Project 11/3005/13 DETAILED PROJECT DESCRIPTION

1. **Project Title:** Public health air pollution impacts of pathway options to meet the UK Climate Change Act commitment to 80% reduction of CO_2 and other greenhouse gas emissions by 2050.

2. **Background**

2.1 Existing research: Climate change is one of the most significant environmental issues facing humanity at the present time. There are major concerns over the increase in global temperatures and the concomitant impacts on weather, extreme events and the spread of disease. The Health Protection Agency has recently assessed the potential impacts of a changing climate on health in the UK and identified important effects on temperature related deaths, diseases, increased ultra-violet light and flooding. (HPA, 2008).

However, measures to mitigate climate change will involve the reduction of emissions of CO_2 and other greenhouse gases and most of these measures will at the same time reduce air pollution, resulting in co-benefits to health and the wider environment. A recent policy document from Defra pointed out the potential benefits of aligning climate and air pollution policies (Defra, 2010). There has been little research directed to the explicit assessment of the co-benefits of climate change policies, either in the UK or elsewhere, although work is now beginning to appear and this is summarised below. The review of the economics of climate change by Stern (Stern, 2006) made brief mention of the monetary co-benefits of climate policies, but did not give details nor specifically mention air quality. A more recent economic analysis (Nemet et al, 2010) concluded that the co-benefits could be on average \$49/tonneCO_2.

Some earlier studies assessed the co-benefits of air quality and climate policies at a regional level in Europe at a relatively coarse spatial scale(generally 25-50km grids). Several of these studies are based on a so-called 'integrated assessment model' RAINS(Regional Air Pollution Information and Simulation) and the extension to include greenhouse gases known as GAINS, developed at the International Institute for Applied Systems Analysis (IIASA) in Austria. These models calculate optimal cost pathways to achieve specified environmental targets. Originally developed in Europe, GAINS is unable to employ spatial resolution better than 25 km x 25 km grid squares. The European Environmental Agency (EEA, 2006) used the model to study the ancillary air pollution benefits in Europe of three scenarios, the most ambitious of which reduced CO2 equivalent emissions by 40% by 2030 on a 1990 base. The work concluded that in the baseline scenario there would be 311,000 premature deaths in Europe from $PM_{2.5}$ and ozone exposures, but that these would reduce to 288,000 in the ambitious climate scenario. For three climate scenarios tested in the UK, compared with a baseline of 6.9 months loss of life expectancy in 2000, the ambitious climate scenario gave a loss of 2.2 months, the scenario aimed solely at air quality targets in future showed a loss of 3.4 months, but the less ambitious climate scenario showed a smaller improvement of 4.8 months.

This early work highlights the importance of optimised scenarios for public health improvements.A study by van Vuuren et al (2006), also using the RAINS model, assessed the monetary benefits for Europe as a whole. For the policies then in place they found the total benefits of implementing Kyoto policies to be 2.5-7 billion Euros as reduced costs of air pollution abatement. A more recent study by the Netherlands Environmental Assessment Agency (2009) performed a global assessment of the local air quality implications of meeting climate change goals in 2050. Their conclusion was that significant health benefits could arise and might be an added incentive for developing countries to pursue climate policies. These local air quality health assessments were carried out in a rudimentary manner at an even coarser level than the RAINS model.

A recent study (Rypdal et al, 2009) illustrated the trade-offs involved in reducing air pollutants such as sulphur dioxide (SO_2) which act to cool the Earth's climate. They suggested that in formulating policies targeted at climate, reductions in SO_2 and NO_x (another important air pollutant) should be ignored, even though such reductions would bring health and environmental benefits.

A global study reporting the ancillary benefits to air pollution from improvements to the world's motor vehicle fleets has been published by Walsh (Walsh 2008). This work showed that stringent emission controls, especially from diesel engines are required to achieve improved public health. An analysis of the UK policy of encouraging the use of diesel cars on climate change/fuel economy grounds (Mazzi and Dowlatabadi, 2007), estimated that the consequent increased emission of particles would be responsible for 20-300 deaths per year in the UK. A recent assessment of the air quality and climate benefits over the globe has been published (UNEP/WMO, 2011) which showed that reducing air pollutants (black carbon and ozone) could have major health benefits, particularly in Asia, as well as mitigating near-term (~40 years) climate change. The Lead Applicant in the current proposal was a lead author in this study.

A paper specifically addressing the implications of climate policies for the UK was published by the Lead Applicant in this project (Williams, 2007). This considered the implications for what was then a hypothetical UK climate change target of 60% reduction in CO2-equivalents by 2050. The study showed that impacts of air pollution on mortality and morbidity in London in 2050 could be roughly halved compared to 'business as usual'. Since that paper, an even more ambitious target of 80% reduction is now in UK law.

