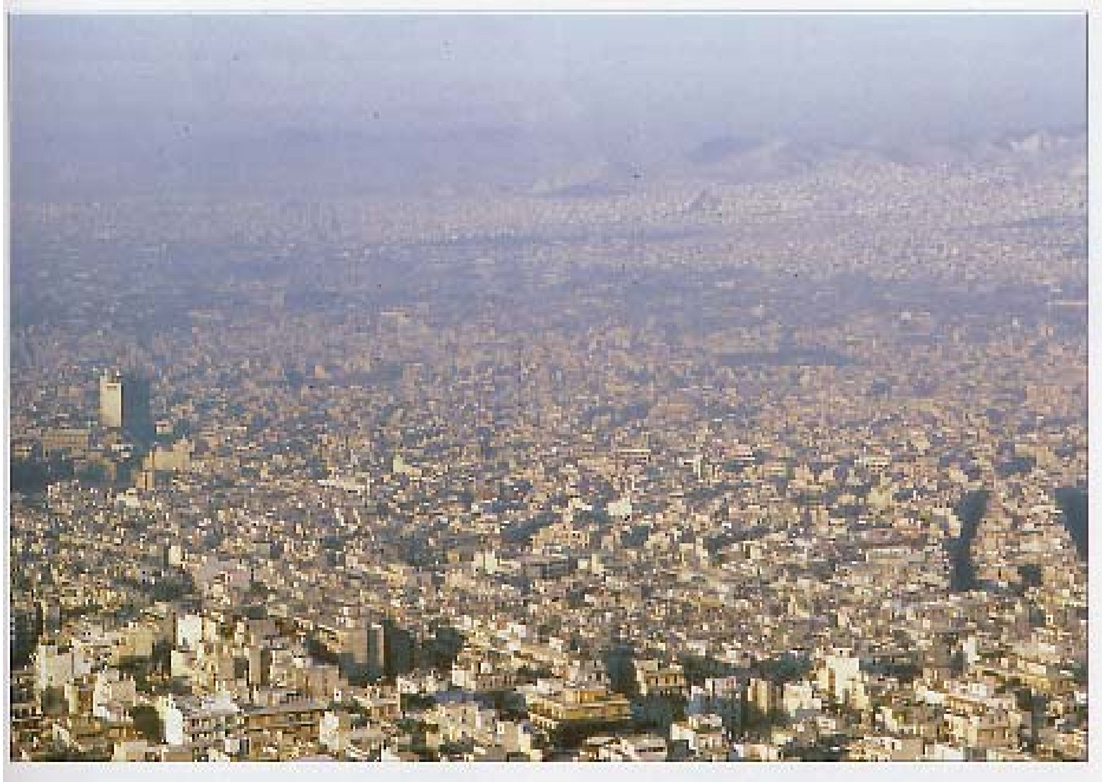
DEFRA Contract AQ0902



Scientific Support for DEFRA in development of National and International Policy in relation to air quality and trans-boundary air pollution
SSNIP

Final Report: Imperial College London

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DEFRA Contract AQ0902: Final Report
Scientific support for DEFRA in development of national and international policy in relation to air quality and transboundary air pollution, SSNIP.

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Introduction

The context of the SSNIP contract is the setting of new emission ceilings for the UK in 2020 under revision of the Gothenburg Protocol and the EC National Emission Ceilings Directive, NECD. It thus involves looking at scenarios for the future, starting with a business as usual approach and implementation of legislation already agreed to control emissions, and investigating alternative scenarios and the effectiveness of introducing further measures in relation to environmental improvement. Because future emissions of air quality pollutants are intimately related to projections of future energy requirements, development of transport and agricultural production, there is a close interaction with greenhouse gas emissions and policies on climate change.

The work by Imperial College lies within the first 2 work packages of the SSNIP contract, the first concerned with development and application of the UK integrated assessment model, UKIAM, for analysis of scenarios with respect to the UK. This is based on projected UK emissions and measures taken to control them combined with future emissions scenarios for the rest of Europe; the resulting pollutant concentrations and deposition over the UK; and the associated environmental impacts on human exposure and health, and on ecosystems. In the current contract a sub-model, BRUTAL, has been developed to enable more detailed modelling of road transport and future urban air quality in relation to air quality legislation at both road side and background locations. UKIAM has also been extended to consider greenhouse gas emissions, which largely originate from the same sources as air quality pollutants; and work has been undertaken on a more integrated approach to the nitrogen cycle. A large part of this report is devoted to applications of UKIAM to scenarios encompassing the energy, transport, and agricultural sectors.

In the second work package of SSNIP, Imperial College has interacted with developments at the European scale towards proposed new emission ceilings for international negotiation. This has included particular scrutiny of GAINS scenarios with respect to emissions and assumptions for the UK, and has involved direct interaction with IIASA and their work with the GAINS model as well as attendance of Task Force meetings and reporting back to Defra as appropriate.

Helen ApSimon also coordinates and co-chairs with Sweden the network of related national integrated assessment activities, NIAM, in parallel with our own in the UK. NIAM works closely with IIASA and reports to TFIAM. Helen ApSimon has also continued to chair the APRIL (Air Pollution Research in London) network, and explore how some activities might continue after the end of June when she steps down from this role. The work has also contributed to other activities such as Defra’s Air Quality Expert Group, AQEG.

Work Package 1: National and local scale modelling using the UK integrated assessment model UKIAM

Modelling future scenarios for the UK with respect to air quality and transboundary pollution involves bringing together a wide range of information drawing on input from other partners in the SSNIP consortium as illustrated in figure 1.1. Over the last 3 years an entirely new version of the UKIAM model has been developed which considers a wider range of pollutants (SO_2, NOx, NH_3, PM_{10}, $PM_{2.5}$, CO_2, N_2O and CH_4). This allows for the simultaneous effect of abatement measures on a combination of pollutants (as opposed to earlier versions based on single pollutant cost-curves), and comparison of future scenarios with respect to changes in greenhouse gas emissions as well as human exposure to air pollution, urban air quality, and effects on natural ecosystems.

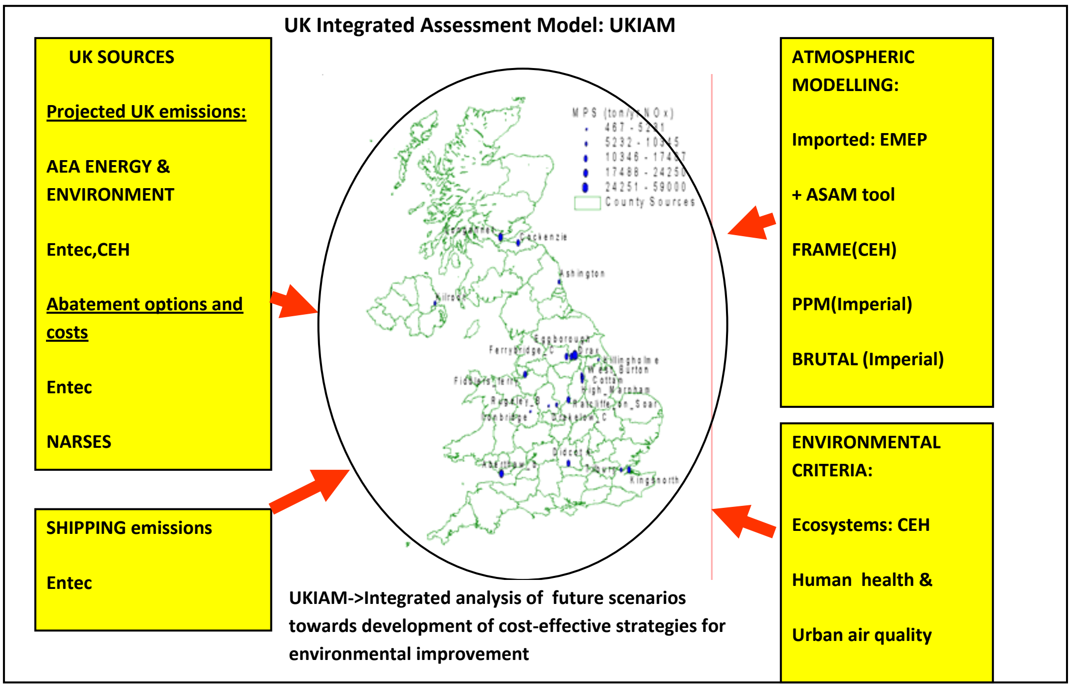

Figure 1.1: Components of UKIAM integrated assessment model indicating links with other Defra contractors and projects

In the following sections of this report we shall first describe the new model, including the BRUTAL sub-model for road transport and urban air quality; and then describe applications of the model in scenario analysis, starting with base case projections to 2020 and then exploration of alternative scenarios for the power sector, road transport and for agriculture with respect to abatement of ammonia emissions and the nitrogen cycle.

Task 1.1.1 The UKIAM model and its development

Under this contract the UKIAM model has been substantially redeveloped and extended for scenario analysis, with updating to reflect new data and modelling undertaken by other Defra contractors. The ASAM model allows the UK scale modelling to be embedded in the larger European scale context with import of pollutants from outside the UK, and this also has been updated and revised as new information has become available.

Sources and emissions

The UK sources and pollutants modelled in UKIAM are those listed in table 1.1, and concentrations and deposition are modelled across the UK. The table gives the emissions of each pollutant from each source for the base case described later (corresponding to UEP32 energy projections from DECC and BAUIII agricultural projections), and each source may be varied in subsequent scenario analysis. Some of these sources are distributed sources mapped across the UK, whereas others are major point sources such as power stations. For stationary sources baseline emission projections are based directly on NAEI projections and emission factors as supplied by AEA Technology. Emissions from road transport are calculated separately on a road by road basis across the UK by the BRUTAL sub model of UKIAM, but still match the NAEI emissions closely using the same speed dependent emission factors (recently updated in line with new work by TRL). For NOx this has recently been extended to also estimate primary NO_2 emissions as well as NOx, as this affects the relationship between subsequent NO_2 concentrations and NOx.

The UK is also affected by sources outside the UK and imported contributions to pollution. For the base case projected emissions from other countries outside the UK in 2020 have been taken from the EMEP web site. Shipping is also an important source, and emissions on a 5x5 km grid for the sea areas surrounding the UK have been compiled by ENTEC (task 1.1.8) and incorporated in UKIAM. These reflect the recent MARPOL agreement with a dramatic reduction in SO2 emissions. [1] Again emissions from other countries and from shipping can be varied relative to the base case to explore the interaction of measures taken to reduce emissions in the UK with emission reductions elsewhere in Europe.

To examine the synergies between reduction of air quality pollutants and greenhouse gases, the latter (CO_2, CH_4 and N_2O) are also assessed for sources subject to change (1.1.5). So far this covers mainly combustion sources such as power stations that have already been included in preliminary scenario analysis, and road transport emissions covered in the BRUTAL model alongside the air quality pollutants. GHG emissions from agricultural sources have also been assessed for a specific set of scenarios, and are ready to be included automatically in UKIAM for future work. This is illustrated in section 1.4 on applications of UKIAM to scenario analysis.

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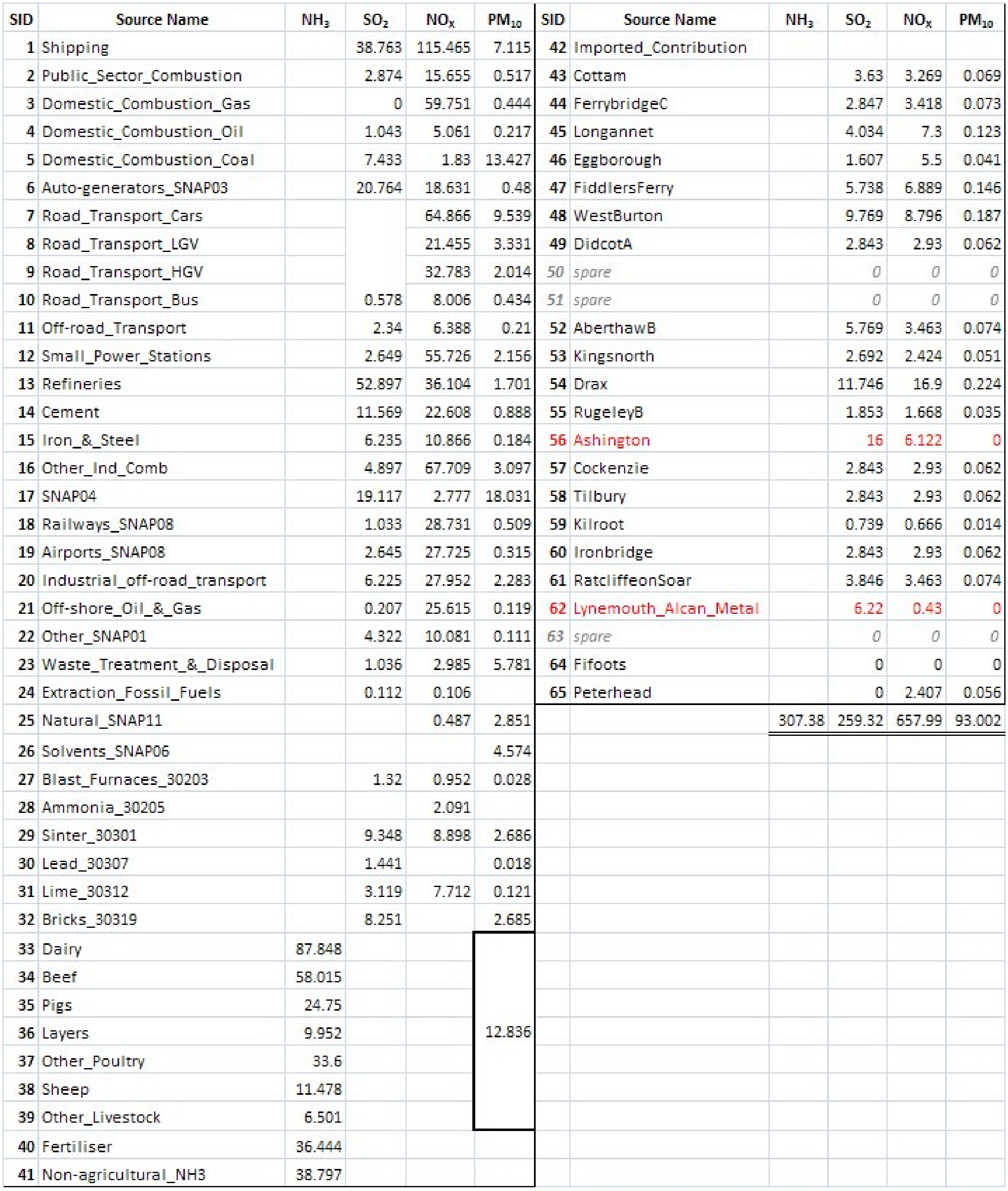
[1] However at the European scale with a coarser 50x50 km grid emissions as specified by EMEP are assumed but with a ~ 80% reduction in SO2 to reflect the MARPOL agreement.



SID	Source Name	NH_3	SO_2	NO_x	PM_{10}	SID	Source Name	NH_3	SO_2	NO_x	PM_{10}
1	Shipping		38.763	115.465	7.115	42	Imported_Contribution				
2	Public_Sector_Combustion		2.874	15.655	0.517	43	Cottam		3.63	3.269	0.069
3	Domestic_Combustion_Gas		0	59.751	0.444	44	FerrybridgeC		2.847	3.418	0.073
4	Domestic_Combustion_Oil		1.043	5.061	0.217	45	Longannet		4.034	7.3	0.123
5	Domestic_Combustion_Coal		7.433	1.83	13.427	46	Eggborough		1.607	5.5	0.041
6	Auto-generators_SNAP03		20.764	18.631	0.48	47	FiddlersFerry		5.738	6.889	0.146
7	Road_Transport_Cars			64.866	9.539	48	WestBurton		9.769	8.796	0.187
8	Road_Transport_LGV			21.455	3.331	49	DidcotA		2.843	2.93	0.062
9	Road_Transport_HGV			32.783	2.014	*50*	*spare*		*0*	*0*	*0*
10	Road_Transport_Bus		0.578	8.006	0.434	*51*	*spare*		*0*	*0*	*0*
11	Off-road_Transport		2.34	6.388	0.21	52	AberthawB		5.769	3.463	0.074
12	Small_Power_Stations		2.649	55.726	2.156	53	Kingsnorth		2.692	2.424	0.051
13	Refineries		52.897	36.104	1.701	54	Drax		11.746	16.9	0.224
14	Cement		11.569	22.608	0.888	55	RugeleyB		1.853	1.668	0.035
15	Iron_&_Steel		6.235	10.866	0.184	56	Ashington		16	6.122	0
16	Other_Ind_Comb		4.897	67.709	3.097	57	Cockenzie		2.843	2.93	0.062
17	SNAP04		19.117	2.777	18.031	58	Tilbury		2.843	2.93	0.062
18	Railways_SNAP08		1.033	28.731	0.509	59	Kilroot		0.739	0.666	0.014
19	Airports_SNAP08		2.645	27.725	0.315	60	Ironbridge		2.843	2.93	0.062
20	Industrial_off-road_transport		6.225	27.952	2.283	61	RatcliffeonSoar		3.846	3.463	0.074
21	Off-shore_Oil_&_Gas		0.207	25.615	0.119	62	Lynemouth_Alcan_Metal		6.22	0.43	0
22	Other_SNAP01		4.322	10.081	0.111	*63*	*spare*		*0*	*0*	*0*
23	Waste_Treatment_&_Disposal		1.036	2.985	5.781	64	Fifoots		0	0	0
24	Extraction_Fossil_Fuels		0.112	0.106		65	Peterhead		0	2.407	0.056
25	Natural_SNAP11			0.487	2.851			307.38	259.32	657.99	93.002
26	Solvents_SNAP06				4.574						
27	Blast_Furnaces_30203		1.32	0.952	0.028						
28	Ammonia_30205			2.091							
29	Sinter_30301		9.348	8.898	2.686						
30	Lead_30307		1.441		0.018						
31	Lime_30312		3.119	7.712	0.121						
32	Bricks_30319		8.251		2.685						
33	Dairy	87.848			12.836						
34	Beef	58.015									
35	Pigs	24.75									
36	Layers	9.952									
37	Other_Poultry	33.6									
38	Sheep	11.478									
39	Other_Livestock	6.501									
40	Fertiliser	36.444									
41	Non-agricultural_NH3	38.797									

Table 1.1: UKIAM (V3) Baseline Emissions (UEP32 – 2020)

Representing abatement options to control emissions

UKIAM is intended as a tool for rapid simulation and comparison of a large number of scenarios, reflecting alternative strategies for controlling emissions. This includes technical abatement measures, which have been selected from the MPMD (Multi-Pollutant Measures Data base- task 1.3.1) compiled by ENTEC, giving the percentage reductions in emissions achieved for each pollutant for a selected source, together with unit costs. This is illustrated for example in some of the scenarios described in section 1.4. In some cases, for example with improved energy efficiencies, a number of pollutants are affected simultaneously, which is the reason for moving away from the original UKIAM model oriented towards add-on technologies to control specific individual pollutants. Comparisons have also been made with abatement measures considered by IIASA in the GAINS model (see work package 2) which can also be implemented. As the most effective technologies are deployed non-technical measures and behavioural change become increasingly important in reducing emissions further. These can also be reflected in UKIAM by changing the activity data as well as the emission factors. Examples may be found in section 1.4.7 on road- transport scenarios reflecting downsizing of cars and changes in driving speeds.

Although UKIAM is now an effective tool for scenario analysis, more work was required than had originally been envisaged in linking abatement measures to emission projections in the NAEI. The NAEI projections reflect current legislation rather than the expected technology in place, so that for example, future power station emissions reflect compliance with the LCPD and National Emission Reduction Plans, rather than assumptions about installation of SCR. This has required more consultation with AEA and ENTEC than anticipated, and detailed scrutiny in developing individual scenarios. Much more could be done to improve this interface between emission projections and abatement options in generating scenarios for analysis if a new front end was developed for UKIAM.

Modelling of pollutant concentrations and deposition

The modelling of pollutant concentrations and deposition by UKIAM is summarised in table 1.2 below. The aim for UKIAM is rapid estimation of concentrations and deposition without full runs of complex atmospheric dispersion models with full chemistry. To achieve this we rely on the use of pre-calculated source- receptor relationships calculated for each source with a full model such as the FRAME model of CEH or the EMEP model as used by IIASA. These calculate a “footprint” for each source by examining the effect of a prescribed reduction in the emissions, and deriving the effect on the gridded maps of concentrations and /or deposition relative to the reference scenario. The resulting source-receptor matrices are used to estimate corresponding maps for a given emission scenario by scaling the changes induced by each individual source in proportion to the emission changes for that source. Care has to be taken where there are non-linear chemical interactions between pollutants. For example reducing ammonia emissions can have a large effect in reducing nitrate aerosol concentrations as well as ammonium ions, because of its role in the formation of ammonium nitrate. This is important because it magnifies the importance of ammonia in reducing secondary particulate concentrations. More has been done on this topic in model inter-comparison work in SSNIP- see section 1.5

With respect to urban scale pollution and primary pollutants the PPM model is used to estimate annual average concentrations using a 1x1 km grid resolution, with contributions of major roads superimposed to estimate road-side concentrations- see section on the BRUTAL model below. Originally the finest grid resolution used was 5 x 5 km in line with the FRAME modelling, but inter-comparisons with the PCM modelling of John Stedman at AEA showed that improved resolution to 1x1 km was desirable for urban modelling. This has therefore been implemented in UKIAM during this contract.

Table 2: Modelling output from UKIAM, and its derivation

Pollutant	Basis of modelling in UKIAM
Deposition of S and N	Derived from FRAME model, using S-R relationships to estimate deposition of S, oxidised N(due to NOx emissions) and reduced N (from NH3 emissions) over 5x5 km grid, distinguishing deposition to different ecosystem types (can also use EMEP modelling for comparison but the spatial distribution is poor) => mapped exceedance of critical loads for a) acidification and b)eutrophication
Secondary inorganic aerosol SIA=SO4+ NO3+ NH4	Either i)derived from FRAME, using source-receptor relationships for each UK source to estimate adjusted concentrations of each component on a 5x5 km grid, and imported contributions from FRAME-Europe OR ii) derived from the EMEP model, using source receptor relationships on a 50x50 km grid to adjust concentrations of each component ⇨ Population weighted mean concn
Primary PM_{10} concns from sources in inventory	Calculated using PPM model for 1x1km grid, with road-side increments superimposed for each road based on ADMS street canyon model + imported contributions from EMEP => population weighted mean concentrations
Total PM_{10} concentrations	Mapped as sum of SIA+ primary+ mapped background of other components not in inventory=> exceedance of AQ limit values
NO_2 concentrations.	NOx concns calculated as grid with roads superimposed for PM using PPM. NOx converted to NO_2 (dependent on primary NO2 and ozone)=> exceedance of AQ limit values (road lengths and area of grid)
Ozone concentrations	Based on the EMEP model and source-receptor relationships derived by IIASA for 50x50 km grid squares. This data-set has only just been obtained so results are not yet fully tested, and ideally should be adjusted for urban decrements.

During the contract there has been collaboration with the FRAME modelling at CEH, with provision of new maps and source-receptor relationships which have been incorporated in UKIAM. CEH have provided 2 versions of these data, one calibrated to match measurements, and the other with unadjusted data directly from the FRAME model. The calibrated version gives higher values of the nitrogen deposition than the uncalibrated (174kt as compared with 152 kt of reduced N, and 114kt as compared with 85kt of oxidised nitrogen), but the sulphur deposition is almost the same (59kt as compared with 58). Having both sets of data is useful for uncertainty analysis.

Likewise we have updated the EMEP maps and source-receptor data to match those used by IIASA. Inter-comparison of the two models shows that FRAME estimates smaller proportions imported into the UK than the EMEP model for both deposition and secondary inorganic aerosol, SIA. With respect to deposition the FRAME model gives a much better spatial distribution, with the coarse resolution of the EMEP model unable to represent effects such as orographic enhancement of wet deposition over higher land. For SIA, FRAME underestimates the imported contributions. However there are also reasons for which the EMEP model may overestimate SIA concentrations, for example assuming 5% of SOx is emitted directly as primary SO_4 aerosol; and the spatial distribution with a 50 x 50 km grid resolution does not reflect smaller scale effects and processes at the UK scale. Using data from both models can be used to explore uncertainties in estimating future SIA concentrations, and both can be deployed in combination for a central “best estimate” between the two. This is reflected later in section 1.4 on scenario analysis.

Assessment of environmental impacts

Critical loads are used as criteria for protection of ecosystems as the maximum deposition tolerable without adverse effects, and compared with the relevant deposition for each ecosystem type to map exceedance. Updated critical load data for the UK have been provided by CEH for both acidification and eutrophication, and incorporated in UKIAM. Figure 2.1 in section 2.1.1 illustrates how the more detailed spatial resolution of the deposition based on the FRAME model with a 5x5 km grid, and reflecting processes such as orographic enhancement of wet deposition over higher land, results in a very different picture of exceedance of critical loads as compared with the GAINS model. The more detailed modelling at the UK scale indicates a far higher proportion of UK ecosystems with exceedance and therefore at risk, especially for eutrophication.

A criticism of this approach is that it does not distinguish between more highly values sites such as SSSIs and SACs, and less important areas of natural vegetation or forest. This is taken up in section 1.2.1

With respect to urban air quality, annual average concentrations of PM_{10} and NO_2 are compared with equivalent air quality limit values for road-side concentrations (to estimate road lengths at risk of exceedance) as well as across the UK grid of 1x1 km grid cells. Population weighted mean concentrations are also used as indicators of health risks for the UK population. For particulates this means superimposing primary and secondary components together with other contributions not directly attributable to inventoried emissions. This is illustrated in the scenario analysis later in this report- section 1.4.4.

The following sections of this report describe in more detail areas where there have been major extensions of the capabilities of UKIAM, especially the BRUTAL model

1.1.2 Projected emissions and emission scenarios

In developing emission scenarios our aim has been to keep as close as possible to NAEI emission projections with help from AEA, and to be able to superimpose potential abatement options including measures taken from the ENTEC data base (see section 1.3). Originally this had been envisaged as very straightforward, but it became a significant task. There were several reasons for this. Firstly the NAEI projections cover the air quality pollutants, but not greenhouse gases; and secondly they reflect compliance with future legislation, rather than assumed technology in place as in the GAINS modelling. Thirdly we needed to go into more depth for a large number of sources to make comparisons with the derivation of emissions in GAINS. A small amount of additional funding for collaboration with AEA, Melanie Hobson, and ENTEC, was extremely helpful in gaining a deeper insight, enabling us to construct spread sheets for some of the more important sources in which we could compare the use of emission factors from the NAEI, and emission factors for different technologies in GAINS. This underpinned subsequent work described in section 2.3 to compare NAEI projections with those produced by IIASA.

Since emission projections rely on forecasts from other government departments, specifically DECC on energy, and DfT on transport, meetings have been held to discuss common issues: for example the assumptions about efficiency of generating plants and boilers ideally need to be consistent with scenarios superimposing further measures to reduce emissions. These meetings helped in recognising the contrasting approaches to making projections even if they did not necessarily resolve potential inconsistencies. They also provided a useful background in the differences between successive energy scenarios, and road transport projections. In future it would be useful if this could be extended to agriculture, where there are also large uncertainties in projections.

Currently it requires considerable effort and time by different partners in SSNIP to start from a new energy scenario such as UEP37 or UEP38 through to emission projections, and then reworking through the potential abatement measures to establish emission reductions in order to define scenarios for analysis with UKIAM. It is even more complex with other energy projections from PRIMES, although at Imperial College we have developed a spread sheet tool that we have used for the power sector to produce emission scenarios directly for UKIAM- see section 1.4.8. Most of the scenario analysis in this report is based on UEP32, which is now quite old and need to be updated in future work to more recent scenarios. Such updating could be made very rapid and easy, to cover a wide range of scenarios for energy, transport and agriculture with a new front end module for UKIAM along similar lines to the tool we have used for the power sector.

Within SSNIP Melanie Hobson has set up a web-site to bring together the underlying information for emission projections and development of scenarios. This is a useful facility for SSNIP partners and could be used to store scenarios analysed as well in future.

1.1.3 Modelling of urban air quality: the BRUTAL model

The BRUTAL model has been developed as a high resolution module of the UK Integrated Assessment Model [Oxley *et al.*, 2003] able to capture the enhanced roadside concentrations of air pollutants in urban street canyons. A complete description of the model has been reported elsewhere [Oxley *et al.*, 2009]. This has been made possible by the derivation of vehicle and technology dependent emissions factors which have been aggregated to represent an 'average' vehicle in a given vehicle mix by the iMOVE model [Valiantis *et al.*, 2007]. Applied to a spatial distribution of vehicles these emissions factors enable us to derive the resultant emissions (from exhaust and tyre & brake wear) from the bottom up, and to calculate the resulting concentrations (annual average) together with roadside enhancement derived using ADMS-Urban for different types of road and traffic mix, and allowing for typical effects of street canyons in urban and city centres on dispersion and concentrations. By nesting this model within the UKIAM and ASAM it is possible to assess the peak local concentrations in urban street canyons which contribute to exceedance of urban air quality Limit Values.

Automatic source-apportionment highlights the relative contributions from local and distant sources, and provides the basis for linking air quality issues and traffic management at the local level with the policy requirements to comply with international agreements on transboundary air pollution and national emissions ceilings.

This multi-scalar nesting of models is represented schematically in Figure 1.2. Within the context of the SSDIM framework for ISBP, the UKIAM and ASAM models are embedded into the BRUTAL model, providing background pollutant concentrations, non-traffic emissions and transboundary contributions to air quality automatically upon demand from BRUTAL.

