Science and Innovation Report

NO_2 and NO_x Trends

Report for Welsh Air Quality Forum and Welsh Government

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Executive summary

Recent work by a consortium led by Kings College London and including AEA (*Trends in NO_x and NO_2 emissions and ambient measurements in the UK,* March 2011[1], hereafter referred to as 'the KCL report') indicates that the ambient concentrations of NO_x and NO_2 in the UK are not decreasing to the extent that had previously been predicted, based on estimates of emissions. The National Atmospheric Emissions Inventory (NAEI) data show a steep decline in emissions from road vehicles over the past ten years but this is not reflected in the ambient concentrations.

The work by the consortium, commissioned by Defra in 2010, analyses these trends and presents illustrative vehicle emission factors for NO_x. This Science and Innovation report reviews and summarises the findings of the KCL study and discusses the potential implications for Local Authorities in Wales.

[1] http://uk-air.defra.gov.uk/reports/cat05/1103041401_110303_Draft_NOx_NO2_trends_report.pdf, Carslaw, D., Beevers, S. Westmoreland, E. Williams, M. Tate, J. Murrells, T. Stedman, J. Li, Y., Grice, S., Kent, A. and I. Tsagatakis (2011). Trends in NO*x* and NO2 emissions and ambient measurements in the UK. Version: 3rd March 2011. Draft for Comment. Accessed 22 July 2011.

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1 Sources of NO_X and NO_2

Across the UK, emissions of oxides of nitrogen (NO_X) arise primarily from combustion sources. The main three combustion sources of NO_X are:

Transport
Since 1990 there has been a steady decline in emissions due to the introduction of catalytic converters on cars and stricter regulations for heavier goods vehicles. Research indicates that conurbations and city centres show high localised emissions due to the combination of road transport, residential and commercial combustion sources. Similarly, around airports, ports and major terminals, significant localised emissions arise from aviation, shipping, railway locomotives and road vehicles.

Power Generation
Since 1988 the electricity generators have adopted a programme of progressively fitting low-NO_X burners to their 500 MWe (megawatt electric) or larger coal fired units. More recently the increased use of nuclear generation and the introduction of Combined Cycle Gas Turbine plant burning natural gas have further reduced NO_X emissions.

Industrial Combustion
The emissions from industrial combustion across the UK have declined by 66% since 1970 and they currently contribute 16% to total UK emissions. This is primarily due to the decline in coal use in favour of gas and electricity.

2 NO_x and NO_2 concentrations in the UK

Figures 1 to 3 show the trends in average measured ambient NO_x concentrations at long running roadside, urban centre and urban background sites in the UK Automatic Urban and Rural Network. These figures are reproduced from the KCL report, Crown Copyright 2011.

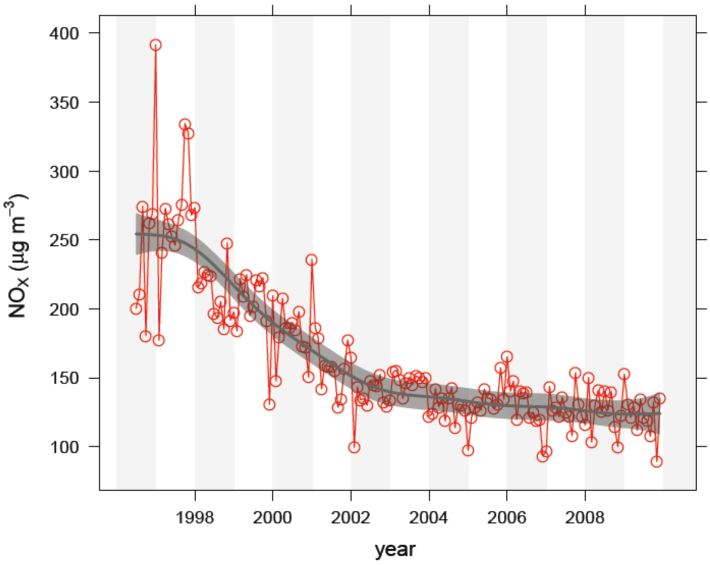

Figure 1: NO_x trend at 12 long-running UK roadside sites

Average change in NO_x concentration per year between 2004 and 2009: -1.4%
Average change in NO_2 concentration per year between 2004 and 2009: -0.6%