A series of papers in The Lancet in 2009 addressed climate change issues. One paper (Woodcock et al, 2009) studied the implications for health of a low carbon vehicle fleet in London, and another (Wilkinson et al, 2009) investigated the benefits of increased energy efficiency in the UK housing stock. An earlier paper (Wilkinson et al 2007) studied the impact of hydrogen fuelled vehicles on air quality and health; Dr Wilkinson is chair of the Advisory Board in the current proposal. None of these papers used scenarios based on government policies across all sectors of the economy– these have only recently emerged - nor did they assess co-benefits across the whole population of the UK.

The broad implications for air quality and public health of choices for climate policies in the UK have recently become clearer. Following the adoption of the Climate Change Act in 2008, HM Government published the Low Carbon Transition Plan (DECC, 2009) which concluded that while some policies would result in large improvements in air quality, the adverse health effects from an unmanaged major uptake of biomass (wood) in the residential sector would outweigh the air quality/health benefits from all the changes in other sectors, at a net air quality cost rising to £2.6 billion in 2022. Very recently, the Department for Energy and Climate Change (DECC, 2011) published The Carbon Plan which sets out several options for achieving the 2050 target. There are many potentially conflicting policies and trade-offs, and the report set out three illustrative scenarios, some of which show wide ranges of air quality benefits and disbenefits. Damage costs arising from air pollution were calculated based simply on total UK emissions with no detailed analysis of health impacts or their relative distribution across the population. There is clearly a need for a more detailed analysis of optimal strategies for both climate mitigation and public health in achieving the 2050 target, hence the submission of this application.

We have assembled an experienced multidisciplinary team, supplementing the capabilities of King's College London, which itself represents one of the leading centres for expertise in air pollution/health and policy research in the UK. King's has extensive experience of regional and national monitoring networks, air quality dispersion modelling for policy options, such as the London Mayor's air quality strategy (GLA, 2010b) and London Congestion

Charging (Kelly et al., 2011), and development of emissions inventories both regionally and nationally (Beevers et al, 2011). We are currently leading DEFRA's model intercomparison exercise (Carslaw and Ropkins, 2012).

Research at King's has focussed on various air quality-related areas including: air quality measurements (NERC -ClearFlo); in-vitro measurements of air quality toxicity (where King's are world leaders); evaluation of traffic control policies, air quality epidemiology and health impact assessments. Members of the King's group have been involved in the authorship of reports on short term climate forcing, emissions inventory development, dispersion model development and research into exposure science. Our expertise was recognised in 2009 by the inclusion of King's College London along with Imperial College and St George's, University of London in the recently established MRC/HPA Centre for Environment and Health (http://www.environment-health.ac.uk/). We recently led a successful research bid to study the effects of traffic pollution and health in London funded by NERC/MRC/DH.

Members of the King's group are represented on influential national and international scientific panels including: UNECE CLRTAP(UN Economic Commission for Europe Convention on Long Range Transboundary Air Pollution), WHO (World Health Organisation), COMEAP (Committee on the Medical Effects of Air Pollutants, the expert advisory group of the Department of Health in the UK), QUARK(Quantification of air pollution health effects, a sub-group of COMEAP) and AQEG(the Air Quality Expert Group, the Defra advisory group on air pollution). We have a great deal of experience in linked policy related model outputs to health data in London for epidemiological studies (Tonne et al, 2008 and 2010).

Finally, in collaboration with colleagues at the London School of Hygiene and Tropical Medicine (LSHTM) we have published research on the influence of climate change policies on air quality and health impacts in London. One paper (Wilkinson et al., 2007) was referred to above and the second, (Woodcock et al., 2009) studied the air quality implications of meeting CO_2 emissions targets in the vehicle fleet in London. Another of this Lancet series with which we were concerned examined the beneficial and non-beneficial effects on air pollution of controlling shorter-lived greenhouse gases (such as black carbon and ozone) (Smith et al 2009).

In addition to King's expertise, we have included in the team two experts in epidemiology with specific expertise in air pollution and in investigating health inequalities, namely Dr Kees de Hoogh and Dr Mireille Toledano of Imperial College. Dr Kees de Hoogh specialises in exposure assessment for studies on environment and health in the Department of Epidemiology and Biostatistics at Imperial College London. He is responsible for exposure modelling and mapping on a number of epidemiological projects for the Small Area Health Statistics Unit (SAHSU), including projects investigating health effects of landfill sites, mobile phone masts and power lines. Both he and Dr Toledano will help investigate the inequalities in health impacts. The issue of health inequalities will be studied extensively using the existing datasets held at the Small Area Statistics Unit (SASHU), Imperial College and including expertise from the LSHTM.

