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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: CPEA4
2. Project title: Analysis of Abatement Strategies Phase V
3. Contractor organisation(s):
   Imperial College London
   Prince Consort Road
   London SW7 2AZ
   Postcode SW7 2AZ
4. Total Defra project costs (agreed fixed price): £ 527,890.39
5. Project: start date .... 01 November 2003
   end date .... 30 June 2007

6. It is Defra's intention to publish this form.
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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Under the UN ECE Convention on Long Range Transboundary Air Pollution (CLRTAP) the development and use of integrated assessment modelling (IAM) played a major role in developing the second sulphur protocol, and the subsequent Gothenburg protocol covering a broader range of pollutants (SO2, NOx, NH3, VOCs and PM) and environmental effects. Integrated assessment brings together information on projected emissions of these pollutants, their subsequent atmospheric transport and resulting concentrations and deposition, criteria for environmental protection and intermediate targets towards their attainment, and data on potential measures to reduce emissions and their costs. These data are used to derive cost-effective strategies towards attainment of environmental targets. In this work Imperial College worked with the European scale ASAM model alongside IIASA with the RAINS model, which has subsequently been used by the EC in their Clean Air For Europe (CAFÉ) programme in setting national emissions ceilings.

In the past 3 years our aim has been to follow closely the continuing work of IIASA in CAFÉ, and undertake complementary research to support national and international policy development preparatory to review of the Gothenburg protocol and revision of the National Emission Ceilings Directive (NECD). In particular we have developed a national scale model, UKIAM, using more detailed information available for the UK. The aim is to investigate cost-effective strategies for attaining emission ceilings prescribed for the UK, and compliance with other international commitments, while maximizing improvements in environmental protection within the UK. This national scale modelling includes urban air quality, which is not directly addressed by IIASA, as well as acidification, eutrophication and long-range transport of particulate matter.[1]

In the accompanying report the development and application of the UKIAM model is described, embedded in the ASAM model for long-range and imported contributions into the UK. As the UK National Focal Centre for Integrated Assessment Modelling we have interacted strongly with other DEFRA contractors, including CEH Monkswood in providing maps of critical loads as maximum levels of deposition for protection of different ecosystems; and CEH Edinburgh in providing data from atmospheric modelling with the FRAME model to define the contributions from different UK sources to sulphur and nitrogen deposition across the UK, in parallel with our own PPM model for urban concentrations of NOx and PM_{10}. We have also had assistance from AEA Technology (NETCEN) on emission data from the NAEI, and from ENTEC on abatement measures and costs. At the European scale we have had cooperation with EMEP-W in providing results from their European scale modelling, as well as with IIASA.

In the results provided we have shown how the UKIAM model can be applied to investigate reduction of ammonia emissions in order to meet tighter emission ceilings anticipated for 2020 in forthcoming revision of the NECD. This has also been used to illustrate the distortion in the European scale modelling by IIASA if geographical variations in agriculture within countries are ignored. We have also undertaken scenario analysis and intercomparison between UKIAM and other modelling for DEFRA of urban concentrations of NO2 and PM in relation to the UK Air Quality Strategy, identifying various uncertainties related to projections of urban concentrations of NO2 and particulate PM_{10}. Although originally only modelling of urban background concentrations was included in the contract specification, we have recently been developing a detailed model for the transport sector, treating the whole UK road network in the new BRUTAL model. This will not only enable modelling of peak concentrations occurring at road-side sites for direct comparison with air quality limit values, but will also allow treatment of some non-technical measures such as congestion charging.

At the European scale we have maintained the ASAM model as a tool for scenario analysis, and undertaken comparison of national scale modelling with that of EMEP across the UK, identifying differences in source-apportionment (particularly with respect to the relative contributions from UK emissions and from the rest of Europe and shipping), and in the spatial patterns of deposition across the UK. The more detailed spatial resolution in UKIAM has been used to investigate several issues resulting from the coarser EMEP grid resolution, such as calculation of transboundary contributions to primary PM concentrations between neighbouring countries due to poor resolution of country boundaries, and the tendency to underestimate exceedance of critical loads as indicators of protection for ecosystems. We have followed the work of IIASA closely, pointing out significant departures in the CAFÉ approach from that in the UN ECE, and commenting to DEFRA on aspects that are significant for the UK. We have played an active part in the UN ECE with regular presentations to the Task Force on Integrated Assessment Modelling and other related meetings.

In looking beyond 2010 to emission ceilings for 2020 there is relatively little scope remaining for further add-on technical measures to reduce emissions of SO2, NOx and PM. However there are potential

[1] In UKIAM we have not however addressed ozone, as this is covered under other DEFRA contracts.

synergies between control of greenhouse gases and air quality pollutants, with corresponding financial savings[2]. Recognising this IIASA have developed the GAINS model, which combines measures such as changes in projected energy generation affecting both greenhouse gases and air quality pollutants as combustion products, with add-on measures for specific pollutants. This requires a different approach from the individual pollutant "cost-curves" used in RAINS, and the PI has contributed to a review of the new optimization approach for CAFÉ. Correspondingly we have taken preliminary steps towards similar adaption of UKIAM , to enable analysis of UK energy and transport scenarios with UKIAM to investigate joint benefits for greenhouse gases and air quality pollutants (this being an important area for further study in collaboration with other work for DEFRA on the NAEI, and on emission abatement and costs). The PI has also reviewed the development of recent scenarios reported by IIASA towards revision of the NECD and commented to members of DEFRA attending associated meetings.

A recent meeting in Saltsjobaden (12-14 March 2007) looking at the way forward in Europe and the UNECE, has confirmed our own views on how the work under this contract could best be taken forward. The most important development is the linking of air quality pollutants and greenhouse gases, since they often come from the same sources and there are large potential benefits from an integrated approach both economically and for the environment. Extension of UKIAM provides a good foundation for this with respect to the UK. The control of UK and European emissions also needs to be set in the context of changing emissions elsewhere in the world, including rapid development in Asia. Collaboration with the Met Office would enable a link between their global scale modelling and our current work on urban to European scales, and allow us to address the influence of the rest of the northern hemisphere on air quality and ecosystem protection in Europe. In addition to an integrated approach to air quality and climate change, there is also a need to take an integrated approach to the nitrogen cycle. This particularly relates to the agricultural sector where reduction of ammonia emissions, arising mainly from livestock wastes and contributing to eutrophication of ecosystems, interacts with other problems of nitrate leaching in nitrate vulnerable zones, and generation of the potent greenhouse gas N_2O. Discussion has already taken place with other DEFRA contractors on how this can be taken forward in the context of the UK, building on the current capabilities of UKIAM; together with more detailed attention to protection of priority ecosystems such as NATURA 2000 sites from effects of excess nitrogen.

Another area requiring specific attention is shipping, which is increasing steadily with emissions of SO2 and NOx forecast to soon exceed land-based emissions in Europe. The particular importance for the UK has been illustrated in this contract, but improved emission data with more detailed spatial resolution round the UK is required to take this forward. Further work is also required on the road transport sector, where the extra effort invested in development of the BRUTAL model in this contract will be valuable.

[2] See for example the report of the Air Quality Expert Group (AQEG) "Air Quality and Climate Change in the UK". The PI is a member of AQEG and the work under this contract has contributed both to this report and other reports by AQEG.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

8. Project Report

PROJECT REPORT: CPEA4

ANALYSIS OF ABATEMENT STRATEGIES:

PHASE V

Centre for Environmental Policy
Imperial College London

June 2007

Analysis of Abatement Strategies Phase V

Table of contents

GLOSSARY

APRIL	Air Pollution Research in London:
ASAM	Abatement Strategies Assessment Model
BRUTAL	Background Road and Urban Transport modelling for Air Quality Limit Values
CAFÉ	Clean Air For Europe
CAPRI	Model for future European agricultural projections following CAP reform
CEH	Centre for Ecology and Hydrology
CH_4	Methane (greenhouse gas)
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO_2	Carbon dioxide
EMEP	European Monitoring and Evaluation Programme
FRAME	Fine Resolution Atmospheric Transport Multi-pollutant Exchange model
GAINS	Greenhouse gas Air quality pollutants INteractions and Synergies
IAM	Integrated Assessment Modelling
IIASA	International Institute for Applied Systems Analysis
MARACCAS	Modelling the Atmospheric Release of Ammonia and Cost Curves for Abatement Strategies
MCDA	Multi-Criteria Decision Analysis
NAEI	National Atmospheric Emissions Inventory
NARSES	National Atmospheric Reduction Strategy Evaluation System
NECD	National Emission Ceilings Directive
NH_3/NH_4	Ammonia/ammonium aerosol
NO_2	Nitrogen dioxide
NO_3	Nitrate aerosol
N_2O	Nitrous oxide (greenhouse gas)
O_3	Ozone
$PM_{10}/PM_{2.5}$	Particulate matter of aerodynamic diameter less than 10 and 2.5 microns respectively (coarse fraction = difference between the two)

PPM	Primary Particulates Model (later extended to other urban air quality pollutants)
PRIMES	Model for European energy scenarios
SIA	Secondary Inorganic Aerosol= SO4, NO3 NH4 etc
SO_2/SO_4	Sulphur dioxide/sulphate aeorosl
TREMOVE	Model for future European transport
TFIAM	Task Force on Integrated Assessment Modelling
UKIAM	U K Integrated Assessment Model

Project Report:Analysis of Abatement Strategies: Phase V

1. Introduction:

Scientific Objectives

The aim of this research project has been to provide technical support to the Air and Environment Quality Division of DEFRA in the context of European policy development under the UN ECE Convention on Long Range Transboundary Air Pollution (CLRTAP) and the CAFÉ programme of the European Commission; and to inform development of national policy and the UK Air Quality Strategy. The work has followed on from previous contracts in which we have worked in parallel with IIASA under the UN ECE programme leading to development of the Gothenburg Protocol (1999) and the subsequent National Emissions Ceilings Directive, both of which are under review as this contract ends.

The work has focused on analysis of abatement strategies to reduce pollutant emissions of SO2, NOx, NH3 and primary fine particulate matter (PM10) using “integrated assessment modelling”. This brings together information on pollutant sources and emissions, atmospheric transport and mapping of resulting concentrations and deposition, criteria for protection of human health and natural ecosystems and the extent to which these are exceeded, and potential abatement measures to reduce emissions together with their costs. These data are used both to analyse specific emission reduction scenarios, and to investigate cost-effective abatement strategies that improve environmental protection at least cost. We are grateful to other DEFRA contractors who have provided the necessary information to support this work, in particular to CEH on critical loads for protection of ecosystems and atmospheric modelling with the FRAME model, and to AEA Technnology and ENTEC on emissions and abatement costs.