Integrated Model Of Vehicle Emissions (iMOVE)

iMOVE is designed as a tool to assess current and future vehicle emissions and to investigate a variety of potential emission reduction strategies to reduce air pollution both at a local or national scale. It brings together information on air quality, population numbers, traffic data, vehicle emission inventories, technical and non-technical measures for transport emission reduction, and GIS mapping techniques.

iMOVE provides the speed dependent emissions factors of NO_X, primary NO_2, PM_{10}, CO_2, N_2O, and Tyre & Brake wear, the fuel factors and the vehicle mix required for BRUTAL model. Nesting BRUTAL within the UKIAM (and thus ASAM) facilitates assessment of the significance of different pollutant sources (controlled by policies applied at different spatial and temporal scales) towards exceedance of air quality Limit Values and to address the abatement measures in integrated assessment modelling which can influence air quality through affecting traffic emissions, vehicle mixes and traffic flows.

The model calculates emissions using data provided by Netcen and is based on the same methodology used in the National Atmospheric Emissions Inventory in the UK (NAEI website). Depending upon the road type, year, and traffic data, iMOVE splits the basic fleet into 14 vehicle categories, plus an additional 5 vehicle categories to allow for the possibility of testing different scenarios including the introduction of new vehicle types such as hybrid or biofuels vehicles. These are further disaggregated by the fleet technology split into varying numbers of emission standards, depending on the legislation governing each category. Some vehicle categories are subject to a further technological disaggregation (petrol and diesel cars by three engine capacity categories, LGVs into three categories, rigid HGVs by eight mass categories, articulated HGVs into five categories, buses by three urban bus categories and two types of coaches, and motorcycles by two engine stroke cycle categories with further sub-divisions). Depending on the pollutant, emission factors or fuel consumption factors are then applied by the model to each of these categories in order to calculate their attributed emissions in g/km/year for each road type. In the model, the road type is classified as urban, rural, motorway and minor roads. Moreover, an additional road type classification is included to allow for specific vehicle mix for specific road.

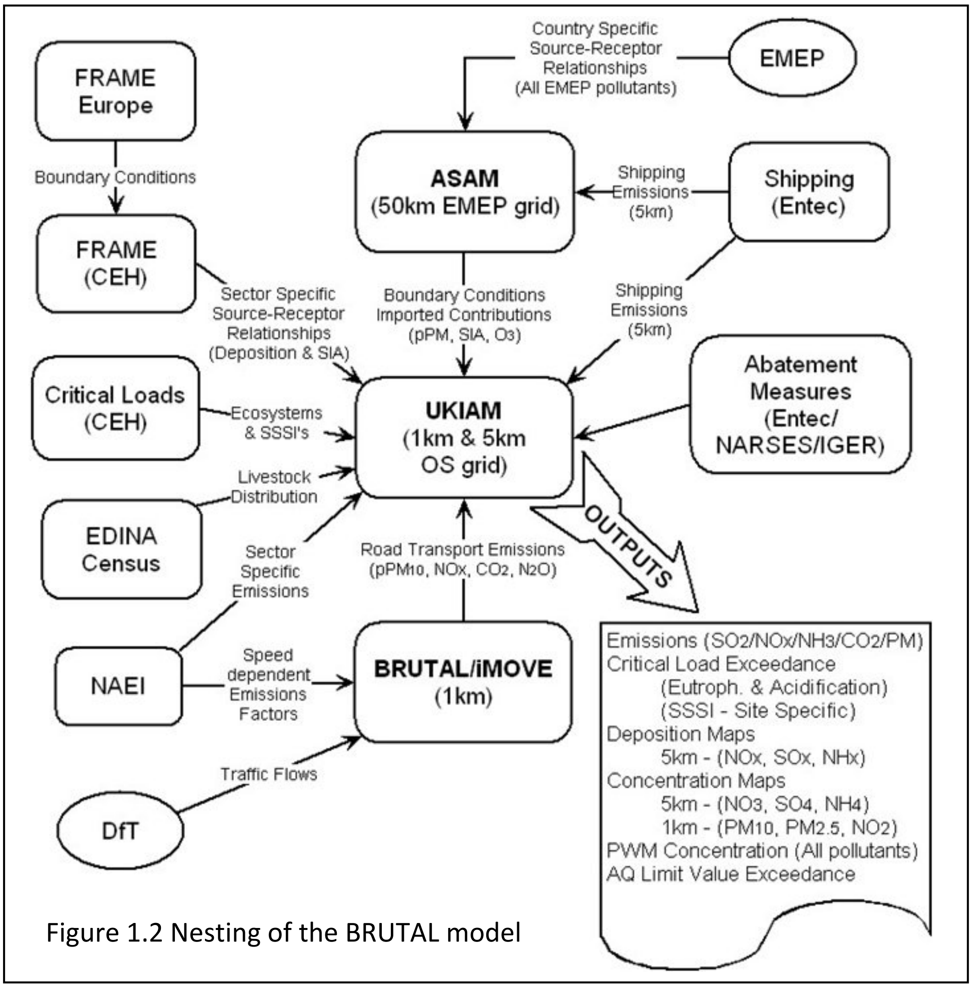


Figure 1.2 Nesting of the BRUTAL model

The model calculates emissions for PM_{10}, NO_X, pNO_2, CO_2, and N_2O for each vehicle category, Euro standard, and engine size when applicable, and also calculates non-exhaust emissions for PM_{10} for each vehicle category. iMOVE processes traffic flows, the vehicle mix, the technology mix, and emission factor for each vehicle category and technology to generate the output emissions (g/km/year), the aggregated emissions factors, fuel factors and vehicle mix. The model includes cold start emissions based upon the COPERT methodology [Ntziachristos and Samaras, 1997], catalytic failure, and the deterioration in emissions with age.

Sensitivity studies with respect to emissions have been undertaken addressing cold starts, catalytic failures etc ., and checks made for consistency with the NAEI emission projections based on the same speed dependent emission factors and vehicle categories- see section 1.5

The BRUTAL Model

The BRUTAL model uses emissions factors calculated by iMOVE (see above) and is able to capture the road-side concentrations of air pollutants in urban street canyons. Applied to a spatial distribution of vehicles these emissions factors enable us to derive the resultant emissions from the bottom up, and to calculate the resultant aerosol and particle concentrations together with road-side contributions calculated using ADMS-Urban. By nesting this model within the UK Integrated Assessment Model (UKIAM) we are able to assess the significance of different pollutant sources (controlled by policies applied at different spatial and temporal scales) towards exceedance of air quality Limit Values and to address non-technical abatement measures in integrated assessment modelling.

The model has been applied to the UK on a 1km resolution spatial grid in order to maintain compatibility with the UKIAM and to facilitate easy mapping between the air pollution models. The operation of the model cycles through calculation of emissions (based upon emissions factors from iMOVE and traffic flows), dispersion of these emissions (using a 1km resolution based on the PPM Gaussian/Lagrangian model), calculation of pollutant concentrations (capturing all other non-traffic sources of the pollutant), and calculation of population exposure and other policy objectives determined by air quality limit values.

Two levels of concentrations are mapped from these traffic flows and emissions. Firstly the *background* (annual average) concentration to which everyone is assumed to be exposed and upon which calculations of population exposure and Population Weighted Mean (PWM) concentrations have to date been based. Secondly, the roadside enhancement (depending upon traffic flow and type of street canyon) is calculated to determine the peak concentration to which an individual will be exposed if present at the roadside.

NO_2 concentrations are calculated using a quadratic equation, thus:

$$NO_2 = q - \sqrt{\left(q^2 - r\right)}$$

where $q=(NO_X+O_X+B)/2$ and $r=O_X+NO_X$, with B representing the ratio between the photo-dissociation rate and reaction rate between NO and O_3, varying between about 24 for daytime dissociation rates of 10^7 mol/dm^3/s to zero at night. The model has been further developed in order to capture the effects of increasing/changing primary NO2 emissions which affect this calculation of NO_2 concentrations. Discussion of the effects of primary NO_2 emissions is provided below in section 1.1.7.

The peak concentrations calculated by BRUTAL (which include roadside enhancement) provide the basis for comparison with EU air quality Limit Values and calculation of total lengths (km) of roads which are at risk of exceeding the limit values, which is used as a metric for assessing compliance with policy and progress in pollution abatement.

1.1.4 Modelling of $PM_{2.5}$ as well as PM_{10}

Initially the BRUTAL and UKIAM models were developed to treat PM_{10} only, as this was of concern with respect to air quality limit values, with exceedance judged against an annual average of 31.5 $\mu g/m^3$ (as a rough equivalent of 37 days per year exceeding the daily limit of 50 $\mu g/m^3$). However in revision of the NECD and Gothenburg protocol the proposed ceiling for primary PM applies to $PM_{2.5}$. In addition legislation on urban air quality is being extended with the aim of reducing population weighted mean exposure in urban agglomerations. It was therefore important to extend UKIAM to cover $PM_{2.5}$ as well as PM_{10}.

This has been done by defining $PM_{2.5}$ emissions as appropriate fractions of PM_{10} for each source in the inventory, and hence deriving an emissions inventory for the primary $PM_{2.5}$ emissions. The secondary inorganic aerosols require adjustment to the nitrate to allow for a fraction (~15%) being coarser particulate rather than the finer ammonium nitrate. Similarly the remaining additional contributions from urban and rural dust, resuspension etc need to be reduced to represent the fine fraction; and are then superimposed as for the PM10 calculations. The resulting maps and a break-down of different contributions are illustrated by comparison with PM_{10} later in this report in section 1.4.5 on source-apportionment of particulate matter.

In future work it is recommended that further work is undertaken on emissions inventories for primary PM, with a more detailed breakdown of chemical composition including black carbon and potentially toxic components.

1.1.5 Inclusion of greenhouse gases

Spread-sheets have been developed to calculate greenhouse gas emissions for many of the stationary sources in table 1.1, using both emission factors supplied by AEA and those in the GAINS model for CO_2, N_2O and CH_4 as well as the air quality pollutants. The aim is to cover sources where abatement measures may change both the GHGs and AQ pollutant emissions, rather than to develop an entire inventory. It has become apparent that there can be significant differences between the GAINS estimates of CO_2 from combustion sources and the UKIAM estimates based on AEA emission factors. It has been beyond the scope of the current contract to look into this in more depth, and this merits attention in future research. Meanwhile an illustration of implications for greenhouse gas emissions from stationary combustion is provided in the scenario analysis for the power sector, comparing different energy projections (section 1.4.8).

For road transport emissions of CO_2 and N_2O are directly calculated in parallel with NOx and PM emissions in the BRUTAL model. Following revision of the emission factors in line with the NAEI based on work by TRL, the N_2O emissions appear less important; and the focus is hence on CO_2 emissions. This has been built into scenarios such as the downsizing of cars, and introduction of electric vehicles with different assumptions about the source of electricity for battery charging.

For agriculture greenhouse gas emissions are important in two ways. First agriculture is major source of both methane (particularly from cows) and N_2O (from soils); secondly abatement measures to reduce NH_3 emissions, such as injection of slurries, can enhance N_2O emissions and also increase risks of nitrate leaching with implications for water quality. This has been addressed in the scenario analysis undertaken for the agricultural sector (see section 1.4.9) where both changes in agricultural activities and application of abatement measures have been considered within the broader context of the nitrogen cycle. These studies provide a basis for direct inclusion of agricultural emissions of CH_4 and N_2O in UKIAM, as well as a risk index for nitrate leaching. However information on abatement measures and their costs for NH_3 emission reduction urgently needs to be revised before this is fully implemented in UKIAM. This has been communicated to Defra and IGER (who have provided information on the current NH3 abatement measures in the form of a cost-curve as well as agricultural projections) but was not within the remit of SSNIP partners in the current contract.

1.1.6 Ammonia and the nitrogen cycle

CEH have helped in providing the agricultural data on livestock numbers coupled with fertiliser use to derive the ammonia emissions, calibrated to match totals for each agricultural sector in accordance with the NAEI. The census data could not be used directly for the 5x5 km grid resolution required because of privacy regulations. Instead a license had to be obtained to use the Edina database at Edinburgh University where almost identical data is available. The total national emissions of NH3 were provided by IGER as supplied to AEA for the NAEI, together with a cost curve summarising the abatement steps available in order of increasing cost per tonne of NH3 reduced. This is not straightforward in the case of NH3 since measures can interact with each other; for example reducing emissions from animal housing may increase emissions from subsequent storage and spreading of manures. There are also some problems with this cost curve; firstly the costing of measures is very out of date, and secondly the NARSES model developed by ADAS to derive such cost curves is unable to allow for some more costly measures deployed in accordance with IPPC legislation in the baseline projections without excluding cheaper measures on other farms not under IPPC. The alternative was to ignore the IPPC legislation, which was felt preferable in the current contract. It is hoped that these problems can be addressed in future, but this requires expertise outside this contract.

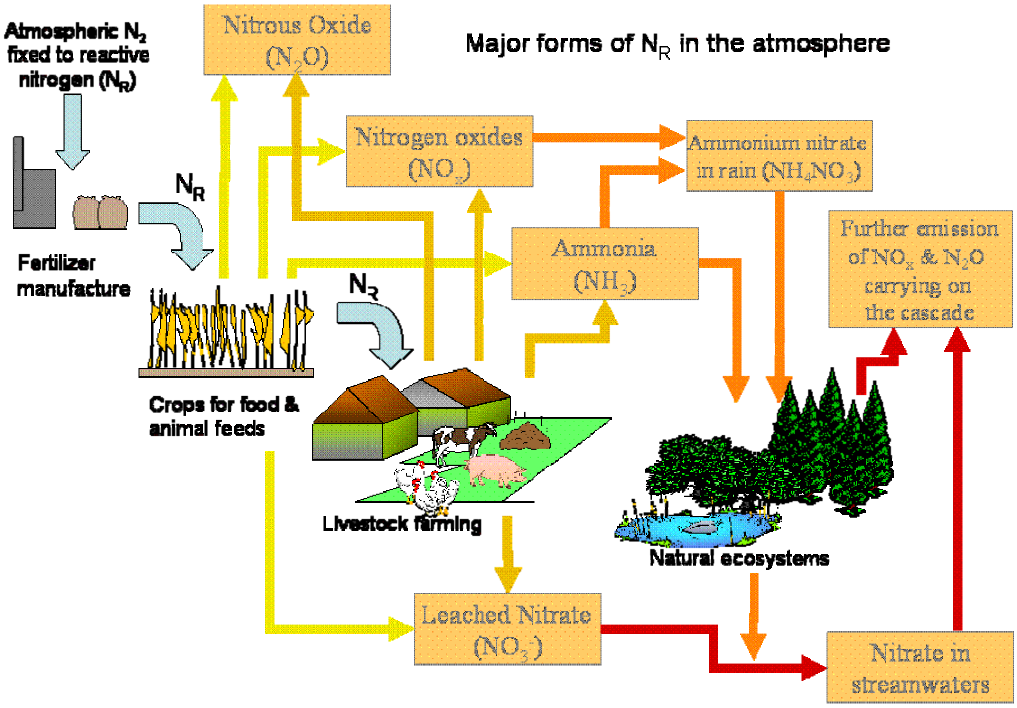


Figure XX The nitrogen cascade

In developing the agricultural scenarios (see section 1.4.9) an integrated approach to the nitrogen cycle has been taken as illustrated in the figure above. In line with the treatment of greenhouse gases for other sectors, allowance has been made for potential additional N_2O emissions arising from abatement measures to reduce NH_3 emissions, and also an index related to the potential for extra nitrate leaching. In addtion CH_4 emissions have also been taken into account, this being highly relevant for comparing scenarios with different livestock numbers reflecting changes in demand for meat products. So far this has been done by detailed examination of selected scenarios to develop the methodology, and is being included directly in UKIAM in the final phases of this contract.This work has largely been undertaken by a PhD student at Imperial, Nighat Hasnain, working alongside the SSNIP project. She has taken a critical look at integrated assessment modelling in this context, and explored the use of Multi Criteria Decision Analysis as a tool to bring different stakeholder views into the ranking of different scenarios for ammonia abatement. The work is fully described in a PhD thesis examined in March 2010, and papers are currently being prepared for publication. Presentations have been made to the Task Force on Reactive Nitrogen, with particular interest in the scenarios reflecting changes in meat consumption resulting from possible trends in human diet.

1.1.7 Relationships between NO2 and urban ozone reflecting trends in primary NO2 emissions

Originally this task was concerned with representing the annual ozone deficit in urban areas due to fresh NOx emissions, as an approximate way of representing the increase in exposure of urban populations to ozone when NOx emissions are reduced. However during the course of the contract it was recognised that trends in urban NO_2 will also be affected by changes in the proportion of NOx emitted as primary NO_2. Hence this task became the larger one of developing a model to represent the relationship between ozone, NO and NO_2 in different situations from rural to road-side. This model is an extension of the quadratic relationship used in our earlier work, and giving very similar results to the widely used empirical equations derived by Dr M Jenkin.

In urban areas where road transport is important, with most emissions during the day, the important "fast chemistry" involves the reaction of fresh NO emissions with O3, and dissociation of NO2 to reform NO and O3. Where air has had time to travel away from fresh NOx sources these reactions come into balance with each other corresponding to the "photo-stationary state" with

$$[NO] \times [O_3] = B_{pstat} [NO_2]$$

and a constraint to conserve total oxidant, $O_3 + NO_2 = O_{3b} + \alpha . NOx$ where O_{3b} is the background total oxidant and α is the fraction of NOx emitted as primary NO_2. Ignoring other reactions and further slower oxidation processes NOx is conserved

$$NO + NO_2 = NOx$$

These equations yield the familiar quadratic equation for NO_2 as a function of NOx, O_{3b} and α. Comparison with past measurements showed that this relationship works well when averaged for annual values of NO_2 and NOx in rural and suburban areas with values of B_{pstat} between 8 and 16, and a mean value of 12 (consistent with the photo-stationary state with low to medium daytime insolation). However this overestimates NO_2 closer to roads and fresh emissions, where there is less time for the formation of secondary NO_2. This can be represented by replacing B_{pstat} by higher values B_{urban} and $B_{roadside}$ for urban centres and close to major roads respectively.

In this model the fraction of primary NO_2 emissions, α, is calculated from the emissions inventory based on data supplied by AEA in 2009. Table 1.3 shows the α values used for road transport, where the big differences lie as compared with previous projections. For stationary sources a higher value has now been used of ~15%, but there are some uncertainties with high values possible for some industrial processes. The values of α have an increasing trend over time with representative values as shown in the table below, but vary with type of site and from road to road according to the contribution from traffic and the traffic mix.

	Petrol cars & LGVs	Diesel cars & LGVs	HGVs & buses
Pre-Euro1	0.04	0.11	0.11
Euro 1	0.04	0.11	0.11
Euro 2	0.04	0.11	0.11
Euro 3	0.03	0.25	0.14
Euro 3 with DPF		0.35	
Euro 4	0.03	0.55	0.14
Euro 5	0.03	0.50	0.10
Euro 6	0.02	0.50	0.10

Table 1.3 : α values (fractions of NOx emitted as primary NO2) for different vehicle types and age (supplied by AEA). For all motorcycles $\alpha = 0.04$.

There are also uncertainties about the total oxidant with variations between years with high ozone and photochemical activity such as 2003, and years with lower background ozone levels in background air. This has been allowed for by assuming higher values of O_{3b} and low values of B, resulting in higher NO_2 concentrations; and lower values of O_{3b} and higher values of B yielding lower values of NO_2. In this way uncertainty bands on NO_2 are defined as well as the central values.

Table 1.4 below summarises the parameter values used for different circumstances (year, location) in calculating central values of NO_2 concentrations and upper and lower uncertainty margins.

Table1.4 : Parameter values used in deriving NO_2 concentrations from NOx

In 2005 α~ 0.1 in 2009 α ~ 0.15 in 2020 α variable up to ~ 0.3

	Mean	High values	Low values
	O3b= 37.5	O3b = 40	O3b = 35
Road-side	B = 25	B = 20	B = 30
Urban Centre	B=20	B = 16	B= 24
Suburban/rural	B=12	B = 8	B = 16

Figure 1.3 shows an illustration comparing calculated NO2 values together with upper and lower limits, against measures values for different types of station. In general the comparison is good except for the occasional station where the model overestimates.

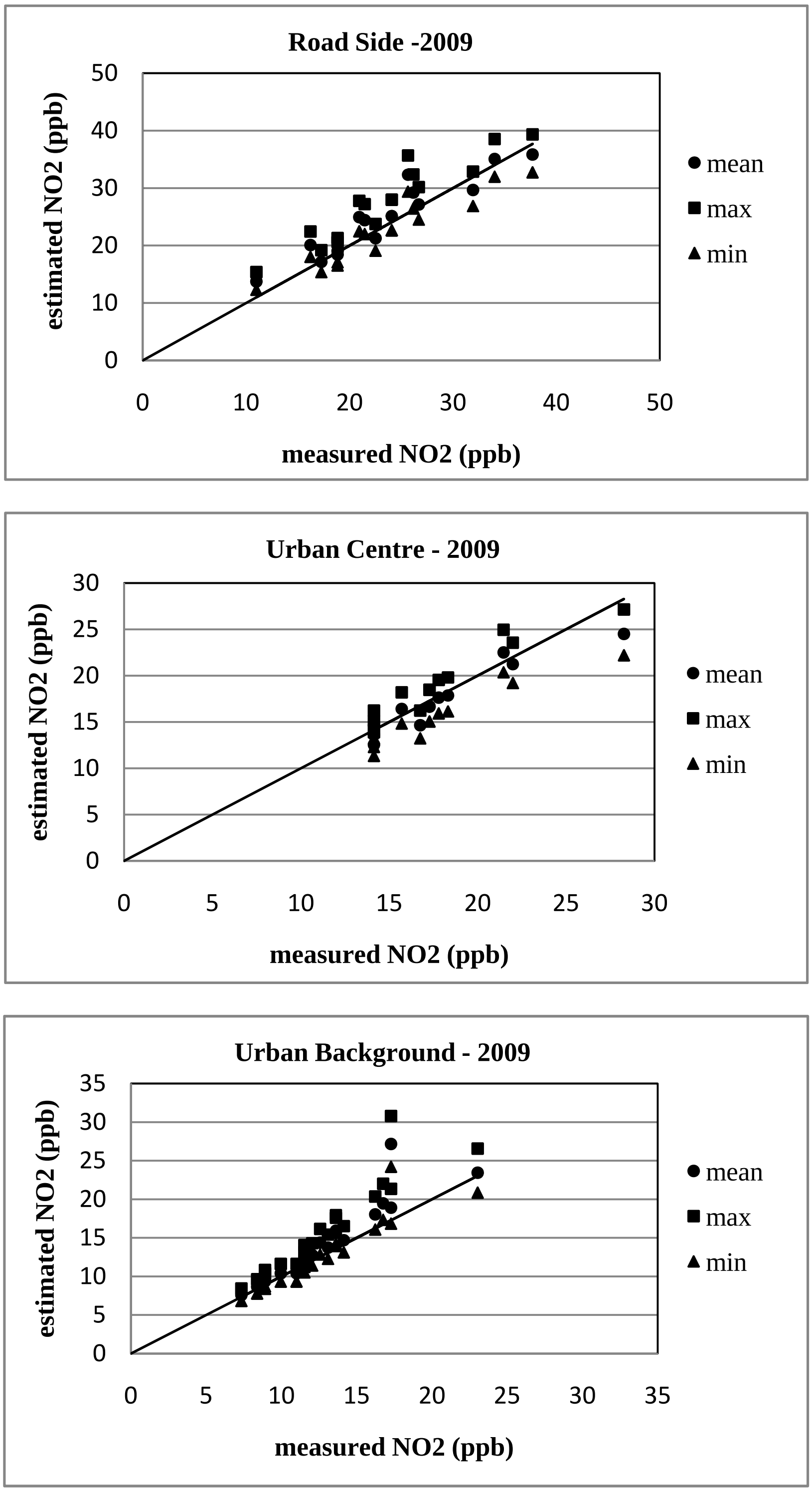
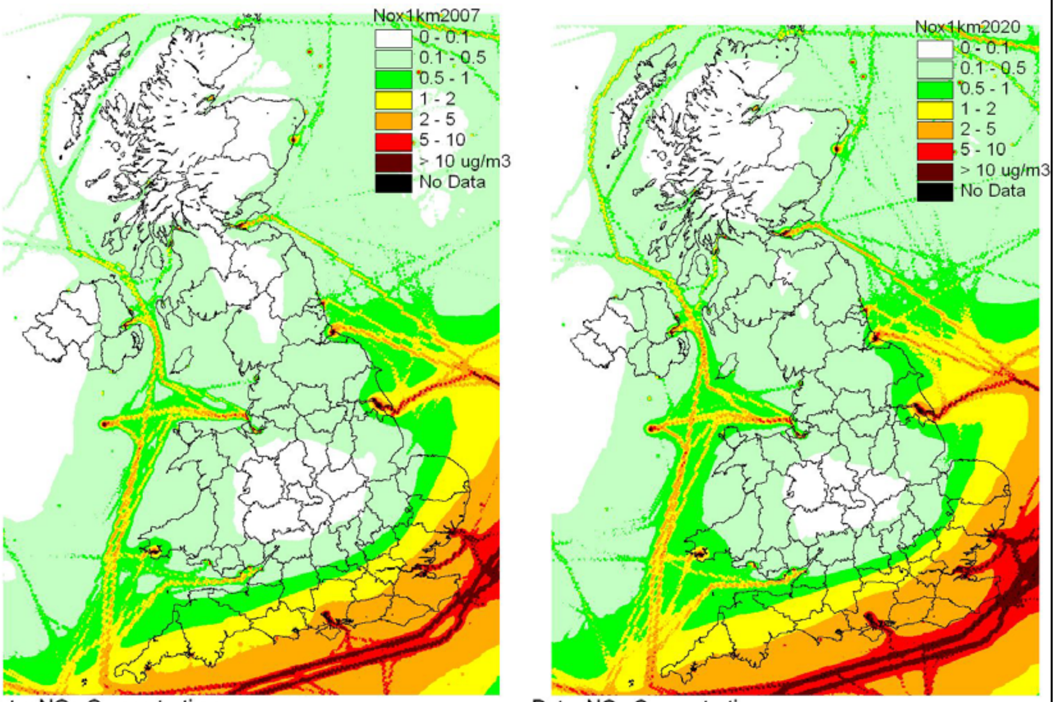


Figure1.3: modelled NO2 against measured data for 2009

The urban ozone deficit can be calculated from the same model, and is equivalent to the difference between the total (secondary plus primary) NO_2 and the primary NO_2. This can be used as an indicator of the change in exposure to ozone due to changes in NOx emissions in urban areas, but has not been taken further at this stage as modelling of background ozone was not included in UKIAM in the current contract.

Task 1.1.8 Shipping emissions

Shipping emissions of SO2, NOx and PM have been supplied by ENTEC mapped on to a 5x5 km grid. These have been used by CEH to provide source-receptor matrices showing the effect of emission reductions on deposition of sulphur and nitrogen, which have been incorporated in UKIAM. CEH have also calculated S deposition using emissions with and without the MARPOL convention in place (see CEH report). At Imperial College we have used the same ENTEC ship emission data to model the contribution of shipping to NOx and PM concentrations across the UK. The map in figure 1.4 below illustrates the contribution to NOx, which can make a considerable contribution in some coastal ports (see scenario analysis on trends in NO_2- section 1.4)



Data: NOx Concentration
Units: ug/m3
Emissions: Entec Shipping (2007/2010)
Source: UKIAM V3

Data: NOx Concentration
Units: ug/m3
Emissions: Entec Shipping (2020)
Source: UKIAM V3

Figure 1.4: Contribution of shipping (ENTEC inventory) to NOx concentrations

1.2.1 Ecosystem exceedance for SSSIs, SACs and SPAs

Ecosystem exceedance for SSSIs, SACs and SPAs

Critical loads are defined as the threshold level for the deposition of a pollutant above which harmful indirect effects can be shown on a habitat or species, according to current knowledge. Additional deposition above the Critical Load is termed **Critical Load Exceedance** and such criteria are typically used to assess the level of ecosystem protection from acidification and eutrophication. In UKIAM detailed ecosystem data for the UK provided by CEH are routinely used with maps of deposition of sulphur and nitrogen derived using the data from the FRAME model for different types of vegetation and freshwaters. Maps of average accumulated exceedance are used to indicate the spatial variation across the UK and to compare different scenarios , together with statistical data on overall exceedance for different ecosystems categories (see base case scenario section 1.4). However this attaches equal importance to each ecosystem area, irrespective of whether it is a site of special scientific interest (SSSI) or Natura 2000 site, or a relatively unimportant area of unfarmed land. It was therefore decided to look into how areas designated as more important might be specifically addressed, helped by recent work at CEH.