To ensure that the project is well grounded in current public health thinking, we have included in the team Dr David Pencheon, Director of the NHS Sustainable Development unit who has a particular interest in climate change issues affecting public health[1]. Quantifying the comparative size of these public health co-benefits is a crucial part of the overall national research need to prioritise actions for health and health research at a national and

[1] This along with the inclusion of Profs Anderson and Wilkinson addresses a comment from the referees to widen the team to include public health expertise.

international level. Although the evidence is strong that action on long term mitigation to climate change can have shorter term public health benefits the research being proposed will be an important part of the discourse, policy and action that is required to help us move to the next level by quantifying these co-benefits (especially in the field of air quality). Dr Pencheon will provide a contribution to the project in terms of policy implications for public health and networking with the rest of the public health and sustainability research community.

We have included in the team Dr Michael Holland, an experienced economist who will carry out the monetisation of the health impacts, including with Dr Pencheon assessments of the economic impacts on the NHS. Dr Holland carried out similar analyses for the UK Air Quality Strategy and for the EU Thematic Strategy on Air Pollution. Dr Holland will translate quantified effects to economic impact and consider how uncertainties develop through the impact pathway chain, using experience gained in work for the UK Government and the European Commission.

The work proposed maps closely to the strategic objectives of the NHS call and builds substantially on existing air quality modelling and health data systems. Within it there are studies that will advance science and policy relating to air pollution, climate change and the associated public health hazards in innovative ways, particularly in terms of exposure assessment. The results will have direct relevance to policy through understanding patterns of exposure in the population, mortality and morbidity effects and their associated monetary evaluation. By bringing in expertise and relevant socioeconomic databases from SAHSU and the LSHTM, we will ensure that the questions of environmental equity and health inequalities are embedded in the project.

2.2 Risks and benefits

There is no direct risk to individuals in this study. Also, there is little risk that the project will not be completed because we shall be using data that are available and methods that are well established. The benefits of the study will be the quantification of the balance of risks and benefits to society over a time period between now and 2050.

2.3 Rationale for current study

In the recent Environmental Audit Committee report (HoC, 2011) it states that: “In 2010 the Environmental Audit Committee reported on air quality and found that it was shortening the life expectancy of people in the UK by an average of seven to eight months and is costing society up to £20 billion per year. It called for an urgent step change in policy to reduce pollution from transport. Over the past year the evidence of the damage caused by air pollution has grown stronger. ....The step change called for has not happened and poor air quality is now found to be shortening the lives of up to 200,000 people by an average of 2 years. Four thousand people died as a result of the Great Smog of London in 1952 and this led to the introduction of the Clean Air Act in 1956. In 2008, 4,000 people died in London from air pollution and 30,000 died across the whole of the UK”. The DH advisory committee COMEAP (2010) reported that levels of particulate matter were associated with 29,000 deaths in 2008 and a loss of life expectancy across the populations of 3-4 months of life in Scotland and Northern Ireland and 6-7 months in England and Wales. The overall societal damage costs are up to £20 billion per year[2].

Current air quality policies will improve matters incrementally in the future, but the potential for a major step change will best be realised by an alignment of climate change and air quality policies. The UK, uniquely in the world, has shown a lead in incorporating in law an ambitious target for an 80% reduction in CO_2 equivalent emissions in 2050 compared with

[2] This and the earlier paper (Williams, 2007) showing that health damages from air pollution could be halved in 2050 addresses the referees’ request for more details on the size of the health problem.

1990. A reduction on this scale will mean major changes in the energy and transport systems and infrastructure in the UK, and if the right choices are made, could remove most air pollution from urban areas in the UK. However, there are options for reaching the 2050 target which might lead to increased air pollution compared with what might otherwise have occurred. One such option involves the use of bioenergy or biomass burning, which is considered to be CO_2 neutral but can be a major disbenefit in air quality terms. Another is the increased use of small scale distributed energy schemes where increased energy efficiency is traded off against potentially increased health damage from air pollution. Careful scrutiny of potential 2050 pathways is required to quantify what are potentially large public health impacts, in both directions.

It is clear from section 2.1 above that there has been little peer- reviewed research on the specific issue of the impacts on UK public health of realistic climate change policies. Where work has been done, it is clear that the potential benefits to public health from reduced air pollution exposure are very large and potentially represent the largest such benefits since the Clean Air Act of 1956 eliminated the notorious ‘smogs’ of the ‘50s and ‘60s. Equally however it is clear that if the wrong choices are made, these improvements could be foregone and the situation could actually worsen. There is a need for more accurate assessments than the fairly broad-brush estimates currently available. Moreover, no study has yet attempted to identify an optimal scenario or pathway to achieve the 2050 climate change target while at the same time maximising the benefits for public health from air pollution exposures.

