainable food systems[3] and other recent research (e.g. Springman *et al*.[4]) have highlighted the need for substantial changes in human diets to safeguard food security, nutrition, human health and well-being within planetary boundaries. Both the implementation of technical and management interventions in agricultural production systems and changes in human diets will affect emissions of NH_3 and other air pollutants. Such changes will vary between regions and agricultural sub-sectors. Full costs and benefits of policy interventions need to be modelled *ex-ante*, to ensure that interventions are designed for maximum positive environmental and human health effects, without negative impacts on UK food security and healthy nutrition. With the exit from the EU, UK environmental, agricultural and health policy reviews (e.g. Rapid Evidence Assessments[5]) present a unique opportunity for a consistent and integrated approach to maximise benefits for public health, the environment and the economy. Reducing exposure to harmful levels of air pollution and thus adverse public health effects, as well as improving diets and nutrition could achieve whole health system cost reductions, benefitting patients and primary/secondary health care provisions. Our proposed research will realise a step change in how we conduct *ex-ante* integrated assessments of policy interventions.

Evidence of public health impacts of PM is well established; summarised by a Committee on the Medical Effects of Air Pollutants report[6] on the effects of particulate air pollution on mortality in the UK. The Air Quality Expert Group (AQEG) has reviewed options for the "Mitigation of United Kingdom $PM_{2.5}$ Concentrations"[7] and concluded that *"Reductions in emissions of primary $PM_{2.5}$ and NH_3 are the most effective in reducing $PM_{2.5}$ mass out of the five alternatives studied"*. In the UK, agricultural sources contributed 82% of total NH_3 emissions in 2016[8], making interventions aiming at the reduction of agricultural emissions a viable pathway to reduce NH_3 and, consequently, population exposure to $PM_{2.5}$. Evidence from The Netherlands, Germany and Denmark[9][10][11][12] provides insights into the effectiveness of technical/management interventions to reduce NH_3 emissions. Specific interventions for reducing NH_3 emissions (e.g. as identified by COGAP[2] based on international expert elicitation in the UNECE Air Convention's Task Force on Reactive Nitrogen[13]) are the starting point for an integrated assessment for the UK.

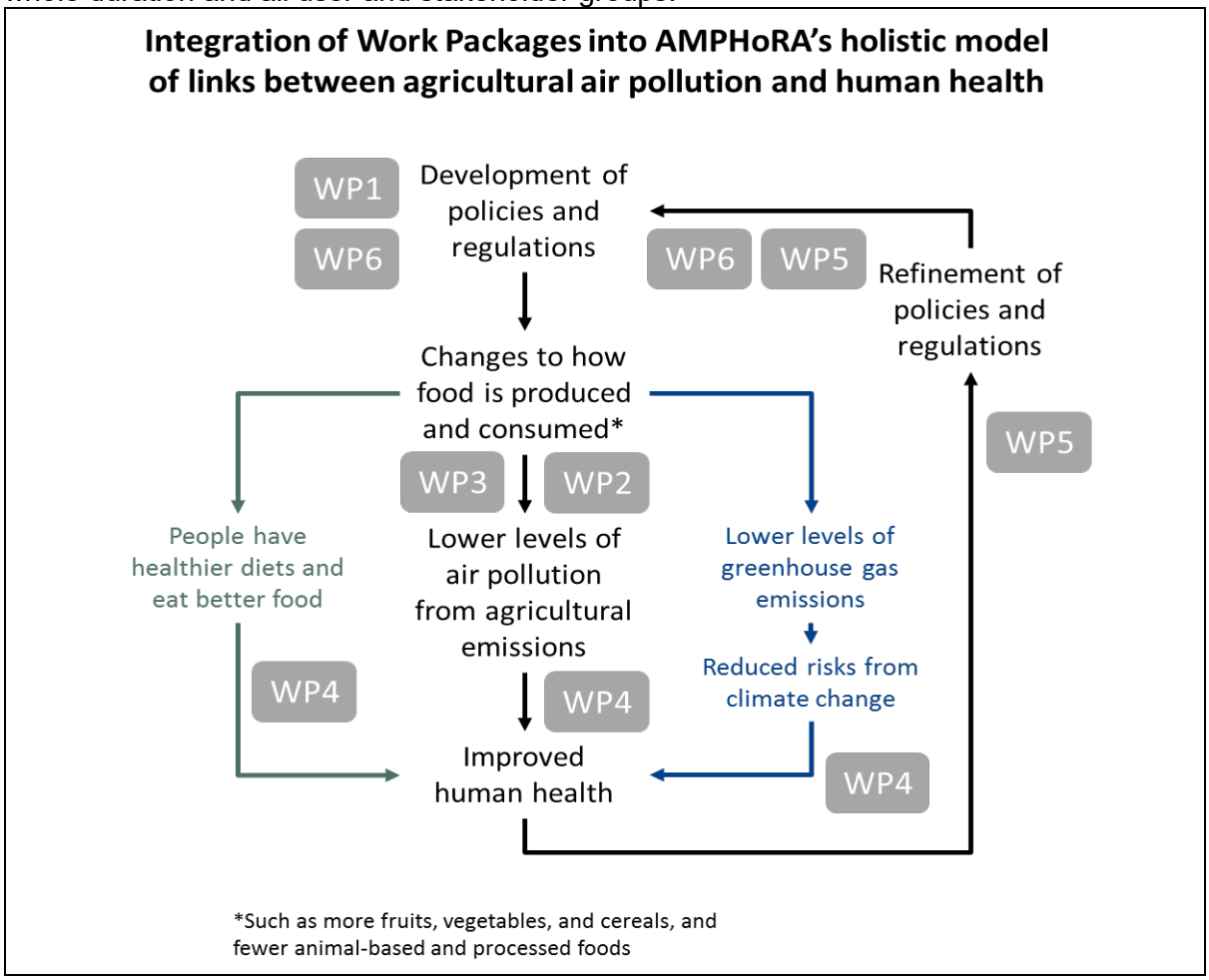
A well-established body of evidence links diets to impacts on both health and the environment. The Global Burden of Disease (GBD) study found that 11% of the total disease burden in England was from dietary risks, including low consumption of fruits, vegetables and whole grains, and high consumption of meat, sugar and salt[14]. Dietary risks in the UK are estimated to cost the NHS £5.8 billion a year[15], more than obesity, physical inactivity, smoking and alcohol consumption. The main diseases responsible for this burden are coronary heart disease, stroke, cancer (particularly colorectal, stomach and oesophageal) and type II diabetes.

Other links between diets and other environmental impacts are evident, with agriculture contributing 10% of GHG emissions in the UK[16]. Recent studies show co-benefits for GHG emissions from moving to healthier diets in the UK[17][18], with a healthy diet reducing emissions by 17% compared to current average diets, and reducing premature deaths from non-communicable diseases. However, previous studies have focused mainly on GHG emissions at the expense of other environmental impacts. A recent study found 74% of papers examining sustainable diets had focused on climate change, while only 4% examined air quality and

ozone depletion[19].
The few previous studies that have explored links between diets and air pollution have found that reducing consumption of animal-based foods would reduce nitrogen emissions, in some cases by up to 40%[20]. For NH_3 and, more generally, reactive nitrogen emissions, the European Nitrogen Assessment[21] has quantified the varying contributions of different livestock categories to air, water and soil pollution and climate change. These studies highlight the need for a comprehensive, integrated assessment due to the complicated relationships between nitrogen impacts and health impacts from diets.

3 Methods

The schema summarises the overall structure and information flows within AMPHoRA. In the following sections each work package is described in detail, covering datasets required as input; research methods used to combine and enhance data; the outputs generated for work packages; and communication/dissemination with stakeholders and the general public.
In order to incorporate feedback from the PPIE process within and across WPs 1-5, preliminary research results will be evaluated through engagement events that enable scenarios and interventions to be refined. All WPs will produce scientific and user-friendly lay summaries to support this, with WP6 facilitating communication and engagement across the whole duration and all user and stakeholder groups.



WP1 applies data analysis and statistical methods to derive quantitative estimates of emission changes due to changes in agricultural production, based on emission factors and activity rates, informed by detailed knowledge of production systems. WP2 will use descriptive statistics to define average diets for various population groups in the UK, and will use autoregressive methods to predict how dietary trends will develop in future. Particular food

policy scenarios will be modelled using linear programming. In WP3, data science methods for spatial data analysis and mapping, utilising geographical information systems and spatial databases will be employed, alongside numerical models to simulate the atmospheric dispersion and chemical transformation of atmospheric pollutants. The quantification of changes in health impacts in WP4 will utilise health data analysis and health statistics methods, in conjunction with systematic evidence review techniques to establish the state of knowledge on differentiation of health impacts from different particulate matter components. In WP5, detailed economic valuation approaches and cost-effectiveness/cost-benefit assessments will be applied, underpinned by Multi-Criteria Decision Analysis methods. Finally, WP6 will include presentations and summaries from WPs as relevant, and draw on a range of methods commonly used in Participatory Action Research (PAR) and Participatory Appraisal (PA) to facilitate interactive, data-rich sessions with a diversity of lay people, including patients and youth groups.

WP 1 provides the basis for the project and develops the core scenarios on which the subsequent modelling in WPs 2 and 3 builds. The work in WP1 will utilise the close links with and support by stakeholders to ensure that the AMPHoRA scenarios are in line with overall UK projections e.g. on agricultural production, food consumption and dietary trends. In case where detailed information is not readily available in the timescale of the project, existing projections for emissions and agricultural production (FAO, Defra, BEIS) will be used as contingency data.

In this context, WP 1 is closely linked to WPs 2 and 3, and provides cost data into WP 5. WP 2 builds on publicly available datasets and the work of WP1 in order to deliver future projections required for WP 4, 5 and 6 respectively. In WP3, the modelling activities will translate the changes in emissions (based on the outputs of WP 1 and 2) into changes in air pollutant concentrations required for the health impact assessment in WP 4, and the subsequent further analysis of WP5. The uncertainty assessment of atmospheric concentration changes will inform the overall assessment of uncertainties and robustness of results (WP5). WP4 draws on the data generated in WP 2 and 3 primarily, as well as publicly available datasets on population statistics, and delivers the key data on changes in public health effects resulting from changes in diets and exposure to air pollutant concentrations. WP 5 is a central work package in AMPHoRA as it draws in data from all previous work packages, and delivers the key results and information into WP 6, as well as drawing on preferences and priorities (e.g. for the MCDA) derived from public and stakeholder engagement activities. WP 6, finally, integrates across all five remaining work packages and synthesises data, as well as channels input from patients, the public, civic society and policy stakeholders to inform the research plan and its execution from start to end.

