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Production of Updated Emission Curves for Use in the NTM and WebTAG

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Executive summary

The National Transport Model (NTM) is the Department for Transport's main strategic policy testing and forecasting tool and it is used to forecast traffic levels and the subsequent congestion and emissions impacts on the National (GB) road network. The NTM calculates fuel consumption and emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x) and fine particulate matter (PM) using a set of equations (referred to as speed-emission curves) that relate emission or fuel consumption factors for different vehicle types to average vehicle speed. The emission curves currently used in the NTM for each main vehicle and fuel type represent the fleet up to 2035 and were developed by Ricardo in 2013/14, based on the information on vehicle emission factors and fleet composition available at the time.

The objective of this work was to provide updated speed-emission factor curves based on the latest version of the European COPERT 5 model and database of emission factors. These factors are used in the UK's latest National Atmospheric Emissions Inventory (NAEI) and air pollutant emission and air quality projections for Defra. The factors in COPERT 5 use the latest evidence publicly available from sources in Europe on the real-world emission performance of vehicles. The updates also include the latest national fleet composition projections developed by the NAEI and detailed fleet composition for London provided by Transport for London (TfL). The fleets for London take into account the introduction of the current Low Emission Zone and the Ultra Low Emission Zone to be introduced in 2019 as well as updated fleet data for TfL's bus fleet.

Updated emission and fuel consumption factors expressed as curves varying by speed (v) have been developed for the NTM in the form of a 6th-order polynomial equation:

$$y = (a + bv + cv^2 + dv^3 + ev^4 + fv^5 + gv^6) / v$$

Fuel consumption curves have been developed for the years 2010, 2015, 2020, 2025, 2030 and 2035 covering each main vehicle category using conventional petrol and diesel fuels and powertrains. Fuel consumption and CO_2 emission curves have also been developed for DfT's Transport Analysis Guidance tool, WebTAG, for the years 2010 and 2015 in the form of a 3rd-order polynomial equation:

$$EF = (a + bv + cv^2 + dv^3) / v$$

Separate speed emission curves representing the fleet in central, inner and outer London, London as a whole and the rest of the UK have been developed for the NTM and WebTAG.

All the emission curves required a statistical re-fitting of the equations in the different COPERT 5 format to match the requirements of the NTM and WebTAG.

This report describes the method, data and assumptions used to update the emission curves. It considers the errors introduced by needing to refit curves, using the statistical software package 'R', from the mathematical form of the equation in COPERT to the specific mathematical forms of equations used in the NTM and WebTAG. It also considers other main causes of uncertainties. The statistical re-fitting reproduces the emission factors from the NTM and WebTAG equations very well at most speeds compared with the original COPERT curves. The differences were less than 1% at most speeds, but somewhat higher at the extreme ends of the valid speed ranges. The largest errors in the WebTAG curves were 7% for petrol cars at the extreme ends of the speed range. The largest error in the NTM curves was 11% in the 2035 curve for coaches. In virtually all other cases, the differences were less than 0.5%, but the emission curves should not be used outside their valid speed ranges.

The report compares the emission factors derived from the new curves with those derived from the curves currently used in the NTM and WebTAG. There are significant differences, and these are mainly due to the adoption of the COPERT 5 emission factors which reflect more up-to-date information on emissions under real-world driving conditions, especially for NO_x and CO_2 from modern vehicle types. Among the most significant changes:

- For NO_x, the emission factors for diesel cars and LGVs in 2015 and 2020 are higher than previous factors and this is due to COPERT 5 taking account of new evidence on the real-world emission performance of Euro 5 and early Euro 6 vehicles. However, in later years the new factors are lower than the old factors due to the fact that COPERT 5 takes into account a third legislative stage of Euro 6 (Euro 6d) that comes into effect in 2020 requiring vehicles to comply with Real Driving Emissions legislation

- The relative differences in emission factors for PM are large with use of the COPERT 5 curves yielding higher emission factors than the older source of emission factors for most vehicle categories. However, the differences are small in absolute terms because of the very low emission factors for the latest Euro standards indicated by both COPERT 5 and the previous TRL source of emission factors for diesel vehicles, both indicating much lower levels for Euro 5 and VI vehicles compared with their predecessors due to fitting with diesel particulate filters

- For CO_2 and fuel consumption, the differences are due to the new COPERT 5 factors. For passenger cars, a new approach treats the gradual changes in the real-world CO_2 and fuel consumption factors for new passenger cars in the fleet since 2005. This method utilises UK specific information on the fleet-average CO_2 emissions of new cars sold in the UK according to industry figures and applies a real-world uplift to scale the emission factors in COPERT for different years. Changes in the fuel consumption and CO_2 curves for HGVs and buses are largely due to the curves being derived solely from COPERT equations. These are no longer calibrated against the independent source of fleet-averaged fuel efficiency data previously provided by DfT from the statistical sources as these data are either no longer available or have limitations in their validity and/or completeness.

The report considers the limitations of the new emission curves in terms of their parameterisations. The curves refer to a relationship between emission factors and average speed of a drive cycle and should not be inferred to represent very localised, instantaneous emission rates at a specific, transient speed.

The emission curves and the input data used to generate them were provided in a series of separate Excel spreadsheets covering the fleet in London and the rest of the UK (representing the national average fleet outside of London), for both the NTM and WebTAG. A new set of total fuel consumption, CO_2, NO_x and PM emission estimates for road transport in the UK and Great Britain was also provided for 2003, 2005, 2010 and 2015, consistent with the latest version of the UK's National Atmospheric Emissions Inventory. These may be used to calibrate outputs from the NTM and WebTAG.

The emission curves refer to hot exhaust emissions for conventional petrol and diesel fuelled vehicles and do not account for the uptake of alternative fuelled- and ultra-low emission vehicles. Emission curves for these types of vehicles have previously been developed by Ricardo and are being reviewed in a separate report.

The emission curves exclude excess cold start emissions and non-exhaust sources of air pollutant emissions from road transport. An approach for dealing with cold start emissions in the NTM is being considered in a separate report to DfT. Emission factors for non-exhaust sources of PM cannot be expressed as continuous speed-emission curves, but a table of averaged factors for different vehicle and road types has been provided. These non-exhaust sources are becoming increasingly dominant as tailpipe emissions of PM are reduced.

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1 Introduction

The National Transport Model (NTM) is the Department for Transport's main strategic policy testing and forecasting tool and it is used to forecast traffic levels and the subsequent congestion and emissions impacts on the National (GB) road network. The NTM has the capability of calculating fuel consumption and emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x) and fine particulate matter (PM) from road vehicles using a set of equations that relate emission or fuel consumption factors for different vehicle types in grammes per kilometre to average vehicle speed. These equations are used together with forecasts of traffic levels and vehicle speed to predict future quantities of fuel use and road traffic emissions.

The model uses speed-emission curves last provided by Ricardo in 2013/2014 and since then there has been further evidence on the real-world emission performance of vehicles which has led to an update of the speed-emission curves in the European COPERT model. COPERT is a tool developed for the European Environment Agency designed to assist countries compiling national emission inventories for reporting under the EU National Emissions Ceilings Directive (2016/2284/EU) (https://www.eea.europa.eu/themes/air/national-emission-ceilings/national-emission-ceilings-directive), the UNECE Convention on Long-range Transboundary Air Pollution (https://www.unece.org/env/lrtap/welcome.html.html) and for reporting Greenhouse Gas emissions under the UN Framework Convention on Climate Change. The latest version of emission factors in COPERT 5 is now used by Ricardo in the compilation of the UK's National Atmospheric Emissions Inventory (NAEI) on behalf of Defra and BEIS (http://naei.beis.gov.uk/) and in national air quality modelling under the *Modelling Ambient Air Quality* (MAAQ) contract for Defra. This includes modelling that underpinned the UK's Plans for reducing roadside nitrogen dioxide concentrations (https://www.gov.uk/government/publications/air-quality-plan-for-nitrogen-dioxide-no2-in-uk-2017).

As well as the speed-emission factor curves from COPERT 5, the NAEI uses updated fleet composition projections. These have been derived from a fleet turnover model using on-road fleet composition data for years up to 2015 provided by DfT from Automatic Number Plate Recognition (ANPR) cameras and updated predictions on new vehicle sales provided by DfT in 2017. The NAEI also uses detailed fleet composition data provided by Transport for London (TfL) representing the specific features of the fleet in central, inner and outer London. These take into account the current London Low Emission Zones and the introduction of the Ultra-Low Emission Zones to be introduced in 2019, restricting access to vehicles not meeting minimum Euro emission standards in central London.

DfT has requested an update to the emission curves used in the NTM based on the latest emission factors in COPERT 5 and fleet composition data used in the NAEI's UK emissions inventory and projections for Defra and BEIS. The NTM requires a single curve to represent each main vehicle type and fuel type representative of the UK fleet in years 2010, 2015, 2020, 2025, 2030 and 2035, with separate curves provided for the fleets in London. The curves are derived by weightings of the individual emission curves for each sub-class of vehicle Euro standard, vehicle weight and engine size in each year and are fitted to the specific 6th order polynomial functional form of the speed-emission equations currently used in the NTM.

DfT also require an update to the fuel consumption and CO_2 emission curves used in DfT's Transport Analysis Guidance tool, WebTAG, for the years 2010 and 2015. These are required in a different 3rd order polynomial functional form and for a slightly different categorisation of vehicles in the case of heavy goods vehicles.

The NAEI updates estimates of emissions and fuel consumption from Ricardo's road transport emissions model from 1990 to the latest inventory year. At the time this work was undertaken, the most recent inventory year was for 2016, and reported under the NECD, UNECE/CLRTAP and UNFCCC in early 2018. DfT require historical emission figures for NO_x, PM, CO_2 and fuel consumption for each vehicle type and fuel type from this 2016 version of the NAEI for the years 2003, 2005, 2010 and 2015 for the purpose of calibrating the NTM. These are required at both Great Britain level and for the UK.

This report describes the derivation and use of the emission factor curves in the NTM and WebTAG and discusses the uncertainties in the emission factors. The report also shows a comparison with the factors previously provided in 2013/14. The speed-emission and fuel consumption curves themselves for each main vehicle category, year and pollutant have been provided to DfT in Excel spreadsheets with all the steps in the derivation from the original COPERT equations and fleet compositions shown, apart from the statistical refitting procedure which was done in separate software.

Consistent with the emission curves currently used in the NTM and WebTAG, the new emission curves are representative of hot exhaust emissions from vehicles running on conventional petrol and diesel fuels and powertrains. In a separate study for DfT in 2015, Ricardo provided a set of speed-emission curves for certain types of non-conventional or Ultra Low Emission Vehicles (ULEVs), namely hybrid electric cars and vans, plug-in hybrid cars and vans, battery electric cars and vans, biomethane/natural gas fuelled heavy goods vehicles and battery electric heavy goods vehicles. These emission and energy consumption curves were based on the limited evidence available at the time on real-world emission performance of these vehicles.

DfT has requested a review that examines latest evidence on emissions and fuel/energy consumption for these and other types of ULEVs and considers whether there is sufficient new evidence available to update the curves developed in 2015. A separate report on the findings of this scoping review is provided, but emissions from these vehicles are not included in the emission curves updated and described in this report.

2 Source of Data and General Approach for Updating Emission Curves for the NTM and WebTAG

The emission curves developed for the NTM and WebTAG follow the general approach used in the NAEI for compiling the national emissions inventory and projections. These are described in the annual NAEI reports for air pollutants at https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1803161032_GB_IIR_2018_v1.2.pdf , for greenhouse gases at https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1804191054_ukghgi-90-16_Main_Issue1.1_UNFCCC.pdf and in the specific report on road transport emission estimation methodology for both air pollutants and greenhouse gases at https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1804121004_Road_transport_emissions_methodology_report_2018_v1.1.pdf .

2.1 COPERT 5 emission factors

COPERT 5 provides emission and fuel consumption factor-speed equations for each of the vehicle types covered in the NTM and WebTAG: petrol cars, diesel cars, petrol LGVs, diesel LGVs, rigid and articulated HGVs, buses and coaches. These are further subdivided into vehicles of different engine capacity range (passenger cars), gross vehicle weight (LGVs, HGVs and buses) and Euro emission standard up to Euro 6/VI. In the case of cars, factors are provided for three different stages of Euro 6 to represent vehicles coming into service from 2015-2016, 2017-2019 and 2020+. A similar 3-staged introduction of Euro 6 is assumed for LGVs delayed by one year relative to cars. These are broadly aimed at representing the individual steps in the Euro 6 regulation (Euro 6c, Euro 6d-temp, Euro 6d).

Equations are provided in the same mathematical formula for all vehicle types in COPERT of the form:

$$EF(v) = (a.v^2 + b.v + c + d/v) / (e.v^2 + f.v + g) * (1 – RF)$$

where EF is the emission factor in g/km, v is average speed in kph and a-g are coefficients. RF is another coefficient referred to as a reduction factor.

The emission factors in COPERT are developed by Emisia on behalf of the European Environment Agency (https://www.emisia.com/utilities/copert/). The development of COPERT is coordinated by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre for Air Pollution and Climate Change Mitigation. The European Commission's Joint Research Centre (JRC) manages the scientific development of the model which has been developed for official road transport emission inventory preparation in EEA member countries.

The factors are developed from a database of emissions test data held through the JRC programme "*European Research group on Mobile Emission Sources*" (ERMES, https://www.ermes-group.eu/web/). ERMES collates data from studies in various countries including Germany, France, Austria, Switzerland, the UK, Netherlands. The emissions test data come from laboratory studies where vehicles are tested on a chassis dynamometer over different real-world drive cycles, or increasingly from measurements done from vehicles on the road using portable emission measurement systems (PEMS). The measured emission factors and other test conditions are extracted from the ERMES database and COPERT generates speed emission curves by plotting the emission factors against the average speed of the test cycle.

The original COPERT 5 emission factor-speed coefficients for all vehicle classes are available with the EMEP/EEA Emissions Inventory Guidebook in an Excel spreadsheet on the EEA website at https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-i-1/view . The same factors for NO_x and PM have been extracted for ease of access to users on the NAEI website at http://naei.beis.gov.uk/data/ef-transport . These spreadsheets allow the user to enter a speed and extract the relevant hot exhaust emission factor.

2.2 Fleet composition projections

The fleet composition data for current and historic years are based on a combination of DfT vehicle registration data and data showing the composition of vehicles on the road provided by DfT from its Roadside Survey covering around 250 ANPR sites in the UK. All the ANPR data are anonymised and provide the NAEI with the number of observations by vehicle type, fuel type, road type and year of first registration. Data for all the sites are combined to yield the composition of the fleet typical of urban, rural and motorway sites. These data have the benefit of showing how the usage of diesel cars is biased towards motorway roads relative to urban roads. ANPR data are not available for every historical year, but for years 2007-2011, 2013 and 2015 are sufficient to show typical usage patterns for different vehicle types on different road types. They provide a means of cross checking fleet composition data derived from registration data combined with estimates of how annual mileage changes with vehicle age which are used to forecast the future fleet composition.

To forecast the composition of the fleet to 2035, the NAEI's fleet turnover model is used to combine vehicle survival rates and mileage with age rates with forecasts in new vehicle sales in the UK. The main change from the previous fleet projections are due to re-basing to the latest inventory year (2016) and updated figures from DfT on new car and LGV sales, split between petrol and diesel and accounting for uptake of hybrid and plug-in hybrid vehicle types. The figures used in this work were provided by DfT in January 2017 for the development of NAEI emission projections and the modelling done for Defra in support of the NO_2 Air Quality Plans in 2017. Therefore, the figures do not include the recent large decline in diesel car sales seen since 2017, although a decline in diesel car sales in future years had been included.

The latest fleet composition projections are provided on the NAEI website at http://naei.beis.gov.uk/data/ef-transport (the version referred to as Base 2016) where further details on the assumptions made are given. These fleet composition projections are in terms of the proportions of vehicle kilometres travelled by each vehicle type, not the proportions of the vehicle stock and therefore take account of the decrease in vehicle usage (mileage) with increasing vehicle age. This is the version of fleet compositions used for this work. They are also the version, together with the latest COPERT emission factors for NO_x and PM, used in the latest version of Defra's Emission Factor Toolkit EFTv8.0.1 (https://laqm.defra.gov.uk/review-and-assessment/tools/emissions-factors-toolkit.html). The EFT is a tool published by Defra to assist local authorities in carrying out Review and Assessment of local air quality as part of their duties under the Environmental Act 1995.