3. Research objectives

The overall objectives of the project are to quantify the air pollution impacts on public health in the UK from various pathways to achieve the 2050 target in the Climate Change Act 2008 of a reduction of 80% in CO_2-equivalent emissions relative to 1990, and to identify one or more pathways which will maximise the benefits to public health while achieving the 2050 target. In achieving this objective, the work will be divided into four Work Packages, with a project timetable and milestones described below. The objectives in summary are:

-To develop a series of policy pathways to achieve the Climate Change Act 2050 target, spanning a maximum health benefit scenario at one extreme and a scenario that rejects the 2050 target at the other. In between these we will identify up to three scenarios which deliver increasingly large benefits for public health.

-On the basis of these scenarios, to produce air pollution emissions estimates for the UK and Europe, for 2050 in grid form across the modelling domain.

- To evaluate the air quality model for the current year and to establish the contribution to concentrations of particulate matter, nitrogen dioxide and ozone from sources within the UK and in Europe. These pollutants are the ones for which concentration-response functions are available to allow health impact assessments.
- To forecast air quality across the UK, including detailed modelling in urban areas for the future year and for the chosen policy scenarios.
- To calculate exposures at 9km x 9km resolution for the UK and at 20m x 20m resolution in major cities. Further calculate personal exposures using the time-activity model incorporating people’s movements in different pollution environments.
- To calculate the impacts of the alternative future policies on mortality (and morbidity) using the life table approach. The monetary implications of the air quality impacts will also be provided.
- To assess the impacts of the climate scenarios on health inequalities in the future years (as in 4 above) will also be undertaken in the UK.
- To identify optimal strategies for maximising the public health benefits of achieving the Climate Change Act target for 2050.

To deliver these objectives the project will be subdivided into Work Packages as follows:

WP1: Future scenarios, emissions, meteorology and model set-up.
WP2: Modelling current and future air pollution concentrations.
WP3: Exposure modelling.
WP4: Public health outcomes from life-table calculations, assessment of health inequalities, and optimal scenario identification.

Work package 1: Future scenarios, emissions, and meteorology and model set-up.

The research will use as a starting point a series of energy scenarios published by Government, consistent with meeting its target to reduce carbon dioxide equivalent emissions by 80% by 2050 relative to 1990 (DECC, 2011). These scenarios will cover a range of different fuel uses and proportions of energy sources. This variation will in turn mean that they are likely to have quite different air pollution emissions and hence public health impacts. The options will include high/low levels of energy efficiency, renewables and nuclear in various combinations. A large number of potential scenarios will be screened using the PC-based 'do-it-yourself calculator' spreadsheet produced by DECC (available at http://2050-calculator-tool.decc.gov.uk/pathways/) to produce a manageable set of scenarios (see objectives above) to use in the detailed air quality modelling. **Milestone: The selection of up to five scenarios and agreement on the treatment of uncertainties will be completed by Q2 of Y1.**

The calculator produces national totals of air pollutant emissions from sectors of the economy for each scenario and these emissions need to be apportioned spatially across the UK to allow accurate modelling of population exposures. This is not a trivial task and needs to be done realistically. The team will use its knowledge of pollution emission inventories in the UK to construct air pollution emission data at a spatial scale of 9km x 9km grid squares. The team already has expertise to calculate such emissions for London and across the UK (Beevers et al, 2011) and can readily convert national scenarios to finer scale emission maps for the important pollutants particulate matter (PM), NO_2 and the precursors of ground-level O_3. Other pollutants can be readily added as required. Emissions in the rest of Europe and from further afield are important for UK air quality and emission maps for Europe are available for current years. Using a knowledge of other countries' published projections and goals for future emissions, an emission grid for Europe will be constructed at a resolution of 81km x 81km, covering an area from North Africa in the south, to north of Finland and Iceland in the north. The west-east extent of the domain is from west of Ireland and Portugal to include the eastern former USSR, the Balkans and Turkey. Published information on emissions in the rest of Europe is available for the period up to 2025 and assumptions will be made about emission profiles beyond that date using advice from the team's extensive network of researchers in Europe. Members of the Advisory Board (Profs Amman and Simpson) are experts in this area.

Man-made and natural emissions will be derived from the European Monitoring and Evaluation Programme (EMEP, http://www.ceip.at/), European Pollutant Release and Transfer Register (EPETR), the UK National Atmospheric Emissions Inventory (Murrells et al., 2010) and the London Atmospheric Emissions Inventory (GLA, 2010a). Biogenic emissions are estimated using high resolution CORINE land cover data, meteorological data from WRF and methods described by Guenther et al. (1995) and Sanderson (2002).

