Report

Analysis of Measured Emission Factors for Euro II and Euro III Diesel LGVs and their Incorporation into the National Atmospheric Emissions Inventory

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Executive Summary

Exhaust emission factors measured by Shell Global Solutions on 20 diesel light goods vehicles, (and one vehicle tested by Ricardo) over 9 drive cycles have been analysed. A dataset comprising test results on 16 vehicles in the heaviest weight Class 3 category (>1700–3500 kg) was examined in detail, with 6 being of Euro II standard and 10 being of Euro III standard. From this dataset, empirical relationships between emission factor and average speed were obtained for Euro II and Euro III Class 3 diesel LGVs by a combination of statistical curve fitting techniques and expert judgement for the pollutants NOx, PM, CO, total hydrocarbons (THC) and CO_2.

Emission factors were assessed for the lighter weight Class 1 and Class 2 categories of diesel LGVs on the basis of the trends in the Type Approval emission standards for the three weight classes and the emission factor data for the 5 lighter vehicles that were tested. With one exception (CO_2 emissions from Class 2 Euro II LGVs), the emission factors for the lighter LGVs tested were less than those for the Class 3 LGVs. An assumption was made that the shape of the emission factor – speed relationship for the lighter vehicles was the same as for the heaviest Class 3 vehicles for each pollutant and Euro standard and from this an emission scaling factor (≤1) relative to Class 3 was derived for each weight class and Euro standard. Using assumptions about the mix of different LGV weight classes in the UK fleet, it was then possible to derive aggregated emission factor – speed relationships representing the diesel LGV fleet in the UK suitable for inclusion in the National Atmospheric Emissions Inventory (NAEI).

The speed related emission factors of Class 1 diesel Euro III LGVs, derived in this work, have been compared with those obtained for diesel Euro III passenger cars in a previous study. The two sets of speed-related emission factors were obtained totally independently from mutually exclusive data sets. Despite this, there is a very high level of similarity between the Class 1 LGVs and the smaller (< 2.0 litre) passenger cars, particularly in the 20 – 80 kph speed range for CO_2 and PM emissions. For NO_X, CO and THC emissions, those from Class 1 Euro III LGVs generally lie between the smaller (<2.0 litre) and larger (> 2.0 litre) passenger cars. However, above 80 kph CO_2, CO and most markedly NO_X emission levels, whilst increasing for all vehicle types, increase more rapidly with increasing speed for the LGVs than for cars.
A comparison has been made between the new Euro II and Euro III emission factors and those currently used in the NAEI obtained from scaling the factors for Euro I LGVs. A re-evaluation has also been made of the current factors used for Euro IV LGVs. Proposed changes to the emission factor-speed equations have been made for these vehicle types on the basis of this re-evaluation.

The study has also evaluated the effect of changes to these emission factors on the UK projections of emissions of each of the pollutants from the road transport sector. A series of emission sensitivity tests were carried out using the NAEI Road Transport Emissions Forecasting model that combines emission factors for current and future vehicle types with assumptions about growth in traffic activity and turnover in the vehicle fleet.

The overall conclusions from the analysis are as follows for each pollutant in turn.

For **NOx**, the Euro II and Euro III factors for diesel LGVs are higher than currently used in the NAEI, particularly at high speeds. We propose an increase in the current emission factors used for both Euro II and III LGVs. Our recommendations for Euro IV LGVs lead to reduced emission factors at low and medium speeds, but higher emission factors at

high speeds than had previously been estimated. The changes would lead to an overall increase of about 2.5% in the estimates of UK NOx emissions from road transport in 2010, with smaller overall increases in 2015 and 2020.

For **PM**, the Euro II and Euro III factors for diesel LGVs are very similar to those currently used in the NAEI at urban speeds, but are lower at high speeds. Our recommendations for Euro IV LGVs also lead to similar emission factors at low and medium speeds, but lower emission factors at high speeds than had previously been estimated. The changes would lead to an overall decrease of about 7% in the estimates of UK PM emissions from road transport in 2020, with smaller overall reductions in earlier years compared with estimates based on the current emission factors used in the NAEI. The emissions inventory for PM is more sensitive to changes in the diesel LGV emission factors than any other pollutant reflecting the important contribution made by diesel LGVs to overall emissions of PM from road transport in the UK.

For **CO**, the Euro II factors for diesel LGVs are higher than current NAEI factors at low speeds, but lower than current NAEI factors at high speeds. The new factors for Euro III vehicles are considerably below current NAEI factors at all speeds. We recommend factors for Euro IV LGVs that are the same as the new lower factors for Euro III, meaning that the new factors for Euro IV are below current NAEI factors that had previously been estimated. The changes would lead to an overall decrease of about 6% in the estimates of UK CO emissions from road transport in 2020, with smaller overall reductions in earlier years compared with estimates based on the current emission factors used in the NAEI.

For **THC**, the new Euro II emission factors for diesel LGVs are quite similar, but less than the current NAEI factors for these vehicle classes at all speeds. The new factors for Euro III vehicles are considerably below current NAEI factors at all speeds. We recommend factors for Euro IV LGVs that are the same as the new lower factors for Euro III, meaning that the new factors for Euro IV are below current NAEI factors that had previously been estimated. The changes would lead to an overall decrease of about 3% in the estimates of UK THC emissions from road transport in years from 2010-2020 compared with estimates based on the current emission factors used in the NAEI.

For **CO_2,** the Euro II and Euro III factors for diesel LGVs are lower than currently used in the NAEI, at all speeds and are also very similar to each other. We propose a reduction in the current emission factors used for both Euro II and III LGVs. We recommend factors for Euro IV LGVs that are the same as the new lower factors for Euro III, meaning that the new factors for Euro IV are below current NAEI factors that had previously been estimated.

On the basis of the review and analysis carried out in this study, we propose discussing and confirming with DfT and Defra our recommendation that the new Euro II-Euro IV emission factors for diesel LGVs be adopted for use in the NAEI.

Contents

1 Introduction

The National Atmospheric Emissions Inventory (NAEI, www.naei.org.uk) compiles estimates of emissions of a range of pollutants to the atmosphere from all UK sources in transport, industry, power generation, domestic households, commerce and agriculture. These emissions are estimated to help to find ways of reducing the impact of human activities on the environment and our health. Road transport is one of the most significant sources of air pollutants affecting local air quality in our towns and cities, climate change and regional air pollution episodes (e.g. ozone formation in the lower atmosphere). Significant amounts of oxides of nitrogen (NOx), fine particulate matter (PM), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOCs, mainly hydrocarbons) are emitted from vehicle exhausts and affect regional and local air quality. CO_2, a greenhouse gas, is emitted in large amounts as the major product of combustion of fossil fuels.

Emissions of these pollutants are estimated in the NAEI using emission factors (in g/km) and traffic activity data (traffic flows or vehicle kilometres) for different types of vehicles travelling on different types of roads. For a given pollutant, emission factors depend on the type and size of vehicle, the type of fuel it runs on and the way the vehicle is driven. It also depends on whether the vehicle is fitted with any engine or exhaust aftertreatment system to control emissions. Emission factors are typically measured over a range of different vehicle operational or drive cycles associated with different average speeds, for example, from slow urban cycles to high speed motorway cycles. Empirical relationships are typically generated between the measured emission factor and the average speed of the test cycle and it is these relationships that are normally used in emission inventories. Such relationships between emission factor and average speed are a fairly crude way of characterising the way emissions vary with different vehicle operational cycles, but it does allow a convenient and pragmatic approach for estimating emissions from traffic flowing along a stretch of road or on a whole road network, as in the national emissions inventory, where average speed is usually the only statistic available representing the general traffic flow condition on a particular type of road.

The NAEI uses emission factor-speed relationships for different types of vehicles manufactured to different European emission standards. For petrol cars, these standards have existed since the 1970s and for diesel cars and other vehicles since the early 1990s. Since the early 1990s, the standards, generally referred to as the Euro emission standards, have set increasingly tighter emission limits at the stage of vehicle type approval on the pollutants NOx, CO and total hydrocarbons (THC) and also PM in the case of diesel vehicles.

To date, the NAEI has used speed-emission factor relationships for vehicles up to Euro II standards taken from reviews and analysis of in-service test data carried out by TRL who hold a large database of emission factors from tests covering a range of vehicle types and drive cycles gathered from sources in the UK and elsewhere in Europe (Barlow et al, 2001). For diesel light goods vehicles (LGVs), emissions test data have been sparse and the TRL report was only able to provide emission factor – speed relationships for vehicle meeting Euro I standards. Since emission factors have not been available from tests on in-service Euro II (new vehicles from 1997) and Euro III LGVs (new vehicles from 2001/2002) for use in the inventory, the NAEI has had to make estimates of factors for different pollutants based on the measurements-based values for Euro I and judgements on the impacts of the tighter type-approval limit values for Euro II and Euro III LGVs. The estimates take into account the nature of the regulatory test cycle and anticipate the approach of vehicle manufacturers to achieving certain emission durability requirements. Without prior knowledge of the emission factor-speed relationship, it has been assumed that the shape of the speed-emission curve of a given pollutant for a Euro II and Euro III LGV is the same as for a Euro I vehicle and a simple scaling factor (less than 1) is applied to the Euro I emission factor-speed relationship. The same estimation approach has also been used to derive emission factors for Euro IV vehicles that need to be included in the NAEI emission projections.

Since the production of the current version of the NAEI, Shell Global Solutions, on behalf of the Department for Transport, have made emission factor measurements on 20 diesel light goods vehicles from tests conducted over several drive cycles. Test data on one vehicle classified as an LGV was also available from Ricardo. The majority of the vehicles tested (16) were in the heaviest weight Class 3 (>1700–3500 kg) and were a mix of vehicles meeting Euro II and Euro III standards. Three vehicles tested were weight Class 1 LGVs (≤1250 kg) and two were weight Class 2 LGVs (>1250-1700 kg). This report provides an analysis of the test data for the pollutants NOx, PM, CO, total hydrocarbons (THC) and CO_2 and the generation of new speed-emission factor functions proposed for inclusion in the NAEI. The statistical treatment of the data used was broadly consistent with the methods used by TRL for the development of factors for Euro I LGVs and in our own recent study for DfT on test data for Euro III cars.

The report describes the analytical method used and the speed-emission factor functions derived for Euro II and Euro III diesel LGVs are presented. The focus of the statistical treatment was on the Class 3 LGVs, but emission factors were also assessed for the lighter Class 1 and Class 2 diesel LGVs on the basis of the Type Approval emission standards for the different weight classes and the emission factor data for the 6 lighter vehicles that were tested. This led to the derivation of aggregate emission functions representing all diesel LGVs in the UK, weighted by the mix of the different weight classes in the fleet. New Euro IV factors are proposed on the basis of the new factors for Euro III LGVs.

Section 3 provides the new speed-emission factor relationships derived for Euro II-IV diesel LGVs and compares them with speed relationships currently used by the NAEI. For each pollutant, the equations are used to calculate average emission factors at typical speeds on urban, rural and highway roads and these are again compared with emission factors currently used in the NAEI.

The study has also evaluated the effect of changes to these emission factors on the UK projections of emissions of NOx, PM, CO and THC from the road transport sector. A series of emission sensitivity tests were carried out using the NAEI Road Transport Emissions Forecasting model that combines emission factors for current and future vehicle types with assumptions about growth in traffic activity and turnover in the vehicle fleet.

Main conclusions from the study are given in Section 4.

2 Data Sample and Analytical Procedure

2.1 DATA RECEIPT AND INCLUSION/EXCLUSION IN THE ANALYSIS

Emissions data for 20 vehicles over 9 different test cycles were received from Shell Global Solutions. In addition, data on one vehicle (a VW Caravelle) which had been tested by Ricardo alongside Euro III passenger cars were included. (These data had been excluded from the analysis of Euro III cars because the vehicle's weight took it into the emission standard of a large LGV, rather than that of the average passenger car.)

Vehicles were tested simulating either a lightly loaded, or an unloaded, van. For each vehicle a data file contained information identifying the individual vehicle, its manufacturer, model, fuel type and engine capacity. Emissions data were given for the pollutants NO_X, PM, CO, THC and CO_2 over 9 different test cycles, shown in Table 1.

Table 1 Test cycles used by Shell for generation of emissions data

- NEDC Combined
- WSL Congested
- WSL Urban
- WSL Suburban
- WSL Rural
- WSL Motorway 90
- WSL Motorway 113
- Artemis urban
- Artemis motorway 130

Repeats of the six Warren Spring Laboratory (WSL) drive cycles were undertaken such that for each vehicle tested by Shell Global Solutions 15 datasets were provided. For the single vehicle tested by Ricardo no repeats were undertaken and 9 datasets were available for analysis.

The list of vehicles tested is given in Appendix 1. The vehicles were divided into the vehicle weight categories given in Table 2.

Table 2 Numbers of diesel LGV datasets used in this analysis

	Number of vehicles tested		
Emissions standard	Weight Class 1 (≤1250 kg)	Weight Class 2 (>1250-1700 kg)	Weight Class 3 (>1700-3500kg)
Euro II	2	2	6
Euro III	1	-	10

An initial screening of the data led to the exclusion of **no** vehicles.