Tasks and work-packages in programme of work funded

1) Development of the European scale Abatement Strategies Assessment Model, ASAM, incorporating source-receptor data from the EMEP model.
2) Review development of IIASA’s RAINS model, and associated activities
3) Critically assess strategies put forward by the EU and UN ECE based on the RAINS model in preparation for review of the Gothenburg protocol and the NECD.
4) Investigate alternative strategies for cost-effective emission reductions in the UK, with attention to trade-offs in other areas affecting air quality such as climate and transport policies
5) Sensitivity analysis and uncertainties in assessment of abatement strategies, and scrutiny of the assumptions made and data used
6) Development and application of UKIAM as a UK scale integrated assessment model focusing on the UK

Additional optional tasks, not originally included in the contract, but eventually addressed at no extra cost

7) Incorporate modelling of urban air quality in UKIAM
8) Investigate a cost-effective balance between local measures and restrictions and control of transboundary sources (emission ceilings) to protect natural ecosystems from excess nitrogen

The programme falls into two interacting strands. The first (tasks 1-3) has been directed to critical evaluation of development and application of the RAINS model of IIASA as the official reference model for the UN ECE, and of scenarios produced for the CAFÉ programme. This includes related atmospheric modelling by EMEP, and extension to the new GAINS project where IIASA is exploring synergies between control of greenhouse gases and transboundary pollutants in Europe. The second strand (task 6, supported by task 1, and underpinning task 4) is focused on the UK and modelling at a national scale, involving development and application of our own integrated assessment model, UKIAM. This complements the European scale, with extension to address local urban air quality issues directly (extra task7); and, with the more detailed information available at a national level, illustrates problems of scale and cruder assumptions in the European scale modelling. Together with comparison with other national modelling, this has contributed to analysis of uncertainties and the robustness of modelling of abatement strategies (task 5). This second strand has assumed more emphasis during the contract, and will be described first since it feeds into the European scale assessment.

Extent to which the objectives have been met

In general the original objectives have been met, the exception being revision of task 1 as explained below; however we have made some adaption in response to evolving developments (e.g. the replacement of the RAINS model of IIASA by the GAINS model) and also achieved additional objectives not initially included.

UKIAM (task 6) has been successfully developed and applied to abatement of UK emissions of SO_2, NO_x and NH_3 (as illustrated below in both optimisation mode and scenario mode); and we have gone beyond the original objectives with respect to modelling of urban air quality (task 7). We have also investigated alternative approaches (task 4); for example, a range of UK scenarios, also the use of dynamic modelling to explore setting of target years to achieve recovery of freshwater ecosystems from acidification; also more geographically targeted and local measures for ammonia (extra task 8). We have also undertaken inter-comparisons with other DEFRA contractors, and explored uncertainties in modelling future situations (extension of task 5).

On the European scale, in consultation with DEFRA, we have not attempted to develop the ASAM model to parallel the complete range of application of the RAINS model of IIASA and its successor GAINS. Instead, for task 1 ,we have kept a simple scenario version of ASAM up-to-date with the latest data from EMEP, and nested UKIAM within it with respect to imported contributions to the UK. We have critically evaluated the work of EMEP and IIASA , including the work undertaken for the CAFÉ programme (tasks 2 and 3). We have drawn attention to critical assumptions and potential problems in this work; and communicated these to TFIAM and DEFRA, often illustrated by more detailed work at the UK scale with UKIAM. The biggest difficulty has arisen in transparency of models used in conjunction with the new GAINS model, specifically the PRIMES model for future European energy generation, and the CAPRI model for European agriculture; and we have not been able to review and assess the use and applications of these models adequately.

2. Methods used and results obtained

Part I. National scale assessment

<u>Development of the UKIAM model *(task 6)*</u>

The UKIAM model (Oxley, ApSimon et al 2003, Oxley and ApSimon 2007) has been developed to investigate emission control strategies in the UK that are cost-effective in maximizing improvement in protection of the environment while helping to comply with the UK's international commitments on national emission ceilings and air quality legislation. Protection of the environment includes human health with respect to human exposure and air quality standards, and protection of natural ecosystems through reducing exceedance of critical loads as the maximum annual deposition sustainable to avoid adverse effects. It brings together UK data based on the work of other DEFRA contractors, with emission data based on the NAEI, source apportionment reflecting the response of concentrations to changes in UK emissions based on atmospheric modelling with the FRAME model of CEH (Fournier et al 2004) and the PPM model of Imperial College (ApSimon et al 2001, Gonzalez del Campo 2003), detailed critical load mapping for different types of ecosystem from CEH; and information on abatement measures on SO_2, NO_x and primary PM_{10} from ENTEC, and from the NARSES model for NH_3 from agriculture as the main NH_3 source. The latter are embodied in cost curves, ranking the potential abatement measures as a series of emission reduction steps for each pollutant and source represented in UKIAM in order of increasing cost per unit emission reduction. Figure 1 summarises the structure and component parts of the UKIAM model.

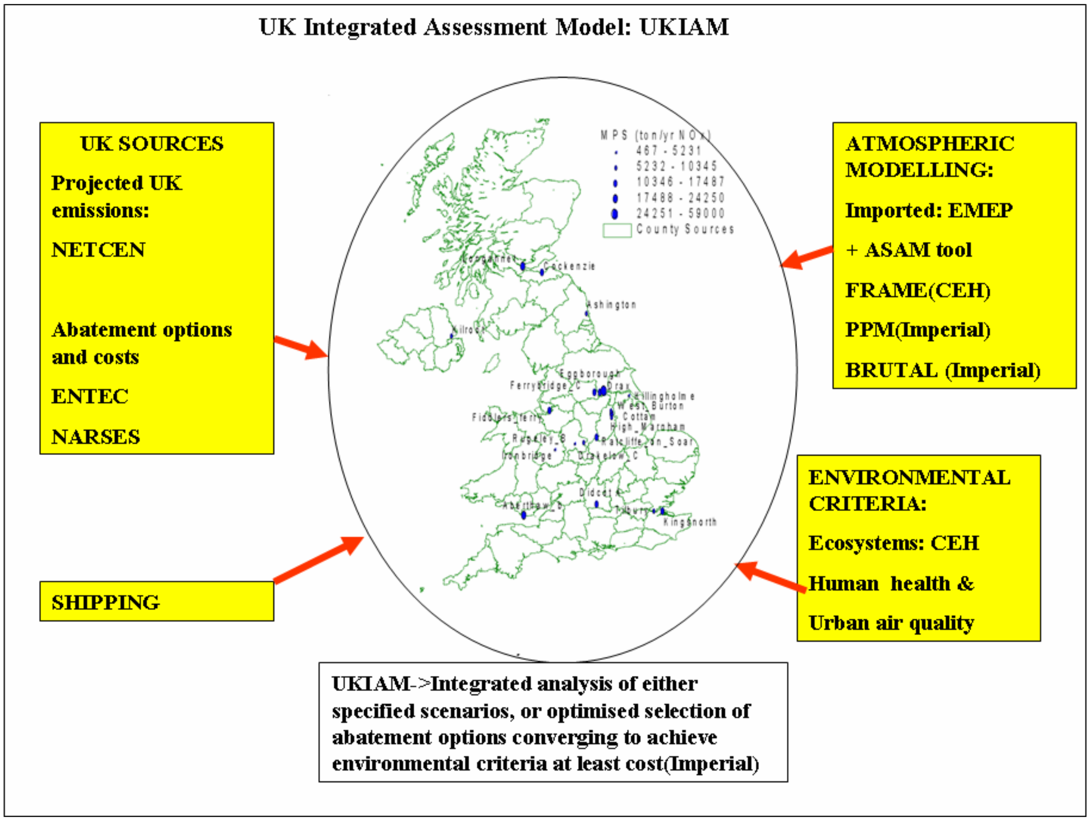


Figure 1: Components of the UK Integrated Assessment Model, UKIAM

UKIAM uses a 5x5 km grid encompassing the UK and parts of the surrounding seas. Geographically emissions of each pollutant can be resolved as individual point sources, or as area sources distributed among different counties. The UK area is embedded in a European grid, and can be linked to the European scale ASAM model (ApSimon et al 1994) as described below, to reflect imported contributions from outside the UK as represented by the European scale EMEP modelling. Comparison of the coarser scale EMEP modelling and that of FRAME is discussed below in Part 2. More recently, as a development of work on urban air quality, a sub-model, BRUTAL (Oxley, Valiantis and ApSimon 2007), has been developed using a finer 1x1 km grid, with the UK road network superimposed in order to assess concentrations at roadside sites. As this contract ends work is in progress to apply the model to London with a finer 1x 1 km grid for background concentrations, and links to the LAEI database of the GLA on road traffic.

The UKIAM model can either be used in scenario mode, or in optimization mode. In scenario mode UKIAM estimates concentrations and/or deposition of prescribed pollutants for a given emission scenario for either a current year or projected emissions for a future year – see table 1. In optimization mode it chooses a sequence of abatement measures, cycling through all the options for each source in each step to select that option for implementation that gives the greatest ratio of environmental improvement to cost of the step. Environmental improvement is defined by a “benefit function” based on a weighted sum of such factors as changes in the integrated accumulated exceedance of critical loads across the UK, and/or the integrated population exposure to PM10.

In the current version of UKIAM developed under this contract a very flexible and general framework has been used, in terms of a set of sources and pollutants coupled to a set of environmental receptors through source- receptor relationships. This makes it very easy to adapt or extend the model. For example during the contract we have collaborated with CEH to explore how the time dimension for recovery of ecosystems can be brought into the assessment using dynamic modelling of acidification of freshwater systems (Oxley, ApSimon and Jenkins 2003b). The model also has the potential to address other coupled pollution problems, such as greenhouse gas emissions or other aspects of the nitrogen cycle as associated effects - see section below on “possible future work”.

Table 1. Pollutants covered and mapping generated over the UK

pollutant	map	application
SO_2 NOx NH_3	S deposition(by ecosystem type) Oxidised N deposition Reduced N deposition	Acidification exceedance maps *Can be broken down by ecosystem type if required; also used with target loads from dynamic modelling*
NOx NH_3	Oxidised N deposition Reduced N deposition	Eutrophication exceedance maps *Again can be total or by ecosystem type*
SO_2 NOx NH_3	Sulphate aerosol Nitrate " Ammonium "	Secondary inorganic aerosol. SIA as part of PM10 (PM2.5); pop. Weighted mean concns.
Primary PM	Primary PM concentrations	Urban and roadside enhancement of PM10 (PM2.5), population weighted mean concn re health effects
NOx	NO_2 concentrations	Urban and roadside concns. Exceedance AQ annual limit values

Applications of UKIAM

During this 3 year contract UKIAM has been used both towards analysis of strategies for controlling UK emissions of SO_2, NOx, NH_3 and primary PM_{10}; and for comparison of the more detailed UK scale analysis with UKIAM and the European scale assessment with RAINS (see section II). Two illustrations of this work are given below- the first using UKIAM in optimization mode to address reduction of NH3 emissions from agriculture, and the second applying UKIAM in scenario mode to NO2 and PM10 concentrations in relation to urban air quality in the context of the UK Air Quality Strategy.