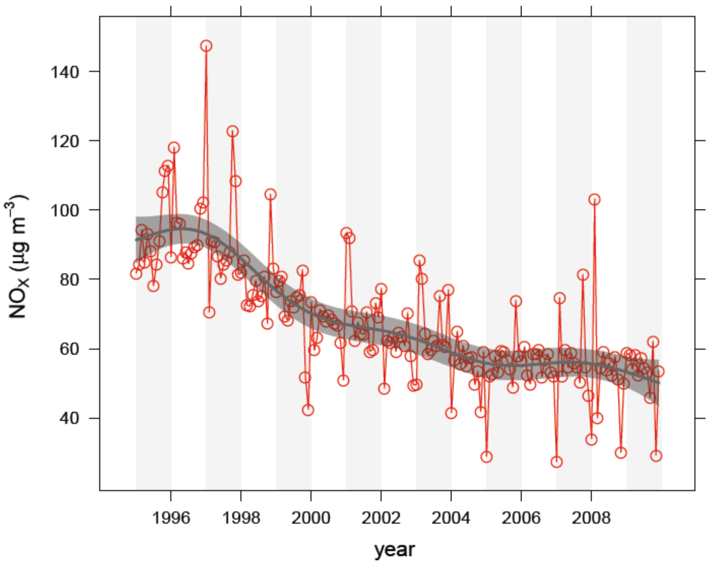

Figure 2: NO_x trend at 11 long-running UK urban centre sites

Average change in NO_x concentration per year between 2004 and 2009: -0.8%
Average change in NO_2 concentration per year between 2004 and 2009: -0.4%

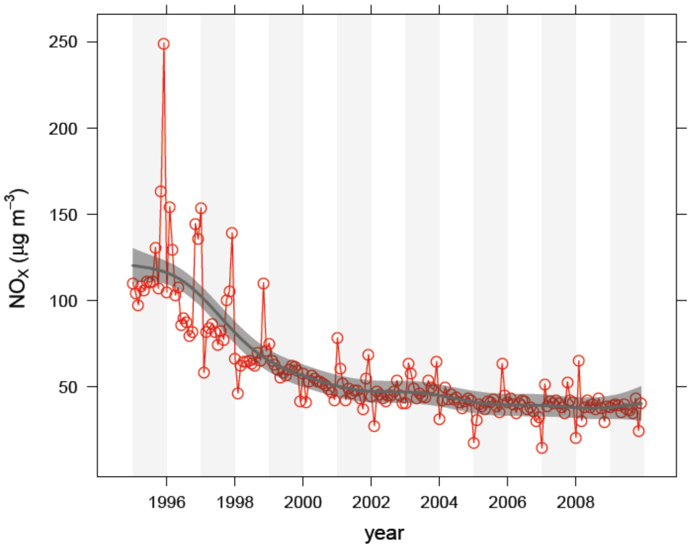

Figure 3: NO_x trend at 17 long-running UK urban background sites

Average change in NO_x concentration per year between 2004 and 2009: -2.1%
Average change in NO_2 concentration per year between 2004 and 2009: -0.8%

The difference in the average change in NO_x and NO_2 concentrations between 2004 and 2009 is due to recent increases in the proportion of NO_2 to total NO_x in vehicle exhausts. The proportion of primary NO_2 to total NO_x expressed as a volume ratio is referred to as *f-NO_2*. *f-NO_2* has increased from around 6% in 1997 to 13% in 2004 and about 15% in 2009 for UK roadside sites (estimated in the KCL report, based on an approach developed by Carslaw and Beevers (2005)[2]). The main reason for the increase in *f-NO_2* is thought to be the increased use of oxidation catalysts and particle filters on light duty diesel vehicles and cars. This has been compounded by a steady increasing proportion of cars in the UK fleet that are diesel.

2.1 NO_x emissions in the UK

Road transport is the largest source of NO_x in the UK with stationary combustion and power generation also forming significant sources. Approximately one third of the UK NO_x emissions arise from road transport. Since 1990 total emissions have declined by 60% mainly as a result of a 67% reduction from power stations and 66% decrease from road transport.

Between 2005 and 2009 the total emissions of NO_x of the UK are reported by the National Atmospheric Emissions Inventory (NAEI) to have declined by 30%[3]. The trends in NO_x concentrations in figures 1 to 3 show a levelling off in the decline from around 2004. This is at odds with the steep downward trend in the emissions reported by the NAEI.

The UK is not alone in this disparity – a similar pattern is also seen in a large proportion of European Member States. The KCL study has analysed data from over 2000 sites in Europe and concludes that *'the trends in NO_x and NO_2 are similar to those …. in the UK'.*

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[2] Carslaw, D. C., Beevers, S. D., 2005. Estimations of road vehicle primary NO2 exhaust emission fractions using monitoring data in london. Atmospheric Environment 39 (1), 167–177.
[3] UK Emissions of Air Pollutants 1970 to 2009, AEA, unpublished draft, September 2011

3 NO_X and NO_2 trends in Wales

Figure 4 shows the trends in measured NO_x concentrations in Wales, between 1993 and 2010. The measured data are from ten long running traffic and background sites, and these data are available on www.welshairquality.co.uk. Following a period of decline from 1993 to around 2006, in the last few years the measured concentrations seem to be increasing slightly. It is, however, important to note that the annual means for Urban Background sites prior to 2002, and for Traffic Urban sites prior to 2004, should be treated with caution as they are based on data from less than four sites.

