London Exhaust Emissions Study

Developing a test programme and analysis of emissions data from passenger cars in London

MAYOR OF LONDON

TRANSPORT FOR LONDON
EVERY JOURNEY MATTERS

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1. Introduction

Transport for London (TfL) recognises that existing methods for assessing road vehicle emissions may not be particularly appropriate for the unique conditions in London, particularly given the high levels of traffic congestion. To address this, TfL has undertaken a study to investigate passenger car emissions in London. This study consisted of:

- Definition of a passenger car drive cycle specifically designed for London. This allows laboratory emissions testing using acceleration; cruising and deceleration phases that were data logged on London streets and as such, represent a typical pattern of driving in London.
- Testing a representative sample of cars on a dynamometer in an emissions test laboratory, over the London drive cycle and measuring the emissions.
- Generation of a series of emissions curves that reflect the measured emissions for a given average speed, for each vehicle.
- Comparing the sample of London emissions curves with standard UK Department for Transport (DfT) emissions curves and identifying any discrepancies. In this respect there is a general and expected tendency for the London emissions curves to show higher emissions than the DfT curves.
- Identifying the reasons for the London curves being higher than the DfT curves. These reasons may be anticipated to be:
  - Differences between driving conditions in London and the average driving conditions on which the DfT curves are based.
  - Differences in the test conditions – for example, in the TfL tests allowance was made for use of certain ancillary systems on the vehicle such as air conditioning and lights. This is not the case with the DfT curves.

This work both extends the range of information available to air quality practitioners, and has implications for the more accurate representation of road traffic emissions in urban emissions inventories. However, it should be noted that the modelling of pollution concentrations will generally include corrections that account, in a general way, for any systematic over- or under-representation of vehicle emissions.

The first step, defining London drive cycles, is described in the separate paper entitled 'Summary of the drive cycle development, test programme and comparison of test data compared with Type Approval data'. This section describes the testing of a range of passenger vehicles and analysis of the emissions data generated by that programme of testing.

Adapting the Passenger Car Drive Cycle for the Exhaust Emissions Study project

The principal subject of this paper is to derive improved data for exhaust emissions from passenger cars in London. In order to do this, it is necessary to consider driving conditions on different road types under various traffic conditions.

To facilitate this, TfL's new drive cycle for London was broken down into nine sub-cycles, representing the three broad road types (urban, sub-urban and motorway) under the three broad traffic conditions (free flow, AM peak and inter peak). The resultant cycles are all of the same duration, but vary considerably in transience for speed and acceleration (see figure 1 for examples of the sub-cycles). Therefore the respective cycle distances vary. Inclusion of both cold and warm starts leads to a programme of fifteen possible sub-cycles. The framework of the sub-cycles is illustrated in table 1.

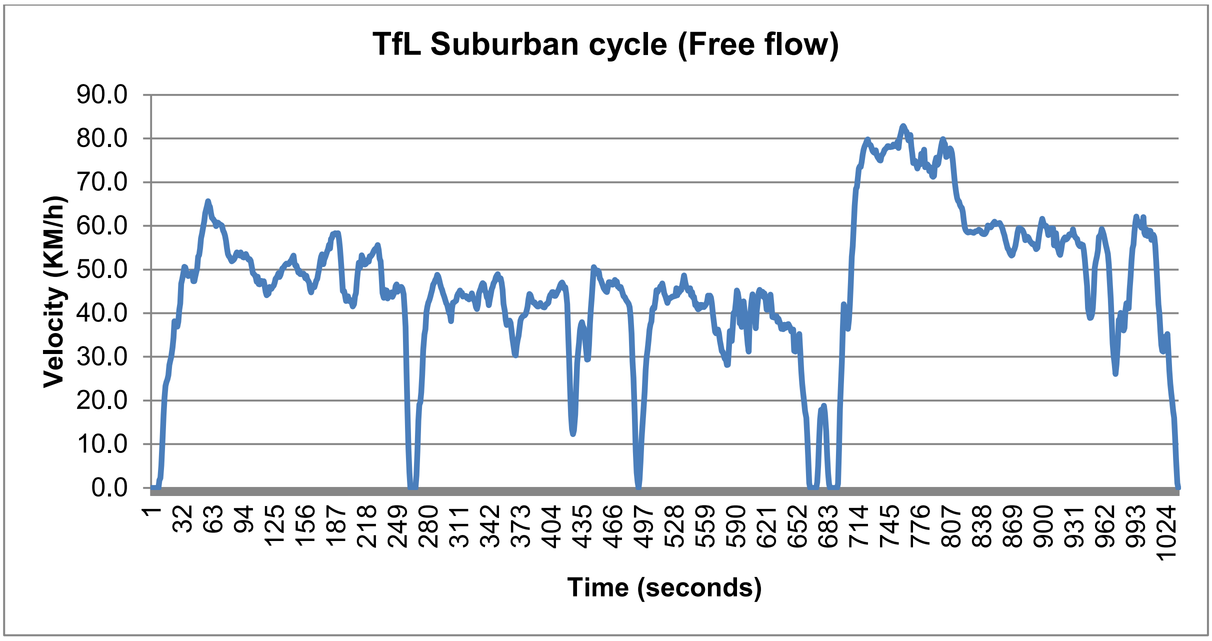
Table 1 Structure of the TfL test programme.

TfL Drive Cycle test programme

Drive cycle	**Cold start Urban**	**Warm start Urban**	**Cold start Suburban**	**Warm start Suburban**	**Warm start Motorway**
Traffic condition	Free flow AM Peak Inter peak	Free flow AM Peak Inter peak	Free flow AM Peak Inter peak	Free flow AM Peak Inter peak	Free flow AM Peak Inter peak

To illustrate how the transient nature of traffic flow varies with time of day, the Suburban Free flow and Suburban AM peak drive cycles are illustrated below. To conserve space, not all the drive cycles are included here, but these two demonstrate the range of variability. Table 2 below, contains details of the drive cycle average speed, and total distance, for each of the drive cycles

Figure 1 TfL Suburban drive cycles.



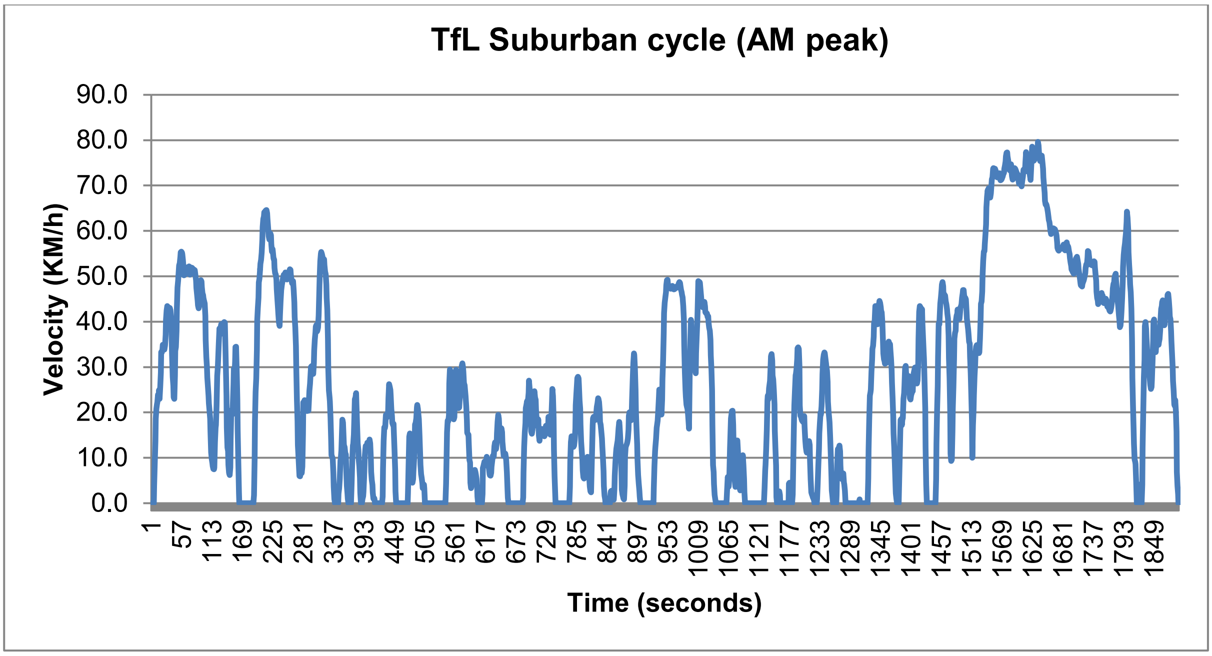


Table 2 TfL drive cycle details.