Illustration 1: Reduction of NH3 emissions from UK agriculture[3] (*Task 4*).

Ammonia emissions (NH3) are contributing a growing proportion of nitrogen deposition as emissions of nitrogen dioxide are reduced, and hence are receiving increasing emphasis. This is likely to lead to tighter emission ceilings in the forthcoming revision of the NECD. However the deposition of reduced nitrogen has a much larger local component correlated with local emissions, whereas deposition of oxidized nitrogen occurs much more over transboundary scales. For NH3, which comes mainly from agriculture, it therefore becomes important to consider the spatial variation of farming across the UK, and where and which abatement measures are most cost-effective in reducing excess deposition to ecosystems in sensitive areas (i.e. exceedance of critical loads). The results generated below are based on application of UKIAM to these questions, resolving agricultural activities at a county scale and allowing independent application of control measures in each county. It is not envisaged that legislation would be different for each county, but this more detailed analysis can help to define whether it is appropriate to set different levels of regulation in different regions (England, Wales, Scotland, Northern Ireland) or other subdivisions of the UK- as opposed to uniform regulation across the whole country.

[3] These illustrative results are based on data provided from the first NARSES project; we plan to update it with more up-to-date data from NARSES when this is available .

Data on ammonia emissions in each UK county, according to the corresponding agricultural activities, and cost curves representing the maximum potential for emission reduction in each county as a function of increasing cost, have been derived from the NARSES model for ammonia emission from agricultural livestock farming. NARSES is based on our work at Imperial College[4] in a preceding MAFF contract, the MARACCAS project, on the potential for abatement of NH_3 emissions in different European countries when the topic was being developed for the Gothenburg protocol: and is based on the MARACCAS model following the history of animal wastes, including transfer from housing to storage to spreading with associated ammonia emissions at each stage. This allows for the fact that reducing emissions in one context such as housing, may increase emissions at a subsequent stage. UKIAM also includes emissions from fertilizer, where use of urea releases much higher NH_3 emissions than other forms of fertilizer.

In the illustration below UKIAM has been applied, aiming to reduce exceedance of critical loads for both acidification and eutrophication across the UK with equal emphasis. The model has selected abatement steps sequentially, each time ranging through the available abatement options in all the counties (summarized as cost curves for each county) to select the step that gives the greatest ratio of improvement in overall exceedance of critical loads to cost of implementation. This leads to an ordered sequence of selection of abatement options, maximizing environmental improvement as a function of cumulative cost as illustrated in figure 2.

It is apparent from this analysis that the steps selected on the first part of the curves illustrated are highly effective, but the rate of improvement becomes increasingly reduced, with the flat part of the curves beyond about £200 million per year indicating virtually no further improvement up to the maximum feasible reduction at an overall annualised cost of £718million. These include measures that are remote from sensitive areas, or are extremely expensive to implement- for example some measures to adapt animal housing. UKIAM provides a breakdown of the abatement measures implemented and maps of the reduction in deposition and exceedance at specified levels of cost. As an example figure 3 illustrates maps of the reduction in average accumulated exceedance over 5x5 km grid squares in the UK with respect to acidification at levels of expenditure of £20 million, £100 million, £200 million and for the maximum feasible reduction with all steps implemented at £718 million. A more detailed breakdown is available, using software provided by CEH, of the breakdown between different types of ecosystem such as acid grassland or coniferous woodland. Corresponding maps and output are available for eutrophication, together with maps of corresponding changes in deposition. The latter clearly illustrate how the model preferentially selects emissions reductions in areas with sensitive ecosystems

[4] With J Webb then at ADAS and input from M Ryan now at DEFRA on abatement costs e.g. see Cowell D and ApSimon HM "Cost effective strategies for the abatement of ammonia emissions from European agriculture" Atmospheric Environment 32-3 (1998), 573-580

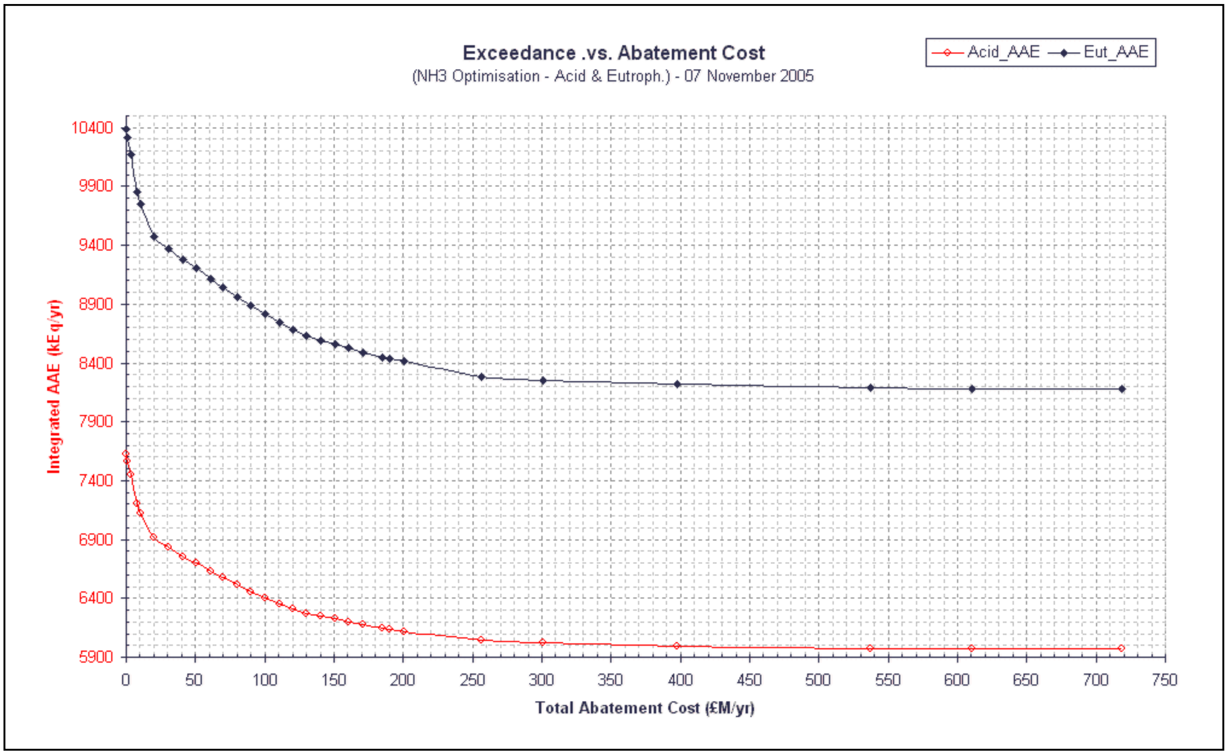


Figure 2. Improvement in integrated exceedance of critical loads for acidification and eutrophication as a function of increasing expenditure in abatement beased on optimisation in UKIAM

Figure 3 (next page) Reduction in average accumulated exceedance of critical loads for acidification after different levels of expenditure of £20 million, £100 million, £200 million per year and the maximum feasible reduction with all measures implemented (MFR) with total expenditure of £718 million per year.

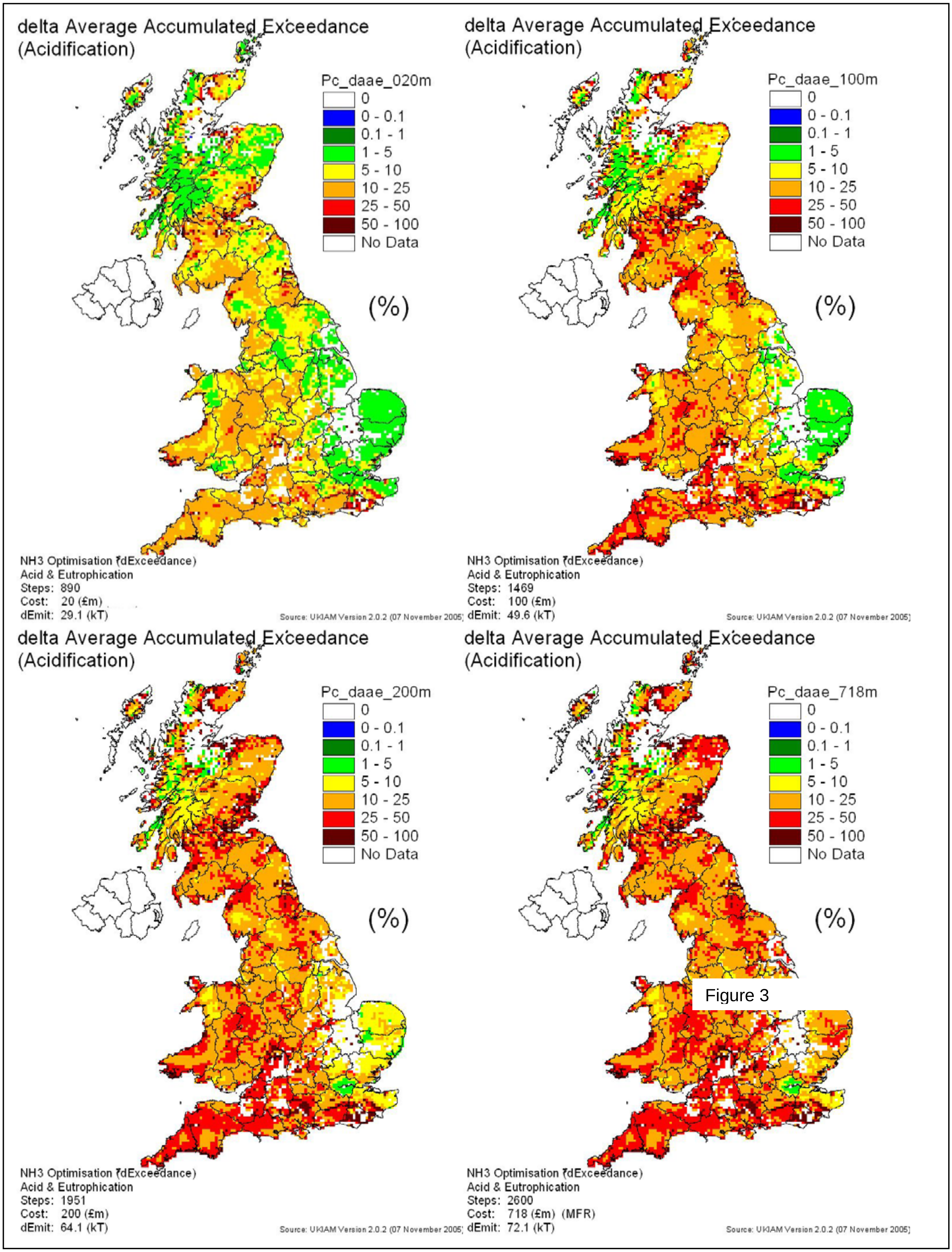
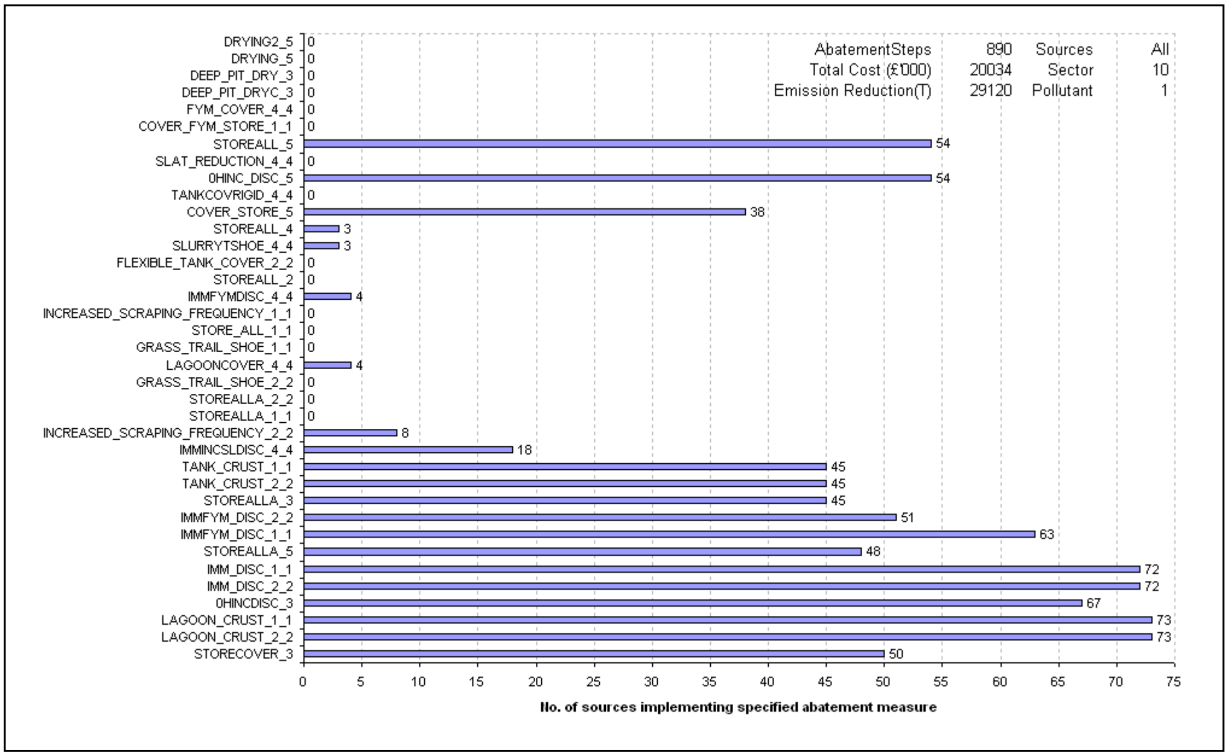