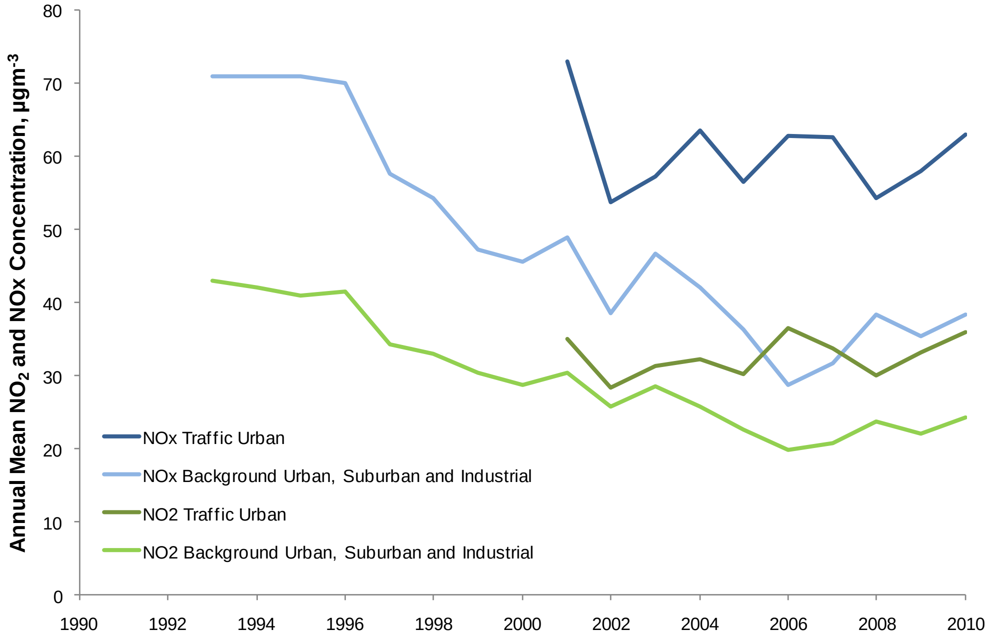

Figure 4: Trends in measured NO_x and NO_2 concentrations in Wales between 1993 and 2010

The raw emissions data from the period are shown in figure 5 and figure 6. Emissions data are from a 2009 report of the NAEI[4],

	1990	1995	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Energy Industries	49.9	35.2	28.5	23.2	32.5	39.2	32.6	32.2	35.1	33.4	40.7	28.3	38.4	31.5
Industrial Combustion	29.3	29.8	28.8	31.2	28.8	26	21.3	21.2	21	19.5	18.4	17.4	16.5	14
Transport Sources	59.7	52.6	48.8	46.9	44.6	42	40	37.7	36.9	35.2	33.1	31.4	29.3	24.9
Commercial and Domestic	17.2	16.6	15.8	15.4	14.5	14.2	13.1	12.4	11.5	10.8	9.7	8.7	8.2	7.6
Other	7.7	8.7	8.3	8.5	8.2	6.3	2.9	3.3	3.7	3.4	3.9	4	3.9	2.8
Total	**164**	**143**	**130**	**125**	**129**	**128**	**110**	**107**	**108**	**102**	**106**	**90**	**96**	**81**

Figure 5: Nitrogen Oxides (as Nitrogen Dioxide) Emissions Inventory for Wales 1990-2009 (ktonnes)