A more thorough screening of the data, particularly checking the emissions between the repeats of WSL drive cycles, led to the exclusion of one drive cycle and one further data point for the following reasons:

- No NEDC test results were included for any vehicle as this is a cold start test. This mirrored the approach of TRL in the previous calculations (Barlow et al 2001).

- For the 2.5 litre Ford Transit NO_X data for one of the WSL Motorway 113 tests was excluded as an unrealistic outlier (its value was around 3.2% of the repeat WSL Motorway 113 test, and the NO_X data from this vehicle for all the other 4 motorway tests were consistent).

All other data points were adjudged to be reasonably similar to their repeat run, or in-line with the other emissions from the vehicle. Consequently no other data points were excluded.

2.2 DATA ANALYSIS AND CURVE FITTING OF TEST DATA

For each vehicle category listed in Table 2, a dataset was constructed from all the data to be included in the analysis, containing each of the measured emission factors for each individual vehicle and test cycle. For each pollutant, the emission factors for vehicles in the same category were plotted against average speed of the test cycle.

Initially, the emission factors were fitted to a polynomial function against average speed using a statistical software package. A series of polynomial expressions were fitted to the data by minimizing the sum of squares of the errors using the fitting routine STATGRAPHICS Plus Version 5.1 (December, 2001). The fitted equation took the general form:

$$EF = a + bv + cv^2 + d/v^3 + e/v + f/v^2 + g/v^3 \qquad \text{Eqn. 1}$$

where EF is the emission factor (in g/km), v is the average speed (in km/h) of the vehicle over the given test cycle and a-g are coefficients. When, as in many cases, the inclusion of a coefficient did not improve the fit to the data, the coefficient was set to zero. All possible combinations of polynomial coefficients were compared using the multiple regression model selection function. The combination providing the minimum mean sum of squares, highest adjusted R^2 and smallest Mallow's statistic was selected. Standard regression (single or multiple) was then used to find the best fit to this equation.

This statistical curve fitting procedure is essentially the same as that used by TRL in their analysis of the Euro I LGV data and Euro I and Euro II passenger car data to generate the speed-emission factor relationships used in the NAEI. It was also the procedure recently used by AEA Technology in the analysis of the emission factors for Euro III cars.

However, our experience was that whilst this procedure worked well for datasets that were not highly scattered (e.g. the factors for CO_2), for some datasets that were highly scattered, it tended to yield statistically best-fit curves that bore little resemblance to the normal 'U'- or 'L'-shaped speed-emission curve. The reason why some datasets were highly scattered is probably due to the low emissions of the vehicles and the closeness to the emission detection limit of the instruments used, worsening the signal-to-noise ratios of the measurements.

After running the statistical curve fitting procedure, the results were therefore given a reality check and if the best-fit curve was deemed abnormal in shape and/or heavily influenced by a spurious outlier in the dataset, the best-fit coefficients were manually adjusted to create a curve that exhibited a more normal speed-emission factor relationship. Although this procedure introduces a degree of subjectivity into the analysis, it was felt that it was more robust if it gave a relationship that captured the bulk of the data whilst still maintaining a recognized curve shape throughout the speed range of the test data. An example of this is where at one end of the speed range, the best-fit coefficients lead to the emission function approaching an asymptote even though the data, and the emissions from earlier Euro standards indicate that emissions do increase at the very highest speeds.

A general protocol was therefore established for obtaining the speed-emission factor relationships from the data which can be summarized as follows:

- Run the fitting routine to achieve the statistical best-fit to the data
- Examine the best-fit given to the test data and judge whether the shape displays a 'normal' emission factor-average speed relationship across the range of speeds associated with the test, without being heavily influenced by spurious outliers
- If it does not, then manually adjust the best-fit coefficients until it does give a reasonable visual representation of the relationship across the speed range
- Compare the form of the polynomial with that obtained for the equivalent polynomial for the other Euro standard (Euro II or Euro III) and see if this provides useful guidance.
- Consider the form of the polynomial recommended by TRL for use in the current speed-emission factor relationships to see if it provides useful guidance.
- Adopt the best-fit coefficients, adjusted by steps above, for the speed-emission factor relationships.

2.3 ASSESSMENT OF DIFFERENT WEIGHT CLASSES

Light goods vehicles fall into three different weight classes with different regulatory emission limit values. The three weight classes are shown in Table 2 where it can be seen that the majority of vehicles tested (16 out of 21) were of the heaviest weight class. The weight class selection is reasonably consistent with the assumptions used in the NAEI that around 62% of LGVs in the UK fleet are in this weight class, based on an unofficial, "best guess'" estimate of officials in the Department for Transport.

The statistical analysis carried out in this study focused on the heaviest Class 3 LGVs as it was considered the sample size of tested LGVs falling in the lighter weight classes for each Euro standard was too small to justify such statistical treatment. Nevertheless, it was necessary to consider how the emission factors for these lighter Class 1 and 2 LGVs might differ from those analysed for Class 3 so as to derive average LGV emission factors for the NAEI that were representative of the UK fleet.

In the assessment for the lighter weight classes, it was assumed that the shape of the emission factor-speed curve for a given pollutant and Euro standard is independent of vehicle weight and an emission scaling factor (≤1) relative to the "best fit" curve derived for the Class 3 LGVs was developed for Class 1 and Class 2 LGVs. Scaling factors were derived from two independent approaches and a judgement made as to which should be used for the NAEI. In one approach, scaling factors were based on the ratio of the type approval limit values on emissions for Class 1 and Class 2 LGVs relative to Class 3 for a given pollutant and Euro standard. In the second approach, the limited test data for the lighter weight classes were plotted against speed and fitted to the corresponding functional form for the relationships shown by the Class 3 vehicles to obtain a scaling factor that gave the "best fit" to the data.

In the case of CO_2, since this is not a regulated pollutant, an assessment was made based on the ratio in average weights of the vehicle in each Class.

Further details of the method are given in Section 3.2

2.4 RE-ASSESSMENT OF FACTORS FOR EURO IV LGVs

The current emission factors for Euro IV vehicles used in the NAEI are based on the assumption that manufacturers only reduce the emission factors over the regulatory cycle enough to meet the type-approval limit vales, making allowance for the fact that emissions will degrade with mileage, but must remain within the limit value over the durability period specified in the Directive.

In the light of changes made to the Euro II and III emission factors, consideration was given as to whether it was prudent to change the factors for Euro IV LGVs accordingly. The approach adopted was to assume the emission factor-speed relationship for the Euro IV LGV took on the same shape as that defined by the new coefficients for Euro III for a given pollutant, but the curve would be re-scaled according to the amount of emission reduction necessary to achieve the regulatory limit value for Euro IV. This meant the coefficients a-g in Eqn.1 for a Euro IV LGV would be the same as the corresponding values for Euro III, but the emission factors at all speeds would be reduced by a scaler (x), generally less than or equal to 1, to imply a curve for Euro IV in parallel to the one for Euro III.

The Euro IV scaling factor (x) would be estimated by using the speed-emission coefficients for Euro III to calculate an emission factor at the average speed of the regulatory NEDC cycle (33.5.kph) and comparing it with the Directive limit value for Euro IV and calculating how much (if any) it would be necessary to scale down the Euro III factor to reach the Euro IV limit value.

When the Euro III emission factors were calculated to be any amount below Euro IV limits at the NEDC speed, the emission factors for Euro IV cars at all speeds were assumed to be the same as for Euro III (i.e. x=1), implying no further reduction in hot exhaust emissions from Euro III to Euro IV. For PM, an account was taken of the need to meet durability standards for this pollutant that would likely to lead to a lower emission level from the vehicle when new so that it remained within limits during the durability period.

This approach is consistent with that adopted in the estimation of emission factors for Euro IV cars in the recent emission factor analysis carried out by AEA Technology for DfT. It should be noted that, as in the analysis for cars, no account is taken on the contribution of excess emissions during the cold start period of the regulatory cycle and how this might effect the conclusions regarding the emission performance of Euro IV LGVs relative to Euro III over the hot part of the cycle. As noted in our previous analysis for cars, cold start excess emissions are smaller for diesel vehicles than catalyst-equipped petrol vehicles and are mainly of concern to PM and HCs, but it is difficult to pre-judge the relative extent that cold start emissions may change for Euro IV diesel LGVs.

In the case of CO_2, there are no emission standards for diesel LGVs that can be used to judge the level of emission factors for Euro IV vehicles on the basis of factors for Euro III. For Euro II-IV diesel LGVs, the NAEI currently uses time trends in average CO_2

factors for new diesel cars provided by DfT/SMMT combined with the absolute levels and the shape of the CO_2 emission factor-speed curve for Euro I diesel LGVs given by the TRL equation to estimate emission factor-speed relationships for these vehicle types. The assumptions made for Euro IV diesel LGVs in this study are re-assessed on the basis of the new measurements on CO_2 emission factors for Euro II and Euro III LGVs and from giving greater consideration to the technical challenges for making further fuel efficiency improvements for Euro IV vehicles in the light of these results.

2.5 UK EMISSION PROJECTION SENSITIVITY TESTS

The NAEI Road Transport Emissions Forecasting Model was used to test the impact on future emission trends of changing the Euro II-IV emission factors for diesel LGVs. Details of the road transport emission estimation methodology and emission projection assumptions are given in various reports including the NAEI annual report (e.g. Baggott et al, 2004) and the latest report of the Air Quality Expert Group on NO_2 (AQEG, 2004).

The September 2004 version of projections were used in this assessment. In brief, the core assumptions made are:

- Vehicles meeting Euro standards up to Euro IV penetrate the fleet (Euro V for heavy duty vehicles), but no further reduction in vehicle emissions are assumed;

- Traffic grows at a rate defined by the latest (July 2004) projections developed by DfT. The Central traffic forecasts for GB by area and vehicle type from "The Future of Transport - White Paper CM 6234" are used.

- Diesel car sales grow to 42% of all new car sales by 2010.

3 Results

3.1 ANALYSIS OF EURO II AND EURO III EMISSION FACTOR DATA FOR CLASS 3 DIESEL LGVs

This section provides graphs showing the measured emission factors for the 6 Euro II and 10 Euro III diesel LGVs in the heaviest Class 3 weight band that were tested plotted against average speed for each pollutant. The best fit of the raw data to the function of the form given in Equation (1) is shown for each vehicle class and pollutant and compared with the curves derived from the relationships currently used in the NAEI. The NAEI factors refer to averaged factors for Class 1-3 LGVs in the fleet.

It should be noted that all the emission factors in these graphs refer to vehicles running on ultra-low sulphur fuels (<50ppm S), available at most filling stations now. This is the grade of fuel used in the Euro II and III LGV emission tests. The NAEI factors used in the comparisons also relate to vehicles running on this grade of fuel having been originally estimated from measured emission factors for Euro I LGVs running on inferior quality fuel (higher sulphur content) taking into account the effect of fuel quality on emissions as well as the effect of tighter emission legislation. Fuel quality effects were based on functions taken from the European EPEFE programme (EPEFE, 1995).

3.1.1 Emission Factors for Nitrogen Oxides (NOx)

Figures 1 and 2 show the measured data and best-fit emission factor-speed relationships for NOx for Euro II and Euro III Class 3 diesel LGVs, respectively. The curve representing the relationships used in the NAEI for fleet-averaged factors are also shown.

Uniquely among the 5 pollutants studied the preferred best fits for **both** Euro II and Euro III LGVs give emission factors **greater** than those assumed in the current NAEI emission factors over the whole speed range. The spread of the data is relatively large, particularly for the Euro III vehicles, hence the coefficients of the polynomial have moderately large error bars on them. For all pollutants, it might be expected that the data for the Class 3 LGVs shown here would be larger than the NAEI estimates because the latter refer to averaged values for the fleet including the weighted contribution of the smaller Class 1 and 2 LGVs. This issue will be discussed further in Section 3.2. However, as will be explained, the emission factors for Class 3 LGVs are not be expected to be more than 10% higher than the fleet average.

For both Euro II and III LGVs, the best-fit curve give factors at 40-70kph that are only 10% higher than the current NAEI estimates, but the differences are greater at lower and higher speeds. The best-fit curves imply NOx factors for Euro III around 30% lower than Euro II. This compares with a figure of 25% assumed in the NAEI.

3.1.2 Emission Factors for Particulate Matter (PM)

Figures 3 and 4 show the measured data and best-fit emission factor-speed relationships for PM for Euro II and Euro III Class 3 diesel LGVs, respectively. The curve representing the relationships used in the NAEI for fleet-averaged factors are also shown.