Drive cycle	Drive cycle average speed (km/h)	Distance (km)
Hot Urban Inter Peak	13.9	9.07
Hot Suburban Am Peak	25.3	13.57
Hot Urban Free Flow	26.7	8.92
Hot Suburban Inter Peak	30.2	13.59
Hot Suburban Free Flow	46.3	13.59
Hot Motorway Am Peak	47.0	24.69
Hot Motorway Inter Peak	86.0	24.82
Hot Motorway Free Flow	86.6	24.61

2. The vehicles selected for test

The initial selection of vehicles to test was designed to capture the full range of passenger car types, taking into account, market segment, typical road-load inertia and most popular fuel type in the segment (table 3).

Whilst nine market segment groups were identified for passenger cars, it was determined that the test inertia, engine size and fuel type for some groups were so similar that the groups could be combined to reduce the number of vehicle tests needed.

In order to provide an equal basis for comparison, the chosen vehicles were of the same Euro standard, Euro 4 in this case. Tests of some Euro 2 vehicles were included to allow comparison between the emissions performance of equivalent vehicles over a spread of approximately 10 years.

Table 3 Vehicle market segment groups identified by TfL.

Category	Example model	Fuel type	Transmission
Compact	C1/107/Aygo	Gasoline	Manual
Supermini	Uno/Fiesta/Polo	Diesel	Manual
Small family	Astra/Focus	Gasoline	Manual
Hybrid Saloon	Prius	Gasoline	CVT
Family	Mondeo/Vectra	Diesel	Automatic
MPV	Galaxy/Zafira	Diesel	Automatic
Prestige saloon	7 Series/S class	Gasoline	Automatic
Premium Sports	911/M3/Ferrari	Gasoline	Auto shift Manual
SUV/4X4	X5/Range Rover	Diesel	Automatic
Family Euro 2	Vectra/Mondeo	Gasoline	Manual
Family Euro 2	Vectra/Mondeo	Diesel	Manual

It should be noted at this stage that the TfL test vehicles were selected as being representative of the majority of vehicles within each market segmentation group. The selection process was not targeted to reveal particularly good, or bad, performers.

Summary of test results

The table below shows key results from the TfL emissions testing and compares them against equivalent results from the NEDC drive cycle. The NEDC (New European Drive Cycle) is the cycle used for emissions testing at Type Approval. It also is used to produce the 'official' fuel consumption and CO_2 emissions data that vehicle manufacturers are required to declare.

In table 4, results for three different tests have been included. These are the type approval NEDC test, the TfL warm start suburban test under free flow traffic conditions and the TfL cold start urban test under inter peak traffic conditions. These have been selected because the warm suburban free flow test produces results most similar to NEDC and the Cold urban inter peak produces the greatest difference from NEDC. All the other TfL cycles produce test results in a range between these. It is clear from table 4 that some of the emissions values are lower than the NEDC results, whilst others are more than double those of the NEDC. This illustrates the scale of the problem when attempting to characterise the emissions of traffic in London. At this stage, only CO_2, NO_x and PM_{10} are considered.

Table 4 Comparison of key emissions from tested vehicles; NEDC versus TfL warm start Suburban free flow and cold start Urban inter peak cycles.

Market segment	Fuel type	New European Drive Cycle			TfL Warm Suburban free flow			TfL Cold Urban Inter peak		
		CO2 g/km	NOx g/km	PM g/km	CO2 g/km	NOx g/km	PM g/km	CO2 g/km	NOx g/km	PM g/km
Compact	Petrol	109	0.01	N/A	91.7	0.011	0	171.4	0.044	0.03
Supermini	Diesel	119	0.203	0.02	125.7	0.489	0.02	189	1.035	0.06
Small family	Petrol	162	0.031	N/A	157.2	0.01	N/A	314.5	0.085	N/A
Family/MPV	Diesel	172	0.237	0	165.2	0.396	0	353.4	0.742	0
Prestige/Sports	Petrol	323	0.051	N/A	288.6	0.154	0	588.2	0.259	0
SUV/4x4	Diesel	214	0.305	0	205.7	0.84	0	447.5	1.21	0
Hybrid saloon	Petrol/electric	92	0.01	N/A	90	0	0	163.7	0.028	0.01
Family E2	Petrol	178	0.086 (HC+NOx)	N/A	190.2	0.135	0	412.9	0.269	0
Family E2	Diesel	151	0.591 (HC+NOx)	0.07	138.7	0.55	0.03	265.6	1.267	0.05

Alignment of TfL test vehicles with DfT vehicle types

The nine passenger cars used by TfL in the vehicle testing programme were matched to the nearest equivalent vehicle category contained in the DfT Road Vehicle Emission Factors 2009 database. The DfT vehicle categories are assigned according to vehicle type, vehicle weight, fuel type, engine capacity and Euro emission standard. Each category contains appropriate emissions factors for CO_2, NO_x and PM for use in emissions modelling. These emissions factors are derived from the results of many vehicle emissions tests, conducted to various drive cycles. The emissions factors are held within the Emissions Factors Toolkit (EFT), compiled by DfT and providing a common foundation for emissions modelling in the UK. The alignment of TfL test vehicles with the respective DfT categories is shown in Table 5. The category codes (Rxxx) are used below to illustrate the comparison of data.

Table 5 TfL test vehicle and nearest equivalent category in DfT Emissions Factors Database.

TfL Test Vehicle	DfT Equivalent Vehicle Category	
	Category Code	Description
Compact saloon 1.0L Petrol Euro 4	R005	Petrol Car Euro 4 (Less than 2.5 tonnes; less than 1400 cc)
Family saloon 1.8L Petrol Euro 2	R010	Petrol Car Euro 2 (Less than 2.5 tonnes; 1400-2000 cc)
Small family 1.6L Petrol Euro 4	R012	Petrol Car Euro 4 (Less than 2.5 tonnes; 1400-2000 cc)
Prestige saloon 3.2L Petrol Euro 4	R019	Petrol Car Euro 4 (Less than 2.5 tonnes; greater than 2000 cc)
Mini saloon TDCi 1.4L Diesel Euro 4	R026	Diesel Car Euro 4 (Less than 2.5 tonnes; less than 1400 cc)
Family saloon 2.0L Diesel Euro 2	R031	Diesel Car Euro 2 (Less than 2.5 tonnes; 1400-2000 cc)
MPV 2.0L TDCi Diesel Euro 4	R040	Diesel Car Euro 4 (Less than 2.5 tonnes; greater than 2000 cc)
SUV/4x4 3.0L Diesel Euro 4		

Key observations from the testing

The main observation to be drawn from Table 4 is that the NEDC cycle is not representative of London driving patterns and is giving rise to significant underestimation of emissions. Another important observation is that there is a wide variation in the extent to which different cars diverge from the NEDC derived type approval emissions levels, when driven over the TfL cycles, according to the vehicle technology being used. For example, the hybrid car follows the type approval levels very closely, and in some cases the cycle allows for an improvement upon them, as it does with the compact car. However, high performance vehicles and in particular, diesel cars, show greater variance from the type-approval levels of emission as a result of the differing drive cycles.

A large body of data was amassed from the vehicle tests, including both bag summary data collected in accordance with directive 70/220 EEC (as amended) and instantaneous emissions data collected on a 1Hz (second by second) basis throughout the emissions test. Bag data exists for both CO_2 and the legislated air quality emissions (carbon monoxide, hydro carbons, oxides of nitrogen). Particulate Matter (PM) is not measured on a 1 Hz basis because this form of measurement is not practicable, since the PM is collected on a filter paper for weighing after the test. However, particle number counts were taken for most of the tests conducted. These are measured on a 1Hz basis.

In the following sections, results from the TfL tests are presented in comparison to the DfT equivalent, for a variety of vehicle types. This is firstly shown over complete drive cycles, then by average speed, then on a road link basis.