Global forecasts of meteorology in future years will be used as initial conditions in the model, and will be sourced from the UK Met Office (HadGem2) climate model-one of the best in the world. Emissions from outside Europe will be represented by boundary conditions (i.e. inputs to the model) to the model grid. **Milestone: Emission maps will be produced by Q4 of Y1.**

Meteorological data are needed to run the air quality model. Data for current years are available and are already in use by the team. However, care will be needed to select such data for 2050 since predictions from climate models suggest that temperatures could change significantly over this time period. The team will discuss these issues with the Meteorological Office to obtain an acceptable data set. **Milestone: Meteorological data will be finalised by Q4 of Y1.**

Work Package 2: Modelling current and future air pollution concentrations

Both physical and chemical processes are critical in determining air pollution concentrations to which people are exposed. Emissions can react chemically to produce toxic pollutants and atmospheric diffusion and transport are critical in determining dilution in the air. The emissions produced in WP1 will be used to run a state-of-the-art chemistry-transport model of air pollution known as CMAQ (Community Multiscale Air Quality model). The model is operational at King's and is capable of calculating air pollutant concentrations across the UK from the sources in WP1. CMAQ is widely used in the USA and Europe and is accepted as a 'standard' model. It performed well in the recent Defra model intercomparison exercise.

Exposure of the population to high levels of PM, NO_2 and O_3 occurs in UK cities and reflecting this adequately requires model predictions at a smaller spatial scale than the 9km grid used for the whole of the UK, in order to capture important exposure differences close to sources such as road traffic.

In the analysis in London, the project will use the CMAQ-urban model developed at King's and which extends the 'basic' CMAQ model to include a dispersion model (ADMS) which is applied to smaller distances, to address near road exposures. The work will use methods similar to those described in Kelly et al., 2011 and Carslaw 2011 and will result in hourly PM (including components of the PM mix such as nitrate, sulphate, primary and secondary organic aerosol), NO, NO_2 and O_3 at 20mx20m grids over London, Greater Manchester and potentially Merseyside, Birmingham, Leeds and Glasgow-Edinburgh.

This Work Package represents the core of the project and it is scheduled to be completed for all scenarios by Q4 in Y2. An interim report on progress will be given in Q2 of Year 2 when at least one scenario will have been modelled. This will give an opportunity to take stock of the direction of the project and to evaluate any problems.
Milestone: Progress report on modelling, results for one scenario, stocktake Q2 in Y2.
Milestone: Results of scenarios modelling, pollution concentrations in the UK Q4 in Y2.

Work Package 3: Exposure modelling[3]

Exposures of the population in the different policy scenarios will be estimated from concentrations in fixed grid squares and also in more detail using time-activity data held by King's. Exposures at the UK level will be based upon annual average concentrations of the target pollutants, $PM_{10/2.5}$, NO, NO_2 and O_3 from the CMAQ model at 9x9km, combined with population data.
In London, we shall use the CMAQ model outputs to estimate exposure to NO_X, NO_2, exhaust and non exhaust PM_{10} and $PM_{2.5}$, and coarse fraction PM at the post code level. We have successfully linked these modelled estimates to health data in London in previous epidemiological studies (Tonne et al, 2008, and 2010). The link between model concentrations and postcodes will be achieved by combining the model grid (20m x 20m) and postcode areas using GIS. Estimates will be annual average for the relevant years.

[3] WPs1 to 3 address the request of the referees to provide more detail on the modelling.

Milestone: Exposure assessments by grid square across the UK, and post code level in London Q1 in Y3.

A more sophisticated representation of personal exposure will also be developed in this Work Package. This will use the time activity exposure model developed as part of the MRC/NERC Traffic and Health project. Using the combination of the CMAQ-urban model we shall model more realistic personal exposures using data from the Transport for London Household survey which is held by King's and which includes highly detailed information for over 200,000 journeys and a sample of 90,000 households, from which detailed assessments of exposure to air pollution can be made. Together these datasets represent a detailed picture of travel in London which provides trip details from start location to end location, by purpose, time of day and day of week, and incorporates extensive demographic and socioeconomic data. This will provide a population-level outdoor exposure estimate based upon the air pollution concentration, time exposed in each location and breathing rate. Furthermore the data will enable us to investigate variations in exposure to air pollution by the socioeconomic and demographic factors such as age, gender, ethnicity and social deprivation.

Milestone: Personal exposures from time-activity/socio-economic data in London Q1 in Y3.