delta Average Accumulated Exceedance (Acidification)
Pc_daae_020m
0
0 - 0.1
0.1 - 1
1 - 5
5 - 10
10 - 25
25 - 50
50 - 100
No Data
(%)
NH3 Optimisation (dExceedance)
Acid & Eutrophication
Steps: 890
Cost: 20 (£m)
dEmit: 29.1 (kT)
Source: UKIAM Version 2.0.2 (07 November 2005)
delta Average Accumulated Exceedance (Acidification)
Pc_daae_100m
0
0 - 0.1
0.1 - 1
1 - 5
5 - 10
10 - 25
25 - 50
50 - 100
No Data
(%)
NH3 Optimisation (dExceedance)
Acid & Eutrophication
Steps: 1469
Cost: 100 (£m)
dEmit: 49.6 (kT)
Source: UKIAM Version 2.0.2 (07 November 2005)
delta Average Accumulated Exceedance (Acidification)
Pc_daae_200m
0
0 - 0.1
0.1 - 1
1 - 5
5 - 10
10 - 25
25 - 50
50 - 100
No Data
(%)
NH3 Optimisation (dExceedance)
Acid & Eutrophication
Steps: 1951
Cost: 200 (£m)
dEmit: 64.1 (kT)
Source: UKIAM Version 2.0.2 (07 November 2005)
delta Average Accumulated Exceedance (Acidification)
Pc_daae_718m
0
0 - 0.1
0.1 - 1
1 - 5
5 - 10
10 - 25
25 - 50
50 - 100
No Data
(%)
NH3 Optimisation (dExceedance)
Acid & Eutrophication
Steps: 2600
Cost: 718 (£m) (MFR)
dEmit: 72.1 (kT)
Source: UKIAM Version 2.0.2 (07 November 2005)

Figure 3

The potential abatement measures depend on the livestock sector, and range from measures for animal housing or drying of poultry manures, to covering and control of emissions from storage of slurries and manure, and measures to reduce emissions when these wastes are subsequently spread on the land. Figure 4 illustrates a breakdown of how many counties have implemented different measures within the first £20 million of expenditure, corresponding to the first map in the figure above.

Figure 4: Extent of selection of abatement measures within first £20 million/year expenditure



Other work with UKIAM has addressed the spatial patterns associated with different sub-sectors, in particular pigs and poultry which are governed by specific legislation under IPPC. In relation to future emissions ceilings for NH_3 further ahead in 2020 under revision of the NECD, it is also important to reflect the changes in agricultural activities following CAP reform. Such projections are somewhat uncertain (for example comparing the EC projections using the CAPRI model, and UK projections), but all imply a significant reduction in cattle numbers, both beef and dairy. UKIAM has been used to show that such changes could make a considerable difference, bringing improvements comparable with that of the £20 million per/year investment in abatement measures in the optimisation runs discussed above. In future work we shall superimpose abatement measures on projected emissions instead of current emissions, and take account of parallel reductions of SO2 and NOx.

In this work with UKIAM we are very aware that ammonia concentrations and deposition, even with the 5x5 km grid resolution in UKIAM, are very variable even within a single grid square; and that **local measures** either to place buffer strips round sensitive ecosystem areas (in particular for small but valuable ecosystem areas) or local measures close to intensive sources may be appropriate. We have provided illustrative calculations on this topic to the UNECE Task Force on Integrated Assessment meetings (TFIAM) and collaborated with CEH (ApSimon,Loh, Oxley and Grossinho,2003;Dragositis, Theobald, Plate ApSimon and Sutton,2006). This is an area requiring further attention, together with an integrated approach to the whole N cycle- see “Possible future work” below.

Illustration 2: NO_2 and PM_{10} in relation to urban air quality and the transport sector (*tasks 5,6 and 7*)

NO_2 and PM_{10} are the two main pollutants causing difficulties for attainment of UK and EC objectives for urban air quality, and have been a major focus in review of the UK Air Quality Strategy. Accordingly UKIAM has been extended to model them in order to take account of requirements to improve air quality and protection of human health as well as protection of ecosystems. Hence this second illustration, this time using UKIAM in scenario mode, is provided from work undertaken in parallel with NETCEN and CERC, to analyze UK scenarios with respect to improvements in urban air quality. A report has been produced for DEFRA comparing results of the different models for "Scenario Q"- the scenario on which results reported below are based (ApSimon.H ,Oxley T and Valiantis M., 2006)

During development of this work various differences between the models became evident and were investigated with sensitivity studies. These included questions of source apportionment, such as the contribution from imported NOx and primary PM; and the treatment of future changes in imported secondary particulate SO_4, NO_3 and NH_4. The illustration below is based on a scenario mainly oriented towards the transport sector with incentives for early uptake of Euro V and VI standards (Scenario Q). UKIAM was applied to simulate the concentrations of NO2 and PM10 across the UK at 5 yearly intervals up to 2020.

Figure 5 shows maps of the projected baseline concentrations in 2020 for both NO_2 and PM_{10}. In calculating NO_2, UKIAM first calculates NOx concentrations and then uses a simple relationship between NO_2 and NOx (depending on background ozone and total oxidant) to convert to NO_2. For PM_{10}, UKIAM calculates the primary PM_{10} in accordance with the UK emission inventory, plus an imported contribution based on ASAM and EMEP data; and adds a separate contribution calculated for secondary SO_4, NO_3 and NH_4 (again based on ASAM and EMEP data in this illustration); there is also a residual contribution from natural emissions and other sources not accounted for in the inventories, which remains constant over time, and ranges between 5 $\mu g.m^{-3}$ in rural areas to 9 in urban areas.

Figure 5: Projected concentrations of NO_2 and PM_{10} in 2020

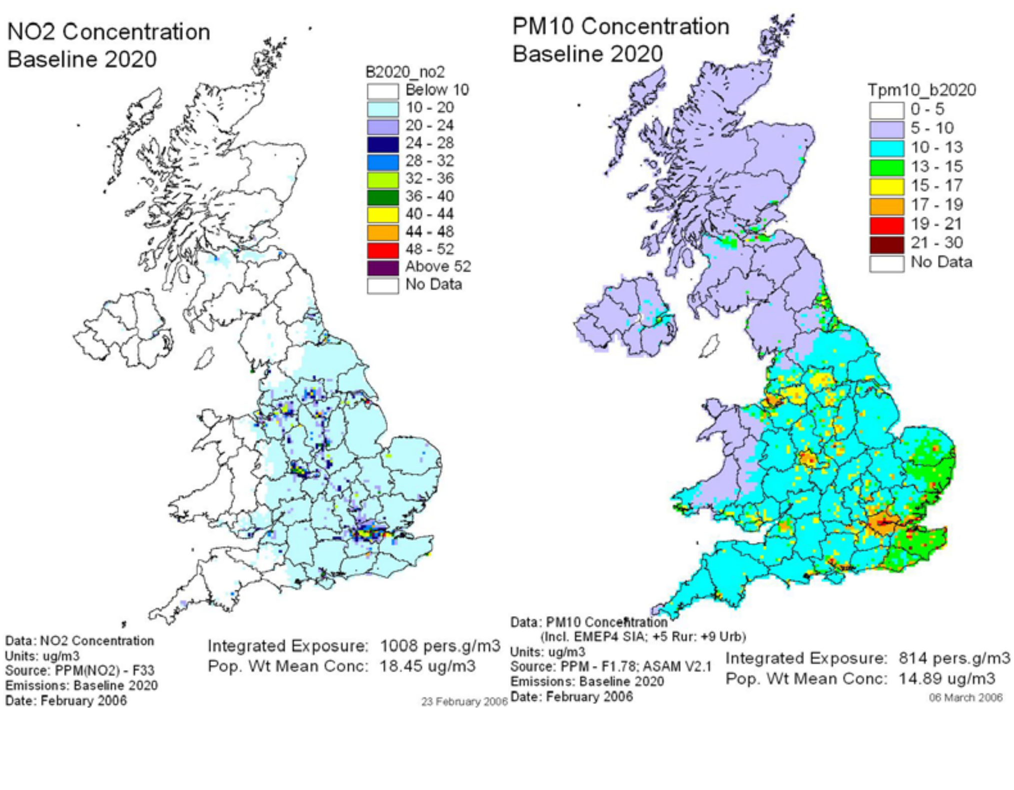


Table2 summarises comparison of population weighted mean concentrations of PM_{10} and NO_2 both for the baseline calculations and for scenario Q in the years 2010 and 2020; the first half of the table gives an average over the whole country, and the second half for London only. For PM_{10} a break down is also provided of the separate NH_4, NO_3 and SO_4 contributions to the secondary inorganic aerosol as calculated using ASAM; and the primary contribution based on the PPM model.