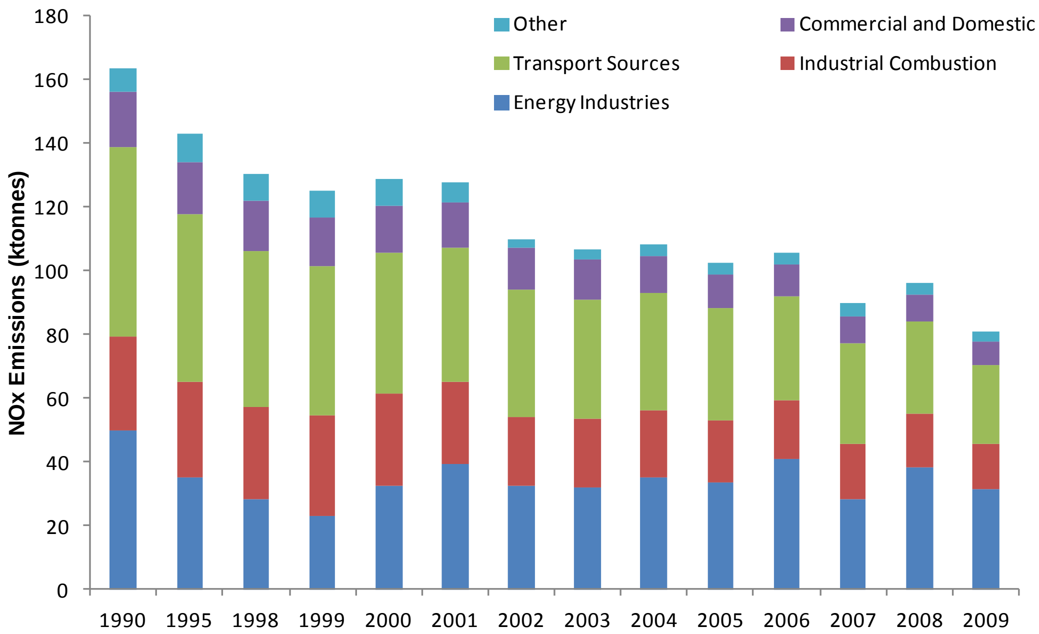

Figure 6: Wales Nitrogen Oxides Emissions by Source, 1990-2008

According to the NAEI, emissions of NO_x in Wales have declined by 51% since 1990 (compared to an overall reduction of 60% across the UK in the same period). This is broadly in agreement with the trend in annual mean concentrations of NO_x at background, suburban and industrial sites, shown in figure 4. Power generation accounts for 39% of the Wales NO_X inventory total in 2009 and emissions from this source have reduced by 37% since 1990. There have, however, been large increases in power generation evident in recent years as Wales increasingly generates electricity that is exported and used in England.

[4] Air *Quality Pollutant Inventories for England, Scotland, Wales and Northern Ireland: 1990 – 2009*, http://uk-air.defra.gov.uk/reports/cat07/1110121007_DA_AQI_2009_Finalr.pdf

Transport NO_x emissions in Wales are reported to be down 58% since 1990 and down 41% between 2001 and 2009. This is however not reflected in the roadside measured NO_x concentrations shown in figure 4.

Road transport is still the primary reason for exceedances of the NO_2 air quality objective in Wales, due to the build up of vehicle emissions in congested, urban areas, causing elevated concentrations of this pollutant in the ambient air. Road transport emissions therefore remain of great significance for Local Air Quality Management.

4 Emission Factors

The KCL report focuses on analysing recently collected data from roadside remote sensing of vehicle emissions, for vehicles registered between 1980 and 2010. The measurements were made during several campaigns between 2008 and 2010 in five urban areas in the UK. Exhaust emissions from around 72,000 vehicles were sampled. The KCL study took the remote sensing data, as a ratio of NO/CO_2 for each vehicle, and converted it into a NO_x/CO_2 ratio using known ratios of NO/NO_2 in emitted NO_x. for different vehicle classes. The proportion of NO_2 to total NO_X in the exhausts of vehicles in the fleet has been increasing in recent years, from about 6% (by volume) in 1997 to around 15% in 2009, in the UK. Estimates are higher for the fleet in London, increasing from around 4% to 21% in the same time period. The NO_x/CO_2 ratios from the remote sensing data are combined with the UK emission factors for CO_2 (in g km^{-1}) appropriate for the average speed of the vehicles sampled by remote sensing to estimate equivalent emission factors for NO_x emission in g km^{-1}.

The data were compared with emission factor information used in the NAEI and available from other sources from previous studies of the testing of cars, heavy and light goods vehicles and buses and coaches. Specific vehicle characteristics including engine size, age, Euro emission standard and fuel type have also been collected from Automatic Number Plate Recognition data at the same roadside sites and this has allowed researchers to assign ratios NO_x/CO_2 emissions to various classes of vehicles. For a detailed discussion of the emissions by vehicle class, technology and time, see section 4.3 of the KCL report.

The KCL report compares emission factors for NO_x derived from the remote sensing data with the current UK emissions factors (http://naei.defra.gov.uk) and recently published Swiss/German emissions factors (HBEFA, www.hbefa.net).

Figure 7 shows the comparison between the emission factors from the three different sources for six different vehicle types and Euro classes within them.