3. Comparison of emissions over complete drive cycles

Initial data analysis focused on complete drive cycle estimates of emissions and emission factors. TfL's approach was in accordance with the methodology used in the derivation of emission factors in the DfT database. This involved bag summary data for each of the TfL vehicle tests and for each of the nine drive cycles being used to determine total pollutant emissions (in grammes) for the whole drive cycle. The total mass of pollutant was divided by the distance travelled in kilometres (described in table 2) to obtain emission factors in grammes per kilometre for the entire drive cycle.

The average vehicle speed in km/h for each drive cycle was calculated from the drive trace and the emission factors tabulated as a function of average vehicle speed. The average drive cycle speed was used with the DfT emission functions to calculate pollutant emission factors for the nearest equivalent DfT vehicle categories. CO_2, NO_X and PM_{10} emission factors as determined from the TfL tests and DfT emission functions were compared for the nine drive cycles.

It can be seen from table 5, 6 & 7 that TfL estimates of CO_2 emissions are, on average, 18 per cent higher than the nearest equivalent DfT curve estimates, TfL NOx emission estimates are around three times greater than the equivalent DfT estimates and PM_{10} emissions estimates are, on average, approximately 5 per cent greater than DfT function predictions. It should be noted that the two light commercial vehicles included in the testing at this time (Ford Transit diesel Euro 2 and Euro 4) were significantly high emitters of NOx. They are skewing the average underestimation considerably. Despite this, many of the diesel vehicles display high emissions of NOx in the table.

Table 6 Comparison of TfL vehicle test emissions factors and DfT emissions factors foe entire drive cycle – Carbon Dioxide.

Drive cycle average speed (km/h)	TfL test result		DfT test result		Ratio of TfL test result : DfT test result
	Vehicle	Emission factor (g/km)	Vehicle category	Emission factor (g/km)	
13.9	Peugeot 107	160.0	R005	226.6	0.71
15.7	Peugeot 107	168.6	R005	208.9	0.81
25.3	Peugeot 107	124.2	R005	158.0	0.79
26.7	Peugeot 107	126.5	R005	154.0	0.82
30.2	Peugeot 107	119.7	R005	146.0	0.82
46.3	Peugeot 107	95.0	R005	128.3	0.74
47.0	Peugeot 107	127.9	R005	128.0	1.00
86.0	Peugeot 107	126.2	R005	133.2	0.95
86.6	Peugeot 107	121.5	R005	133.5	0.91
13.9	Ford Fiesta	225.5	R026	192.5	1.17
15.7	Ford Fiesta	239.8	R026	179.8	1.33
25.3	Ford Fiesta	176.4	R026	138.1	1.28
26.7	Ford Fiesta	173.6	R026	134.1	1.29
30.2	Ford Fiesta	167.0	R026	125.6	1.33
46.3	Ford Fiesta	128.2	R026	100.6	1.27
47.0	Ford Fiesta	165.9	R026	99.8	1.66
86.0	Ford Fiesta	159.5	R026	90.1	1.77
86.6	Ford Fiesta	153.8	R026	90.4	1.70
13.9	Ford Focus	311.1	R012	280.7	1.11
15.7	Ford Focus	308.4	R012	259.7	1.19
25.3	Ford Focus	227.7	R012	196.7	1.16
26.7	Ford Focus	225.9	R012	191.4	1.18
30.2	Ford Focus	208.6	R012	180.4	1.16
46.3	Ford Focus	162.9	R012	152.4	1.07
47.0	Ford Focus	189.9	R012	151.7	1.25
86.0	Ford Focus	176.0	R012	145.1	1.21
86.6	Ford Focus	171.7	R012	145.3	1.18
13.9	Vauxhall Vectra Petrol Euro 2	437.9	R010	307.2	1.43
15.7	Vauxhall Vectra Petrol Euro 2	375.3	R010	286.2	1.31
25.3	Vauxhall Vectra Petrol Euro 2	302.5	R010	223.2	1.36
26.7	Vauxhall Vectra Petrol Euro 2	272.2	R010	217.9	1.25
30.2	Vauxhall Vectra Petrol Euro 2	248.7	R010	206.9	1.20
46.3	Vauxhall Vectra Petrol Euro 2	193.4	R010	178.9	1.08
47.0	Vauxhall Vectra Petrol Euro 2	229.3	R010	178.2	1.29
86.0	Vauxhall Vectra Petrol Euro 2	202.8	R010	171.6	1.18
86.6	Vauxhall Vectra Petrol Euro 2	197.4	R010	171.8	1.15
13.9	Vauxhall Vectra Diesel Euro 2	268.0	R031	239.7	1.12
15.7	Vauxhall Vectra Diesel Euro 2	263.1	R031	227.0	1.16
25.3	Vauxhall Vectra Diesel Euro 2	192.2	R031	185.3	1.04
26.7	Vauxhall Vectra Diesel Euro 2	205.8	R031	181.3	1.13
30.2	Vauxhall Vectra Diesel Euro 2	181.0	R031	172.9	1.05
46.3	Vauxhall Vectra Diesel Euro 2	141.4	R031	147.8	0.96
47.0	Vauxhall Vectra Diesel Euro 2	178.2	R031	147.1	1.21
86.0	Vauxhall Vectra Diesel Euro 2	171.8	R031	137.4	1.25
86.6	Vauxhall Vectra Diesel Euro 2	168.2	R031	137.6	1.22

Drive cycle average speed (km/h)	TfL test result		DfT test result		Ratio of TfL test result : DfT test result
	Vehicle	Emission factor (g/km)	Vehicle category	Emission factor (g/km)	
13.9	Ford Galaxy	360.3	R040	276.1	1.31
15.7		331.9		263.4	1.26
25.3		243.7		221.7	1.10
26.7		255.2		217.7	1.17
30.2		227.0		209.2	1.08
46.3		168.4		184.1	0.91
47.0		261.4		183.4	1.43
86.0		205.8		173.7	1.18
86.6		199.1		173.9	1.14
13.9	BMW X5	469.2	R040	276.1	1.70
15.7		406.3		263.4	1.54
25.3		300.0		221.7	1.35
26.7		278.0		217.7	1.28
30.2		252.1		209.2	1.21
46.3		209.7		184.1	1.14
47.0		269.6		183.4	1.47
86.0		275.7		173.7	1.59
86.6		255.8		173.9	1.47
13.9	BMW M3	546.2	R019	415.5	1.31
15.7		542.4		384.0	1.41
25.3		408.6		288.9	1.41
26.7		415.2		280.8	1.48
30.2		384.3		263.9	1.46
46.3		299.1		219.5	1.36
47.0		314.7		218.4	1.44
86.0		280.3		202.5	1.38
86.6		272.4		202.8	1.34
13.9	Ford Transit Euro 2	335.5	R107	371.7	0.90
15.7		311.3		342.4	0.91
25.3		244.1		260.7	0.94
26.7		248.8		254.5	0.98
30.2		235.4		242.5	0.97
46.3		180.6		220.7	0.82
47.0		257.3		220.5	1.17
86.0		272.5		262.7	1.04
86.6		258.1		263.9	0.98
13.9	Ford Transit Euro 4	298.2	R109	354.2	0.84
15.7		269.8		323.8	0.83
25.3		230.5		238.0	0.97
26.7		217.1		231.4	0.94
30.2		220.5		218.6	1.01
46.3		170.3		194.7	0.87
47.0		239.0		194.5	1.23
86.0		255.5		242.0	1.06
86.6		237.4		243.5	0.97
Average – all vehicles and cycles		**230.4**		**195.0**	**1.18**

Table 7 Comparison of TfL vehicle test emission factors and DfT emission factors for entire drive cycle – Oxides of Nitrogen (NOx).