As it is the nature of this (and any) integrated research project, data flows and timing of results may affect the timely progress of subsequent work. To safeguard against critical delays, the project team has already identified all relevant datasets, most of which are either publicly available, or have access already established by the relevant researchers. As illustrated in the GANTT chart, sufficient overlap between all WP timelines has been built in to ensure that any delay that would occur does not have unmanageable impacts on subsequent work. Finally, the main risk to delays would thus occur due to unavailability or loss of key staff during the project runtime. Contingencies to counter such a situation are in place in all research organisations involved in the work with complementary staff and skills availabilities safeguarded.

4 Methods

4.1 Outputs and Outcomes

AMPHoRA will utilise a Theory of Change approach1 to map out refined primary and secondary outcomes, which will reflect on detailed outputs from each WP. Key outputs of the project are datasets (emission scenarios – WP1; mapped connections between policies and diets – WP2; quantitative assessments and maps of air pollutant concentration changes – WP3; quantitative assessments and maps of changes in health impacts – WP4; and monetary valuations of costs and benefits of different scenarios – WP6) and additional information about uncertainties and robustness of the assessments (led by WP6, with input from all other WPs). Based on these outputs, primary and secondary outcomes will be realised through engagement activities, i.e. workshops, focus groups and stakeholder events, and the material produced to underpin these.

Primary outcomes

Primary outcomes of AMPHORA are considered changes in the perception and knowledge of stakeholders and members of the public (participants in Focus Groups and other engagement events) with regard to the role and importance of changes in air pollutant concentrations as a result of changes in farming and food production practices. In addition, behavioural changes and increased awareness of the role of dietary choices and food production on both individual and public health. In the context of the quantitative assessment of public health impacts, AMPHoRA will assess primary health outcomes including mortality and morbidity impacts attributable to long-term exposure to secondary fine particular matter ($PM_{2.5}$) and other air pollutants, and its constituent primary and secondary components.

Secondary outcomes

Secondary outcomes are increased knowledge of the uptake of interventions, including barriers and enablers, and distribution of uptake across the UK through direct engagement with policy makers, regulators and public health experts by linking policies and impacts in a way that informs about the costs and benefits (and potential unintended consequences) of policies directed at reducing the environmental and public health impacts of UK agricultural production. In addition, through the economic assessment, policy decision makers, industry stakeholders and the general public will be empowered to conduct better informed discussions on societal, economic and distributional effects of policies.

5 Literature Review [UED]

A literature review will be performed at the outset of the project to ascertain the current state of knowledge regarding the health effects of agricultural emissions, with a focus on cardiorespiratory endpoints. The following text relates to the methodology of the systematic review of human epidemiological studies. Further details of the remit of this review, and the toxicological review, can be found in the 'health' work package of the data analysis section (Section 6.4).

5.1 Search strategy

We will perform a systematic search of Ovid EMBASE, MEDLINE, Web of Science and Global Health using the following keywords: 'agriculture' and 'air pollution', 'particulate matter' or 'ammonia' or 'ammonium sulphate' or 'ammonium nitrite' AND 'cardiovascular disease', 'myocardial infarction', 'stroke', 'chronic obstructive pulmonary disease', 'asthma', 'pulmonary tuberculosis', 'pneumonia', 'lung cancer', 'acute lower respiratory infections', or 'all-cause mortality'. In addition, we will manually search relevant review articles and bibliographic reference lists of the studies identified. Initially search terms will be restricted to include studies performed in agricultural/rural settings. Searches will be conducted from the inception of each

[1] https://assets.publishing.service.gov.uk/media/5964b5dd40f0b60a4000015b/UK-Aid-Connect-Theory-of-Change-Guidance.pdf

of the databases to present day for the initial search in the first instance, but this may be revised based on the number of relevant references obtained.

5.2 Data screening

All studies identified in the systematic literature search will be reviewed by the study investigators. Conflicts will be adjudicated by an experienced independent investigator using a pre-specified protocol registered on PROSPERO. References from these databases will be de-duplicated and imported into Covidence software. Titles and abstracts of each reference will be screened for eligible studies.

We will not impose any language restriction but will include only original peer-reviewed articles. Where there are multiple articles from the same cohort, the article with the largest number of participants will be included.

5.3 Data extraction

Data extraction will be carried out independently by two investigators and conflicts will be adjudicated by a third. We will contact authors for additional data or clarification where required. The study methodology, reporting and presentation will be performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[1]

Epidemiological studies, either longitudinal or cross sectional in design, will be identified and the relative risks extracted for mortality and hospital admissions for major disease categories including cardiac conditions, respiratory disease and overall mortality. We will pool relative risks for each individual cardiorespiratory endpoint. We expectsignificant heterogeneity across the studies due to multiple factors such as different study designs, differingbaseline risk of populations studied and geography. As such we will calculate the pooled estimates using the randomeffects model.

Where appropriate and if adequate number of studies are identified, we will conduct a formal meta-analysis of the evidence to provide quantitative evidence of the association between exposure and outcome. If more than three risk estimates are available evaluating exposure-outcome pairs we will pool relative risks for each relevant endpoint. We expect significant heterogeneity across the studies due to multiple factors such as different study designs, differing baseline risk of populations studied and geography. As such we will calculate the pooled estimates using the random effects model if a meta-analysis will be carried out.

5.4 Subgroup analysis. Where possible, we will evaluate the relative risks in the pre-specified subgroups as follows:

- Age (≤65 or >65 years)
- Sex
- Geography

[1]Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7):e1000097.

5.5 Quality assessment

Risk of Bias. Optimal methods of assessing risk of bias in exposure studies for air pollution remain uncertain. We envisage that a large proportion of studies highlighted in our review will be ecological in nature. Risk of bias will be assessed at a study level and will attempt to incorporate:

a) Exposure misclassification
b) Case ascertainment bias
c) Degree of adjustment for important confounding factors such as age, sex and comorbidity

Publication bias. Funnel plots will be constructed for assessment of publication bias and assessed for asymmetry using Egger's regression test. Asymmetry will then be corrected using the trim and fill method, with adjusted relative risks and number of studies adjusted presented.

Risk of bias in individual studies. We will assess each individual study for risk of bias across endpoint assessment and adjustment for confounders. Studies that used International Classification of Disease (ICD) codes, physician diagnosis or that used all clinical information to define endpoints will be deemed at low risk of bias. Studies that used less robust definitions such as those reliant on participant questionnaires alone will be considered as high risk of bias. Studies that have adjusted for age, sex and at least two other relevant covariates will be deemed at low risk of bias. Studies that have only adjusted for age or sex will be considered at moderate risk of bias whilst those that have not made any adjustment for confounders will be classified as high risk of bias. Two reviewers will be involved in the quality assessment and disagreements resolved by consensus.

6 Data analysis

6.1 Delineation of agricultural and food interventions [WP1]

Lead: Rothamsted Research (Tom Misselbrook)
Contributing Partners: LHSTM, UKCEH

Input Data required:

- Baseline agricultural production projections – FAPRI;
- Defra Clean Air Strategy (and any equivalent for the devolved administration (DA) ambitions/proposals relating to agricultural practices – Defra/DA governments
- Food production projections relating to different dietary scenarios as defined in WP2

Description of work

A simplified version (Excel spreadsheet based) of the model used to compile the UK agriculture ammonia and greenhouse gas emission inventory (Defra project SCF0107[22], 2017 submission) will be used in this project to provide the baseline and scenario emission estimates. The model will operate at a DA spatial resolution and an annual time resolution, but by using the appropriately weighted parameters from the full inventory model (which uses greater spatial, temporal and sectoral resolution) will provide good representation of the structures and practices of the agricultural sectors for the different DA. The model structure will include the ability to represent different uptakes of a wide range of mitigation measures and practices. We will ensure that UK, DA and subcategory level emission totals for the simplified model match those as submitted in the 2019 inventory submission. Model output will be total UK and DA-level air quality pollutant and GHG emission estimates and a set of emission factors per livestock type (subcategories of dairy cattle, beef cattle, sheep, pigs, poultry, horses, goats and deer), and management component (grazing, housing, manure storage, manure application). These will be provided to WP3 for spatial downscaling according to knowledge of location of livestock and crops.

A review of emission reduction progress to date based on the UK agricultural emission inventory estimates in terms of uptake of specific on-farm interventions (mainly focusing on manure storage, handling and application, and fertiliser use), changes in production efficiencies and changes in overall sector size. Outputs will be passed to WP3 to be combined with changes in the emissions of other air pollutants over this time period to highlight the impact of these historical trends on air quality.

Baseline projections to 2030 will be made using 2017 emission estimates as the base year and Food and Agricultural Policy Research Institute (FAPRI)[23] agricultural activity data projections for a 'business-as-usual' scenario. This will include the best estimate of current implementation of mitigation measures and practices and any projected increases under existing policy.

Emission reduction scenarios will be defined which fall into two categories: 1) those arising from on-farm interventions i.e. the implementation of specific mitigation technologies or practices so that emission per unit of food commodity produced is lower; 2) those arising from

changes in human diet and a shift in the balance of consumption/demand for different food commodities, with associated impacts on level of UK production. These latter scenarios will be developed as part of WP2, to inform on the required levels of production for different agricultural sectors for each scenario. Scenario descriptions will be developed and refined through consultation and engagement with stakeholders from an early stage of the project.