Details of the fleet composition in London were provided by TfL in the latter part of 2016 and are also used in the London Atmospheric Emissions Inventory (LAEI), the NAEI and EFT v8.0.1. It is also available as a spreadsheet on the NAEI website link shown above. TfL provide current and future fleet projections (up to 2030) for the fleet in central, inner and outer London for all vehicle and fuel types taking account of the current London Low Emission Zone and the Ultra-Low Emission Zone (ULEZ) scheme to be introduced from 2019. As for the national fleet, the TfL fleet data for London provide the proportion of each Euro standard in the fleet for each vehicle type in each part of London. Differences reflect the different age distribution of vehicles in the different parts of London. Particularly detailed information is provided for TfL's own bus fleet, and the measures TfL are taking to reduce emissions from buses, separate from other buses and coaches operating in London. The information provided by TfL at the time this work was carried out does not include the expansion of the LEZ and extension of the ULEZ scheme from 2021. At the time this report was completed, TfL are currently working on the development of revised fleet composition data for these expanded LEZ/ULEZ schemes.

Several other pieces of information were used in the update of the emission curves for the NTM and WebTAG. These will be described in the following sections. However, these are mainly of secondary importance compared with the primary data being the COPERT speed-related emission and fuel consumption factors and the NAEI fleet composition projections.

Fleet composition data for other cities in the UK were not available for this work.

Fleet composition projections are provided up to 2035. By this time >98% of the fleet of conventional petrol and diesel fuelled vehicles will be comprised of the latest defined Euro 6d/Euro VI emission standards, so little further change in the emission factor curves will be expected beyond that year. Further improvement in fleet emissions will mostly come about as a consequence of the penetration of

ULEVs in the fleet. The inclusion of these were outside the scope of the current emission curves as will be addressed separately.

2.3 General Approach for Development of Emission Curves for the NTM and WebTAG

The main task in developing the emission curves for the NTM and WebTAG was to:

a) convert the many separate emission curves provided for the different vehicle sizes and Euro standards of each main vehicle category in COPERT into a single curve for a specific year that is weighted by the fleet compositions for that year, and
b) to refit the curve from the mathematical form of the equation in COPERT to the specific mathematical forms of the equations used in the NTM and WebTAG.

The approach involved first calculating emission factors for all the detailed vehicle types from the COPERT equations at 1 kph speed intervals within the valid speed ranges specified in COPERT. The COPERT factors must not be used outside their valid speed range, particularly at the lower end of the range where the curve can be very steep and where emission factors from the COPERT equations can become negative values. The speed range set by COPERT is largely a reflection of the range of average speeds where measurements were taken.

Depending on the pollutant some further, usually minor, year-specific adjustment is made to account for other detailed features included in the NAEI and the overall COPERT model approach. This includes accounting for the effect of fuel quality on emissions and degradation of emissions with accumulated mileage. Further details of these are provided in the following sections and in NAEI reports referred to previously.

In the case of HGV and bus and coach emission factors, COPERT provides separate emission curves for different vehicle loadings and road gradients. Emission coefficients for a vehicle at 50% load and 0% road gradient were used in all cases, consistent with the assumption used in the NAEI and considered to be valid, on average, for the UK situation.

The emission factors at each 1 kph speed interval calculated for each sub-class of vehicle are then weighted according to the fleet composition for the specified year. This gives a single fleet-weighted value for each main vehicle type for the specified year at 1 kph intervals which are then fitted to the NTM or WebTAG form of mathematical equation using the non-linear least squares fitting function in the R statistical software package, a free software programming language and environment for statistical programming and graphics.[1] This software was used in the fitting required to develop the previous set of emission curves in 2013/14 and further details of the fitting process were provided in the accompanying report (Ricardo-AEA, 2014). The curve fitting generally produced very good results minimising the differences over the entire speed range with the COPERT-derived values. An indication of the quality of the fits is provided in Section 6.

Note that all the PM mass emitted from vehicle engines from the combustion of fuel is in the 2.5 micron range. Therefore, the PM exhaust emission factors in COPERT refer to both mass of PM_{10} and $PM_{2.5}$ emissions, i.e. in mass terms, $PM = PM_{10} = PM_{2.5}$. This is also confirmed in the EMEP/EEA Emissions Inventory Guidebook and is typical of most PM emissions emitted from combustion of gaseous and highly refined petroleum fuels. The PM mass emissions cover both filterable and condensable particulate matter.

[1] http://www.r-project.org

3 Updated Curves for CO_2 Emissions and Fuel Consumption for Use in WebTAG

WebTAG required curves for fuel consumption and CO_2 for years 2010 and 2015 fitted in the form of a third-order polynomial:

$$EF = (a + bv + cv^2 + dv^3) / v$$

where EF is the emission factor in g/km or fuel consumption factor in litre/100km, v is average speed in kph and a-d are coefficients.

Curves were required for the following vehicle types:

1. Petrol Cars;
2. Diesel Cars,
3. Petrol Vans;
4. Diesel Vans,
5. OGV1;
6. OGV2;[2]
7. All PSV's (buses & coaches) combined

3.1 Fuel consumption equations in COPERT

COPERT does not now directly provide curves for fuel consumption or CO_2 emissions, but curves of energy consumption factors in MJ/km versus average speed. Energy consumption can be converted to fuel consumption in mass terms using the net calorific values of petrol and diesel. For consistency with the EMEP/EEA Emissions Inventory Guidebook (EMEP, 2016) for road transport, in Table 3-28, values of 43.774 MJ/kg for petrol and 42.695 MJ/kg for diesel were used.

To further convert the fuel consumption into litres/100km, the mass densities of petrol and diesel sold in the UK were used according to the UK Digest of Energy Statistics (DUKES, 2017). This provides average values of 1368 litre/tonne for petrol (all grades) and 1194 litre/tonne for diesel.

These simple conversion factors allowed the COPERT curves for energy consumption to be converted into curves for fuel consumption in litre/100 km for each vehicle type.

3.2 Fuel consumption factors for passenger cars

A particularly important consideration was necessary in the use of the COPERT curves for passenger cars. For each pollutant, COPERT differentiates vehicles in different age groups by their manufacturers' specified Euro emission standard which are introduced in stages. This is logical for air pollutants where these standards tend to introduce step-change reduction in emissions, but not for fuel consumption or CO_2 emissions where factors are not defined by the vehicle's Euro standard but do change incrementally with each new year of registration as vehicles become more fuel efficient. For passenger cars, COPERT uses an approach described in the EMEP/EEA Emissions Inventory Guidebook (2016) to deal with this, based on applying country-specific correction factors to the emission curves for Euro 4 passenger cars first introduced in 2005. It is assumed that the shape of the Euro 4 curve for each of the engine size categories for petrol cars and diesel cars in COPERT 5 remains constant but is scaled up or down each year according to the relative change in the average mass and manufacturers' reported CO_2 emissions from cars sold in the country each year. Although the COPERT emission curves for Euro 4 cars themselves are based on laboratory measurements of CO_2 emissions and fuel consumption over different real-world test cycles, a further empirically-based, real-world correction factor is applied to account for the fact that the manufacturers' reported CO_2 emissions are based only on the EU NEDC test cycle. The 'real-world' correction factors are derived from equations in the EMEP/EEA Guidebook

[2] OGV1 includes Rigid HGV's up to 26 tonnes GVW. OGV2 is Rigids >26 tonnes GVW plus Artic HGV's

which relate in-use fuel consumption to the manufacturers' reported value, average engine capacity and vehicle mass:

Petrol cars:

$FC_{In\ use}$(l/100km) = 1.15 + 0.000392 x CC + 0.00119 x m + 0.643 x FC_{TA}

Diesel cars:

$FC_{In\ use}$(l/100km) = 0.133 + 0.000253 x CC + 0.00145 x m + 0.654 x FC_{TA}

where FC_{TA} stands for type-approval fuel consumption (in l/100km), m stands for the vehicle reference mass (empty weight + 75 kg for driver and 20 kg for fuel), and CC stands for the engine capacity in cm^3. Compared to the type-approval fuel consumption the Common Artemis Driving Cycle (CADC) leads to 25% higher fuel consumption values.

The approach therefore takes account of:

a) How the CO_2 emissions of the pool of passenger cars sold each year in a country differs from the Euro 4 cars that were originally tested leading to the COPERT emission curves for fuel consumption and CO_2 emissions in each of the different engine capacity bands
b) How the CO_2 emissions according to manufacturers' data for new cars sold in a country have changed each year within specified engine capacity bands, taking into account the average engine capacity and vehicle mass of new cars sold within each size band

Correction factors are derived this way for passenger cars in the following engine capacity bands used in COPERT:

	Engine capacity (cc)
Petrol cars	<0.8
	0.8-1.4
	1.4-2.0
	>2.0
Diesel cars	<1.4
	1.4-2.0
	>2.0

The EMEP/EEA Guidebook provides the COPERT sample mean fuel consumption of the vehicle sample used in developing COPERT emission factors over the three CADC parts (Urban, Road and Motorway).

The NAEI has used data provided by the Society of Motor Manufacturers and Traders (SMMT, 2017) for each year from 2005 up to 2016 on sales-weighted values for the average engine capacity, vehicle mass and manufacturers' reported CO_2 emissions of petrol and diesel passenger cars in each of these engine capacity bands from which the correction factors were derived and applied to the Euro 4 emission curves in COPERT. It is then necessary to account for the fleet proportions (according to distances travelled) of new cars registered each year since 2005 in the model years (in this case 2010 and 2015) to derive an overall, fleet-weighted correction factor which is applied to the COPERT curves for Euro 4 cars.

The overall, fleet-averaged correction factors for 2010 and 2015 are shown in Table 1. These are scaling factors that are only applied to the COPERT curves for Euro 4 cars. The small reduction in scaling factors from 2010 to 2015 is an illustration of how fuel consumption and CO_2 emissions have slightly decreased for cars registered since 2005.

Table 1: Correction factors to apply to COPERT curves for Euro 4 passenger cars in 2010 and 2015 derived from equations in the EMEP/EEA Guidebook and based on new car sales weighted values for the average engine capacity, vehicle mass and manufacturers' reported CO_2 emissions of petrol and diesel passenger cars provided by SMMT

		2010	2015
Petrol cars	<0.8	0.918	0.915
	0.8-1.4	0.854	0.808
	1.4-2.0	0.930	0.896
	>2.0	1.157	1.153
Diesel cars	<1.4	1.146	1.107
	1.4-2.0	1.009	0.938
	>2.0	1.076	0.993

These correction factors were used to scale the COPERT curves for Euro 4 passenger cars to derive an overall fleet-weighted curve representative of the entire fleet of post-2005 passenger cars of nominal Euro 4-6 standard in these years. The final fuel consumption and emission curves for all passenger cars in the fleet in 2010 and 2015, i.e. including pre-Euro 4 cars remaining in the fleet, were then derived by accounting for the COPERT curves for pre-Euro 1 to Euro 3 cars and their fleet proportions in the fleet in 2005 and 2010 as well as corrected curves for post-Euro 4 cars. The fuel consumption curves for pre-Euro 1-3 passenger cars are taken directly from COPERT 5 and EMEP/EEA Emissions Inventory Guidebook.

3.3 Fuel consumption factors for LGVs, HGVs and buses

For petrol and diesel LGVs, HGVs and buses and coaches, COPERT and the EMEP/EEA Emissions Inventory Guidebook provide factors for all the normal Euro emission categories up to Euro 6/VI and do not provide a method for correcting fuel consumption and CO_2 emissions analogous to the approach possible for passenger cars. For these vehicle types, fuel consumption and emission curves were therefore developed using the same approach as used for air pollutants described in Section 5. This implies small step-wise changes in fuel consumption/CO_2 emission introduced by each successive Euro standard rather than a gradual change with new year of registration.

The previous fuel consumption and CO_2 emission curves provided for WebTAG and the NTM in 2013/14 were normalised to fuel efficiency data for HGVs available from DfT's Continuous Survey of Road Goods Transport (CSRGT). Similarly, the curves for buses were normalised for consistency with consumption data made available through the Bus Service Operators Grant system (BSOG). However, these data are either no longer available or have limitations in their validity and/or completeness. For example, the BSOG system no longer covers buses in Wales, Scotland and London and in the rest of England has only covered buses on certain commercial services since 2014. This means BSOG data for different years are not available on a consistent basis. For these reasons, no further normalisation of the COPERT-based curves for HGVs and buses to these data was possible and the factors are now only based on the COPERT 5 curves for different sizes of HGVs, buses and coaches and relevant fleet composition data.

3.3.1 Curves for OGV1 and OGV2

COPERT provides emission factor curves for 8 different weight classes of rigid HGVs from <7.5 t GVW to >32 t GVW and 6 different weight classes of artic HGVs from the 14-20 t GVW range to the 50-60 t GVW range.

WebTAG requires emission curves for two classes of HGVs: the OGV1 category refers to rigid HGVs < 26 GVW and OGV2 refers to rigid and articulated HGVs > 26 GVW. To develop fleet-weighted curves for OGV1 it was necessary to weight the COPERT curves for rigid HGVs according to the composition of the rigid HGV fleet <26 t GVW. To develop fleet-weighted curves for OGV2 it was necessary to weight the COPERT curves for rigid HGVs >26 t GVW and all artic HGVs.

The fleet weightings were based on the fleet compositions for rigid and artic HGVs by weight class according to DfT road freight statistics and the relative distribution of rigid and artic HGVs on roads. The weightings used for the fleets in 2010 and 2015 are shown in Table 2

Table 2 Composition of rigid and artic HGV vehicles of different weights within the OGV1 and OGV2 classes of HGV vehicles

		2010	2015
OGV1	Rigid HGV 3.5-7.5 t	48.2%	44.8%
	Rigid HGV 7.5-12 t	8.8%	7.3%
	Rigid HGV 12-14 t	3.5%	2.9%
	Rigid HGV 14-20 t	16.7%	17.9%
	Rigid HGV 20-26 t	22.9%	27.1%
		100.0%	**100.0%**
OGV2	Rigid HGV 26-28 t	6.8%	6.7%
	Rigid HGV 28-32 t	13.6%	13.4%
	Rigid HGV >32 t	3.4%	3.3%
	Artic HGV 14-20 t	1.7%	1.5%
	Artic HGV 20-28 t	2.3%	2.0%
	Artic HGV 28-34 t	1.7%	1.5%
	Artic HGV 34-40 t	13.5%	9.4%
	Artic HGV 40-50 t	57.0%	62.3%
		100.0%	**100.0%**

The weighted curves for OGV1 and OGV2 were then refitted to the WebTAG third-order polynomial.

3.3.2 Curves for buses & coaches

COPERT provides speed emission and fuel consumption curves for three weight classes of urban buses and two weight classes of coaches. Initially, DfT requested for WebTAG emission curves for PSVs as a combination of buses and coaches over the speed range weighted by the split between these two vehicle types on GB roads. This was not possible because the maximum of the valid speed range of the curves for urban buses is less than that for coaches: 85 kph for buses compared with 100 kph for coaches. By weighting the curves for buses and coaches according to the fleet split between these two vehicle categories leads to a situation where there is a step-change in the emission curve at 85 kph, because above this speed the curve is only a reflection of coach emissions whereas below this speed the curve is a reflection of both urban buses and coaches.

For this reason, separate speed curves have been provided for urban buses and coaches each weighted by their relevant fleet compositions. A weighted curve for PSVs is provided, but only valid up to maximum of the speed range for urban buses. Outside of London, the split between buses and coaches used in the generation of curves for PSVs for non-motorway roads is unchanged from that previously assumed in the 2013/14 curves, namely 72% urban bus/28% coach. This was estimated from unpublished information on a split in vehicle km by local bus and other bus services.

3.4 Emission curves for London

Emission curves for the fleet in London were developed in the same way as for the rest of the UK, but using the very specific fleet composition data provided by TfL for central, inner and outer London. The Central London area is the area covered by the ULEZ scheme. The fleets tend to be newer in central London and become progressively older, i.e. with a higher proportion of lower Euro standards, in inner and then outer London. The London fleet is also generally older than the national fleet outside of London leading to generally higher emission factors for London than the national average. This is apart from the ULEZ where in the early 2020s, the fleet is newer. But even here the differences with the national fleet are eventually reduced by 2025 when the age composition of the national fleet has virtually caught up with the fleet in the ULEZ through natural vehicle turnover.

