MODELLING NATIONAL AIR QUALITY STRATEGY SCENARIOS WITH UKIAM: UNCERTAINTIES EMERGING FROM THE INTEGRATION OF MULTIPLE SPATIAL SCALES

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INTRODUCTION

As part of the review of the UK's Air Quality Strategy the UK National Focal Centre for Integrated Assessment Modelling assessed a range of different scenarios involving additional reductions of emissions from traffic. This assessment was carried out based upon results calculated using the UK Integrated Assessment Model (UKIAM) for national emissions changes, integrated with European scale results from the Abatement Strategies Assessment Model (ASAM) [Oxley & ApSimon, 2007]. UKIAM is designed to investigate a range of environmental benefits from scenarios with changing pollutant emissions both within and outside the UK, including relatively simple modelling of urban concentrations in relation to urban air quality and health impacts. In this work we explored sensitivity to different aspects of modelling human exposure to NO_2 and PM_{10} in relation to future projections up to 2020. Parallel work was carried out by Netcen using the PCM model, and by CERC using ADMS, to provide a comparison of results from models designed to support policy development [Stedman *et al.*, 2006].

The scenarios assessed were based upon projected Business-As-Usual (BAU) scenarios for 2010 and 2020, combined with additional measures relating to programmes of incentives for early uptake of Euro V/VI standards and increased penetration of low emissions vehicles (eg. hybrids), together with non-transport measures relating to the implementation of the Small Combustion Plant Directive (SCPD).

We discuss here the assumptions and uncertainties resulting from modelling these scenarios using a variety of different models and data resolutions ranging from calculations with ASAM at 50km to determine 'imported' contributions from continental Europe and shipping, through UKIAM and PPM at 5km resolution for all UK pollutant sources, to comparisons with other model outputs defined at 1km resolution. Quantification of these uncertainties, together with assumptions relating to the percentage of primary NO_2 contributing to NO_X concentrations, the scaling of background NO_X concentrations, and definition of background primary PM_{10} concentrations must be included in interpretation of results and comparison with other models.

UNCERTAINTIES

The modelling results produced by the UKIAM should be interpreted in the context of a number of assumptions and uncertainties in the representation of NO_2 and PM_{10}. These primarily include:

- Background primary PM_{10};
- The representation of primary NO_2;
- Scaling of background NO_X concentrations; and
- NO_3 source-apportionment.

The key results from the UKIAM and the effects of the assumptions made are summarised in Table 1, providing both a source-apportionment of PM_{10} concentrations and a comparison between different assumptions regarding NO_2. Further information is provided in the complete description of AQS simulations carried out with UKIAM [ApSimon *et al.*, 2006].

Nitrogen Dioxide (NO_2)

In respect of primary NO_2 we ran simulations based upon the assumption of an NO_2:NO_X emission ratio of 5%. However, recent findings suggest that in some urban locations this relationship may increase to 15% or more [Carslaw, 2005; AQEG, 2006]. The AQS scenarios were thus also simulated based assuming 15% of NO_X emitted directly as NO_2, resulting in a different overall relationship between NO_2 and NO_X concentrations from the simple chemical sub-model. Table 1 highlights the relative effect of these assumptions, with Population Weighted Mean (PWM) concentrations increasing by 3-4% (whole UK) and 6-8% (London only) when higher primary NO_2 is assumed.

DEFRA Air Quality Scenario Q (UEP21 Emissions projections)
Population Weighted Mean (PWM) Concentration (µg/m^3)

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

Table 1: Results from UK Integrated Assessment Model

Simulations were also repeated with differing assumptions regarding the origin of remote rural background NO_X concentrations. As stated by Stedman and others (2006), PCM and ADMS have assumed that these rural background NO_X concentrations respond directly in proportion to changes in UK emissions. However, the UKIAM assumes a lower (50%) response to UK emissions changes taking into account increasing emissions from shipping and other varying transboundary contributions; these are the baseline results which have been compared with PCM and ADMS. Preliminary investigations using PPM(Europe) suggested that this 50% scaling of rural background NO_X in relation to UK emissions is a reasonable interim assumption; details are provided by ApSimon and others (2006). In Tables 1 & 2 we present four alternative sets of results for NO_2 based upon the following assumptions:

- NO_2 - Scenario with un-scaled rural background NO_X provided by Netcen
- NO_2i - Scenario with 50% of rural background NO_X scaled to UK NO_X emissions
- NO_2i+ - Scenario NO_2i with increased NO_2:NO_X ratio (15%)
- NO_2a - Scenario with 100% of rural background NO_X scaled to UK NO_X emissions

Taking scenario NO_2i as the base case representing UKIAM assumptions, we can observe a 5% (approx.) reduction in PWM concentrations when all the rural background is scaled (assumed by PCM and ADMS), whereas a 5% increase is observed if background NO_X remains unchanged. These findings highlight the need to investigate further these assumptions since such variations can significantly affect the predicted trends due to abatement scenarios.

Primary Particulate Matter (PM_{10})

Further assumptions were also made which affect the results for PM_{10}. Firstly the source-apportionment of secondary aerosols, and secondly the treatment of coarse background PM_{10}. In the latter case the UKIAM assumes background PM_{10} = 5µg/m^3 and 9µg/m^3 for rural and urban areas, respectively (labelled *PM10(59)* in Table 1), but for comparison with PCM simulations were also carried out assuming background PM = 9µg/m^3 for all areas. These assumptions have minimal effect in London (mainly urban) but imply an 8% reduction in PWM and implied health effects for the UK as a whole. The results presented in Table 2 are based upon the assumption of ~9µg/m^3 for all areas (as assumed in the PCM modelling).

Figure 2: Tabulated Results of Exceedance of 40µg/m^3 (NO_2) and 20µg/m^3 (tPM_{10})

			UKIAM Results				PCM Results (5km)			
Pollutant	Scenario	µg/m^3	Pop (M)	Pop %	Area (Mha)	Area %	Pop (M)	Pop %	Area (Mha)	Area %
NO_2	B2010	40	2.694	4.93	0.1	0.13				
	B2010a	40	2.041	3.74	0.085	0.11	0.423	0.77	0.007	0.01
	B2010i	40	2.229	4.08	0.087	0.11				
	B2010i+	40	3.231	5.91	0.135	0.17				
	Q2010	40	2.427	4.44	0.095	0.12				
	Q2010a	40	2.041	3.74	0.085	0.11	0.423	0.77	0.007	0.01
	Q2010i	40	2.229	4.08	0.087	0.11				
	Q2010i+	40	3.138	5.74	0.13	0.16				
	B2020	40	2.027	3.71	0.085	0.11				
	B2020a	40	1.415	2.59	0.058	0.07	0.235	0.43	0.005	0.01
	B2020i	40	1.874	3.43	0.075	0.1				
	B2020i+	40	2.257	4.13	0.1	0.13				
	Q2020	40	1.639	3	0.07	0.09				
	Q2020a	40	1.395	2.55	0.055	0.07	0.035	0.06	0.003	0
	Q2020i	40	1.415	2.59	0.058	0.07				
	Q2020i+	40	2.054	3.76	0.092	0.12				
tPM_{10}	B2010	20	2.406	4.4	0.153	0.19	0.352	0.64	0.015	0.02
	Q2010	20	2.168	3.97	0.135	0.17	0.18	0.33	0.01	0.01
	B2020	20	0.59	1.08	0.06	0.08	0.174	0.32	0.007	0.01
	Q2020	20	0.36	0.66	0.055	0.07	0.082	0.15	0.003	0

Particulate nitrate, NO_3

Contributions to particulate NO_3 concentrations from UK, European and other sources have been estimated by running emissions scenarios using ASAM and source-receptor data from the EMEP model, derived by reducing different sources in turn. Table 3 indicates the resulting source apportionment and relative contributions to exposure to particulate nitrate. This implies a large proportion from transboundary source, including shipping emissions which are increasing. "Other sources" includes imported contributions across the boundaries of the European map area.