- On-farm intervention scenarios will be based around different ambitions in terms of the implementation of specific mitigation technologies across the different agricultural sources (i.e. measures aimed at reducing emissions from livestock housing, manure storage, manure application to land, nitrogen fertiliser application to land). These will all assume baseline projections in terms of agricultural productivity.
- Clean Air Strategy ambitions – details of the Defra and DA clean air strategies will be used to define two levels of ambition (medium and high) in terms of implementation of specific mitigation measures and practices.
- Meeting the EU National Emissions Ceilings Directive (NECD) target for 2030 – measures implemented under the Clean Air Strategy scenarios will not necessarily achieve the 2030 NECD emission reduction target and, if this is the case, a further scenario will be developed which ensures that the target will be met under the assumption of continued current production levels.
- Higher ambition strategies for on-farm interventions – here we will explore emission reduction scenarios associated with maximum feasible uptake of current and emerging mitigation measures and strategies that go beyond what is currently envisaged for the previous Clean Air Strategy and NECD scenarios.

Specific on-farm interventions will be associated with annualised costs (capital and operating), updating previous estimates where necessary, to provide total scenario costs and cost benefits (£ per kg of pollutant reduction) for WP5.

Human diet scenarios will be defined in WP2 and their implications in terms of the size of the different agricultural sectors will be detailed and applied to the model in this WP. Changes in the size of the livestock sectors will be associated with changes in the required arable crop production to produce livestock feed for those sectors and in the quantities of fertilizer that may be required to replace lower amounts of livestock manure available for land spreading. Specific scenarios may include:

- Reduction in red meat consumption offset to some extent by an increase in poultry consumption
- Reduction in all meat and dairy consumption with an increase in human edible crops

Finally, we will explore the impact of combining certain on-farm interventions with human dietary change scenarios

Outputs generated:

- Baseline and scenario ammonia emission estimates at DA level
- Component emission factors for livestock types and management categories (housing, grazing, manure storage, manure spreading), crop types and nitrogen fertiliser for use in WP3 spatial emission mapping
- Costs associated with specific scenarios for use in WP5

6.2 Characterisation of connections between policies, dietary patterns and nutrition [WP2]

Lead: LSHTM (Alan Dangour, Rosie Green)
Contributing Partners: RRes, UKCEH

Input Data required:

- Publicly available UK food consumption data for 2012-2017 from National Diet and Nutrition Survey (NDNS: https://data.gov.uk/dataset/22d06941-4921-4115-aab8-e4be264427a5/national-diet-and-nutrition-survey-years-5-9)
- UK food production data for 2012-2017 (publicly available from Defra: https://www.gov.uk/government/collections/food-farming-and-bio-security-statistics)

- UK import and export data for major crops and livestock (database held at LSHTM)
- UK food price elasticity data (publicly available from Defra: https://www.gov.uk/government/publications/food-and-drink-elasticities)

Description of work

This work package focuses on how lower emissions of air pollutants from the agriculture sector can be in part achieved by alignment with desirable changes to dietary patterns (and hence to resulting changes to UK agricultural production) motivated by health and environmental sustainability. Such alignment may occur through such changes such as reduction in consumption in red meat and dairy produce, for example. Translating between dietary changes in a population and production changes in a food system is a major challenge for any research exploring links between agriculture and health. Many previous projects have concentrated solely on national food availability as a proxy for consumption. However, because the proposed research aims to investigate both current trends of dietary change and regional differences in food consumption, we will use data from UK food diaries and will link these to UK food production data. To fully articulate the complex links between diets, food production, imports and exports would require a detailed trade model which is beyond the scope of this project. Instead we will explore trends in consumption and imports of different food groups over a five year period and derive conversion factors which will enable us to predict likely changes in UK food production arising from future dietary changes.

First, average diets in the UK for the baseline year 2017 will be produced using the publicly available NDNS data. To facilitate matching to the nitrogen pollutant and greenhouse gas data produced in WP1, consumed foods will be aggregated into 12 groups following Leip *et al.*[24][25] cereals, vegetable oils, fruits and vegetables, legumes, potatoes, sugar, dairy products, beef and veal, chicken, pork, sheep and goat meat, and eggs. Composite food items will be disaggregated into their main ingredients among the 12 food groups according to common recipes, e.g. biscuits would be divided among the categories of sugar, cereals, dairy products and eggs proportionally according to their average composition in the recipe.

An overall average diet for the UK will be described according to this method, and trends in consumption of the 12 food groups over the five years of the NDNS survey preceding 2017 will also be explored. Average diets in Northern Ireland, Scotland, Wales, and each of the nine regions of England (East of England, East Midlands, London, North East, North West, South East, South West, West Midland and Yorkshire and the Humber) will also be described, giving a total of 12 regional diets. Key nutrition-related aspects of the diets (including fruit and vegetable consumption, salt, fat and sugar content) will be provided to WP4 for use in health modelling.

'Business-as-usual' future diets: The observed trends in consumption of the 12 food groups from 2012-17 will be projected into the future to 2030 and 2050 under 'business-as-usual' scenarios, using both average national diets and the 12 separate regional diets. An autoregressive model using a first-order random walk will be used to simulate the most likely future dietary changes. Trends in imports / exports of the food groups over the same time period will also be extrapolated in order to account for food groups where imports appear to be increasing / decreasing over time. Nutritional content of the future diets will be estimated and delivered to WP4 for use in modelling future changes to diet-related health outcomes.

Production / consumption linkages: We will compare production data for the 12 main commodities over the period 2012-17 (publicly available from Defra) against the NDNS data for the same year and food group in order to derive conversion factors that can be used to predict likely changes in UK food production that will arise from observed trends in consumption. A database on trade of major crops and livestock products will be combined with the food consumption data from NDNS to derive estimates of the proportion of each food group produced domestically and how this is changing over time. We will also explore consumption and production trends w*ithin* each food group, e.g. if fruit consumption is rising but this is mostly due to an increase in imports of tropical fruits rather than UK-grown species, this will be factored into the conversions. The resulting set of conversion factors will be feed into WP1 to model food production changes from the dietary change scenarios.

Dietary change scenarios: A subset of the emission reduction scenarios described in WP1 will focus on future dietary changes and their impacts on UK food production. These scenarios will be refined in consultation with WP5 and WP6 and will explore the impacts of particular policy levers on UK diets. Policies of interest may include a red meat tax or carbon pricing of food items. In each case, changes in consumption of the food group in question and among other potential substitute or complementary foods will be modelled using food price elasticity data for the UK, e.g. a 20% red meat tax may lead to a 10% reduction in red meat consumption but a 5% increase in poultry consumption. Changes to UK food production data under each scenario will be estimated using the conversion factors generated in this work package and then delivered to WP1 for estimation of changes to N pollutants and GHG emissions. Some scenarios will also explore potential changes in consumption of imported foods vs UK-produced foods, which will not be explicitly modelled but will be noted in terms of their potential impact on N pollution in the source countries. Data on nutritional content of the scenario diets will also be provided to WP4 in order to model changes to health outcomes.

Outputs generated:

- Conversion factors describing relationships between UK food production and consumption
- Estimates of changes to food production resulting from dietary change scenarios (for WP1)
- Baseline and scenario-generated estimates of nutritional content in UK diets (for WP4)

6.3 Quantifying impacts of air pollutant emission changes on population-weighted concentrations [WP3]

Lead: UK Centre for Ecology & Hydrology (Stefan Reis, Ulli Dragosits, Massimo Vieno)
Contributing Partners: RRes, LHSTM

Input Data required:

- Emission datasets for 2017 (base case) from the UK NAEI for air pollutants and greenhouse gases; http://naei.beis.gov.uk
- Scenario datasets for projected emissions for 2030 and 2050 for UK and Europe based on outcomes of WP1 and WP2, combined with UK BEIS projections and EMEP CEIP data (https://www.ceip.at) for non-agricultural and non-UK emissions; https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2018
- Projected statistical datasets of UK population distribution based on UK 2011 Census; https://www.ons.gov.uk/census/2011census/2011ukcensuses

Description of work

T3.1 Emission mapping (1 km x 1 km grid resolution)

This task will generate spatially explicit emission maps as input to atmospheric chemistry transport modelling for all relevant air pollutants (based on WP1), with agricultural and non-agricultural emission scenarios, based on existing UK and European projections (e.g. BEIS, Defra, IIASA, FAPRI). While the focus of the effort is on ammonia, other key PM precursors will also be mapped (e.g. NO_x, SO_2) for use in the atmospheric modelling Task (T3.2). Emission maps for Europe will be produced, to provide boundary conditions the EMEP4UK model, as a realistic quantification of the European background concentrations and cross-boundary is essential. Given that the UK's annual emission inventory compilation cycle is complex and the necessary data become available with a time delay, the most recent available base year for the project (~ spring 2020) will be the year 2017.

For agricultural ammonia, the UKCEH AENEID model[26][27][28] will be used to spatially distribute emissions, thereby taking into account high-resolution agricultural practice by combining agricultural statistics with land cover information. For future projections of agricultural activities, country-level (England, Scotland, Wales, Northern Ireland) data from the FAPRI model[23] would be incorporated into the emission modelling.

Other emission sources (e.g. waste sector, transport sector) are modelled annually for the UK National Atmospheric Emission Inventory (naei.beis.gov.uk), using detailed dataset such as

statistics on landfill, anaerobic digestion, fuel combustion and road transport statistics etc. These methods and data, and government projections to 2030, as part of the UK inventory work, and which take into account policies currently in train (e.g. National Emission Ceilings Directive) would be used in the modelling.

T3.2 Atmospheric modelling

We will quantify changes in concentrations of $PM_{2.5}$ using the atmospheric chemistry transport model EMEP4UK[21] in high spatial and temporal resolution (1 km x 1 km; hourly) for 2020, as well as project concentrations for 2030 and 2050. GHG emission scenarios based on outcomes of WP1 will be generated at national scale, and not modelled in spatially explicit terms.

The current version of the EMEP-WRF is virtually identical to the open source EMEP MSC-W (https://github.com/metno/emep-ctm). The EMEP MSC-W model is currently used to support European policy development by the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) and the European Commission. The EMEP-WRF model framework consists of an atmospheric chemistry transport model (ACTM) which simulates 3D hourly atmospheric composition and deposition of various pollutants and the weather research and forecast model (WRF). Pollutants simulated include PM_{10}, $PM_{2.5}$, secondary organic aerosols (SOA), elemental carbon (EC), secondary inorganic aerosols (SIA), SO_2, NH_3, NO_x, and O_3. Dry and wet deposition of pollutants are also calculated by the model. The WRF model is used to calculate the required 3D plus time meteorological input data for the ACTM. The EMEP-WRF model can operate at different horizontal resolutions ranging from 1.0 × 1.0 degrees for a typical global domain to 1 km x 1 km for a typical UK domain. The default vertical domain ranges from ~45 m for the first layer near the surface up to ~16 km at the top of the vertical domain at 100hPa. The default chemical scheme has 72 species and 137 reactions.