TfL was unable to provide separate information on the distribution of HGVs by different weight classes in each part of London, but was able to provide the distribution within the rigid group and artic group for London as a whole and was able to provide different figures on the share of rigid and artic vehicle km in each part of London. In the absence of further information, the distribution of weight classes within each of the rigid and artic HGV fleets is assumed to be the same in each part of London and this was used in conjunction with different rigid/artic splits to develop separate curves for OGV1 and OGV2 for each part of London. The rigid/artic split from information provided by TfL is as follows in Table 3:

Table 3. Share of HGV km in each part of London according to TfL

	Central	Inner	Outer
Rigid	91%	87%	72%
Artic	9%	13%	28%

For urban buses, the very detailed fleet data provided for TfL operated buses were used separate from fleet data for coaches in London not operated by TfL. To provide curves for PSVs in London (for non-motorway roads), the TfL bus/coach split was 80%/20% on all parts of London.

DfT requested emission curves for the central ULEZ and inner parts of London combined and for London as a whole. This was done by weighting the coefficients for the emission curves generated for each of the central, inner and outer parts of London according to the share in vehicle kilometres travelled by each vehicle type in each part of London using data provided by TfL for 2010 and 2015.

3.5 CO_2 emission curves

Ultimate emissions of CO_2 are directly proportional to the amount of fuel consumed. Therefore, emission curves for CO_2 can be derived directly from the curves developed for fuel consumption by a simple factor that accounts for the mass carbon content of petrol and diesel. Such emission curves refer to 'ultimate CO_2' and are defined on the basis that virtually all the carbon present in the fuel consumed will ultimately form CO_2 in the atmosphere even though a small amount will be emitted in less oxidised forms such as carbon monoxide and unburnt hydrocarbons.

The fuel carbon contents used in the UK's Greenhouse Gas Inventory were provided by personal communication with the UK Petroleum Industry Association and remain constant in all years at 85.5% for petrol and 86.3% for diesel (UKPIA, 2004). These figures refer to the percentage carbon content by mass, thus 100 g diesel comprises 86.3 g carbon and leads to 316 g CO_2 emissions. The carbon contents here refer to fossil fuel petrol and diesel.

These values were used to convert the fuel consumption curves to CO_2 emission curves in gCO_2/km after first converting the units of fuel consumption from litre/100km to grammes fuel/km using the fuel mass density figures from DUKES (2017) given in Section 3.1.

4 Updated Curves for CO_2 Emissions and Fuel Consumption for Use in the NTM

The NTM required curves for fuel consumption and CO_2 emission for years 2010 and 2015 and in 5 year intervals projected to 2035 fitted in the form of a sixth-order polynomial:

$$y = (a + bv + cv^2 + dv^3 + ev^4 + fv^5 + gv^6) / v$$

where EF is the emission factor in g/km or fuel consumption factor in litre/100km, v is average speed in kph and a-g are coefficients.

Curves were required for the following vehicle types:

1. Petrol Cars;
2. Diesel Cars;
3. Petrol Vans;
4. Diesel Vans;
5. Rigid HGVs;
6. Articulated HGVs;
7. All HGVs (combining rigid and artic);
8. PSVs;
9. Coaches; and
10. Buses.

Fuel consumption and CO_2 emissions were derived for the NTM following exactly the same procedures as for WebTAG, the main difference being the fitting to the 6^{th}-order polynomial using the R statistical software instead of the 3^{rd}-order polynomial derived for WebTAG.

In the case of the NTM, it was not necessary to derive HGV curves in the OGV1 and OGV2 categories, but in the rigid and artic categories which matched the categorisation in COPERT. However, additional curves were developed for all HGVs which was a weighting of the rigid and artic curves according to the split in total UK vehicle kilometres for rigid and artic HGVs. This split used the historical and future vehicle km projections consistent with the NAEI emission projections. The splits for each year to 2035 are shown in Table 4

Table 4: Split in rigid and artic HGV km used to derive emission curves for 'all HGVs' in the NTM

	2010	2015	2020	2025	2030	2035
Rigid	50%	47%	47%	46%	45%	44%
Artic	50%	53%	53%	54%	55%	56%

The rigid/artic split of HGV km in London for future years was maintained at the levels shown in Table 3.

4.1 Projections in CO_2 emissions and fuel consumption for conventional fuels

The curves provided to the NTM for future years refer to conventional petrol and diesel fuels. In deriving the emission curves for future years, for all vehicle types, no further reduction in fuel consumption and CO_2 emission factors were assumed beyond that specified for the Euro 6/VI standards in COPERT 5. This meant that only modest reductions in the overall fleet-weighted emission curves are achieved out to 2035 as Euro 6/VI vehicles increasingly penetrate the fleet and older vehicles expire.

In the case of passenger cars, a set of correction factors for the 2016 fleet of Euro 4-6 petrol and diesel cars was developed from SMMT data showing a small reduction from the factors for 2015 in Table 1, but no further reductions were assumed to occur out to 2035, i.e the correction factors applied to the

COPERT Euro 4 curves were assumed to remain at the 2016 levels. In reality, fleet-averaged fuel consumption and CO_2 emissions in the car fleets as a whole are expected to decrease more significantly, but this may be largely achieved through penetration of ULEVs in the car fleet (hybrids and battery electric vehicles) and it has to be remembered that the curves provided here are solely for conventional petrol and diesel cars. The NTM may choose to use curves derived specifically for these non-conventional types of vehicles in combination with their fleet penetration to account for this. Curves for ULEV cars were provided separately to DfT in 2015 (Ricardo-AEA, 2015) and are currently being reviewed as a separate part of this project.

Fuel consumption and CO_2 emissions for the future fleet of conventional cars will also be influenced by shifts in the engine size distribution of new car sales. No such information was available for this work and the curves developed for the NTM are based on the assumption that the mix of cars in different engine size bands remains at current levels. However, the spreadsheet of NTM curves provided to DfT has the capability to change the mix between small, medium and large cars in the fleet so that DfT can see how this affects the overall fleet-averaged emission curves in future years if this information does become available or for carrying out sensitivity tests. By providing separate curves for petrol and diesel curves, combined with current fleet projections of the mix of petrol and diesel car activities in future years from the NAEI's fleet projections, also gives DfT scope for modelling the effect of changing these fuel-split assumptions.

The future emission curves for London are based on TfL's fleet projections. This includes the uptake of hybrid buses and hydrogen fuel cell buses in central, inner and outer London. The ULEV buses were included in the projections for London because these are policies committed by the London Mayor and were provided with TfL's own assumptions on the impacts these vehicles have on fuel consumption and emissions relative to conventional fuelled buses.

As for WebTAG, curves were provided for central ULEZ, inner and outer London and for central/inner London combined and for London as a whole. This was done by weighting the coefficients for the emission curves generated for each of the central, inner and outer parts of London according to the share in vehicle kilometres travelled by each vehicle type in each part of London according to data provided by TfL for 2010 and 2015 and each year out to 2035.

4.2 Further consideration in future consumption and CO_2 emissions for alternative fuels

As stated above, the curves provided to the NTM for future years refer to conventional petrol and diesel fuels, reflecting the type of fuels used during the vehicle emission test procedures that sourced the emission factors in COPERT and EMEP/EEA Emissions Inventory Guidebook. They are therefore a reflection of the energy and carbon content of contemporary, mainly fossil-based feedstocks for petrol and diesel fuels. These are not likely to change in the future, but DfT may need to consider how these would relate to alternative fuels of the future, particularly biofuels from renewable feedstocks. These can have quite different energy and carbon contents and therefore the mass quantity of fuel consumed and CO_2 emitted per kilometre would be different to the amounts derived from the curves provided here for the NTM.

In essence, the fuel consumption calculated from the curves provided for the NTM are related to the total energy required to propel the vehicles. This can be converted to the fuel consumption rate of a different fuel using simple conversion factors based on the mass fuel densities and energy contents of the alternative fuel relative to petrol or diesel.

For conventional petrol and diesel fuels, the energy content expressed as the net calorific value (in Gigajoules/tonne) and mass densities were given in Section 3.1, but are summarised again in Table 5. The calorific values are taken from the EMEP/EEA Guidebook for internal consistency with the fuel consumption factors used from this and COPERT source.

Table 5 Mass density and net calorific values of conventional petrol and diesel

	Mass density (litre/tonne)	Net calorific value (GJ/tonne)
Petrol	1368	43.774
Diesel	1194	42.695

Mass densities and calorific values for other fuels, including biofuels, are available in the BEIS 2018 GHG Conversion Factors for Company Reporting, available at https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018 . The 'Fuel Properties' tab of the Excel spreadsheet that can be download from this site provides the conversion factors for different types of biofuels. The Conversion factors are reviewed and updated annually by BEIS.

Using these conversion factors would allow DfT to estimate consumption of different types of biofuels, separately from fossil fuels for different biofuel scenarios. Section 11.2 of this report explains how for reporting greenhouse gas emissions under the UN Framework Convention on Climate Change (UNFCCC), the NAEI must separate out CO_2 emissions from fossil fuel and biofuel consumption, with only the fossil fuel carbon emissions being included in national totals. DfT may or may not want to follow this convention, and/or consider whether to include lifecycle emissions. Lifecycle emission factors for different biofuels are given in the report accompanying the BEIS GHG conversion factors and are based on figures taken from reports on DfT's Renewable Transport Fuel Obligation (RTFO)[3]. For an individual type of biofuel, the carbon emissions at point of consumption are not likely to change in future, but the mix of biofuels may change and the corresponding lifecycle emission factors may also change. It is advisable to consider with the RTFO the scope for including carbon emissions from biofuel consumption in the NTM and whether factors may change in future.

[3] https://www.gov.uk/government/collections/biofuels-statistics

5 Updated Curves for NO_x and PM Emissions for Use in the NTM

The NTM required curves for NO_x and PM exhaust emission for years 2010, 2015 and in 5 year intervals projected to 2035 fitted in the form of a sixth-order polynomial:

$$y = (a + bv + cv^2 + dv^3 + ev^4 + fv^5 + gv^6) / v$$

where EF is the emission factor in g/km, v is average speed in kph and a-g are coefficients. Emission curves were required for the same vehicle categories as for CO_2 described in Section 4. These were developed following the same procedures as for CO_2, using the COPERT 5 emission factors for vehicles up to Euro 6b-d/VI standards and the same fleet projections for vehicles in the UK and London. However, some additional features had to be taken into account relating to other factors that influence the emissions of these pollutants.

Unlike for fuel consumption and CO_2 emissions, significant changes occur in the COPERT emission factors across the range of Euro standards. The changes in factors across the Euro standards for cars as defined in COPERT up to Euro 6 are currently sufficient to define the changes in the fleet-averaged emission curves over time and a further correction using information from SMMT is not applied.

5.1 Accounting for effects of emission degradation, fuel quality and exhaust abatement technologies

There are other factors that need to be taken into account when estimating NO_x and PM emissions from road transport that are not fully captured in the COPERT emission curves alone. These are:

- The effect of emission degradation - how emission factors change as the vehicle's accumulated mileage increases
- The effect of fuel quality – where changes have occurred since emission factors were first measured
- The effect of retrofit technology – where a particular abatement technology is retrofitted to reduce emissions from a vehicle of an older Euro standard.

5.1.1 Emission degradation

Following the method in COPERT and EMEP/EEA Emissions Inventory Guidebook, the NAEI takes account of the fact that emission factors are not always constant but can increase with accumulated mileage. The COPERT speed-emission curves for NO_x are meant to be used with a factor that accounts for this degradation effect. Degradation factors are given in the Guidebook for NO_x emissions from petrol cars and LGVs for different Euro standards, engine sizes and speed ranges. In general, the degradation rates are slower for more recent Euro standards due to more stringent durability requirements set in the emission legislation. There are no degradation factors for PM.

Based on accumulated mileage data for petrol cars provided by TRL and used in the previous emission curves developed for the NTM, degradation factors for NO_x were calculated in the NAEI and used as emission scaling factors for petrol cars and LGVs, for each Euro standard, speed and year in the model used to develop the emission curves for the NTM. There are no scaling factors applied to emissions from diesel vehicles.

Note that the spreadsheet with COPERT factors for NO_x provided on the NAEI website includes the equations used to calculate degradation factors.

5.1.2 Fuel quality

Following the method in COPERT and EMEP/EEA Emissions Inventory Guidebook, the NAEI takes account of the fact that emission factors can be affected by changes in the composition of petrol and diesel fuels since the emission factors were first measured. This mainly affects the emission factors for the early Euro standards (Euro 1, 2) measured in the 1990s since when changes in fuel composition have occurred to meet more stringent requirements of the EU Fuel Quality Directive. The main impact of this Directive was to significantly reduce the sulphur content of fuels which can affect NO_x and PM emissions, partly due to the effect sulphur has on the efficiencies of exhaust aftertreatment systems. However, other fuel properties have also changed which can affect emissions.

Since the early 2000s, commercial petrol and diesel fuels have been blended with small amounts of biofuels (bioethanol and biodiesel). Although typically at blend strengths no higher than 10%, this can also affect emissions, particularly on PM exhaust emissions. Based on a review of the literature undertaken by Murrells and Li (2008), PM emissions from petrol vehicles can be reduced by up to 40% for E10 (10% bioethanol) compared with fossil fuel petrol (E0), though it should be noted that PM exhaust emissions are low anyway for petrol engines compared with diesel engines. The effect of biodiesel on emissions from diesel vehicles is lower (<10% reduction) compared with conventional fossil fuel diesel.[4] . The effects on NO_x are much smaller. The effects of fuel quality are also smaller (or zero) on the more recent Euro standards (Euro 4 onwards) than on the earlier Euro standards.

The NAEI takes into account the changes in fuel quality and the uptake of biofuels and the effect they have on emissions. This is done through a set of scaling factors that are applied to the emission factors calculated from the COPERT emission curves. Further details are provided in the NAEI reports, such as Brown et al (2018) and Murrells and Li (2008). These scaling factors were also used in the development of the NTM emission curves for both NO_x and PM and for all vehicle types. The scaling factors are provided on the various vehicle tabs in the spreadsheets that provide the NTM emission curves for NO_x and PM.

5.1.3 Exhaust aftertreatment technologies and retrofits

Certain vehicles were fitted with devices to reduce exhaust emissions when manufactured or retrofitted whilst in service.

In the case of diesel cars, some Euro 3 and 4 models were fitted with diesel particulate filters (DPFs) which reduces PM emissions relative to those vehicles not equipped with these technologies. In the case of HGVs and buses, some Euro V vehicles would use Selective Catalytic Reduction to control NO_x emissions while other manufacturers use Exhaust Gas Recirculation (EGR). COPERT provides separate emission curves for each of these technologies and the NAEI fleet compositions provide the relevant fleet information to account for these effects in the NTM curves.

The fleet composition data provided by TfL for London is more complex and takes into account some diesel LGVs, HGVs and non-TfL buses retrofitted with DPFs. TfL's own fleet of buses is particularly complex with significant proportions being of notionally older Euro standards, but retrofitted with SCR and DPF systems, while some have hybrid or hydrogen fuel cell powertrains. TfL provided NO_x and PM emission reduction factors for each of the technologies relative to their conventional counterparts of the same Euro standard. The hybrid and fuel cell buses were included in the emission curves for London because their uptake was included in policies committed by the London Mayor and were based on TfL's own assumptions on the impacts these vehicles have on emissions relative to conventional fuelled buses.

The fleet compositions and emission reduction factors were taken into account in the development of the NTM emission curves for London and the rest of the UK. Particularly from 2020 onwards, the fleet in central London (ULEZ) has a higher proportion of these technologies and hence lower overall emission factors than in other parts of London.

[4] It should be noted that these biofuel effects on PM emissions from petrol engines have been revised recently by the NAEI following a review of more recent literature. However, these revised scaling factors have not been used in this work in order to provide emission curves that are consistent with the emission modelling done for Defra's Air Quality Plans and in the current release of the Defra Emission Factor Toolkit (EFT v8)

6 Errors Introduced by Fitting Procedure

The refitting process using the R statistical software was necessary because WebTAG and the NTM required the speed-emission curves in a polynomial equation that differs from the formula used in COPERT 5. This can introduce some differences in the emission factors calculated from the refitted equation compared with the original COPERT equation. The errors may be expected to be higher for WebTAG than for the NTM curves because WebTAG uses a lower order polynomial equation. These differences were assessed for both WebTAG and the NTM and demonstrated in the Excel spreadsheets provided to DfT with the emission curves.