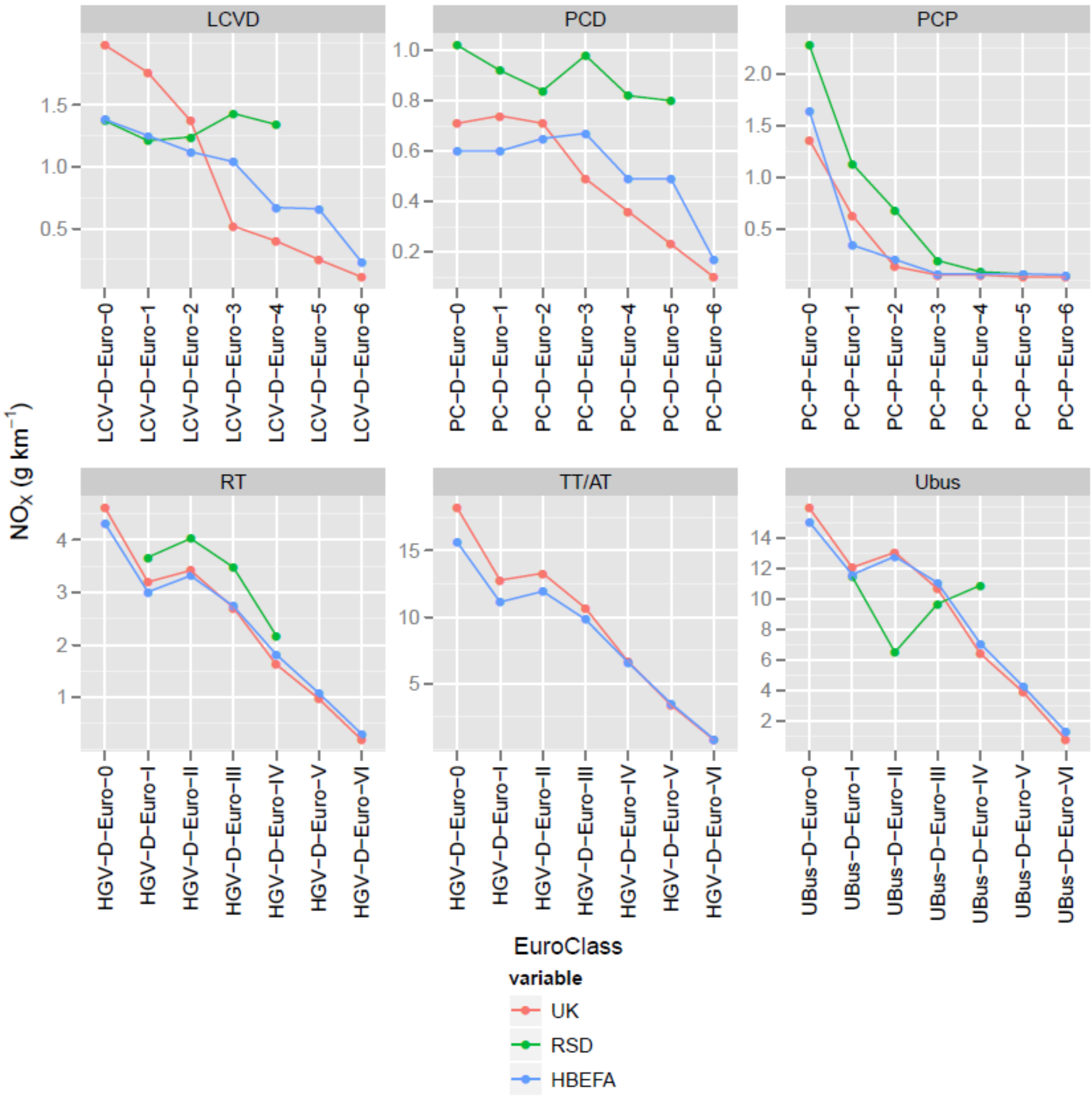

Figure 7: Comparison between UK emission factors, HBEFA and remote sensing (RSD) data

Heavy Goods Vehicles (HGVs)

For rigid HGVs (RT) and articulated HGVs (TT/AT) the emissions estimates are very similar. There was insufficient remote sensing data to include for articulated HGVs.

Buses

The remote sensing data emissions estimates for buses (Ubus) are very different from the UK and HBEFA emissions factors. The remote sensing testing for Euro II buses took 98% of the data from London buses. London buses accounted for 50% of the Euro III class data and only 6% of the Euro IV class data. However, the London buses have been fitted with particle filters and are not representative of buses across the whole of the UK. The remote sensing data emissions estimates for Euro II and Euro III buses are therefore likely to be lower than the UK average. However, the remote sensing data for Euro IV buses are thought to be more representative of the UK fleet implying that the current UK and HBEFA emission factors are underestimated.