The spread of the data is relatively large. Hence the coefficients within the polynomial have moderately large error bars on them. However, the data show PM emissions for Euro III LGVs significantly lower than the emissions for Euro II LGVs. For both Euro II and III LGVs, the best fit curve give emission factors in fairly close agreement with the

Figure 1: NOx Emission factor for Euro II diesel LGVs (>1700-3500kg) (ULS fuel, 50 ppmS)

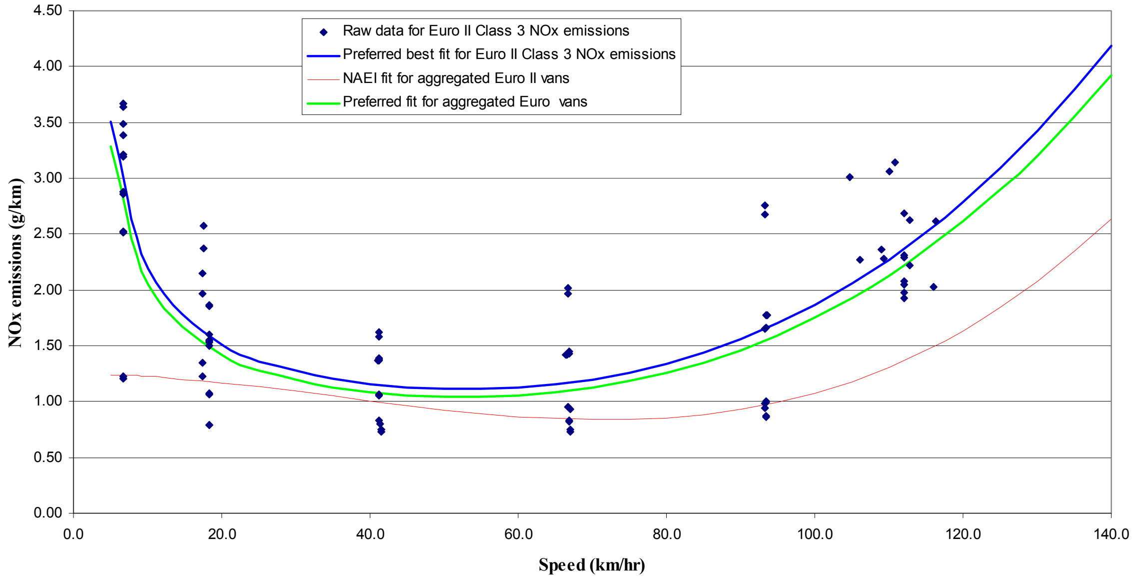


Figure 2: NOx Emission factor for Euro III diesel LGVs (>1700-3500kg) (ULS fuel, 50 ppmS)

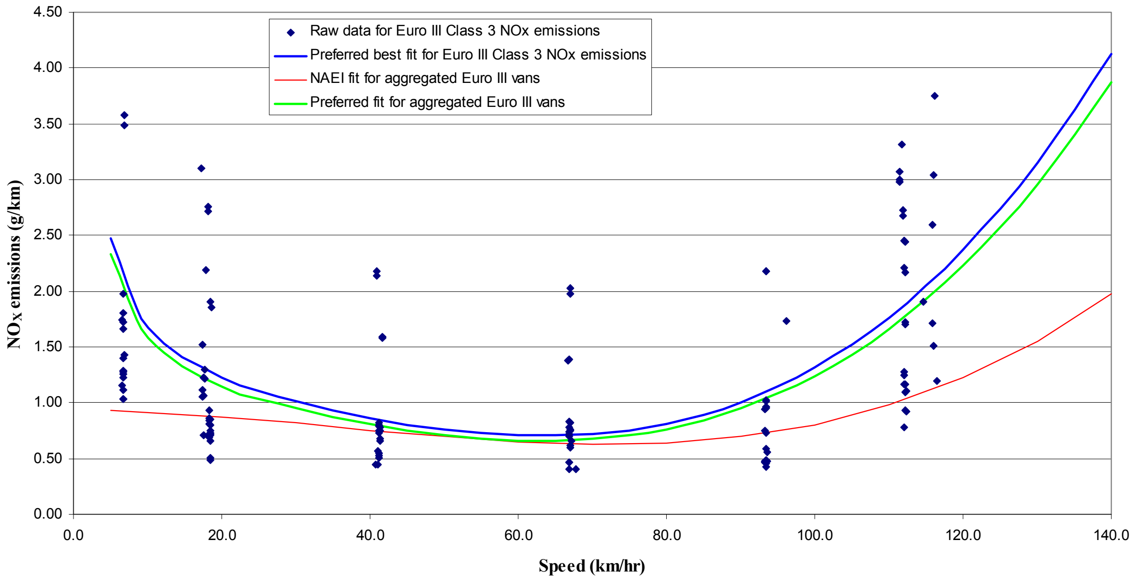


Figure 3: PM Emission factor for Euro II diesel LGVs (>1700-3500kg) (ULS fuel, 50 ppmS)

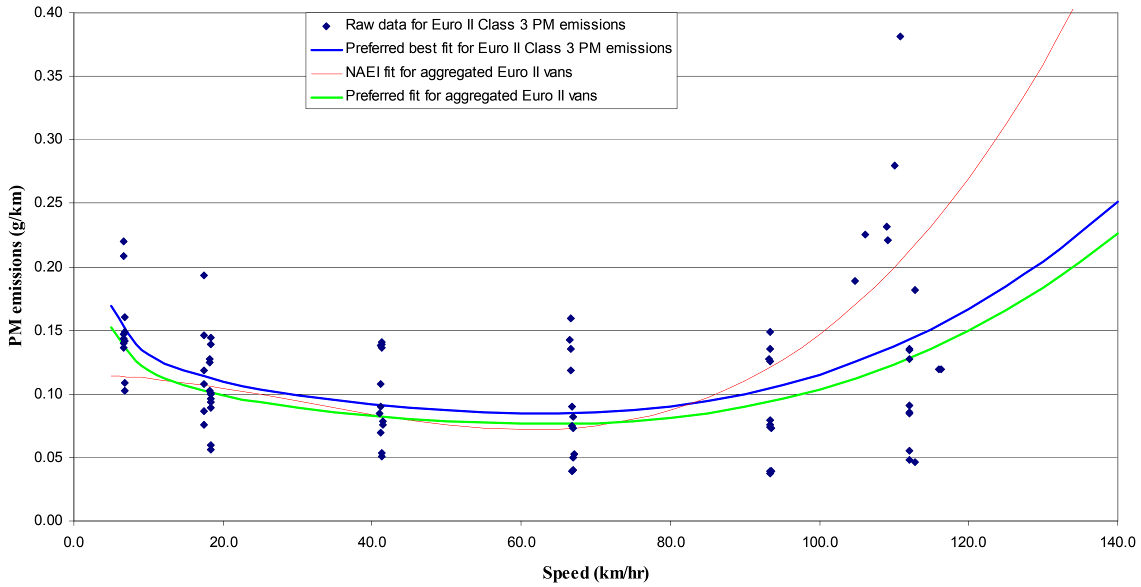
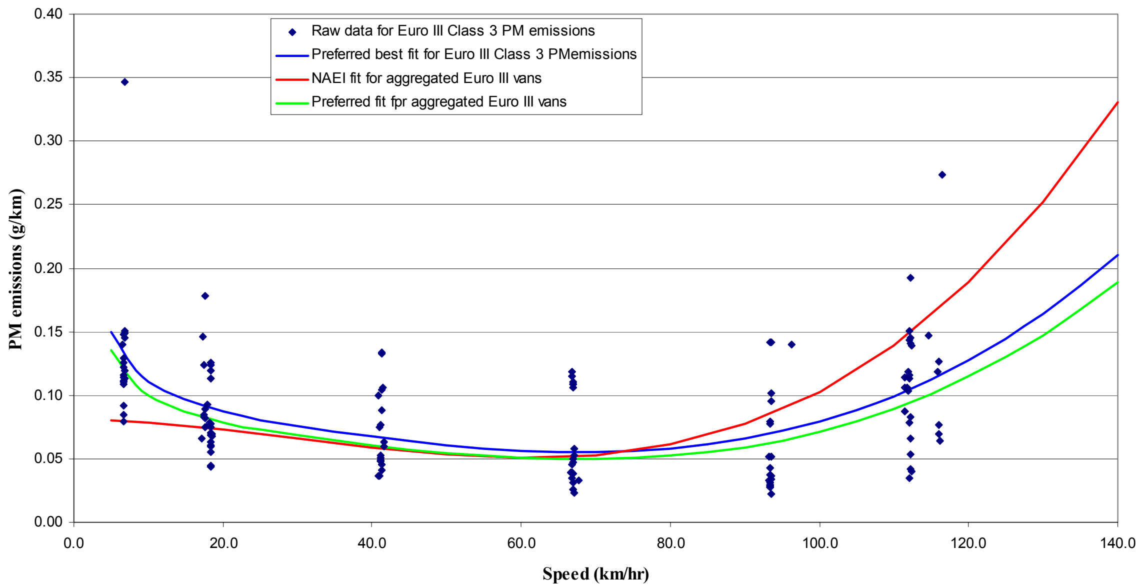


Figure 4: PM Emission factor for Euro III diesel LGVs (>1700-3500kg) (ULS fuel, 50 ppmS)



current NAEI estimates at speeds below 80 kph, but at higher speeds the new factors for both Euro II and III LGVs are lower than values currently assumed in the NAEI by as much as 40-50%. The best-fit curves imply PM factors for Euro III around 30% lower than Euro II. This compares with a figure of 33% assumed in the NAEI.

3.1.3 Emission Factors for Carbon Monoxide (CO)

Figures 5 and 6 show the measured data and best-fit emission factor-speed relationships for CO for Euro II and Euro III Class 3 diesel LGVs, respectively. The curve representing the relationships used in the NAEI for fleet-averaged factors are also shown.

The data are quite noisy, particularly for the Euro II LGVs, however the data show CO emissions for Euro III LGVs significantly lower than the emissions for Euro II LGVs. For the Euro II LGVs, the best fit curve imply emission factors slightly above those currently used in the NAEI over the speed range 25 – 70 kph. However, for speeds above 75 kph the best fit curve imply emission factors lower than the currently used NAEI data. The details of the coefficients for Euro II vehicles are affected by a few data points with some vehicles tested having CO emissions as much as three times higher than others.

For the Euro III LGVs, the best fit curve gives emission factors less than those currently used in the NAEI at all speeds. The difference is relatively small at around 50kph, but becomes greater at higher speeds as the curve deviates from becoming less 'U'-shaped to more 'L'-shaped. The best-fit curves imply CO factors for Euro III around 70-80% lower than Euro II at different speeds. This compares with a much lower reduction figure of 40% assumed in the NAEI.

3.1.4 Emission Factors for Total Hydrocarbons (THC)

Figures 7 and 8 show the measured data and best-fit emission factor-speed relationships for THC for Euro II and Euro III Class 3 diesel LGVs, respectively. The curve representing the relationships used in the NAEI for fleet-averaged factors are also shown.

The data show THC emissions for Euro III LGVs significantly lower than the emissions for Euro II LGVs. The spread of the data is less than for CO, particularly for the Euro II LGVs where the data is relatively tightly grouped. For the Euro II LGVs, the best fit curve is both of the same shape and magnitude as the emission function currently used in the NAEI, with the two curves almost superimposed.

For the Euro III LGVs, the best fit curve gives emission factors considerably less than those currently used in the NAEI at all speeds. The best-fit curves imply THC factors for Euro III around 60-80% lower than Euro II at different speeds. This compares with a much lower reduction figure of 22% assumed in the NAEI.

Both CO and THC show markedly more emission reductions from Euro II to Euro III than required by the Type Approval limit values. It may well be a consequence of the significant changes in fuelling systems between vehicles engineered to meet Euro II and Euro III standards, leading to better combustion characteristics and consequently a marked reduction in both CO and THC emissions.

3.1.5 Emission Factors for Carbon Dioxide (CO_2)

Figures 9 and 10 show the measured data and best-fit emission factor-speed relationships for CO_2 for Euro II and Euro III Class 3 diesel LGVs, respectively. The curve representing the relationships used in the NAEI for fleet-averaged factors is also shown.

Figure 5: CO Emission factor for Euro II diesel LGVs (>1700-3500kg) (ULS fuel, 50 ppmS)

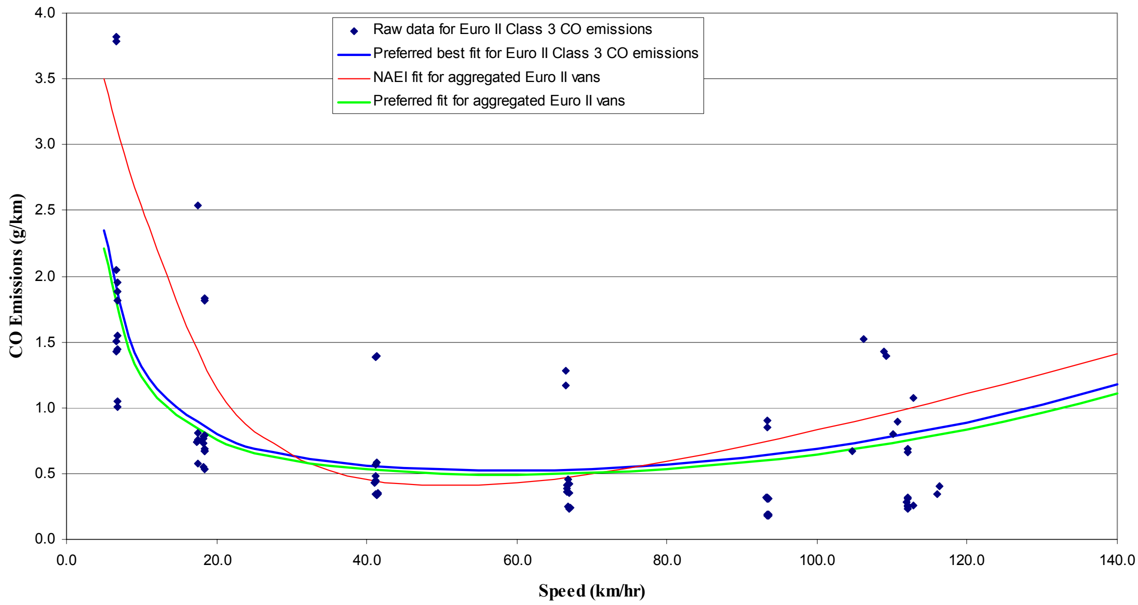


Figure 6: CO Emission factor for Euro III diesel LGVs (>1700-3500kg) (ULS fuel, 50 ppmS)