One of the major uncertainties in both the NO_2 and PM_{10} maps is the imported contribution and its derivation from sources outside the UK, including shipping. This is important because these sources may change over time quite differently from UK emissions- for example, whereas the introduction of Euro V and VI would be a European wide measure affecting other countries emissions in a similar way, shipping emissions are increasing steadily. Hence sensitivity studies have been undertaken to explore the assumptions about source attribution and the non-UK contributions. Other sensitivity studies include variation in the proportion of NOx emitted as primary NO_2, because of concerns about this increasing (AQEG 2007). Hence in addition to a base-line assumption of 5% of NOx emitted directly as NO_2, additional calculations were performed with up to 20% of NOx emitted directly as NO_2 (and also for variations in ozone in relation to the secondary NO_2 formation).

The effect of further measures in scenario Q on the secondary NH_4, SO_4 and NO_3 concentrations was found to be very small, and further work has been undertaken to investigate this. An important factor is the non-linear behaviour of the chemistry. Thus, for example, if NH3 emissions are reduced, a larger proportion of the remaining emissions reacts with the acidic products from oxidation of NOx and SO_2 to form NH_4 aerosol. Similar effects apply to other components, with different compounds becoming limiting in different circumstances. This can become extremely complex, as illustrated by modelling of individual episodes producing high concentrations of secondary aerosol by Andrea Fraser, a PhD student working with us using a UK version of Models 3 (an advanced Eulerian modelling system produced in America and used by the EPA in the US).

TABLE 2: Results from UK Integrated Assessment Model (July 2006)

DEFRA Air Quality Scenario Q (UEP21 Emissions projections)

Population Weighted Mean (PWM) Concentration (µg/m3)

UK	PPM	NH_4	NO_3	SO_4	PM_{10}(59)	*PM_{10}(9)*	NO_2	NO_2a	NO_2i	NO_2i+
B2010	2.629	1.135	2.986	1.314	15.639	*17.064*	19.809	17.907	18.867	19.652
Q2010	2.573	1.135	2.974	1.314	15.571	*16.996*	19.619	17.618	18.628	19.390
B2020	2.559	1.119	2.629	1.059	14.941	*16.366*	18.461	15.484	16.990	17.616
Q2020	2.334	1.119	2.575	1.055	14.658	*16.083*	17.520	14.058	15.811	16.345
Greater London										
B2010	4.077	1.325	3.473	1.493	19.259	*19.369*	33.772	32.075	32.933	35.557
Q2010	3.936	1.325	3.466	1.493	19.110	*19.220*	33.478	31.687	32.593	35.149
B2020	3.940	1.304	3.121	1.219	18.473	*18.584*	31.630	28.891	30.282	32.421
Q2020	3.317	1.304	3.088	1.215	17.813	*17.923*	30.049	26.797	28.451	30.287
		SIA results are calculated by ASAM using EMEP4 2010/2020 projections & dispersion with the UK emissions scaled to scenario			Background PM: Rural 5µg/m^3, Urban 9µg/m^3	*Background PM: 9µg/m^3*	Un-scaled Background NO_X	All background NO_X scaled to scenario emissions	Only 50% background NO_X scaled to scenario	50% background NO_X scaled, plus increased NO_2:NO_X

The maps produced by UKIAM were used to deduce areas and urban populations exceeding prescribed thresholds as well as population weighted mean concentrations. However UKIAM had not originally been intended for this purpose, and it was recognised that the 5x5 km grid resolution is rather too coarse for such calculations. Hence work has since been undertaken in order to use a finer 1x 1 km grid over London, and other selected cities. Also, for comparison with air quality limit values, it is necessary to consider peak concentrations at the road side.

Although an option to develop more detailed urban air quality modelling for this purpose was excluded in the original contract, we have developed a new traffic sub-model of UKIAM, the BRUTAL

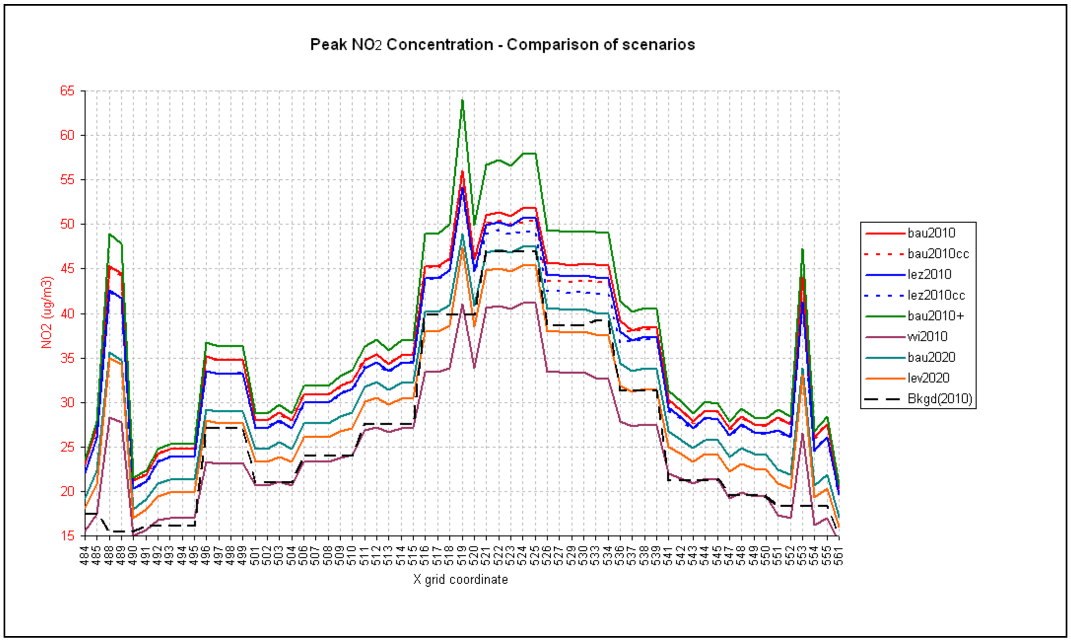


***Figure 16**: Comparison of peak NO_2 concentrations for a London transect for each of the scenarios described above. Note the significance and contrasting influences of an increased NO_2:NO_X ratio (bau2010+) and of the early uptake of Euro V and Euro VI (vvi2010).*

model, to address these problems. This has been assisted by Marios Valiantis, a PhD student linked to our work with UKIAM, and will also enable us to simulate additional local measures in cities, such as LEZs, as well as technological measures applied at the national scale. BRUTAL superimposes roadside increments, using traffic data for the whole UK road network[5], on the gridded background concentrations. Figure 6 illustrates a graph drawn through peak road-side concentrations of NO2 at the busiest roads in a series of grid-squares forming a cross-section of London from west to east. The different graphs compare baseline projections to 2010 and 2020 with an LEZ scenario, and two sensitivity studies with higher primary NO_2 (15% instead of 5%), and higher average background ozone of 40 ppb instead of 35ppb. Also included are some hypothetical scenarios based on early uptake of Euro V and Euro VI and low emission vehicles (e.g. hybrid vehicles).

The BRUTAL sub-model still requires some checking of the new source-receptor relationships from atmospheric dispersion modelling, and comparison of model results with measurements for road-side sites to complete refinement to a 1x1 km grid. This model can then be used in UKIAM for future analysis of transport scenarios. Work is in progress to apply it to $PM_{2.5}$ as well as PM_{10}.

<u>Energy scenarios</u>

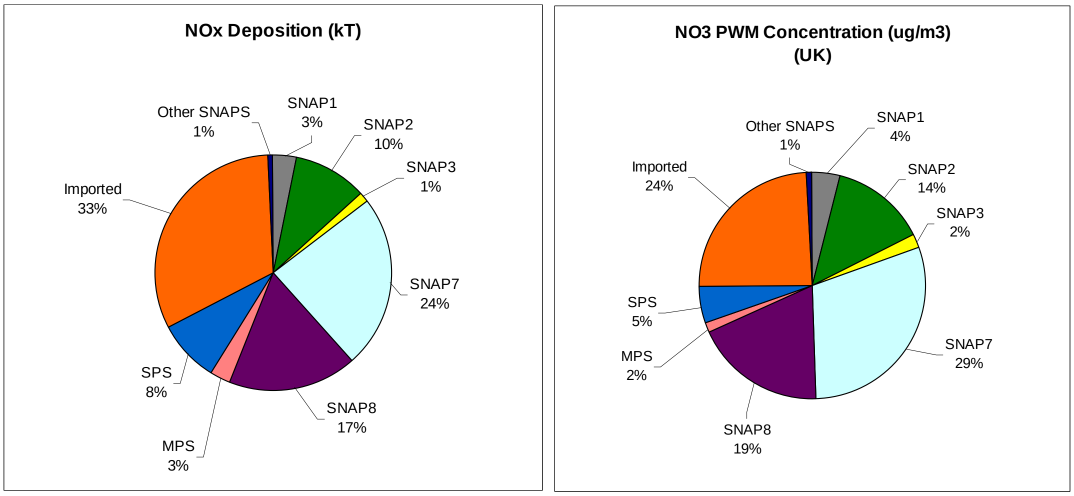
Recognising that there are potential synergies between control of greenhouse gases and air quality[6], exploratory studies have been undertaken to see how alternative energy scenarios can be analysed in this context using UKIAM (see additional work under Part 3 below). Energy generation by combustion produces emissions of SO_2, NOx and PM as well as greenhouse gases; and hence changes in energy generation can directly reduce these air quality pollutants and may avoid costs of add-on technology. A meeting was organised with DTI, DEFRA (AEQ and Global Atmospheres), NETCEN and ENTEC to discuss this topic. A preliminary scenario was provided by DTI, and processed to provide emissions in the NAEI format. This initial scenario (a “favourable to coal” scenario) implied only a small change in NOx of around 19 kT, but has proved useful as an exercise to recognise some of the issues, and how such work may be taken forward. Meanwhile “footprints” have been produced for the contributions of different sectors as represented in the NAEI (e.g. power industry, domestic, industry, transport etc),mapping the contribution of each to sulphur and nitrogen deposition, and to urban air quality. This provides for a rapid approximate assessment of the environmental implications of future UK energy scenarios; and it is planned to apply them to new energy scenarios emerging from both EC and UK

[5] Based on data from NETCEN, the London Atmospheric Emission Inventory LAEI, and statistics from Dept. of Transport.
[6] AQEG (2007) Air Quality and climate change: a UK perspective

scenarios towards attainment of recent targets set including a minimum 20% reduction in CO_2 emissions by 2020.