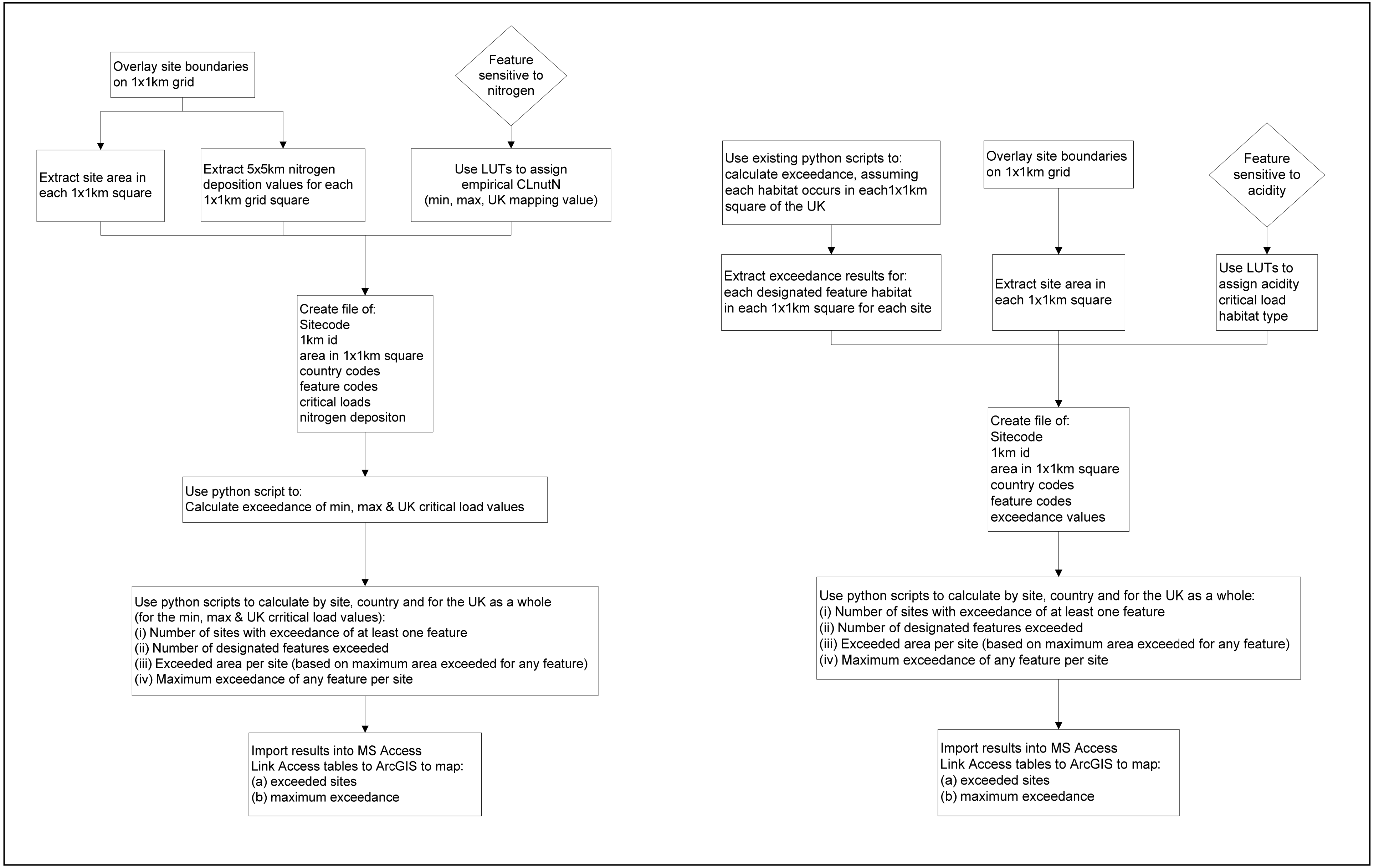
Based on preliminary data from CEH a scheme has been devised for looking in more detail at SSSIs, SACs and SPAs as opposed to attaching equal importance to all areas of natural ecosystems.

- **SSSIs**: Sites of Special Scientific Interest.
- **SACs**: Special Areas of Conservation. These are protected sites designated under the EC Habitats Directive and in the UK aim to protect 78 habitats and 43 species (of those listed in the Directive Annexes I & II).
- **SPAs**: Special Protection Areas. These are protected sites of the EC Birds Directive for the protection of rare and vulnerable birds and regularly occurring migratory species. In terms of critical load exceedance the aim is to protect the habitats required by these bird species.

Together the SACs and SPAs form part of the European Natura 2000 network of protected sites established under the EC Habitats and Birds Directives. Some SACs (or SPAs) incorporate one or more SSSIs.

The CEH methods used for applying critical loads and calculating exceedances for the designated sites have been discussed and agreed with JNCC. Each site has one or more designated features (habitats and/or species). Look-up tables (LUTs) have been developed (by JNCC/CEH) to relate the designated features to the most relevant habitat critical loads. In some instances a feature may be associated with critical loads for more than one habitat type, especially in relation to nutrient nitrogen where a wider range of habitat categories exist. The processes for calculating critical load exceedances are summarised in Figure 1.5. The same basic methodology can be applied to SSSIs, SACs and SPAs, though small modifications to the programmes are required as the site features are coded differently for

Figure 1.5. CEH processes for calculating exceedance of nutrient nitrogen and acidity critical loads for features of designated sites



SSSIs and for SACs/SPAs. In counting the number of sites with exceedance (of one or more features) the results are summed according to the country the site is assigned to; when calculating the area exceeded the results are based on the country each 1x1km square is allocated to. Exceeded areas are the sum of the area of 1x1km squares (or parts thereof) with exceedance of the critical loads for one or more features for each site.

CEH results generated to date are provisional as updates to the designated site boundaries and critical loads databases for the SSSIs and SACs are expected in the near future. Figure 1.6 illustrates the kind of outputs that can be generated using the CEH approach. At present analysis of exceedance is being performed for: i. maximum critical loads, ii. minimum critical loads and iii. UK average critical loads for each site feature (although a feature may be assigned more than one of each critical load type if it is composed of multiple habitat types). It is important to emphasise that the nitrogen critical load exceedance maps presented in figure 1.6 only relate to nitrogenous atmospheric deposition. In reality a number of sites that our analysis indicates to be below critical loads, may well be exceeded due to localised issues such as agricultural run-off and sewage overflow events.

Imperial College, CEH, JNCC and Natural England have met to discuss how these assessments could be incorporated into UKIAM activities. The following data sets have been provided to Imperial College:

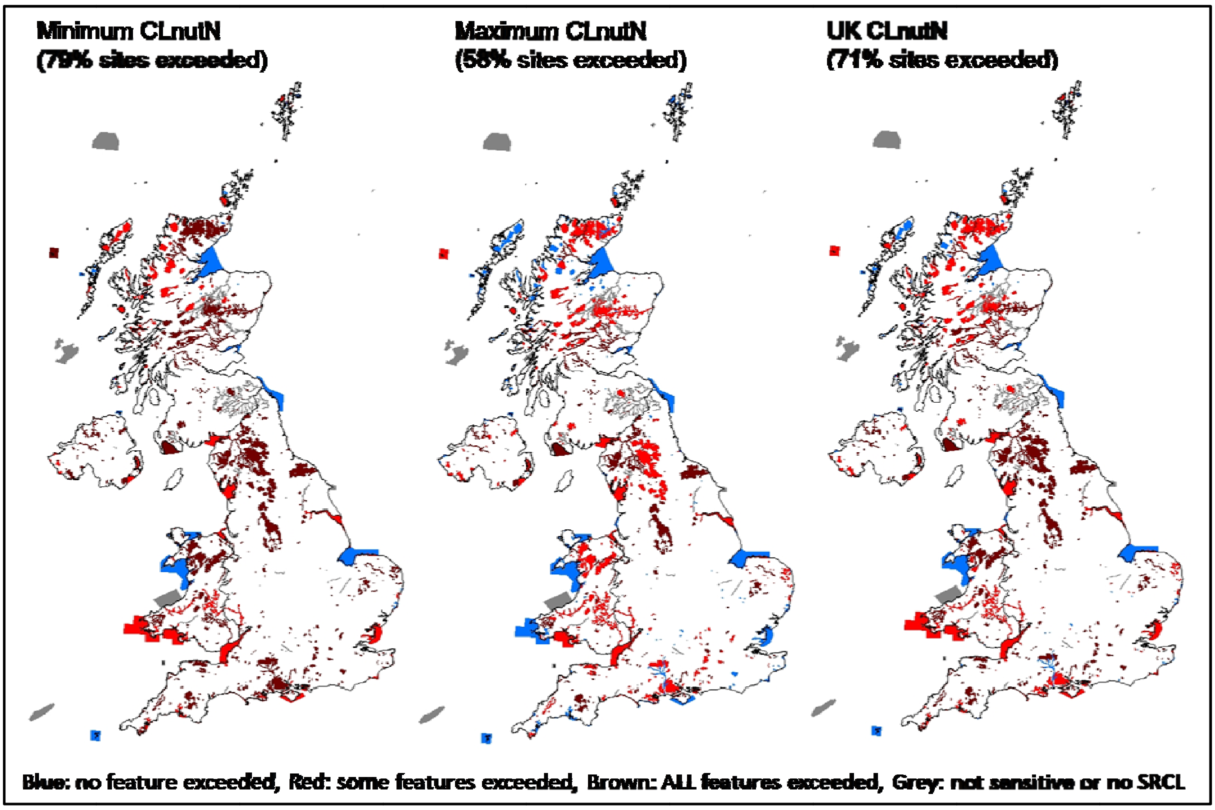
- 1x1 km habitat-specific acidity critical loads
- Preliminary Access databases of acidity and nutrient nitrogen critical loads and exceedances for SSSIs
- Python scripts developed at CEH for calculating exceedances and summarising results

In order to facilitate incorporation into UKIAM, the python scripts have been re-written in MATLAB and may be additionally re-written in C. Data provided in Access format by CEH is being utilised in ASCII format to link it to UKIAM. As such UKIAM could be utilised to assess the impact of different scenarios (e.g. transportation, energy) on ecosystems of designated significance that contain specific features of interest.

A scheme has been devised for ranking risk to each site and feature based on the magnitude of exceedance compared with the maximum and minimum critical loads, as well as the mean values usually assumed. This scheme will distinguish very high levels of exceedance, which can not be eliminated, from intermediate levels where further mitigation action could make a difference to the level of protection and facilitate ecosystem recovery. It is hoped to complete this work in an extension to this contract, when final data sets become available from CEH broken down by region.

A further ecosystem services based approach to the UKIAM analysis of ecosystem impacts is proposed as an extension to this contract. The primary limitation of the present analysis is that it assumes the impact of different deposition types on all sites can be assessed solely through the exceedance of critical loads. There are a number of problems with this assumption. The main one being that the value of sites cannot be reduced to a single factor such as critical load exceedance. Instead the true value of each SSSI is a product of the different goods and benefits that are derived from it. The ecosystem services that contribute to the goods and benefits derived from UK sites of designated ecological importance are arguably highly difficult to place an accurate economic value on. For these reasons, it is perhaps advisable that a preliminary attempt to link nitrogen deposition to ecosystem services focuses on a restricted range of ecosystem types (e.g. deciduous & coniferous forests) with the analysis limited to only the principle services deemed affected by deposition. Recent work by de Vries *et al.* (2009) illustrates how such an analysis may be conducted.

Figure 1.6. Exceedance of site-relevant critical loads of nutrient nitrogen for SAC features by CBED 2004-06 nitrogen deposition (preliminary results)



1.2.2 Targets for protection of human health

The development of the BRUTAL model described above, which enables calculation of road-side concentrations, allows UKIAM to assess if and where there are risks of exceeding air quality limit values at both road-side and urban background sites. However a more direct indicator of human health effects is provided by combining mapped concentrations with population data to calculate population weighted mean concentrations, PWMC. This can be broken down into major cities such as London, or regions, as well as for the whole country. The additional work described above to include PM2.5 as well as PM10, enables this to be done for both PM components and also for NO2. The inclusion of PM2.5 is also important in relation to new EC legislation to reduce population exposure in urban agglomerations by 10% between 2010 and 2020.

Task 1.3 Multi-Pollutant Measures Data base. MPMD

The major role for ENTEC in the SSNIP contract has been to provide a data base of potential abatement measures beyond the Business As Usual, BAU scenario represented in the NAEI emission projections. As described above UKIAM has been reconfigured as a new version to consider simultaneous emissions of a range of air quality pollutants and greenhouse gases in SSNIP. The base case was set up to use UEP32 energy projections as for ENTEC's work in developing the MPMD, and we have liaised with ENTEC accordingly. As illustrated in section 1.4 on scenario analysis measures from this database have been used in some of the scenarios analysed, although many of the scenarios have been developed independently- partly because the MPMD became available in the later stages of this contract. It is hoped to model far more of the measures in the MPMD in an extension of SSNIP, in conjunction with updating to more recent energy projections (UEP37 and/or UEP38)

1.4 Applications of UKIAM and Scenario Analysis

This section of the report describes work undertaken with the UKIAM model and related programs to analyse future scenarios for the UK. This begins with a base case of a "business as usual" scenario, illustrating the changes expected over the next ten years between 2010 and 2020. This base case (referred to as "UEP32") assumes the UEP32 energy projections from DECC, road transport projections based on DfT statistics of 2008, and the "BAU III" agricultural projections. The results first illustrate changes in deposition and exceedance of critical loads for ecosystem protection to 2020. Next we consider changes in particulate concentrations starting with secondary inorganic aerosol (SIA=SO4 +NO3 + NH4) components, and build up the other components of particulate matter, PM10 and PM2.5, to indicate their relative importance and changes in source-apportionment. This is then taken forward to look at exceedance of air quality limit values with respect to PM_{10} in relation to urban air quality. Finally we consider trends in NO_2 concentrations over the decade to 2020, and again make comparison with air quality limit values to assess where there may be risks of exceedance.

This analysis of the "base case" is then followed by comparison with alternative scenarios for 2020, focusing on different sectors. Thus following on from the work on urban air quality we have looked at a range of alternative scenarios for road transport, including behavioural change as well as technical measures. We have also considered the effect of changes in the power generation sector, both assuming a range of different energy projections from DECC and IIASA and applying additional abatement technology, together with a sensitivity study to assumptions about the sulphur content of coal. Finally we turn to the agricultural sector, and scenarios for reducing NH3 emissions, introducing the broader approach developed for the nitrogen cycle in a wider policy context.

1.4.1 The base case emissions

The UKIAM model and its development under the SSNIP contract has already been described in previous sections of this report. In order to define a scenario emissions are required for both UK sources, and from European countries. We also require emissions from shipping, where although the MARPOL agreement will reduce emissions of SO_2, emissions of NOx become increasingly important by 2020. Table 1.5 summarises the emissions assumed in the base case scenarios for 2010 and 2020, with a breakdown by sector for the UK emissions (a more detailed breakdown of emissions for UK sources for 2020 is given in section 1.1.1, and of the road emissions in section 1.5).

Emissions (Tons)

2010	PM10	PM2.5	NH3	SO2	NOX
Power	4,457	2,998	0	137,939	296,087
Domestic	16,440	9,904	0	15,492	93,030
Industry	42,871	24,560	38,797	180,651	229,079
Roads	25,105	20,084	0	578	338,915
Offroad	9,424	7,444	0	11,060	152,900
Agri/Nat	15,687	6,709	268,587	0	487
Total UK	113,983	71,699	307,384	345,721	1,110,498
Shipping(ENTEC)	32,917	30,320	-	355,761	841,064
EU27	1,964,190		4,212,630	5,928,430	8,749,600

2020	PM10	PM2.5	NH3	SO2	NOX
Power	4,088	2,709	0	71,098	144,358
Domestic	14,088	8,487	0	8,476	66,642
Industry	43,640	24,941	38,797	166,854	223,687
Roads	15,498	12,399	0	578	124,294
Offroad	3,317	2,688	0	12,243	73,028
Agri/Nat	15,687	6,709	268,587	0	487
Total UK	96,318	57,934	307,384	259,249	632,496
Shipping(ENTEC)	21,318	20,196	-	57,255	1131,323
EU27	1,648,982	0	4,124,378	4,424,223	6,339,408

Table 1.5 : emissions assumed for base case (UEP32) scenario

(NB UK emissions of NH3 for 2020 correspond to the starting point on the abatement cost curve supplied by IGER, which does not allow for implementation of IPPC measures. The same emissions have been assumed in 2010, although in practise IPPC measures should achieve the 10kT reduction needed to meet the UK's emission ceiling in 2010.)

1.4.2 The base case: deposition of sulphur and nitrogen and protection of ecosystems from acidification and eutrophication

.Here the data from the FRAME model have been used to estimate deposition over the UK as these give a much better spatial pattern than the larger scale EMEP model (see also the inter-comparisons with the EMEP model in section 1.5). Figure 1.7 shows maps of deposition of sulphur, oxidised nitrogen, and reduced nitrogen in 2020 in units of keq/ha/year for direct comparison with respect to acidification. It is evident that by 2020 the major reductions achieved in SO_2 emissions results in a much smaller acidifying input than from NOx whose emissions are also very much reduced, and that the greatest contribution comes from reduced nitrogen, NH3.

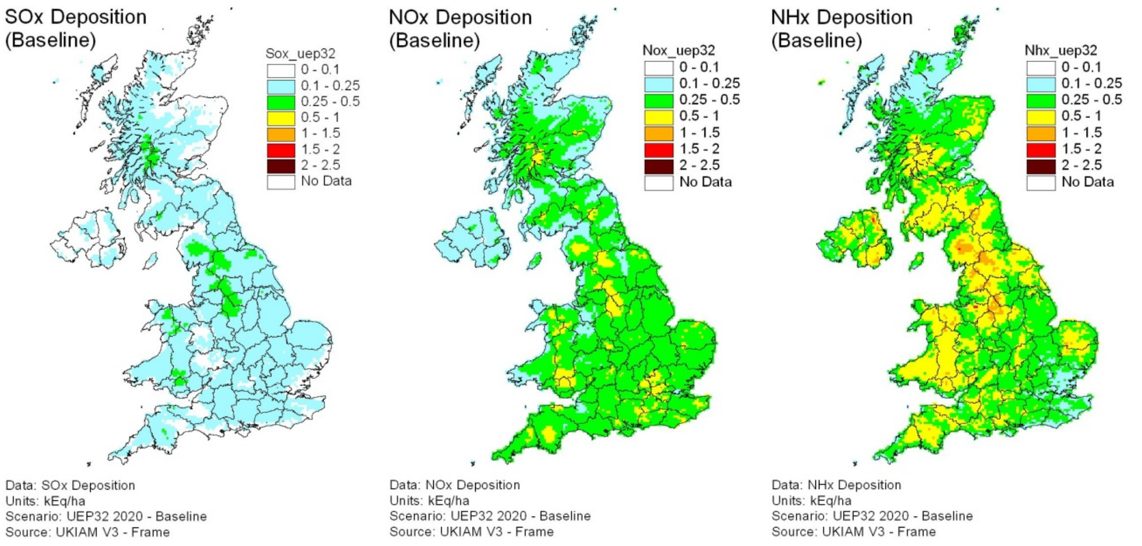
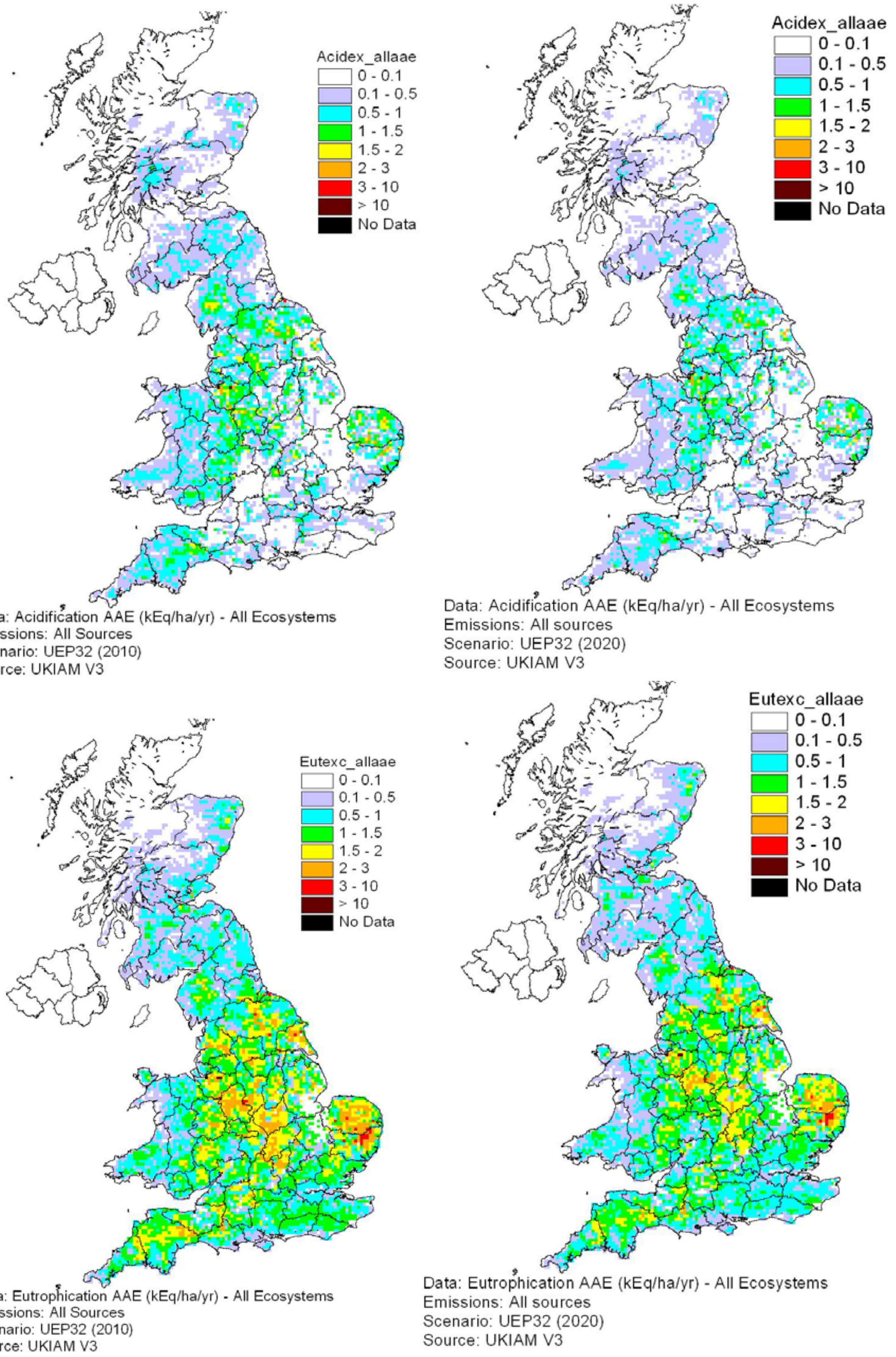


Figure 1.7: deposition of sulphur, oxidised nitrogen and reduced nitrogen in 2020 (keq/ha/yr)

To investigate the improvement in acidification over the next decade implied in the base case scenario, combined maps adding the contributions of all 3 components need to be compared with critical loads for protection of ecosystems from acidification. Similarly with respect to eutrophication the combined contributions of the oxidised and reduced nitrogen need to be compared with critical loads as the maximum levels of nitrogen deposition sustainable to avoid ecosystem damage from excess nitrogen. This needs to allow for the differential rates of deposition within grid squares to forests, grassland etc as compared with the average deposition as mapped above. The resulting maps of exceedance of critical loads, summed and averaged over all ecosystems in each grid square, are shown in figure 1.8 for both acidification and eutrophication. The left-hand maps refer to 2010 and the right-hand maps to 2020. For both acidification and eutrophication there is considerable improvement, but eutrophication still remains the more difficult problem with much greater levels of exccedance. This is in contrast to results obtained by IIASA with the GAINS model, implying little exceedance of critical loads and problems of eutrophication in the UK (see section 2.1.1)

A breakdown indicating the areas of exceedance for different types of ecosystem habitat, and the resulting percentages of the respective total areas exceeded is given in tables 1.6 and 1.7. Again this is given for both 2010 and 2020 with respect to ecosystems at risk with respect to acidification and to eutrophication. These tables illustrate the large proportions, over 90%, of some habitats at risk from excess nitrogen; and it becomes more important to know in more detail what can be protected by further effort. It is for this reason that we have been in discussion with CEH about differentiating SSSIs and other areas of particular importance, and investigating uncertainties in critical loads and different levels of risk (see section 1.2.1).



Data: Acidification AAE (kEq/ha/yr) - All Ecosystems
Emissions: All Sources
Scenario: UEP32 (2010)
Source: UKIAM V3

Data: Acidification AAE (kEq/ha/yr) - All Ecosystems
Emissions: All sources
Scenario: UEP32 (2020)
Source: UKIAM V3

Data: Eutrophication AAE (kEq/ha/yr) - All Ecosystems
Emissions: All Sources
Scenario: UEP32 (2010)
Source: UKIAM V3

Data: Eutrophication AAE (kEq/ha/yr) - All Ecosystems
Emissions: All sources
Scenario: UEP32 (2020)
Source: UKIAM V3

Figure 1.8. Exceedance maps for 2010(left) and 2020(right) for acidification and eutrophication

Broad_Habitat	Habitat Area (km2)	Exceeded Area (km2)	Percentage Area Exceeded	Accumulated Exceedance (keq/year)
Acidity exceedances for Great Britain				
Acid grassland	14,147	10,171	71.89	619,650
Calcareous grassland	1,766	0	0.00	0
Dwarf shrub heath	23,731	5,986	25.22	241,913
Bog	5,021	2,271	45.22	132,307
Montane	3,054	2,566	84.01	117,078
Coniferous woodland (managed)	7,874	4,652	59.08	350,273
Deciduous woodland (managed)	7,452	3,965	53.21	341,881
Unmanaged woods	3,803	1,551	40.80	105,851
Freshwaters	3,482	311	8.95	20,267
All habitats	70,329	31,473	44.75	1,929,221
Nutrient nitrogen exceedances for Great Britain				
Acid grassland	14,049	7,545	53.71	256,466
Calcareous grassland	3,508	1,397	39.82	44,173
Dwarf shrub heath	23,844	6,647	27.88	224,281
Bog	5,068	1,925	37.99	119,993
Montane	3,129	2,983	95.31	125,898
Coniferous woodland (managed)	7,881	7,212	91.51	711,720
Broadleaved woodland (managed)	7,482	7,304	97.62	1,019,059
Unmanaged woods (ground flora)	3,049	2,921	95.83	386,645
Atlantic oak (epiphytic lichens)	822	785	95.48	63,730
Supralittoral sediment	2,099	212	10.08	2,922
All habitats	70,931	38,932	54.89	2,954,888

Table 1.6 Ecosystem Critical Load Exceedances for Great Britain - Scenario: UEP32 (2010)

Broad_Habitat	Habitat Area (km2)	Exceeded Area (km2)	Percentage Area Exceeded	Accumulated Exceedance (keq/year)
Acidity exceedances for Great Britain				
Acid grassland	14,147	9,456	66.84	470,455
Calcareous grassland	1,766	0	0.00	0
Dwarf shrub heath	23,731	4,712	19.86	150,784
Bog	5,021	1,850	36.84	101,063
Montane	3,054	2,265	74.16	77,906
Coniferous woodland (managed)	7,874	3,985	50.60	240,141
Deciduous woodland (managed)	7,452	3,371	45.23	247,132
Unmanaged woods	3,803	1,217	32.00	69,189
Freshwaters	3,482	255	7.32	15,012
All habitats	70,329	27,110	38.55	1,371,682
Nutrient nitrogen exceedances for Great Britain				
Acid grassland	14,049	6,154	43.80	169,976
Calcareous grassland	3,508	1,047	29.86	31,190
Dwarf shrub heath	23,844	5,243	21.99	151,500
Bog	5,068	1,849	36.49	97,041
Montane	3,129	2,818	90.05	93,207
Coniferous woodland (managed)	7,881	6,858	87.01	576,616
Broadleaved woodland (managed)	7,482	7,237	96.72	863,841
Unmanaged woods (ground flora)	3,049	2,874	94.27	322,315
Atlantic oak (epiphytic lichens)	822	703	85.56	50,509
Supralittoral sediment	2,099	147	7.01	1,961
All habitats	70,931	34,930	49.25	2,358,157

Table 1.7 Ecosystem Critical Load Exceedances for Great Britain - Scenario: UEP32 (2020)

1.4.3 Secondary inorganic aerosol (SIA)

Emissions of SO_2, NOx and NH_3 give rise to secondary inorganic aerosol (SIA) as combinations of sulphate, nitrate and ammonium ions. These are responsible for a considerable proportion of fine particulate concentrations, PM_{10} and $PM_{2.5}$, and resulting human exposure. In this section we shall introduce estimates of concentrations of SIA for both 2010 and 2020, mapped over the UK; and the resulting population weighted mean concentrations. This will feed into the next section concerned with total PM_{10} and $PM_{2.5}$ concentrations in relation to air quality.

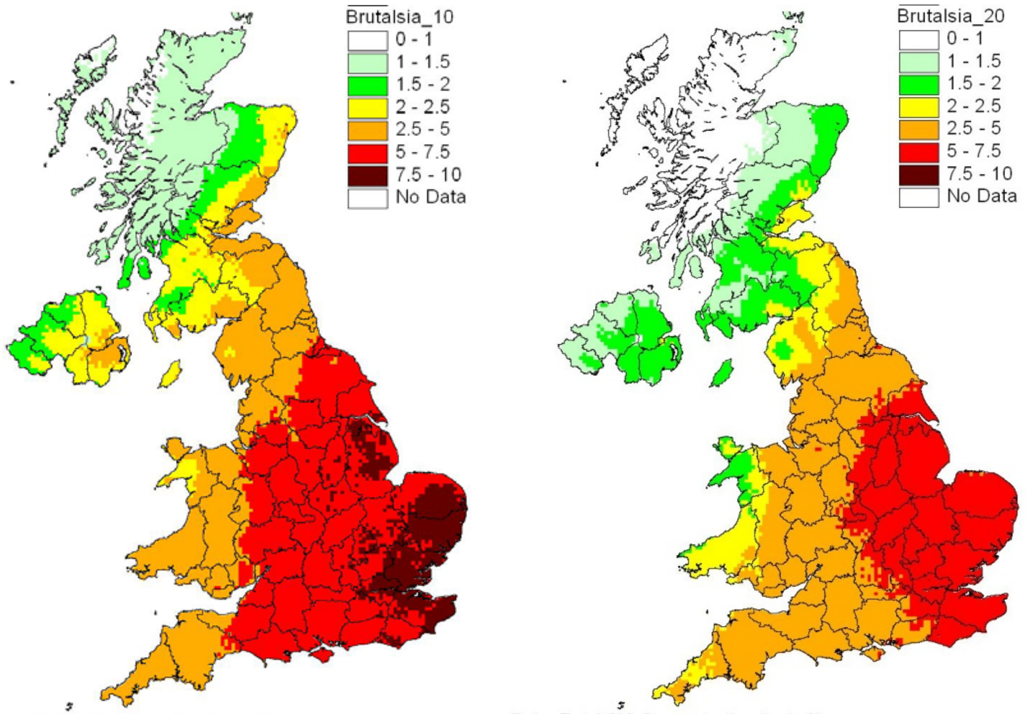
In modelling SIA concentrations we need to capture both contributions from UK sources and transboundary contributions (from shipping and other European sources). The situation is also complicated by the interactive chemistry, whereby changing emissions of one pollutant, NH_3 for example, can affect concentrations of others- NO_3 and SO_4 as well as NH_4. Within SSNIP different atmospheric dispersion models with different chemical schemes have been compared with respect to such responses to changes in precursor emissions, showing qualitative agreement but some significant differences- see section 1.5.