Drive cycle average speed (km/h)	TfL test result		DfT test result		Ratio of TfL test result : DfT test result
	Vehicle	Emission factor (g/km)	Vehicle category	Emission factor (g/km)	
13.9	Peugeot 107	0.066	R005	0.075	0.87
15.7		0.073		0.068	1.08
25.3		0.028		0.047	0.60
26.7		0.019		0.046	0.42
30.2		0.007		0.042	0.16
46.3		0.012		0.034	0.37
47.0		0.027		0.034	0.80
86.0		0.016		0.030	0.53
86.6		0.009		0.030	0.30
13.9	Ford Fiesta	1.113	R026	0.530	2.10
15.7		0.985		0.488	2.02
25.3		0.749		0.369	2.03
26.7		0.692		0.360	1.92
30.2		0.727		0.342	2.12
46.3		0.498		0.311	1.60
47.0		0.821		0.311	2.64
86.0		0.768		0.381	2.02
86.6		0.800		0.383	2.09
13.9	Ford Focus	0.019	R012	0.073	0.26
15.7		0.014		0.068	0.20
25.3		0.024		0.057	0.42
26.7		0.041		0.056	0.73
30.2		0.016		0.054	0.29
46.3		0.011		0.049	0.23
47.0		0.038		0.049	0.78
86.0		0.041		0.048	0.84
86.6		0.037		0.048	0.77
13.9	Vauxhall Vectra Petrol Euro 2	0.283	R010	0.208	1.36
15.7		0.233		0.200	1.16
25.3		0.209		0.180	1.16
26.7		0.164		0.179	0.92
30.2		0.167		0.176	0.95
46.3		0.151		0.176	0.86
47.0		0.188		0.176	1.07
86.0		0.435		0.200	2.18
86.6		0.257		0.200	1.28
13.9	Vauxhall Vectra Diesel Euro 2	1.263	R031	1.245	1.01
15.7		1.211		1.127	1.07
25.3		0.883		0.787	1.12
26.7		0.878		0.760	1.16
30.2		0.754		0.705	1.07
46.3		0.561		0.587	0.95
47.0		0.851		0.585	1.45
86.0		0.807		0.666	1.21
86.6		0.811		0.670	1.21

Drive cycle average speed (km/h)	TfL test result		DfT test result		Ratio of TfL test result : DfT test result
	Vehicle	Emission factor (g/km)	Vehicle category	Emission factor (g/km)	
13.9	Ford Galaxy	0.756	R040	0.634	1.19
15.7		0.620		0.570	1.09
25.3		0.623		0.386	1.62
26.7		0.606		0.371	1.64
30.2		0.633		0.340	1.86
46.3		0.406		0.270	1.50
47.0		1.003		0.269	3.73
86.0		0.836		0.288	2.90
86.6		0.858		0.290	2.96
13.9	BMW X5	2.418	R040	0.634	3.81
15.7		2.142		0.570	3.76
25.3		1.447		0.386	3.75
26.7		1.287		0.371	3.47
30.2		0.978		0.340	2.87
46.3		0.856		0.270	3.17
47.0		1.098		0.269	4.08
86.0		0.989		0.288	3.43
86.6		0.871		0.290	3.01
13.9	BMW M3	0.114	R019	0.197	0.58
15.7		0.094		0.176	0.53
25.3		0.278		0.115	2.41
26.7		0.184		0.110	1.67
30.2		0.243		0.100	2.43
46.3		0.174		0.075	2.33
47.0		0.308		0.074	4.17
86.0		0.320		0.062	5.20
86.6		0.308		0.062	5.02
13.9	Ford Transit Euro 2	10.081	R107	2.005	5.03
15.7		9.298		1.850	5.03
25.3		7.204		1.421	5.07
26.7		7.253		1.390	5.22
30.2		7.219		1.330	5.43
46.3		5.486		1.244	4.41
47.0		6.420		1.245	5.16
86.0		5.699		1.630	3.50
86.6		5.181		1.640	3.16
13.9	Ford Transit Euro 4	1.267	R109	0.560	2.26
15.7		1.096		0.518	2.11
25.3		1.010		0.404	2.50
26.7		0.841		0.396	2.12
30.2		0.935		0.381	2.45
46.3		0.672		0.366	1.84
47.0		1.936		0.366	5.28
86.0		2.208		0.511	4.32
86.6		1.962		0.514	3.81
Average – all vehicles and cycles		**1.227**		**0.411**	**2.98**

Table 8 Comparison of TfL vehicle test emission factors and DfT emission factors for entire drive cycle – Particulate Matter.

Drive cycle average speed (km/h)	TfL test result		DfT test result		Ratio of TfL test result : DfT test result
	Vehicle	Emission factor (g/km)	Vehicle category	Emission factor (g/km)	
13.9	Peugeot 107	0.003	R005	0.003	1.04
15.7		0.004		0.003	1.50
25.3		0.002		0.002	0.97
26.7		0.002		0.002	0.99
30.2		0.001		0.002	0.52
46.3		0.001		0.002	0.54
47.0		0.002		0.002	1.08
86.0		0.002		0.003	0.80
86.6		0.002		0.003	0.79
13.9	Ford Fiesta	0.064	R026	0.037	1.75
15.7		0.050		0.035	1.44
25.3		0.038		0.030	1.27
26.7		0.046		0.030	1.54
30.2		0.036		0.029	1.25
46.3		0.021		0.029	0.75
47.0		0.026		0.029	0.91
86.0		0.026		0.033	0.78
86.6		0.034		0.034	1.00
13.9	Ford Focus	No Data	R012	0.002	No Data
15.7		No Data		0.002	No Data
25.3		No Data		0.001	No Data
26.7		No Data		0.001	No Data
30.2		No Data		0.001	No Data
46.3		No Data		0.001	No Data
47.0		No Data		0.001	No Data
86.0		No Data		0.002	No Data
86.6		No Data		0.002	No Data
13.9	Vauxhall Vectra Petrol	0.003	R010	0.002	1.60
15.7		0.004		0.002	2.29
25.3		0.006		0.001	4.24
26.7		0.001		0.001	0.72
30.2		0.002		0.001	1.47
46.3		0.003		0.001	2.14
47.0		0.008		0.001	5.68
86.0		0.011		0.002	4.74
86.6		0.010		0.002	4.27
13.9	Vauxhall Vectra Diesel	0.059	R031	0.047	1.25
15.7		0.048		0.044	1.09
25.3		0.043		0.035	1.25
26.7		0.043		0.034	1.27
30.2		0.038		0.033	1.17
46.3		0.027		0.032	0.84
47.0		0.073		0.032	2.25
86.0		0.073		0.049	1.50
86.6		0.049		0.049	0.99

Drive cycle average speed (km/h)	TfL test result		DfT test result		Ratio of TfL test result : DfT test result
	Vehicle	Emission factor (g/km)	Vehicle category	Emission factor (g/km)	
13.9	Ford Galaxy	0.002	R040	0.017	0.11
15.7		0.003		0.015	0.18
25.3		0.017		0.010	1.72
26.7		0.008		0.009	0.90
30.2		0.001		0.008	0.11
46.3		0.001		0.005	0.17
47.0		0.007		0.005	1.23
86.0		0.001		0.004	0.24
86.6		0.002		0.004	0.49
13.9	BMW X5	0.009	R040	0.017	0.55
15.7		0.004		0.015	0.25
25.3		0.004		0.010	0.38
26.7		0.004		0.009	0.40
30.2		0.002		0.008	0.22
46.3		0.001		0.005	0.17
47.0		0.003		0.005	0.53
86.0		0.002		0.004	0.49
86.6		No Data		0.004	No Data
13.9	BMW M3	0.001	R019	0.007	0.15
15.7		0.002		0.006	0.31
25.3		0.001		0.005	0.20
26.7		0.002		0.005	0.41
30.2		No Data		0.005	No Data
46.3		0.001		0.005	0.22
47.0		0.001		0.005	0.22
86.0		0.002		0.006	0.31
86.6		0.005		0.007	0.76
13.9	Ford Transit Euro 2	0.056	R107	0.132	0.43
15.7		0.055		0.126	0.44
25.3		0.045		0.111	0.41
26.7		0.048		0.110	0.43
30.2		0.046		0.108	0.42
46.3		0.025		0.108	0.23
47.0		0.138		0.109	1.27
86.0		0.232		0.131	1.77
86.6		0.253		0.132	1.92
13.9	Ford Transit Euro 4	0.057	R109	0.075	0.76
15.7		0.034		0.067	0.50
25.3		0.036		0.044	0.83
26.7		0.027		0.042	0.65
30.2		0.037		0.038	0.98
46.3		0.027		0.029	0.93
47.0		0.028		0.029	0.97
86.0		0.029		0.036	0.81
86.6		0.030		0.036	0.83
Average – all vehicles and cycles		**0.031**		**0.029**	**1.05**

4. Deriving polynomial emissions functions from the TfL test data

To compare against DfT emissions factors, it is necessary to derive equivalent polynomial emissions curves from the test data. Therefore, to allow predictions of emission factors from the TfL vehicle test data over the range of speeds commonly encountered in on-highway driving (i.e. 0 km/h to 120 km/h) polynomial emission-speed curves were fitted to the data using least squares regression. This means that TfL equivalent curves are based on the whole range of the test data. However, it must be remembered that the TfL data is from a smaller sample of vehicles.