As an illustration of the relative contributions of different source sectors taken from these footprints, figure 7 gives the estimated contributions in 2010 to nitrogen deposition within the UK, and to population weighted mean nitrate concentrations, from the major point sources (MPS) modelled explicitly in UKIAM, other smaller point sources detailed in the inventory (SPS), and other emissions according to SNAP sector.

Figure 7. Contributions of NOx emissions from point sources and different SNAP sectors to nitrogen deposition and population weighted mean exposure in the UK (projection for 2010).
MPS=major point sources; SPS= smaller point sources in inventory



Discussion of the results and their reliability *(Task 5)*

In this part of the project we have successfully developed UKIAM for integrated assessment modelling with respect to abatement of air quality pollutants in the UK, and applied it both to straight scenario analysis, and in optimization mode to derive cost-effective measures for reducing emissions while maximizing environmental improvements. This has been illustrated with respect to ammonia emissions from agriculture, and scenario analysis for urban air quality and control of emissions from road transport.

As indicated above, effort has been devoted to model inter-comparisons, uncertainty studies, and scrutiny of data used. In general the reliability of results varies with individual applications: for example uncertainties about emissions of ammonia and the effectiveness of measures to reduce them, will be much greater than corresponding uncertainties about urban emissions of NOx from transport. However there are other limitations more related to model structure and the conceptual approach that affect the reliability of the results.

Even though some progress has been made towards including non-technical measures for reducing traffic emissions with the BRUTAL sub-model, the abatement options reflected in cost-curves are largely restricted to add-on measures to abate the relevant pollutants. A critical review has been produced on the use of cost curves in integrated assessment, and an alternative approach designed to overcome problems where abatement measures affect a combination of pollutants. The need to consider synergies between control of air quality pollutants and greenhouse gases has provided the impetus to take this forward, and is discussed further in the section on future possible work below.

Despite the 5x5 km grid resolution there are still problems of scale, especially for pollutants like NH_3 which can lead to very localized deposition close to sources; and for NO_2 and PM_{10} in urban situations, especially close to roads (where modelling of “street canyons” is a very simplified approximation) and with large uncertainties about the coarse component. There are also uncertainties about source apportionment- that is the relative importance of different source categories to concentrations and deposition. For example the differences in the model inter-comparison of urban air quality, explained in sensitivity studies by different assumptions about imported contributions to NOx and PM concentrations, have been indicated above. A particular problem is the contribution from shipping, which is of increasing importance, especially for the UK; and which requires better spatial resolution of emissions than is currently available.

Part II. European scale assessment

EMEP model intercomparison *(task 2)*

At the European scale modelling to simulate the long-range atmospheric transport of transboundary pollutants is undertaken by EMEP at the MSC Centre West in Oslo. From their modelling EMEP derive source-receptor relationships indicating the response of concentrations and deposition to emission reductions in each country: these data are used in both the RAINS model and our own ASAM model. At the start of the contract EMEP had replaced their Lagrangian model used in development of the Gothenburg Protocol, with a more complex Eulerian model. This has several advantages, particularly more complete source apportionment; but comparison studies revealed some significant differences, including the estimated contributions due to UK emissions.

In order to assess the EMEP model in more detail, especially with reference to the UK, and also to investigate consistency with our modelling in UKIAM based on the FRAME model, an inter-comparison study of the EMEP and FRAME models was undertaken in conjunction with CEH. In UKIAM we use data from a calibrated version of FRAME that has been adjusted to match measurements, and so were able to compare both calibrated and original versions. NETCEN also contributed to this assessment of the EMEP model with respect to ozone modelling, and comparison with the OSPM model. These model intercomparisons emphasized the role of orographic enhancement, increasing wet deposition over higher land where sensitive ecosystems often occur. The EMEP model does not include such enhancement, and also averages out emissions over the coarser grid; hence it tends to give a rather different spatial pattern of deposition of sulphur and nitrogen over the UK. Moreover the more detailed maps of deposition with a 5x5 km resolution imply greater exceedance of critical loads and more ecosystem areas unprotected than is predicted by the EMEP model, in which deposition is averaged over 50x50 km grid squares smoothing out any higher peaks. For the components of secondary inorganic aerosol comparisons were also made directly with measurements of SO_4, NH_4 and NO_3. These comparisons underlined the importance of chemistry, and the partitioning between HNO_3 and NH_4NO_3. Differences in source apportionment were also investigated- that is the relative contributions of different sources to concentrations and deposition. This underlined the need for more attention to the contribution of shipping, and the role of background concentrations outside the EMEP area as well as fluxes from other European countries.

This inter-comparison study has been written up in a report[7], and was extremely useful in understanding the strengths and weaknesses of the different models. There has since been ongoing work to resolve some of the questions raised, and UKIAM has since been updated with new data from the FRAME model of CEH, and also the ASAM model-see below.

The ASAM model (*Task 1)*

The ASAM model uses source-receptor calculations from the EMEP model to represent the response of concentrations and deposition across Europe to emission reductions in different countries. This is the same data used by the RAINS model of IIASA. Since the model inter-comparison there have been further improvements in the EMEP model, and we have continued to keep ASAM up-to-date with the most recent data. This still provides us with a tool for scenario analysis at the European scale, although not retaining a full integrated assessment capability for Europe in parallel with RAINS. We

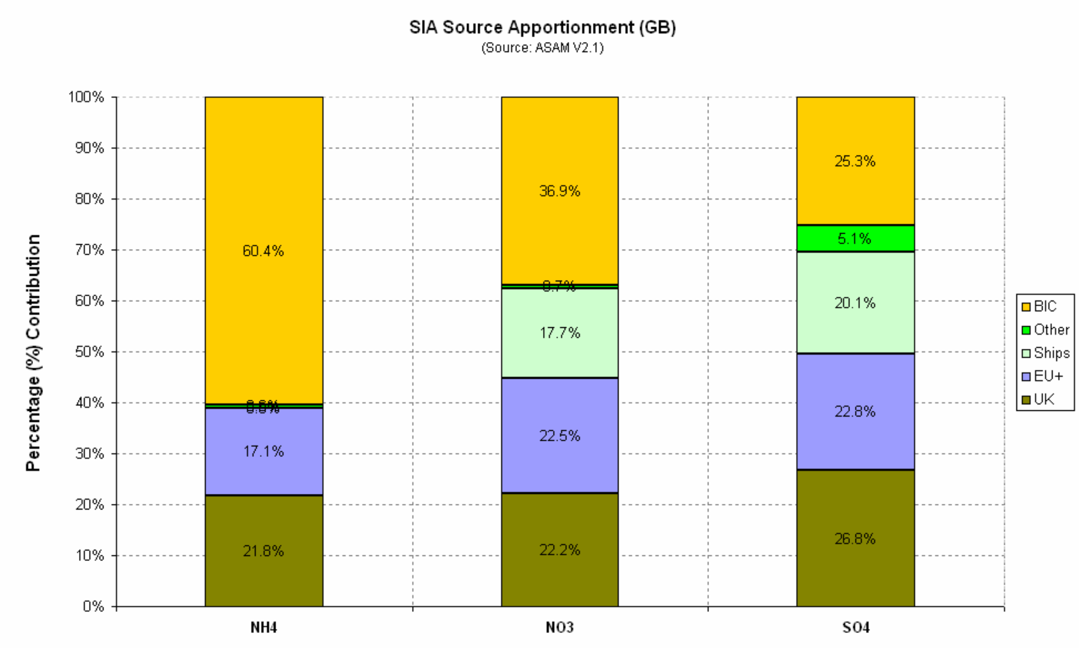
[7] ApSimon H Oxley T(in association with EMEP, CEH Edinburgh, and NETCEN, 2004) Comparison of the EMEP Unified model and DEFRA models for the UK region. Report to DEFRA

also use ASAM to represent future imported contributions to deposition and concentrations of SO_4, NO_3 and NH_4 in the UK- see section above on UKIAM and UK scale assessment.

Using the latest data from EMEP in 2006 we have recently contributed to work for DEFRA to examine trends in SO_4, NO_3 and NH_4 as compared with measurements, using ASAM to estimate changes in concentration resulting from changing emissions. This work is ongoing, and has raised several questions concerning both measurements and modelling whose resolution will help to give more confidence in future predictions.

Figure 8 is taken from this work to illustrate application of ASAM, and indicates the modelled response of population weighted mean concentrations of SO_4, NO_3 and NH_4 across the UK to changes in emissions of SO_2, NOx and NH_3 relative to projected emissions in the year 2010 (year for attainment of the Gothenburg protocol and NECD ceilings). In this figure the effect of emission reductions in the UK, in other EU countries, from shipping, and from the remaining sources is distinguished. Thus, for example, if UK emissions of SO2 were reduced by a fraction X (say one tenth), then the corresponding reduction in SO4 exposure of the UK population is estimated to be only 27% of this fraction (or 2.7% overall).By comparison a corresponding fractional change in emissions of SO_2 from all other countries in the EU-25 yields a 23% change in SO_4 exposure, and so on for other components. The fact that the additive effect of a hypothetical uniform reduction of emissions everywhere does not add up to an equivalent reduction in, for example SO_4 exposure, is mainly due to non-linearity in the chemistry of these pollutants (equivalent to the top yellow portion of each column). The importance of shipping emissions for the UK is again clearly apparent.