Two types of emissions are present in the model: anthropogenic and natural. Anthropogenic emissions of NO_x, NH_3, SO_2, primary $PM_{2.5}$, primary PM_{coarse} (the difference between PM_{10} and $PM_{2.5}$), CO, and non-methane volatile organic compounds (NMVOC) are included from different sources at respective spatial resolutions. For the UK, emissions values are taken from the National Atmospheric Emission Inventory (NAEI), for the rest of the European domain, the model emission estimates are provided by the EMEP Centre for Emission Inventories and Projections (CEIP). Biogenic, volcano, forest fire emissions are also included.

T3.3 Model validation

Model results will be validated against present-day atmospheric monitoring datasets, e.g. from the Automatic Urban Rural Network, and EMEP Supersites (for speciated PM[29]). Estimations of uncertainty ranges for $PM_{2.5}$ and component species concentrations for future model results will be based on methodology developed by UKCEH[30].

The model evaluation is carried out for the most recent year available (i.e. 2017 for this project) and for two additional (historical) meteorological years to account for inter-annual variability of sensitive parameters. Serval UK monitoring networks will be used to evaluate the model also, including the AURN and the AGANET network. A QA/QC analysis on the model results will also be carried out.

Outputs generated:

- Maps of annual mean concentrations of total $PM_{2.5}$, $PM_{2.5}$ species, NO_2, Ozone for base case and intervention scenarios for WP4 *(gridded maps for the UK; aggregated values on LSOA, DA and other administrative boundaries as required)*
- Population-weighted concentrations and concentration-changes *(gridded maps for the UK; aggregated values on LSOA, DA and other administrative boundaries as required)*
- Assessment of overall emission budget changes (air pollutants and greenhouse gases) as a result of scenarios for WP5.

6.4 Economic analysis [WP4]

WP4 Quantification of health impacts
Lead: LSHTM (Ai Milojevic, James Milner, Paul Wilkinson)
Contributing Partners: UKCEH (Reis), UED (Miller, Shah)

Input Data required:

- Annual mean ambient concentration of $PM_{2.5}$ (total & species), NO_2, O_3 by 1 km × 1 km spatial resolution –baseline and scenarios of emission controls and/or land use change (from WP3);
- Estimates of nutritional content in UK diets under baseline and emissions control scenarios of dietary and/or production/trade interventions (from WP2)
- Relative risks of all-cause mortality and the incidence/prevalence of selected cardio-pulmonary outcomes associated with exposure to $PM_{2.5}$, NO_2 and O_3 – to be assembled from review of published studies/meta-analyses;
- Relative risks for ischaemic heart disease (IHD), stroke, selected cancers and type-2 diabetes associated with (change in) consumption of dietary food groups (e.g. fruits, vegetables, red meat) – to be assembled from review of published studies/meta-analyses;
- Annual population statistics by sex, age groups, socioeconomic status (SES) and region in 2000-2020 (Office for National Statistics (ONS) 2011 Population Census and projections);
- Mortality and morbidity statistics by age, sex, groups, SES and region (from ONS and other sources).

Description of work

T4.1 Systematic Literature Review (UED)

There is a substantial volume of epidemiological research demonstrating the harmful health effects associated with both short- and long-term exposure to particulate and gaseous air pollution[31][32][33][34]. Cardiorespiratory effects account for the vast majority of morbidity and mortality associated with air pollution, which have been the subject of extensive international research activity, of which our groups have played a major contributing role. However, while much is known about the effects of health of air pollution in urban environments, relatively little is known about that of pollutants derived from agriculture and specifically about the relative toxicity of the particle constituents compared with those in the urban mix more generally. The review will consider the set of functions adopted by the *Interdepartmental Group on Costs and Benefits* (IGCB) that underpins Defra's policy analysis, and additional literature especially in areas where the evidence base has been limited.

At the outset of the project a systematic search of the existing literature on the health impacts of agriculture emissions will be performed. Using methodology already described in our previous work, literature searches will be conducted across primary databases (e.g. Pubmed, Embase, Web of Science, etc.). UED has considerable experience performing systematic searches of literature on the health effects of air pollution and efficiently screening large volumes of research publications for extraction of key data[31][32]. Initial searches will include search terms for the exposure, including ammonium sulphate and ammonium nitrite, for a broad range of cardiorespiratory outcomes and mortality. Initially search terms will be restricted to include studies performed in agricultural/rural settings. Epidemiological studies either longitudinal or cross sectional in design will be identified and the relative risks extracted for mortality and hospital admissions for major disease categories including cardiac conditions, respiratory disease and overall mortality. Where appropriate and if adequate number of studies are identified, we will conduct a formal meta-analysis of the evidence to provide quantitative evidence of the association between exposure and outcome.

We will conduct searches across multiple databases including Medline, EMBASE, Web of Science and Global health. Searches will be conducted from the inception of each of the databases to present day. References from these databases will be deduplicated and imported into Covidence software. Titles and abstracts of each reference will be screened for eligible studies. There will be no language restrictions. Identified studies will undergo full text review by two independent investigators. The bibliography of each relevant study will be also screened to potentially eligible studies. Epidemiological studies either longitudinal or cross sectional in design will be identified and the relative risks extracted for mortality and hospital admissions for major disease categories including cardiac conditions, respiratory disease and

overall mortality. Risk estimates evaluating exposure outcome pair relationships will be extracted by two independent investigators. We will initially create a narrative synthesis of the studies evaluating the health effects of exposure to agricultural emissions. Where appropriate and if adequate number of studies are identified we will conduct a formal meta-analysis of the evidence to provide quantitative evidence of the association between exposure and outcome. Given the likely nature of these ecological studies we will conduct a random effects meta-analysis. The study methodology, reporting and presentation will be performed in accordance with the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) guidelines[35].

A similar approach to the epidemiology will used to search through the 'toxicology' literature. In the first instance the same databases (Medline, EMBASE, Web of Science) will be searched using pairs of search terms (format: "pollution" AND "health parameter" OR "organ" OR "disease"). Pollution terms will be focused on the primary pollutants related to agriculture or terms that capture the settings of rural areas where primary agricultural emissions will predominate. Studies of non-rural areas that use suitable source apportionment for agricultural emissions will also be targeted. Cardiorespiratory and blood biochemistry endpoints will be used in the first instance, but this will be expanded in later searches to include other organs of the body. Secondary search terms will be broader (e.g. format of: … AND "laboratory test" OR "biological pathway") to capture studies that could be used to provide insight into comparative toxicology of pollutants with that of more commonly studied pollutants, such as urban PM and diesel exhaust particles. Should limited studies be identified through the main databases, the search will be extended to the 'grey literature' including book chapters, advisory reports (e.g. DEFRA, COMEAP) etc. based on the knowledge and connections within the UoEd group. Studies will be screened at abstract level and then full text. Information from relevant studies tabulated in a master spreadsheet, before being separated into categories, as required, for synthesis with epidemiological data and comparison to other pollutants.

PM is recognised to be one of the major pollutants driving the health effects of air pollution, the relative contribution of which depends on the toxicology of the particulate mixture and the organ system of interest. Studies in animals, cell culture and with *in-vitro* assays of particle reactivity will be screened to assess the relative toxicological potential of agricultural-derived PM. Studies directly comparing agriculture-derived PM with that of more widely studied PM (e.g. urban dust, diesel exhaust particles) are likely to be few in number. However, data from selected assays with defined protocols (e.g. cytotoxicity to cell models, oxidative potential of particulates) will be used to generate comparative toxicity between broad categories of PM that, together with the results from modelling of the change in PM mixture, can be incorporated into the later modelling iterations of the health benefits of intervention scenarios.

T4.2 Modelling and Quantification of Health Effects (LSHTM, UKCEH)

We quantify the impacts on the health of the UK population of the policies/actions defined in WP1 that reduce air pollution emissions from agriculture. This work will be based on life table methods extended to include impacts on disease morbidity associated with both exposure to ambient air pollution and changes in dietary patterns (changes in consumption of food groups). The estimates for air pollution-related impacts will be derived from a spatially-explicit model with population counts, socio-demographic structure and exposure data (from WP3) defined at the level of Lower-layer Super Output Areas (LSOAs) (1,000 to 3,000 people or 400 to 1200 households per LSOA) – a model that thus reflects spatial heterogeneity in air pollution exposures, population structure, underlying health status and socio-economic deprivation and will show variations of impact with respect to such factors as urban/rural location and socio-economic status.

The impacts relating to changes in food consumption (from WP2) will be integrated within the same model as those for air pollution but available dietary (food survey) data are representative only at regional level, so integration will be based on regional and demographic stratification only rather than being LSOA-specific.

Exposure-response functions (air pollution and dietary intake) will be derived from published studies, drawing on meta-analyses where available, as well as the Global Burden of Disease (GBD) initiative. For air pollution, we will examine the impacts on cardio-pulmonary outcomes, and for food intake the impacts of changes associated with consumption of fruits, vegetables and red meat in relation to heart disease, stroke, selected cancers (including oesophageal, stomach and colorectal) and type II diabetes.

The methods of integrated mortality/morbidity modelling will be based on an adaptation of methods used by the applicants for modelling the effects of $PM_{2.5}$ air pollution on cardiovascular morbidity for the Committee on the Medical Effects of Air Pollutants (COMEAP). However, given the added complexity here, of multiple exposure-outcome combinations relating to both air pollution and dietary intake, we will adopt a simplified structure based primarily on all-cause mortality with disease-specific incidence risks applied to the age- and sex-specific surviving populations.