The curves took the form $y = a + bx + cx^2 + dx^3 \ldots /x$, where x = cycle average speed in km/h, to be consistent with the approach used in the DfT emission factors database.

Carbon Dioxide (CO_2)

The parameters thus generated were used to calculate CO_2 emission factors at 5km/h intervals from 5 km/h to 120 km/h for each TfL test vehicle and smooth curves were plotted. The TfL test vehicle curves were compared against the DfT emission curves for the closest corresponding vehicle category. For some TfL test vehicles it was possible to fit good curves to the test data (e.g. Compact saloon –

Figure 2 and Small Family saloon – Figure 3) and the curves displayed a very similar shape to the equivalent DfT curves despite the much smaller number of data points used in fitting curves to the TfL test vehicle data.

Figure 2 Comparison of fitted CO_2 emission curve for Compact saloon and DfT category R005.

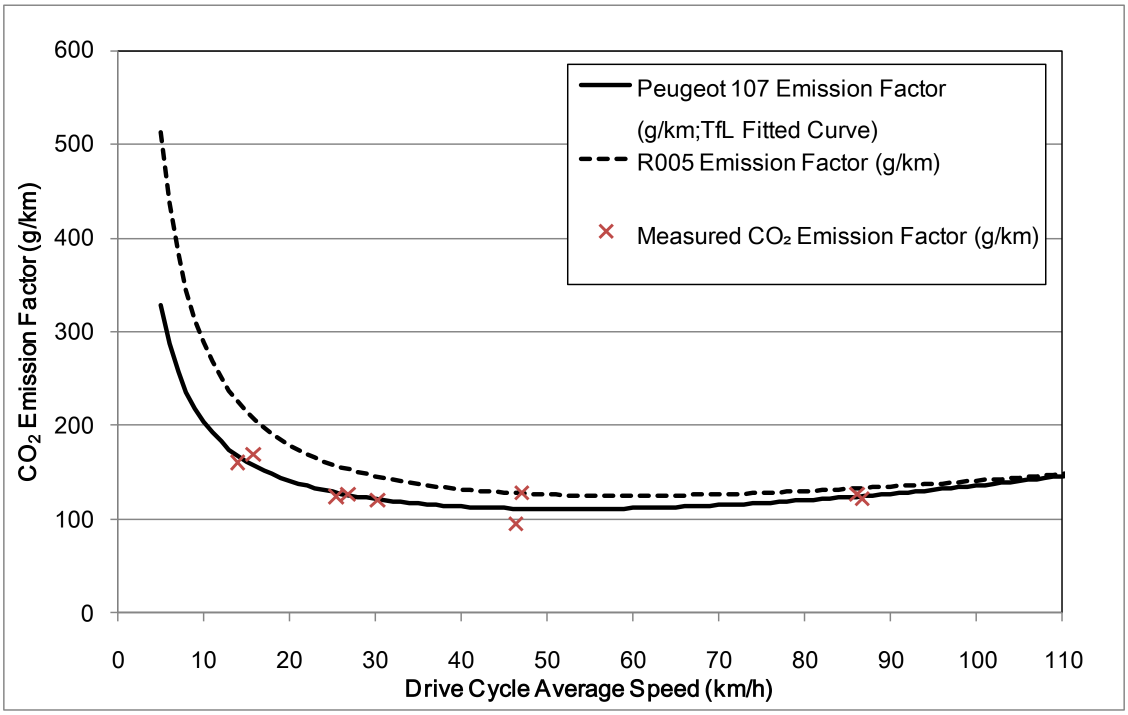
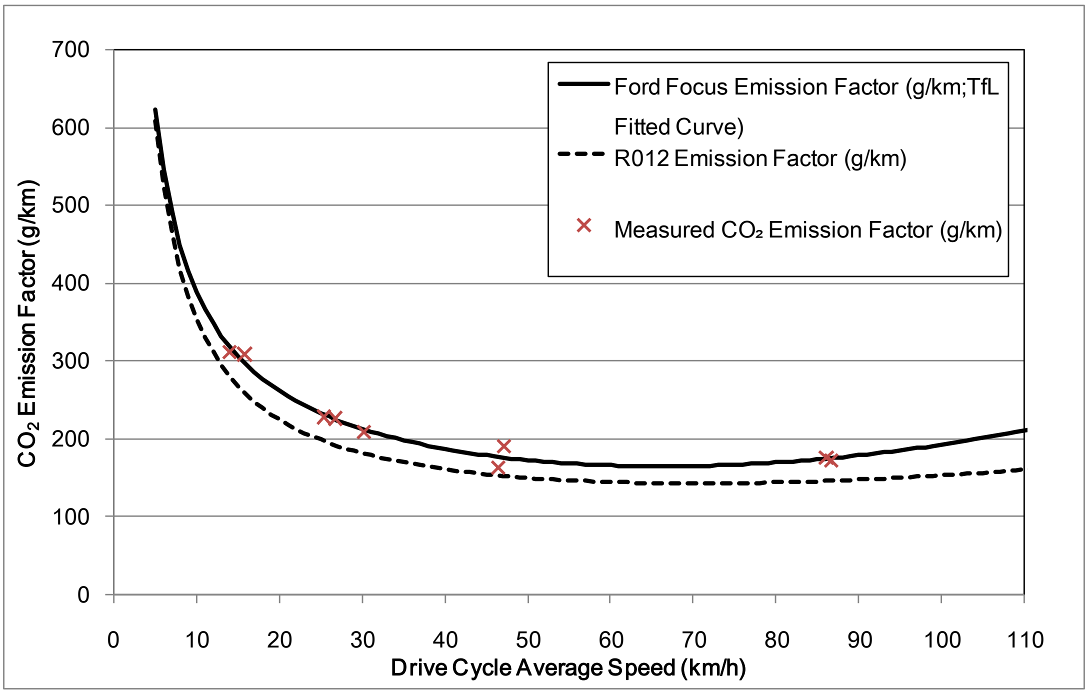
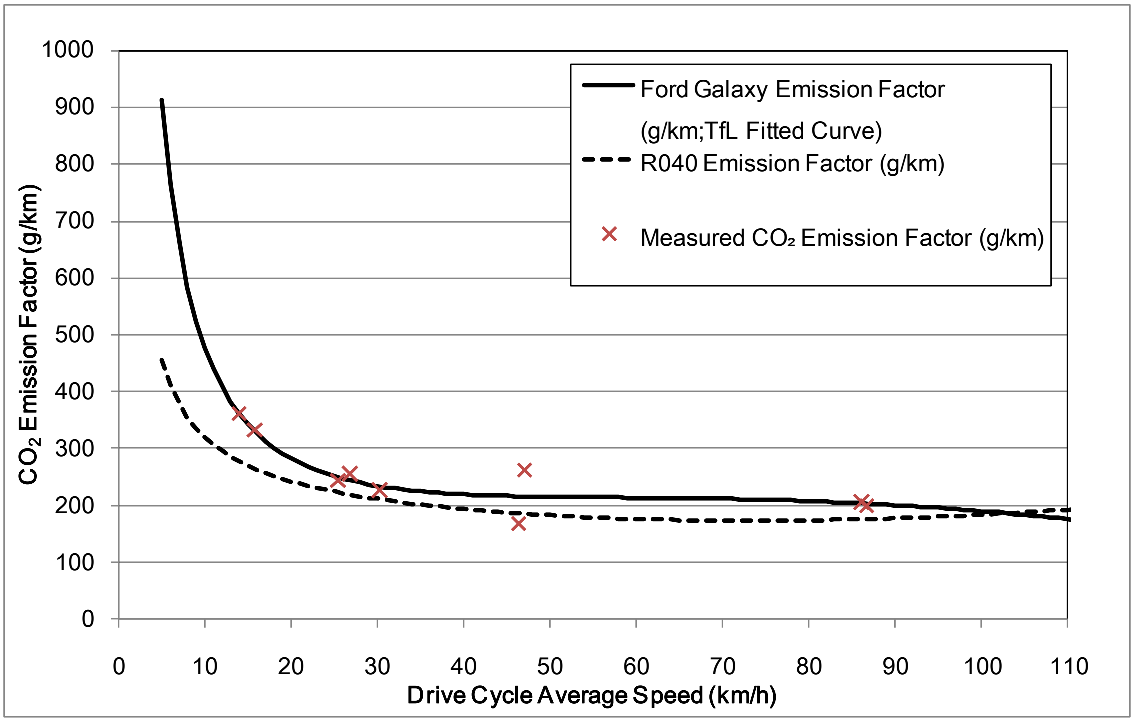


Figure 3 Comparison of fitted CO_2 emission curve for Small Family and DfT category R012.