Diesel cars and Light Goods Vehicles (LGVs)
There is significant disagreement between the three emissions estimates for diesel cars (PCD) and LGVs (LCVD). The UK emissions factors for diesel LGVs suggest that there should have been about an 80% reduction in NO_x emissions from these vehicles since the introduction of the Euro standard, but the remote sensing data indicates that the emissions are similar for all Euro vehicle classes (although pre-Euro standard UK are substantially higher than RSD). This implies that inventories based on the UK and HBEFA factors are being too optimistic in defining the rate of decline in emissions from diesel LGVs. The situation for diesels cars is similar, with the remote sensing data indicating higher emission factors and a smaller rate of decline across the Euro standards.

Petrol cars
All three sets of emission factors show a marked decrease in emissions from pre-Euro to Euro 4. However, the remote sensing data estimates are higher than the UK and HBEFA estimates for Euro 1 and 2 cars. This would act to slow down the rate of decline in emissions from petrol cars than currently indicated by the inventory, while there were sufficient numbers of these vehicles on the road, but the decline would continue beyond that currently indicated by the inventory as these vehicles were removed from the fleet.. The remote sensing data suggest that older petrol vehicles with catalysts emit more NO_x than was previously thought. It is possible that these differences in emissions estimates are due to catalytic converter failures and/or incorrect assumptions of catalyst degradation.

The KCL study also reports that *'A potentially important issue to emerge from this work is that selective catalytic reduction used on HGVs is shown to be ineffective under urban driving conditions, Currently it is difficult to judge the importance of this issue due to a lack of data concerning the proportion of HGVs with selective catalytic reduction in urban areas. Euro VI legislation is expected to include a specific slow speed driving cycle that should address this issue.'* If this finding proves to be correct it is an indication that reductions associated with the use of selective catalytic reduction NO_x emission abatement technology is not operating as effectively as would be expected.

5 New Illustrative Emissions Factors

Based on this information, the KCL study created different scenarios using varying applications of the remote sensing data instead of the current UK emissions factors. The current UK factors are calculated from the set of speed-related emission factors developed by the Transport Research Laboratory (TRL) on behalf of the Department for Transport (DfT). The scenarios used combinations of factors derived from the remote sensing data with factors derived from the COPERT 4 database of factors (recommended in the EMEP Emissions Inventory Guidebook), the current UK emission factors and various assumptions about emission degradation. All the scenarios should be regarded as illustrative to indicate the sensitivity of trends in calculated traffic emissions to different sets of emission factors and degradation assumptions.

The results are shown in figure 8 indicating the relative change in UK road transport emissions from 2002 levels for each scenario. More details of these are given in the project report. The base is the emissions estimate using current UK emissions factors and the NAEI model. The base shows a reduction in total NO_x emissions since 2002 of around 45%. Using factors derived from the remote sensing data combined with more pessimistic assumptions about emission degradation does slow down the rate of decline in NO_x emissions but still does not sufficiently close the gap with trends in observed NO_x concentrations. At worst, the reduction in total emissions since 2002 is estimated to be just 20% when based on the results of the remote sensing data. This is closer to the trend in actual measured concentrations described in section 2, although it is not consistent with the 1.4% annual reduction of NO_x measured in the ambient air at roadside sites.

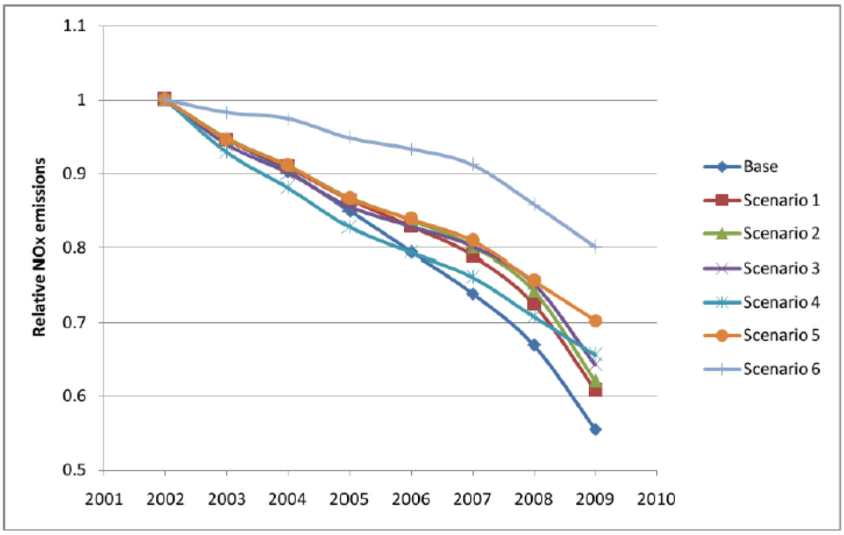

Figure 8: UK NO_x emissions for road transport relative to emissions in 2002.