For air pollutant-related impacts, our main analyses will derive from assessment of the impact of changes in exposure to $PM_{2.5}$, but we will also run calculations for NO_2 and O_3. However, there are substantial uncertainties regarding the independent effect of these pollutants from that of $PM_{2.5}$ and limitations on the evidence for robust assessment in a multi-pollutant context. There is also uncertainty about the relative toxicity of the secondary particles derived from agricultural emissions compared with other particulate constituents of the (usually urban) $PM_{2.5}$ fraction on which much of the published epidemiology is based – and hence whether exposure-response functions derived from semi-ecological cohort studies need to be adjusted accordingly. The evidence review of both toxicological and epidemiological evidence performed in T4.1 will inform our understanding of this issue and model parameterization.

The models will be run for each intervention scenario and compared with a 'business-as-usual' counterfactual, with explicit assumptions about underlying trends (e.g. in disease risks) and inception/cessation lags. Model outputs will include changes in deaths, disease incidence and prevalence, life years lived (with and without disease), and life expectancy over time. Models runs will be used to quantify the independent and joint effect of air pollution and dietary changes.

Our sensitivity analyses to test the robustness of the results to uncertainties in model parameters and data inputs will include deterministic models which take high and low values for key parameters as well as Monte Carlo simulation that examines joint uncertainty across multiple model parameters by repeated sampling from plausible ranges for a key set of parameters. We will report estimates separately for different components of $PM_{2.5}$ (as a minimum, primary and secondary particles).

The outputs will be used in WP5 to quantify the associated health-related costs including health care and social care costs, monetization of gain in quality-adjusted life-years and reduced productivity, under a range of assumptions about time discounting and considering the recommendations of the Interdepartmental Group on Costs and Benefits.

Thus, in summary, this work package consists of the following work stages:

1. Performing a systematic review of the current literature on the health effects of agriculture-derived emissions;
2. Assembling required data and model inputs, including mortality/morbidity and population statistics and exposure-response relationships by specified temporal and spatial resolution;
3. Development of multi-health state transition models (programmed in R) combining change of air quality and dietary intake parameters;
4. Running 'business-as-usual' and intervention models to compare the impact of interventions on air pollution- and diet-related outcomes;
5. Undertaking uncertainty analyses (using deterministic and sensitivity analyses, Monte Carlo simulation).

Outputs generated:

- A scientific and lay summary of the current knowledge as to how agricultural emissions may have effects on health;

- Estimates of health benefits/costs (in terms of total life years gained, cases of morbidity) from reduced air pollutant impacts and dietary change;
- Estimates of impacts on health and health-inequalities (under uncertainty) of interventions for inclusion in the cost-benefit and MCDA analyses of WP5.

6.5 Assessment of the costs and benefits of policies using multi-criteria decision analysis (MCDA) [WP5]

Lead: EMRC (Mike Holland)
Contributing Partners: LHSTM, UKCEH, RRes

Input Data required:

As the final analytical task of the study, this work package is dependent on the others for the following inputs:

- WP1: Definition of future and baseline scenarios. Listing of options for emissions control (including dietary change) and associated costs and other details of measures for each scenario. Identification of key uncertainties relevant to WP5.
- Estimates of greenhouse gas (GHG) emissions as population totals (from WPs 2 & 3);
- WPs 2 & 3: Identification of key uncertainties relevant to WP5.
- WP4: Estimates of health benefits or detriments from reduced air pollutant impacts and dietary change. Identification of key uncertainties relevant to WP5.
- WP6: Information from the stakeholders on the practicality, costs, and ancillary effects of the scenarios under investigation and proposed measures for emissions control. Prioritisation of effects for the MCDA.

In addition to interaction with other WPs, the task is also reliant on background information on measures, response functions and valuations, from Defra, European Commission, and national statistics.

Description of work

This Work Package will identify cost-effective strategies for reducing ambient air pollution from agriculture, that maximise associated benefits for health relative to air pollution and dietary change, based on cost-benefit analysis (CBA). There are limitations to the effects that can be quantified for integration with CBA because of data limitations. In addition, therefore, we will use MCDA to bring in additional variables and see whether they have the potential to affect the outcomes in relation to cost-effective strategies and CBA. Analysis will proceed through the following stages:

T5.1 Description of the modelling framework

This work package requires a high level of interaction with each of the others. In the first stage of the project a detailed description of the modelling framework will be generated, with information on the logic to be used, required inputs from each work package and outputs. Discussion will be held with each other work package, for example to discuss how results from this work package can feed back to scenario definition and how to maximise benefits of the stakeholder engagement process.

T5.2 Identification of effects

A thorough evaluation of the scenarios developed in the study requires knowledge of the following:

- Cost-effectiveness of interventions
- Health impacts of interventions through changes in air pollutant exposure
- Changes in greenhouse gas emissions
- Environmental effects of interventions through changes in air pollutant emissions
- Ancillary costs of interventions (e.g. additional costs that farmers or society may incur that are not accounted for in the analysis carried out in WP1)
- Ancillary benefits of interventions (e.g. dietary change) that are not accounted for via impacts on greenhouse gas emissions or linked to air pollutants.

Debate will commence at the project start to make sure that all relevant elements are addressed.

T5.3 Integration of data on costs and benefits to the CBA modelling framework

Other activities undertaken during the research will be kept under review by this Work Package to ensure consistency in the assumptions, etc. used. The basic methods for the CBA will align with those identified in the Treasury Green Book. Using the results of the previous Work Packages, a crude comparison of cost and benefits will be made, with further evaluation in the steps that follow. The costs and benefits will be summarized from multiple perspectives (societal, government, public etc.), and compared with analysis elsewhere on air pollution control measures for other sectors.

T5.4 Comparison of costs and benefits taking account of uncertainties

The uncertainty analysis will use methods that have been developed in previous research for both the European Commission and for Defra. This distinguishes three groups of uncertainties:

- Uncertainties that can be described quantitatively and can be brought together using standard Monte Carlo techniques. These will, for example, include statistical uncertainty around exposure-response functions and valuation data.
- Methodological factors and other uncertainties that are best suited to sensitivity analysis. Defra's 2019 analysis of air pollutant damage costs, for example, distinguishes health effects that can be quantified with different levels of confidence. Another sensitivity specific to the proposed study would concern public willingness for dietary change.
- Additional biases for which quantification is not possible. This could include uncertainty linked to the eventual outcome of the Brexit process. These biases will be identified and their broad magnitude and the likely direction in which they affect the outcome of the quantified analysis will be reported.
- A concise and understandable report will be prepared describing the outcome of the uncertainty analysis.

An additional component of this activity is analysis of the value of information using established methods used in analysis of health interventions. This will assist in the identification of priorities in the study conclusions, and assessment of inputs from stakeholder consultation. Again, both quantified and unquantified elements will be considered.

Identification of key uncertainties will be undertaken using an iterative approach designed to focus assessment on the most critical parts of the analysis relative to the main conclusions of the research. A first step will be to identify all of the uncertainties that are present without consideration of which are likely to be most important. Each uncertainty will be catalogued and described to the extent possible, in both quantitative and qualitative terms. Results will be reviewed to consider how these uncertainties can propagate through the analysis, how they combine with others to become more or less important to the conclusions.

A 3-stage analysis will follow using Monte Carlo simulations, sensitivity analysis and consideration of unquantified elements (qualitative biases), as follows.

1. Monte Carlo analysis (probabilistic): this will be used to assess the sensitivity of the health impact results to combinations of model parameters sampled from their uncertainty distributions. These include modelled changes in PM2.5 concentrations (from WP3) and exposure-response functions for PM2.5. The research team has well-developed methods for performing Monte Carlo analyses of complex health impact models.
2. Univariate sensitivity analysis (deterministic): where full Monte Carlo analysis is not feasible, we will assess the effects of varying selected model parameters using plausible high and low estimates. Changes in the nutritional content of UK diets (from WP2), for example, may not be amenable to Monte Carlo simulation and is likely to be considered using this deterministic method. Another concerns the toxicity of different particle components, to be considered through the systematic literature review (T4.1) which could open the way for adjustment of the existing exposure-response functions to better represent agricultural PM2.5 emissions.
3. Review of unquantified biases will seek to provide further understanding of the robustness of the conclusions drawn in the research. Consideration will be given to the potential importance of each identified bias, and its likely direction of effect on the CBA (whether it would increase costs and/or reduce benefits, reducing the attractiveness of policies, or vice-versa).

Consideration can be given to testing the effect on the CBA of extreme changes in parameters, to the extent that these may be plausible. If it is found that bias could affect the conclusions, an open discussion will be provided regarding the conditions under which such bias could operate, what part of the conclusions would remain sound, and which part may be more questionable.

T5.5 Application of MCDA to assess robustness of the conclusions reached from the CBA

The MCDA extends the CBA and associated uncertainty analysis in three ways:

- Ensure that less tangible effects are not ignored
- Discussion of the preliminary results of the CBA (etc.) to a wider audience
- Ensure that the views of stakeholders are reflected in the analysis

The MCDA will apply methods that have been used in previous studies for Defra and the European Commission. There will be particularly close collaboration between this activity and WP6 to ensure that the views of stakeholders are reflected in the analysis. It will involve:

- Development of the framework for MCDA and discussion of that framework with stakeholders
- Identification of the major factors that drive the outcome of the CBA, including both those that are quantified and those that are not. Some of these factors may lead to co-benefits, raising the question of how they could be enhanced, and some may generate trade-offs, raising questions regarding possible mitigation.
- Structured discussion of the weight that should be applied to these factors and analysis focused on investigation of the extent to which the additional effects could change the recommendations based on the CBA alone. This to include consideration of actions for enhancing co-benefits and mitigating trade-offs where appropriate.
- Reporting of results in both technical and non-technical formats.

The MCDA process will be discussed in iterative engagements with stakeholders to explore their perspectives on preferences and option comparisons. There will be close interaction between this work package and WP6 throughout the research.