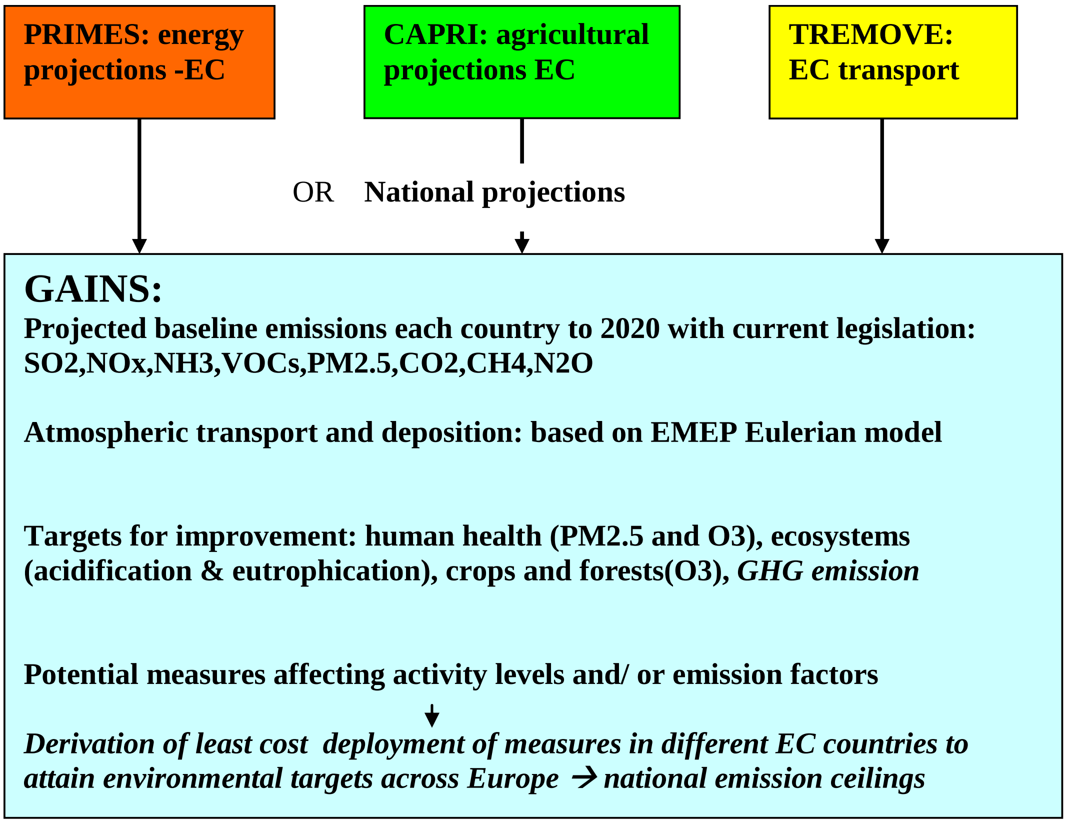
Figure 8. Relative response of population weighted mean exposure to NH4, SO4, and NO3



Review of work by IIASA and input to UNECE

Throughout the contract we have monitored modelling developments by IIASA, including reports produced under the CAFÉ programme towards the EC's Thematic Strategy on Air Quality, and subsequent developments of the GAINS model which is now replacing RAINS. The GAINS model explores synergies between control of greenhouse gas emissions as well as transboundary pollutants- see figure 9 below. It has been linked to models for European energy generation (the PRIMES model), European agriculture following CAP reform (CAPRI model) and the European transport model TREMOVE. There are also other major changes in the transition to GAINS, which are to be the subject of a review for which Prof ApSimon will serve on the panel. These changes will also be relevant to the review of the Gothenburg Protocol and the revision of the National Emissions Ceilings Directive, NECD.

Figure 9: The GAINS model of IIASA and related European models for energy, transport and agricultural scenarios



During the contract we have reported on these developments to DEFRA in various briefing notes, and on the scenarios generated for CAFÉ and their implications for the UK. We have also participated in various meetings at IIASA and under the UN ECE Convention on Long-Range Transboundary Air Pollution; in particular the Task Force for Integrated Assessment Modelling (TFIAM) has acted as a regular forum for discussion of these developments. A list of presentations to TFIAM is appended with other reports and papers. These have included our development of UKIAM as a national scale model, and demonstration of the significant differences that result from this more detailed spatial resolution as compared with the RAINS/GAINS models. For example in RAINS/GAINS ammonia emissions are scaled uniformly across the UK to represent the implementation of abatement measures, whereas UKIAM indicates a large geographical variation due to variations in farming. Similarly RAINS/GAINS have substantial difficulties in representing enhanced pollutant concentrations in urban areas, and do not even consider urban NO2; whereas UKIAM treats urban air quality specifically for both NO2 and PM. These problems in RAINS/GAINS have not been resolved by the City-Delta project, and are under discussion with IIASA.

We have also indicated other criticisms of the CAFÉ approach, many of them also relevant to review of the Gothenburg protocol as well as revision of the NECD. To give a few examples, in relation to target setting we have pointed out the distortion introduced by the radically different approach adopted in CAFÉ (based on closing the gap between the projected current legislation (CLE) scenario and the maximum technically feasible reduction (MTFR), instead of directly trying to reduce exceedance of critical loads as in the work of the UN ECE). Whereas the critical load data have been mapped using a well defined procedure, the MTFR is subject to distortion and uncertainty. One reason for this is because in modelling the MTFR in RAINS/GAINS, the implied reductions in national emissions are represented as though the emissions in each country are scaled uniformly in proportion across each country. The more detailed modelling with UKIAM is helpful in illustrating such distortion. For example mapping the change in deposition across the UK corresponding to the maximum feasible reduction in NH_3 emissions in UKIAM shows a highly variable percentage reduction, with little or no reduction in areas dominated by sheep farming as compared with reductions of over 25% in other areas with more intensive livestock farming. This alters the implied benefit in reducing exceedance of critical loads significantly.

As another example we have indicated exaggeration of the transboundary transport of primary PM by RAINS/GAINS, due to the coarse spatial resolution of the EMEP model in treating grid squares spanning country boundaries. RAINS/GAINS did not differentiate between low level emissions in urban areas, and those in rural areas or from tall stacks, in relation to health impacts from primary PM; although more recently IIASA have attempted to make better allowance for enhanced concentrations in urban areas. We have identified many other limitations and uncertainties in integrated assessment modelling, and pointed to the need to consider the wider context of abatement strategies- such as taking a broader perspective on the overall nitrogen cycle when addressing control of ammonia emissions from agriculture. .

A particular aspect of the work has concentrated on particulate matter, and work undertaken by IIASA to incorporate both primary and secondary $PM_{2.5}$ in their integrated assessment modelling, leading to calculation of possible national emission ceilings for primary $PM_{2.5}$ as an additional pollutant. In the UK context we have been concerned with the UK Air Quality Strategy and compliance with limit values on concentrations of PM_{10}. Drawing on this experience independent research notes were prepared for DEFRA. Thus when consideration was being given to different ways of setting limit values for $PM_{2.5}$ to complement those for PM_{10} (and how to induce more emphasis on reducing population exposure rather than acting to eliminate hot-spots of maximum concentration as with current limit values for PM_{10}) a paper was prepared by the PI on the relative merits of "Emission control versus limit values"[8]. Similarly, in view of the potential extension of the NECD to primary PM2.5, a research note was provided on "Geographical scales of control- feasibility of an emission ceiling for PM"[9].

Various other communications have been made to DEFRA as briefing notes and comments on specific reports and papers from IIASA and EMEP, or issues arising from CAFÉ or UNECE fora and other international meetings. These include IIASA reports prepared for recent NECPI meetings, developing scenarios towards revision of the National Emissions Ceilings Directive.

Discussion of the results and their reliability

The work of IIASA has progressed rapidly over the last 3 years, especially with respect to the development of GAINS to explore synergies between control of greenhouse gases and transboundary air pollutants. Whereas RAINS was limited to add-on abatement measures, GAINS now reflects the effect of changes in energy programmes, agricultural activities and transport. However there is widespread concern among European countries about the use of the PRIMES, CAPRI and TREMOVE models, all of which are complex models with many assumptions, and lack transparency. The current review of the GAINS model for NECPI (in which the PI on this contract is participating) will help to understand the many differences between GAINS and RAINS and their implications.

Many other limitations affecting the reliability of RAINS/GAINS and their application in CAFÉ and for the UN ECE have been indicated above; and UKIAM has proved a useful tool for demonstrating these and assessing their importance with respect to the UK. At the western edge of Europe the UK is affected rather differently from other countries by changes in European emissions, and other emissions from shipping and outside Europe are relatively more important.

Thus a further consideration is that as Europe invests more effort in reducing its pollutant emissions, the contributions of global scale transport from other parts of the world become more important- especially with growth in Asia. There is a need to bring together the European and global

[8] ApSimon H M.(2005) Emission control versus limit values. Research note for DEFRA

[9] ApSimon HM (2005) Geographical scales of control- feasibility of an emissions ceiling for PM. Research note for DEFRA.

scales. Also, as the EU has expanded to include more countries, there is less involvement and more uncertainty about future emissions from the remaining countries in the UN ECE area not covered by the work of CAFÉ; although in general these have a fairly modest effect on the UK..

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Part III. Additional work drawing on the above

Preparatory work towards combined treatment of air quality pollutants and green-house gases with UKIAM *(extension of task 4)*

During the course of this contract it has become increasingly evident that there are important synergies between control of air quality pollutants and greenhouse gases, since they frequently originate from the same sources: there are both economic and environmental arguments for considering both together. The potential for further application of add-on or "end of pipe" measures to control specific air pollutants is limited, and some of these measures may have side effects for other pollutants, or for energy consumption and green house gases. Looking to the future further changes in emissions of air quality pollutants will depend very much on future energy generation, transport, and agricultural activities; and will include measures such as energy conservation and fuel switching which may avoid additional expenditure on emission control technologies. As discussed elsewhere IIASA is already addressing this at the European scale, with transition to the GAINS model. Towards the end of this contract we have been planning similar adaption of UKIAM to a broader multi-pollutant approach including both air quality pollutants and green-house gases.

This involves representing simultaneous effects of measures, both technical and non-technical, on a combination of pollutants; and moving away from the cost-curve approach whereby add-on measures have been associated with the individual pollutants principally affected, and ordered according to increasing cost per unit emission abated (generating cost-curves for abatement of each individual pollutant). This new measure oriented approach requires major restructuring of UKIAM, although many of the sub-modules and routines will still be applicable. The new design involves a matrix of measures applicable to specific sources, with the effects of each measure on a list of pollutants (SO_2, NOx, NH_3, PM_{10} & $PM_{2.5}$ as air quality pollutants, and CO_2, CH_4 and N_2O as greenhouse gases), together with the associated cost where available. Scenarios can be explored using selected combinations of these measures. Environmental benefits can still be estimated in the same way as before based on the improvements towards attainment of different environmental targets for human health and ecosystem protection, but with added benefits in terms of equivalent CO_2 for reductions in greenhouse gas emissions. It should also be possible to develop an optimisation routine, as in the current UKIAM, which selects measures according to their cost-effectiveness in converging to attain environmental objectives. However at present we have concentrated mainly on scenario analysis.

In order to apply this new version of UKIAM successfully it will be necessary to incorporate the necessary data on the available measures. In this context we have started to extend the BRUTAL transport module to include CO_2 and N_2O emissions from vehicles as well as NOx and PM_{10}. This is based on emission factors supplied by AEA Technology on an equivalent basis for different vehicle types: these are speed dependent at present for CO_2, but not for N_2O as there is insufficient data and greater uncertainty. This work is already well advanced, and will allow investigation of scenarios involving both technical measures, and non-technical measures affecting volumes of traffic or the vehicle mix.