For other vehicles the curve fit was poorer with a tendency for predicted emission factors to decrease sharply at the extreme high speed and low speed of the emissions curves (e.g. MPV – **Error! Not a valid bookmark self-reference.**). It was noted that the TfL fitted curves for CO_2 tended to produce higher estimates for emission factors than predictions using the DfT emission functions.

Figure 4 Comparison of fitted CO_2 emission curve for MPV and DfT category R040.



On average, CO_2 emissions factors derived from the TfL vehicle test data were around 14 per cent higher than equivalent DfT predictions based on analysis of a complete drive cycle. The difference observed seems to be the result of specific London driving conditions but also influenced by a combination of other factors. These include the use of ancillary equipment in the TfL vehicle tests and the fact that the DfT vehicle categories for comparison to the TfL test data, are rather broad and perhaps not well matched to the current market for new vehicles. This supports the hypothesis that the TfL test findings are representative of 'real-world' driving conditions in London.

Oxides of nitrogen and particulate matter

The outcomes of the regression analysis on NO_X and PM_{10} were similar to that of CO_2 – for some vehicles good curve fits were possible producing a smooth curve across the whole speed range between 5 km/h and 120 km/h. However, the curve fit for some vehicles was poor and in some cases, such as the diesel MPV, for PM_{10}, it was not possible at all. This can be expected due to the very small number of data points against which to perform the regression and the much lower measured masses of NO_X and PM_{10} in comparison with CO_2. For example, a Euro 4 Petrol Family Car will emit around 160 g/km CO_2 compared with 0.05 g/km NO_X and 0.0015 g/km PM_{10}, based on the output of the DfT's Emission Factors Toolkit for a Euro 4 Petrol Car (1400cc – 2000cc) travelling at 40 km/h. This serves to illustrate the relative quantum of the emission factors; CO_2 emission factors are typically 10^3 times greater than NO_X and 10^5 times greater than PM_{10}. NO_x curves are illustrated for a Euro 4 petrol compact saloon (figure 5) and a Euro 2 diesel family saloon (figure 6) below. These show a reasonable agreement between the TfL data and the DfT data, albeit that petrol vehicles equipped with catalytic convertors are frequently lower emitters of NO_x than the DfT factors might suggest.

Figure 5 Comparison of fitted NO_X emission curve for Compact Saloon and DfT category R005.

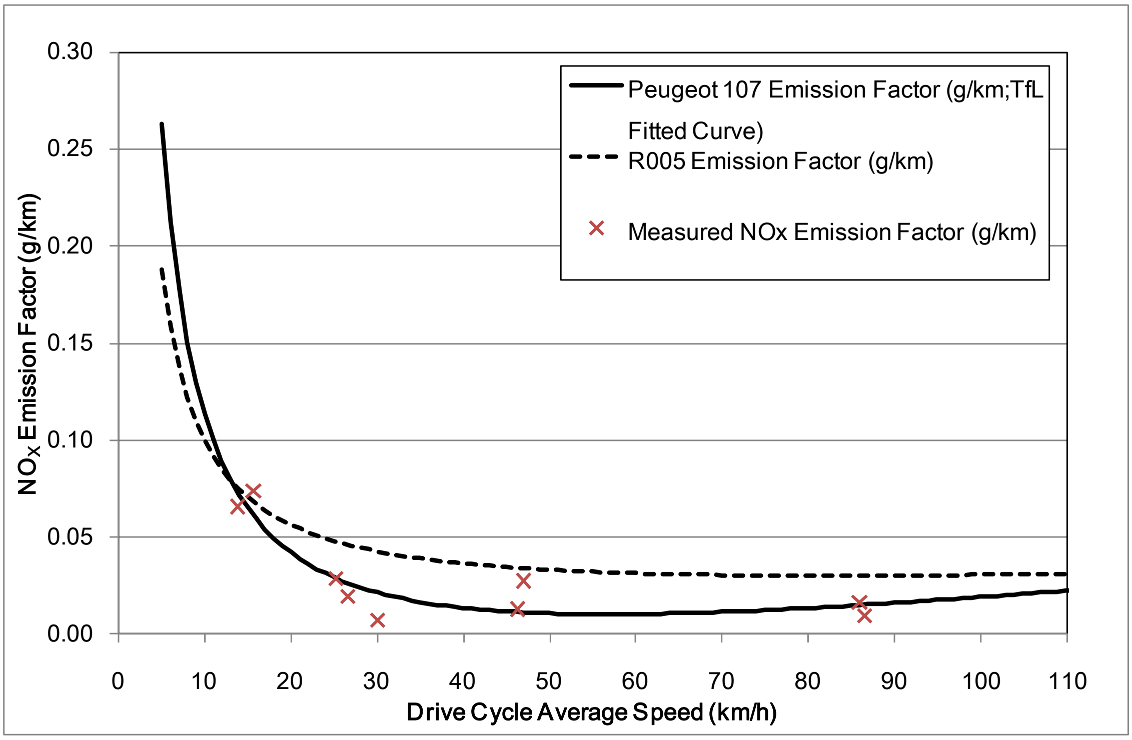
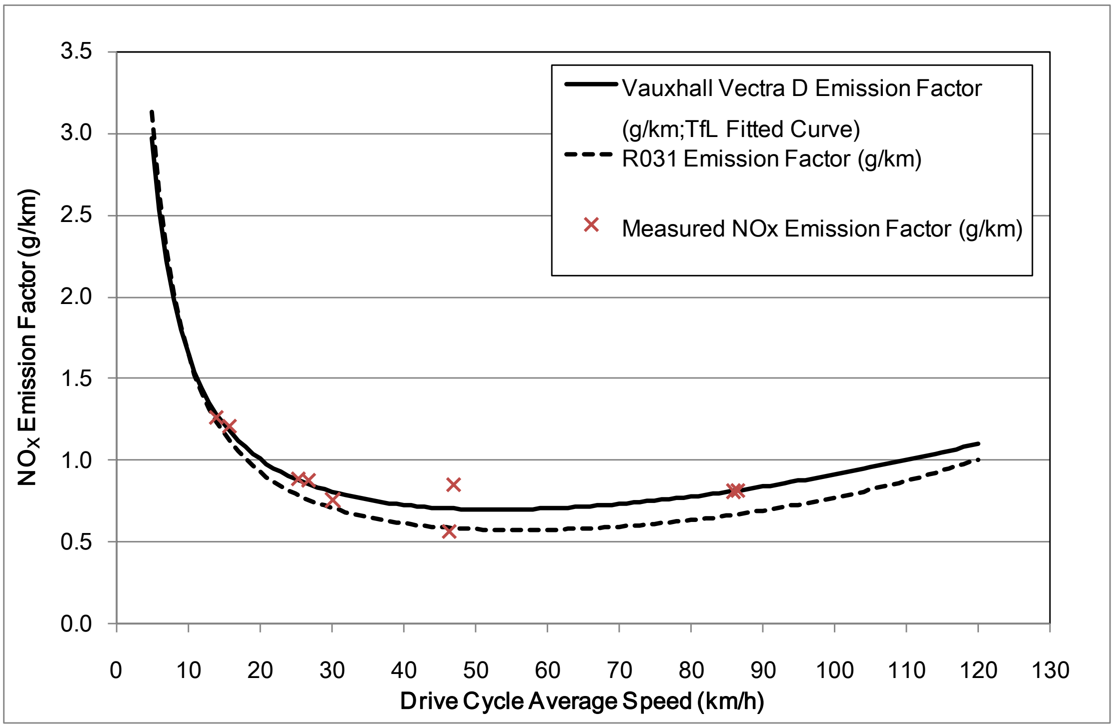


Figure 6 Comparison of fitted NO_X emission curve for Euro 2 Family Saloon Diesel and DfT category R031.