The different measures of exposures will be used to assess inequalities in exposure by socio-economic factors in each scenario to assess where the priorities will lie in the investigation of the inequalities in health impacts in the next Work Package. Exposure measures for the different scenarios will be rescaled to Output Areas (OA), the area unit for which census data has been collected to inform the deprivation indexes used in this study. The rescaling will be performed within a GIS by intersecting the exposure grids with the OA boundaries and subsequently population- weight the exposures using postcode headcount data. We will consider several approaches to measure deprivation. We will explore inequalities in exposure according to several different measures of deprivation including the Carstairs Index and Indices of Multiple Deprivation, in order to account for multiple dimensions of deprivation. The Carstairs Index has one advantage over alternatives in that it is a UK-wide deprivation score which includes information about unemployment, car ownership, overcrowding and low social class, and will be used to assess the inequalities between exposure and socio-economic status. We will also investigate the availability of data on possible future trends in deprivation across the UK. To analyse national and regional trends, the associations will be explored at country, regional and city level.

Milestone: Assessment of scale of exposure inequalities across the UK and in detail in London Q2 in Y3[4].

Work Package 4: Public health outcomes from life-table calculations and optimal scenario identification

The impacts of the various scenarios on public health will be assessed using methods currently used in Government impact assessments. This assessment involves the use of concentration-response relationships derived from epidemiological studies and applied to spatially resolved pollution concentration data in a well-established and accepted methodology. Throughout the lifetime of the project, the literature will be scrutinised to keep abreast of developments in research which might lead to the current concentration-response functions being updated. This will draw on a systematic literature review and meta-analyses already being undertaken by one of the team (Prof. Anderson). The first step in WP 4 will be

[4] This and the subsequent health impact work in WP4 deal with the comment of the referees to clarify how inequalities would be addressed.

to decide on such functions to be used. **Milestone: Decide on concentration-response functions for health impact assessment Q1in Y3.**

Mortality outcomes will be expressed as life-years lost or gained and as deaths brought forward associated with air pollution using well-established life-table methods (Miller and Hurley, 2003), and taking due account of uncertainties in the lag between exposure and health outcome. Morbidity impacts in terms of hospital admissions will also be estimated. Mortality and morbidity impacts will be assessed using methods agreed by COMEAP (the Department of Health expert advisory Committee on the Medical Effects of Air Pollutants) (COMEAP, 2010 and earlier reports) in the main analysis and further concentration-response functions from reviews of the literature in certain areas as the project progresses e.g. on wood burning. The main analysis will cover emergency respiratory and cardiovascular hospital admissions and all cause mortality as a result of short-term exposure to ozone, sulphur dioxide and $PM_{10.}$ In addition, it will cover the most important outcome, the effect of long-term exposure to $PM_{2.5}$ on life-expectancy (Pope *et al* 2002).The current impact assessment methodology implicitly considers all components of the ambient particle mix as being equally toxic. Given the possibility of different levels of biomass (wood) combustion in the future scenarios, the study team, who have considerable experience in health evidence evaluation and health impact assessment, will also consider the evidence for the use of relationships between health outcomes and particles from specific sources such as wood burning. There is also emerging evidence that particles generated by tyre and brake wear could be toxic and should this be confirmed these sources will also be considered.
Milestone: Quantification of mortality and morbidity impacts of the various scenarios across the UK, and in detail in London.

The mortality and morbidity outcomes will be analysed against socio-economic factors obtained in WP3 and inequalities quantified in each of the scenarios, using the approaches described under WP3 above.
Milestone: Assessment of health inequalities[5] in each scenario and the extent to which they have been reduced. Q2 in Y3

The scenarios will be further compared through an assessment of the costs and benefits of the measures within them. A team member is an economist with extensive experience in assessing the costs and benefits of air pollution and climate change policy measures. The costs to health will be calculated using the methodology developed by the Intergovernmental Group on Costs and Benefits (IGCB); the emission control costs will be estimated from the information supplied by DECC in their ‘do-it-yourself’ calculator for scenario testing. In addition, health impacts will be expressed in terms of NHS costs (costs of hospital stays and other data from the NHS Institute for Innovation and Improvement) and Quality Adjusted Life Years. **Milestone: Assessment of costs and benefits of each scenario Q3 in Y3.**

Bringing together all the results and conclusions from the previous elements of WP 4 will allow the team to evaluate options for achieving the 2050 Climate Change Act target in terms of maximising the benefits for public health. Moreover, it will enable the team to also quantify the benefits which would be foregone if other, less optimal, scenarios were chosen. A final recommendation will therefore be made regarding the optimal route to achieving the 2050 target. **Milestone: Optimal scenario(s) identified to maximise the air quality public health benefits from achieving the Climate Change Act target for 2050, Q4 in Y3. Workshop with stakeholders and other researchers.**

3. Research design

This has been covered in the previous section.