For UK urban areas (2002-2009) the total urban road transport emissions reduce on average by 6% per year, according to the current UK estimates. However, when the remote sensing data is used to estimate emissions, the reduction is only an average of 4.2% per year. Variations in the local fleet composition from the national fleet mix (by age and Euro standard) used in these calculations may at least partially explain this.

Additional research is already underway in the UK to revise and update NOx emission factors and degradation rates, in particular for diesel cars and light goods vehicles. Fleet composition data are also under review. The outcome of these studies is not yet available but more information is given in Section 9.

6 Comparison with ambient measurements

Pollution Climate Mapping (PCM) models used by The UK and Welsh Government have also been used in the KCL study to estimate what the implications would be of using the illustrative emissions factors developed in the study to model ambient concentrations.

The PCM estimates background and roadside NO_x and NO_2 concentrations at over 9000 major road links in the UK. The model results have been compared with monitoring data and assessed against the 40µg m^{-3} annual mean limit value for NO_2.

Scenario 1: Baseline model, using 2008 as the calibration base year.
At background locations, the baseline model (using existing model results) compares well with monitoring data for the 2008 year, and over predicts concentrations for 2002. This was also true for roadside sites. This suggests that the emissions estimate decreased too steeply over time, so working backwards to 2002 the model over-estimated ambient concentrations. In future years this would be likely to have the opposite effect and underestimate real concentrations.

Scenario 2: Baseline model, using 2002 as the calibration base year.
At roadside and background locations, the same conclusion is drawn – that the emission projections fall more steeply than is true in reality and therefore the model underestimates real concentrations for 2008.

Scenario 3: Uses one of the illustrative emissions factor scenarios calculated in the KCL study, using 2002 as the calibration base year.
Comparison of real ambient measurements with these modelled results for the base year show no evidence of under or over estimating ambient concentrations. The results indicate that the model slightly underestimates for 2008, but this is significantly less than the underestimation in scenario 2 and a considerable improvement.

Differences in actual and estimated emissions cause a greater disparity between modelled and measured NO_x concentrations at roadside sites than at background sites. There is no significant under or overestimation in the modelled data for any of the scenarios for the year which is also used as the calibration base year, so if incorrect emissions estimates are used this will only affect the future or back projections.

The three scenarios were also used in the PCM model to estimate the number of exceedances of the annual mean limit value for NO_2 in the 43 zones and agglomerations in the UK. The results of this are shown in figure 9.

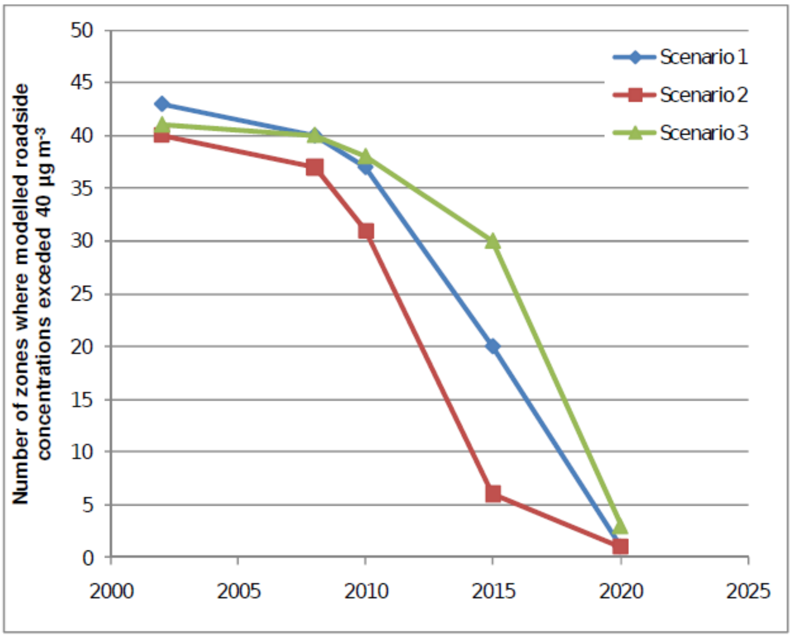

Figure 9: Number of UK zone where roadside modelled NO_2 concentrations exceed 40 µg m^{-3}

The projected extent of exceedance using the illustrative emissions factors (scenario 3) is far higher than using the baseline method (scenarios 1 and 2), however, it is likely to be more realistic. Both the current baseline method and the illustrative emissions factors assume that the Euro VI and VII standards for HGVs/buses and Euro 6 for cars and LGVs will drive large reductions in NO_x emissions relative to earlier standards, which is why the projection of emissions for all scenarios continues to fall sharply.