In UKIAM we have a choice of models for modelling SIA concentrations. In each case we start from a model calculation for a given set of emissions, and then adjust the resulting map of concentrations using source-receptor relationships indicating the response of SIA components to unit changes in emissions, including cross-pollutant effects. In UKIAM(FRAME) we use only data from the FRAME model to calculate SIA components, which gives a better spatial resolution, but tends to underestimate the contribution due to precursor emissions outside the UK. Alternatively we have UKIAM(ASAM) that calculates maps of SIA components based entirely on the EMEP model (EMEP5). This has a much coarser resolution, but implies a much higher proportion of the SIA over the UK as resulting from emissions outside the UK. The third alternative is to use a combination of the two models, relying more on the EMEP model in relation to the response to imported emissions, but the FRAME model for the UK contribution with finer resolution. This will be referred to as UKIAM(hybrid), and is used linked to the BRUTAL sub-model in assessing urban air quality and human exposure to particulate matter. This hybrid version, UKIAM(hybrid) has been shown to give a more pessimistic picture of future SIA concentrations than UKIAM(FRAME) as illustrated below. It is UKIAM(hybrid) that has been used for the subsequent results in this section, and for particulate concentrations in the base case. This may result in an overestimate of population weighted mean concentrations in 2020. As shown in the table below UKIAM(FRAME) gives population weighted mean concentrations that are 1.3 $\mu g.m^{-3}$ lower, which can make quite a difference with respect to exceedance of air quality limit values. However we aim to identify where there are risks of exceeding air quality limit values and hence the more pessimistic estimates of UKIAM(hybrid) are appropriate.

Figure 1.9 shows maps of the total SIA in 2010 and 2020. Table 1.8 is based on the response of SIA concentrations to changes in precursor emissions in the UK, and in emissions from outside the UK to give an approximate source apportionment. Further details of model inter-comparisons between FRAME and EMEP5 modelling of SIA are given in section 1.5.

Contribution	UKIAM(hybrid) 2010	UKIAM(hybrid) 2020	UKIAM(FRAME) 2020
NO3 due to UK	1.572	1.100	1.100
NH4 due to UK	0.686	0.535	0.535
SO4 due to UK	0.863	0.685	0.685
NO3 imported	1.308	1.057	0.611
NH4 imported	0.617	0.470	0.179
SO4 imported	0.942	0.703	0.134
Total	5.988	4.550	3.244

Table 1.8 Comparisons of contributions to population weighted mean concentrations of SIA across the UK from emissions within and outside the UK for 2010 and 2020 using the UKIAM(hybrid) approach; and corresponding values based entirely on the FRAME model (UKIAM(FRAME)) for 2020.



Data: Total SIA Concentration (ug/m3)
Emissions: All Sources
Scenario: UEP32(2010/BASE2010
Source: BRUTAL

Data: Total SIA Concentration (ug/m3)
Emissions: All Sources
Scenario: UEP32(2020)/CLE2020
Source: BRUTAL

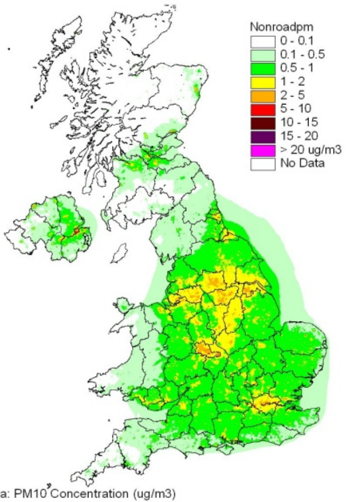
Figure 1.9: total SIA concentration for 2010 and 2020 based on the UKIAM(hybrid approach)

1.4.4 Total PM10 concentrations, human exposure and urban air quality

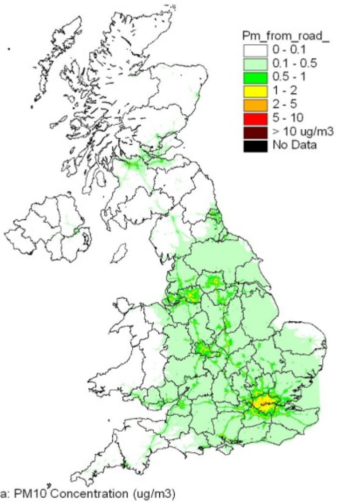
In addition to the secondary inorganic aerosol (SIA) considered in the previous section, total PM10 concentrations include “primary PM10” contributions for those sources of primary PM10 covered in the NAEI and UKIAM emission inventories, plus a number of “other components” comprising water, secondary organic aerosol, sea-salt and urban and rural dusts differentiated as Fe and Ca dusts representing contributions from resuspension, road abrasion, and urban dust and soil particles. The SIA, primary PM10 and other contributions are mapped and added to estimate both gridded concentrations on a 1x1 km grid, and road-side concentrations along the road network for England, Wales and Scotland (detailed road data is not yet available for N Ireland).

The main contributions to primary PM10 come from within the UK, with road transport considered in detail in the BRUTAL model, building up emissions and concentrations across the road network (see section 1.1.3). The road-side concentrations have canyon enhancement factors reflecting different street characteristics for different population densities (population is also mapped on a 1x1 km grid). Each road contribution is superimposed on a background concentration at 1x1 km resolution derived from gridded emissions for both road transport, and for other UK distributed sources and major point sources (based on the PPM model). There are also other small contributions from shipping (based on PPM), which is reduced in line with the lower sulphur content in fuels under the MARPOL agreement: and imported from other countries (based on ASAM/EMEP) amounting to between 0.1 and 0.2 $\mu g.m^{-3}$ over S.E. England .

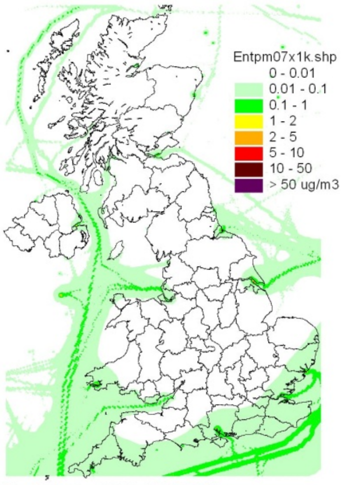
This is illustrated in figure 1.10 showing the separate components of PM10 in 2010 and 2020. It can be seen how all the contributions reduce significantly from 2010 to 2020 in line with emissions, with reductions in exhaust emissions by 2020 resulting in emission from brakes and tyres dominating road transport contributions by 2020.



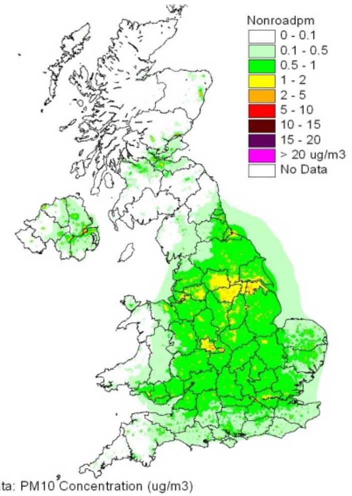
Data: PM10 Concentration (ug/m3)
Emissions: UK non-road sources only
Scenario: UEP32 (2010)
Source: UKIAM V3



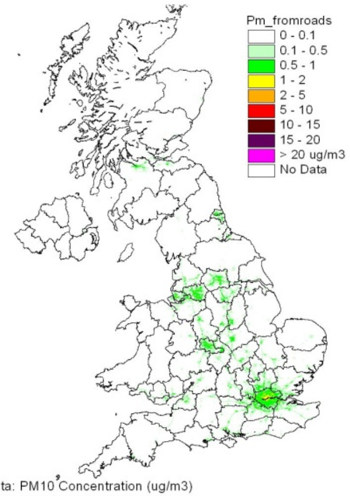
Data: PM10 Concentration (ug/m3)
Emissions: UK Road Transport only
Scenario: UEP32 (2010)
Source: BRUTAL



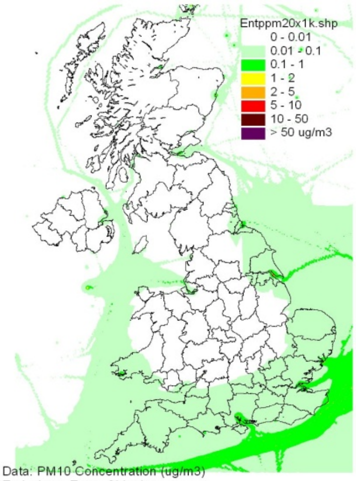
Entec Shipping PM10 (2007/2010)
5km Resolution; ug/m3
Source: PPM (1km)



Data: PM10 Concentration (ug/m3)
Emissions: All UK non-road sources
Scenario: UEP32 (2020)
Source: UKIAM V3



Data: PM10 Concentration (ug/m3)
Emissions: UK road transport
Scenario: UEP32 (2020)
Source: BRUTAL



Data: PM10 Concentration (ug/m3)
Emissions: Entec Shipping
Scenario: 2020
Source: UKIAM V3

A break down of the “other components” of PM_{10} is given in figure 1.11. These closely match the additional contributions used in modelling work at AEA for Defra on urban air quality, and we are grateful for help from John Stedman and his team in developing source attribution for these contributions to achieve mass closure. The secondary organic aerosol, SOA contribution, is based on modelling with the HARM model by Sarah Metcalfe and colleagues. The water content is related to the SIA components as hygroscopic particulate components. In the results presented here they have been calculated for the year 2020 and left the same for 2010, though strictly they should be varied in line with the sulphate and nitrate components (this can be built into UKIAM in future work). The sea salt contribution, supplied by AEA, is based on 2008 monitoring data and the correction usually made to derive non-sea sulphate, and is a natural contribution which strictly can be excluded when comparing with air quality limit values. Here it is included for more direct comparison of total modelled PM with monitoring data, but this gives a pessimistic picture when considering exceedance of air quality limit values. The final components are the urban and rural Fe and Ca dust components, also supplied by AEA, where the rural soil dust component over E England gives a large contribution, in excess of 3 $\mu g.m^{-3}$- see map of Ca based dust component.

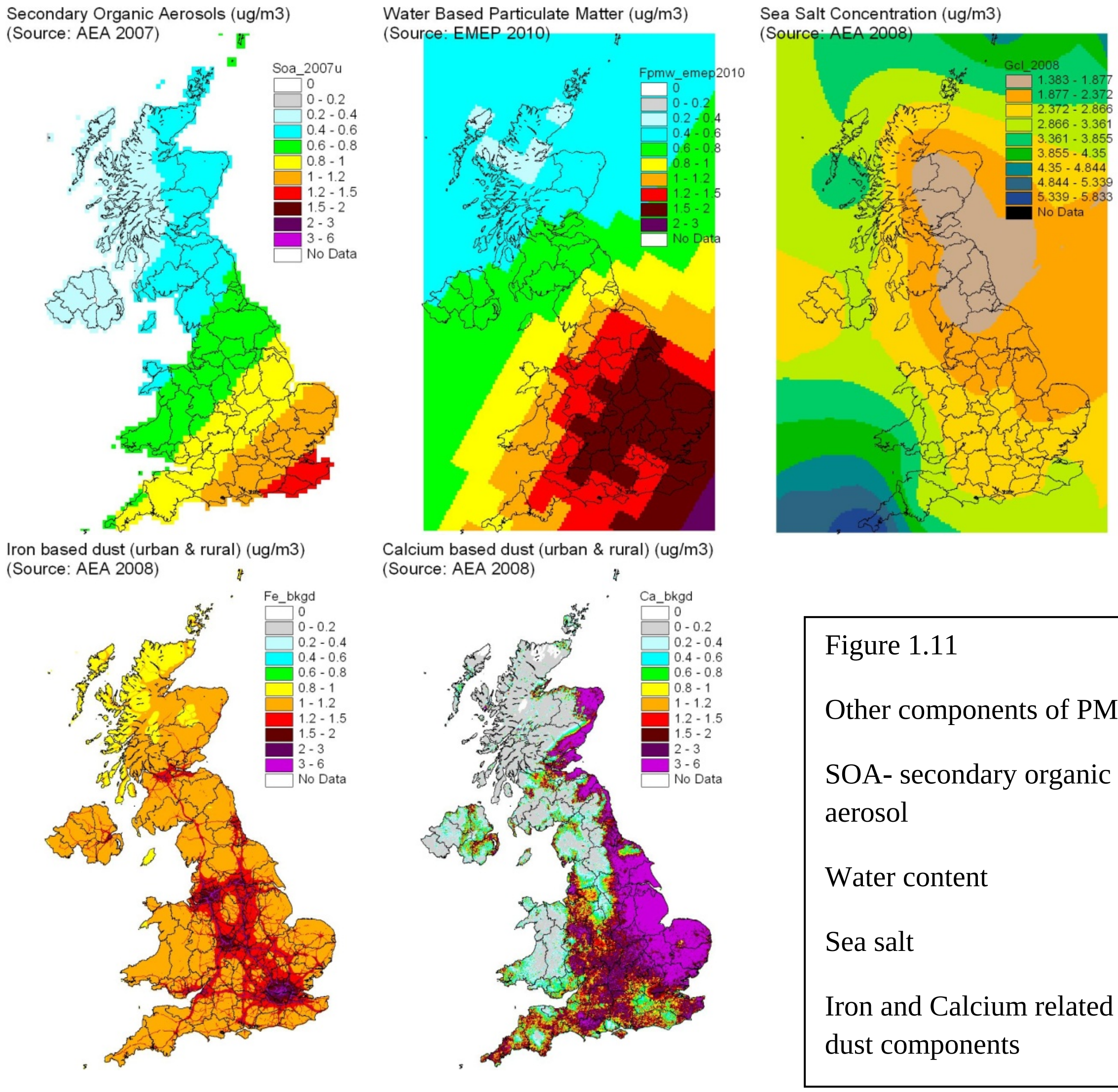


Figure 1.11

Other components of PM10:

SOA- secondary organic aerosol

Water content

Sea salt

Iron and Calcium related dust components

The total PM_{10} gridded concentrations are derived by adding the three component parts, the secondary inorganic aerosol, the modelled primary PM_{10} concentrations and the other components indicated above. Figure 1.12 summarises the 3 components to show how they compare with each other in both 2010 and 2020. Figure 1.13 gives the resulting total PM_{10} concentrations for 2010 and 2020, indicating the expected changes under the base case UEP32 scenario over the next decade. The maximum concentration in 2020 in this map of the gridded background concentrations of PM_{10} is 23.8 $\mu g.m^{-3}$.

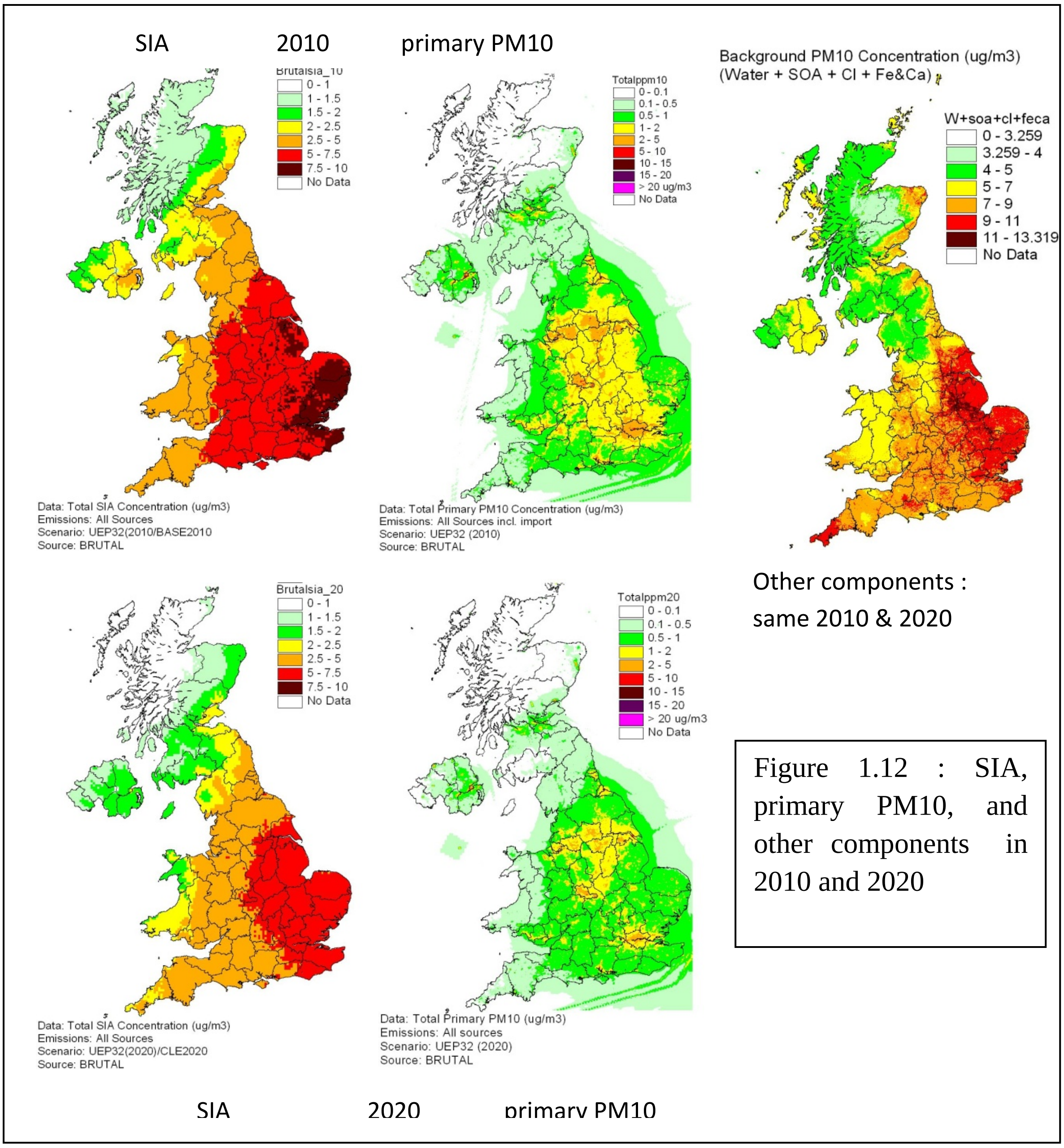


Figure 1.12 : SIA, primary PM10, and other components in 2010 and 2020

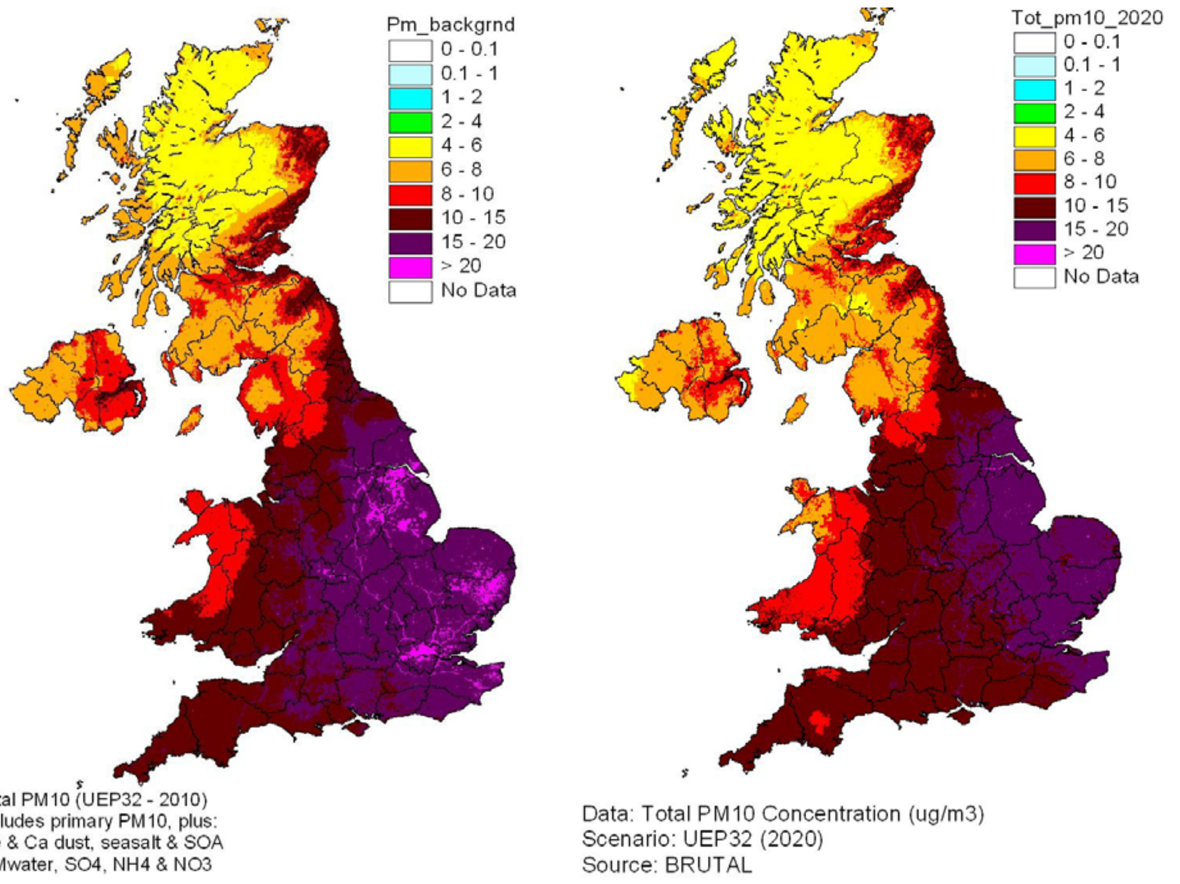


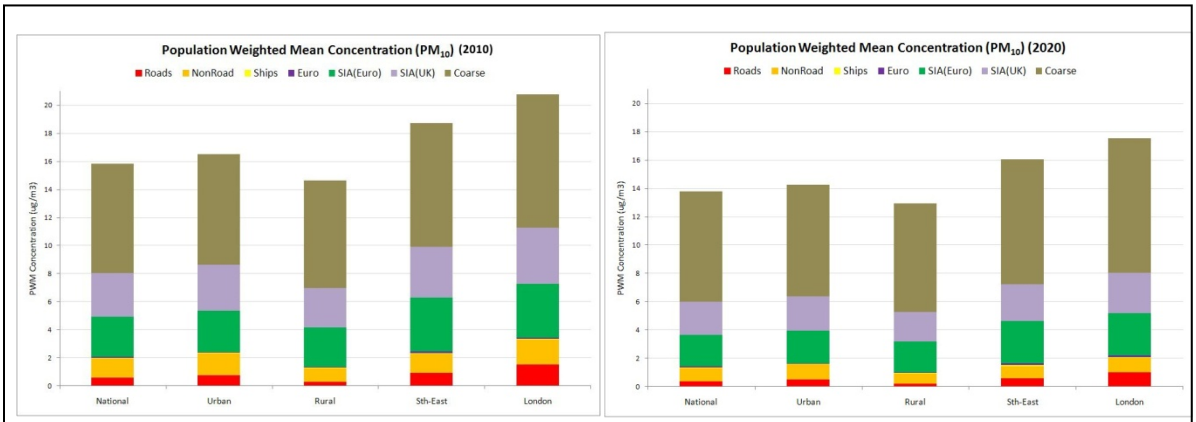
Figure 1.13 Change in total PM10 concentrations (including all background and aerosol contributions) between 2010 and 2020 (UEP32 Scenario)

Population weighted mean concentrations and source apportionment

There is no threshold established for the health effects attributed to exposure to fine particulate matter, nor any definitive evidence of which chemical components are responsible; though it does seem probable that the finer fraction, $PM_{2.5}$, which can penetrate more deeply into the lungs, is more likely to cause problems than the coarser fraction between 2.5 and 10 microns. In UKIAM we integrate the exposure to total PM_{10}, and also $PM_{2.5}$ (see section1.4.5) over different parts of the UK by combining concentrations and population in each grid square, and summing over the relevant areas. This is then used to calculate the average exposures in each area, the population weighted mean concentration, PWMC, as an indicator of health risks.

For the base case the PWMC for the whole of the UK decreases by 2 $\mu g.m^{-3}$ from 15.8 $\mu g.m^{-3}$ in 2010 to 13.8 $\mu g.m^{-3}$ in 2020. Of this 8 $\mu g.m^{-3}$ is due to the “other components” , and the reduction comes from a 24% reduction in the secondary inorganic aerosol, and a 31%

reduction in primary PM_{10} concentrations from UK sources. A more detailed breakdown for different regions and components is given in figure 1.14 below.



PM_{10}	National	Urban	Rural	SthEast	London
Roads	0.609	0.770	0.319	0.930	1.514
NonRoad	1.347	1.563	0.956	1.361	1.792
Ships	0.037	0.039	0.033	0.066	0.040
Euro	0.074	0.076	0.070	0.116	0.116
SIA(Euro)	2.867	2.917	2.776	3.819	3.836
SIA(UK)	3.121	3.279	2.836	3.622	3.994
Other	7.795	7.875	7.649	8.822	9.499
	15.850	16.520	14.639	18.736	20.789

PM_{10}	National	Urban	Rural	SthEast	London
Roads	0.404	0.515	0.205	0.609	1.009
NonRoad	0.936	1.052	0.728	0.860	1.038
Ships	0.034	0.037	0.029	0.068	0.040
Euro	0.068	0.070	0.064	0.106	0.107
SIA(Euro)	2.230	2.273	2.152	2.995	3.014
SIA(UK)	2.320	2.432	2.116	2.598	2.837
Other	7.795	7.875	7.649	8.822	9.499
	13.786	14.254	12.943	16.057	17.544

Fig 1.14. PWM (background) concentrations of PM_{10} for UEP32 Baselines 2010 & 2020

Roadside concentrations and exceedance of air quality limit values

Under the EC's Air Quality Directive there is a limit on the number of days, 37, on which concentrations of PM_{10} exceed 50 $\mu g.m^{-3}$. This is more restrictive than the limit set for the annual average, being approximately equivalent to an annual average of 31.5 $\mu g.m^{-3}$. Nowhere do the background concentrations exceed this value. However the contributions from heavily trafficked roads can be considerable. Hence we consider where the road-side increment superimposed on the background concentrations may exceed 31.5 $\mu g.m^{-3}$, and sum occurrences across links in the UK road network to estimate the total road length at risk of exceeding the air quality limit values for PM10. This is not as precise as the detailed calculations undertaken with models such as ADMS for specific sites, treating combinations of streets in limited urban areas; but it does give a general picture across the whole of the country (except N Ireland for which road data is not available).

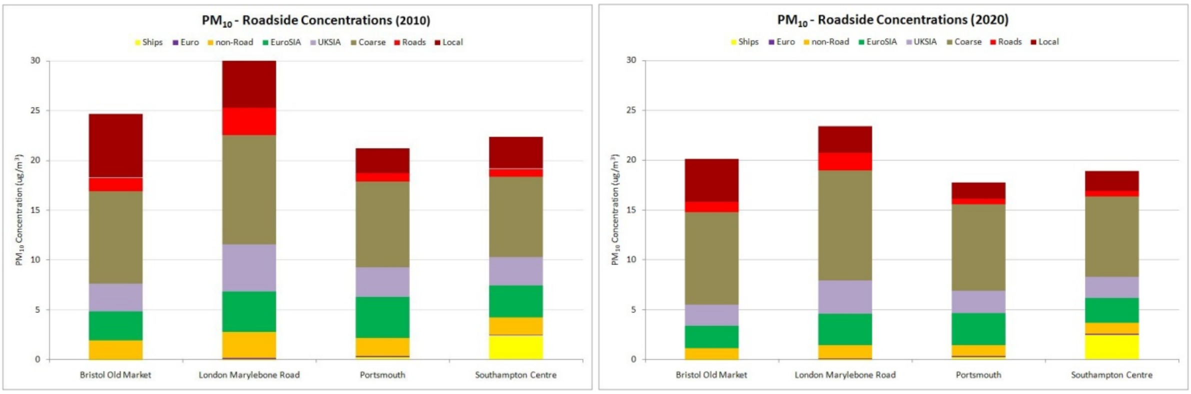
Thus for the base case in 2010 this leads to an estimated 157 km of roads with a risk that road side concentrations are over the limit value, or which 34km are in London. By 2020 this has fallen to 14 km with only 2 km in London. Preliminary comparisons with modelling at AEA with the PCM model, which is more empirical, is encouraging but has suggested the need to make more detailed comparisons of the underlying components, specifically the SIA concentrations which, as we have indicated earlier, may err a little on the high side by ~1 $\mu g.m^{-3}$ in 2020. It is hoped to look into this more in future work.

By comparison with the source-apportionment differentiating contributions to the background concentrations and population exposure in figure 1.14, figure 1.15 gives a similar breakdown for a selection of road-side sites with "local road" indicating the increment due to the road itself. It is interesting to note the contribution of shipping for the site in the port of Southampton. Only the Marylebone Road site in 2010 is close to the air quality limit of 31.5 $\mu g.m^{-3}$.