6.1 Fitting for WebTAG

The errors associated with limiting the WebTAG fuel consumption and CO_2 curves to a four coefficient, 3rd-order polynomial equation can be assessed by comparing the speed dependent emission factors calculated with WebTAG equations with the emission factors calculated from the COPERT equations.

Table 6 presents an analysis of the maximum absolute percentage difference errors between fuel consumption factors calculated with the WebTAG 3rd-order equations and the COPERT equations. Percentage error is defined as:

$$\%error = (EF_3 - EF_{COPERT})/EF_{COPERT}$$

where EF_3 and EF_{COPERT} are the fuel consumption factors calculated using the 3rd-order and COPERT speed-consumption factor equations, respectively. The table shows that the absolute values of percentage errors are small and are not more than 7% over the valid speed range. The largest errors are for petrol cars at the lowest speed within the valid range (5-10 kph) and for diesel cars at the highest speed within the valid range (130 kph). The maximum percentage error in the WebTAG factors calculated for vehicles other than cars is less than 1%.

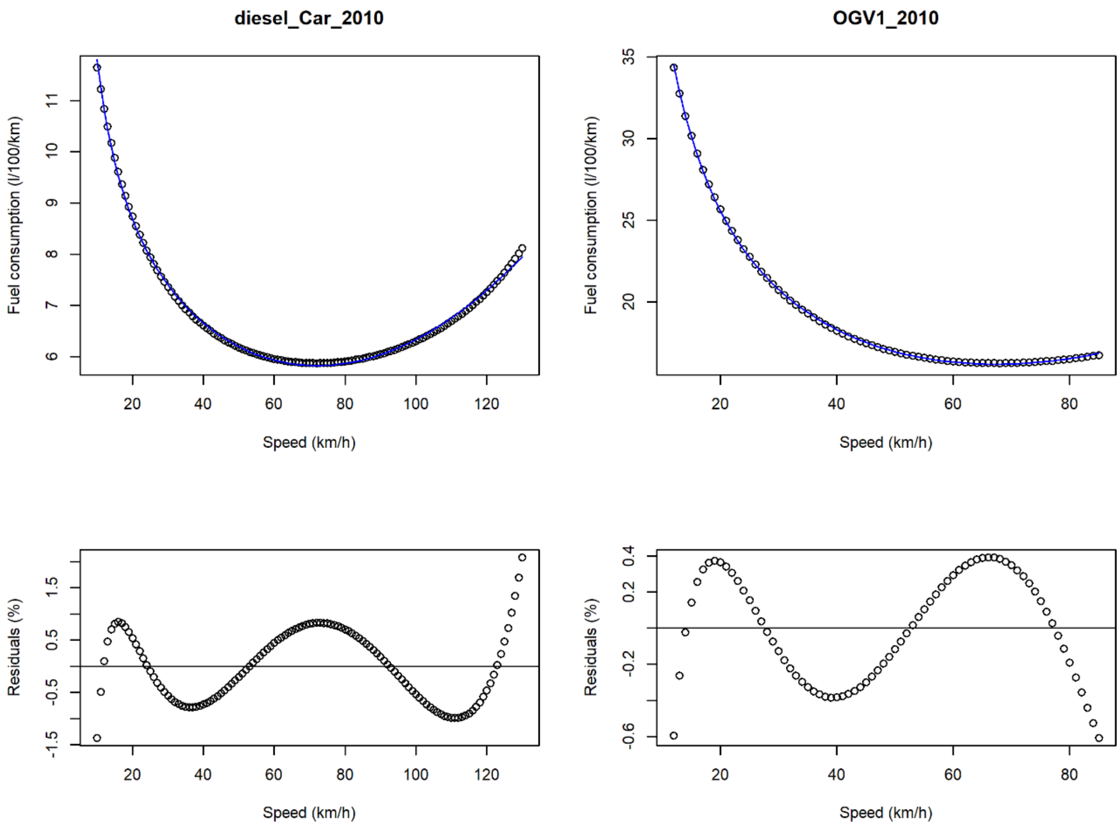
Table 6: Maximum absolute percentage difference in factors calculated with the WebTAG 3rd-order equations and the COPERT equations

Vehicle category	Year	Max % difference
Petrol Car	2010	2.8
	2015	7.2
Diesel Car	2010	2.1
	2015	2.3
Petrol LGV	2010	5.5×10^{-7}
	2015	0.28
Diesel LGV	2010	7.2×10^{-7}
	2015	0.56
OGV1	2010	0.61
	2015	0.48
OGV2	2010	0.71
	2015	0.70
Bus	2010	0.79
	2015	0.71
Coach	2010	0.49

	2015	0.61
PSV	2010	0.62
	2015	0.59

Figure 1 shows that the speed dependent percentage errors take an oscillating shape as a consequence of the changes in the functional form of the curve in the fitting process. The oscillations are a feature of the fit and have no physical meaning, the magnitude of the percentage errors however provide guidance on the quality of the fit. The largest errors tend to be seen at the lowest and highest speeds for which the emission curves are valid. For example, the maximum percentage error of the WebTAG speed-fuel consumption curve for diesel cars is no more than 1% at most speeds. Greater errors are only seen at speeds below 11 kph and above 126 kph

Figure 1*: Example plots of fit and residual as percentage errors between emission factors calculated using 3rd-order WEBTAG polynomial equations and aggregated COPERT speed-emission curves. Plots are shown for diesel cars in 2010 and OGV1 HGVs in 2010.*



6.2 Fitting for the NTM

In a similar manner, the errors associated with fitting the NTM curves to a seven coefficient, 6^{th}-order polynomial equation can be assessed by comparing the speed dependent emission factors calculated with NTM equations with the emission factors calculated from the COPERT equations.

Table 7 - Table 9 present an analysis of the maximum absolute percentage difference errors between factors for fuel consumption, NO_x and PM for each vehicle type and year calculated within the allowed speed range of the NTM 6^{th}-order equations and the COPERT equations.

The maximum percentage errors are typically less than 0.5% for all vehicle types when used within the COPERT speed range, indicating that the 6^{th}-order polynomial equations capture the shape of the speed-emission factor curves very well and are a valid representation of the true speed emission factor curves. In many cases, the error is significantly less than 0.5% at all speeds.

The largest errors are typically at the lowest or highest end of the speed range. The largest errors were up to 11% for NO_x emissions from coaches in 2035 at the upper end of the allowed speed range (100 kph) where NO_x emissions are lowest for this vehicle type. Apart from buses and coaches in 2025 to 2035 the absolute percentage errors in NO_x emission factors for all vehicle types and speeds were less than 1%. The maximum absolute percentage error in fuel consumption (and hence CO_2) emission factors is less than 1% for all vehicle types, and no more than 1.5% for PM emission factors for all vehicle types.

The percentage error at each speed is a measure of the fit quality when fitting the 6^{th}-order polynomial equation to curves derived from the weighted COPERT equations. As such, the errors presented depend on the form of contributing COPERT equations and how closely they can be approximated by a 6^{th}-order polynomial equation.

Table 7: Maximum absolute percentage difference in fuel consumption factors calculated with the NTM 6^{th}-order equations and the COPERT equations

Vehicle category	Year	Max % difference
Petrol Car	2010	0.25
	2015	0.58
	2020	0.51
	2025	0.50
	2030	0.50
	2035	0.50
Diesel Car	2010	0.28
	2015	0.29
	2020	0.29
	2025	0.29
	2030	0.29
	2035	0.29
Petrol LGV	2010	$4.6x10^{-7}$
	2015	0.0085
	2020	0.027
	2025	0.036
	2030	0.036
	2035	0.11
Diesel LGV	2010	$4.4x10^{-7}$
	2015	0.074
	2020	0.12
	2025	0.13
	2030	0.13

	2035	0.70
HGV	2010	0.031
	2015	0.071
	2020	0.085
	2025	0.088
	2030	0.088
	2035	0.088
Rigid HGV	2010	0.018
	2015	0.062
	2020	0.086
	2025	0.092
	2030	0.093
	2035	0.093
Artic HGV	2010	0.041
	2015	0.077
	2020	0.084
	2025	0.085
	2030	0.085
	2035	0.085
Bus	2010	0.054
	2015	0.13
	2020	0.16
	2025	0.16
	2030	0.16
	2035	0.15
Coach	2010	0.082
	2015	0.12
	2020	0.12
	2025	0.11
	2030	0.10
	2035	0.10

Table 8: Maximum absolute percentage difference in NO_x emission factors calculated with the NTM 6^th^-order equations and the COPERT equations

Vehicle category	Year	Max % difference
Petrol Car	2010	0.36
	2015	0.49
	2020	0.19
	2025	0.053
	2030	0.06
	2035	0.06
Diesel Car	2010	0.25
	2015	0.14
	2020	0.074
	2025	0.0768
	2030	0.16
	2035	0.16
Petrol LGV	2010	0.26
	2015	0.23
	2020	0.37
	2025	0.037
	2030	0.039
	2035	0.038
Diesel LGV	2010	4.9×10^{-7}
	2015	0.18
	2020	0.23
	2025	0.25
	2030	0.25
	2035	0.25
HGV	2010	0.087
	2015	0.14
	2020	0.045
	2025	0.30
	2030	0.51

	2035	0.54
Rigid HGV	2010	0.070
	2015	0.12
	2020	0.073
	2025	0.26
	2030	0.63
	2035	0.70
Artic HGV	2010	0.10
	2015	0.16
	2020	0.035
	2025	0.34
	2030	0.43
	2035	0.43
Bus	2010	0.052
	2015	0.049
	2020	0.18
	2025	0.96
	2030	2.85
	2035	4.4
Coach	2010	0.021
	2015	0.022
	2020	0.42
	2025	2.4
	2030	7.6[a]
	2035	11.0[b]

[a] largest % differences are at high end of speed range (97-100 kph) where the NOx EFs are smallest. Below these speeds the % difference is <3%.
[b] largest % differences are at high end of speed range (97-100 kph) where the NOx EFs are smallest. Below these speeds the % difference is <5%.

Table 9: Maximum absolute percentage difference in PM emission factors calculated with the NTM 6th-order equations and the COPERT equations

Vehicle category	Year	Max % difference
Petrol Car	2010	0.20
	2015	1.4
	2020	0.71

	2025	0.19
	2030	0.15
	2035	0.16
Diesel Car	2010	1.0×10^{-3}
	2015	0.019
	2020	0.07
	2025	0.21
	2030	0.29
	2035	0.3
Petrol LGV	2010	6.1×10^{-7}
	2015	0.025
	2020	0.21
	2025	0.27
	2030	0.27
	2035	0.27
Diesel LGV	2010	1.9×10^{-6}
	2015	1.1×10^{-3}
	2020	0.0060
	2025	0.015
	2030	0.019
	2035	0.019
HGV	2010	0.041
	2015	0.081
	2020	0.13
	2025	0.16
	2030	0.16
	2035	0.16
Rigid HGV	2010	0.031
	2015	0.093
	2020	0.19
	2025	0.37
	2030	0.46
	2035	0.48

Artic HGV	2010	0.049
	2015	0.066
	2020	0.044
	2025	0.012
	2030	0.021
	3035	0.022
Bus	2010	0.069
	2015	0.14
	2020	0.15
	2025	0.24
	2030	0.44
	2035	0.52
Coach	2010	0.094
	2015	0.092
	2020	0.072
	2025	0.044
	2030	0.011
	2035	0.0058

7 Quality Assurance

A number of quality assurance checking procedures were carried out to ensure the new emission curves and supporting information provided for WebTAG and the NTM are robust.

The previous chapter showed the method used to check the integrity of the curve fitting procedure used to translate the speed-emission curves from the formats used in COPERT to the 6^{th}-order polynomial equations required of the NTM and the 3^{rd}-order polynomial equations required by WebTAG.

The errors introduced by changing the equation formats were shown to be less than 11% at all speeds and for all years, vehicle types and pollutant (fuel consumption/CO_2, PM and NO_x). In the vast majority of cases the errors introduced were less than 0.5%.

Several additional checks were made to ensure the data were consistent with the NAEI and showed the expected trends. The spreadsheets showed how the curves were derived from the source data.

The following checks were carried out:

- ✓ The fleet composition data used in the model was checked against data used in the NAEI road transport emissions model and the data provided for London by TfL
- ✓ The original raw COPERT equations used in the working spreadsheets were checked against the original source
- ✓ The fuel scaling factors used in the NO_x and PM calculations were checked against data used in the NAEI road transport emissions model
- ✓ The emission degradation factors used in the NO_x were checked against data used in the NAEI road transport emissions model
- ✓ The CO_2 correction factors for passenger cars were checked against the NAEI model and SMMT data used to generate them
- ✓ The fuel density factors were checked against those in DUKES and carbon factors checked against those used in the NAEI
- ✓ The flow of equations from raw COPERT speed-curves and fleet compositions through to fleet-weighted curves was checked in detail
- ✓ A sense check was made of factors derived at three different test speeds from the new speed curves against factors from previous 2013/14 speed-curves and the differences rationalised in terms of the different COPERT 5 factors
- ✓ A sense check of the factors derived at an urban and rural speed from the new emission curves with hot exhaust emission factors implied by the NAEI model when emissions were divided by vehicle km data. Small differences were understood in the context of the NAEI model producing implied emission factors aggregated at several different speeds.
- ✓ The trend in values of the factors over time was checked to see that it showed the expected decline consistent with the trends implied by the NAEI model
- ✓ The curves for OGV1 and OGV2 were checked for consistency against curves for rigid and artic HGVs

8 Comparison with the 2013/14 Emission Curves for the NTM and WebTAG

The new emission curves developed in this work differ from those developed in 2013/14 for several reasons. By far the main contributing factor is the use of the COPERT 5 emission factors, with smaller changes due to updates to the fleet composition data.

The previous curves for PM and fuel consumption/CO_2 were based on a set of speed-emission curves developed by TRL in 2009 (TRL, 2009). At the time, very few measurements had been made on Euro 4-6 vehicles entering service after 2005. The previous curves for NO_x had been updated in 2013/14 to be consistent with the COPERT 4.10 factors which had just been updated following revelation of the poor real-world NO_x performance of diesel cars and LGVs (https://www.emisia.com/utilities/copert/versions/). All the factors are now based on the common COPERT 5 source, as used in the NAEI.

A number of small changes have been made to the fleet composition projections, mainly to re-base these to more up-to-date data for 2016 and, as a more significant change, taking into account a slower uptake of diesel cars relative to petrol cars in future years. This is expected with the decline in popularity of diesel cars and the likely introduction of policies and measures to restrict use of diesel cars in urban centres in order to tackle exceedance of air quality standards for NO_2.

Table 10 -Table 12 show the emission factors calculated from the new curves *vs* the old 2013/14 curves for each year for NO_x, PM and CO_2, respectively, at an illustrative urban and rural speed. These tables show the ratio of the emission factors from the new curves relative to the old curves.

For NO_x, there are significant increases in the emission factors for diesel cars in 2020 and 2025 and LGVs in 2015, 2020 and 2025. This is mainly due to the increases in the COPERT factors for Euro 5 and first stage of Euro 6 vehicles due to new evidence on their real-world emission performance. However, in later years the new factors are lower than the old factors due to the fact that COPERT 5 takes into account a third legislative stage of Euro 6 (Euro 6d) that comes into effect in 2020 that will require vehicles to comply with emission limits with a tighter conformity factor when tested on the road using portable emissions measurement systems (PEMS). This was not taken into account in COPERT 4 and leads to lower emission factors for vehicles introduced after 2020.

There are significant differences in the emission factors for petrol LGVs from 2020 onwards. This is due to re-interpretation in the NAEI of the number of failing catalyst vehicles remaining in the fleet. New assumptions suggest far less catalyst failure for the later Euro standards affecting the factors from 2020 onwards. It should be recognised though that the number of petrol LGVs in the fleet is very low compared with their diesel counterparts, so this change will not have a large overall effect on calculated emissions.

The changes in NO_x factors for HGVs and buses are partially due to changes in emission factors and partially due to changes in the fleet mix, particularly for rigid HGVs in the more recent years. For future years, the new emission factors are lower than the old factors with the penetration of low emission factors for the Euro VI class.

Table 10: Comparison of fleet-averaged emission factors for NOx calculated for each year at average speeds of 44 and 78 kph from new emissions curves (2018 EFs) with curves developed for NTM in 2013/14 (2013 EFs). 2018 EF / 2013 EF is the ratio of the new to old emission factors.