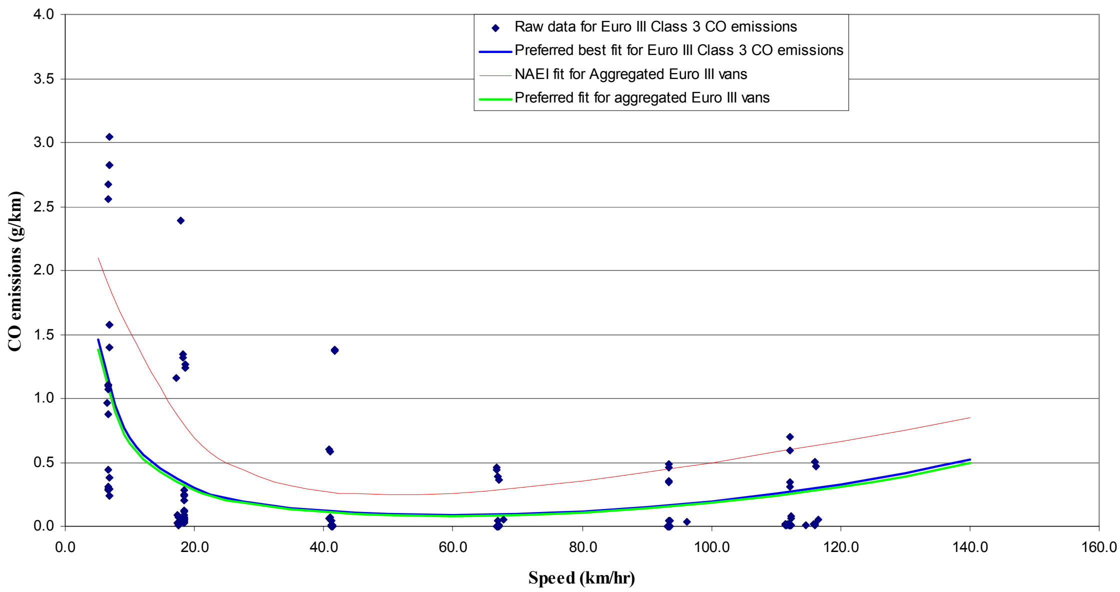


Figure 7: THC Emission factor for Euro II diesel LGVs (>1700-3500kg) (ULS fuel, 50 ppmS)

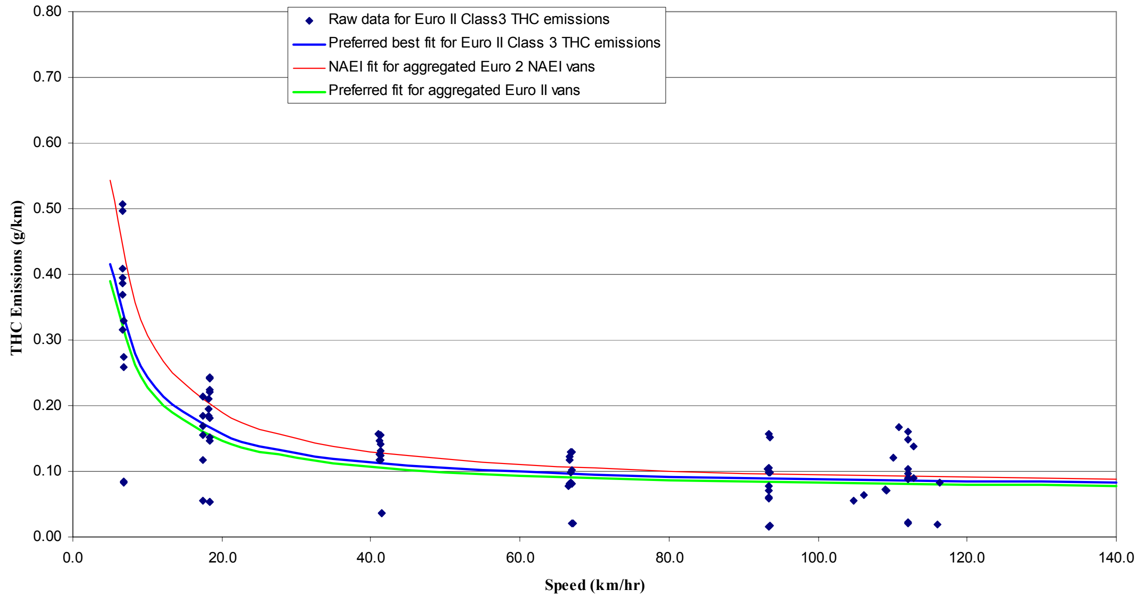


Figure 8: THC Emission factor for Euro III diesel LGVs (>1700-3500kg) (ULS fuel, 50 ppmS)

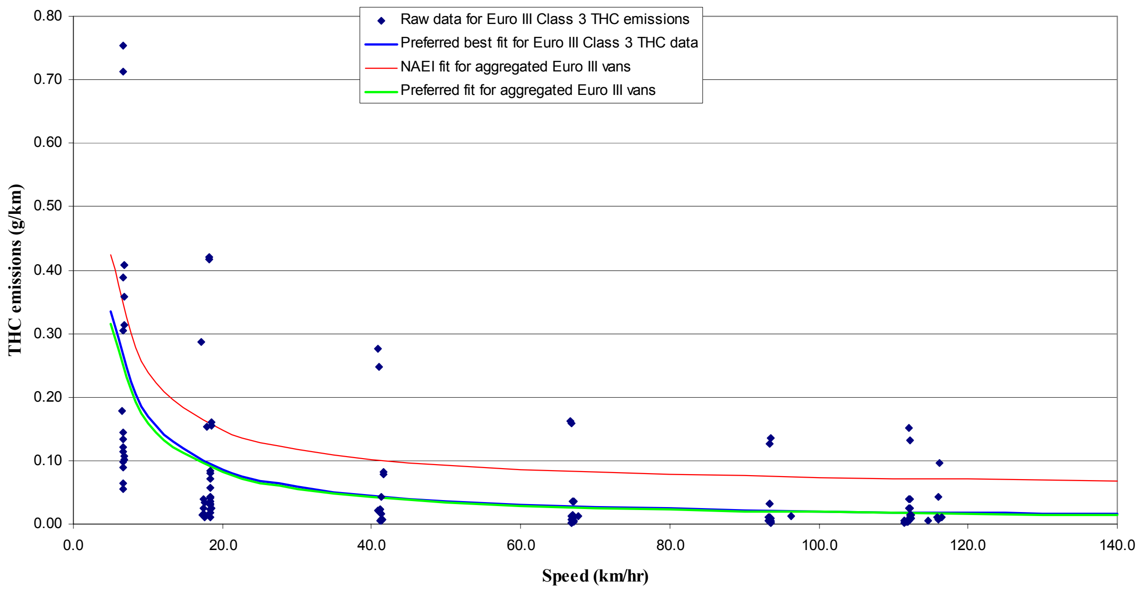


Figure 9: CO_2 Emission factor for Euro II diesel LGVs (>1700-3500kg) (ULS fuel, 50 ppmS)

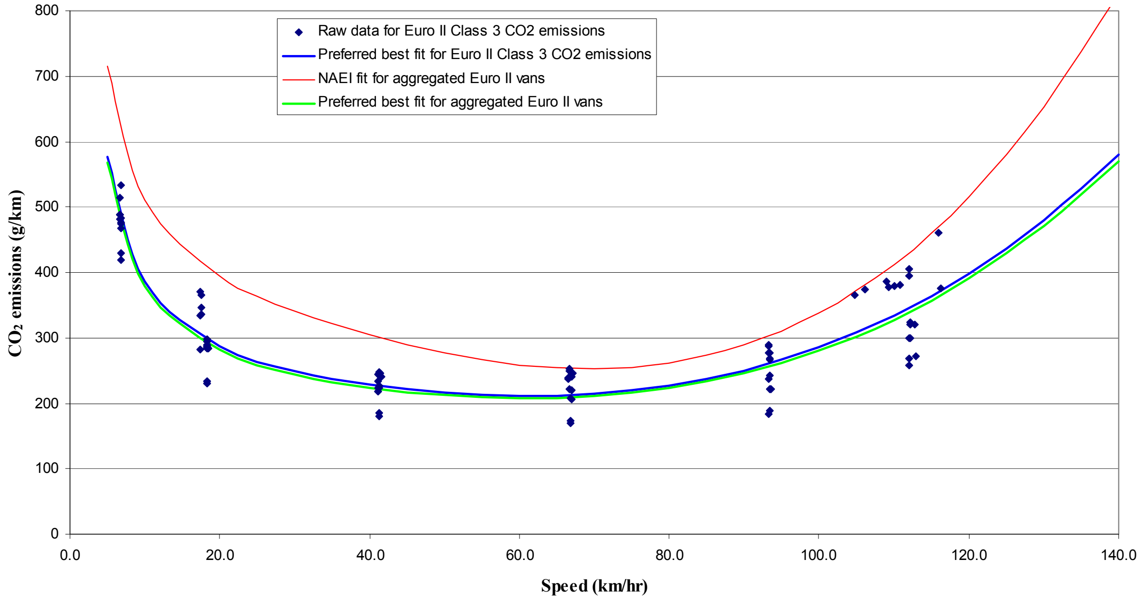
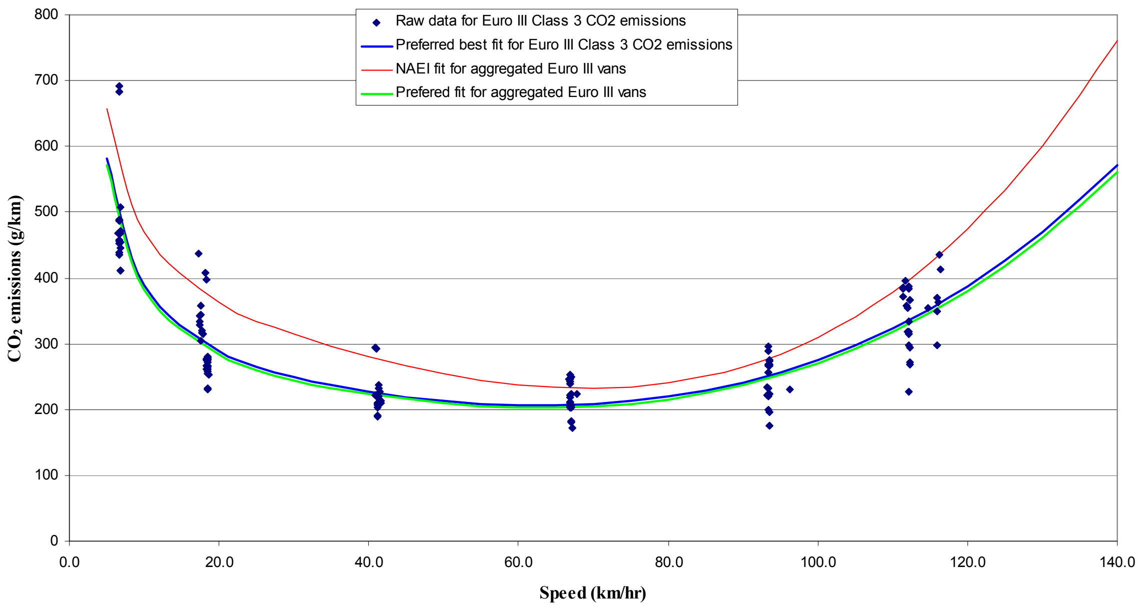


Figure 10: CO_2 Emission factor for Euro III diesel LGVs (>1700-3500kg) (ULS fuel, 50 ppmS)



The raw data and best-fit curves refer to the actual 'tailpipe CO_2' emissions measured in the test while the curves for the currently used NAEI factors refer to 'ultimate CO_2'. 'Ultimate CO_2' refers to the CO_2 mass-equivalence of all the carbon emitted at the tailpipe in the form of not only CO_2 itself, but also CO, THC and PM. As discussed in our recent report on emissions factors for Euro III cars, the reason that factors are presented in this form is that it relates directly to fuel consumption and the carbon content of fuels, as, following internationally agreed emission reporting protocols (e.g. to the UN Framework Convention on Climate Change), this is the form by which CO_2 emissions from road transport and other sectors are calculated and reported by the NAEI. Now that emissions of CO, THC and PM have been reduced so much in modern Euro III light-duty vehicles, more than 99% of all carbon in the fuel is emitted at the tailpipe in the form of CO_2, so the difference between the 'tailpipe CO_2' and 'ultimate CO_2' emission factors is now very small (<0.5%). Throughout the rest of this report, no distinction will be made between 'tailpipe' and 'ultimate' CO_2 emission factors.

The data points for Euro II and III LGVs are very similar to each other at any given average speed and the best fit curves are virtually indistinguishable. The best fit curves are significantly lower than the current emission factor curves used in the NAEI with the difference become greater with increasing speed.