Figure 1.15: Source apportionment of PM_{10} at road-side locations

PM_{10}		Bristol Old Market	London Marylebone Road	Portsmouth	Southampton Centre
Contributing Sources	Ships	0.017	0.038	0.233	2.400
	Euro	0.068	0.118	0.117	0.096
	non-Road	1.863	2.656	1.818	1.737
	EuroSIA	2.894	4.018	4.151	3.245
	UKSIA	2.803	4.732	2.925	2.839
	Other	9.266	10.988	8.661	8.061
	Roads	1.351	2.728	0.834	0.793
	Local road	6.403	4.824	2.472	3.148
Background Concentration		**18.264**	**25.277**	**18.739**	**19.171**
Roadside Concentration		**24.667**	**30.101**	**21.211**	**22.319**

PM_{10}		Bristol Old Market	London Marylebone Road	Portsmouth	Southampton Centre
Contributing Sources	Ships	0.011	0.039	0.260	2.508
	Euro	0.062	0.108	0.108	0.087
	non-Road	1.092	1.312	1.077	1.126
	EuroSIA	2.223	3.147	3.232	2.461
	UKSIA	2.137	3.356	2.212	2.104
	Other	9.266	10.988	8.661	8.061
	Roads	1.008	1.806	0.561	0.576
	Local road	4.296	2.647	1.627	2.013
Background Concentration		**15.799**	**20.755**	**16.109**	**16.923**
Roadside Concentration		**20.095**	**23.403**	**17.737**	**18.937**



1.4.5 Concentrations of $PM_{2.5}$ and source apportionment

Legislation on air quality is being extended to cover $PM_{2.5}$ as well as PM_{10}. In this case the emphasis is on reducing overall population exposure, and hence on background concentrations: as compared with the air quality limit values for PM_{10} which apply to peak concentrations at the worst locations, where roadside concentrations are important. The aim will be to reduce population exposure in urban agglomerations by 10% between 2010 and 2020. This will require monitoring of $PM_{2.5}$ at sites representative of population exposure in those agglomerations. In this section we give maps of background concentrations of $PM_{2.5}$ in 2010 and 2020, together with a breakdown of different contributions to population exposure.

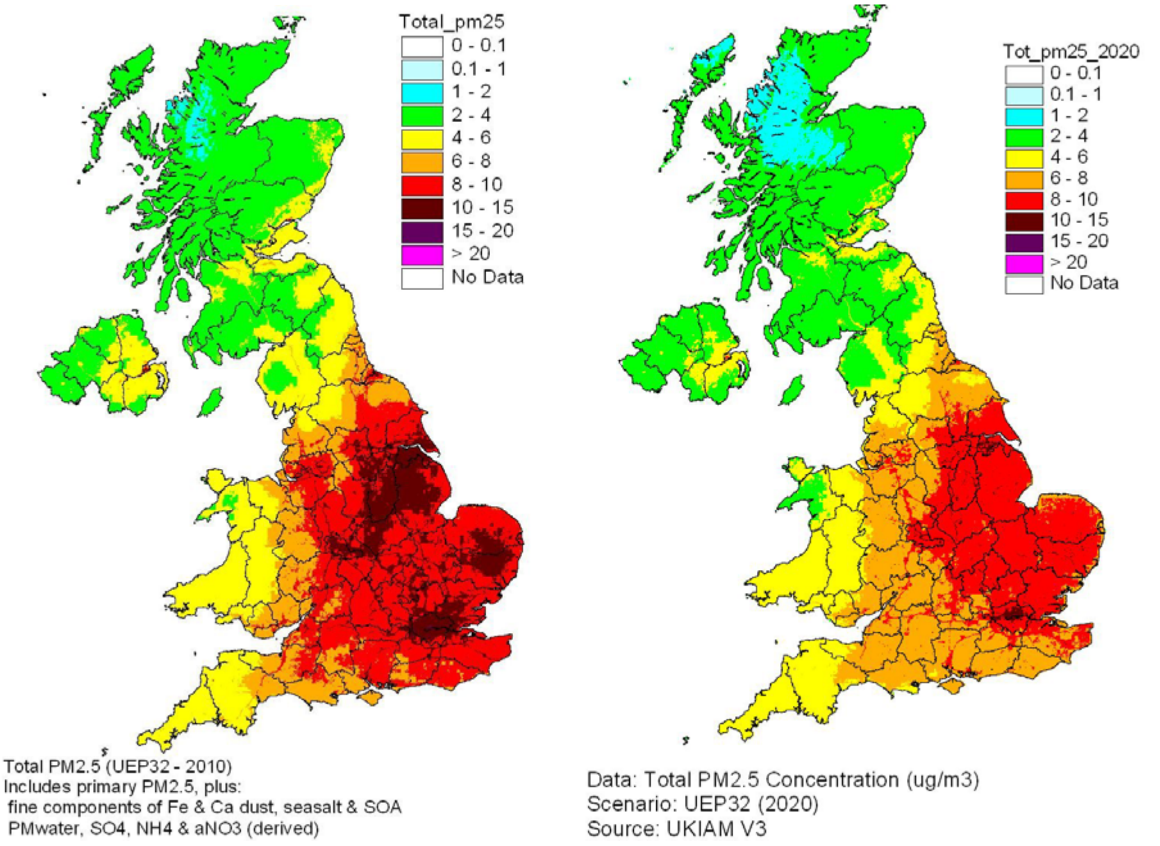
Gridded concentrations of $PM_{2.5}$ are assembled in an analogous way to the background PM_{10} concentrations, superimposing SIA, modelled contributions from primary emissions, and “other components”. For the SIA the contribution is less than for PM_{10} because some of the nitrate aerosol is in the coarse 2.5 to 10 micron range. For the primary emissions and other contributions scaling factors are applied to the values assumed for PM_{10}. Generation of PM emissions comes mainly from combustion or abrasive processes; together with some processes which are difficult to quantify and model, such as re-suspension of road dust which is included in the “other components”. For many combustion sources which are already highly controlled the emissions of $PM_{2.5}$ and PM_{10} are very similar, but for sources such as dust and soils the proportion of finer $PM_{2.5}$ is relatively small. Table below gives a breakdown of the components of the finer $PM_{2.5}$ showing direct comparison with PM_{10}. This breakdown is in terms of the population weighted mean concentrations over the whole of the UK, but can be broken down in future to cover urban agglomerations in relation to the extension of air quality legislation to $PM_{2.5}$ as well as PM_{10}.

Components of PM_{10}			
Background PM_{10}	Ca Rural	1.12395	
	Ca Urban	0.483883	
	Fe Rural	0.976262	
	Fe Urban	0.623307	
	SeaSalt	2.461312	
	SOA	0.871544	
	Pmwater	1.364296	7.904554
Primary PM_{10}	Shipping	0.03698	
	EuroPM	0.074259	
	ukppm10	1.676904	1.788143
SIA	NH4	0.865043	
	SO4	0.997047	
	NO3	2.183719	4.045809
TOTAL PM_{10} (μg/m^3)			**13.73851**

Components of $PM_{2.5}$			
Background $PM_{2.5}$	Ca Rural Ca Urban	0.466731	
	Fe Rural Fe Urban	0.633814	
	SeaSalt	0.664456	
	SOA	0.653658	
	Pmwater	1.365644	3.784303
Primary $PM_{2.5}$	Shipping	*(included in ukppm2.5)*	
	EuroPM	n/a	
	ukppm2.5	1.333028	1.333028
SIA	NH4	0.865043	
	SO4	0.997047	
	aNO3	1.869187	3.731277
TOTAL $PM_{2.5}$ (μg/m^3)			8.848608

Table 1.8: Source apportionment of $PM_{2.5}$ as compared with PM_{10} (based on PWMC for UK)

Figure 1.16 shows maps of total concentrations of PM2.5 in 2010 and 2020 based on a 1x1 km grid. These may be compared with the corresponding maps of PM$_{10}$ in figure XX. The maximum concentration of PM$_{2.5}$ in 2020 is 15µg.m^{-3},as compared with 23.8 µg.m^{-3} for PM$_{10}$.



Total PM2.5 (UEP32 - 2010)
Includes primary PM2.5, plus:
fine components of Fe & Ca dust, seasalt & SOA
PMwater, SO4, NH4 & aNO3 (derived)

Data: Total PM2.5 Concentration (ug/m3)
Scenario: UEP32 (2020)
Source: UKIAM V3

Figure 1.16: maps of PM$_{2.5}$ concentration in 2010 and 2020 for baseline scenario

1.4.6 NO2 concentrations and urban air quality

This section addresses trends in NO_2 concentrations between 2010 and 2020. It has been observed that NO_2 concentrations are not reducing in accordance with estimated reductions in NOx emissions, a topic that is now to be addressed by AQEG. One contributing factor is the increasing proportion of NOx emissions emitted as primary NO_2. This is largely attributed to diesel cars and LGVs from Euro 3 onwards, and hence this increasing trend in the primary proportion of NO_2 is likely to continue over the next decade, although the overall NOx emission will be reduced. To estimate the overall effect on NO_2 concentrations now and in 2020 we have used the BRUTAL sub-model of UKIAM linking road transport and urban air quality, incorporating the new module developed to relate NO_2 concentrations to NOx concentrations in UKIAM, which is described in section 1.1.7.

The first step is defining the NOx and NO_2 emissions. In the analysis below, although still related to the UEP32 base case, we have used updated emission factors for road transport in line with recent updates in the NAEI, and information supplied by AEA on the primary fractions of NO_2 for different vehicle categories (see table 1.3 in section 1.1.7), and also for non-road transport sources (source: *An emission inventory for primary NO2 and projections for road transport, NAEI Ref 48954007*).

Incorporation of these primary NO_2 contributions into the BRUTAL model follows a 3-tier approach:

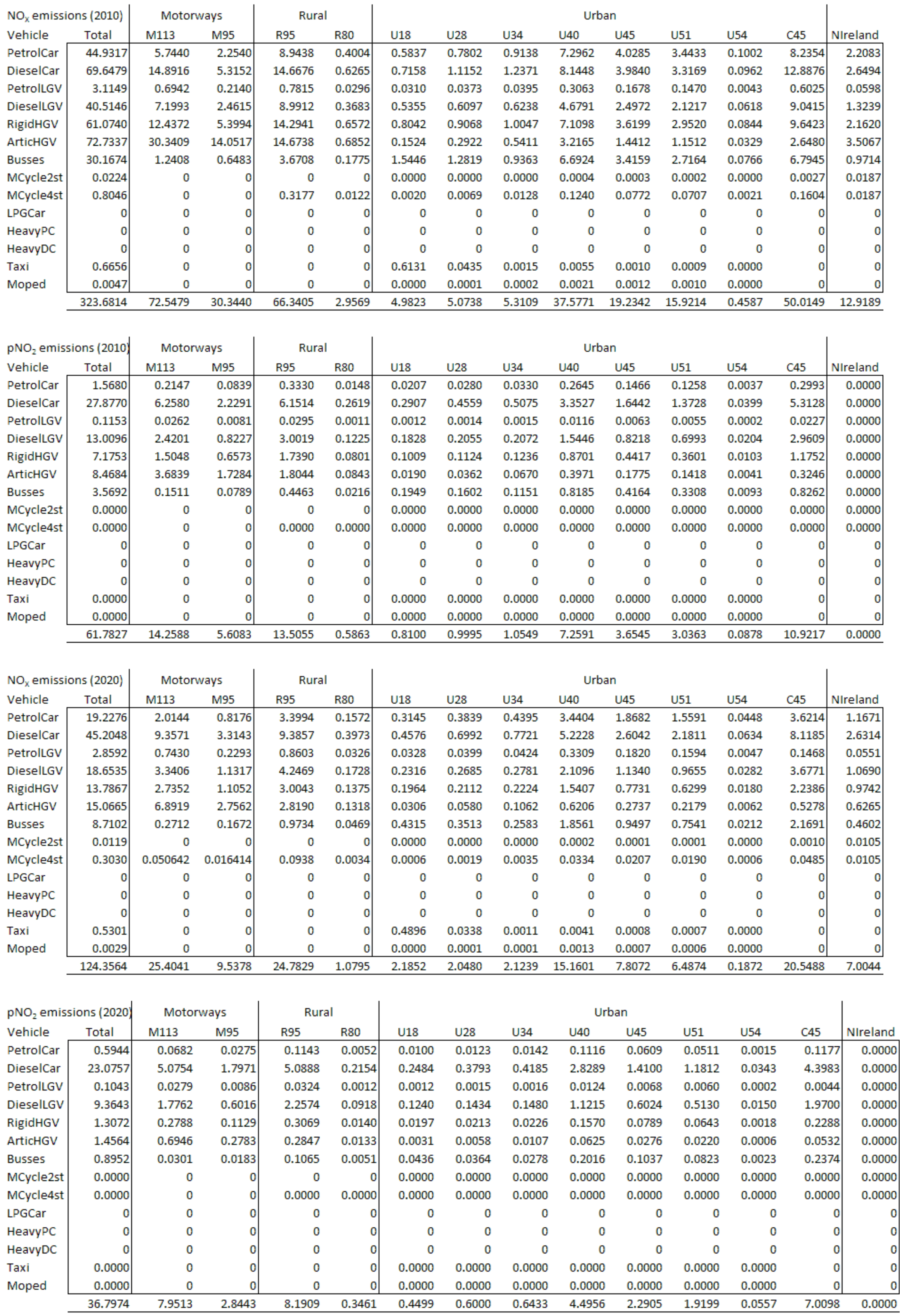
1. Estimation of pNO_2 from non-traffic sources is calculated by the UKIAM; currently this approximates to 10%.
2. Both NO_X and pNO_2 emissions from road transport are calculated based upon emissions factors provided by iMOVE; these emissions are independently ‘dispersed’ assuming no chemical conversion to provide spatialised representations of both NOX and pNO_2. Thus the proportion of pNO_2 from road transport can be spatially defined, giving *alpha* values for the background effects including road transport (see figure 1.17 below).
3. Finally, the proportion of pNO_2 at the roadside will be dominated by the emissions on the specified road links (ie. in the given grid square) because the emissions at the roadside have not yet had an opportunity to disperse; thus values for *alpha* at the roadside can be determined within each grid square.

Thus, *alpha* (ie. the percentage of pNO_2 wrt NO_X) at the roadside is defined by:

$$\alpha = \frac{(pNO2_{other} + pNO2_{traffic} + pNO2_{roadside})}{(NOX_{other} + NOX_{traffic} + NOX_{roadside})}$$

Where: $pNO2_{other}$ & $pNO2_{traffic}$ and NOX_{other} & $NOX_{traffic}$ relate to background concentrations of pNO_2 and NO_X from both non-traffic and traffic sources, and $pNO2_{roadside}$ & $NOX_{roadside}$ relate to emissions of pNO_2 and NO_X in specific grid squares (ie. at the roadside)

Road transport emissions of NOx and primary NO_2 broken down by vehicle type, and by road type and speed are summarised in table 1.9. This clearly shows how the diesel cars and LGVs dominate the primary NO2 emissions, and that whereas total NOx emissions reduce by ?% NO2 emission reduce by only % between 2010 and 2020.



NO$_x$ emissions (2010)		Motorways		Rural		Urban								
Vehicle	Total	M113	M95	R95	R80	U18	U28	U34	U40	U45	U51	U54	C45	NIreland
PetrolCar	44.9317	5.7440	2.2540	8.9438	0.4004	0.5837	0.7802	0.9138	7.2962	4.0285	3.4433	0.1002	8.2354	2.2083
DieselCar	69.6479	14.8916	5.3152	14.6676	0.6265	0.7158	1.1152	1.2371	8.1448	3.9840	3.3169	0.0962	12.8876	2.6494
PetrolLGV	3.1149	0.6942	0.2140	0.7815	0.0296	0.0310	0.0373	0.0395	0.3063	0.1678	0.1470	0.0043	0.6025	0.0598
DieselLGV	40.5146	7.1993	2.4615	8.9912	0.3683	0.5355	0.6097	0.6238	4.6791	2.4972	2.1217	0.0618	9.0415	1.3239
RigidHGV	61.0740	12.4372	5.3994	14.2941	0.6572	0.8042	0.9068	1.0047	7.1098	3.6199	2.9520	0.0844	9.6423	2.1620
ArticHGV	72.7337	30.3409	14.0517	14.6738	0.6852	0.1524	0.2922	0.5411	3.2165	1.4412	1.1512	0.0329	2.6480	3.5067
Busses	30.1674	1.2408	0.6483	3.6708	0.1775	1.5446	1.2819	0.9363	6.6924	3.4159	2.7164	0.0766	6.7945	0.9714
MCycle2st	0.0224	0	0	0	0	0.0000	0.0000	0.0000	0.0004	0.0003	0.0002	0.0000	0.0027	0.0187
MCycle4st	0.8046	0	0	0.3177	0.0122	0.0020	0.0069	0.0128	0.1240	0.0772	0.0707	0.0021	0.1604	0.0187
LPGCar	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HeavyPC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HeavyDC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taxi	0.6656	0	0	0	0	0.6131	0.0435	0.0015	0.0055	0.0010	0.0009	0.0000	0	0
Moped	0.0047	0	0	0	0	0.0000	0.0001	0.0002	0.0021	0.0012	0.0010	0.0000	0	0
	323.6814	72.5479	30.3440	66.3405	2.9569	4.9823	5.0738	5.3109	37.5771	19.2342	15.9214	0.4587	50.0149	12.9189

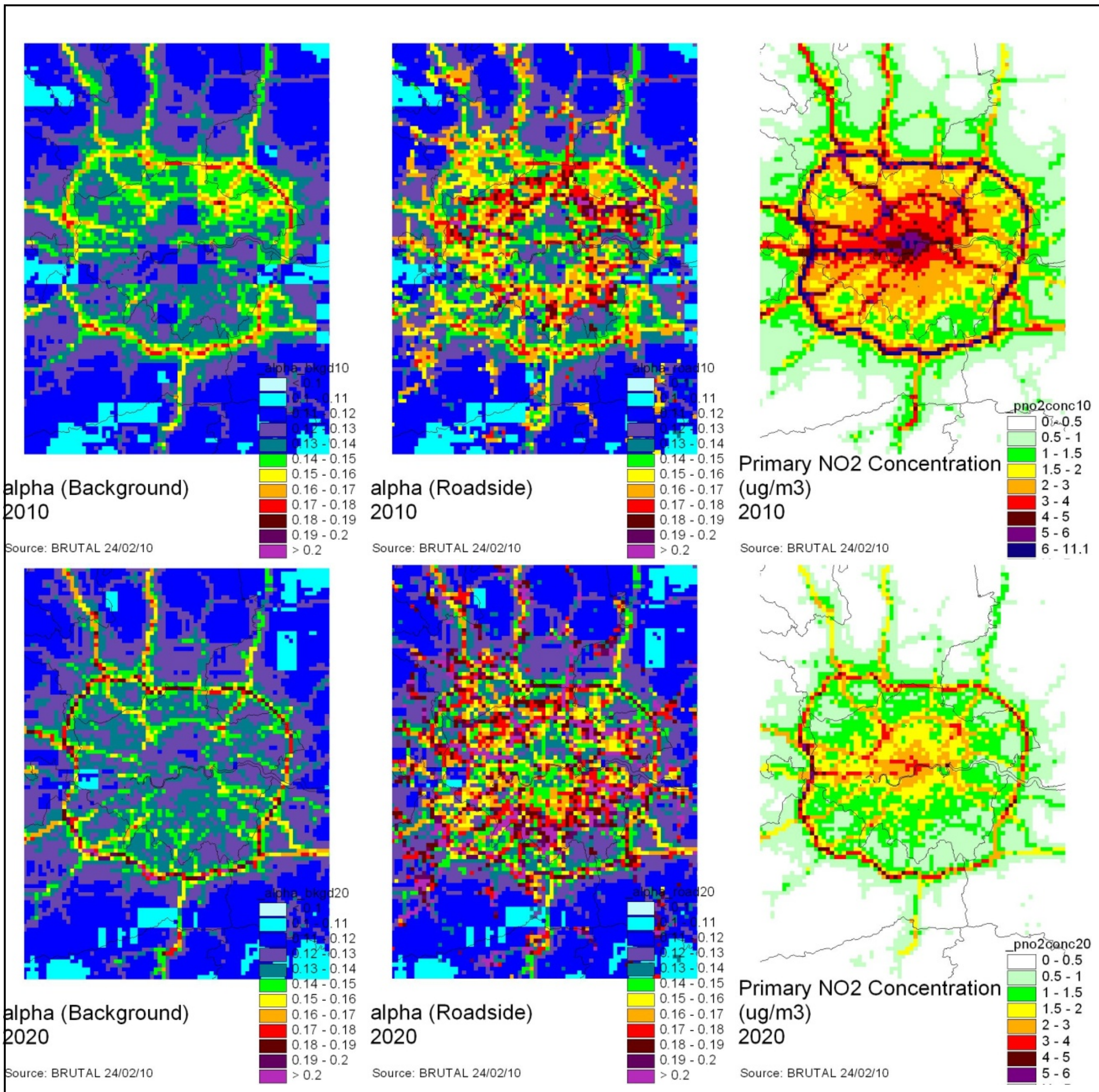
pNO$_2$ emissions (2010)		Motorways		Rural		Urban								
Vehicle	Total	M113	M95	R95	R80	U18	U28	U34	U40	U45	U51	U54	C45	NIreland
PetrolCar	1.5680	0.2147	0.0839	0.3330	0.0148	0.0207	0.0280	0.0330	0.2645	0.1466	0.1258	0.0037	0.2993	0.0000
DieselCar	27.8770	6.2580	2.2291	6.1514	0.2619	0.2907	0.4559	0.5075	3.3527	1.6442	1.3728	0.0399	5.3128	0.0000
PetrolLGV	0.1153	0.0262	0.0081	0.0295	0.0011	0.0012	0.0014	0.0015	0.0116	0.0063	0.0055	0.0002	0.0227	0.0000
DieselLGV	13.0096	2.4201	0.8227	3.0019	0.1225	0.1828	0.2055	0.2072	1.5446	0.8218	0.6993	0.0204	2.9609	0.0000
RigidHGV	7.1753	1.5048	0.6573	1.7390	0.0801	0.1009	0.1124	0.1236	0.8701	0.4417	0.3601	0.0103	1.1752	0.0000
ArticHGV	8.4684	3.6839	1.7284	1.8044	0.0843	0.0190	0.0362	0.0670	0.3971	0.1775	0.1418	0.0041	0.3246	0.0000
Busses	3.5692	0.1511	0.0789	0.4463	0.0216	0.1949	0.1602	0.1151	0.8185	0.4164	0.3308	0.0093	0.8262	0.0000
MCycle2st	0.0000	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MCycle4st	0.0000	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
LPGCar	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HeavyPC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HeavyDC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taxi	0.0000	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0
Moped	0.0000	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0
	61.7827	14.2588	5.6083	13.5055	0.5863	0.8100	0.9995	1.0549	7.2591	3.6545	3.0363	0.0878	10.9217	0.0000

NO$_x$ emissions (2020)		Motorways		Rural		Urban								
Vehicle	Total	M113	M95	R95	R80	U18	U28	U34	U40	U45	U51	U54	C45	NIreland
PetrolCar	19.2276	2.0144	0.8176	3.3994	0.1572	0.3145	0.3839	0.4395	3.4404	1.8682	1.5591	0.0448	3.6214	1.1671
DieselCar	45.2048	9.3571	3.3143	9.3857	0.3973	0.4576	0.6992	0.7721	5.2228	2.6042	2.1811	0.0634	8.1185	2.6314
PetrolLGV	2.8592	0.7430	0.2293	0.8603	0.0326	0.0328	0.0399	0.0424	0.3309	0.1820	0.1594	0.0047	0.1468	0.0551
DieselLGV	18.6535	3.3406	1.1317	4.2469	0.1728	0.2316	0.2685	0.2781	2.1096	1.1340	0.9655	0.0282	3.6771	1.0690
RigidHGV	13.7867	2.7352	1.1052	3.0043	0.1375	0.1964	0.2112	0.2224	1.5407	0.7731	0.6299	0.0180	2.2386	0.9742
ArticHGV	15.0665	6.8919	2.7562	2.8190	0.1318	0.0306	0.0580	0.1062	0.6206	0.2737	0.2179	0.0062	0.5278	0.6265
Busses	8.7102	0.2712	0.1672	0.9734	0.0469	0.4315	0.3513	0.2583	1.8561	0.9497	0.7541	0.0212	2.1691	0.4602
MCycle2st	0.0119	0	0	0	0	0.0000	0.0000	0.0000	0.0002	0.0001	0.0001	0.0000	0.0010	0.0105
MCycle4st	0.3030	0.050642	0.016414	0.0938	0.0034	0.0006	0.0019	0.0035	0.0334	0.0207	0.0190	0.0006	0.0485	0.0105
LPGCar	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HeavyPC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HeavyDC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taxi	0.5301	0	0	0	0	0.4896	0.0338	0.0011	0.0041	0.0008	0.0007	0.0000	0	0
Moped	0.0029	0	0	0	0	0.0000	0.0001	0.0001	0.0013	0.0007	0.0006	0.0000	0	0
	124.3564	25.4041	9.5378	24.7829	1.0795	2.1852	2.0480	2.1239	15.1601	7.8072	6.4874	0.1872	20.5488	7.0044

pNO$_2$ emissions (2020)		Motorways		Rural		Urban								
Vehicle	Total	M113	M95	R95	R80	U18	U28	U34	U40	U45	U51	U54	C45	NIreland
PetrolCar	0.5944	0.0682	0.0275	0.1143	0.0052	0.0100	0.0123	0.0142	0.1116	0.0609	0.0511	0.0015	0.1177	0.0000
DieselCar	23.0757	5.0754	1.7971	5.0888	0.2154	0.2484	0.3793	0.4185	2.8289	1.4100	1.1812	0.0343	4.3983	0.0000
PetrolLGV	0.1043	0.0279	0.0086	0.0324	0.0012	0.0012	0.0015	0.0016	0.0124	0.0068	0.0060	0.0002	0.0044	0.0000
DieselLGV	9.3643	1.7762	0.6016	2.2574	0.0918	0.1240	0.1434	0.1480	1.1215	0.6024	0.5130	0.0150	1.9700	0.0000
RigidHGV	1.3072	0.2788	0.1129	0.3069	0.0140	0.0197	0.0213	0.0226	0.1570	0.0789	0.0643	0.0018	0.2288	0.0000
ArticHGV	1.4564	0.6946	0.2783	0.2847	0.0133	0.0031	0.0058	0.0107	0.0625	0.0276	0.0220	0.0006	0.0532	0.0000
Busses	0.8952	0.0301	0.0183	0.1065	0.0051	0.0436	0.0364	0.0278	0.2016	0.1037	0.0823	0.0023	0.2374	0.0000
MCycle2st	0.0000	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
MCycle4st	0.0000	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
LPGCar	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HeavyPC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HeavyDC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taxi	0.0000	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0
Moped	0.0000	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0
	36.7974	7.9513	2.8443	8.1909	0.3461	0.4499	0.6000	0.6433	4.4956	2.2905	1.9199	0.0557	7.0098	0.0000

Table1.9: Road transport emissions of NOx and primary NO2 in 2010 and 2020

In the modelling *alpha*, the primary NO_2 fraction, will vary from one grid square to another for the background concentrations, and for each road in the UK network. This is illustrated in figure 1.17 below, together with the road side “primary NO2” concentrations mapped as the corresponding *alpha* fraction of the NOx concentration for the busiest road in each 1x1 km grid square. It is clear that the overall alpha values increase between 2010 and 2020, but that coupled with the NOx reductions the primary NO_2 concentrations still reduce considerably.


lpha (Background)
2010
ource: BRUTAL 24/02/10

alpha (Roadside)
2010
Source: BRUTAL 24/02/10

Primary NO2 Concentration
(ug/m3)
2010
Source: BRUTAL 24/02/10

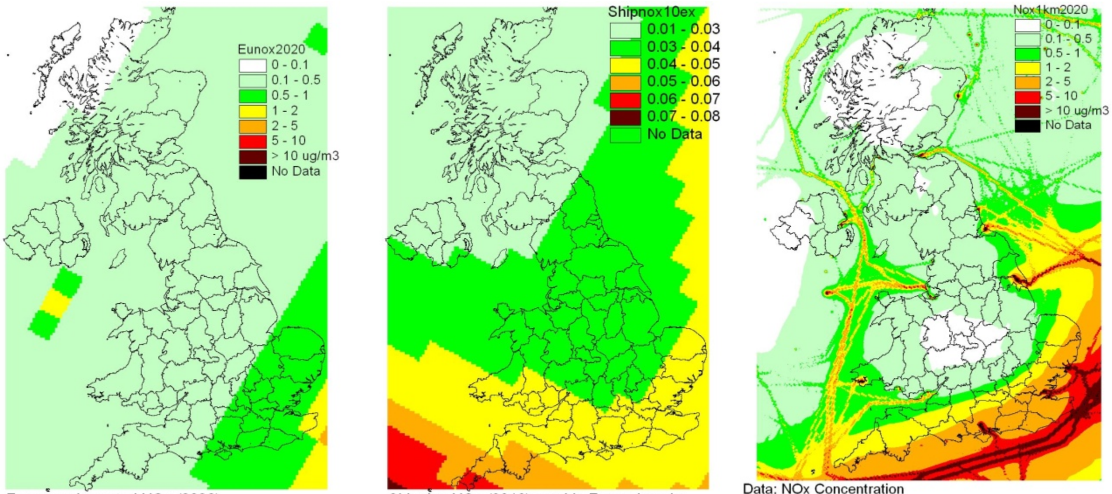
lpha (Background)
2020
ource: BRUTAL 24/02/10

alpha (Roadside)
2020
Source: BRUTAL 24/02/10

Primary NO2 Concentration
(ug/m3)
2020
Source: BRUTAL 24/02/10

Figure 1.17 Primary NO2 contributions from road and other UK sources – UEP32 (2010 & 2020)

Future NOx and NO_2 concentrations depend not only on UK sources but also on imported contributions and shipping in the sea areas surrounding the UK (see section 1.1.8 re the inventory provided by ENTEC). This is illustrated in figure 1.18 showing the different contributions to NOx in 2020.