			Urban (44 kph)				Rural (78 kph)		
			2013 EFs (g/km)	**2018 EFs (g/km)**	**2018 EF/ 2013 EF**		**2013 EFs (g/km)**	**2018 EFs (g/km)**	**2018 EF/ 2013 EF**
Car	Petrol	2010	0.190	0.188	0.991		0.197	0.198	1.001
Car	Petrol	2015	0.093	0.085	0.912		0.080	0.077	0.958
Car	Petrol	2020	0.067	0.058	0.874		0.053	0.051	0.972
Car	Petrol	2025	0.062	0.056	0.901		0.050	0.050	0.990

Car	Petrol	2030	0.062	0.056	0.912		0.050	0.050	0.996
Car	Petrol	2035	0.061	0.056	0.915		0.050	0.050	0.999
Car	Diesel	2010	0.586	0.582	0.993		0.532	0.528	0.993
Car	Diesel	2015	0.563	0.558	0.991		0.495	0.484	0.978
Car	Diesel	2020	0.383	0.438	1.142		0.332	0.372	1.120
Car	Diesel	2025	0.275	0.298	1.086		0.237	0.252	1.063
Car	Diesel	2030	0.229	0.210	0.917		0.198	0.178	0.898
Car	Diesel	2035	0.223	0.181	0.812		0.193	0.153	0.795
LGV	Petrol	2010	0.588	0.612	1.040		0.682	0.703	1.031
LGV	Petrol	2015	0.416	0.404	0.972		0.488	0.472	0.966
LGV	Petrol	2020	0.340	0.060	0.178		0.408	0.063	0.154
LGV	Petrol	2025	0.324	0.046	0.142		0.392	0.048	0.122
LGV	Petrol	2030	0.324	0.047	0.146		0.392	0.049	0.126
LGV	Petrol	2035	0.325	0.048	0.149		0.393	0.050	0.128
LGV	Diesel	2010	0.807	0.822	1.019		0.745	0.760	1.020
LGV	Diesel	2015	0.850	0.962	1.132		0.785	0.978	1.246
LGV	Diesel	2020	0.496	0.732	1.477		0.458	0.773	1.689
LGV	Diesel	2025	0.353	0.426	1.208		0.326	0.455	1.399
LGV	Diesel	2030	0.321	0.292	0.910		0.296	0.313	1.057
LGV	Diesel	2035	0.318	0.251	0.789		0.293	0.269	0.915
HGV-rigid	Diesel	2010	4.460	4.472	1.003		3.569	3.585	1.004
HGV-rigid	Diesel	2015	2.542	2.787	1.096		1.609	1.857	1.154
HGV-rigid	Diesel	2020	0.824	1.055	1.280		0.396	0.590	1.491
HGV-rigid	Diesel	2025	0.404	0.410	1.013		0.154	0.187	1.218
HGV-rigid	Diesel	2030	0.356	0.282	0.794		0.133	0.116	0.869
HGV-rigid	Diesel	2035	0.356	0.267	0.749		0.133	0.109	0.816
HGV-Artic	Diesel	2010	6.368	6.475	1.017		4.444	4.538	1.021
HGV-Artic	Diesel	2015	2.671	2.559	0.958		1.405	1.408	1.002
HGV-Artic	Diesel	2020	0.655	0.724	1.105		0.314	0.351	1.118
HGV-Artic	Diesel	2025	0.430	0.341	0.792		0.208	0.152	0.732
HGV-Artic	Diesel	2030	0.430	0.306	0.711		0.208	0.134	0.647
HGV-Artic	Diesel	2035	0.430	0.303	0.705		0.208	0.133	0.641

Bus	Diesel	2010	5.381	5.415	1.006		3.902	3.908	1.002
Bus	Diesel	2015	3.460	3.183	0.920		2.410	2.135	0.886
Bus	Diesel	2020	1.534	1.514	0.987		1.019	0.962	0.944
Bus	Diesel	2025	0.576	0.539	0.936		0.357	0.293	0.821
Bus	Diesel	2030	0.319	0.283	0.889		0.180	0.119	0.661
Bus	Diesel	2035	0.269	0.231	0.858		0.147	0.085	0.579
coach	Diesel	2010	7.184	7.200	1.002		5.116	5.109	0.999
coach	Diesel	2015	5.065	4.684	0.925		3.205	2.841	0.887
coach	Diesel	2020	2.510	2.375	0.946		1.387	1.301	0.938
coach	Diesel	2025	1.116	0.951	0.852		0.522	0.439	0.840
coach	Diesel	2030	0.736	0.574	0.780		0.290	0.214	0.739
coach	Diesel	2035	0.651	0.486	0.747		0.249	0.173	0.696

For PM, the changes are mainly due to the adoption of a completely new set of emission factors changing from the TRL (2009) set to COPERT 5; unlike for NO_x, COPERT 4 had not been used for PM in the 2013/14 curves, so this marked a more significant switch in emission factor source. In relative terms the increase in factors for diesel cars and LGVs in the fleet from 2015 onwards is particularly significant, by more than a factor of 2 in some cases. It has to be recognised that in absolute terms the change is very small and less than 2 mg/km as the majority of vehicles in the fleet in these later years will have diesel particulate filters; the differences are mainly due to how efficiently these reduce PM emissions, although both sources of emission factors imply very large reductions at the Euro 5 stage. The same is generally the case for HGVs and buses, with COPERT 5 generally giving higher PM emission factors than the previous TRL data set. It should be noted that the TRL source would not have been based on any actual measurements of emission factors from vehicles entering the fleet after 2010 and factors for Euro V-VI vehicles would have been based on expert judgement at the time.

Table 11: Comparison of fleet-averaged emission factors for PM calculated for each year at average speeds of 44 and 78 kph from new emissions curves (2018 EFs) with curves developed for NTM in 2013/14 (2013 EFs). 2018 EF / 2013 EF is the ratio of the new to old emission factors.

			Urban (44 kph)				Rural (78 kph)		
			2013 EFs (g/km)	**2018 EFs (g/km)**	**2018 EF/ 2013 EF**		**2013 EFs (g/km)**	**2018 EFs (g/km)**	**2018 EF/ 2013 EF**
Car	Petrol	2010	0.00182	0.00147	0.8071		0.00245	0.00146	0.5954
Car	Petrol	2015	0.00129	0.00092	0.7111		0.00173	0.00085	0.4901
Car	Petrol	2020	0.00083	0.00064	0.7699		0.00111	0.00054	0.4894
Car	Petrol	2025	0.00083	0.00068	0.8172		0.00111	0.00056	0.5055
Car	Petrol	2030	0.00083	0.00069	0.8353		0.00111	0.00057	0.5144
Car	Petrol	2035	0.00083	0.00070	0.8383		0.00111	0.00057	0.5161
Car	Diesel	2010	0.01958	0.02142	1.0939		0.02123	0.02060	0.9703
Car	Diesel	2015	0.00815	0.00966	1.1851		0.00877	0.00882	1.0058

Car	Diesel	2020	0.00275	0.00397	1.4434		0.00294	0.00329	1.1196
Car	Diesel	2025	0.00091	0.00204	2.2256		0.00095	0.00153	1.6060
Car	Diesel	2030	0.00068	0.00172	2.5370		0.00070	0.00125	1.7994
Car	Diesel	2035	0.00067	0.00170	2.5362		0.00069	0.00124	1.7966
LGV	Petrol	2010	0.00181	0.00199	1.0967		0.00246	0.00199	0.8092
LGV	Petrol	2015	0.00108	0.00104	0.9627		0.00137	0.00130	0.9485
LGV	Petrol	2020	0.00064	0.00051	0.8074		0.00077	0.00093	1.2114
LGV	Petrol	2025	0.00063	0.00050	0.8010		0.00075	0.00100	1.3311
LGV	Petrol	2030	0.00063	0.00050	0.8010		0.00075	0.00100	1.3370
LGV	Petrol	2035	0.00063	0.00050	0.8009		0.00075	0.00100	1.3362
LGV	Diesel	2010	0.03079	0.02911	0.9455		0.03393	0.03829	1.1284
LGV	Diesel	2015	0.01014	0.01309	1.2910		0.01110	0.01697	1.5290
LGV	Diesel	2020	0.00235	0.00369	1.5656		0.00254	0.00438	1.7260
LGV	Diesel	2025	0.00088	0.00159	1.8176		0.00092	0.00157	1.7164
LGV	Diesel	2030	0.00072	0.00128	1.7846		0.00074	0.00115	1.5497
LGV	Diesel	2035	0.00069	0.00125	1.8170		0.00071	0.00111	1.5657
HGV-rigid	Diesel	2010	0.07390	0.07370	0.9974		0.06465	0.05812	0.8990
HGV-rigid	Diesel	2015	0.02945	0.03852	1.3077		0.02500	0.02981	1.1922
HGV-rigid	Diesel	2020	0.00614	0.01282	2.0865		0.00511	0.00970	1.8983
HGV-rigid	Diesel	2025	0.00261	0.00489	1.8724		0.00216	0.00358	1.6531
HGV-rigid	Diesel	2030	0.00226	0.00352	1.5596		0.00187	0.00252	1.3461
HGV-rigid	Diesel	2035	0.00226	0.00336	1.4902		0.00187	0.00239	1.2806
HGV-Artic	Diesel	2010	0.08619	0.09366	1.0867		0.07310	0.06966	0.9530
HGV-Artic	Diesel	2015	0.02388	0.03242	1.3579		0.01971	0.02380	1.2076
HGV-Artic	Diesel	2020	0.00520	0.00987	1.8986		0.00425	0.00712	1.6742
HGV-Artic	Diesel	2025	0.00347	0.00537	1.5466		0.00284	0.00382	1.3477
HGV-Artic	Diesel	2030	0.00340	0.00498	1.4634		0.00278	0.00354	1.2725
HGV-Artic	Diesel	2035	0.00340	0.00495	1.4545		0.00278	0.00351	1.2646
Bus	Diesel	2010	0.07443	0.08414	1.1304		0.05623	0.07032	1.2507
Bus	Diesel	2015	0.03862	0.04091	1.0592		0.02873	0.03482	1.2121
Bus	Diesel	2020	0.01523	0.01856	1.2192		0.01109	0.01609	1.4512
Bus	Diesel	2025	0.00517	0.00659	1.2736		0.00366	0.00576	1.5760

Bus	Diesel	2030	0.00282	0.00375	1.3300		0.00196	0.00331	1.6945
Bus	Diesel	2035	0.00243	0.00321	1.3205		0.00169	0.00282	1.6712
coach	Diesel	2010	0.13727	0.13275	0.9670		0.09322	0.08948	0.9599
coach	Diesel	2015	0.07010	0.06489	0.9256		0.04688	0.04352	0.9284
coach	Diesel	2020	0.02650	0.02937	1.1082		0.01745	0.01988	1.1395
coach	Diesel	2025	0.00837	0.01052	1.2566		0.00541	0.00705	1.3021
coach	Diesel	2030	0.00432	0.00617	1.4295		0.00276	0.00406	1.4703
coach	Diesel	2035	0.00373	0.00537	1.4403		0.00239	0.00349	1.4634

For CO_2 and fuel consumption, as for PM, a wholesale change in the source of emission factors is mainly the cause of the change in emission factors, with the previous 2013/14 curves being based on the TRL (2009) source and in the case of HGVs and buses, calibrations against fuel efficiency data provided at the time by DfT from the CSRGT and BSOG sources (see Section 3.3) which are no longer used.

A significant increase in the factors for petrol and diesel cars, particularly for later projection years, is due to the new COPERT 5 factors, but more significantly the new procedure in COPERT described in Section 3.2 for accounting for the marginal change in CO_2 factors for new cars sold in the UK using data from SMMT, applying a real-world correction factor and using these to scale the new COPERT 5 factors for Euro 4 cars. This leads to a slower reduction in the fleet-averaged CO_2 factor for conventional petrol and diesel passenger cars than implied by the TRL factors. As stated earlier, at the time the TRL curves were developed, very few measurements had been made on Euro 4-6 vehicles entering service after 2005 and far little was known about how laboratory-based measurements differed from the real-world behaviour. There was little understanding by TRL of how fuel efficiencies of cars would develop in future, so the differences in factors for current years based on measurements carry forward to the factors for future years.

The factors for HGVs and buses tend to be lower than previously implied by the 2013/14 curves. This is mainly due to the fact that the emission curves are no longer calibrated against the independent source of fleet-averaged fuel efficiency data previously provided by DfT from the CSRGT and BSOG sources. The factors are now completely based on COPERT which reflect average emissions from these vehicles Europe-wide and it is not known how representative these are to vehicles used in the UK.

Table 12: Comparison of fleet-averaged emission factors for CO_2 calculated for each year at average speeds of 44 and 78 kph from new emissions curves (2018 EFs) with curves developed for NTM in 2013/14 (2013 EFs). 2018 EF / 2013 EF is the ratio of the new to old emission factors.

			Urban (44 kph)				Rural (78 kph)		
			2013 EFs (g/km)	2018 EFs (g/km)	2018 EF/ 2013 EF		2013 EFs (g/km)	2018 EFs (g/km)	2018 EF/ 2013 EF
Car	Petrol	2010	162.6	168.4	1.035		154.2	149.6	0.971
Car	Petrol	2015	147.7	158.8	1.075		139.2	142.3	1.022
Car	Petrol	2020	129.7	155.8	1.201		121.3	139.8	1.153
Car	Petrol	2025	121.6	155.6	1.279		113.1	139.6	1.234
Car	Petrol	2030	119.7	155.6	1.300		111.2	139.6	1.255
Car	Petrol	2035	119.5	155.6	1.302		111.1	139.6	1.257

Car	Diesel	2010	149.7	169.6	1.133		134.6	156.4	1.162
Car	Diesel	2015	136.2	160.4	1.178		121.1	147.9	1.221
Car	Diesel	2020	123.0	158.1	1.285		107.9	145.7	1.350
Car	Diesel	2025	116.4	158.0	1.357		101.3	145.6	1.436
Car	Diesel	2030	114.4	158.0	1.381		99.3	145.6	1.466
Car	Diesel	2035	114.2	158.0	1.383		99.1	145.6	1.469
LGV	Petrol	2010	206.2	282.6	1.371		186.8	207.2	1.109
LGV	Petrol	2015	205.2	241.3	1.176		183.5	184.0	1.002
LGV	Petrol	2020	203.8	183.4	0.900		181.9	151.0	0.830
LGV	Petrol	2025	203.3	164.5	0.809		181.3	140.3	0.773
LGV	Petrol	2030	203.1	163.4	0.804		181.2	139.6	0.770
LGV	Petrol	2035	203.1	163.2	0.804		181.2	139.7	0.771
LGV	Diesel	2010	188.8	207.3	1.098		215.2	197.8	0.919
LGV	Diesel	2015	186.7	208.1	1.115		215.4	201.6	0.936
LGV	Diesel	2020	185.7	208.8	1.124		214.6	204.1	0.951
LGV	Diesel	2025	185.4	208.9	1.127		214.4	204.7	0.955
LGV	Diesel	2030	185.4	209.0	1.127		214.3	204.8	0.956
LGV	Diesel	2035	185.4	208.4	1.124		214.3	205.1	0.957
HGV-rigid	Diesel	2010	778.6	593.6	0.762		741.8	523.2	0.705
HGV-rigid	Diesel	2015	768.0	612.2	0.797		730.1	532.7	0.730
HGV-rigid	Diesel	2020	763.9	609.0	0.797		725.6	528.9	0.729
HGV-rigid	Diesel	2025	764.0	608.6	0.797		725.6	528.3	0.728
HGV-rigid	Diesel	2030	764.0	608.7	0.797		725.6	528.3	0.728
HGV-rigid	Diesel	2035	764.0	608.7	0.797		725.6	528.3	0.728
HGV-Artic	Diesel	2010	1053.0	992.6	0.943		938.2	768.0	0.819
HGV-Artic	Diesel	2015	1039.6	977.7	0.940		924.9	770.0	0.832
HGV-Artic	Diesel	2020	1038.7	975.5	0.939		924.0	770.8	0.834
HGV-Artic	Diesel	2025	1038.8	975.4	0.939		924.0	771.1	0.835
HGV-Artic	Diesel	2030	1038.8	975.5	0.939		924.0	771.1	0.835
HGV-Artic	Diesel	2035	1038.8	975.5	0.939		924.0	771.1	0.835
Bus	Diesel	2010	789.1	700.8	0.888		727.9	601.2	0.826
Bus	Diesel	2015	781.0	678.9	0.869		719.5	592.1	0.823

Bus	Diesel	2020	778.2	670.2	0.861		716.0	587.9	0.821
Bus	Diesel	2025	777.2	667.9	0.859		714.6	587.4	0.822
Bus	Diesel	2030	777.1	667.3	0.859		714.5	587.2	0.822
Bus	Diesel	2035	777.1	667.5	0.859		714.5	587.4	0.822
coach	Diesel	2010	854.4	860.6	1.007		691.8	651.4	0.942
coach	Diesel	2015	851.5	863.6	1.014		686.9	660.2	0.961
coach	Diesel	2020	851.8	869.7	1.021		685.7	668.2	0.974
coach	Diesel	2025	851.6	874.2	1.027		685.2	673.0	0.982
coach	Diesel	2030	851.8	875.6	1.028		685.3	674.4	0.984
coach	Diesel	2035	851.8	876.0	1.028		685.3	674.6	0.985

The emission curves provided for the fleet in London are different to the curves provided previously, partly due to all the factors mentioned above that have led to changes in the factors for the rest of the UK, but also because of changes to the London fleet composition, and in particular the treatment of London in three different zones accounting for the effect of the ULEZ.