3.2 EFFECT OF DIFFERENT WEIGHT CLASSES ON EMISSIONS

The analysis and data presented in Section 3.1 referred to emissions from the heaviest Class 3 group of diesel LGVs. Consideration was given to the emission factors for the lighter Class 1 and Class 2 LGVs by examination of the type approval emission standards that apply to these weight classes and the limited emission test data for 5 such vehicles that were measured.

3.2.1 Regulated Pollutants: NOx, PM, CO, THC

The emission levels specified by the type approval regulations for the three weight classes of diesel LGVs to meet the Euro II and Euro III standards are shown in Table 3. The table shows how heavier vehicles are permitted to have higher emissions.

From the data in Table 3 the ratio of the emission standards for weight Classes 1 and 2 relative to Class 3 can be calculated for both Euro II and III vehicles. These are shown in the lower section of Table 3.

The emission factors for the few Class 1 and Class 2 LGVs that were tested were analysed by assuming that the shape of the emission factor – speed curve is the same as the shape of the curve for Class 3 LGVs, i.e. that the curve shape is independent of vehicle weight and that the change in weight merely scales each speed related emission function. On this basis, the value of the linear scaling factor relative to Class 3 that provides the best fit to the available data for Class 1 and 2 LGVs was determined for each Euro standard and pollutant. In each case, this factor was optimised by minimising the sum of the squares of the errors. The results of this analysis are listed in Table 4, and plotted in Figure 11. The analysis was possible for Class 1 and 2 Euro II vehicles, but only Class 1 for Euro III vehicles because no Class 2 Euro III vehicles were tested, see Table 2.

Table 3 Type approval emission standards, and their ratios, for the three LGV weight classes

		CO g/km	HC g/km	NO_X g/km	PM g/km	HC + NO_X g/km
Euro II	Class 1 (≤1250 kg)	1.00	0.07[1]	0.63[2]	0.08	0.70
	Class 2 (>1250 ≤1700 kg)	1.25	0.10[1]	0.90[2]	0.12	1.00
	Class 3 (>1700 ≤3500 kg)	1.50	0.12[1]	1.08[2]	0.17	1.20
Euro III	Class 1 (≤1250 kg)	0.64	0.06[3]	0.50	0.05	0.56
	Class 2 (>1250 ≤1700 kg)	0.80	0.07[3]	0.65	0.07	0.72
	Class 3 (>1700 ≤3500 kg)	0.95	0.08[3]	0.78	0.10	0.86
Ratios for Euro II	Class 1/Class 3	0.667	0.583	0.583	0.471	0.583
	Class 2/Class 3	0.833	0.833	0.833	0.706	0.833
Ratios for Euro III	Class 1/Class 3	0.674	0.75	0.75	0.50	0.75
	Class 2/Class 3	0.842	0.875	0.875	0.70	0.875

Table 4 Scaling factors for the lighter weight classes obtained from Class 3 polynomials

		CO_2	CO	THC	PM	NOx
Euro II	Class 1	0.620	0.519	0.617	0.703	0.486
	Class 2	1.048	0.436	0.496	0.463	0.750
Euro III	Class 1	0.671	0.657	0.328	0.428	0.354

The ratios from Table 3 and Table 4 (and Figure 11) are shown alongside one another in Figure 12 so that the ratios predicted from considering changes in type approval standards (Table 3) are directly compared with the ratios measured (Table 4).

Note that there are no type approval values for CO_2 and the comparison in Figure 12, i.e. the first four columns of the CO_2 data, are based on theoretically estimated differences for the various weight classes. Further details on the methodology used are described in Section 3.2.2.

[1] Calculated from 10% of (HC + NO_X) value specified in regulations
[2] Calculated from 90% of (HC + NO_X) value specified in regulations
[3] Calculated from (HC + NO_X) value – NO_X value specified in regulations

Figure 11: Emission scaling factors for Class 1 (≤1250 kg) and Class 2 (>1250 ≤1700 kg) diesel LGVs relative to Class 3 (>1700 ≤3500 kg) vehicles.

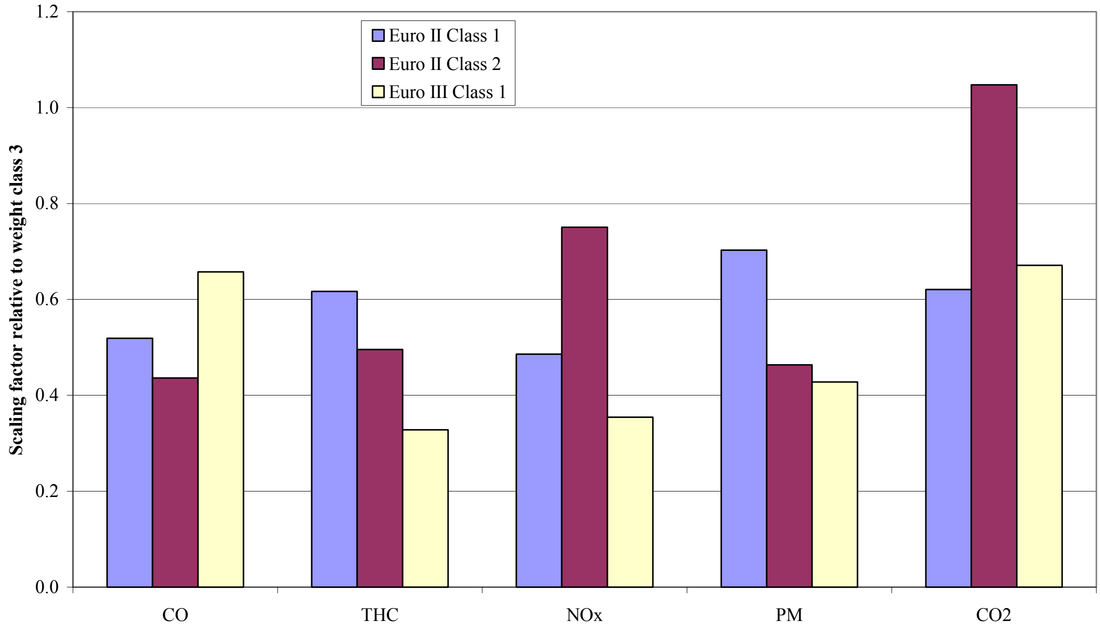
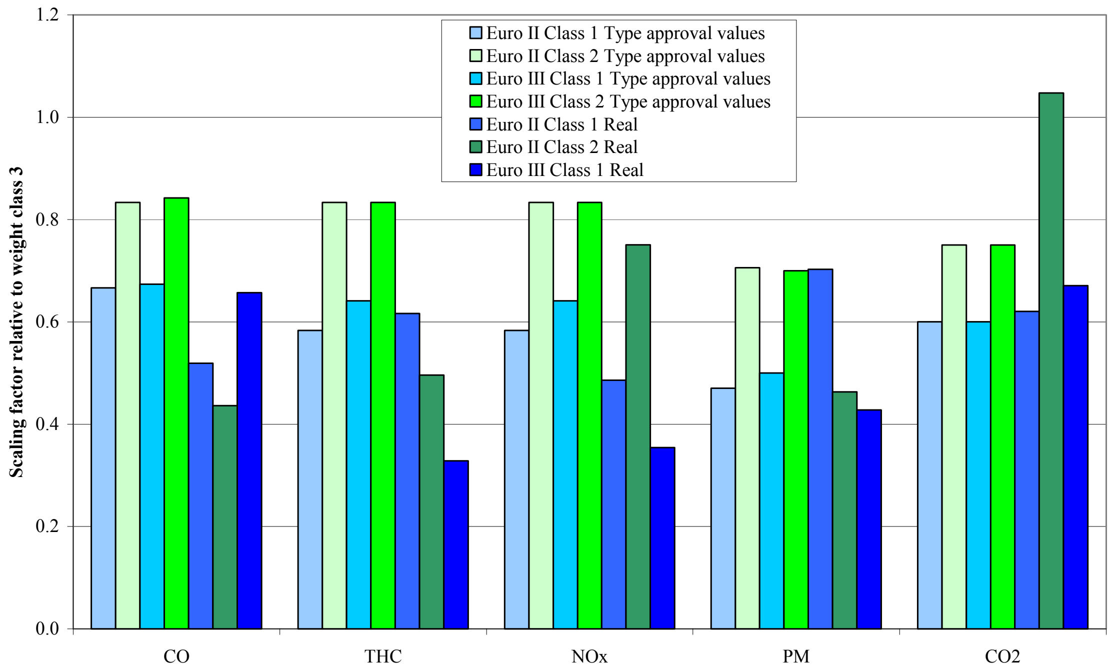


Figure 12: Measured emission scaling factors and ratio in type approval emissions for Class 1 (≤1250 kg) and Class 2 (>1250 ≤1700 kg) diesel LGVs relative to Class 3 (>1700 ≤3500 kg) vehicles[4]



[4] For CO_2 the four columns labelled "Type approval values" are theoretical ratios, Section 3.2.2, whereas the three columns labelled "Real" are ratios of measured CO_2 emissions

For NOx, PM, CO and THC, the test results show that the lighter LGVs are consistently emitting less than their heavier Class 3 counterparts. It must be remembered though that the data from measurements are based on very limited numbers of vehicles, a maximum of two for any specific weight class and Euro standard. Consequently, the statistical validity of the measured values is reduced. Also, for weight Class 2, **no** Euro III LGVs were tested.

Of all the pollutants, NOx shows the type of behaviour in the measurements that might be expected from the ratios in the type approval emissions among the different weight classes. The test data suggest NOx emissions decrease with decreasing weight of vehicle roughly in line with the decrease in type approval limit values. Relative to Class 3 emissions, the measured emissions for Class 1 and 2 LGVs are slightly lower than would be expected on the basis of the type approval emissions. This is more apparent in the trends for Euro III LGVs than for Euro II vehicles. At least for NOx, the relatively close agreement between the reductions predicted for the lighter vehicles on the basis of the type approval standards, and the reductions measured, suggests the former are a useful basis for calculating emissions from the lighter weight classes.

For PM and THC, the results from the limited number of tests on the lighter Euro II LGV weight classes show rather counter-intuitive trends, with the lightest Class 1 vehicles emitted more than the medium Class 2 vehicles. In fact, for PM the Class 1 vehicles appear to emit at levels that would expected for Class 2 vehicles and Class 2 vehicles appear to emit at levels that would expected for Class 1 vehicles. The Euro III Class 1 LGV emits PM at levels slightly below that expected from the ratio of the type approval emissions. For THC, the Class 2 Euro II LGVs and the Class 1 Euro III LGV are emitting significantly less relative to the Class 3 vehicles than expected on the basis of the type approval emission trends.

For CO, the lighter LGVs are consistently emitting less than might be expected relative to Class 3 vehicles on the basis of type approval emission trends, particularly for the Euro II vehicles, and again the medium weight Class 2 vehicles are emitting less than the lightest Class 1 vehicles.

Overall, for the regulated pollutants, the limited test data suggest the lighter vehicles are tending to emit less relative to the Class 3 vehicles than might be expected on the basis of trends in the type approval emissions. This would mean that using the ratios in the type approval emissions between weight classes as a means of estimating emission factors for the lighter vehicles would err on the conservative side of slightly overestimating emissions on the evidence of the measurements made.

3.2.2 CO_2

For CO_2, there are no type approval emission standards to guide the estimation of emission factors for the lighter LGVs. Ratios of CO_2 emissions for Class 1 and 2 LGVs relative to Class 3 have been calculated assuming emissions scale linearly with vehicle weight and assuming the following values for the average weights in the three weight classes:

- Class 1 1,200 kg
- Class 2 1,500 kg
- Class 3 2,000 kg.