[5] See footnote 4.

4. Study population

The population considered by the project is the total UK population.

5. Socioeconomic position and inequalities

This has been described in Section 3 above, but it is worth re-emphasising that there is a danger in implementing some policies aimed at mitigating climate change which may disproportionally impact on poorer communities. Introducing new decentralised heating/power schemes is one example. The team has considerable expertise in assessing health inequalities and this coupled with the uniquely fine spatial resolution of the air quality modelling will allow detailed estimates of inequalities to be made along with the identification of possible mitigation measures.

6. Planned interventions

The interventions are the policy options for achieving the Climate Change Act target and have been described in Section 3 above. They will span the range of potential impacts on public health from air pollution and an optimal course will be identified.

7. Proposed outcome measures

The outcome measures are (i) quantified and monetised public health impacts of a series of climate change policy pathways to the 2050 Climate Change Act target (ii) an assessment of the inequalities in health and pollutant exposures inherent in the scenario pathways and (iii) a recommended scenario/pathway that maximises the benefit to public health while at the same time achieves the target in the Act.

8. Assessment and follow-up
9. Proposed sample size
10. Statistical analyses
11. Ethical arrangements

These headings are not strictly appropriate to the present project.

12. Research governance

Project management:

Prof. Williams will lead this interdisciplinary project with the assistance of Dr. Beevers. Both are experienced PI's and have experience in research consortia. Williams and Beevers along with Dr Walton, Dr Carslaw, Professor Anderson, Dr Pencheon, Dr Holland, Dr de Hoogh and Dr Toledano will make up the internal steering committee which will meet every 3 months. Every six months all collaborators will attend this meeting.

The project will be overseen by an Advisory Board made up of external experts. The composition will be: Chair: Prof. Roy Harrison (Chair of Environmental Health, Univ. of Birmingham), Prof. Bob Lee (Law School, Cardiff Univ.), Prof. Paul Wilkinson (London School of Hygiene and Tropical Medicine, an epidemiologist with expertise in air pollution, climate change and health inequalities), Prof. Markus Amman (International Institute for Applied Systems Analysis, Austria, an expert on emission scenarios at European and global scales for air pollutants and greenhouse gases), Prof David Simpson (University of Gothenburg, a leading modeller of air pollution on a European scale), Dr Cathryn Tonne (London School of Hygiene and tropical Medicine, expert in health inequalities and deprivation). The Board will also consist of nominated members from DoH, Transport for London, DEFRA, DECC, and DfT. The Advisory Board will meet for a kick-off meeting at the start of the project and once per year thereafter, and will provide critical review and advice to the project team.

13. Project timetable and milestones

The project timetable is given in Annex A; milestones are marked with an asterisk and match those given in Section 3 above.

14. Expertise

Prof. Martin Williams will direct the work, act as project manager and will advise on the initial selection of scenarios and the final selection of optimal pathways.
Dr Sean Beevers will assist in project management and will direct the emission inventory and air quality modelling work.
Professor Ross Anderson will assist with project management and will advise on the epidemiological aspects of the project, including the literature reviews of concentration-response functions and health impact analysis. He will donate his time at no cost.
Dr David Carslaw will assist in scenario selection, emission inventory work and evaluation of model performance.
Dr Nutthida Kitwiroon will carry out the modelling work.
Dr Emily Westmoreland will assist with the modelling and will carry out the exposure calculations and the life table impact assessment.
Dr Gary Fuller will advise on impacts of wood burning emissions.
Dr Heather Walton will evaluate the literature on concentration-response functions, will oversee the life-table work and will advise on health impact assessment.
Drs Kees de Hoogh and Dr Mireille Toledano will undertake the assessment of health inequalities and health impacts.
Dr Michael Holland will calculate damage costs of health impacts, costs of control and undertake cost-benefit analysis, including uncertainty assessments.
Dr David Pencheon will advise on the public health implications of the results.
All will participate in the selection of a pathway(s) for optimum public health benefit.

15. Members of the Public

The MRC-HPA Centre for Environment and Health of which King's is a part has a Community Advisory Board established to bridge the gap between the Centre's work and the wider community. It is composed of representatives from the general public, patient groups, local government, and various industries. Progress reports will be made to this group, who will also be invited to attend project meetings. A description of the project and findings in lay terms will be incorporated into the ERG website (http://www.erg.kcl.ac.uk). ERG works directly with several London local authorities and is therefore well positioned to communicate the findings of this research to them via presentations and/or via newsletters[6].