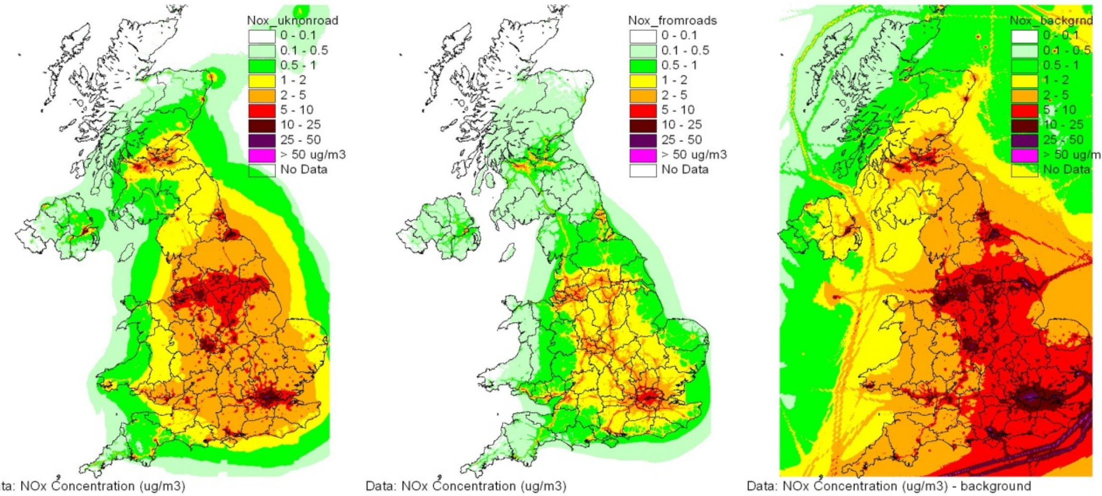


European Imported NOx (2020)
50km resolution; ug/m3 NOx
Source: EuroPPM

Shipping NOx (2010) outside Entec domain
50km resolution; ug/m3 NOx
Source: EuroPPM

Data: NOx Concentration
Units: ug/m3
Emissions: Entec Shipping (2020)
Source: UKIAM V3

(a) Imported NO_X Contributions



Data: NOx Concentration (ug/m3)
Emissions: UK non-road only
Scenario: UEP32 (2020)
Source: UKIAM V3

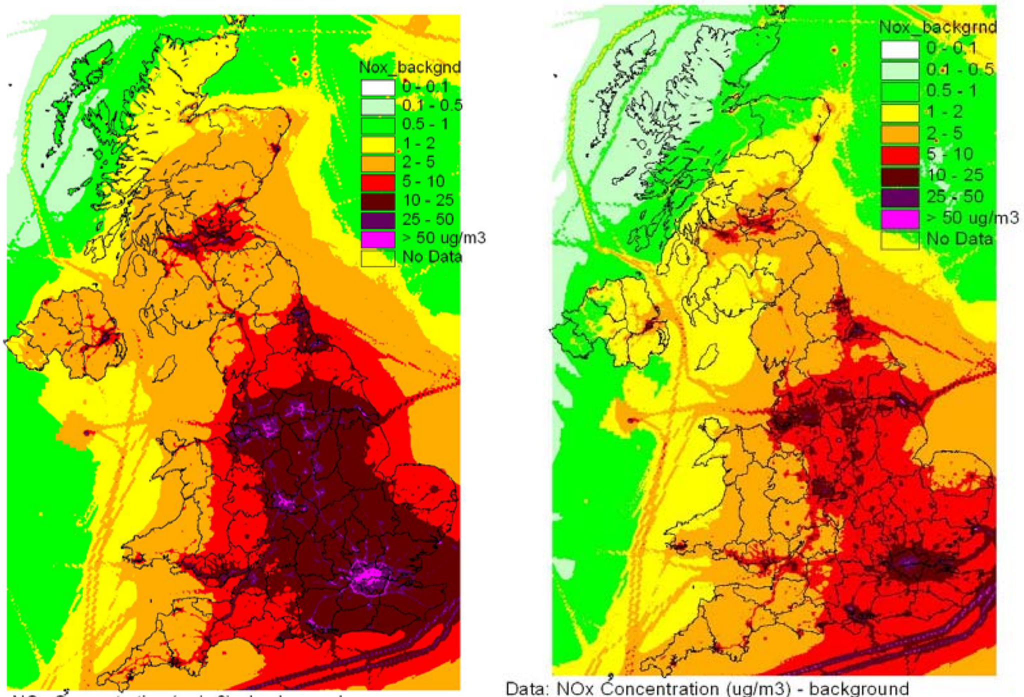
Data: NOx Concentration (ug/m3)
Emissions: UK road transport
Scenario: UEP32 (2020)
Source: BRUTAL

Data: NOx Concentration (ug/m3) - background
Emissions: All Sources
Scenario: UEP32 (2020)
Source: BRUTAL

(b) UK Contributions & total NO_X concentration

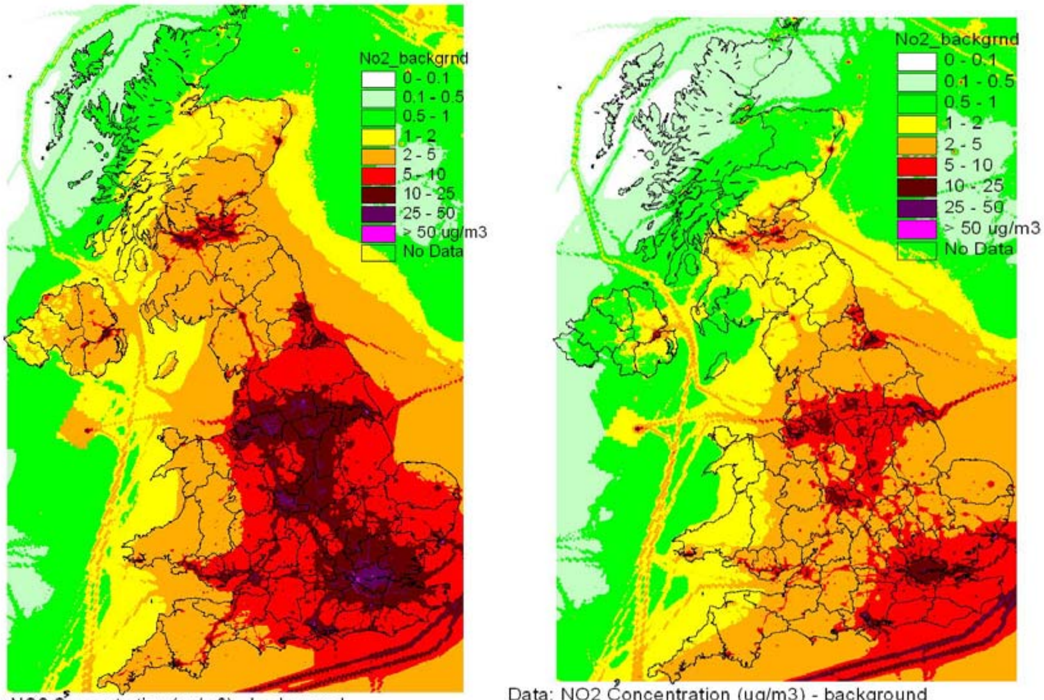
Figure 1.18 Relative contributions from different UK and non-UK sources to NOx concentrations in 2020

Maps of the total gridded NOx concentrations, and derived NO_2 concentrations for both 2010 and 2020 are given in figure 1.19. These show a clear improvement; as an indication population weighted mean concentrations of NOx are roughly halved from 25.7 μg.m^{-3} in 2010 to 12.58 μg.m^{-3} in 2020. A break for different parts of the UK, indicating contributions from different source categories, is given in figure 1.20.



Data: NOx Concentration (ug/m3) - background
Emissions: All Sources
Scenario: UEP32 (2010)
Source: BRUTAL

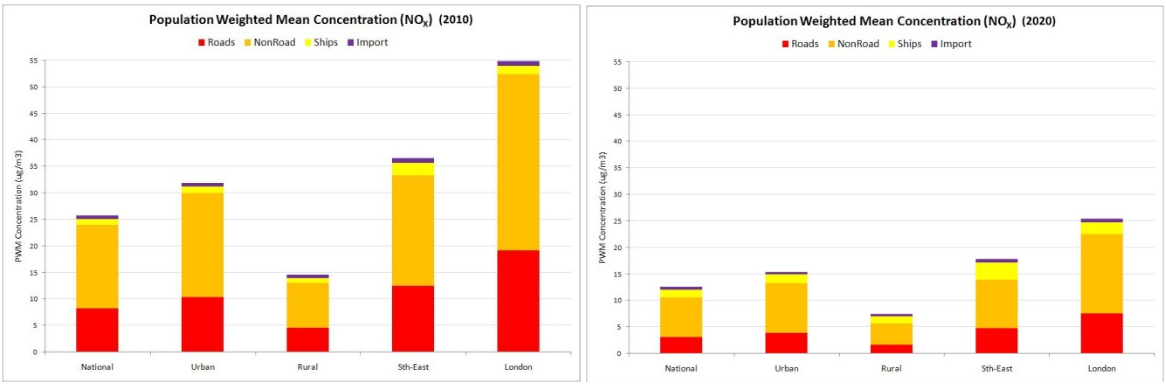
Data: NOx Concentration (ug/m3) - background
Emissions: All Sources
Scenario: UEP32 (2020)
Source: BRUTAL



Data: NO2 Concentration (ug/m3) - background
Emissions: All Sources
Scenario: UEP32 (2010)
Source: BRUTAL

Data: NO2 Concentration (ug/m3) - background
Emissions: All Sources
Scenario: UEP32 (2020)
Source: BRUTAL

Figure 1.19: NOx and NO2 concentrations in 2010 (left) and 2020 (right)



UEP32 (2010) UEP32 (2020)

PWM Concentrations (2010)

NO_X	National	Urban	Rural	SthEast	London
Roads	8.308	10.375	4.575	12.487	19.137
NonRoad	15.655	19.659	8.423	20.816	33.245
Ships	1.148	1.246	0.972	2.371	1.595
Import	0.620	0.634	0.596	0.869	0.876
	25.731	31.913	14.566	36.543	54.853

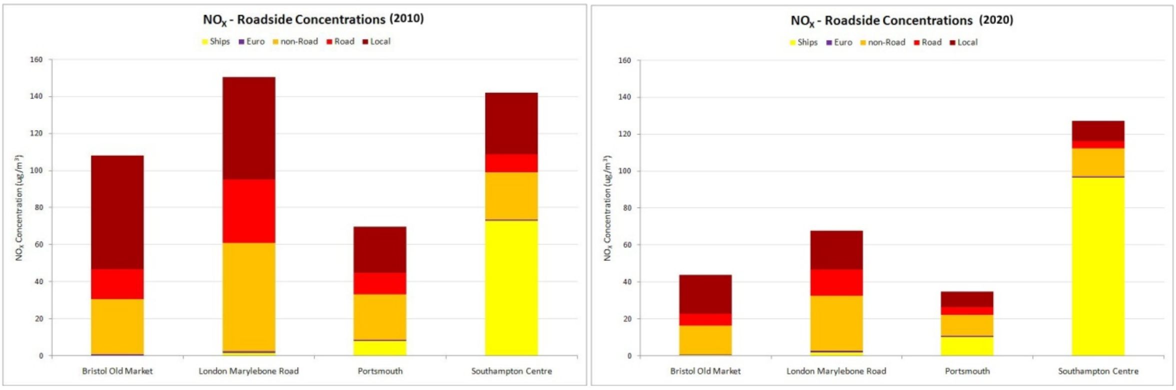
PWM Concentrations (2020)

NO_X	National	Urban	Rural	SthEast	London
Roads	3.156	3.957	1.710	4.814	7.606
NonRoad	7.416	9.299	4.014	9.125	14.962
Ships	1.527	1.657	1.292	3.196	2.160
Import	0.482	0.492	0.462	0.680	0.686
	12.580	15.406	7.478	17.815	25.414

Figure 1.20: Source apportionment of population weighted mean NOx concentrations showing changes between 2010 and 2020

By comparison the road-side concentrations show some contrasting trends in NOx. This is illustrated in figure 1.21 for the same selection of roads as in the earlier section on PM_{10} concentrations in relation to air quality. Busy inland roads where road traffic contributions (red sections of column) exceed non-road contributions, are reduced by a larger percentage than the average background concentrations. However Portsmouth and Southampton as coastal ports reveal a large contribution from shipping, especially for Southampton where the increased contribution from shipping largely negates the reduction from road traffic and other

UK sources. This needs more detailed investigation, preferably with a finer scale model that can resolve the shipping and other contributions in more detail spatially.



NO_X(2010)		Bristol Old Market	London Marylebone Road	Portsmouth	Southampton Centre
Contributing Sources	Ships	0.417	1.534	8.008	72.920
	Euro	0.586	0.892	0.844	0.731
	non-Road	29.661	58.567	24.289	25.390
	Road	16.031	34.127	11.855	9.796
	Local rd	61.495	55.159	24.627	32.964
Background Conc.		**46.695**	**95.121**	**44.996**	**108.837**
Roadside Conc.		**108.191**	**150.279**	**69.623**	**141.801**

NO_X(2020)		Bristol Old Market	London Marylebone Road	Portsmouth	Southampton Centre
Contributing Sources	Ships	0.539	2.077	10.346	96.536
	Euro	0.451	0.700	0.657	0.567
	non-Road	15.465	29.670	11.194	15.066
	Road	6.320	14.384	4.351	3.822
	Local rd	21.100	20.754	8.424	11.265
Background Concentration		**22.775**	**46.831**	**26.548**	**115.991**
Roadside Concentration		**43.875**	**67.586**	**34.972**	**127.256**

Figure 1.21: Break down of Nox concentrations at road-side sites in 2010 and 2020

Road-lengths where NO_2 exceeds air quality limit values.

The BRUTAL sub-model has been used to identify where road-side concentrations are at risk of exceeding air quality limit values of 40 μg.m-3. The resulting road lengths have been summed, and a preliminary comparison made with some recent results from air quality modelling at AEA with the PCM model. In 2010 UKIAM/BRUTAL indicates 2416 km of road with NO2 concentrations $\geq$ 40 μg.m-3, of which 1073 are in London. This is in close agreement with the AEA estimates, but we have rather less roads (300km) with high exccedance (ie > 60μg.m-3) of which 74km are within London. In 2020 the exceedance has fallen dramatically to just 51 km at risk of exceeding 40 μg.m-3, of which only 2km are in London. This is thought to be due to the role of shipping and exceedance in ports such as Southampton, as pointed out above and figure 1.21.

In future work we shall wish to undertake sensitivity analysis, using upper and lower estimates of NO_2 concentrations as described in section 1.1.7: and also to undertake more detailed model inter-comparisons with the PCM model of AEA and other urban modelling studies. Currently work is in progress on model evaluation against monitoring data.

This work on urban NO_2 concentrations will also be made available to AQEG.

1.4.7 Road transport scenarios

Having studied the UEP32 baseline scenarios in detail, this part of the report now turns to scenarios deviating from this. In this section we shall describe some of the road transport scenarios we have addressed, starting with some work earlier in the contract when we were interested in how behavioural change could help to improve air quality as well as technical measures: and continuing with some recent work on scenarios introducing electric vehicles.

Scenarios involving changes in driving behaviour

The following example, taken from a study using the UK integrated assessment model UKIAM (Oxley *et al*, 2003, 2009) as a national equivalent of the GAINS model, illustrates the need for careful consideration of both greenhouse gas emissions and air quality issues to identify win-win situations. Three different scenarios are considered as shown in figure 1.22 below.

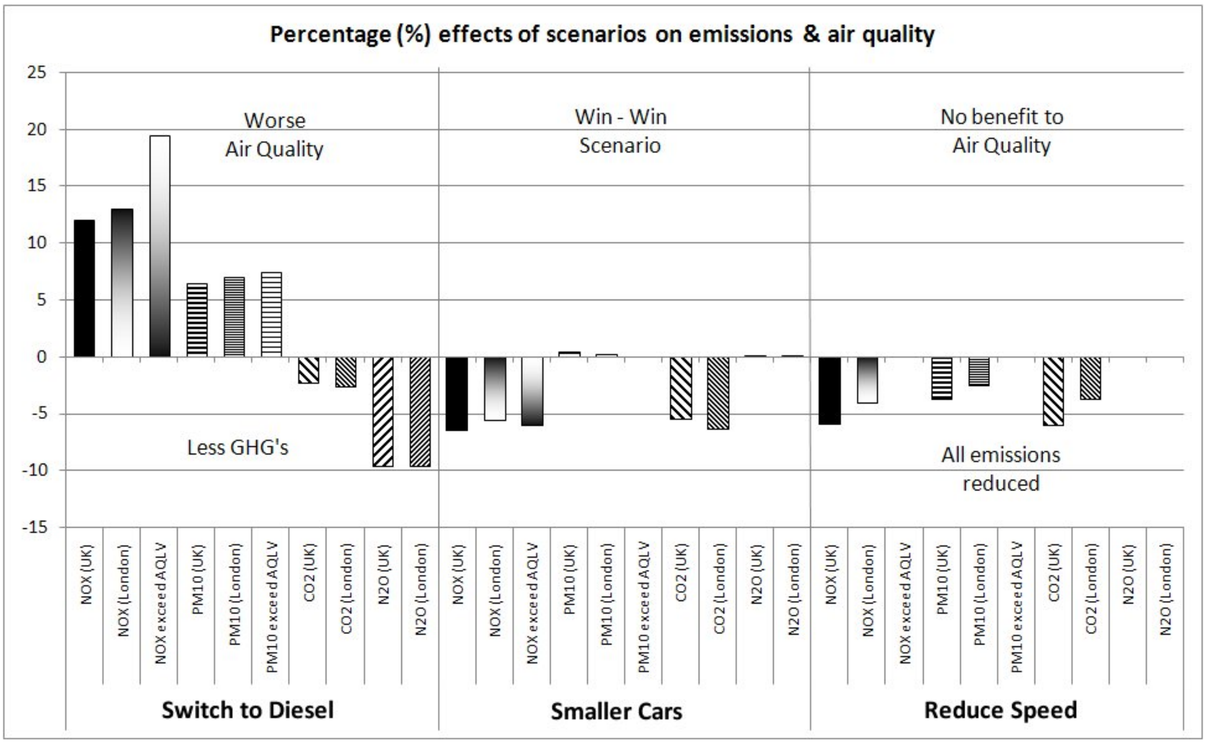


Figure 1.22: Comparison of 3 different scenarios with respect to effects on emissions of air quality pollutants and urban air quality, and emissions of greenhouse gases.

In the first scenario, on the left hand side of the figure, all petrol cars with engine capacity $\geq$ 2 litres are replaced with diesel cars as an extension of the current trend in the UK from petrol to diesel. This leads to a small reduction of the order of 2% in CO_2 emissions from road transport in the UK, and a slightly greater reduction within London where exceedance of limits for urban air quality is of particular concern. The reduction in nitrous oxide emissions, which have increased with the introduction of 3 way catalysts, is larger in percentage terms:

but the total emission from petrol cars is still only about 12 % of the UK N_2O emissions (which are dominated by emissions from soils), and more recent catalysts have addressed this problem and give lower N_2O emissions (AEA 2008). By contrast emissions of NO_X are increased with the switch to diesel, by more than 10% (see two left hand columns for NO_X emissions in the UK and in London respectively); and emissions of fine particulate PM_{10} by around 6 to7 % even with the fitting of particulate filters. However, modelling of concentrations across urban areas implies that the effect of these increases in emissions leads to proportionately larger increases in the road lengths at risk of exceeding air quality standards; particularly for NO_2 where the UK, along with many other countries, is having difficulties in complying with EC legislation. This situation would therefore be a “win” for greenhouse gas control, but a “loser” with respect to air quality.

The second scenario in the middle of the figure represents a behavioural change with a switch of the same larger petrol cars to smaller petrol cars. This by contrast is a “win-win” situation with reductions of NO_X, and also larger reductions in CO_2; and negligible effects on PM_{10} and N_2O.

The third scenario is another widely suggested behavioural change; to reduce CO_2 emissions in the form of lower speeds on faster roads. This also leads to lower emissions of NO_X and PM_{10}, but has negligible benefit for urban air quality where speeds are already restricted. Thus although this might at first sight seem favourable by reducing emissions of both greenhouse gases and air quality pollutants, it does little to help compliance with air quality legislation.

This example illustrates that it is important to consider how changes will affect emissions of both air quality pollutants and greenhouse gases, and also to assess the associated environmental impacts.

NB The above work was undertaken earlier in the SSNIP contract before traffic emissions had been updated, and before the recent work on primary NO_2.

Scenarios introducing electric vehicles

Electric Vehicles (EVs) offer the potential to prevent all tailpipe emissions as all GHG and air pollution costs are accrued at the site of power generation. Even with the current fossil fuel dominated energy production within the UK, well-to-wheel CO_2 emissions of EVs can be 30-40% of conventional IC vehicles (e.g. the REVA G-Wiz, emits $63gCO_2$/km when CO_2 emitted at the power station is included, Spowers 2009). Moreover EVs offer a potential zero carbon form of road transport providing the power generation sector becomes increasingly based on renewables and other low carbon technologies. Note that in 2007, the UK vehicle fleet included 33.9 million registered vehicles of which only 2,000 were electric cars and 4,000 electric LGVs (less than 0.02% in total). No electric HGVs or buses were registered (DfT Vehicle Licensing Statistics 2007).

The main difficulty in modelling the air quality and greenhouse gas emissions associated with EVs is that they lead to associated emissions from other sources, and can therefore not be treated purely as a conventional vehicle type within the BRUTAL model. Hence an integrated assessment model such as UKIAM is invaluable for the modelling of EVs, permitting the energy infrastructure output to be altered in response to a modelled uptake of EVS.

Entec’s work:

In Entec’s recent multi-pollutant measures database (2009) they published a number of results for electric vehicle scenarios. Their assumed uptake of electric vehicles only involved the replacement of pre-Euro 5/V vehicles and not Euro 5/V or Euro 6/VI vehicles. This was guided by recent analysis undertaken for a related study for Defra which showed that total emissions for some pollutants from an electric vehicle powered by electricity from the grid are actually higher in some years than those from an equivalent Euro 5/V or 6/VI petrol or diesel vehicle (e.g. PM emissions from diesel cars and LGVs). In terms of the potential uptake rates of EVs, the BERR/DfT study (2008) looked at a range of scenarios including business as usual (70,000 electric vehicles in UK by 2020), mid-range (600,000), high-range (1,200,000) and extreme range (2,600,000) each of which is based on differing assumptions on the availability of incentives and charging infrastructure as well as changes in the costs of purchasing an electric vehicle.

For their study for cars and LGVs they assumed an uptake rate of 0.01% in 2010 (i.e. in place of petrol or diesel equivalent vehicles) rising by 0.05% per year to 2015 (recognising limitations on supply, sufficient charging infrastructure and technology development) and then increasing by 0.5% per year between 2015 and 2020. This results in the following number of vehicles being replaced by 2020 (cumulative total):

- 391,224 petrol cars (approximately 18% of pre-Euro 5 petrol car numbers in 2020);
- 249,939 diesel cars (approximately 16% of pre-Euro 5 diesel car numbers in 2020);
- 188,779 diesel LGVs (approximately 12% of pre-Euro 5 diesel LGV numbers in 2020).

If these uptake rates were achieved by 2020, this would result in approximately 0.8 million electric vehicles being added to the UK car fleet; this falls in between the mid- and high-range scenarios from the BERR/DfT study.

Our work:

Imperial College have built upon the work of Entec developing two electric vehicle scenarios for the year 2020 each of which was considered for two energy scenarios. The work uses identical efficiency assumptions (electric cars- 0.13 kWh/km in 2020, electric LGVs- 0.30 kWh/km in 2020) but also incorporates energy losses associated with the distribution of electricity to charging stations (assumed as 7%). In addition, local air quality consequences are taken into consideration, unlike Entec's work, the focus of which was on reducing total national level emissions.

EV scenario 1 assumes that in 2020 approximately 1.2 million electric vehicles will be added to the UK fleet, replacing:

- 586,836 pre Euro 5/V petrol cars (approximately 27% of pre-Euro 5 petrol car numbers in 2020)
- 374,909 pre Euro 5/V diesel cars (approximately 24% of pre-Euro 5 diesel car numbers in 2020)
- 283,168 pre Euro 5/V diesel LGVs (approximately 18% of pre-Euro 5 diesel LGV numbers in 2020)

Associated electricity requirements for this scenario are 10.71PJ assuming no energy losses at the point of charging.

EV scenario 2 assumes that in 2020 approximately 50% of the anticipated Euro 6/VI petrol and diesel cars will be replaced by electric cars. This constitutes approximately 8.7 million vehicles and is recognised as a highly ambitious scenario.

Associated electricity requirements for this scenario are 73.44PJ assuming no energy losses at the point of charging.

It was assumed that the electricity requirements for each transport scenario would be met entirely by additional electricity generation and not by utilisation of base load capacity. Transport scenario energy requirements were modelled through UKIAM by changing the outputs, within operating capacities, of respective power stations in 2020. For each electric vehicle scenario two energy scenarios were modelled. One assumes that all electricity requirements are met by the 2020 coal fired power stations, while the other assumes that all electricity requirements are met by the gas fired power stations. As such, in total four scenarios were run through UKIAM:

Code	Description
S10c	Electric vehicle scenario 1, with all electricity requirements coal derived (UEP32)
S10g	Electric vehicle scenario 1, with all electricity requirements gas derived (UEP32)
S70c	Electric vehicle scenario 2, with all electricity requirements coal derived (UEP32)
S70g	Electric vehicle scenario 2, with all electricity requirements gas derived (UEP32)

The assessment of electric vehicles is limited to CO_2 and NO_x. Additional work incorporating PM into the analysis could be addressed in a contract extension, but this is expected to be less important and would need appropriate emission factors for tyre and brake wear.

Results and Conclusions:

Entec found that replacement of 0.8million existing pre-Euro 5 petrol and diesel cars and diesel LGVs with similar sized electric vehicles results in a 2.3kt reduction in NOx emissions in 2020 (multi-pollutant measures database 2009). This is comparable to the NOx reductions for our S10c and S10g scenarios shown in figure 1, although we find greater reductions as we assume a replacement of 1.2 million vehicles. Note that whereas our approach separately assesses the emissions from either coal derived or gas derived additional electricity, Entec use the projected future grid mix from all sources including renewable (NAEI2007, UEP32).

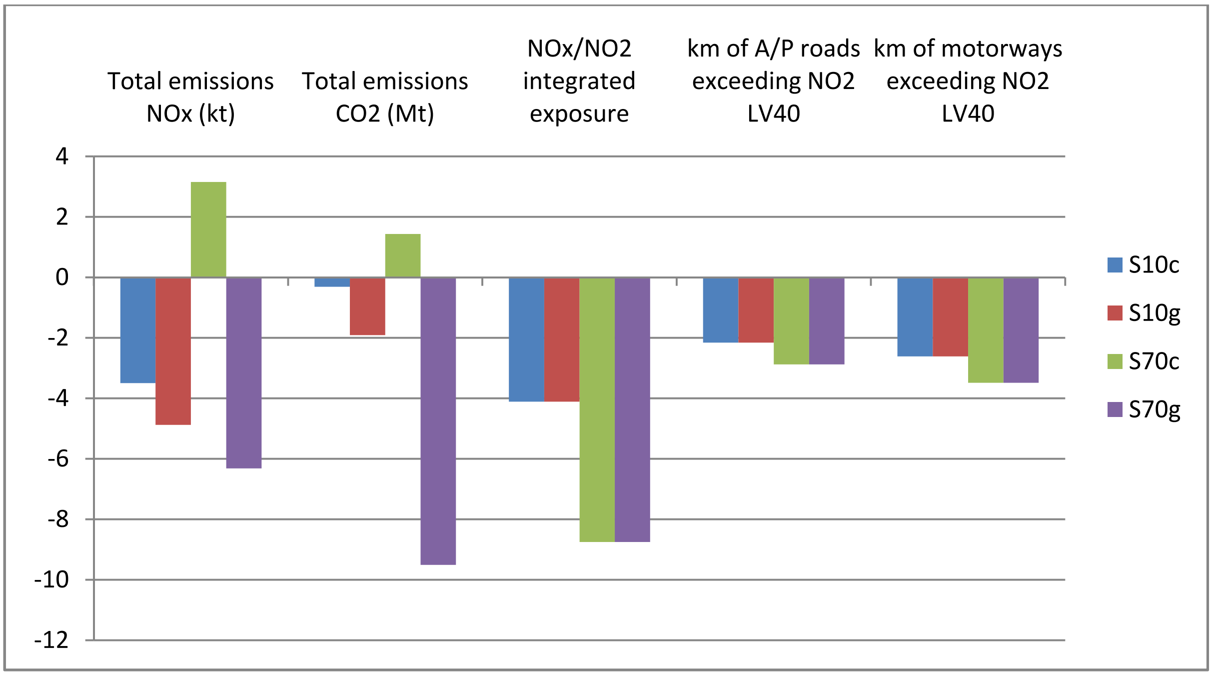


Figure 1.23. Change in emissions, integrated exposure and km of roads exceeding limit values for the four scenarios relative to the 2020 baseline scenario.

As shown in figure 1.23, we find that all scenarios reduce exposure to NO_x /NO_2 and reduce the distance of Motorways and A roads exceeding the NO_2 limit value of 40µgm^{-3}.Figure1.23

also shows that NO_x / NO_2 integrated exposure and km of A roads and motorways exceeding the NO_2 limit value of 40µgm^{-3} are unchanged by the form of additional electricity generation (coal or gas derived)- presumably because the emissions are not in urban areas.

In terms of changes in total emissions of NO_x and CO_2, the S10c, S10g and S70g scenarios were shown to reduce national emissions of both NO_x and CO_2. However, due to the relatively high levels of emissions of 2020 coal fired power stations and the low emission factors of Euro 5/V and Euro 6/VI cars, total emissions of NO_x and CO_2 were found to increase under the S70c scenario. The S70c scenario illustrates an interesting situation. If a large proportion of anticipated Euro 6/VI cars are replaced by electric vehicles there are localised air quality benefits in terms of reduced exceedance of limit values and reduced exposure. However, if the electricity requirements of these electric vehicles are met by relatively “dirty” forms of power generation such as coal, the total national emissions of GHGs and air quality pollutants can increase. As such, there is the potential for electric vehicles to create trade-offs between the need to improve urban air quality and the need to remain within National emissions ceilings.