The results of the analyses of NO_X and PM_{10} emissions test data provided less clear evidence of a distinction between TfL emissions estimates and current DfT emission functions than did the results for CO_2. The TfL vehicles did appear to produce higher emissions of NO_X and PM_{10} than the equivalent DfT function predictions but showed a large range of variation. However, due to the small dataset upon which these conclusions were based it was considered inappropriate to eliminate NO_X emissions from further investigation at this stage. With no second-by-second (1 Hz) emissions data for PM_{10} available, no further analysis could be carried out for this pollutant. However, 1-Hz particulate number count data was collected during some of the TfL vehicle tests, which was examined for any trend that might help inform predictions of PM_{10} emissions. Unfortunately no clear trend was visible, other than the rather vague conclusion that cycles with lower overall average speeds tend to produce a smaller number of particles. Further investigation into particle dynamics may be useful here. In particular, there may be issues with coagulation of small particles before they reach the analyser.

5. Comparison of emissions according to second-by-second vehicle speed

For each of the TfL test vehicles and each drive cycle, tailpipe emissions of pollutants (in grammes) were measured on a second-by-second (1 Hz) basis, along with vehicle speed (km/h). Using the 1 Hz data allowed the sample size for analysis to be increased from nine samples for each vehicle (one measurement per drive cycle) to several hundred samples. The increased number of samples for plotting emissions allows for greater confidence in the resultant curves.

To investigate the relationship between vehicle speed and emissions in greater detail the emissions were grouped in 1km/h categories and mean emissions calculated. For example, for all instances when drive cycle trace speed was between 10 km/h and 11 km/h the mean emissions were calculated. The calculation was repeated for all valid speeds in each drive cycle from 5 km/h to 120 km/h. Emission factors were calculated by dividing the sum of the emission in each 1 km/h speed increment by the sum of the distance travelled in the same 1 km/h increment. The TfL vehicle tests were conducted at 23°C and so the calculated emission factors were temperature corrected to 10°C according to the DfT methodology[i] to allow direct comparisons to be drawn between the TfL data and DfT emissions factors.

The mean vehicle speed for each speed increment was calculated from the drive trace and emission factors were calculated using the DfT Emission Factors Toolkit. The DfT calculations were then compared with the TfL test vehicle results. Since the DfT emission factors are not valid at speeds less than 5 km/h, drive trace vehicle speeds of less than 5 km/h were excluded from the analysis.

Comparisons between TfL and DfT results were carried out for:

- All drive cycles and all vehicles combined;
- Urban, Suburban and Motorway drive cycles individually;
- AM Peak, Inter Peak and Free Flow traffic drive cycles;
- Each of the nine drive cycles individually;
- Each of the ten TfL test vehicles individually.

Whilst the results exist for all the above comparisons, the "all cycles, all vehicles" comparison provided a much larger data set. Consequently, this is the one that has been utilised here.

The emissions factors are mean values calculated from all TfL test cycles. The results for selected TfL test vehicles are presented graphically in **Error! Reference source not found.** to **Error! Reference source not found.** alongside emissions curves for the equivalent DfT vehicle category.

Carbon Dioxide (CO_2) emissions as a function of second-by-second vehicle speed.

All TfL test vehicles showed the same trend in variation in emissions with vehicle speed for CO_2, with the highest g/km emissions occurring at lower vehicle speeds and the minimum emissions corresponding with vehicle speeds between 50 km/h and 70 km/h before increasing again at higher speeds. For all of the tested vehicles the maximum g/km emissions factors for CO_2 occurred in the 5-6 km/h speed interval. With the exceptions of the Euro 2 diesel Family Saloon and Premium Sports Saloon the minimum CO_2 emissions factors fell in the 69-70 km/h speed interval for the TfL test vehicles.

In comparison with DfT emission function predictions at equivalent speeds the TfL test vehicles tended to display higher emissions factors than DfT functions, particularly at vehicle speeds up to approximately 40 km/h. A notable exception to this observation was the Compact Saloon, for which TfL measurements of CO_2 emissions were lower than DfT predictions. This may be a consequence of the small engine size of the vehicle (1.0 litre), which would lie at the lower end of the equivalent DfT category – category R005 represents small petrol cars with engine capacity up to 1.4 litres. It would also have a relatively low mass amongst vehicles in DfT category R005.

The measured CO_2 emissions for the Euro 2 petrol Family Saloon were higher than the equivalent DfT category up to approximately 55 km/h. Above this speed the TfL measurements and DfT emission predictions were similar. TfL measured CO_2 emissions for the Small Family Saloon were slightly higher than DfT predictions at speeds below 50 km/h. At speeds higher than 50 km/h the two data sources produced similar values. Similar trends were found for the MPV and Euro 2 Diesel Family Saloon. The Premium Sports Saloon had higher CO_2 emissions than the DfT predictions. However, it is likely that this may be explained by this vehicle having a very high power output compared with the typical vehicle represented by the DfT category. Similar conclusions can also be drawn from the SUV data.

Ratios of TfL CO_2 emissions factors (as calculated from the emissions speed curves) to the equivalent DfT emissions factors are shown in Table 8. The ratios range from 0.80 (Compact Saloon) to 1.43 (Mini Saloon). Along with the compact saloon, the two vans vehicles used in the TfL tests had lower CO_2 emissions factors than the equivalent DfT categories; the remaining vehicles tested by TfL produced higher emissions factors than the equivalent DfT category.

Table 8 Ratios of measured TfL CO_2 emissions factors to equivalent DfT vehicle category emissions factors for second-by-second speed-based analysis.

Vehicle	**Ratio**
Compact saloon : DfT R005	0.80
Family Euro 2 Petrol : DfT R010	1.20
Small family : DfT R012	1.11
Prestige saloon : DfT R019	1.35
Supermini saloon : DfT R026	1.43
Family Euro 2 Diesel : DfT R031	1.12
MPV : DfT R040	1.13
SUV/4x4: DfT R040	1.36

Figure 7 Variation of measured CO_2 emissions factors and average speed (second-by-second) – compact saloon and DfT category R005.

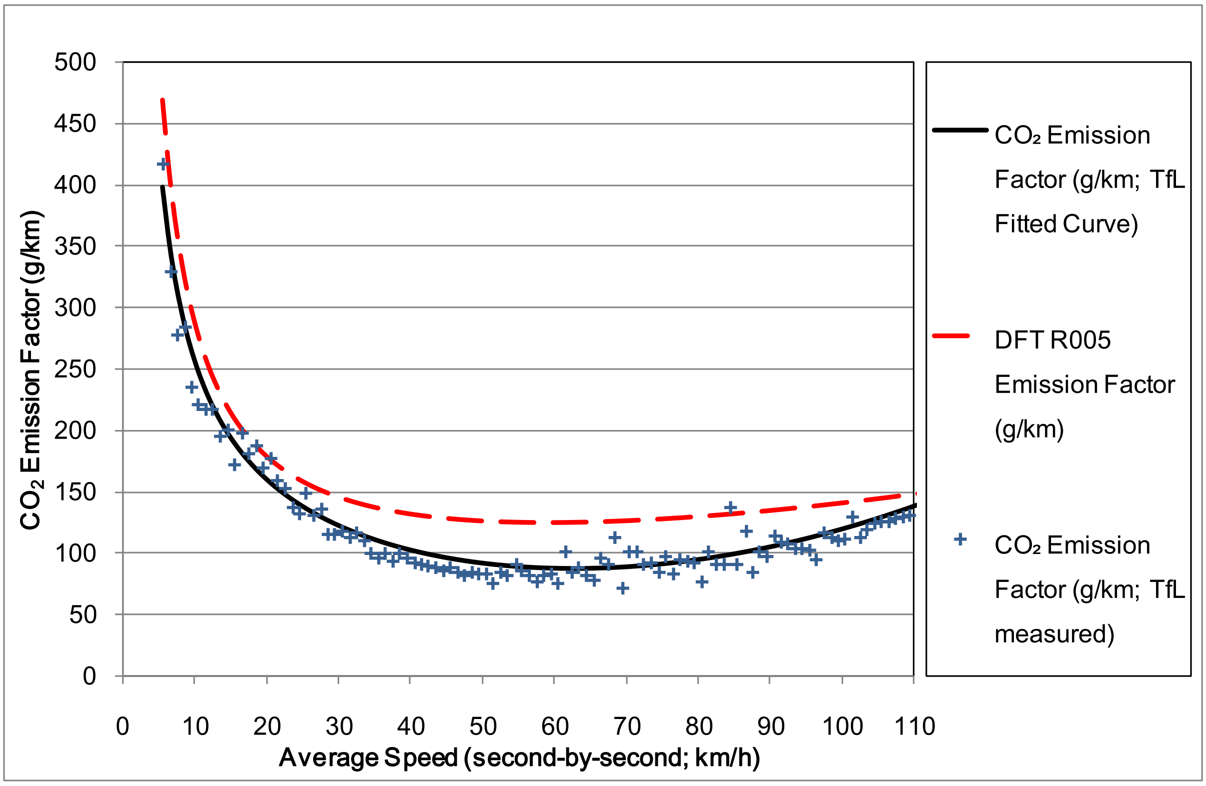


Figure 8 Variation of measured CO_2 emissions factors and average speed (second-by-second) – small family saloon and DfT category R012.