16. Justification of support required

King's College staff (% of FTE): Prof. Martin Williams (15%); Dr Sean Beevers (10%); Dr Nutthida Kitwiroon (35%); Dr Emily Westmoreland (35%); Dr David carslaw (10%); Dr Gary Fuller (2%); Dr Heather Walton (15%).
Imperial College Staff: Dr Kees de Hoogh (5%); Dr Mireille Toledano (5%)
NHS Sustainable Development Unit: Dr David Pencheon (3%). Ecometrics research & consulting: Dr Mike Holland (5%).
The largest staff time is associated with the two researchers (Drs Kitwiroon and Westmoreland) who will undertake the air quality modelling, exposure and health impact calculations which are the core of the project. The state-of-the-art models are complex and

[6] This paragraph, the organisation of workshops, and the involvement of key government departments in the Advisory Board address the dissemination issue raised by the referees.

have stringent requirements for large amounts of set-up time and compilation of input data. The exposure model is also at the forefront of current science in this area and requires considerable staff time to compile data and check and process output.
Considerable effort will be required to spatially disaggregate the chosen emissions pathways to 2050 and given that there are several scenarios for the future year, the work in this area alone will be considerable.

Combining this with the state of the art CMAQ-urban model and Hadgem2 global models plus model run time for the associated alternative emissions pathways is also a considerable task. For example the 20x20m pollutant data in London alone results in ~30 billion records per pollutant per year, a considerable staff time and computing overhead is likely. The cost of additional computing facilities has been included in the bid to reflect this.

Finally the city wide and UK datasets will be combined with population and deprivation datasets and the life table calculations applied. This is exposure analysis at an unprecedented scale and will constitute the most comprehensive assessment of the health impacts of climate change strategy undertaken in the UK to date. The considerable support required by Dr's Kitwiroon and Westmoreland reflect the size of the task being proposed[7].

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[7] These paragraphs address the request of the referees to justify the investigator time.

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Annex A. Timetable for project. Asterisks denote end of task and deliverable product. Grey shading denotes duration of activity.

Year	Lead/co-worker	Year 1					Year 2					Year 3			
Quarter		Q1	Q2	Q3	Q4		Q1	Q2	Q3	Q4		Q1	Q2	Q3	Q4
WP1 Scenarios, emissions, meteorology and model set-up	MW/SB/DC MH														
WP 1.1 Assess scenarios and prepare candidates to model-number of scenarios to be determined at this stage[8] and agree uncertainty analysis.	MW/DC/SB/ MH		*												
WP 1.2 On basis of WP1.1 prepare gridded emission inventories for UK and Europe	SB/EW				*										
WP1.3 Current/base year met data and prepare future 2050 met data	SB/NK				*										
WP 2 Modelling of current and future pollutant concentrations	SB/NK/EW														
WP 2.1 Model PM, NO2 and ozone at UK scale for scenarios selected under WP 1.1 and 1.2.	NK/EW									*					
WP 2.2 Fine scale urban model for each pollutant and emission scenario	SB/NK/EW									*					
WP 3 Exposure modeling															
WP 3.1 Modelling of population exposures at 9km resolution for UK and post-code/20m level in London. Also using hybrid model and time-activity data in London to model	EW/NK											*			

[8] The scenarios will include a 'do nothing' case, ie no Climate Change Act target, a scenario with target and maximum feasible air pollution reductions, a scenario with minimal air pollution reductions and a 'central' scenario. Depending on the emissions obtained from these scenarios, more than one 'central' scenario might be chosen.

personal exposures.															
WP 3.2 Assessment of inequalities in pollutant exposures in urban centres in the various scenarios	SB/HW/MW											*			
WP 4 Public health outcomes from life-table calculations and optimal scenario identification	HW														
WP 4.1 Continuing appraisal of literature developments in concentration-response functions and final choice for calculation	HW										*				
WP 4.2 Life-table calculations of loss of life expectancy across the UK population, estimates of deaths brought forward and morbidity, as informed by WP 4.1	EW/NK/HW											*			
WP 4.3 Assessment of effect of policies on inequalities in health outcomes	KdeH/MT/HW/MW/SB											*			
WP 4.4 Assessment of costs and benefits of the scenarios in relation to health outcomes	MH/KdeH/SB												*		
WP 4.5 Identify optimal scenario for public health while achieving the Climate Change Act target. Workshop to disseminate results.	MW/HW/SB/DC													*	

Flow chart for Project 11/3005/13

Project title: Public health impacts of different pathways to meet the UK Climate Change Act commitment to 80% reduction on CO_2 and other greenhouse gas emissions by 2050.