1.4.8 Scenarios for the power generation sector

Future emissions of air quality pollutants, and their potential for further abatement, depend strongly on the power generation sector and the underlying energy projections. This section describes some scenarios assuming different energy projections for the power generation sector to 2020. These have been analysed with the UK integrated assessment model, UKIAM, to look at environmental benefits relative to the UEP32 baseline scenario based on NAEI projections, together with some variants on the baseline scenarios itself. For each scenario, UKIAM requires a spatial distribution of pollutant emissions, broken down into different sources, to assess atmospheric concentrations and deposition across the UK; from this it derives human exposure to NO_2 and PM as air quality pollutants together with exceedance of air quality limit values, and exceedance of critical loads for acidification and eutrophication with respect to ecosystem protection. Since synergies exist between control of air quality pollutants (SO_2, NO_X, NH_3 and PM_{10}/$PM_{2.5}$) and greenhouse gases (CO_2, CH_4, and N_2O) the UKIAM also considers the implications for greenhouse gases.

In developing these scenarios for the power generation sector we have considered 3 different UK energy projections provided by DECC (UEP32 as the baseline, and UEP30, and UEP37 as variants); and one PRIMES energy scenario for the power sector from IIASA in their work for the European Commission with GAINS. These scenarios show some considerable differences in coal consumption, and in reliance on existing plant: and also in gas consumption for power generation. They also imply different potential emission reductions and costs from the application of different abatement technologies. For each energy projection, there is a reference case that corresponds to the matching emissions based on NAEI assumptions and emission factors. These emissions were carefully matched to technologies assumed to be in place, the Business As Usual (BAU) case, before additional measures beyond the BAU were considered. The scenarios are summarised in table 1.10

Table 1.10: summary of energy projections for scenarios considered

	UEP 32		UEP30		UEP37		IIASA	
	Mtherms	*pJ*	Mtherms	*pJ*	Mtherms	*pJ*	Mtherms	*pJ*
Coal	8371	*883*	6573	*693*	8761	*924*	7181	*758*
Gas	10648	*1123*	13689	*1444*	10340	*1090*	13792	*1474*
Total	19019	*2006*	20252	*2137*	19101	*2014*	21153	*2232*

A more detailed break down of table 1.10, down to individual power stations, was provided in a research note compiled on these scenarios for Defra (Scenarios for the Power Generation Sector for analysis with UKIAM). The UK energy scenarios are based on modelling by DECC, each of which is broken down to give energy generation for each coal fired power plant still assumed to be operating in 2020, plus some additional new plant (including provision for carbon capture and storage, CCS) for which some assumptions have to be made about their location. Gas fired stations are not individually identified but differentiated as total old and new plant, scaled to the current spatial distribution.

UEP32 is taken as the base case (corresponding to NAEI projections undertaken early in 2009), and also underlies studies by ENTEC to develop a data base of abatement measures. UEP30 was the energy scenario used by AEA in their previous NAEI projections to 2020 undertaken in 2008. This energy scenario includes some significant differences in energy generation from coal and gas as compared with UEP32. UEP37 is the most recent energy scenario from DECC for which emission projections have been analysed, undertaken since the credit crisis: this is the scenario for which data have recently been provided to IIASA for use in the GAINS model as the new national UK projection. However this scenario turns out to be extremely close to UEP32, and hence we have not taken it forward beyond the baseline projections. The IIASA scenario, based on the PRIMES modelling of UK energy projections corresponding to the EC Climate and Energy package, has been taken as the IIASA baseline case in their analysis with GAINS of the emission reductions required to achieve the environmental targets of the EC’s Thematic Strategy on Air Pollution, TSAP (the “Ref 6” scenario-see Amann 2008). This is a case we have already analysed in some detail in the context of possible future emission ceilings for 2020, and will be referred to simply as the IIASA scenario. It assumes a much greater contribution from biomass rather than new coal plants.

Table 1.11 compares emissions of the key pollutants for these scenarios. For UEP32 there are two additional variants. The first is a sensitivity study with respect to the sulphur content of coal used in different power stations, where data provided by ENTEC was used in place of the assumptions by DECC (which also change between scenarios, as well as the efficiency of FGD assumed to be fitted to all coal fired power stations in 2020). The second is a variation on the 3 stations under the NERP (National Emission Reduction Plan) where the NAEI projections specify emissions in accordance with the allocations, whereas in practise the stations have flexibility to negotiate within the emissions bubble. The variation considers one way of achieving this by fitting SCR to one station but not the others. This effectively keeps the total NOx almost the same, but redistributes the emissions spatially between stations.

Table 1.11: Summary of emissions for the different scenarios

Scenario	Coal				Gas			Total			
	SO_2 Kt	NOx kt	PM_{10} kt	CO_2 Mt	NOx Kt	PM_{10} kt	CO_2 Mt	SO_2 Kt	NOx kt	PM_{10} kt	CO_2 Mt
UEP32	65.6	75.5	1.36	76.0	41.4	1.15	57.1	65.6	117	2.51	133
“ S coal varied	72.2	“	“	“	“	“	“	72.2	117	2.51	133
“ NERP varn.	65.6	73.6	“	“	“	“	“	65.6	115	2.51	133
UEP30	37.7	67.7	1.01	54.5	53.0	1.48	73.5	37.7	121	2.49	128
UEP37	68.9	78.4	1.45	78.8	40.2	1.11	55.5	68.9	119	2.56	134
IIASA	40.6	69.2	1.14	49.2	54.2	1.50	75.0	40.6	123	2.64	124

The swings between the amount of energy generated from coal and from gas between scenarios results in bigger differences between the SO_2 emissions, but there is relatively little difference between the total energy generated and the total NOx. The PM_{10} also remains almost constant as the NAEI has emission factors for gas comparable with those from coal, but the total of these highly controlled PM emissions is still a small percentage of the UK total. The scenarios with more gas also generate a saving in CO_2 as might be expected.

We can now consider how the scenarios compare with respect to their environmental impacts, bearing in mind that there are spatial differences as well as in the total emissions. This sector makes a relatively small contribution to concentrations of NOx and primary PM_{10} in urban areas, and hence there is a negligible difference between scenarios in considering resulting health impacts. There is however the contribution of secondary SO4, NO3 and NH4 to concentrations of PM_{10}, which we have investigated by calculating the population weighted mean concentrations, PWMCs. The scenarios with the biggest difference from the baseline UEP32, are those with more gas, that is UEP30 and the IIASA scenarios which are rather similar to each other. These give differences in the PWMCs of SO4, NO3 and NH4 of less than 8%, 0.5% and 3% respectively (these being upper limit based on the UKIAM(FRAME) version as compared with the UKIAM(hybrid) version which implies a greater proportion imported from outside the UK- see section 1.4.3).

With respect to protection of ecosystems, table 1.12 shows the differences from the UEP32 baseline case in the ecosystem areas for which critical loads are exceeded, and in the accumulated exceedance, with respect to both acidification and eutrophication. Again the differences are very modest, even though there is some variation in the deposition patterns. As might be expected the scenarios with less coal and SO_2 lead to some improvement in acidification, but perversely their spatial distribution of the NOx leads to an opposite effect with respect to eutrophication.

$\delta\text{Exceed}_{ACID}$	Area	km^2	***27,172***	49	49	-159	26		-207
		%	***38.71***	0.07	0.07	-0.23	0.03		-0.30
	AE	kEq/yr	***1,381,408***	4,479	2,652	-22,530	3,980		-25,017
$\delta\text{Exceed}_{EUT}$	Area	km^2	***35,351***	141	-24	140	1		111
		%	***47.50***	0.19	-0.03	0.19	0.00		0.15
	AE	kEq/yr	***2,397,513***	5,080	-1,109	23,572	-341		20,533

Table 1.12: Comparison of scenarios with respect to acidification and eutrophication of ecosystems

The overall conclusion is that the different energy scenarios make little difference for the environmental impacts within the UK. The reduction in SO_2 with a shift from coal to gas seems to be the biggest factor, with a matching benefit for greenhouse gases in reducing CO_2. Since new energy projections have recently been produced with a greater contribution from renewables and bigger differences in fossil fuel use (e.g. UEP38) it is proposed to extend this scenario analysis in future work. However what may be more significant is the siting of smaller CHP plants within urban areas in lieu of the current larger power stations sited away from urban areas.

1.4.9 Agricultural scenarios

Future emissions of NH_3, and the potential for further abatement, depend primarily upon changes in the agricultural sector. Whereas with other air pollutants it has been possible to achieve dramatic reductions in emissions mainly through technological abatement measures (~90% and ~62% reductions in SO_2 and NO_X, respectively, between 1990 and 2010), this is not the case with NH_3 where only a 16% reduction has been evident over the same period. A further ~25% reduction in NH_3 appears feasible based upon technical measures, although costs may become prohibitive before reaching this target (see MFR abatement of BAUIII scenario below). Alternative strategies therefore need to be developed which involve changes in activity levels (ie. livestock numbers), for example resulting from changes in human diets and demand for agricultural products. In addition to the MFR scenario we therefore consider 4 scenarios, A to D involving different sets of abatement measures, and 3 scenarios involving changes in agricultural activities. For the purposes of illustration we have adopted a tentative ceiling for UK emissions in 2020 of 240 kt of NH3, based on case studies analysed by IIASA in the "Ref 6" scenarios with the GAINS model (IIASA 2008).

The scenarios presented here are based on BAUIII projections for agricultural activity levels in the UK up to 2025 defined by Defra (2007) [Misselbrook, 2008]. These projections build upon earlier projections to 2015, include impacts of the CAP reform, responses from questionnaires and national trends. Only changes in animal census data up to 2020 are considered here as this corresponds to the timeframe addressed by the GAINS model to examine various strategies to implement the EU Thematic Strategy on Air Pollution (TSAP).

Most livestock sectors show a decline in animal numbers in 2020 compared to 2005, with poultry being the exception. In the dairy sector, greater productivity of cows, low farm gate prices, and removal of the milk quota from 2015 are expected to decrease herd sizes. For beef the situation is similar primarily due to decoupling of CAP subsidies from production. Pig numbers reduce due to little financial investment made in the last decade, high feed prices, the implementation of the IPPC directive and Nitrate Vulnerable Zones (NVZ). Only poultry is expected to grow with the trend of larger sized farms.

It is important to point out that the UKIAM baseline emissions of NH_3 in 2020 (~307 kT/yr) assume IPPC measures have **not** been applied, as the the cost curve described below for reduction of ammonia emissions from livestock assumes a starting point with no measures introduced. This cost curve is based on the NARSES model, which derives the least cost way of achieving successively larger emission reductions up to the maximum feasible reduction. IPPC measures reduce NH_3 emissions nominally by ~16% but at the same time are costly to implement (Dragosits *et al.*, 2005), and, as 2020 is not that far in the future from an investment perspective, it is logical to analyse these measures as part of an overall ammonia reduction scheme. On this basis we determine scenario *options* or policy *alternatives*, these being the strategies policy makers would like to investigate and can be developed by taking into account current and future legislation.

Since most livestock sectors are under significant financial strain due to reduced or no subsidies, low market prices and higher feed costs, it is useful to compare the effectiveness of different types of options as introducing abatement measures on farms will only add an extra burden. These options may be those based purely on meeting legislative requirements, or those that go beyond the legislative boundaries and include external factors. Options A-D (below) address legislative requirements such as the IPPC Directive and the NEC Directive, and Options 1-3 bring in external factors such as animal welfare and farmer’s affordability. For both sets of options, BAUIII animal projections for 2020 are used along with cost steps that select abatement measures on the basis of increasing marginal cost of emission reduction (Misselbrook 2008 – census, Misselbrook 2008 – report with measures). The full cost-curve is shown in table 1.13 and graphically in figure 1.24

Table 1.13: Cost curve for reduction of UK ammonia emissions in 2020 from agricultural livestock

Step	UKIAM Source	Measure	Delta_Emit	Emit	Cost £M
		Baseline	**307.388**	**307.388**	**0.000**
1	37	4HINCDISC_DCK	0.319	307.069	0.090
2	33	EXTRA_STRAW_DRY	2.793	304.276	1.219
3	36	4HINCDISC_LYR	1.683	302.593	1.978
4	34	EXTRA_STRAW_BEEF	4.587	298.006	4.194
5	33	LAGOON_CRUST_DAIRY	3.059	294.947	5.703
6	34	LAGOON_CRUST_BEEF	0.710	294.237	6.064
7	37	4HINCDISC_PLT	8.145	286.091	10.702
8	36	FREQUENT_REMOVAL_BELT	0.731	285.361	11.149
9	36	STORE_SHEET_LYR	0.300	285.061	11.378
10	37	DRYING_TURKEYS_PLT	0.554	284.506	11.839
11	33	4HINCDISC_SLURRY_DAIRY	1.661	282.845	13.266
12	34	4HDISC_SLURRY_BEEF	0.221	282.624	13.460
13	33	WASH_COLL_YARD_DRY	5.034	277.591	19.029
14	37	STORE_SHEET_PLT	0.796	276.795	19.967
15	37	DRYING_DUCK_PLT	0.145	276.650	20.155
16	34	SHEET_FYM_BEEF	3.883	272.767	28.092
17	34	4HDISC_FYM_BEEF	2.081	270.686	32.407
18	37	DRYING_BREEDERS	0.642	270.044	33.763
19	33	TANK_CRUST_DAIRY	0.713	269.331	35.273
20	33	SHEET_FYM_DRY	2.041	267.290	39.842
21	33	4HINCDISC_FYM_DAIRY	1.094	266.197	42.327
22	34	TANK_CRUST_BEEF	0.140	266.057	42.688
23	33	GRASS_TRAILSHOE_DAIRY	14.070	251.987	80.705
24	37	STOREALL_BROILERS	1.082	250.905	83.795
25	37	STOREALL_BREEDERS	0.469	250.436	85.154
26	34	GRASS_TRAILSHOE_BEEF	3.745	246.692	97.117
27	33	ARABLE_INJECTION_DAIRY	3.177	243.515	107.512
28	35	LAGOON_COVER_PIG	0.992	242.523	111.126
29	34	ARABLE_INJECTION_BEEF	0.367	242.157	112.538
30	35	4HINCDISC_SLURRY_PIG	0.476	241.680	114.822
31	36	STOREALL_LYR	0.280	241.400	116.282
32	34	INCREASED_SCRAPING_BEEF	0.500	240.900	119.386
33	33	STOREALL_DAIRY	1.854	239.046	130.968
34	36	STOREALL_PERCH	0.004	239.042	130.995
35	35	4HINCDISC_FYM_PIG	1.947	237.095	145.590
36	33	INCREASED_SCRAPING_DAIRY	2.130	234.966	162.680

37	35	COVER_FYM_PIG	1.675	233.291	176.444
38	34	STOREALL_BEEF	1.439	231.852	188.510
39	37	DRYING_BROILERS	0.856	230.996	196.000
40	35	BIOFILT_FATTENER_PIG	1.847	229.149	213.486
41	35	BIOFILT_SOW_PIG	0.306	228.843	216.814
42	35	GRASS_TRAILSHOE_PIG	1.241	227.602	233.175
43	35	RIGID_TANK_COVER_PIG	0.557	227.046	242.309
44	35	SLAT_DESIGN_GILT_PIG	0.016	227.030	242.589
45	37	STORE_SHEET_DCK	0.510	226.520	252.949
46	35	BIOFILT_GILT_PIG	0.029	226.491	253.615
47	35	ARABLE_TRAILHOSE_PIG	0.339	226.152	262.047
48	35	STOREALL_PIG	1.140	225.012	296.773
49	35	SLAT_DESIGN_FATTENER_PIG	0.166	224.846	304.117
50	35	SLAT_DESIGN_SOW_PIG	0.027	224.819	305.515
51	35	BIOFILT_WEANER_PIG	0.174	224.645	316.333
52	35	SLURRY_REMOVAL_FAT_PIG	0.097	224.548	325.201
53	35	SLURRY_REMOVAL_SOW_PIG	0.016	224.532	326.889
54	35	SLURRY_REMOVAL_GILT_PIG	0.002	224.530	327.227
55	35	SLAT_DESIGN_WEANER_PIG	0.013	224.517	331.770
56	35	SLURRY_REMOVAL_WEAN_PIG	0.008	224.510	337.256

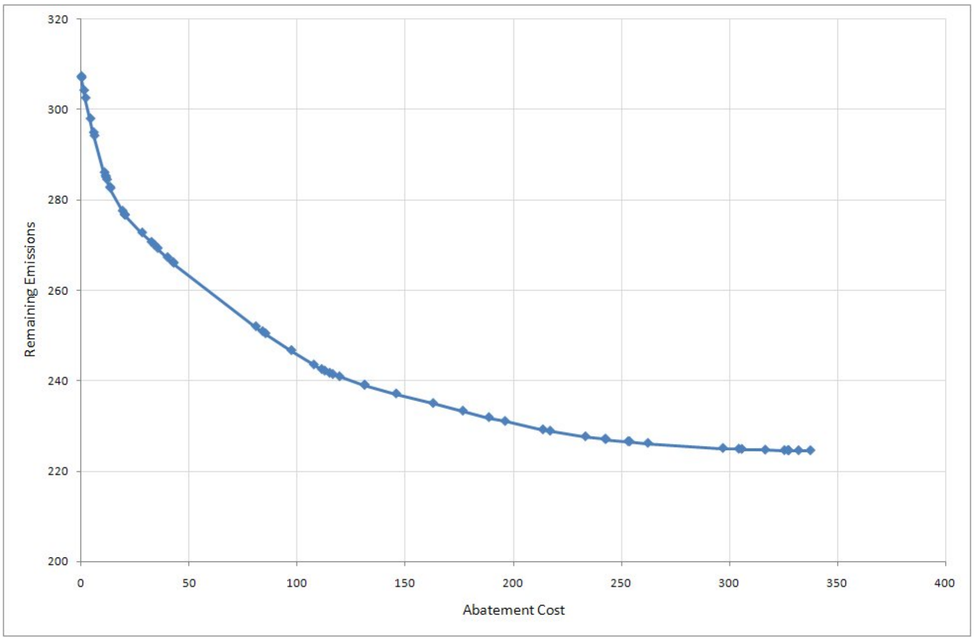


Figure 1.24: Cost curve relating reduction of emissions to the associated least costs in £million

The scenarios: options A –D and 1-3

Options A-D based solely on use of abatement measures:

Options A and B address IPPC legislation. These include only those measures that are either verifiable or there is less uncertainty about their effectiveness, so, for example, measures that involve incorporation of manure/slurry within 4 hours, or addition of straw bedding to animal housing are excluded. Also, although the IPPC legislation applies to farms above a certain size, for simplicity and for determining the maximum benefits arising from the option, the measures are assumed to apply across all farm sizes.

Options C and D adopt a least cost approach to meet a possible NEC target of 240 kT/yr by 2020; an illustrative target based upon IIASA scenarios in the NEC Ref6 Report. In the least cost approach, measures are chosen in order of least marginal cost across all livestock sectors. Options C and D include measures excluded in Options A and B. Option C includes the minimum set of measures required to bring emissions down to 240 kT/yr as a tentative ceiling. Option D allows for some uncertainty in the abatement options and aims to achieve an even lower target of 230 kT/yr to compensate for this uncertainty.

Options 1-3 involving changes in agricultural production

Options targeting the beef and dairy sectors are assessed as these are the biggest contributors of NH_3 emissions. Other ruminants such as sheep are excluded from the analysis as currently no abatement measures are applied to them and are not likely to be in the future. These options focus on changes in animal numbers resulting from changes in production and consumption of meat and changes in the dairy production cycle. Options 1 and 2 relate to consumption patterns and Option 3 brings in elements of welfare and farm income by focusing on the dairy sector.

Options 1 and 2 investigate the effects of UK meat production in the UK. Note that significant quantities of meat consumed are imported, up to 30% in 2006 (DEFRA 2008c) so these options will also have an environmental impact in the source countries; however for the purpose of this analysis these impacts are excluded. Exports of UK meat, averaging around 20% in 2006, are excluded for the same reason, giving a net balance of 10% imports.

The BAUIII scenario for 2020 predicts a reduction in the beef herd size largely due to decoupling of CAP subsidies and resulting lower profitability in the sector. It is assumed that part of the UK Government’s strategy for a low carbon economy (HM Government 2009) will start having some effect on consumer lifestyle and consumption patterns. Cattle are major sources of methane resulting from enteric fermentation in their digestive system (FAO 2007, Garnett 2007). Methane has a global warming potential 23-25 times higher than CO_2 so substituting cattle with poultry is a reasonable option. Consequently, both Options 1 and 2 assume a reduction in the consumption of beef by 10% which is replaced by increases in poultry or pork:

Option 1: Reduce beef production by 10% compensated by an equivalent increase in poultry. This option assumes that UK beef production, and hence consumption, will be 10% less than that projected for 2020 with consumers opting for an equivalent quantity of poultry meat. This assumes that consumers do not change their meat eating habits but instead switch from one form to another. Poultry is chosen because feed is more efficiently converted into edible body weight compared to cattle (Smil 2002). Table XX shows that poultry are the most efficient convertors of feed into live and edible weight followed by pigs and then beef cattle; conversion efficiency of plant protein into animal protein is estimated to be 5 times higher for poultry than for beef.

	Poultry	Pigs	Beef
Feed conversion (kg of feed/kg of live weight)	2.5	5	10
Feed conversion (kg of feed/kg of edible weight)	4.5	9.4	25
Plant protein conversion efficiency (%)	20	10	4

Table XX: Animal feed conversion efficiencies. (Source: Smil, 2002)

As poultry is a more efficient convertor of plant protein into body weight a greater proportion of the nitrogen in feed will be utilised and less nitrogen will be excreted, which, in turn means there is the possibility of further reducing NH_3 and N_2O emissions. Greater conversion efficiency also means less feed per body weight gain is required, needing fewer feed crops and thus less fertiliser usage per unit weight of poultry meat produced.

Option 2: Reducing beef production by 10% compensated by an equivalent increase in pork.
This option is similar to Option 1 with poultry being substituted by pork. Although the feed conversion efficiency is not as high as for poultry it is still 2.5 times that for beef. Both pigs and poultry are mono-gastric animals and are fed high energy concentrates. These concentrates have a high grain and oil seed meal content and therefore can place a burden on prime environmental resources. On the other hand, cattle have the ability to digest cellulose in grass and thus usually use land resources that have limited cropping potential or alternate use. There are strengths and limitations of the two options which make Multi-Criteria Decision Analysis (MCDA) a useful tool to employ.

The effect of reducing beef consumption is to reduce the cattle numbers to less than BAUIII projections. As the meat requirements are being met by either poultry or pig meat, there will be a corresponding increase in the number of poultry and pig heads. Calculation of the new animal numbers for the two options required data on meat consumption in 2006 (Defra 2008, 2009), with consumption in 2020 based on animal number changes from 2006 to 2020. Using meat consumption in 2020 the extra pigs or poultry to compensate for beef can be calculated. These livestock adjustments will also impact upon emissions and abatement costs since these are a function of animal numbers.

As welfare concerns vary between livestock sectors only options applying to the dairy sector are examined as dairy cattle are a major source of NH_3 emissions as well as greenhouse gases. BAUIII projections for dairy suggest a decrease in herd size attributable to greater productivity of cows, low farm gate prices and removal of the milk quota in 2015. However, greater productivity may have adverse effects on the lifespan of dairy cows and so longevity is brought into the analysis for Option 3. Most milk produced in the UK is consumed domestically with only 0.3% imported and 4.5% exported in 2006, so for this study imports and exports are ignored.

Option 3: Increasing the longevity of cows to add another lactating cycle
Since the 1980's excessive in-breeding of higher yielding Holstein-Freisian varieties has been accompanied by a decline in the average number of lactations per herd. An IGER report examining longevity in dairy herds suggests the average number of lactations in the dairy

cow’s life has decreased over the last thirty years from 4.76 to 3.44 (IGER, 2003) after which the animal is culled. The factors that influence a farmer’s decision to cull an animal are age, yield performance, reproductive ability, other illnesses such as lameness and mastitis, as well as economic considerations and availability of replacement herd (Essel, 1998; Beaudeau *et al.*, 2000). A report by DairyCo (2008) for the UK suggests that 51% of the culling could be attributed to reproductive failures, mastitis and lameness, 25% to unproductive yields and age and another 24% to accidents and other illnesses. with 25-28% of the UK herd culled.

Table 1.14 summarises the NH_3 abatement scenarios assessed in this study. Table 1.15 quantifies the effects of these scenarios on NH3 emissions required by the UKIAM.

Category	Option	Description
Policy based	A	IPPC type measures applied to pig and poultry sectors only
	B	IPPC type measures applied to pig, poultry, beef and dairy sectors
	C	Least cost measures to meet 240 kt ammonia ceiling, all sectors included
	D	Least cost measures but accounting for uncertainty in the analysis, aim to meet 230 kt ammonia ceiling, all sectors included
External factors	1	10% reduction in beef consumption to be compensated by poultry meat
	2	10% reduction in beef consumption to be compensated by pig meat
	3	Increasing longevity of dairy cows by adding one lactation cycle

Table 1.14: Options for NH_3 abatement from the UK livestock sector

	UEP32 (BAUIII)	BAUIII (MFR)	A	B	C	D	1	2	3
Dairy	87.84792	50.24792	87.84792	55.74792	52.34792	50.24792	54.24792	52.34792	53.17692
Beef	58.01456	40.31456	58.01456	47.21456	41.81456	40.31456	39.79311	37.90311	42.31456
Pigs	24.74972	13.64972	16.14972	16.14972	23.24972	17.84972	23.74972	28.39625	23.74972
Layers	9.952042	6.952042	9.952042	8.252042	6.952042	6.952042	7.252042	6.952042	7.252042
Poultry	33.59983	19.99983	28.49983	28.49983	21.29983	20.49983	22.00948	21.29983	21.29983
Sheep	11.477	11.477	11.477	11.477	11.477	11.477	11.477	11.477	11.477
Other	6.499	6.499	6.499	6.499	6.499	6.499	6.499	6.499	6.499
Fertilizer	36.448	36.448	36.448	36.448	36.448	36.448	36.448	36.448	36.448
Non-Ag	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8	38.8
Total NH_3	307.3881	224.3881	293.6881	249.0881	238.8881	229.0881	240.2763	240.1232	241.0171

Table 1.15 : NH_3 livestock scenario emissions

The abatement costs (in £Million per year) are give in table XX below, together with indicators summarising their potential environmental impacts. It can be seen that the IPCC scenarios A and B are expensive in the emission reductions they achieve as compared with the least cost scenarios C and D. Also scenarios 1 and 3 with changes in cattle numbers (beef and dairy respectively) achieve similar reductions to scenario C at less cost, and they also have other environmental benefits.

The first environmental indicator is the population weighted mean concentration, PWMC, of the secondary inorganic aerosol ($SIA=SO_4+NO_3+NH_4$) as the contribution to human health impacts through exposure to PM_{10}. (In this case this was based on UKIAM(FRAME) rather than UKIAM(hybrid) with the higher imported contributions). The modest reductions in NH3 have little impact on the overall PWMC

Table 1.16 Comparison of agricultural scenarios

	Emissions Kt	Cost £M	PWMC SIA ($\mu g.m^{-3}$)	>acid km^2	>eut km^2	NO_3 leached kt	GHGs Mt CO_2 equiv.
UEP32	**307**	-		27323	35357	300	
	Reduction			Reduction		Increase	
MFR	83	337	-	4986	6310	-	
A	15.4	176	3.24	470	766	3.8	27.0
B	57.9	303	3.15	3423	4430	14.3	27.3
C	68.5	131	3.13	4274	5312	16.9	27.4
D	78.4	213	3.11	4833	6039	19.4	27.5
1	64.9	110	3.13	4264	5264	16.0	26.2
2	67.2	129	3.14	4454	5466	16.6	26.5
3	64.2	112	3.14	4141	5119	15.9	26.5

With respect to eutrophication and acidification these scenarios reducing NH_3 have far bigger effects than the different energy scenarios changing NOx and SO_2 emissions in the previous section. Nevertheless on their own they still leave large areas of ecosystem unprotected. In future work it will be important to investigate combined scenarios reducing emissions of all three pollutants across a wide range of sources; and also to explore how this affects the ecosystems of greater importance (see section 1.2.1 on proposed scheme for considering SSSIs in this context).

Some abatement measures to reduce NH_3 emissions, particularly those which involve more effective incorporation in soils when applying slurries and manure to land, result in increased risks of leaching. An indicator has been developed for the potential additional amounts leached, as shown in the sixth column in the table with the baseline value and the increments to this value for the other scenarios. This is only an approximate indication and makes no differentiation between nitrate vulnerable zones and elsewhere.

Agriculture is also an important source of greenhouse gases, including CH_4 from cattle, and N_2O emissions from soils- the latter again being potentially increased by some measures to abate NH_3 emissions. The final column compares GHG emissions between the scenarios allowing for the changes in these contributions. The extra N_2O emissions between scenarios

A to D add up to 0.5 Mt of CO_2 equivalent. However in scenarios 1-3 the reduction in cattle numbers, and hence in CH_4, leads to an overall decrease.

These scenarios have been investigated by a PhD student, Nighat Hasnain, working in parallel with the SSNIP contract. A more complete account may be found in her PhD thesis, now successfully completed; together with her critical appraisal of applying integrated assessment modelling to abatement of NH_3 emissions, the development of a broader approach, and exploration of multi-criteria decision analysis (MCDA) as a way of involving different stakeholders in comparing alternative strategies for the nitrogen cycle. This also takes account of other environmental factors such as land-use and water consumption in agriculture.

NB. The Task Force on Reduced Nitrogen noted the need to revise costs of abatement measures, and the cost curve used in this work is based on very old cost estimates. It is hoped that new cost estimates can be provided for future work , but this lies outside the scope of the current SSNIP contract and requires additional expertise.

1.5 Consideration of uncertainties and model intercomparisons

Throughout the SSNIP contract Imperial College have tried to investigate and allow for uncertainties, for example section 1.1.7 in the relationship between NOx and NO2, and in the various comparisons reported in scenario analysis in section 1.4; or the inter-comparisons with the GAINS modelling at the European scale in part 2 of this report. Here we shall give some further examples where we have made inter-comparisons between different models to understand the implications when considering the robustness of our scenario analysis with UKIAM and related models.