Outputs generated:

- Description of the modelling framework
- Listing of relevant effects
- Results of the preliminary CBA
- Results and conclusions following the uncertainty analysis
- Results and conclusions following the MCDA

6.6 Stakeholder engagement, co-design and interpretation [WP6]

Lead: Mind the Gap Research and Training (Scott Jones)
Contributing Partners: UKCEH, LSHTM, RRes, EMRC

Input Data required:

The stakeholder engagement process will inform and be informed by all WPs. Engaging lay and scientific summaries are needed periodically for PPIE activities, especially regarding:

- WP1: (1) Baseline emission estimates; (2) emission reduction scenarios; (3) on-farm intervention scenarios; (4) impact of combining on-farm interventions with dietary change scenarios.
- WP2: (1) Regional and UK-wide ‘average’ diets; (2) trends in consumption; (3) dietary change scenarios including taxes, carbon pricing and their implications.
- WP3 & 4: Health and climate change implications for public and patients if emissions are reduced. “What’s in it for me” (as patient, parent, carer) and “what’s in it for us” (in this Region or UK / planet as a whole).
- WP5: Understanding the format in which stakeholder data are required to inform modelling, assessment of uncertainties and benefit-cost analysis.

Description of work

Our working definition of ‘stakeholder’ is any individual, group or organisation that has an *interest* in, is *affected* by or can *influence* the project, positively or negatively. This cross-cutting WP requires a multi-stakeholder process designed with the principles, values, concepts and strategies that such processes require[36]. We have clustered stakeholders into

five groups (Table 6.1, Figure 6.1) who will be involved throughout the project. We will review with the wider team whether this is sufficient for project purposes, especially regarding key change agents or publics that are harder to reach, and remain open throughout to including other stakeholders who may identified.

We have had the benefit of helpful feedback from INVOLVE and NIHR's Research Design Service (RDS) on our initial drafts for PPIE and for stakeholder engagement generally. We have drawn heavily on a wealth of literature in participatory and multi-stakeholder processes, as well as our own experience as ex-NHS practitioners and managers, and UK / worldwide work on community-agency engagement in multi-stakeholder participatory research[37][38].

In particular we have drawn on the Principles and Features described in NIHR/INVOLVE's '*Guidance on co-producing a Research Project'* [39], and INVOLVE's earlier methods guidance '*People and Participation'* [40]. Although the Research Call has identified the issue and project questions follow naturally from this, we are mindful that *"Actively engaging [community] group members in the design of research can improve it"*[41]. The early stakeholder and community engagement events will therefore provide opportunities for community groups to reflect on project design, identify possible improvements, and inform the practical links with other WPs (particularly WP5 analyses).

A *Core Stakeholder Group* (Table 6.1, Fig, 6.1), will engage with all WPs in four ways:

1. Throughout the process using a bi-monthly project blog linked to a closed-group social media platform,
2. Throughout the process with periodic one-to-one, personal Skype and telephone calls as required, and to discuss specific issues,
3. A 6-monthly public e-newsletter that will include their contributions as desired. This will be linked to a project Facebook page and Twitter feed that WP6 will administer, and
4. Three practical, interactive workshops (months 3, 15 and 30) that will critically examine and contribute suggestions for different scenarios. Workshops will include a mixture of focussed small-group work; clear, easy-to-follow presentations; and participatory consensus-building tools, to ensure that workshop outcomes are pragmatic and easy to understand for the general public, policy makers and policy implementers.

'Membership' of any single stakeholder group may be fluid; some stakeholders may wear more than one hat on occasion.

The Core Stakeholder Group will help refine the project's focus and shape additional questions that we may need to address as work proceeds. It will also help guide the format and dissemination of research findings, and identify ways in which wider groups can meaningfully be engaged.

Table 6.1. Membership of the Core Stakeholder Group

Policymakers/ Regulators	Producers and sellers	Health professionals	Food & environ-mental change advocates	The public/ consumers
1. Dept. for Environment, Food & Rural Affairs 2. Scottish Govt. 3. Scottish Environment Protection Agency 4. NHS Health Scotland 5. National Farmers Union (NFU) / NFU Scotland 6. Environment Agency 7. Welsh Govt. 8. Northern Ireland Environment Agency /Dept. of Agriculture, Environment and Rural Affairs 9. Natural Resources Wales	1. Agricultural Industry Confederation 2. National Federation of Young Farmers Clubs 3. Scottish Association of Young Farmers Clubs	1. Public Health England 2. Health NGOs 3. NHS PH consultants 4. Royal Colleges 5. British Heart Foundation 6. Planetary Health 7. British Dietetic Association 8. EAT-Lancet Commission	1. The Food Foundation 2. Other nutritionist groups	1. Existing NHS panel reps; public/ patient groups 2. Three community groups - mid-Wales - central England - southwest Scotland 3. Youth group (London)

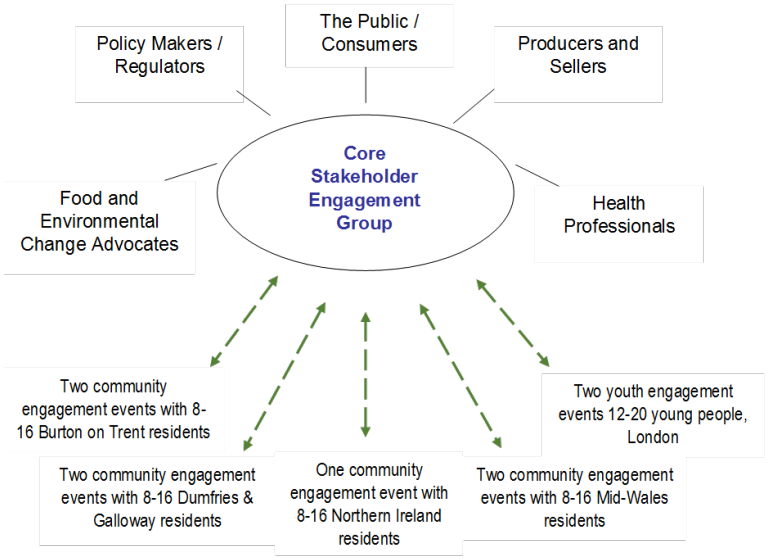
With only 27 people in the Core Stakeholder Group, we need to consider representation, legitimacy, and a mix of people and institutions who will be able to work well together. To add breadth and depth, we will hold nine community engagement events, with around 100 diverse members of the public from all four UK countries: two in Burton on Trent (Staffordshire – central England); two in Dumfries and Galloway (southwest Scotland); two in mid-Wales[2] in London (Figure 6.1). Each community event will have 8-12 people, while the youth groups will have 12-20 people. These groups will include people who may now be patients, have experience of being so, or have family members who are (e.g. parents of asthmatic children, older adults and people with heart/lung disease). We will seek a balance with respect to gender, ethnicity, age and geographic representation.

We will ensure that issues relating to confidentiality are managed ethically, with written consents covering confidentiality and data protection in our use (for example) of social media, photography and people's data. We will manage important resource considerations such as costs, time, locations, energy and facilitation processes. Summaries of relevant evidence and potential scenarios from other WPs will inform the community engagement events and the stakeholder workshops.

This evidence will help make clear how farming practices, food production and wider public interests relate to one another. Evidence and scenarios will be presented in easy-to-understand, accessible formats so that public stakeholders in particular can relate to and comment on the practical opportunities and constraints of different interventions.

Some tools will likely be co-designed the people at each event, as interests and needs require. Data from these events will be collated and finalised in ways that make sense for the participants involved and for project colleagues, especially those in WP5 to inform their work on modelling, assessment of uncertainties and benefit-cost analysis. Unless they do not wish to be further involved, participants will receive the 6-monthly newsletters and each group will elect a representative with whom we can communicate periodically (Burton, SW Scotland, Wales, N. Ireland, London Youth), and who will be invited to participate in the second and third Stakeholder workshops (months 15 and 30).

Fig. 6.1. Relationship between Core Stakeholder Group and Participatory Research/Public Engagement events



Community engagement events will be like focus groups facilitated as mini-workshops, and:

i) Include presentations of summaries outlined above and accessible data from other WPs,

ii) Involve interactive, participatory tools commonly used in Participatory Appraisal (PA) and Participatory Action Research (PAR) such as timelines, and various mapping, ranking and prioritising diagrams[38][40][42].

Together, the Core Stakeholder Group and these events will:

- Provide data and help support triangulation,

[2] This will be with existing A level groups studying agriculture, health and climate change-related issues, and with young people in one (or both) of two community projects – for disadvantaged young people, and a sustainable community gardening project

- Help delineate the interventions to be tested and the criteria for the MCDA, uncertainties assessment, benefit-cost and other analyses,
- Inform results interpretation and the development of policy messages, and
- Keep us in touch and well-grounded with various publics.

Outputs generated:

- Plain English reports from each event for individual WPs and the project's communications and dissemination purposes. With due regard for confidentiality and consents, these will include photographs, diagrams and other materials that can add value to project connectedness, and enhance overall communication and dissemination.
- Tailored data for WP5 modelling and other WPs as requested, and as agreed with public and other stakeholders.
- A *Communication & Dissemination Strategy* and *Engagement Plan* as a key output from the Inception Meeting and subsequent engagement with all WPs and stakeholders

7 Project management

7.1 Governance

AMPHoRA is coordinated by Stefan Reis, Science Area Head – Atmospheric Chemistry and Effects at UKCEH, who has 22 years of experience, including the coordination and scientific management of national and international research projects. He will be supported by experienced scientific staff, and finance and project support experts in the delivery of project management, reporting and communication with the funding agencies. All work package leads and co-leads have ample experience in project management in a research environment.

The project executive management will be overseen by the coordinator and a project executive board (PEB), comprising one representative of each of the 6 work packages. The PEB will safeguard representation of all research organisations participating in AMPHoRA at the same time. In addition, three members of the Core Stakeholder Group will be consulted by the PEB on all project-related matters affecting the direction of research and the review of key project outcomes and outputs. They will be invited as non-executive members of the PEB to all meetings. The PEB will meet at least every 3 months by tele- or videoconference and have a closed meeting at the end of each of the Project Progress Meetings scheduled every 6 months (see GANTT). Ad hoc PEB meetings will be convened as the need arises. All PEB meetings will be chaired by the coordinator.

As the research draws on existing data, the generation of model outputs is based on these datasets and is classed as a secondary study of a scale and duration which does not present substantive data management and study design challenges. Therefore, it is not foreseen that an SSC or DMEC are required. However, UKCEH has designated data management staff, which will advise on and review a Data Management Plan for AMPHoRA which will be developed in the first 3 months of the project and reviewed/updated at 6 the 6 monthly progress meetings.