These ratios are plotted as the columns labelled "Type approval values" in Figure 12 (i.e. the first four columns of the CO_2 data). The figure compares these ratios with the ratios from the actual measurements. Figure 13 shows the CO_2 emissions/drive cycle data for all three weight classes among the Euro II vehicles. It can be seen that the factors for

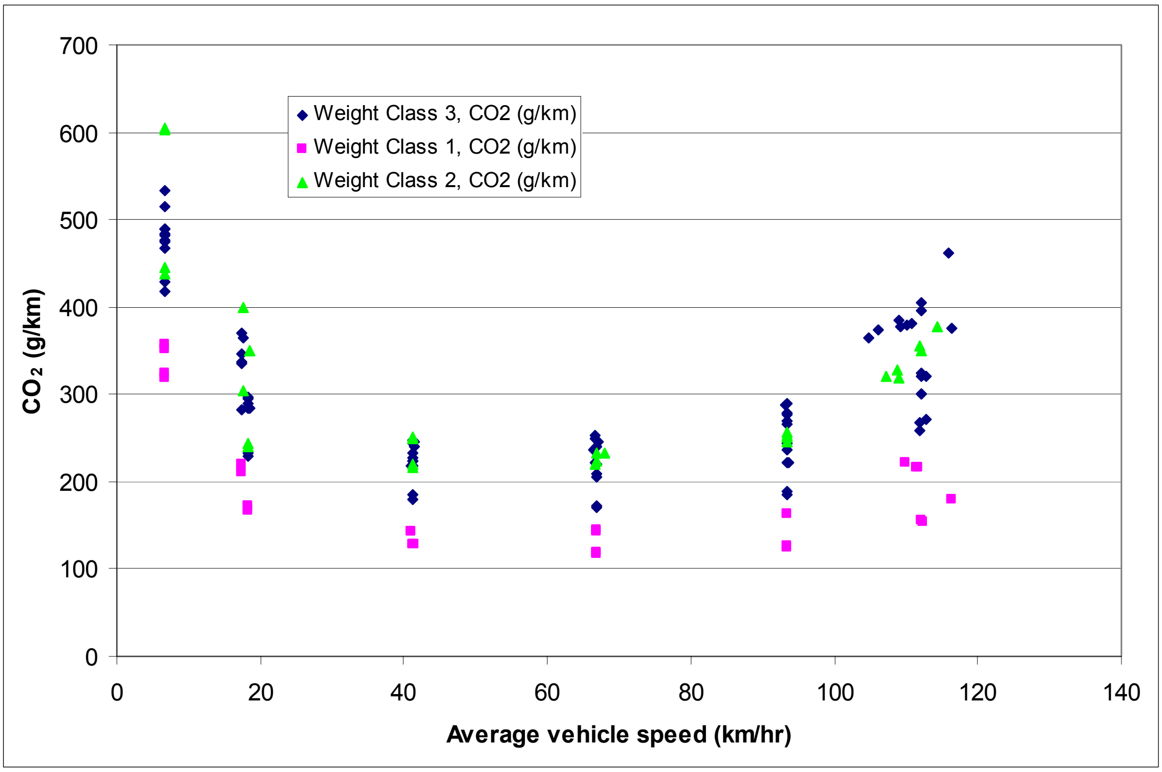
Class 1 vehicles are consistently below those for Class 3 and Figure 12 indicates that they are on average less than Class 3 emission factors by the amount that would be expected assuming emissions varied by vehicle weight making the above weight assumptions. This is not the case for the two Class 2 LGVs tested where there appeared to be no significant difference between the CO_2 factors for these vehicles and the heavier Class 3 vehicles. Figure 13 shows how the data for the two Class 2 vehicles are intermingled within the Class 3 data. It is not the case that one Class 2 vehicle had anomalously high CO_2 emissions.

The measured data for the lighter LGV weight classes indicate that adoption of emission factors for CO_2 based on those predicted from vehicle weight would systematically underestimate CO_2 emissions. Therefore we recommend basing the scaling factors (relative to Class 3) on the measured ratios, and are:

- Class 1 0.65
- Class 2 1.00

for both Euro standards.

Figure 13: CO_2 Emission factor for the Class 1, 2 and 3 weight classes of Euro II diesel LGVs (ULS fuel, 50 ppmS)



For Euro III LGVs, only one Class 1 vehicle was tested and no Class 2 vehicles were tested. The single Class 1 vehicles tested showed 67% of the CO_2 emissions of Euro III Class 3 LGVs, which is close to the ratio shown by Class 1 Euro II LGVs. On the basis of this single measurement, and lack of any other data as a guide, it is recommended that the scaling factors of 0.65 (Class 1) and 1.00 (Class 2) estimated for Euro II LGVs also apply to Euro III LGVs.

3.2.3 Recommended Emission Scaling Factors for Class 1 and 2 LGVs

Overall, the recommendation is that the speed related emission factors derived for the Class 3 LGVs be scaled by factors derived from changes in the type approval standards for CO, HC, NO_X and PM emissions, and derived from the measured ratios for CO_2. These scaling factors are chosen to reflect the uncertainties associated with the meagre amount of measured data available, whilst at the same time probably slightly underestimating the emission reductions systematically relative to Class 3 vehicles.

The scaling factors recommended are listed in Table 5.

Table 5 Recommended scaling factors for different weight classes of diesel LGVs relative to the Class 3 emission factors

		CO	THC	NO_X	PM	CO_2
Euro II	Class 1	0.67	0.58	0.58	0.47	0.65
	Class 2	0.83	0.83	0.83	0.71	1.00
	Class 3	1.00	1.00	1.00	1.00	1.00
Euro III	Class 1	0.67	0.64	0.64	0.50	0.65
	Class 2	0.84	0.83	0.83	0.70	1.00
	Class 3	1.00	1.00	1.00	1.00	1.00

3.2.4 Derivation of Aggregated Emission Factors for LGVs in the Fleet

From the emission scaling factors for the different weight classes and the emission factor – speed relationships for Class 3 LGVs, it is possible to develop emission factor – speed relationships aggregated for the UK fleet of LGVs using estimates of the mix of the different weight classes in the fleet.

The aggregated emission factor would be:

$$EF_{av}(v) = (F_1.W_1 + F_2.W_2 + W_3).\ EF_3(v)$$

Where $EF_{av}(v)$ is the aggregated speed - emission factor function for the fleet-average LGV; $EF_3(v)$ is the speed - emission factor function for Class 3 LGVs; W_1, W_2 and W_3 are the proportions of the different weight classes 1, 2 and 3, respectively, in the LGV fleet; and F_1 and F_2 are the scaling factors for Class 1 and Class 2 LGVs, respectively, in Table 5.

Vehicle licensing and roadworthiness testing do not require a breakdown of light goods vehicles by weight class. Hence there are no centrally recorded statistics that indicate the proportions of each weight class present in the fleet or tested per year. Also, the traffic surveys do not provide a breakdown of data, subdividing the LGV activity by weight classes.

AEA Technology was provided with a “best guess” estimate of the proportion of LGVs in each weight class in the UK in a private communication from the DfT in the late 1990s, but there has been no more recent estimates. These are the data within the current NAEI database. However, whilst originally emission factors were provided for the three different weight classes, the 2001 review of emission factors (Barlow et al, 2001) only provided single fleet aggregated emission factors. Consequently, all current calculations for the NAEI of emissions from Euro I and later LGVs have not required a breakdown by weight class.

The original breakdown in the proportion of weight class provided for the NAEI was:

Weight Class 1	7.7%	(5%)
Weight Class 2	30.8%	(25%)
Weight Class 3	61.5%	(70%)

Informal discussions have since given the authors the impression that this split might over estimate the number of lighter LGVs, and a 5%, 25%, 70% split might be more appropriate, as shown in brackets.

Such a change in the breakdown would lead to an increase in the fleet average emission factors of between 1% for CO_2 to 3.5% for PM (from evaluating equation 1) reflecting the closeness to unity for the CO_2 coefficients and the lower values of the scaling factors for PM.

3.3 SUMMARY OF SPEED-EMISSION FACTOR RELATIONSHIPS FOR EURO II AND EURO III DIESEL LGVs

Tables 6 and 7 list the coefficients obtained for Euro II and Euro III diesel LGVs from fitting the emission factor-speed data to the function of the general form given by Equation (1) above the tables. Coefficients are given for CO, THC, NOx, PM and CO_2 for the heaviest (Class 3) LGVs. Scaling factors (≤1.0) for the emissions from lighter vehicle classes are given in the third column of the tables, as too are the scaling factors, and the resulting coefficients, for the aggregated LGV fleet, assuming a mixture of 5% Class 1, 25% Class 2 and 70% Class 3 vehicles in the fleet.

Table 6. Coefficients of the fitted functions for the relationship between emission factor and average speed for Euro II diesel LGVs

EF (g/km) = $a + bv + cv^2 + dv^3 + e/v + f/v^2 + g/v^3$ where v = average speed in kph
The emission factors all refer to LGVs running on ultra-low sulphur grade fuels (<50ppm S)

Pollutant	Vehicle weight class	Vehicle Weight emission scaling factors	a	b	c	d	e	f	g
CO	Class 3	1.00	0.286			3.00E-07	10.3		
CO	Class 1	0.67							
CO	Class 2	0.83							
CO	Aggregated	0.942	0.2694			2.83E-07	9.70		
THC	Class 3	1.00	0.0704				1.73		
THC	Class 1	0.58							
THC	Class 2	0.83							
THC	Aggregated	0.938	0.0660				1.62		
NOx	Class 3	1.00	0.885		-1.12E-4	1.97E-06	13.1		
NOx	Class 1	0.58							
NOx	Class 2	0.83							
NOx	Aggregated	0.938	0.830		-1.05E-4	1.85E-06	12.29		
PM	Class 3	1.00	0.0953		-1.40E-5	1.56E-07	0.371		
PM	Class 1	0.47							
PM	Class 2	0.71							
PM	Aggregated	0.900	0.0858		-1.26E-5	1.40E-07	0.334		
CO_2	Class 3	1.00	199		-0.0235	3.02E-04	1895		
CO_2	Class 1	0.65							
CO_2	Class 2	1.00							
CO_2	Aggregated	0.983	195.6		-0.0231	2.97E-04	1863		

Table 7. Coefficients of the fitted functions for the relationship between emission factor and average speed for Euro III diesel LGVs

EF (g/km) = $a + bv + cv^2 + dv^3 + e/v + f/v^2 + g/v^3$ where v = average speed in kph
The emission factors all refer to LGVs running on ultra-low sulphur grade fuels (<50ppm S)

Pollutant	Vehicle weight class	Vehicle Weight emission scaling factors	a	b	c	d	e	f	g
CO	Class 3	1.00	-0.0831			2.00E-07	7.71		
CO	Class 1	0.67							
CO	Class 2	0.84							
CO	Aggregated	0.944	-0.0785			1.89E-07	7.28		
THC	Class 3	1.00	0.00331				1.66		
THC	Class 1	0.64							
THC	Class 2	0.83							
THC	Aggregated	0.940	0.00311				1.56		
NOx	Class 3	1.00	0.922		-2.89E-4	3.21E-06	7.8		
NOx	Class 1	0.64							
NOx	Class 2	0.83							
NOx	Aggregated	0.940	0.867		-2.72E-4	3.02E-06	7.34		
PM	Class 3	1.00	0.0733		-1.64E-5	1.66E-07	0.386		
PM	Class 1	0.50							
PM	Class 2	0.70							
PM	Aggregated	0.900	0.0660		-1.48E-5	1.49E-07	0.347		
CO_2	Class 3	1.00	201		-0.0262	3.17E-04	1906		
CO_2	Class 1	0.65							
CO_2	Class 2	1.00							
CO_2	Aggregated	0.983	197.6		-0.0258	3.12E-04	1874		

3.4 COMPARISON OF EMISSION FACTORS FOR EURO III DIESEL LGVs AND CARS

In the preceding analysis the speed-related emission factors for Class 1 diesel LGVs were derived from the emissions measured by Shell. In a recent study by AEA Technology the speed-related emission factors for Euro III diesel passenger cars were derived from the emissions measurements made by Ricardo. It is useful to compare these two sets of emission factors.

Direct comparison of the coefficients used to generate the speed-related emission factors is problematic because the forms of the "best fit" polynomials recommended from the analysis vary for the different vehicle types. A better comparison is obtained by superimposing the emission factors, as a function of speed, for the different vehicle types.

Figure 14 shows the speed-related emission factors for:

1. Euro III diesel passenger cars of engine size < 2.0 litres,
2. Euro III diesel passenger cars of engine size > 2.0 litres,
3. Weight Class 1 Euro III diesel LGVs, and
4. Weight Class 3 Euro III diesel LGVs,

for CO_2, PM and NO_X emissions.

For CO_2 the speed-related emission factors for diesel passenger cars (< 2.0 litres) and Class 1 diesel LGVs are virtually indistinguishable between 30 and 80 kph. Above 80 kph the emission factor for LGVs increases markedly more rapidly than for the smaller diesel passenger cars.

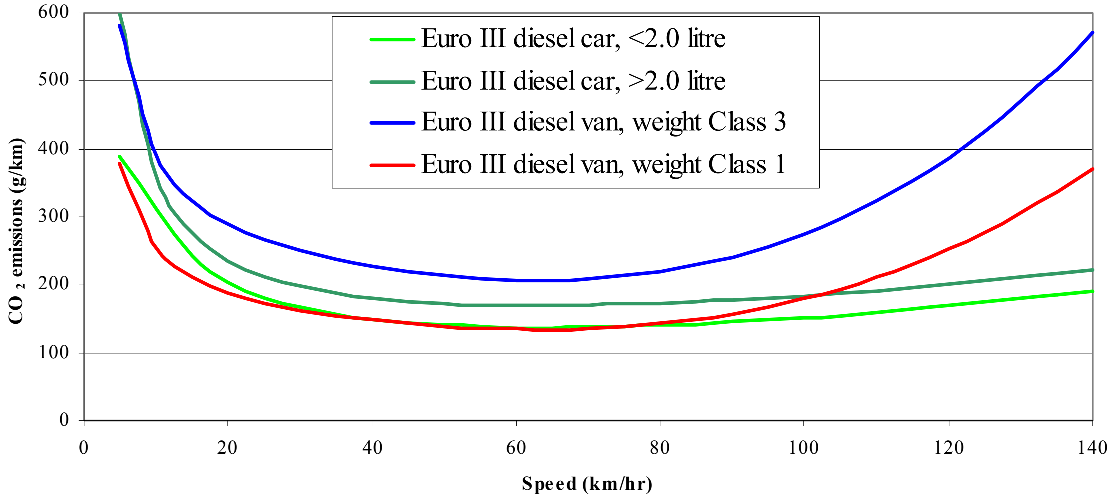
For PM the degree of coincidence is greater, with the speed-related emission factors for smaller diesel passenger cars and Class 1 diesel LGVs being within 10% over the speed range 20 – 140 kph (for CO_2 the difference increased from 10% at 90 kph to 95% at 140 kph).