Table 3: Source apportionment of NO_3 concentrations based upon EMEP data

NO_X Source	NO_3 Exposure (UK)			NO_3 Exposure (London)		
	Exposure (pers.g/m^3)	PWM (µg/m^3)	% Contrib.	Exposure (pers.g/m^3)	PWM (µg/m^3)	% Contrib.
EMEP 2010 Baseline	161	2.95		23	0.42	
UK Contribution	36	0.65	22%	3	0.05	12%
EU25 (excl.UK Contrib.)	47	0.85	29%	7	0.12	30%
Shipping Contribution	29	0.52	18%	4	0.07	17%
All other sources	50	0.92	31%	10	0.18	42%
			100%			100%

Spatial resolution

Finally there are effects of spatial resolution in the modelling: PCM models air quality at 1km resolution whereas the UKIAM model was applied at 5km resolution. Comparisons between the models thus requires aggregation of the PCM results to 5km resolution. Such comparisons should be interpreted with caution since up to a 5% reduction in PWM concentrations of PM_{10} and 8% reduction of NO_2 for the UK as a whole can result from aggregation from 1km to 5km (see Table 4); reductions for London range from 2.5% (PM_{10}) to 13% (NO_2), but it should be noted that these concentrations are further distorted by calculations at 5km being for Greater London and at 1km resolution for Inner London. The UKIAM model is currently being refined to a 1x1 km grid for the London sub-region.

Table 4: PCM 1km results aggregated to 5km resolution

PCM Results				
Population Weighted Mean Conc. (µg/m^3)				
	5km Resolution		*1km Resolution*	
UK	tPM_{10}	NO_2	tPM_{10}	NO_2
B2010	18.877	18.160	19.880	19.522
Q2010	18.728	17.960	19.713	19.311
B2020	17.559	15.512	18.543	16.777
Q2020	16.829	13.811	17.740	14.980
Greater London			Inner London	
B2010	22.798	29.573	23.567	34.022
Q2010	22.513	29.292	23.231	33.699
B2020	21.031	26.65	21.772	30.927
Q2020	19.722	24.438	20.258	28.276

CONCLUSIONS

These findings suggest that in relation to both NO_2 and PM_{10} concentrations there are significant uncertainties in the modelling assumptions of the UKIAM and PCM. In relation to both increased urban primary NO_2 and background NO_X from non-UK sources the potential effect on the PWM results is an increase between 3% and 12% can be observed depending upon the year and whether results are for the UK or London only (see Table 5). In relation to PM_{10} further investigation is needed to quantify the imported contributions of secondary aerosols and the coarse background PM in urban and rural areas.

We show that in relation to NO_2 concentrations an increase from 5% to 15% in the ratio of NO_2 to NO_X emissions in urban areas could result in an increase of 6-8% in population weighted mean concentrations in London. We also show that assumptions relating to the changing proportion of background NO_X in relation to UK or non-UK emissions may vary projected concentrations by 5-12% for the UK as a whole.

Further uncertainties were observed with contributions to NO_3 (secondary PM_{10}) being dominated by non-UK sources, with 17-18% from international shipping. Finally, comparisons with outputs from PCM illustrate the effects of smoothing over a coarser grid size with the effects of aggregation from 1km to 5km resulting in a 5-7% reduction of PWM concentrations.

To conclude, therefore, it is crucial both to explicitly highlight all the assumptions and associated uncertainties in models, and to interpret results and model comparisons in the light of these uncertainties. Research is ongoing to further quantify these uncertainties and refine and extend UKIAM to directly address road-side concentrations and air quality limit values.

	Assumptions		Effect on PWM (%)			
			2010		2020	
	PCM	UKIAM	National	London	National	London
Rural Bkgd PM_{10}	9µg/m^3	5µg/m^3	-8.7	-0.5	-8.7	-0.5
Bkgd NO_X scaling	100%	50%	5.5	2.8	9.7 - 12.5	4.8 - 6.2
Primary NO_2	5%	15%	4.2	7.9	3.5	6.5 - 7.1
Resolution (NO_2)	1km	5km	-7.0	-13.1	-7.7	-13.7
Resolution (PM)			-5.0	-3.2	-5.2	-3.0

Table 5: Summary of uncertainties in relation to percentage (%) variation in Population Weighted Mean Concentrations

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