7.2 Ethics

AMPHoRA does not involve any clinical trials or experimentation. Ethics approvals will be sought at project inception to cover the interaction with patients, stakeholders and the public through the PPIE activities primarily organised through WP6. We will utilise the decision tools provided by the NHS Health Research Authority (http://www.hra-decisiontools.org.uk/ethics/) to safeguard that all ethics-related issues (including consent and data management) are adequately addressed, and will request formal ethics approval through the LSHTM Research Ethics Committee, informed by the plan agreed at the Inception Meeting (https://www.lshtm.ac.uk/research/research-governance-integrity/ethics).

Ethics approval has been sought by the PI in collaboration with the PPIE lead (Mind the Gap, Scott Jones) through the Reading Independent Ethics Committee (RIEC) on 5/10/2020. RIEC has requested some minor changes, which have been submitted to the RIEC Administrator on 21/10/2020. Final approval of the ethics application has been received on 22/10/2020.

7.3 Dissemination, outputs and impact

What do you intend to produce from your research?

The individual products and outputs are detailed in each work package description above. Primary outputs will comprise scientific publications in peer-reviewed literature (WPs 1-4), with resources included in the budget to ensure that all publications emerging from AMPHoRA are published as Gold Open Access in order to maximise access beyond academic audiences. These publications will draw from the substantial datasets generated by WPs 1-4, which will be documented and stored in in UKCEH's Environmental Information Data Centre for use by the wider scientific community after the conclusion of AMPHoRA. Based on these datasets, data science tools and virtual labs to explore alternative scenarios or evaluate interventions may be developed through spin-off projects (e.g. under the UKRI Digital Environment Strategic Priority Fund or EPSRC funding streams). WP5 outputs will take the form of reports and a novel, well-documented framework for the integrated, comprehensive assessment of environmental and public health benefits of interventions, which will, in addition, be presented to policy stakeholders and domain experts in workshops and symposia. WP6 will produce plain-English reports and accessible information materials for use in Focus Group events, and contribute to wider dissemination and engagement activities e.g. through joint activities with charitable organisations (British Lung Foundation, British Heart Foundation) or the Planetary Health Network and other organisations promoting ecological public health concepts. Furthermore, WP6 will lead on the utilisation of social media information and outreach activities. Jointly, all WPs will contribute to the production of policy briefs and evidence fact sheets summarising key results, and identifying research gaps, which can inform research strategies and future funding calls (e.g. UKRI future highlight topics).

How will you inform/engage patients, NHS & the wider population about your work?

At project inception we will work with our partners and stakeholder engagement group to develop a list of our key audiences, reviewing and updating this as an agenda item at each project meeting. Drawing on NIHR and other agencies' dissemination guidance to support our discussions, we will develop a Stakeholder Engagement Table to decide and verify the levels of engagement needed at different stages of the project (e.g. who should be informed, consulted or partnering with us). This will inform our *Engagement Plan* and *Communications & Dissemination Strategy* to ensure maintaining effective relationships with key audiences at appropriate frequency and formats for them.

We will take advantage of conferences and networking events that are known now to be held during the project, again linking to our Communications and Dissemination Strategy. Specific public audiences may be harder to reach and we will monitor opportunities to do so. Examples include *ad hoc* or planned collaborations with public action groups campaigning for health or air quality causes and advocate related policy changes (e.g. pensioner groups, care givers, parent groups for those with asthmatic children). Where possible, we will work with these groups to develop models for supporting stakeholders to take their key messages forward (e.g. sharing information, networking, advocating for change).

There are inevitable capacity limitations in these activities and will consider creative, resource-effective ways of ensuring key messages are heard and used. These could include invited webinars, conference calls with scientists, presentations to Trusts and Boards, and participatory events with decision makers and local people. For example, gallery presentations with visual and participatory activities recently worked well for a mixed group of policy makers and public/patient groups following multi-stakeholder research for the Scottish Mental Health Strategy.

How will your outputs enter our health and care system or society as a whole?

Since AMPHoRA will ultimately inform policy, practice and behaviour change, we will use a variety of different approaches to enable project outcomes to be accessed and understood by

key stakeholders, agents for change and the general public. We will emphasise locally relevant information with local projections for air quality at Super Output Area level (WP4) and local food systems at Regional level (WP2).
We will quickly co-develop a Communications and Dissemination Strategy that will specifically address links between policy, strategy and practice, and seek confirmation from key policy shapers and practitioners that our outputs are clear and useable. During implementation we will undertake informed assessments of assumptions and risks that would need addressing in order for dissemination and uptake to be successful.
Our Communications and Dissemination Strategy will have three broad aims - ensuring effective communications within the project, and between the project, partners and external stakeholders; keeping relevant stakeholders and the interested public up-to-date with project activities; and disseminating information as the project progresses and at its completion. This will include the approaches described in WP6 and based on consultations with the NIHR Dissemination Centre, the Science Media Centre, the Core Stakeholder Group, the community events (WP6), and other advisory and interested bodies.
Our route to market will be developed through consultations with key individuals in representative Primary Care Trusts, Health Trusts and Health Boards, mindful of the need to know a number of things, for example: how patients may adapt to scenarios we identify; the needs of clinicians and advisory bodies; specialists who work with key patient groups (e.g. heart-lung, paediatricians, geriatricians, public health and health promotion).
Our public and consumer stakeholders in particular will help design dissemination to ensure that project recommendations are relevant, accessible and achievable. Therefore, strategies for dissemination will be informed by a balance of academic (including peer-reviewed publications & conference presentations) and practitioner/public-facing activities, including policy briefs, meetings with target groups, engagement with committees, and social media campaigns.

What further funding or support will be required if this research is successful (e.g. from NIHR, other Government departments, local government, charity or industry)?

By establishing the key data flows and conducting a full-chain assessment of potential interventions, AMPHoRA will identify the main knowledge gaps which may prevent a full, quantitative evaluation of the public health improvements achieved by the policy interventions evaluated.
Follow-on research funding, e.g. through the UKRI Strategic Priority Fund Clean Air – Actions and Solutions, or MRC funding streams focusing on the prevention of non-communicable diseases, can be targeted at the knowledge and evidence gaps highlighted by AMPHoRA's outcomes. These could, for instance, be around clinical and epidemiological research into multiple pathways of respiratory, cardiovascular and other (including cognitive development, diabetes, cancer) disease incidence related to exposure to select species of fine particulate matter. Additionally, the work will provide the necessary foundations for developing protocols to sample and characterise agricultural PM for future toxicology investigations and panel/controlled exposures studies in humans. Dedicated funding will be sought for these avenues of research, with the funder and funding stream chosen to be appropriate to the study design.
Government departments at national and DA level will require targeted information and source-apportionment of particular emission sources contributing to local hotspots of exposure, often for multiple pollutants emerging from a range of sources. In order to design and implement cost-effective and cost-beneficial interventions and sub-national and local level, the assessment approach developed and applied in AMPHoRA could be tailored to and applied at finer scale, with applied funding focusing on design and implementation of local scale interventions.

What are the possible barriers for further research, development, adoption and implementation?

The interdisciplinary nature of AMPHoRA's research topic, requiring the integration of a wide range of scientific expertise areas and policy domains has traditionally presented a barrier for funding, when primary research funding was awarded based on domain excellence, rather than integrative capacity, or cross-disciplinary novelty. While this may still present challenges in the near term, novel funding mechanisms such as the UKRI Strategic Priority Funds (e.g. on Clean Air – Actions and Solutions) are designed for, and actively require, interdisciplinary research teams forming to address scientific challenges which cannot be adequately tackled by single-discipline project teams. A further barrier in the uptake, adoption and implementation of the new evidence generated by AMPHoRA may be rooted in the slow progress in forming cross-domain policy teams, which can bridge across policy silos to recognise and realise the benefits of integrated environmental interventions over single-objective policies. Recent developments at UK and DA policy decision maker level indicate a growing realisation of the value of co-benefits, which will benefit projects such as AMPHoRA. At the level of the general public and agricultural practitioners, acceptability and feasibility of implementing interventions will heavily depend on communicating the overall economic, environmental and health benefits. Fostering a mutual understanding and communication between policy decision makers, regulators, food producers and consumers will be key and AMPHoRA aims to contribute to this dialogue.

What do you think the impact of your research will be and for whom?

The key impact of our research will be to establish a full chain assessment of the whole pathway how agricultural food production contributes to air pollution, and how systemic changes, e.g. through changes in diets driven by a growing societal awareness of sustainability and ethical aspects of food production may affect this pathway. By providing quantitative evidence through the evaluation of different interventions and scenarios, we anticipate impacts of our research for: *Policymakers and regulators* by providing a framework for a consistent assessment of various interventions and policy options; *producers and sellers* by enabling them to connect farming and consumption practices with environmental and public health impacts, and informing choices between alternative approaches; *health professionals*, by providing a systematic review of a key evidence gap in the treatment of different particulate matter species, and quantifying avoided public health and health system costs through preventive interventions at the source of pollutant emissions; *food & environmental change advocates* by connecting environmental, public health and dietary change data in a consistent, integrated fashion to inform planetary health and ecological public health concepts; and *the public/consumers* by informing and consulting on the connections between food, agricultural, health and the environment, responding to a growing awareness and information needs, in particular in younger generations.

7.4 Success criteria and barriers to proposed work

A key measure of success for AMPHoRA will be that the resulting policy interventions implemented in the UK in the next 3-5 years to achieve the objectives of the Clean Air Strategy are firmly based on a quantitative assessment of costs and benefits of different options. These will include appraisals of the cost-effectiveness of interventions, the ratio between costs and benefits of alternative options, and the integrated assessment of the benefits of improving public health through reducing air pollution and promoting healthier diets. At the same time, unintended consequences for achieving greenhouse gas emission reduction targets are accounted for, while co-benefits of integrated strategies for climate change, planetary health and biodiversity are explicitly recognised. In this context, a quantifiable reduction of UK population exposed to $PM_{2.5}$ concentrations through agricultural emission reductions by 2030, informed by AMPHoRA results, will demonstrate success. In addition, the identification of specific future research needs emerging from the systematic evidence review regarding the different mechanisms and contributions of individual particle species to a range of health effects, will be a key success in informing the public health research agenda.