To illustrate this point, Table 13 shows a comparison of NO_x emission factors calculated at 50 kph for buses in London from the previous 2013/14 curves and from the current curves. The factors from the current curves are shown for central, inner and outer London and are shown as ratios to the previous factors which were only derived for London as a whole. It can be seen how much lower are the factors in the central area once the ULEZ scheme is introduced in 2019, compared with previous estimates, but how in all parts of London the factors will be lower than previously estimated from 2030 onwards and in most areas from 2020 onwards.

Table 13 Comparison of emission factors for NO_x calculated for urban buses in London at 50 kph from new emissions curves with curves developed for NTM in 2013/14

			2013 EFs (g/km)		2018 EFs (g/km)					2018 EF/ 2013 EF			
			All London		Central London	Inner London	Outer London	All London		Central London	Inner London	Outer London	All London
Bus	Diesel	2010	5.118		5.162	5.162	5.162	5.162		1.01	1.01	1.01	1.01
Bus	Diesel	2015	3.400		2.913	3.197	3.515	3.350		0.86	0.94	1.03	0.99
Bus	Diesel	2020	1.966		0.186	0.893	1.958	1.429		0.09	0.45	1.00	0.73
Bus	Diesel	2025	0.884		0.186	0.621	1.041	0.819		0.21	0.70	1.18	0.93
Bus	Diesel	2030	0.312		0.186	0.189	0.190	0.190		0.60	0.61	0.61	0.61
Bus	Diesel	2035	0.312		0.186	0.189	0.190	0.190		0.60	0.61	0.61	0.61

Other diesel vehicles (LGVs and HGVs) show a broadly similar pattern for NO_x. This pattern is also evident for PM, particularly for buses, though for other vehicle types the differences due to changes in the London fleet composition are masked by changes in the emission factors.

9 Use of Emission Curves in the NTM and WebTAG

The spreadsheets provided to DfT for the NTM have the coefficients in a 6th-order polynomial equation for calculating emission factors in g/km and fuel consumption factors in litre/100km from average speed for each main vehicle type in the fleet in years from 2010 to 2035. Separate spreadsheets are provided for each pollutant and for London and the rest of the UK. The spreadsheets provided for WebTAG have the coefficients in 3rd-order polynomial equation for calculating CO_2 emission factors in g/km and fuel consumption factors in litre/100km from average speed for each main vehicle type in the fleet in years for 2010 and 2015. Again, separate spreadsheets are provided for the fleets in London and the rest of the UK. Each spreadsheet demonstrates the calculation of emission factors from a speed using the polynomial equation.

9.1 Valid speed range

All the emission curves defined by the coefficients have a valid speed range outside of which the curves should not be used. This is particularly the case at the low end of the speed range where the curve can be very steep. The valid speed ranges are specified in the original COPERT model and EMEP/EEA Guidebook and are shown in Table 14.

Table 14: Valid speed range for speed-emission curves

Vehicle type	Valid speed range (kph)		
	PM curves	**CO_2 curves**	**NOx curves**
Petrol cars	10-130	5-130[b]	10-130
Diesel cars	10-130	10-130	10-120[e]
Petrol LGV	10-110	10-120[c]	10-110
Diesel LGV	10-100[a]	10-110[d]	10-110
HGV	12-85	12-85	12-85
Rigid HGV	12-85	12-85	12-85
Artic HGV	12-85	12-85	12-85
Bus	11-85	11-85	11-85
Coach	12-100	12-100	12-100

[a] Valid speed range of 12-110 kph applies for 2010
[b] Valid speed range of 10-130 kph applies for 2010
[c] Valid speed range of 10-110 kph applies for 2010 and 5-140 kph applies for 2035
[d] Valid speed range of 5-130 kph applies for 2035
[e] Valid speed range of 10-130 applies for 2030 and 2035

The valid speed ranges in the latest version of COPERT have been slightly reduced compared with previous versions, in particular through increasing the lower limit of the range. The reasons for this are not clear, but are likely to be a reflection of the conditions of the test cycles used in the measurement of the factors and the considerable uncertainty and sparsity of data at the extreme ends of the range. This is particularly the case for HGVs and buses where very few measurements will have been made at these speeds. The developers of COPERT will also have applied some expert judgement when considering where the curves are a realistic reflection of emission factors in the real world.

It is recognised that these speed ranges are quite limiting and that DfT may have occasions where it would like to have emission factors for speeds outside this range. It does have to be appreciated that

COPERT factors are designed primarily for national emission inventories and many countries do not have detailed speed data and are not likely to need to use the COPERT equations at the extreme ends of the speed range. Rather, these counties will simply use them to represent an emission factor at one typical urban, rural and motorway average speed, rather than over many different traffic situations.

Although not advisable, if DfT wishes to use these emission curves outside their valid ranges, the steepness of the curve at the end of the range should be checked alongside checking that the curves do not return negative values or unrealistically high or low values compared with values at the end of the range. This is more likely to be the case at the low end of the range where the curves can be particularly steep. Where the curve is shallower, often at the high end of the range, a small extrapolation may be possible, but the factor used with caution.

Further discussions on the validity of average speed emission curves for certain applications are provided in Section 10.3.

9.2 Fuel splits for cars and LGVs

The emission curves are expected to be used with vehicle kilometre or traffic flow data from the NTM and WebTAG users. Fleet compositions are embedded within the curves themselves, but what users may still require are the fuel splits in vehicle km or traffic flows between petrol and diesel cars and petrol and diesel LGVs. All other fleet compositional information is provided with the emission curve spreadsheets.

The fuel splits for cars and LGVs in current and future years are available with the fleet composition data on the NAEI website that also underpins the emission curves. Table 15 shows the fuel split for cars on urban, rural and motorway roads in England, Wales and Scotland and the central, inner and outer parts of London for 2010-2035. This table includes the proportion of battery electric cars in urban areas. Although not shown here, the fractions of hybrid cars are included with conventional vehicles in the relevant fuel rows and the hybrid splits themselves are available in the same fleet composition tables on the NAEI website as used for the Euro fleet compositions. The inclusion of battery electric and hybrid vehicles in this table is shown for completeness, but it should be emphasised that consideration of speed-emission curves for these low emission technologies was outside the scope of this study and the curves provided here are solely for conventional petrol and diesel cars. Emission factor curves for ULEVs are considered in a separate study for DfT.

The figures derived from the fleet turnover model informed by DfT car sales projections take account of the fact that diesel cars tend to do more mileage than petrol cars using evidence from ANPR data and account for newer vehicles doing greater mileage than older ones. The ANPR data were also used to define how the diesel/petrol car share varies by road type; this provides evidence for a bias towards diesel car usage on motorways. Note that for London, TfL do not provide figures for 2035, so in this table are assumed to be the same as for 2030.

Table 15: Proportion of car km by fuel type by region, area and road type.

			2010	2015	2020	2025	2030	2035
England	Urban	Electric	0%	0%	0%	1%	2%	4%
		Petrol	66%	58%	53%	54%	58%	61%
		Diesel	34%	42%	47%	45%	40%	35%
	Rural	Petrol	64%	52%	46%	48%	53%	58%
		Diesel	36%	48%	54%	52%	47%	42%
	Mway	Petrol	56%	43%	35%	38%	44%	50%
		Diesel	44%	57%	65%	62%	56%	50%
Scotland	Urban	Electric	0%	0%	0%	1%	2%	4%
		Petrol	64%	57%	52%	53%	57%	60%
		Diesel	36%	42%	48%	46%	41%	36%

	Rural	Petrol	61%	51%	45%	47%	52%	57%
		Diesel	39%	49%	55%	53%	48%	43%
	Mway	Petrol	53%	42%	34%	37%	43%	49%
		Diesel	47%	58%	66%	63%	57%	51%
Wales	Urban	Electric	0%	0%	0%	1%	2%	4%
		Petrol	61%	56%	50%	51%	55%	58%
		Diesel	39%	44%	50%	48%	43%	38%
	Rural	Petrol	59%	49%	43%	45%	50%	55%
		Diesel	41%	51%	57%	55%	50%	45%
	Mway	Petrol	51%	39%	31%	34%	41%	47%
		Diesel	49%	61%	69%	66%	59%	53%
London	Central	Electric	0%	0%	1%	2%	3%	3%
		Petrol	66%	60%	58%	58%	58%	58%
		Diesel	34%	40%	42%	40%	39%	39%
	Inner	Electric	0%	0%	1%	2%	3%	3%
		Petrol	66%	60%	54%	56%	58%	58%
		Diesel	34%	40%	45%	42%	39%	39%
	Outer	Electric	0%	0%	1%	2%	3%	3%
		Petrol	66%	60%	54%	56%	58%	58%
		Diesel	34%	40%	46%	42%	39%	39%

Table 16 shows the corresponding fuel mix for LGVs. In this case, the same mix is assumed for each devolved country (hence shown for the UK as a whole) and for each part of London.

Table 16: Proportion of LGV km by fuel type by road type

			2010	2015	2020	2025	2030	2035
UK	Urban	Electric	0%	0%	0%	3%	9%	19%
		Petrol	5%	4%	2%	2%	1%	1%
		Diesel	95%	96%	97%	96%	89%	80%
	Rural	Petrol	5%	4%	2%	2%	1%	1%
		Diesel	95%	96%	98%	98%	99%	99%
	Mway	Petrol	5%	4%	2%	2%	1%	1%
		Diesel	95%	96%	98%	98%	99%	99%
London	All parts	Electric	0%	1%	3%	6%	10%	10%
		Petrol	5%	2%	3%	2%	1%	1%
		Diesel	95%	98%	95%	93%	88%	88%

10 Uncertainties in the Emission Curves

The quantification of traffic emissions by the NTM and WebTAG using these speed-emission curves will have inherent uncertainties associated with them. Whilst very difficult to quantify, an understanding of the main uncertainties in the factors themselves and their limitations will help DfT understand the main factors contributing to these uncertainties in the NTM outputs.

Previous sections of the report have focused on some aspects of these uncertainties by considering the effects of re-fitting the speed emission factor relationships to different mathematical formulae and on using them outside their intended speed range. The errors introduced by re-fitting the curves are generally very small, but using them outside the low end of their intended speed range does introduce greater uncertainty.

However, there are other additional factors which influence the overall uncertainties in the speed-emission curves used in the NTM and WebTAG. These are related to

- the provenance and uncertainties in the key input data
- the completeness of the factors as representative of all traffic-related emissions, and
- the limitations of the emission factor parameterisations themselves

Many of these issues were discussed in the report for the previous curves developed for the NTM and WebTAG in 2013/14 and still apply, but are addressed again in the context of the latest emission curves.

10.1 Uncertainties in key input data

10.1.1 COPERT emission factors

The emission curves developed for WebTAG and the NTM are only as accurate as the original (raw) emission factor-speed curves provided in COPERT.

The provenance of the COPERT sources is good in the sense that it draws on a centralised set of emissions test data from around Europe managed by the European Commission's Joint Research Centre through the ERMES programme, as described in Section 2.1. COPERT is also the model and source of emission factors consistent with the EMEP/EEA Emissions Inventory Guidebook, recommended for national emissions inventory reporting to the EU National Emissions Ceilings Directive (2016/2284/EU), the UNECE Convention on Long-range Transboundary Air Pollution and for reporting Greenhouse Gas emissions under the UN Framework Convention on Climate Change. COPERT provides the most up-to-date source of publicly available emission factors on road vehicles and has been updated several times since the previous emission curves were developed in 2013/14. These updates mostly reflect new evidence on the real-world emission performance of vehicles recently entering the fleet, especially on diesel vehicles where there has been much public scrutiny since the recent Volkswagen scandal. The COPERT emission factors and methodology are more up-to-date than the TRL (2009) factors that the emission curves previously relied on.

COPERT derives the emission factors through analysis of raw emission test data measured by various institutes around Europe. Whereas for the 2013/14 curves, the samples tested would have been quite limited for Euro 4/5 light duty vehicles compared with older Euro standards, the sample size is now much better and in particular a much larger database of emissions test data exists for diesel cars and vans. The test data for Euro 5 and Euro 6 diesel cars in the ERMES database includes the data measured in DfT's Vehicle Emissions Testing Programme published in 2016 (DfT, 2016). Some of the test data that underpins the COPERT emission factors now come from more realistic test cycles using PEMS.

Although the situation has much improved and there should be more confidence in the NO_x emission factors in COPERT for current Euro 5 and early generation Euro 6 diesel cars and vans, there is some uncertainty in how the Euro 6 Real Driving Emission (RDE) regulations will play out for new vehicles entering the fleet, although evidence from remote sensing studies in the UK and elsewhere in Europe do suggest that NO_x emissions are reducing for new models in line with legislative requirements and with the trend in emission factors shown for Euro 6 in COPERT.

There remains far fewer test data on HGVs and buses and these vehicles can take on many different configurations and operate under many different load conditions. The factors for these vehicles therefore remain fairly uncertain. Nevertheless, a lot of evidence does suggest that the large reduction in NO_x emission factors at Euro VI stage implied by the factors in COPERT is being realised in the real-world (ICCT, 2016). It is regrettable that there are no longer reliable fuel consumption data available from DfT's CSRGT and BSOG to validate or calibrate the factors for HGVs and buses in COPERT for UK situations.

The factors and methodology in the EMEP/EEA Emissions Inventory Guidebook for treating incremental changes in CO_2 factors for passenger cars used in the development of the new emission curves is more robust than the curves previously derived from the TRL source. It also provides a means of capturing UK fleet-specific trends in CO_2 factors for new car models through use of data provided by SMMT.

10.1.2 Fleet composition

The DfT has a robust source of fleet composition data for historic years via the comprehensive vehicle licensing statistics. However, representing future years is more challenging and requires a range of assumptions on fleet turnover and new vehicle sales. There are no centralised sources of data on fleet projections.

The fleet compositions used to develop the emission curves for specific years is based on the fleet composition data developed by the NAEI and used for forecasting future emissions in modelling work for Defra. The NAEI uses its own fleet turnover model based on historic trends in vehicle survival rates and estimates of future trends in new vehicle sales. DfT contribute key information to the NAEI on the split between petrol and diesel among future car sales, as well as the uptake of ULEVs and new LGV sales. Vehicle sales projections and the turnover in the future HGV fleet is particularly limited and the NAEI is totally dependent on its own assumptions, largely based on historical trends. As far as is practicable, the fleet turnover assumptions made by the NAEI are shared with DfT officials for comment.

The NAEI continues to use anonymised ANPR data provided by DfT to develop fleet compositions for different road types. This data is provided roughly every 2 years and gives a very useful indication of trends in the usage of vehicles on Britain's roads, e.g. the greater use of diesel cars relative to petrol cars, especially on motorways, and the tendency for new HGVs to be used more than older vehicles.

Detailed data on the future fleet projections for vehicles in London are provided directly by TfL. Although not published, this information is regularly updated and considers all the latest policies and measures to be introduced in London to improve air quality committed by the London Mayor. This includes the introduction of the Ultra Low Emission Zone in central London from 2019 which had not been accounted for in the previous 2013/14 curves. The fleet data used for London in development of London-specific curves for the NTM and WebTAG are more detailed than previous versions and cover three different areas of London: central, inner and outer London. It also includes very detailed data on the composition of TfL's bus fleet. The fleet and vehicle activity data used for the emission curves is consistent with data used by TfL itself in its own analysis and modelling of emissions and air quality in London.