Comparison of different emission estimates- road transport

In compiling emission projections part of the uncertainty lies in the emission factors, and part in the forecast levels of activity. The last is best dealt with by comparison of different scenarios as in section 1.4. However we have also done considerable work looking into emission factors, including comparison of those used in the NAEI (and UKIAM) and those in GAINS. A particular area where we have been keen to establish consistency between UKIAM and the NAEI has been in road transport emissions, where the BRUTAL model assembles emissions in a bottom-up approach across road links in the road network. Even though the same speed-dependent emission factors are used for each vehicle category as in the NAEI (including recent updates), there are various reasons why the totals may still differ from the NAEI national projections. A lot of cross-checking was undertaken to compare underlying factors, such as total vehicle kilometres driven by different vehicle types on different categories of road, as well as in total emissions. This is very dependent on traffic mixes and density on different roads, and delineation between urban and rural roads (defined in BRUTAL on the basis of population density). Table 1.17 gives a summary comparison of emissions in UKIAM as calculated by BRUTAL and its sub-model i-MOVE, and those provided by AEA for the NAEI. The agreement is well within uncertainty margins.

Table 1.17: Comparison of road transport emissions from the BRUTAL model and in the NAEI.

	NOX				PM10			
vehicle	BRUTAL (2010)	NAEI (2010)	BRUTAL (2020)	NAEI (2020)	BRUTAL (2010)	NAEI (2010)	BRUTAL (2020)	NAEI (2020)
PetrolCar	44.931656	42.80299042	19.227643	14.92642201	0.699944	0.586985753	0.63781	0.269176056
DieselCar	70.313491	68.96865563	45.73482	54.03824728	5.863602	4.953048659	1.117345	0.887864327
PetrolLGV	3.114871	2.809589971	2.859185	3.063013191	0.015903	0.01218678	0.015972	0.006757719
DieselLGV	40.514574	39.34609418	18.653527	18.33443613	3.705205	3.312426789	0.644612	0.53694583
RigidHGV	61.074004	63.66319973	13.786707	13.45618769	0.95389	1.012014191	0.109607	0.108675438
ArticHGV	72.733719	79.54838314	15.066468	15.90281781	1.111339	1.195054184	0.08681	0.106273936
Busses	30.167371	33.31801866	8.710197	8.596033326	0.441977	0.47578247	0.171668	0.08933484
Mcycle	0.831756	1.507103712	0.317825	0.960552269	0.087934	0.069161649	0.040987	0.016084417
Total	323.681442	331.9640355	124.356372	129.2777097	12.879794	11.61666047	2.824811	2.021112564

During the course of these comparisons various sensitivity studies were undertaken to investigate effects such as cold starts and catalyst failures, recognising also that different emission models gave different results- for example in updating from COPERT II to COPERT IV (from which GAINS derives emission factors).

Cold start emissions were found to be one cause of differences between models, and also raised questions as to how they should be distributed spatially between urban and rural areas, and different road types. A number of sensitivity studies were undertaken to investigate this- see below.

Scenario No.	Description of the scenarios
SC1	No cold start emissions
SC2	Cold start emissions for Urban roads based on COPERT II and the trip length is 8.4 km
SC3	Cold start emissions for Urban &Rural roads based on COPERT II and the trip length is 8.4 km
SC4	Cold start emissions for Urban &Rural roads based on COPERT IV and the trip length is 8.4 km
SC5	Cold start emissions for Urban &Rural roads based on COPERT II and the trip length is 10 km
SC6	Cold start emissions for Urban &Rural roads based on COPERT II and the trip length is 6 km
SC7	Cold start emissions for Urban roads based on COPERT II and trip length is 6 km

In addition sensitivity studies were undertaken to the road-speeds assumed, and the effect of omitting catalytic failure.

Scenario No.	Description of the scenarios
SC8	Cold start emissions for Urban &Rural based on COPERT II and the trip length is 8.4 km - speed similar to NAEI, Rural95==Motorway
SC9	Cold start emissions for Urban &Rural based on COPERT II and the trip length is 8.4 km - speed similar to NAEI, Rural95==Rural80
SC10	Cold start emissions for Urban &Rural based on COPERT II and the trip length is 8.4 km – no catalytic failure

Table 1.18 summarises the results for NOx and PM10 as the important pollutants for urban air quality. This table illustrates how the cold start assumptions are important for NOx emissions from petrol cars, and that there is a significant difference between COPERT II and COPERT IV (SC3 and SC4), although the effect of assumed trip length is less important. For PM10 the inclusion of cold starts makes more difference with respect to diesel cars and LGVs, because emissions from petrol vehicles are low.

The sensitivity studies to road speed make as much difference as the cold start emissions to NOx (SC8 and SC9), emphasizing the need to take this into account in estimating emissions (whereas GAINS estimates emissions rather crudely in a top down way from fuel consumed or total kilometres driven). This also motivated the scenario analysis in section 1.4 to reducing speeds.

Finally scenario 10 indicates the importance of catalytic failure, now thought to be possibly more common than previously assumed.

Table 1.18: results of sensitivity studies for emissions of NOx and PM_{10} from road transport

NOx emissions											
Vehicle	BAU	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10
Petrol Car	44.931656	36.155887	41.771105	44.931656	39.344855	42.131582	48.602988	44.109457	45.422605	43.792676	28.2204
Diesel Car	69.647937	67.026578	69.647937	69.647937	69.647937	68.769813	70.762242	70.762242	72.146828	67.791055	69.647937
Petrol LGV	3.114871	2.70836	3.114871	3.114871	2.835306	2.983987	3.284589	3.284588	3.267263	2.836761	1.325378
Diesel LGV	40.514574	38.997707	40.514574	40.514574	40.514574	40.028656	41.147867	41.147859	41.918496	38.491547	40.359059
RigidHGV	61.074004	61.074004	61.074004	61.074004	61.074004	61.074004	61.074004	61.074004	60.377465	59.64718	61.074
ArticHGV	72.733719	72.733719	72.733719	72.733719	72.733719	72.733719	72.733719	72.733719	73.448992	72.886398	72.733719
Busses	30.167371	30.167367	30.167371	30.167371	30.167371	30.167371	30.167371	30.167371	52.246898	52.231832	30.167371
MCycle2st	0.022434	0.022434	0.022434	0.022434	0.022434	0.022434	0.022434	0.022434	0.022396	0.022396	0.022434
MCycle4st	0.804635	0.804635	0.804635	0.804635	0.804635	0.804635	0.804635	0.804635	0.866675	0.706151	0.804635
Taxi	0.665554	0.665554	0.665554	0.665554	0.665554	0.665554	0.665554	0.665554	0.561957	0.561957	0.665554
Moped	0.004687	0.004687	0.004687	0.004687	0.004687	0.004687	0.004687	0.004687	0.004687	0.004687	0.004687
total	323.68144	310.36093	320.52089	323.68144	317.81508	319.38644	329.27009	324.77655	350.28426	338.97264	305.02517

PM10 emissions											
Vehicle	BAU	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10
PetrolCar	0.699944	0.699944	0.699944	0.699944	0.699944	0.699944	0.699944	0.699944	0.726873	0.648079	0.679136
DieselCar	5.766743	4.721174	5.766743	5.766743	5.766743	5.436713	6.207018	6.207018	5.891292	5.629197	5.766743
PetrolLGV	0.015903	0.015903	0.015903	0.015903	0.015903	0.015903	0.015903	0.015903	0.016526	0.014881	0.011974
DieselLGV	3.705205	3.053323	3.705205	3.705205	3.705205	3.49601	3.979307	3.979307	3.893052	3.529488	3.68721
RigidHGV	0.95389	0.95389	0.95389	0.95389	0.95389	0.95389	0.953891	0.953891	0.960011	0.944715	0.95389
ArticHGV	1.111339	1.111339	1.111339	1.111339	1.111339	1.111339	1.111339	1.111339	1.104339	1.088275	1.111339
Busses	0.441977	0.441976	0.441977	0.441977	0.441977	0.441976	0.441976	0.441976	0.776315	0.771939	0.441976
MCycle2st	0.018711	0.018711	0.018711	0.018711	0.018711	0.018711	0.018711	0.018711	0.018711	0.018711	0.018711
MCycle4st	0.056966	0.056966	0.056966	0.056966	0.056966	0.056966	0.056966	0.056966	0.056966	0.056966	0.056966
Taxi	0.096859	0.096859	0.096859	0.096859	0.096859	0.096859	0.096859	0.096859	0.070925	0.070925	0.096859
Moped	0.012257	0.012257	0.012257	0.012257	0.012257	0.012257	0.012257	0.012257	0.012257	0.012257	0.012257
total	12.879794	11.182342	12.879794	12.879794	12.879794	12.340568	13.594171	13.594171	13.527267	12.785433	12.837061

Atmospheric deposition: model intercomparisons and source apportionment

Having incorporated data from both the FRAME model and the EMEP model (via the ASAM module) in UKIAM, together with source-receptor relationships, we can compare projections of deposition using both models for equivalent emission scenarios. The FRAME model reflects smaller scale processes such as orographic enhancement, and has much finer spatial resolution giving a spatial pattern of deposition in much better agreement with observations. But the EMEP model has the advantage of a full Eulerian treatment of long-range contributions imported from outside the UK. (In general the results from UKIAM presented in this report for deposition have been based on FRAME.)

Deposition budgets (kT (N/S)) have been calculated and the spatial distribution of deposition patterns have been mapped to provide a comparison between the UKIAM and ASAM representations (in effect comparing FRAME 7.1 with EMEP5 data (Dec 2006)). The emissions used in the UKIAM are based upon UEP32 projections to 2020. The emissions assumed by ASAM are the baseline EMEP 2020 emissions (downloadable from http://www.ceip.at/); These do not account for changes in shipping emissions due to MARPOL or updates to the Current Legislation (CLE2020) or Current Policy (CP2020) scenarios documented in NEC Report 6 (Amann *et al.*, 2008). Deposition budgets based upon the EMEP data have been adjusted in Table1.19 to show the effect of using the EMEP shipping emissions with an 80% reduction of SO_2 emissions in all shipping areas as opposed to the pre-MARPOL emissions.

Scenario	Model	NH_X	SO_X	NO_X
Baseline	EMEP	144.055	63.712	76.058
	UKIAM	174.530	57.569	121.780
UK Sources	EMEP	100.369	28.784	21.365
	UKIAM	139.695	41.781	56.206
Europe	EMEP	44.803	29.340	33.333
	UKIAM	33.906	12.466	12.112
Shipping	EMEP	0	5.589	21.360
	UKIAM	0	3.321	53.462

Table 1.19 - Deposition Budgets (pseudo-MARPOL)

The UKIAM results (based on FRAME) give higher N deposition than the ASAM (EMEP) estimates projecting forward from EMEP modelling for 2010, especially for oxidised N where the uncertainties in atmospheric modelling are larger. FRAME also implies a smaller proportion imported from outside the UK. This comparison illustrates the bigger differences that can occur in estimated deposition when projecting forward in time to different emission scenarios, as compared with comparison between models calibrated to fit current observations.

Secondary particulate concentrations: model intercomparisons and sensitivity to changes in precursor emissions

Similar comparisons have been made for secondary inorganic aerosol components, SO4, NO3, and NH4. Aerosol budgets (Population Weighted Mean Concentrations, µg/m^3) have been calculated and the spatial distributions of concentrations have been mapped to provide a comparison between the UKIAM and ASAM representations (in effect comparing FRAME 7.1 with EMEP5 data (Dec 2006)).

The outputs presented here correspond to the EMEP reference baseline (ie. Webdab 'CLE'2020) with emissions of SO_2 from shipping reduced by 80% across the board; this reflects reasonably the Entec shipping emissions which account for MARPOL effects of up to 85% reduction, but applies the 80% reduction for all shipping in all regions.

Scenario	Model	NH_4	SO_4	NO_3	SIA
Baseline	EMEP	0.934	0.844	2.483	4.261
	UKIAM	0.719	0.818	1.738	3.275
UK Sources	EMEP	0.464	0.141	1.425	2.031
	UKIAM	0.540	0.684	1.127	2.351
Europe	EMEP	0.338	0.649	0.552	1.539
	UKIAM	0.063	0.129	0.074	0.267
Shipping	EMEP	0.132	0.053	0.505	0.691
	UKIAM	0.116	0.005	0.537	0.658

Table 1.19 Comparison SIA components and total, EMEP and UKIAM(FRAME)

1.7 The APRIL network (Air Pollution Research in London)

The APRIL network was established over 10 years ago to bring together the research community and those responsible for urban air quality, including Defra, to review research needs and work in progress and identify priorities where more research is needed. APRIL has been chaired by Helen ApSimon, and has a part-time coordinator to organise and manage its activities. Defra has provided some support within the SSNIP contract in addition to other funding from the TfL, the GLA, the Environment Agency and research councils. These bodies are represented on the steering committee, together with those heading working groups or leading major projects. The working groups cover emissions, modelling and monitoring of air quality pollutants; road transport; the natural environment in cities; and a more recent extension to climate change in London.

APRIL has given rise to some major projects such as the DAPPLE project to investigate dispersion in and between streets at Marylebone Road, and the REPARTEE project using the BT tower to give a vertical dimension to pollutant concentrations. During the SSNIP contract APRIL has been active in organising workshops and meetings to bring the research community together, including such topics as economic valuation of the natural environment, road transport emissions, monitoring of greenhouse gases (leading to new collaboration for such measurements in London), model inter-comparisons, and source apportionment of particulate matter. APRIL also collaborated with the international network NIAM (see section 2.3.2) in a joint workshop in London in January 2009, addressing behavioural change with respect to road transport, this being identified as a particular challenge in integrated assessment modelling. We have also initiated new research, such as the pilot study at Imperial College to quantify the contribution from road abrasion in PM monitoring samples.

One year ago Helen ApSimon indicated that she would be stepping down as chair of APRIL at the end of the current SSNIP contract. She has since been following up various possibilities on how it might continue, but at present there is no clear way forward and the GLA may try to establish its own activity in this area.

Work package 2

2.1.1 European and international scale modelling

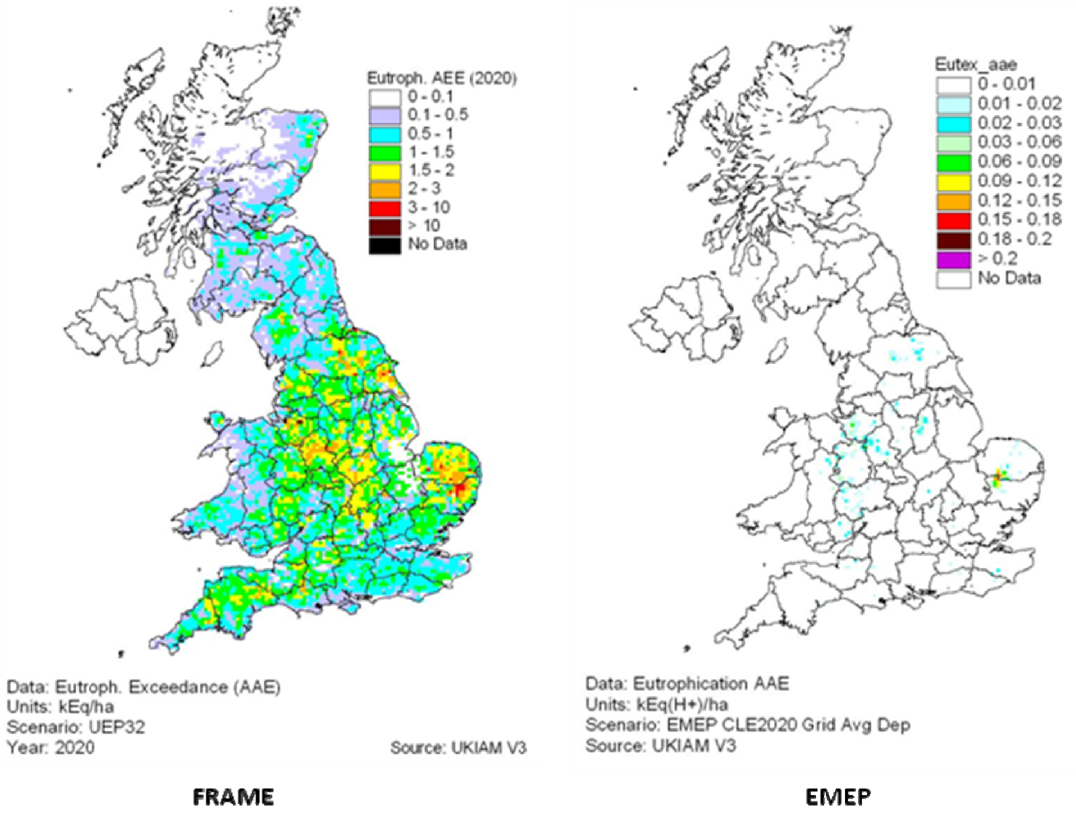
Integrated assessment at the national scale, using the more detailed information available, can give a very different picture from the GAINS modelling at the European scale. This has been illustrated in many ways during the course of this contract, and fed into the international fora as well as communicated to Defra.

One example is the urban modelling work where the GAINS model assumes a rather crude enhancement of concentrations over cities, and does not distinguish the contribution of road transport from other sources in contributing to exposure of the population (that is in GAINS the effect of reducing emission of a pollutant from any source in a country by the same amount has the same effect in reducing concentrations and/or deposition). It addresses concentrations of $PM_{2.5}$ only, and not PM_{10} or NO_2. Hence its ability to address urban air quality is very weak. By contrast the BRUTAL submodel of UKIAM has been designed to assess compliance with EC air quality limit values, resolving road-side concentrations as well as background concentrations on a 1x1 km grid. The scenario analysis described in section 1.4 shows how this enables detailed investigation of different road transport scenarios involving both technical and non-technical measures- something which is not possible with the GAINS model.

Similarly it has been shown that GAINS indicates much smaller exceedance of critical loads in the UK than the more detailed modelling in UKIAM- see figure 2.1. This difference is partly due to the much finer spatial grid used for both the critical load data and the deposition, which, for example, resolves locally enhanced areas of deposition over higher land where sensitive ecosystem areas often occur; and secondly due to the fact that in the FRAME model different deposition rates apply to different ecosystem types, with higher deposition over forest than over grassland for example. Although the EMEP model is capable of this differentiation too, this improvement could not be included in GAINS because it made it impossible to attain the targets set for improved ecosystem protection in the Thematic Strategy of the CAFE programme.

A very enlightening task has been detailed comparison of UK projected emissions to 2020 with those calculated for the UK in GAINS. This was taken up with IIASA subsequently in collaboration with AEA and Melanie Hobson from Aether, and ENTEC; and has helped to understand the assumptions in the GAINS model as well as feeding into development of baseline scenarios to be used in GAINS towards setting new ceilings.

Reciprocally collaboration with IIASA has led to transfer of source-receptor relationships used in GAINS, and based on the EMEP model, which enable the transboundary contributions from other countries outside the UK to be assessed. These have been incorporated in the ASAM model and linked to UKIAM for this purpose. They also include data for estimating ozone concentrations if desired in future, although not included in the current contract.



Data: Eutroph. Exceedance (AAE)
Units: kEq/ha
Scenario: UEP32
Year: 2020
Source: UKIAM V3

Data: Eutrophication AAE
Units: kEq(H+)/ha
Scenario: EMEP CLE2020 Grid Avg Dep
Source: UKIAM V3

These 2 maps produced using UKIAM both represent exceedance of critical loads for eutrophication as an indication of ecosystems at risk from excess nitrogen. The map on the left is based on modelling of deposition by the FRAME model of CEH, with a 5x5 km grid, with allowance for different rates of deposition in different types of ecosystem within each square e.g. higher deposition on forest areas. This shows that in 2020 we still expect substantial problems of eutrophication in the UK. The figure on the right shows the equivalent map derived using the same approach as the GAINS model, that is based on the EMEP model smoothing deposition over the larger ~50x50km grid squares and using this average deposition for all ecosystem types. Although the EMEP model has been improved to differentiate between ecosystems, this is ignored in the GAINS calculations because it implied it was impossible to meet the targets set in the CAFE programme of the EC for improvements in ecosystem protection. This results in an artificially optimistic picture of eutrophication problems in the UK.

Figure 2.1 : Modelled exceedance of critical loads for eutrophication ecosystems

2.1.3 A global scale tool: an initial step towards global integrated assessment modelling

The objective of this task was to develop a simple tool to assess the influence of sources outside Europe on the effectiveness of scenarios proposed for European action to control ozone and secondary particulates. It is the one task that has not been fulfilled by Imperial College under the current contract, as it was felt more important at the present time to extend some of the other tasks- in particular the work at the urban scale on trends in NO_2 which was not envisaged in the original proposal.

However global scale issues have been kept in mind, noting that the EMEP model does indicate some contribution to UK concentrations of SIA from outside Europe although equivalent data is not available from the Met Office. We also attended the Saltsjobaden workshop in October 2009 on synergies between climate and air quality, at which the need to consider radiative forcing in future integrated assessment modelling was agreed. As noted above Helen ApSimon and Tim Oxley also produced a joint paper with Markus Amann and Stefan Astrom published in Climate Policy on “Synergies in addressing air quality and climate change”

2.2.1 Modellers forum and model intercomparison

Imperial College has reported model developments in UKIAM at meetings of the modellers forum linked to contract meetings to discuss progress. Most of this work is described under work package 1, and includes the urban modelling with BRUTAL, model intercomparisons and source-receptor relationships (for example between the EMEP and FRAME models); also the work described in section 1.5 on uncertainty analysis, specifically with respect to responses of SIA concentrations to changes in precursor emissions.

2.3.1 Review of the GAINS model

Detailed analysis of emissions:

In parallel with the development of UKIAM and investigation of emission projections in the NAEI (see section 1.1.2), detailed comparison has been undertaken with emissions as calculated in the GAINS model. This highlighted the assumptions behind the projections, where the NAEI reflects, for example, the National Emission Reduction Plan, NERP, for power plant emissions, whereas the GAINS model is based on assumed technologies and associated emission factors. Summary reports were produced on comparison of the emissions for significant sources, and forwarded within the SSNIP consortium and to Defra. This work was further developed in collaboration with AEA, ENTEC and Aether (Melanie Hobson) under a small extension of the contract remit, with a visit to IIASA to discuss the differences found. This covered activity data, and emission factors assuming different levels of abatement, and was very constructive; providing a good basis for interaction with IIASA in subsequent work- see section 2.3.3

Review of models in EC4MACS (including the GAINS model)

The GAINS model uses data generated by a range of other models and research supported by the European Commission in the EC4MACS Life project. During the second half of this SSNIP contract there has been a review of all the models covered in EC4MACS, including the PRIMES model for energy projections, the CAPRI model for agricultural projections in the EC27, the TREMOVE model for road transport, the work of the Coordinating Centre on

Effects at RIVM, and the GAINS model itself. At Imperial College we have played an active part in this review, culminating in a meeting at IIASA in October 2009. Here Tim Oxley led the discussion on the work of the Coordinating Centre for Effects on assessing protection of ecosystems, forests and crops; illustrating aspects such as the effects of scale and the importance in the way deposition is modelled when mapping exceedance of critical loads (see figure 2.1).

Similarly Helen ApSimon led on the review of the PRIMES model, for which there was much concern about the lack of transparency and paucity of information. As the chair of NIAM (see below) she was asked to gather views from different countries on the main areas of concern, and communicate these to the PRIMES team. Unfortunately the dissemination of the research with PRIMES is restricted to the EC's network of national energy economists, and it has been very difficult to make headway in extending this to the integrated assessment modelling community as other users of the PRIMES scenarios and research. However the EC4MACS meetings provide a forum at which questions can be raised on general characteristics of the scenarios produced, and how they differ from previous ones.

2.3.2 Contributions to TFIAM

Helen ApSimon and Tim Oxley have regularly attended TFIAM meetings, reporting on modelling work at Imperial College and on activities in NIAM, plus requested contributions such as a review of the PRIMES model. In the early stages of SSNIP we participated in the review of the Gothenburg protocol, raising several issues on differences between the EC's CAFE programme and the CLRTAP approach- for example in target setting, and a lack of flexibility in accommodating improvements in the science in CAFE.

We have commented on new developments by IIASA, especially in relation to an integrated approach to both air quality pollutants and green-house gases. In future this is to be extended to cover short-term radiative forcing (an outcome of the Saltsjobaden workshop in 2009), raising many new questions.

In presenting our own work we have illustrated where a national perspective results in different conclusion from the European scale GAINS modelling, including questions of scale, and more specific treatment of different sources and their characteristics. Our more detailed urban modelling has also been useful here, illustrating parallel concerns such as compliance with air quality legislation as well as future emission ceilings and the objectives under CLRTAP. This can alter the priorities for abatement, and highlight common issues- for example current upward revision of emissions of NOx where real world emissions have not followed expectations based on Euro standards, and which are outside the control of individual countries.

Helen ApSimon has also attended other related Task Force meetings under CLRTAP, including the Task Force on Reactive Nitrogen. Here the work undertaken with UKIAM towards an integrated approach to the nitrogen cycle has been presented, together with the agricultural scenarios described in section 1.4.9. This raised interest with respect to the later scenarios, with changed patterns of meat consumption, since TFRN has established a panel on dietary change. This parallels interest in TFIAM in addressing behavioural change as well as technical measures in relation to reducing emissions and environmental impacts.

Reports have been made back to Defra on Task Force meetings when no Defra representative has been present, and we have responded with comments to various requests from Defra on matters arising from other meetings related to CLRTAP and other queries.

Additional task: coordination of NIAM

In parallel with our own modelling for the UK several other countries are undertaking integrated assessment modelling at a national scale, some using downscaled versions of RAINS/GAINS and some developing independent modelling as we have with UKIAM. It was decided that it would be useful to establish a network of these national integrated assessment modelling activities, NIAM, working closely with IIASA as the Centre for Integrated Assessment Modelling under CLRTAP. The UK (Helen ApSimon) and Sweden (Stefan Astrom) took on joint responsibility for chairing and coordinating this network, which now officially reports to TFIAM.

After the initial work in setting the network up with an agreed remit, we organised the first meeting in the UK as a joint APRIL-NIAM workshop in London on “Reducing the Environmental Impacts of Transport with Behavioural Change” in January 2009. This had been identified as a challenge for integrated assessment modelling, and drew out many of the problems in treating measures involving behavioural change on a similar basis to technological measures, especially in assigning costs (which may be negative) and allowing for other barriers to uptake. This has been useful for our own work on modelling of road transport scenarios, which we fed into this meeting.

There have also been 2 meetings organised at IIASA back to back with meetings of the EC4MACS project supporting development of both GAINS and other European scale models being used for policy development by the European Commission. At the NIAM meetings countries have reported their progress in IAM, and have addressed specific topics. At the most recent these included longer-term projections to 2050, and modelling of urban air quality. NIAM members have also played an active role in review of the EC4MACS models, and drawing attention to factors not allowed for in setting of the original Gothenburg ceilings. The most recent NIAM initiative is collaboration on how to address uncertainty in integrated assessment modelling, which Helen ApSimon is coordinating. This will feed into a meeting at IIASA in November 2010, and joint interests have also been raised with Task Force on Emissions Inventories and Projections (TFEIP).

The leading role of the UK in coordination and development of NIAM has been partly supported from the SSNIP contract by diversion of funds from coordination of the APRIL network.

2.3.3 Assess strategies from RAINS/GAINS modelling

Following considerable delays in developing new scenarios for revision of the NECD where the EC hoped to have close interaction with agreements on greenhouse gases, there are now new developments under CLRTAP. Two baseline scenarios are being developed by IIASA, one based on national projections and the other on projections from PRIMES 2009 for energy and the CAPRI model for agriculture. In the case of the national scenarios data for the UK has been provided to IIASA by AEA for the UEP37 energy projections, and IIASA have produced corresponding emission projections to 2020 from GAINS. Under SSNIP these have been compared with NAEI emission projections for the UEP37 case, initially showing some considerable differences- especially for SO2 and NOx where the GAINS figures were considerably lower- see table 2.1. This was of concern because it would feed through to subsequent emission ceilings, which would be even lower with further abatement superimposed. Experience from previous comparisons with GAINS helped to identify where the major differences arose, and discussions with IIASA and AEA have helped to bring the GAINS and NAEI projections very much closer, with changes on both sides. This has been summarised in research notes to Defra.

Table 1.2 . Initial comparisons of GAINS and NAEI projectionsfor the UEP 37 “ UK national scenario”

Emissions are in Ktonnes

Scenario	**Pollutant**	**2010**	**2015**	**2020**
GAINS	Nox	1229	963	699
NAEI	Nox	1212	1014	780
Difference (NAEI minus GAINS)	Nox	-17	51	81

Emissions are in Ktonnes

Scenario	**Pollutant**	**2010**	**2015**	**2020**
GAINS	SO2	373	321	291
NAEI	SO2	410	356	335
Difference (NAEI minus GAINS)	SO2	37	35	44

Emissions are in Ktonnes

Scenario	**Pollutant**	**2010**	**2015**	**2020**
GAINS	PM2.5	73	64	59
NAEI	PM2.5	69	59	55
Difference (NAEI minus GAINS)	PM2.5	-5	-5	-4

Although total projected emissions of PM2.5 from GAINS and the NAEI are fairly close, there are very big differences in the underlying individual sources, both in what is included in the inventories and the magnitude of emissions from source included in both. This needs further investigation. With respect to VOCs agreement is closer, and Melanie Hobson at Aether has looked into differences and raised them with IIASA. It is therefore anticipated that the baseline emission projections for the UK in the national scenarios case to be presented at the TFIAM meeting in Dublin will be in acceptable agreement with UK projections. However it will be important to look closely at the PRIMES projections, and also to take into account more recent updated projections for the UK based on UEP38 energy projections.

The development of GAINS scenarios towards setting new ceilings will be an ongoing process after the end of the current SSNIP contract, still requiring further scrutiny- including the treatment of abatement measures and costs, and conclusions about environmental impacts. In this context it is expected that new scenarios developed by IIASA will place emphasis on abatement of NH3, since most of the cost-effective measures for other pollutants have already been taken or are covered under existing legislation. It is therefore envisaged that future work will be required on agricultural scenarios in the UK, where revision of abatement costs will be important.