Potential barriers could be the often still disparate responsibilities in environmental, agricultural, health and energy departments with policy makers and regulators having to deliver to different objectives. This can make integrated approaches challenging to communicate and implement, leading to sub-optimal assessments of the full range of possible interventions. Last, but not least, the prevention of adverse public health outcomes, which is at the core of the evaluation of interventions in AMPHoRA, does not always receive the same attention as remedial actions and treatments of disease. Here, the uptake of outcomes may be hampered by the different budgets and funding mechanisms for preventative vs. remedial health care provision. In AMPHoRA, we intend to mitigate against both types of barriers by direct inclusion of key stakeholders across the full range of policy domains and regulatory and health care agencies, to break down silos and foster trans-disciplinary dialogues.

7.5 Budget overview

	WP1	WP2	WP3	WP4	WP5	WP6	PPIE	Total
Budget in £	79,871	124,052	206,320	246,081	74,992	105,844	38,550	875,689

The budget breakdown by work package illustrates that WPs 1 and 2, which focus on the generation of intervention scenarios based on existing data sources require ~23% of the total resources. WP3 is both labour-intensive due to the intensive spatial data analysis and data processing, as well as conducting a substantial number of atmospheric model runs, including validation and QA/QC (24% of the budget). The health impact assessment (WP4) is at the core of AMPHoRA and equally requires substantial staff resources for a spatially explicit evaluation of health impacts at different scales, requiring 28% of the total budget. The economic analysis and MCDA in WP5 (9%) and the PPIE activities in WP6 (12%) require primarily staff resources, resp. (7.6) Travel & Subsistence for participation in PPIE activities. The focus of resources on the spatially explicit assessment of air pollutant concentrations and health effects is commensurate with the objectives of AMPHoRA.

8 PPIE, Stakeholder engagement, co-design and interpretation

As detailed in *Section 7.6*, due to the nature of the research proposed, we focus PPI activities on the following key groups: The general public/consumers; policymakers/regulators; producers and sellers (of food & agricultural products); health professionals; and food & environmental change advocates.

The following table provides an overview of dedicated resources set aside in the project budget for PPIE activities, drawing on the guidance provided by NIHR and INVOLVE. Reflecting on the review comments from the Stage 1 evaluation, we have substantially increased the resources for PPIE activities to ensure sufficient resources for a wider participation:

Activity	Explanation	Costs
Fees for individuals	Day rates to cover staff time for in-depth expert advice and feedback, estimated at 15 days x £500/person-day	£7,500
Donations to Focus Group organisations	Donations/support calculated as 9 FG events x £200/event	£1,800
Travel costs for stakeholder events	3 stakeholder events x 30 external participants each in London/central locations x £100 p.p.	£9,000
Travel costs for Core Stakeholder Group to project meetings	10 participants x 6 meetings in London/Edinburgh x £150 per trip p.p.	£9,000
Venue & catering costs for stakeholder events	3 stakeholder events x 30 external participants each in London/central locations x £1,500/event	£4,500
Venue & catering costs for Focus Groups	9 Focus Group events x 5-10 participants each x £750/event	£6,750
Total		£38,550.00

While the formal engagement process on the substance of the research will commence with the project inception meetings and PPIE activities (highlighted in Section 7.1 and the project GANTT chart above), the project team has already consulted with and secured expressions of interest and 10 letters of support from representatives of these key groups:

- General public/consumers: We will conduct 9 public involvement events with a diversity of over 100 people from all four UK countries, and establish a Core Stakeholder Group with 27 representatives. Mind the Gap (see WP6 for details) has already held discussions with representatives from several of these groups in London, Staffordshire and SW Scotland. These people appreciate our project's relevance to their lived experience, and will be pleased to be involved through meaningful consultation in focus-group like events and participatory activities. In addition, a group of individuals from these groups and the wider public will join the Core Stakeholder Group to ensure balanced views/inputs from non-expert backgrounds throughout the project.
- Policymakers/Regulators: Scottish Government, SEPA, Environment Agency have provided letters of support, Defra and DEARA expressed their intent to contribute to and participate in stakeholder events. Through existing research led by UKCEH on complementary topics with the Welsh Government, close links to relevant DA departments exist and will be used to engage.
- Producers and sellers: National Farmers Union Scotland and the National Federation of Young Farmers Associations have provided letters of support, the National Agri-Industry Confederation and the Scottish Association of Young Farmer Clubs will be invited to join events.
- Health professionals: Public Health England, NHS Health Scotland and the British Heart Foundation have provided letters of support and the research team is in dialogue with the British Diabetic Association to secure their input and participation.
- Food & environmental change advocates: Food Foundation has provided a letter of support and has a strong interest to engage with AMPHoRA, enabling the team to draw on additional expertise and complementary work currently underway developing a UK Food Strategy. Planetary Health Network has provided a letter of support and is keen to engage with AMPHoRA.

Our approach to stakeholder engagement will have two phases. Phase 1 (months 1-14) will be an open-ended process seeking stakeholder input into the research process. Phase 2 (months 15-30) will be explore stakeholder reflections on the relevance of research findings and different policy scenarios; and the implications of these for them, their constituencies and communities. Both phases will involve ongoing communication with the Core Stakeholder Group and representatives from the four community engagement events (one each in England, Wales, Scotland, and Northern Ireland).

Stakeholder events will be engaging and interactive. We will use existing research questions (Phase 1) and research findings (Phase 2) as discussion starters, followed by open-ended discussions with a variety of participatory tools relevant for small group and plenary work. In this way stakeholders can formulate questions about the research for themselves in Phase 1, rather than simply answering pre-determined questions; and in Phase 2 they can interrogate policy scenarios and research findings in ways that are meaningful for them.

Due to the dynamic and situation-specific nature of multi-stakeholder processes (MSP), especially community consultation, our approach and choice of tools will be organic and flexible. We will use appropriate clustering, consensus-building, ranking and prioritisation tools in order to agree the conclusions and wording that accurately capture the outcomes from each event. This will enable us to collate and report on stakeholders' questions, suggestions, concerns, and hopes for the research. In this way, the wider Research Team will be able to keep stakeholders' perspectives in mind and respond to them throughout the research process.

Phase 1 will involve building relationships, establishing rapport, learning about each other, and making sure the groups are fit for purpose and that the Research Team is able to respond to stakeholders' perspectives. In Phase 1, we will work with public and other stakeholder groups to:

a) Ensure they understand the AMPHoRA research model,
b) Learn from them what aspects of the research they find most exciting or relevant, and what aspects they find most concerning or difficult to relate to,
c) How they would like findings to be presented and what sort of issues/potential scenarios they would most be interested in learning about in Phase 2, and
d) Seek their guidance on key areas for public input identified in the Inception Meeting, and any elements of the research process that they wish to comment on or influence.

In the coming months we will begin confirming logistics for stakeholder engagement with collaborators in Scotland, Wales, England, and Northern Ireland. We will also work with all 27 members of the Core Stakeholder Group to confirm how they wish to be involved, and set a date for the first meeting(s).

In Phase 2, we will work with the public and other stakeholder groups to:

a) Ensure that the preliminary findings from AMPHoRA WP1-5 are clear for them, and can be understood,
b) Clarify what aspects of the findings they find most significant or confusing,
c) Debrief the multi-criteria decision analysis (MCDA) framework from WP5 and give input into the final version, and
d) Engage in collaborative participatory processes to identify a range of potential policy and decision-making recommendations stemming from the research.

Throughout Phase 2, stakeholder events will be integrated with and disseminated to the wider Research Team to ensure that we can all integrate stakeholder perspectives into policy reports, scientific communications and other research outputs.

9 Study timetable

The below GANTT chart illustrates the sequence and timing of the work packages, as well as the timing of project meetings and PPIE activities. The inception meeting at the project start (Month 1) is vital to refine the research plan, incorporating input from stakeholders and reflecting on any recent policy or societal developments relevant for the research programme. This meeting will as well lay the foundations for the final design of PPIE activities, the formation of the *Core Stakeholder Group*, the specific nature of ethics approvals to be sought and aim to sign off the draft *Communication & Dissemination Strategy* and the *Engagement Strategy*. In Year 1, the focus will be on collating datasets and the development of interventions and emission scenarios (iteratively between WPs 1 and 2), with preparatory work in WP3 in setting up models and data infrastructures for spatial data analysis. Year 2 will focus on spatially explicit modelling (WP3) informing the health impact assessments (WP4) and the set up and model framework design for the economic valuation in WP5. In Year 3, finally, the focus will be on dissemination and communication of project results. Intensive phases of PPIE activities in the early stage of Year 1 will inform research plans, and later in Year 1 review and comment on draft interventions and scenarios, while in Year 2, the emphasis will shift towards review and evaluation of draft results from the health impact assessment and economic valuation by different stakeholder and public groups.

	2020									2021												2022								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Work package	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
WP1: Delineation of agricultural and food interventions																														
WP2: Characterization of connections between policies, dietary patterns and nutrition																														
WP3: Quantifying impacts of air pollutant emission changes on population-weighted concentrations																														
WP4: Quantification of health impacts																														
WP5: Assessment of the costs and benefits of policies using multi-criteria decision analysis (MCDA)																														
WP6: Stakeholder engagement, co-design and interpretation																														
Project Meetings	I					P						P						P						P						F
Reporting/Milestones	EA						RE						RE						RE						RE					RE
PPIE Activities			S	FG			FG	FG	FG						S					FG	FG	FG			FG	FG				S

Project Meetings: (I) Inception Meeting, (P) Progress Meeting, (F) Final Meeting - **Reporting/Milestones:** (EA) Ethics Approval, (RE) Periodic/final Reports - **PPIE Activities:** (S) Stakeholder core group event, (FG) Focus Group

In the light of the current restrictions on travel and meetings due to the COVID-19 crisis, this GANTT chart is currently being reviewed and further detailed at task level for all Work Packages. This will be completed in the first month of the project (April 2020), and a revised GANTT chart and time table will be published, as well as any implications on the timing and execution of the project discussed with the Funding Agency and Project Officer.

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