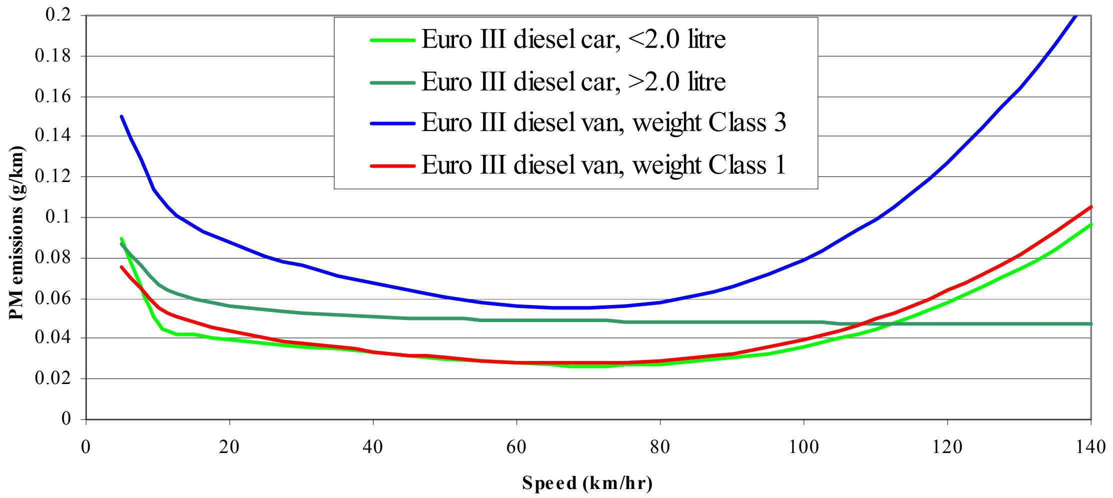
The general shape of the speed-related emission factors are similar for NO_X, particularly over the 20 – 80 kph range, with the factor for Class 1 LGVs lying between those of the < 2.0 litre and > 2.0 litre cars. This is in contrast to them being nearly identical to those of the < 2.0 litre cars as was the case for PM and CO_2 emissions. However, at higher speeds, above 90 kph there is a notable difference with NO_X emissions from LGVs increasing much more rapidly than from cars. For CO_2, emissions at 120 kph are around 200% of those at 60 kph for LGVs, whilst for NO_X emissions at 120 kph are around 400% of those at 60 kph for LGVs and 200% at 60 kph for cars.

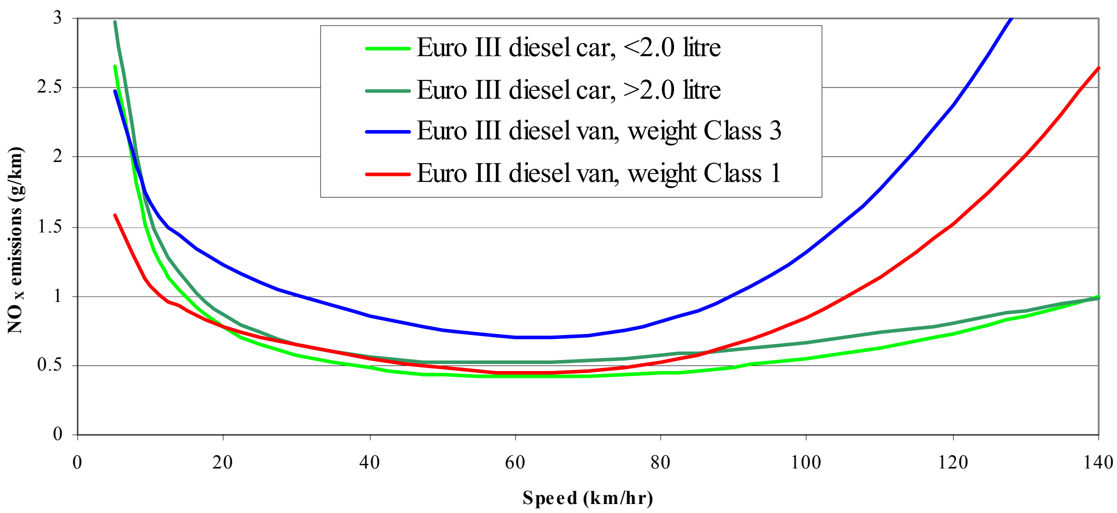
For CO and THC it was noted that emission from diesel LGVs (and from passenger cars) are generally very low (< 0.1 g/km for CO and < 0.05 g/km for THC) and that the speed-related emission factors have moderately high uncertainties. Notwithstanding, the speed-related emission factors for CO and THC for Class1 diesel LGVs generally lies between those for < 2.0 litre and > 2.0 litre diesel passenger cars between 20 and 70 kph. For THC this continues up to 100 kph (at which speed emission factors are < 0.02 mg/km, whereas for CO the emission factor for Class 1 LGVs increases more rapidly than for cars, in a fashion similar to the CO_2 emission factors.

To summarise, speed related emission factors of Class 1 diesel Euro III LGVs have been compared with those obtained for diesel Euro III passenger cars. The two sets of speed-related emission factors were obtained totally independently from mutually exclusive data sets. Despite this, there is a very high level of similarity between the Class 1 diesel LGVs and the smaller (< 2.0 litre) diesel passenger cars, particularly in the 20 – 80 kph speed range for CO_2 and PM emissions. For NO_X, CO and THC emissions, those from

Figure 14: CO_2, PM and NO_X Emission factor for the weight Class 1, and 3 Euro III diesel LGVs compared with those for Euro III diesel passenger cars (ULS fuel, 50 ppmS)







Class 1 Euro III LGVs generally lie between the smaller (<2.0 litre) and larger (> 2.0 litre) passenger cars. However, above 80 kph CO_2, CO and most markedly NO_X emission levels, whilst increasing for all vehicle types, increase more rapidly with increasing speed for the LGVs than for cars. There are several possible reasons for this, including:

- differences in power train engineering (gearing ratios etc),
- differences in average vehicle weight,
- differences in aerodynamic characteristics.

Overall, however, this comparison indicates a high degree of consistency between the speed-related emission factors for all 5 species between 20 and 80 kph for Class 1 Euro III diesel LGVs and passenger cars.

3.5 EMISSION FACTORS FOR EURO IV DIESEL LGVs

The average speed for the NEDC is 33.5 kph. Consequently the emissions predicted from the speed-related emission factors at 33.5 kph can be directly compared with the regulatory standards (measured over the NEDC) after taking into account that the latter is a cold start test, whereas the speed-related emission factors are for emissions from vehicles at their normal operating temperature.

Table 8 contains the emission factors for Euro II and III vehicles, calculated using the recommended emission factors at 33.5 kph, together with the type approval standards for Euro II, III and IV LGVs.

Table 8 Emission factors for LGVs at 33.5 kph and the type approval standards (for Class 3 vehicles)

g/km		CO	HC	PM	NO_X	CO_2
Emission factor	Euro II	0.605	0.122	0.0965	1.224	240.6
	Euro III	0.155	0.053	0.0727	0.951	240.4
Type approval standards		**CO**	**HC**	**PM**	**NO_X**	**HC + NO_X**
	Euro II	1.5	0.096	0.17	1.104	1.2
	Euro III	0.95	0.08	0.10	0.78	0.86
	Euro IV	0.74	0.07	0.06	0.39	0.46

The measured emission factors for both CO and HC for Euro II and Euro III LGVs are below the type approval standards, and the Euro III LGVs are **below** the Euro IV standards. We therefore assume that vehicle manufacturers will devote little attention to these emissions, and consequently we recommend that Euro IV emission factors be assumed to remain at the observed Euro III levels.

The emission factors for PM emissions at 33.5 kph have gone from being well below the Euro II limit to being closer to the standard for Euro III LGVs (0.073 g/km relative to 0.100 g/km). Further reductions will be required to meet Euro IV limits. It is recommended to reduce the PM emission factors such they reach a level of 0.05 g/km at 33.5 kph, 20% below the Euro IV type approval limit in order to remain within the durability requirements of the directive. This implies a 31% reduction and a scaling factor of 0.69 going from Euro III to Euro IV.

For NOx, the measured emissions for both Euro II and Euro III vehicles are greater than their type approval standards. This is not the forum to discuss the possible reasons for this, but merely to acknowledge this fact when recommending emission factors for Euro

IV vehicles. It is assumed emission factors from Euro III will be reduced by an additional amount than implied by the ratio in type approval standards in order to meet the standards for Euro IV. This implies a 59% reduction and a scaling factor of 0.41 going from Euro III to Euro IV.

It should be noted that the situation regarding NOx and PM emission factors for Euro III diesel LGVs in relation to their type approval standards exactly mirrors the situation regarding the emission factors for Euro III diesel cars, as assessed recently by AEA Technology.

The emission factors for CO_2 for Euro II and III LGVs are within 0.1% of each other.

There are some changes in vehicle technology that are anticipated to cause a small increase in fuel efficiency (e.g. further increases in injection pressure) and other changes that are anticipated to cause a small decrease in fuel efficiency (e.g. cooled EGR allowing higher rates of EGR). It is also the case that there is no regulatory driver for changes in CO_2 emissions, and that for LGVs the financial advantages of improved fuel efficiency are markedly less than for heavy-duty vehicles. Overall, the recommendation, based on caution, is that the CO_2 emission functions for Euro IV LGVs are assumed to remain unchanged from Euro III levels.

Table 9 summarises the scaling factors recommended for calculating emission factors for Euro IV diesel LGVs from the values calculated for Euro III LGVs using the speed-related coefficients in Table 7. It is assumed that the shape of the emission factor – speed relationship for Euro IV LGVs is the same as for Euro III vehicles so these scaling factors apply at all speeds.

Table 9 Emission scaling factors for Euro IV relative to Euro III for diesel LGVs

Pollutant	Euro IV/Euro III scaling factor (x)
CO	1.00
THC	1.00
NOx	0.41
PM	0.69
CO_2 Tailpipe	1.00
CO_2 'Ultimate'	1.00

3.6 COMPARISON OF CURRENT NAEI AND NEW EMISSION FACTORS FOR EURO II-IV DIESEL LGVs

This section discusses the new Euro II-IV diesel LGV emission factors for each pollutant in turn, comparing with existing factors used in the NAEI. The values refer to aggregated emission factors for the average diesel LGV in the fleet, using the weighting factors discussed in Section 3.2.

3.6.1 Nitrogen Oxides (NOx)

Table 10 shows NOx emission factors for average-sized diesel LGVs calculated from the new and current speed-emission factor relationships at typical average speeds on urban, rural and motorway roads.

Table 10 NOx Emission factors for average diesel LGVs (in mg/km) on ULSD

mg NOx (as NO_2)/km	Urban	Rural	Motorway
Current Euro II	983	848	1315
Current Euro III	737	636	986
Current Euro IV	383	331	513
New Euro II	1091	1188	2140
New Euro III	790	720	1675
Recommended Euro IV	324	295	687

Averaged over the fleet, the new Euro II and III emission factors are higher than the current NAEI factors for these vehicle classes on these road types. The difference is particularly significant at high speeds.

The method for re-shaping and scaling the estimated emission factor-speed equations for Euro IV LGVs leads to a lower estimate of emission factors for Euro IV diesel LGVs at low and medium speeds, but higher emission factors at high speeds than had previously been estimated.

3.6.2 Particulate Matter (PM)

Table 11 shows PM emission factors for average-sized diesel LGVs calculated from the new and current speed-emission factor relationships at typical average speeds on urban, rural and motorway roads.

Table 11 PM Emission factors for average diesel LGVs (in mg/km) on ULSD

mg PM/km	Urban	Rural	Motorway
Current Euro II	81.9	81.1	200.3
Current Euro III	57.5	56.9	140.5
Current Euro IV	37.1	36.7	90.7
New Euro II	82.1	78.9	123.3
New Euro III	59.2	50.9	89.1
Recommended Euro IV	40.7	35.0	61.3

Averaged over the fleet, the new Euro II and III emission factors are very similar to the current NAEI factors for these vehicle classes on urban and rural road types, but at higher speeds the new factors are significantly lower.

The method for re-shaping and scaling the estimated emission factor-speed equations for Euro IV LGVs leads to fairly similar estimates at urban and rural speeds, but lower emission factors at high speeds than had previously been estimated.

3.6.3 Carbon Monoxide (CO)

Table 12 shows CO emission factors for average-sized diesel LGVs calculated from the new and current speed-emission factor relationships at typical average speeds on urban, rural and motorway roads.

Averaged over the fleet, the new Euro II emission factors are higher than current NAEI factors at low speeds, but lower than current NAEI factors at high speeds. The new factors for Euro III vehicles are considerably below current NAEI factors at all speeds.

Currently in the NAEI, CO emission factors for Euro IV diesel LGVs are assumed to be unchanged from Euro III vehicles. This assumption is made with regard to the new emission factors meaning that the new factors for Euro IV are below current NAEI factors that had previously been estimated.