Whilst the emission curves developed for the NTM make optimum use of available fleet data in current years, predicting the future fleet is inherently uncertain. Future trends in new vehicle sales and fleet turnover will depend on future economic conditions, fuel prices and consumer behaviour in response to transport and other policies and measures brought in to influence purchasing choice, travel demand and modal shift. A major source of uncertainty in the emission curves for the NTM relates to their relevance to local situations where low emission strategies may be introduced to tackle current levels of air pollution by restricting access to vehicles not meeting minimum emission standards. How these schemes may be introduced is still being considered by local authorities, but apart from London, the emission curves continue to be based on national trends and may not reflect how fleet compositions will develop in some areas in the future. This is an area which will need to be reviewed regularly.

10.2 Other traffic-related emissions not covered by the NTM emission curves

The speed-emission curves provided for the NTM represent hot exhaust emissions from vehicles. For the pollutants covered, particularly NO_x and PM, there are other significant sources of traffic-related emissions: cold start emissions and non-exhaust emissions of PM.

10.2.1 Cold start emissions

These are the excess emissions released by a vehicle during the time it takes the engine and exhaust to warm up to its normal operating temperature. This can take several minutes or kilometres travelled from the start of a trip if the engine is cold. The excess emissions occur because the engine is operating less efficiently when cold and therefore requires more fuel to move a given distance. Furthermore, and more significantly, excess emissions also occur because catalyst-based exhaust aftertreatment systems do not function until the catalyst has reached a certain temperature by the flow of hot exhaust gas. These include three-way catalysts fitted on petrol cars, diesel oxidation catalysts on diesel vehicles and selective catalytic reduction systems used for NO_x control on Euro V and VI diesel vehicles.

For NO_x and PM, the NAEI uses a trip-based approach to estimate cold start emissions recommended by the EMEP/EEA Emissions Inventory Guidebook. The approach calculates cold start emissions as a fraction of hot exhaust emissions and is dependent on ambient temperature and trip length, as well as pollutant type, technology and Euro standard. Cold start factors are only available for NO_x emissions from petrol and diesel cars and LGVs and PM emissions from diesel cars and LGVs; no factors are available for heavy duty vehicles.

The NAEI has used this approach to develop implied fleet-weighted grammes per trip emission factors that vary by year. In relation to hot exhaust emissions, they are more important for PM than NO_x, as will be apparent from data provided in Section 11.

The NAEI does not directly estimate cold start emissions for CO_2 or fuel consumption, although these emissions do occur. This is because the NAEI estimates of fuel consumption are calibrated against national fuel sales data so the calibration process effectively captures cold start effects through the excess amount of fuel consumed at the start of trips. The EMEP/EEA Guidebook provides the same approach for estimating cold start emissions of CO_2 and fuel consumption and from this it would be possible to derive analogous g/trip based factors.

Recommendations for potentially including cold start emissions in future NTM calculations are being provided in a supplementary report as part of this project.

10.2.2 Non-exhaust sources of PM from traffic

There are several types of non-exhaust sources of PM emissions to air that arise from mechanical processes such as tyre wear, brake wear and road surface abrasion. The NAEI includes these sources of PM in the UK inventory following methods and emission factors provided in the EMEP/EEA Emissions Inventory Guidebook. The factors are in grammes per km and are available for cars, LGVs and heavy duty vehicles (HGVs and buses).

Quantifying these emissions is limited by lack of available data and the emission factors are highly uncertain. Although there is a rough speed-dependence, with factors decreasing with increasing speed, lack of data has meant that a continuous speed-emission relationship has not been developed. Factors for tyre and brake wear emissions used by the NAEI for typical traffic situations on urban, rural and motorway road conditions are shown in Table 17 and are taken directly from the NAEI report (Brown et al, 2018). Factors for road abrasion are not available for different speeds or road types, but average values for all road types are shown in Table 18. In the same table are factors shown for tyre wear and brake wear for comparison purposes, where the different values on each road type have been weighted according to the vehicle kilometres travelled by each vehicle type on each road type in 2016.

Table 17: ***Emission factors for PM_{10} from tyre and brake wear (in mg/km)***

mg PM_{10} /km		Tyre	Brake
Cars	Urban	8.74	11.68
	Rural	6.80	5.53
	Motorway	5.79	1.36
LGVs	Urban	13.80	18.22
	Rural	10.74	8.62

	Motorway	9.15	2.12
Rigid HGVs	Urban	20.74	51.00
	Rural	17.39	27.14
	Motorway	13.98	8.44
Artic HGVs	Urban	47.07	51.00
	Rural	38.24	27.14
	Motorway	31.49	8.44
Buses	Urban	21.18	53.60
	Rural	17.39	27.14
	Motorway	13.98	8.44
Motorcycles	Urban	3.76	5.84
	Rural	2.92	2.76
	Motorway	2.49	0.68

Table 18: ***Emission factors for PM_{10} from road abrasion (in mg/km). The figures for tyre wear and brake wear are also shown for comparison as averages taken from*** **Table 17** ***weighted by the vehicle km travelled on each road type***

mg PM_{10}/km	Road abrasion	Tyre wear	Brake wear
Cars	7.5	7.3	7.0
LGVs	7.5	11.4	10.5
HGVs	38.0	26.6	21.8
Buses	38.0	19.4	41.4
Motorcycles	3.0	3.3	4.2

These sources of PM are not regulated and the relationship between emissions and tyre, brake and road surface material is not known. The factors therefore remain constant over time. However, with PM factors from vehicle exhausts decreasing due to better engine and exhaust treatment technologies necessary to achieve compliance with more stringent exhaust emission standards, the relative contribution of these non-exhaust sources of PM from traffic is becoming greater with time. This is evident from the figures in Table 11, Table 17 and Table 18 which show, for example, how exhaust emissions of PM from diesel cars in 2020 are predicted to be ~4 mg/km in urban areas compared with ~28 mg/km for all the non-exhaust sources combined. From these tables, it becomes clear why the current predictions from the NAEI show that non-exhaust sources will contribute 94% of total road transport emissions of PM_{10} by 2030.

Unlike exhaust emissions, PM emissions from these non-exhaust sources are relatively coarse and a small fraction occur in the $PM_{2.5}$ range. The emission factors for $PM_{2.5}$ are therefore smaller than values shown in these tables, with the $PM_{2.5}$/PM_{10} ratio different for each type of non-exhaust source. Based on factors in the EMEP/EEA Emissions Inventory Guidebook, the fraction of PM_{10} emitted as $PM_{2.5}$ for these non-exhaust sources are:

- Tyre wear 0.7
- Brake wear 0.4
- Road abrasion 0.54

These ratios apply to all vehicle and road types.

An additional source of PM from traffic occurs from traffic-induced resuspension of road dust. This source is very difficult to quantify using conventional emission inventory approaches based on emission factors and is not required to be included in national inventories. Emissions are expected to be dependent on road surface conditions, traffic flow and weather conditions. Further details on this source of PM are given in the report of the Defra Air Quality Expert Group on $PM_{2.5}$ (AQEG, 2012).

10.2.3 Other pollutants

Traffic is a source of many other pollutants emitted to air. These include hydrocarbons, of which there are many individual components some of which are toxic such as benzene, carbon monoxide, ammonia, polyaromatic hydrocarbons (PAHs) and other air toxics, as well as other greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4). Inventories for these pollutant emissions from road transport are provided by the NAEI. However, from a human health exposure point of view, the focus of attention remains on the significant contribution that traffic makes to emissions of NO_x and PM.

10.3 Limitations of the emission factor parameterisations

It is recognised that the speed-emission curves provided for the NTM and WebTAG are currently the only practical way of defining the variability in emission factors for the different roads and traffic situations represented by the NTM and WebTAG on a national scale.

The method of parameterising emissions as simple average speed related emission factor functions is a convenient way of expressing how emissions vary with traffic conditions. However, whilst acceptable for national inventory reporting, the method is quite simplistic and prone to high uncertainty for more local scale assessments and potentially as a means of expressing how emissions change in response to changes in traffic conditions.

The original emission factor-speed equations themselves are developed by fitting a measured emission factor averaged over a drive cycle that may be several tens of kilometres long to the average speed of the cycle. Factors are measured for a number of different cycles with different averaged speeds and a curve fitted to the data. Each drive cycle itself has many periods of acceleration, deceleration, cruise and idling included within it.

In reality, a vehicle’s emissions is very transient in behaviour and varies second-by-second according to the load on the engine and various factors that influence it such as driving style (aggressive or mild), level of congestion and number of stop-starts, vehicle weight (the current factors assume a 50% load carried by HGVs) and road gradient. More complex, engineering-based vehicle emission simulation models are required to deal with these factors. These types of models are better suited for simulating emissions for specific traffic situations such as congested traffic, idling, and at road junctions, for example, but are not available for all types of vehicles and technologies. Such models have not yet been used by the NAEI for national scale modelling.

Using the average speed-related emission curves to calculate the emission effects of incrementally small changes in speed is pushing them beyond their limits of acceptability. The variability in emission factor at any given average speed cannot be easily quantified but is expected to be high, especially at the low end of the speed range, and dependent of vehicle type and technology. Whilst the speed-emission curves allow the effect of a small change in speed to be estimated, the magnitude of change in emission factor shown by the calculations will not be very meaningful and should be regarded with a high degree of uncertainty. The shape of the curve gives a better sense of the directional change in emissions and how, for example, a generally slow urban emission factor compares with a less congested one, a rural and a free-flowing motorway emission factor. The evaluation of a change in speed limit of a particular road should ideally consider not just the change in average speed, but the dynamics of the traffic flow, e.g. how it changes the whole traffic situation and extent of stop-starts and free-flowing traffic.

According to the developers of the COPERT model who have compared emissions calculated by COPERT with instantaneous vehicle emission simulation models, the agreement is quite good when used to estimate average emissions along a length of road of around a few hundred metres or more (or in a network of roads that cover that sort of area), but not at specific points along that length of road.

How applicable an emission factor calculated from a COPERT-based curve at 40 mph is to a stop-start motorway rather than free-flowing rural road with the same average speed, for example, depends on how much the emission curve at this speed is weighted towards measurements made under each of these different conditions; this is not known, but at these moderate to higher speeds, the COPERT curves are probably more weighted towards, and therefore more applicable to, free-flowing traffic.

A measure of how well the emission factors and modelling approach serve the inventory at least for total road transport CO_2 emissions and fuel consumption at national level is given by the agreement between model estimates of fuel consumption and national statistics on fuel sales as given in the Digest of UK Energy Statistics. As reported in the UK's National Inventory Report produced each year on the UK's greenhouse gas inventory,[5] the NAEI's bottom-up method using these fuel consumption factors underestimates petrol and diesel consumption by <10% in 2016. This issue is further discussed in Section 11.2. However, this agreement should not be taken as a measure of uncertainty at local level, on a specific road or type of vehicle, nor should it be inferred the same level of uncertainty applies to emissions of NO_x and PM.

[5] https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1804191054_ukghgi-90-16_Main_Issue1.1_UNFCCC.pdf

11 National Emission Totals from the NAEI

DfT required figures on total emissions of NOx, PM and CO_2 and fuel consumption in 2003, 2005, 2010 and 2015 reported by the latest version of the NAEI at GB and UK level grouped by vehicle category: cars, LGVs, HGVs and buses/coaches. The NAEI data will be used to "calibrate" the baseline figures from the NTM using the new emission curves.

Some differences in bottom-up estimates of emissions from the NTM and NAEI can be expected for several reasons even though they are from the same source of emission factors and are based on broadly the same input assumptions. One reason is the assumptions made about average vehicle speed in the NTM and NAEI models and the number of vkm travelled at different speeds. The NAEI uses speeds from a variety of sources, including figures reported in DfT statistics Bulletins and from the London Atmospheric Emissions Inventory in the case of roads in London. Various sources, including outputs from the NTM model itself and also the 2007 Annual Average Daily Flow data from the DfTs national traffic census, are used by the NAEI to estimate the relative vehicle km travelled on different road and area types at different speeds. These speeds may not be the same as those used in the baseline NTM.

Although the NTM curves include allowance for a range of additional factors such as degradation, another main reason for the differences is the NAEI total figures include the contribution of cold start emissions, the excess emission that occurs when a vehicle is started with its engine below normal operating conditions. The emission curves all refer to hot exhaust emissions only.

Further details on the methodology and assumptions used to develop the current UK inventory for NO_x, PM and CO_2 emissions from road transport are given in the latest NAEI report (NAEI, 2018a).

11.1 NO_x and PM emissions from the NAEI

The NAEI model was used to provide figures on NO_x and PM_{10} exhaust emissions by main vehicle and fuel type at UK level and at GB level by separating out the emissions in Northern Ireland. The Northern Ireland emissions were taken from the latest inventories prepared for each of the Devolved countries (NAEI, 2018b). The NAEI also normally includes emissions from motorcycles, but these were left out of the figures provided as this vehicle type is not covered in the NTM. The modelling methodology used is consistent with the emission factors and assumptions that underpin the emission curves and are those used for the 2016 version of the NAEI published in 2018 and the road transport emission projections for Defra (Base 2016) published in 2017. They are also consistent with the EFT v8.0 and air quality modelling done for Defra to underpin the Government's air quality plan for nitrogen dioxide (NO_2) in the UK, published in 2017.[6]

Table 19 and Table 20 show the GB and UK emissions of NO_x and PM, respectively in 2003, 2005, 2010 and 2015 by vehicle and fuel type. Hot exhaust and cold start emissions in kilotonnes/year are shown separately. Cold start emissions are only estimated for cars and LGVs. As the NTM does not currently include cold start emissions, the NAEI figures for hot exhaust emissions are more directly comparable, but by including the cold start contribution gives DfT the opportunity to provide a cold start 'uplift' to its output should it wish. Further comments on cold start emissions were given in Section 10.2.1 and recommendations for potentially including them in future NTM calculations are being provided in a supplementary report.

11.2 CO_2 emissions and fuel consumption from the NAEI and DUKES

Table 21 and Table 22 show the corresponding figures for fuel consumption and CO_2 emissions expressed in million tonnes/year. These figures are 'bottom-up' estimates from the NAEI's road transport model using the same vehicle activity information as used for the NO_x and PM inventories and consistent with the emission curves provided for the NTM and WebTAG. However, these are not the

[6] https://www.gov.uk/government/publications/air-quality-plan-for-nitrogen-dioxide-no2-in-uk-2017

official figures reported by the UK for GHG inventory reporting under the UN Framework Convention on Climate Change (UNFCCC). The official figures on UK CO_2 emissions from road transport also include emissions from mopeds and motorcycles and the totals for all vehicle types are constrained to be consistent with the total fuel sales figures given in the Digest of UK Energy Statistics (DUKES) after correcting the latter for small amounts of these fuels used for off-road transport and machinery and recognising that the DUKES consumption figures exclude biofuels. This is in accordance with rules for reporting national CO_2 emissions to the UNFCCC which require an overall energy balance and with emissions of CO_2 from consumption of biofuels not included in national totals. Even after accounting for the differences in scope, there is normally a gap between the bottom up estimates of fuel consumption and DUKES-based fuel sales figures which fluctuates from year to year, but with the bottom-up estimates being consistently lower. This gap reflects both the uncertainty in the fuel consumption factors, modelling methodology and activity data (e.g. the vehicle km figures broken down into the components of the fleet). 'Fuel tourism', whereby fuel is purchased abroad (and therefore not reported in DUKES) and consumed on UK roads, and vice versa, can also have an effect on this comparison.

The NAEI forces agreement with DUKES at a vehicle type level by normalising the bottom-up estimates in Table 21 to the petrol and diesel consumption figures in DUKES (after excluding off-road consumption), as shown in Table 23. However, the unconstrained figures in Table 21 provide a better comparison with the outputs from the NTM because they are based on the same emission curves and fleet compositions at a vehicle type level.

DfT may also wish to normalise outputs from the NTM and WebTAG to DUKES and the official CO_2 inventory, but if it wishes to understand and reconcile the differences, it is important to recognise that the petrol and diesel figures in DUKES refer only to the delivery of fossil fuels for consumption; as stated above, they exclude the consumption of biofuels which currently make up around 5-10% of all fuels sold. Since they are based on a bottom-up modelling procedure from vehicle activity information and consumption factors, the unconstrained consumption figures from the NAEI model in Table 21 refer to the total fuel or energy required to propel the UK fleet of vehicles and therefore include the consumption of biofuels as well as fossil fuels. The same would be the case in the fuel consumption outputs from the NTM and WebTAG.