Interaction with other activities

Our work in this contract has also contributed to other activities. This includes the work of the Air Quality Expert Group (of which Prof ApSimon is a member), particularly their reports on "Particulate Matter in the United Kingdom", "Air Quality and Climate Change- a UK Perspective", and the current report on ozone concentrations (currently we are liasing with IIASA to address questions concerning ozone raised in this AQEG study). We have also interacted with other DEFRA contractors such as NETCEN, CEH and ENTEC, providing data generated using ASAM on projected transboundary contributions to pollution in the UK, or results from UKIAM for future scenarios. In support of the UK Air Quality Strategy we have collaborated in model inter-comparisons between modelling of specified scenarios by NETCEN and by CERC, drawing out several significant uncertainties and assumptions- especially concerning imported contributions from other countries and from shipping. We have contributed to initial developments towards an ammonia strategy in the UK, working with experts on ammonia emissions and abatement including members of the NARSES project.

In relation to urban air quality the contract has also contributed to the work of the APRIL (Air Pollution Research in London) network, which the PI for this contract, Prof ApSimon, chairs); and vice versa. The aim of this research network is to bring together the research community and those responsible for governing air quality at national to local level to identify research priorities and develop research programmes accordingly- such as the DAPPLE project to study dispersion and pollutant concentrations round a busy road intersection in London. The network has several sub-groups undertaking work relevant to this contract including the natural environment group with interests in protection of ecosystems and biodiversity, the modelling group (which has worked with the NERC Centres for Atmospheric Science to review advanced modelling and foster collaboration in implementing and applying Models 3 from the USA and development of a UK equivalent linked to the Met Office's Unified Model for weather prediction modelling). Other groups are concerned with measurements, transport and emissions, and health impacts- particularly of PM. In response to DEFRA's support, APRIL has arranged meetings of experts to discuss specific questions, and kept DEFRA informed of research initiatives and progress. Over the past year Prof ApSimon has participated in a PECE project, separately funded by DEFRA through APRIL, for collaboration between London and Moscow in addressing urban air pollution.

Work in the contract has also contributed to and benefited from post-graduate research students. It has generated a number of M Sc projects which have helped in model validation and development- for example a current project on CO_2 emissions from road transport. Work by two PhD students has been particularly helpful for the BRUTAL traffic model in UKIAM- first by Marios Valiantis on transport scenarios and emissions from the UK road network (Valiantis, Oxley and ApSimon, 2007); and secondly by James Milner on pollutant dispersion in streets and around buildings, and its relationship to indoor pollution. These students have jointly compared street canyon models, and made comparison with measurements to produce a paper on the application and limitations of such modelling for roadside concentrations in a regulatory context (Vardoulakis,Valiantis, Milner and ApSimon, 2007). A third PhD student, Nighat Hasnain, is working on how wider stake holder views might be linked to integrated assessment modelling, and use of multi-criteria decision analysis (MCDA). Currently this is set in the context of ammonia emission from agriculture, exploring the limitations of cost curves in ignoring important factors such as ease of implementation and enforcement, the broader policy context, and fairness and equity issues for different sections of the farming community, side effects on other pollution problems, and environmentalist priorities for ecosystem protection.

3.Main implications of the findings

Integrated assessment modelling is increasingly being used by the European Commission as well as under the UN ECE, with the GAINS model now superseding the RAINS model. We have monitored development of this work by IIASA closely, and communicated out findings both to DEFRA and international fora such as TFIAM; and directly with IIASA. Of particular importance is the recognition that there are now limited options for further add-on technical measures to reduce pollutant emissions, but that there are potential synergies between control of greenhouse gases and air quality pollutants. It is this that has led to the development of the GAINS model, linked to models for future energy programmes in EC countries (PRIMES), future transport (TREMOVE) and future agricultural development following CAP reforms (CAPRI).

Our own integrated assessment modelling with UKIAM linked to ASAM complements the coarser scale modelling over Europe by IIASA, allowing us to investigate assumptions made in RAINS/GAINS and test the robustness of scenarios derived by IIASA at the UK scale. As a tool to support UK policy, UKIAM is now well developed to address future scenarios for a combination of different pollutants generated by different sectors from energy generation and transport, to agriculture. Initial work has already been undertaken to extend UKIAM to include consideration of greenhouse gas emissions as well as air quality pollutants, in order to explore synergies between the two; this parallels the transition by IIASA from the RAINS model to GAINS.

Applications of UKIAM have been illustrated above with respect to ammonia in preparatory studies for an anticipated tighter emissions ceiling under revision of the NECD, emphasizing the need to consider geographical variations in farming activities and emissions in relation to the areas with ecosystems at risk from eutrophication and/or acidification. Future projections for agricultural change have also been shown to reduce ammonia emissions and improve protection of ecosystems significantly, and need to be compared with those used by IIASA based on the CAPRI model. By comparison the current implementation of IPPC regulation for major pig and poultry farms is expected to bring relatively little improvement.

Modelling of urban air quality scenarios has indicated broad agreement with other modelling approaches used by DEFRA contractors, but has raised a number of assumptions and uncertainties requiring further investigation. Many of these are related to source apportionment, and the contribution of shipping and other emissions outside the UK; or to assumptions about future emissions, and sensitivity to, for example, the fraction of NOx emitted directly as primary NO_2.

4.Possible future work

A meeting in Saltsjobaden (12-14 March 2007) has provided a very constructive review of the way forward for UN ECE under the Convention on Long-Range Transboundary Air Pollution alongside the CAFÉ programme in **addressing synergies between air quality and climate change.** As indicated by AQEG[10] it is very important to take an integrated approach to these problems, and it is clear that this will be a major focus for IIASA in developing and applying the GAINS model. Since this is likely to affect future international legislation by the EC and revision of the Gothenburg protocol, it will be important to both follow this work closely, and to accompany this by parallel studies in more detail at the UK scale using UKIAM. The preliminary consideration of an alternative energy scenario indicated above was a first step towards this, but it will require broader collaboration to take this work forward. Some further work and restructuring will also be required to UKIAM to consider a range of measures, each of which may affect a combination of pollutants including both air quality pollutants and greenhouse gases. This will require a data-base on both technical and non-technical measures, covering the effect of each on the full range of pollutants and a single overall cost; instead of the current approach based on independent cost-curves summarising potential measures applicable to individual pollutants. (Similar changes have been made in developing the GAINS model as compared with the original RAINS model.)

Another important conclusion of the Saltsjobaden workshop was the need to take an **integrated approach to the nitrogen cycle**. Thus some measures to reduce ammonia emissions (in order to ameliorate eutrophication and/or acidification of ecosystems) could exacerbate nitrate leaching in vulnerable areas (NVZs) and/or enhance emissions of nitrous oxide as a greenhouse gas. However measures that reduce the amount of nitrogen applied as fertiliser (for example by making better allowance for that applied in manures), or reducing nitrogen in animal diets, can be beneficial for all these environmental effects. This is a topic that has been raised previously in UN ECE by both CEH and ourselves, and on which W Asman is working at IIASA to extend integrated assessment capabilities of GAINS/RAINS. There is particular expertise on this topic in the UK and the potential to make a significant contribution in the European arena. Collaboration has been agreed between CEH and Imperial College in planning to take this forward, and develop an integrated assessment capability at the UK scale linked to UKIAM. Similarly collaboration is required in tackling **problems of scale with respect to reduced nitrogen** deposition, and an appropriate combination of very local to nation-wide

[10] A presentation was made in Saltsjobaden by Prof ApSimon on the AQEG study on "Air Quality and Climate Change: a UK perspective".

measures in protection of sensitive ecosystems, especially those of particular importance such as the NATURA 2000 sites..

In the discussion of limitations and uncertainties of the scenario analysis undertaken with UKIAM above the importance of **shipping emissions** was highlighted: again this was a topic addressed by a sub-group at the Saltsjobaden workshop. While land-based emissions of SO_2 and NOx are being greatly reduced in Europe, shipping emissions are growing steadily. Surrounded by seas with major shipping routes this is particularly a problem for the UK. However current emission inventories used by EMEP and IIASA have a very coarse spatial resolution which is insufficient to model the impacts on the UK. Again there is expertise in the UK to remedy this, requiring a coordinated effort to address refinement of the emissions and potential control measures and associated costs; and also undertake atmospheric modelling. Measures to control shipping can then be simulated in scenario analysis with UKIAM, and compared for cost-effectiveness with further measures to reduce UK emissions in order to reach proposed emissions ceilings.

A new hemispheric task force has been established under the UN ECE in recognition of the intercontinental transport of pollutants, and the influence of other parts of the northern hemisphere on European air quality. This will take time to produce results, and will be able to feed into global scale IAM initiated by JRC Ispra in collaboration with IIASA. In the meantime discussion with the UK Met Office has confirmed that relevant source-receptor data to investigate the role of emissions from outside Europe could be provided in conjunction with their global modelling. This is especially relevant for the UK on the western edge of Europe.

5.Any action arising from the research (e.g. IP, Knowledge Transfer)

In addressing the synergies between air quality and greenhouse gases there will be a need to interact more widely with the climate change community, and with divisions of government concerned with climate and energy policy. Similarly broader connections are indicated in relation to agriculture and the nitrogen cycle, and ecosystem protection.

References:

A list of references from the work on this project and directly related work is given in the next section, section 9. The following is a list of other references outside the contract, mentioned in the report.

AQEG (Air Quality Expert Group) 2007. Nitrogen dioxide emissions in the UK.

Fournier N Dore AJ Vieno M Weston KJ Draogisitis U Sutton MA (2004) Modelling the deposition of atmospheric oxidised nitrogen and sulphue to the UK, using a multi-layer long-range transport model. Atmos Env 38(5),683-694

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

Papers and reports from contract period

1)Oxley, T., ApSimon, H., (2007) Space, time and nesting integrated assessment models, Environmental Modelling and Software (in press).
2)Oxley T. Valiantis M and ApSimon HM (2007) Background, Road and Urban Transport modelling of Air quality Limit values (the BRUTAL mode)- in preparation
3)Vardoulakis S, Valiantis M, Milner J, ApSimon HM Operational street canyon modelling in the UK- applications and challenges. (2007) AtmosphericEnv (in press)
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5)Dragositis U Theobald MR Plate CJ ApSimon HM Sutton MA (2006) The potential for spatial planning at the landscape level to mitigate the effects of atmospheric ammonia deposition. Env Sci and Policy 9, p626-638
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9)ApSimon H M.(2005) Emission control versus limit values. Research note for DEFRA
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Presentations at Task Force and other UN ECE meetings during contract period:-

1)ApSimon H Oxley T and Valiantis M Modelling urban pollution within the UK scale integrated assessment model. Nov 2006
2)ApSimon H Oxley T and Valiantis M Attaining urban air quality objectives- links to transboundary air pollution. May 2006
3)ApSimon H and Oxley T A broader view of controlling NH3 and N deposition. Dec 2005
4)ApSimon H and Oxley T. Linking European, national and city scales. Oct 2005
5)Oxley T and ApSimon H. Spatial considerations. May 2005
6)ApSimon H and Oxley T Progress at the UK National Focal Centre for Integrated Assessment Modelling May 2004

7)Also a presentation was made in Saltsjobaden by Prof ApSimon on the AQEG study on “Air Quality and Climate Change: a UK perspective”