Table 12 CO Emission factors for average diesel LGVs (in mg/km) on ULSD

mg CO/km	Urban	Rural	Motorway
Current Euro II	453	510	909
Current Euro III	288	324	578
Current Euro IV	288	324	578
New Euro II	531	519	735
New Euro III	116	99	240
Recommended Euro IV	116	99	240

3.6.4 Total Hydrocarbons (THC)

Table 13 shows THC emission factors for average-sized diesel LGVs calculated from the new and current speed-emission factor relationships at typical average speeds on urban, rural and motorway roads.

Table 13 THC Emission factors for average diesel LGVs (in mg/km) on ULSD

mg THC/km	Urban	Rural	Motorway
Current Euro II	122.9	98.4	88.4
Current Euro III	100.3	80.4	72.2
Current Euro IV	52.7	42.2	38.0
New Euro II	105.6	88.0	80.8
New Euro III	41.2	24.3	17.4
Recommended Euro IV	41.2	24.3	17.4

Averaged over the fleet, the new Euro II emission factors are quite similar, but less than the current NAEI factors for these vehicle classes at all speeds. The new factors for Euro III vehicles are considerably below current NAEI factors at all speeds.

The method for re-shaping and scaling the estimated emission factor-speed equations for Euro IV LGVs leads to lower estimates of THC emission factors for Euro IV LGVs at all speeds than had previously been estimated.

3.6.5 Carbon Dioxide (CO_2)

Table 14 shows CO_2 emission factors for average-sized diesel LGVs calculated from the new and current speed-emission factor relationships at typical average speeds on urban, rural and motorway roads.

Averaged over the fleet, the new Euro II and III emission factors are lower than the current NAEI factors for these vehicle classes on all these road types. The factors are also very similar to each other implying no major differences in fuel efficiency of LGVs in the two Euro standards.

Table 14 CO_2 Emission factors for average diesel LGVs (in mg/km) on ULSD

g CO_2/km	Urban	Rural	Motorway
Current Euro II	299	258	417
Current Euro III	275	237	384
Current Euro IV	256	221	358
New Euro II	223	217	330
New Euro III	221	210	319
Recommended Euro IV	221	210	319

The method for re-shaping and scaling the estimated emission factor-speed equations for Euro IV LGVs leads to a lower estimate of emission factors for Euro IV diesel LGVs at all speeds than had previously been estimated.

3.7 SENSITIVITY OF ROAD TRANSPORT EMISSION PROJECTIONS TO CHANGES IN EURO II-IV EMISSION FACTORS FOR DIESEL LGVs

The NAEI Road Transport Emissions Forecasting Model was used to test how the new emission factors for Euro II-IV diesel LGVs affect the overall inventory of road transport emissions in the UK projected to 2020.

The model was used to calculate transport emissions in 2000, 2010, 2015 and 2020 for the original and new set of Euro II-IV diesel LGV emission factors, leaving all other parameters in the model unchanged. This includes the parameters for calculating cold start emissions when in fact the assumptions made for estimating Euro IV emission factors could affect the assumptions made for estimating cold start emissions from these vehicles. However, consideration of cold start emissions is outside the scope of this study.

The effect of changing the Euro II-IV emission factors differs each year as these vehicles penetrate the fleet at different rates. Projections were modelled for NOx, PM, THC and CO. Table 15 shows UK emissions of each these pollutants from diesel LGVs and all road transport using the original factors and the new emission factors and shows the percentage differences between them.

The new emission factors lead to a reduction in the overall inventory of emissions for all pollutants except NOx. For this pollutant, the biggest changes occur in the inventory for 2010 and lead to a 22% increase in NOx emission estimates for diesel LGVs and an overall increase of 2.5% in NOx emission estimates for all road transport.

For PM, the largest changes occur in 2020. Although the maximum effect on emission estimates for diesel LGVs themselves is a reduction of 15%, the smallest percentage change in emission estimates for this class of vehicle among all the pollutants, the overall effect on emission estimates for all road transport is larger than for any other pollutant, reflecting the important contribution that diesel LGVs make to the overall inventory. The results show the changes lead to a 7% reduction in overall PM emission estimates for all road transport in 2020 compared with the estimate using the current NAEI emission factors.

Table 15 UK road transport emissions: current (base) and new emission factors (ktonnes). A negative value indicates a reduction in estimated emissions due to the new factors.

		2000			2010			2015			2020		
	ktonnes	Base	New EF	% diff	Base	New EF	% diff	Base	New EF	% diff	Base	New EF	% diff
		kt	kt	%	kt	kt	%	kt	kt	%	kt	kt	%
NOx	Diesel LGVs	53.5	63.3	18.3%	45.3	55.4	22.1%	37.8	41.9	10.8%	36.7	38.9	6.0%
	All road transport	826	836	1.2%	396	406	2.5%	290	295	1.4%	268	270	0.8%
PM	Diesel LGVs	11.0	10.1	-8.0%	8.8	7.8	-10.5%	6.8	5.8	-14.5%	6.6	5.5	-15.5%
	All road transport	31.1	30.2	-2.8%	18.7	17.8	-4.9%	14.5	13.5	-6.8%	14.0	13.0	-7.2%
CO	Diesel LGVs	35.5	35.0	-1.5%	35.1	17.5	-50.0%	36.4	14.5	-60.1%	38.5	14.8	-61.5%
	All road transport	2548	2548	0.0%	634	616	-2.8%	422	401	-5.2%	393	369	-6.0%
THC	Diesel LGVs	7.1	6.8	-5.0%	5.9	3.4	-41.6%	5.0	3.0	-40.2%	4.9	3.1	-37.0%
	All road transport	329	329	-0.1%	85.0	82.6	-2.9%	66.1	64.1	-3.0%	63.7	61.9	-2.8%

CO and THC both show large effects of the emission factor changes on the emission estimates for diesel LGVs themselves, but because of the relatively small contribution that these vehicles make to the overall inventory, the effect they have on emission estimates for all road transport is much suppressed. For CO, the new emission factors lead to a 61% reduction in the CO emission estimate for diesel LGVs in 2020, but the effect it has on the overall emission estimate for all road transport is only a 6% reduction. For THC, the new emission factors lead to a maximum 42% reduction in the THC emission estimate for diesel LGVs in 2010, but the effect it has on the overall emission estimate for all road transport is only a 3% reduction.

It is interesting to consider how the effect of these changes in diesel LGV emission factors combine with the effect of the changes in the emission factors for petrol and diesel cars and petrol LGVs assessed recently in another study by AEA Technology for DfT on the basis of new Euro III emission factors.

For NOx, the increase in diesel LGV emissions would somewhat offset the decrease in emissions from petrol and diesel cars found in the previous study. Overall, using all the new emissions factors for petrol and diesel cars and LGVs would still lead to a small decrease in NOx emissions.

For PM, the situation is reversed and the decrease in emissions from diesel LGVs would almost completely offset the increase in emissions from diesel cars found in the previous study so that the overall PM inventory for road transport would hardly be changed at all.

For CO, the decrease in diesel LGV emissions would offset the increase in emissions from petrol cars and, with the decrease in diesel car emissions also predicted, would lead to an overall decrease in CO emissions in the inventory for road transport.

For THC, the predicted decrease in diesel LGV emissions would combine with the larger decrease in emissions from petrol and diesel car emissions to lead to an even larger decrease in overall THC emissions in the inventory for road transport.

4 Conclusions

Emission factors measured by Shell Global Solutions on 20 diesel light goods vehicles, (and one vehicle tested by Ricardo) over several drive cycles have been analysed. A dataset comprising test results on 16 of the heaviest Class 3 vehicles (>1700–3500 kg) was examined in detail, with 6 being of Euro II standard and 10 being of Euro III standard. From this dataset, empirical relationships between emission factor and average speed were obtained for Euro II and Euro III Class 3 diesel LGVs by a combination of statistical curve fitting techniques and expert judgement for the pollutants NOx, PM, CO, total hydrocarbons (THC) and CO_2.

Emission factors were assessed for the lighter Class 1 and Class 2 diesel LGVs on the basis of the trends in the Type Approval emission standards for the three weight classes and the emission factor data for the 5 lighter vehicles that were tested. With one exception (CO_2 emissions from Class 2 Euro II LGVs), the emission factors for the lighter LGVs were less than those for the Class 3 LGVs. However, an assumption was made that the shape of the emission factor – speed relationship for the lighter vehicles was the same as for the heaviest Class 3 vehicles for each pollutant and Euro standard and from this an emission scaling factor (≤1) relative to Class 3 was derived for each weight class and Euro standard. Using assumptions about the mix of different LGV weight classes in the fleet, it was then possible to derive aggregated emission factor – speed relationships representing the diesel LGV fleet in the UK.

A comparison has been made between the new Euro II and Euro III emission factors and those currently used in the NAEI obtained from scaling the factors for Euro I LGVs. A re-evaluation has also been made of the current factors used for Euro IV LGVs. Proposed changes to the emission factor-speed equations have been made for these vehicle types on the basis of this re-evaluation.

As in our recent analysis of test data for Euro III cars, the statistical treatment of the data generally showed that apart from CO_2, there was often a relatively weak relationship (low R^2) between the emission factor and speed. In many cases, expert judgement was used in combination with the best-fit results to obtain the speed-emission factor functions from general understanding on the shape of the speed-emission curve for LGVs.

The study has also evaluated the effect of changes to these emission factors on the UK projections of emissions of each of the pollutants from the road transport sector. A series of emission sensitivity tests were carried out using the NAEI Road Transport Emissions Forecasting model that combines emission factors for current and future vehicle types with assumptions about growth in traffic activity and turnover in the vehicle fleet.

The overall conclusions from the analysis are as follows for each pollutant in turn.

For **NOx**, the Euro II and Euro III factors for diesel LGVs are higher than currently used in the NAEI, particularly at high speeds. We propose an increase in the current emission factors used for both Euro II and III LGVs. Our recommendations for Euro IV LGVs lead to reduced emission factors at low and medium speeds, but higher emission factors at high speeds than had previously been estimated. The changes would lead to an overall increase of about 2.5% in the estimates of UK NOx emissions from road transport in 2010, with smaller overall increases in 2015 and 2020.

For **PM**, the Euro II and Euro III factors for diesel LGVs are very similar to those currently used in the NAEI at urban speeds, but are lower at high speeds. Our recommendations for Euro IV LGVs also lead to similar emission factors at low and medium speeds, but lower emission factors at high speeds than had previously been estimated. The changes would lead to an overall decrease of about 7% in the estimates of UK PM emissions from road transport in 2020, with smaller overall reductions in earlier years compared with estimates based on the current emission factors used in the NAEI. The emissions inventory for PM is more sensitive to changes in the diesel LGV emission factors than any other pollutant reflecting the important contribution made by diesel LGVs to overall emissions of PM from road transport in the UK.

For **CO**, the Euro II factors for diesel LGVs are higher than current NAEI factors at low speeds, but lower than current NAEI factors at high speeds. The new factors for Euro III vehicles are considerably below current NAEI factors at all speeds. We recommend factors for Euro IV LGVs that are the same as the new lower factors for Euro III, meaning that the new factors for Euro IV are below current NAEI factors that had previously been estimated. The changes would lead to an overall decrease of about 6% in the estimates of UK CO emissions from road transport in 2020, with smaller overall reductions in earlier years compared with estimates based on the current emission factors used in the NAEI.

For **THC**, the new Euro II emission factors for diesel LGVs are quite similar, but less than the current NAEI factors for these vehicle classes at all speeds. The new factors for Euro III vehicles are considerably below current NAEI factors at all speeds. We recommend factors for Euro IV LGVs that are the same as the new lower factors for Euro III, meaning that the new factors for Euro IV are below current NAEI factors that had previously been estimated. The changes would lead to an overall decrease of about 3% in the estimates of UK THC emissions from road transport in years from 2010-2020 compared with estimates based on the current emission factors used in the NAEI.

For **CO_2,** the Euro II and Euro III factors for diesel LGVs are lower than currently used in the NAEI, at all speeds and are also very similar to each other. We propose a reduction in the current emission factors used for both Euro II and III LGVs. We recommend factors for Euro IV LGVs that are the same as the new lower factors for Euro III, meaning that the new factors for Euro IV are below current NAEI factors that had previously been estimated.

On the basis of the review and analysis carried out in this study, we propose discussing and confirming with DfT and Defra our recommendation that the new Euro II-Euro IV emission factors for diesel LGVs be adopted for use in the NAEI.

5 References

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Appendix 1- The list of vehicles tested by Shell Global Solutions

Euro II Class 1 diesel LGVs
V.W. Caddy 1.9D Pickup
Vauxhall Combo 1.7D van

Euro II Class 2 diesel LGVs
Toyota Hiace Van
Citroen Dispatch Van 1.9D

Euro II Class 3 diesel LGVs
LDV Convoy 2.5D panel van
Ford Transit 120 2.5D
Ford Transit 190 2.5D chassis
Land Rover Defender 90 Td5
Nissan 2.5 TD Pickup
Mercedes Sprinter 208

Euro III Class 1 diesel LGVs
Renault Kangoo Van 1.9

Euro III Class 3 diesel LGVs
Renault Master 2.2 cDi Van
V.W. LT35 2.5TDi panel van
Ford Transit 90 T350 lwb
Vauxhall Movano 2.2DTI
Mitsubishi L200 Double Cab
LDV Convoy Minibus
Mercedes Sprinter 213
Ford Transit 280 swb 2.0
Isuzu NKR Dropside
VCA Volkswagen_Caravelle (Tested by Ricardo)