To give DfT the option of comparing and reconciling outputs from NTM and WebTAG with DUKES, the quantity of biofuels consumed in the UK is required. These are shown in Table 24 and Table 25 in two different forms for the years 2003, 2005, 2010 and 2015. Bioethanol is the main biofuel component of petrol. Table 24 shows consumption figures of biodiesel and bioethanol in litres, as provided directly by the source of this information HMRC (2017). Table 25 provides the biofuel consumption figures in terms of their fossil fuel petrol and diesel equivalence, in kilotonnes, taking account of the mass fuel density of these fuels and their different energy contents. In effect, these figures provide the amount of fossil fuel petrol and diesel they have displaced and when added to the fossil fuel figures based on DUKES, make a more valid comparison of bottom-up estimates of fuel consumption. To make a further valid comparison, DfT will need to include the NAEI's estimates for fuel consumption by mopeds and motorcycles which is the purpose for including these vehicles in Table 21.

Table 26 illustrates the agreement between the NAEI model estimates of fuel consumption and statistical values from DUKES when the scope is the same and the fossil fuel equivalence of the fuel displaced by biofuels is added to DUKES. This table makes comparisons easier by bringing together consumption values taken from other tables, as indicated, and shows the ratio of NAEI model estimates to DUKES equivalent values (as indicated in the third row of the table for petrol and diesel). This ratio is a measure of agreement between the model estimates and independent statistical sources of data on fuel consumption. The table shows how the ratio is consistently <1 indicating that the NAEI model tends to underestimate fuel consumption, but the differences are less than 10% across all years and nearer 5% in recent years.

One of the requirements for greenhouse gas inventory reporting to the UNFCCC is not to include the CO_2 emissions from the consumption of biofuels, hence normalising the UK's CO_2 inventory for road transport to DUKES meets these requirements. However, this is not the case for air pollutants, NO_x and PM. The consumption of biofuels will lead to emissions of these pollutants and this will be included in the bottom-up estimates of emissions of these pollutants using vehicle activity data and the emission curves. The effect that the presence of biofuels has on exhaust emissions of these pollutants is accounted for in the fuel quality scaling factors described in Section 5.1.2, but being a result of the combustion process in a rather complex manner means that the emissions themselves cannot be allocated between the fossil fuel and biofuel components of a fuel blend in the way that CO_2 emissions can be.

Table 19: UK and GB exhaust emissions of NO_x from road vehicles from the NAEI (in kilotonnes/year)

Region	Source	Fuel	Hot or Cold Exhaust	2003	2005	2010	2015
Great Britain	Passenger Cars	DERV	Hot	62.9	77.9	92.3	111.6
	Passenger Cars	DERV	Cold	3.5	4.3	6.0	6.6
	Passenger Cars	Petrol	Hot	202.3	153.0	49.7	19.6
	Passenger Cars	Petrol	Cold	30.8	24.4	9.2	2.3
	Light duty vehicles	DERV	Hot	57.1	60.4	56.2	85.7
	Light duty vehicles	DERV	Cold	3.0	3.0	2.6	4.2
	Light duty vehicles	Petrol	Hot	12.9	7.0	1.6	0.4
	Light duty vehicles	Petrol	Cold	0.8	0.5	0.2	0.0
	HGV - Articulated	DERV	Hot	92.9	90.6	57.5	20.6
	HGV - Rigid	DERV	Hot	78.0	75.0	51.5	28.4
	Buses and coaches	DERV	Hot	46.4	42.4	34.1	19.1
	Total			**590.4**	**538.5**	**360.8**	**298.4**
UK	Passenger Cars	DERV	Hot	66.9	82.6	97.4	117.1
	Passenger Cars	DERV	Cold	3.7	4.6	6.4	7.0
	Passenger Cars	Petrol	Hot	209.3	158.5	51.6	20.3
	Passenger Cars	Petrol	Cold	32.0	25.4	9.6	2.4
	Light duty vehicles	DERV	Hot	58.1	61.3	57.1	87.0
	Light duty vehicles	DERV	Cold	3.1	3.0	2.7	4.3
	Light duty vehicles	Petrol	Hot	13.0	7.0	1.6	0.4
	Light duty vehicles	Petrol	Cold	0.8	0.5	0.2	0.0
	HGV - Articulated	DERV	Hot	96.3	93.6	59.3	21.1
	HGV - Rigid	DERV	Hot	81.5	78.1	53.9	29.7
	Buses and coaches	DERV	Hot	47.1	43.0	34.6	19.4
	Total			**611.6**	**557.8**	**374.4**	**308.7**

Table 20: UK and GB exhaust emissions of PM from road vehicles from the NAEI (in kilotonnes/year)

Region	Source	Fuel	Hot or Cold Exhaust	2003	2005	2010	2015
Great Britain	Passenger Cars	DERV	Hot	4.07	3.95	3.36	2.07
	Passenger Cars	DERV	Cold	1.46	1.42	1.45	0.75
	Passenger Cars	Petrol	Hot	0.57	0.49	0.31	0.26
	Passenger Cars	Petrol	Cold	0.00	0.00	0.00	0.00
	Light duty vehicles	DERV	Hot	4.60	4.28	3.00	1.60
	Light duty vehicles	DERV	Cold	1.57	1.37	0.92	0.35
	Light duty vehicles	Petrol	Hot	0.02	0.01	0.00	0.00
	Light duty vehicles	Petrol	Cold	0.00	0.00	0.00	0.00
	HGV - Articulated	DERV	Hot	2.14	1.88	0.92	0.36
	HGV - Rigid	DERV	Hot	1.85	1.62	0.87	0.43

	Buses and coaches	DERV	Hot	0.99	0.77	0.45	0.23
	Total			**17.26**	**15.78**	**11.28**	**6.04**
UK	Passenger Cars	DERV	Hot	4.32	4.18	3.55	2.17
	Passenger Cars	DERV	Cold	1.56	1.52	1.54	0.79
	Passenger Cars	Petrol	Hot	0.59	0.50	0.32	0.27
	Passenger Cars	Petrol	Cold	0.00	0.00	0.00	0.00
	Light duty vehicles	DERV	Hot	4.68	4.35	3.05	1.63
	Light duty vehicles	DERV	Cold	1.60	1.39	0.93	0.35
	Light duty vehicles	Petrol	Hot	0.02	0.01	0.00	0.00
	Light duty vehicles	Petrol	Cold	0.00	0.00	0.00	0.00
	HGV - Articulated	DERV	Hot	2.21	1.94	0.94	0.37
	HGV - Rigid	DERV	Hot	1.93	1.69	0.91	0.45
	Buses and coaches	DERV	Hot	1.00	0.78	0.46	0.23
	Total			**17.92**	**16.36**	**11.72**	**6.27**

Table 21: UK and GB fuel consumption (unconstrained) from road vehicles from the NAEI (in Million tonnes/year)

Region	Source	Fuel	2003	2005	2010	2015
Great Britain	Passenger Cars	DERV	4.77	5.81	7.93	9.64
	Passenger Cars	Petrol	16.64	15.72	13.02	10.54
	Light duty vehicles	DERV	3.77	4.21	4.64	5.24
	Light duty vehicles	Petrol	0.55	0.43	0.30	0.21
	HGV - Articulated	DERV	3.21	3.39	3.21	3.51
	HGV - Rigid	DERV	2.51	2.60	2.36	2.28
	Buses and coaches	DERV	1.41	1.36	1.32	1.10
	Mopeds + Motorcycles	Petrol	0.21	0.20	0.17	0.16
	Total	**DERV**	**15.68**	**17.36**	**19.46**	**21.77**
	Total	**Petrol**	**17.40**	**16.35**	**13.49**	**10.90**
UK	Passenger Cars	DERV	5.07	6.17	8.38	10.12
	Passenger Cars	Petrol	17.17	16.26	13.50	10.93
	Light duty vehicles	DERV	3.84	4.27	4.71	5.32
	Light duty vehicles	Petrol	0.56	0.43	0.30	0.21
	HGV - Articulated	DERV	3.33	3.50	3.31	3.60
	HGV - Rigid	DERV	2.63	2.71	2.47	2.38
	Buses and coaches	DERV	1.43	1.38	1.35	1.13
	Mopeds + Motorcycles	Petrol	0.21	0.20	0.17	0.16
	Total	**DERV**	**16.30**	**18.02**	**20.22**	**22.55**
	Total	**Petrol**	**17.94**	**16.88**	**13.97**	**11.30**

Table 22: UK and GB emissions of CO_2 (unconstrained) from road vehicles from the NAEI (in Million tonnes CO_2/year)

Region	Source	Fuel	2003	2005	2010	2015
Great Britain	Passenger Cars	DERV	15.09	18.39	25.09	30.50
	Passenger Cars	Petrol	52.15	49.30	40.82	33.03
	Light duty vehicles	DERV	11.94	13.32	14.68	16.57
	Light duty vehicles	Petrol	1.74	1.33	0.94	0.65
	HGV - Articulated	DERV	10.17	10.71	10.15	11.11
	HGV - Rigid	DERV	7.96	8.23	7.48	7.22
	Buses and coaches	DERV	4.46	4.30	4.18	3.49
	Mopeds + Motorcycles	Petrol	0.65	0.62	0.52	0.49
	Total	**DERV**	**49.61**	**54.94**	**61.58**	**68.89**
	Total	**Petrol**	**54.54**	**51.25**	**42.28**	**34.17**
UK	Passenger Cars	DERV	16.03	19.52	26.52	32.02
	Passenger Cars	Petrol	53.84	50.96	42.32	34.28
	Light duty vehicles	DERV	12.15	13.52	14.92	16.84
	Light duty vehicles	Petrol	1.74	1.34	0.94	0.65
	HGV - Articulated	DERV	10.54	11.07	10.46	11.38
	HGV - Rigid	DERV	8.32	8.56	7.82	7.54
	Buses and coaches	DERV	4.53	4.36	4.26	3.56
	Mopeds + Motorcycles	Petrol	0.66	0.63	0.53	0.50
	Total	**DERV**	**51.57**	**57.03**	**63.98**	**71.34**
	Total	**Petrol**	**56.25**	**52.93**	**43.79**	**35.43**

Table 23: Total UK petrol and diesel fossil fuel consumption by road transport based on DUKES (2017) after subtraction of consumption by off-road transport and machinery

Mtonnes fuel	2003	2005	2010	2015
Petrol	19.518	18.432	14.172	11.629
Diesel	17.343	18.985	20.334	23.216

Table 24: Total UK biofuel consumption according to figures from HMRC

Million litres	2003	2005	2010	2015
Bioethanol	0	85	631	796
Biodiesel	19	33	1049	670

Table 25: Total fossil fuel equivalence by energy content of consumption of bioethanol and biodiesel. Equivalent to the amount of fossil fuel displaced by biofuels

Mtonnes	2003	2005	2010	2015
Petrol	0	0.041	0.300	0.379
Diesel	0.015	0.025	0.811	0.518

Table 26: Comparison of NAEI model calculated fuel consumption with data from DUKES (excluding consumption by off-road machinery). Biofuel equivalent refers to the figures from Table 25 in Mtonnes. Ratio NAEI consumption/fuel sales is the ratio of NAEI bottom-up estimates of fuel consumption with the sum of consumption from DUKES plus fossil fuel equivalence of biofuels

Mtonnes fuel			2003	2005	2010	2015
Petrol	DUKES (exc off-road)	Table 23	19.52	18.43	14.17	11.63
	Biofuel equivalent	Table 25	0.00	0.04	0.30	0.38
	Total fuel sales		19.52	18.47	14.47	12.01
	NAEI consumption est (UK)	Table 21	17.94	16.88	13.97	11.30
	Ratio NAEI consumption/fuel sales		**0.92**	**0.91**	**0.97**	**0.94**
Diesel	DUKES (exc off-road)	Table 23	17.34	18.98	20.33	23.22
	Biofuel equivalent	Table 25	0.02	0.03	0.81	0.52
	Total fuel sales		17.36	19.01	21.14	23.73
	NAEI consumption est (UK)	Table 21	16.30	18.02	20.22	22.55
	Ratio NAEI consumption/fuel sales		**0.94**	**0.95**	**0.96**	**0.95**

12 Conclusions

A new set of speed-emission and fuel consumption curves have been developed for WebTAG and the NTM covering each of the main vehicle categories and conventional petrol and diesel fuels covered in these DfT models. The emission curves provided to DfT have been weighted by the vehicle fleets in 2010, 2015, 2020, 2025, 2030 and 2035. Separate curves were developed for the fleet in London and the rest of the UK (representing the national average fleet outside of London), for both the NTM and WebTAG. The emission curves are based on the latest COPERT 5 emission factors used in the UK's national emissions inventory and projections for Defra and BEIS. The updates to the emission curves also reflect changes to the fleet composition data used to weight the emission curves for different years. A much more detailed set of fleet composition data provided by TfL has allowed emission curves for different parts of London to be developed which take into account the introduction of the ULEZ scheme in central London.

Compared with the emission curves developed in 2013/14, the changes are mainly due to updates to the source of emission factors from the COPERT database. The new curves take account of more recent evidence on the real-world emission performance of Euro 5 and Euro 6 diesel cars and vans. Compared with the previous curves this has led to an increase in the factors for NO_x in years up to 2025, but in later projection years the new factors are lower than the previous factors because COPERT 5 takes into account a third legislative stage of Euro 6 (Euro 6d) that comes into effect in 2020 requiring vehicles to comply with Real Driving Emissions legislation.

A new method in COPERT and the EMEP/EEA Emissions Inventory Guidebook has been used to treat the gradual changes in the real-world CO_2 and fuel consumption factors for new passenger cars in the fleet since 2005. This method utilises UK specific information on the fleet-average CO_2 emissions of new cars sold in the UK according to industry figures and applies a real-world uplift to scale the emission factors in COPERT for different years. Changes in the fuel consumption and CO_2 curves for HGVs and buses are largely due to the curves being derived from COPERT rather than an older source of factors from TRL equations and are no longer calibrated against the independent source of fleet-averaged fuel efficiency data previously provided by DfT from the CSRGT and BSOG sources.

Development of the emission curves for the NTM and WebTAG required refitting the emission curves in the new COPERT equation format to the 6^{th}-order and 3^{rd}-order polynomial equations used in the NTM and WebTAG, respectively. The statistical re-fitting reproduced the emission factors from the NTM and WebTAG equations very well at most speeds compared with the original COPERT curves. The differences were less than 1% at most speeds, but somewhat higher at the extreme ends of the valid speed ranges. The largest errors in the WebTAG curves were 7% for petrol cars at the extreme ends of the speed range. The largest error in the NTM curves was 11% in the 2035 curve for coaches. The emission curves should not be used outside their valid speed ranges.

A new set of total fuel consumption, CO_2, NO_x and PM emission estimates for road transport in the UK and Great Britain was provided for specific years up to 2015, consistent with the latest version of the UK's National Atmospheric Emissions Inventory (the 2016 NAEI published in 2018). These may be used to calibrate outputs from the NTM and WebTAG.

The limitations in the emission curves were considered. The curves refer to a relationship between emission factors and average speed of a drive cycle and should not be inferred to represent instantaneous emission rates at a specific, transient speed and therefore are not representative of very localised emissions from road transport sources.

The emission curves refer to hot exhaust emissions for conventional petrol and diesel fuelled vehicles and do not account for the uptake of alternative fuelled- and ultra-low emission vehicles. Consideration of the uptake of these vehicle types will be important for the NTM and WebTAG to make a true reflection of the emission performance of the future fleet, particularly for CO_2 emissions and fuel consumption. Emission curves for these types of vehicles are being considered in a separate report. For NO_x and PM, the curves for future years reflect the penetration of vehicles meeting standards up to Euro 6d/Euro VI, but for fuel consumption and CO_2, no further improvement in the factors for conventional fuelled petrol and diesel vehicles entering the fleet in 2016 are considered and the same COPERT correction factors that applied to new cars in 2016 are applied to new cars in future years. However, the spreadsheet providing the NTM curves to DfT has the capacity to change the engine size distribution of new car sales in future years and so account for the effect of downsizing engine size, for example.

The emission curves exclude excess cold start emissions and non-exhaust sources of air pollutant emissions from road transport. An approach for dealing with cold start emissions in the NTM is being considered in a separate report to DfT. Emission factors for non-exhaust sources of PM cannot be expressed as continuous speed-emission curves, but a table of factors for different vehicle and road types has been provided.

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