7 Implications

The following conclusions are drawn by the KCL study:

- Provided that Euro 4/5 do not deteriorate in the same way as older catalyst vehicles, policies that incentivise small, modern (Euro 5/6) petrol vehicles, petrol hybrids and electric vehicles in urban areas in place of diesel (5 and probably Euro 6) vehicles should be encouraged. Uptake of measures for low emission vehicles should be monitored.

- Measures that encourage the removal of older petrol vehicles from the fleet (to be replaced by modern petrol vehicles, or petrol hybrids etc.) or which ensure their maintenance at a higher level, would be beneficial.

- Consideration should also be given to tightening the MOT, which currently only provides a measure of CO/hydrocarbons. High emitters of NOx (but low emitters of CO/HC) would not be captured by the MOT.

- It will be essential to ensure that Euro 6 vehicles result in a considerable reduction in NO_x emissions, particularly under urban driving conditions. Defra and other relevant agencies should monitor the implementation of Euro 6 vehicles through European emission standards to ensure there is sufficient evidence to support claims of significantly reduced NO_x emissions under 'real world' driving conditions.

- The accelerated introduction of Euro VI diesel HGVs should be considered beyond the incentives already in place. Alternative technologies such as hybrids, electric, even hydrogen could offer advantages and should be considered as serious alternatives to conventional fuels.

- Targeting of specific fleets e.g. urban bus fleets for retrofitting does have the potential to reduce NO_x emissions.

- Remote sensing data have been an essential tool for understanding the discrepancies between emission inventories and ambient measurements. Without these data it would have been very difficult or impossible to understand these issues and so KCL encourage Defra to make use of such a system in the coming years as a way of ensuring emissions change as expected. In addition, the use of more recent remote sensing instruments that measure NO and NO_2 would further enhance these possibilities.

8 Local Air Quality Management

In September 2010 the Local Air Quality Management Helpdesk published an FAQ which addressed the issue that many local authorities are finding – that measured NO_x and NO_2 concentrations do not appear to be declining in line with national forecasts, due to the reasons discussed above. The FAQ can be found at http://laqm.defra.gov.uk/documents/Measured-nitrogen-oxides-(NOx)-and-or-nitrogen-dioxide-(NO2)-concentrations-do-not-appear-to-be-declining-in-line-with-national-forecastsv1.pdf .

At the time of writing the FAQ the KCL report had not been published and the reason for the disparity was not fully understood, although it did correctly identify that the problem is linked to the difference between actual on-road performance of vehicles when compared with calculations based on the Euro standards. We now know that this is primarily due to the calculated emissions not fully reflecting the nature of the fleet on different types of roads and areas of the country, and that the current emission factors used for the UK's inventory (UKEF) are different to the emission factors since provided in European compilations of emission factors, namely COPERT 4 developed by the EEA and the Swiss-German Handbook of Emission Factors (HBEFA), particularly for diesel cars and vans. Current revisions of UK emissions factors aim to address this.

The FAQ notes that there was no evidence to suggest that background concentrations associated with non-traffic source contributions should not behave as forecast, and the KCL study also concludes that the issue primarily affects roadside locations.

The FAQ recommends that, where existing forecasting information is used for decision making or review and assessment and action planning work, Local Authorities may wish to take account of the emerging findings on the performance of different vehicle types, the performance of Euro standards overall, and the expected effect on forecast background concentrations. The KCL report provides an extremely useful source of information to help with this and is built upon here through summarising the major findings and placing them in a Wales-specific context.

9 Future Developments

In light of these findings, some additional research has been commissioned by Defra and the Devolved Administrations to look into the road transport emission factors used by the UK's NAEI.

- NO_x emission factors and degradation rates are being revised and updated so that they are consistent with factors in COPERT and HBEFA. This will mean changes in the NAEI factors for diesel cars and LGVs for all Euro classes and changes to the degradation rates. NAEI factors for petrol cars were consistent with the previous version of COPERT 4 so these are unlikely to change significantly. NAEI factors for HGVs and buses are also unlikely to change.

- Fleet composition data for different road types, used by the NAEI, will be developed based on observations from DfT's Automatic Number Plate Recognition (ANPR) database, combined with DA-country specific vehicle licensing data. This will reflect differences in petrol/diesel mix and Euro standard mix on urban, rural and motorway road types across a whole time-series (1990-2025) for GB as a whole and will include further adjustment factors to account for the different age mix of the fleet in Wales and the other Devolved Administrations. A set of fleet data will be developed for the Emission Factor Toolkit.

It is expected that these updates will be made in early 2012, and will be used in the compilation of the 2010 pollution emission inventory for the UK and Wales. The updates will also then feed through to national models and other tools used for Local Authority air quality Review and Assessments Action Planning and Local Authority CO_2 inventories.

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