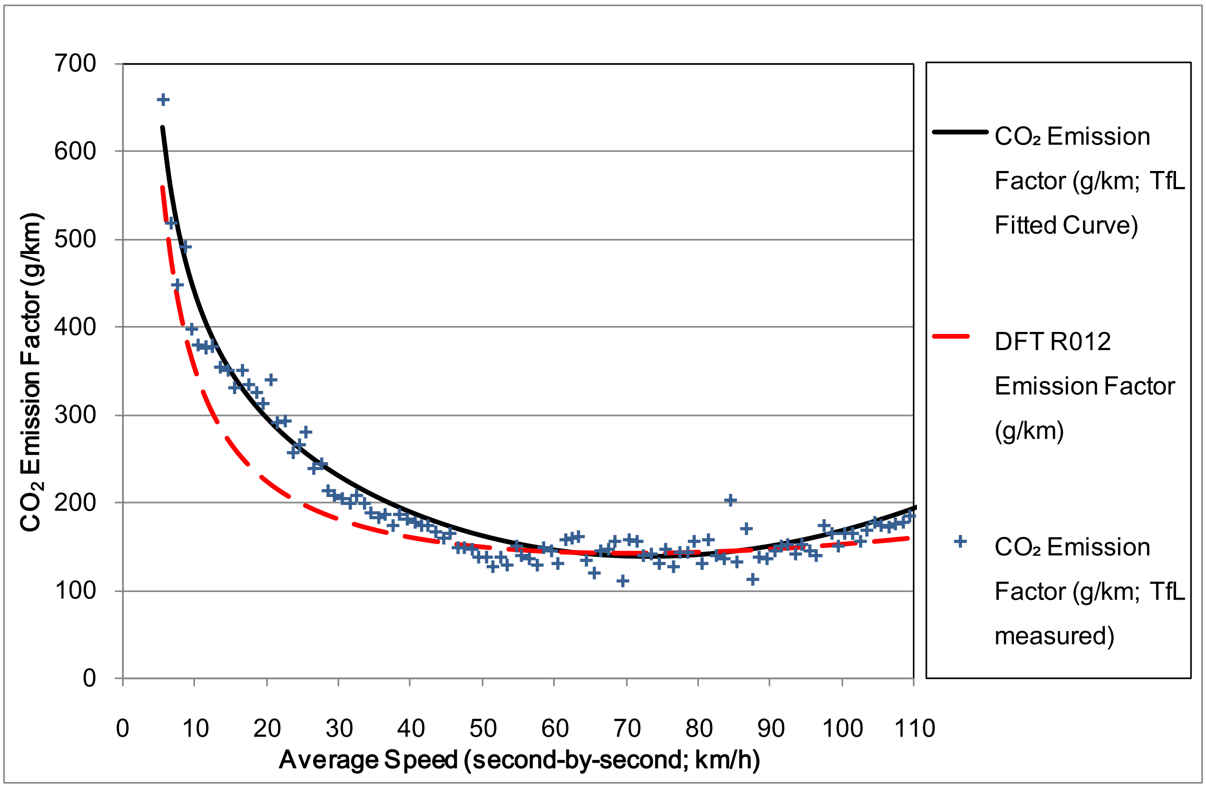
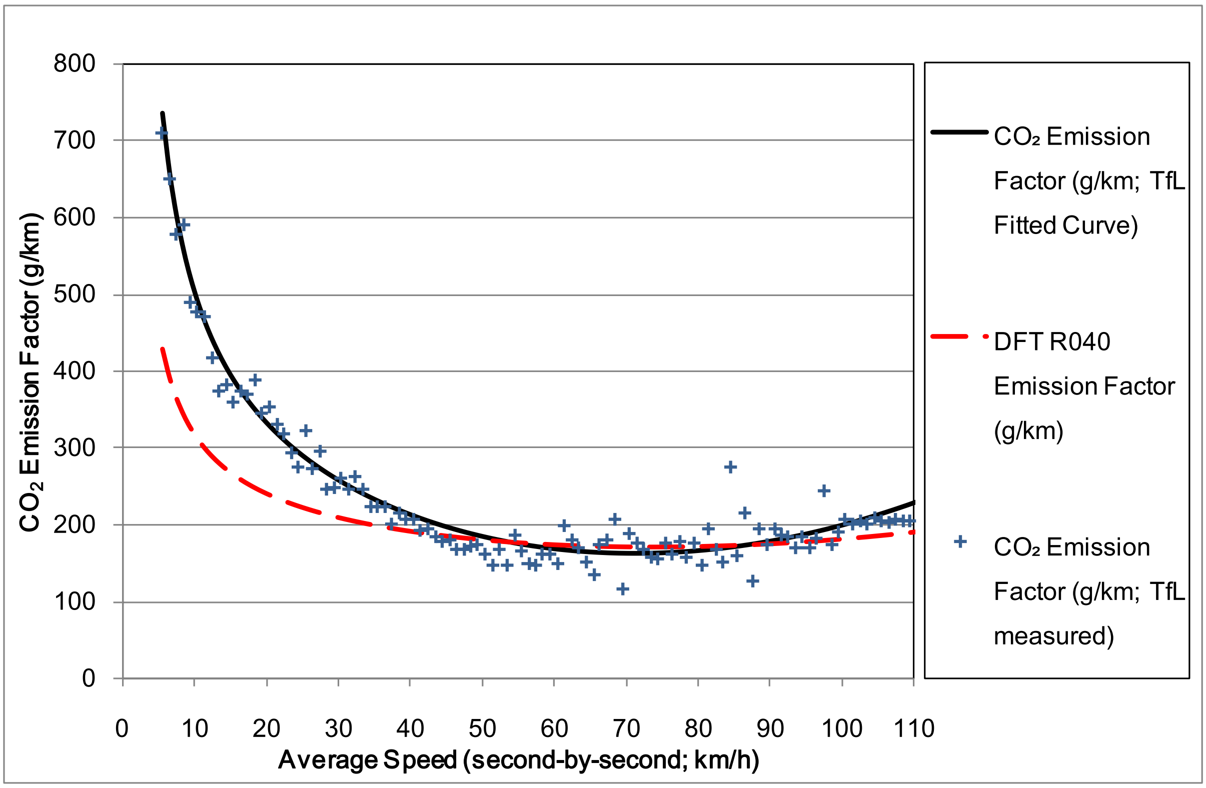


Figure 9 Variation of measured CO_2 emissions factors and average speed (second-by-second) – MPV and DfT category R040.



Good curve fitting was possible for all vehicles with the exception of the Euro 2 Diesel Family Saloon. In comparison to the DfT emission functions the TfL emission curves were generally higher, in particular at speeds of less than 45 km/h. Thus the conclusion of the vehicle emissions versus speed analysis for CO_2 is consistent with the preliminary investigations which focused on emissions over the complete drive cycle.

Oxides of Nitrogen (NOx) emission factors as a function of second-by-second speed

Table 11 shows the ratios of TfL NOx emissions factors to equivalent DfT vehicle category emissions factors, using second-by-second speed based analysis.

Table 11 Ratios of measured TfL NOx emissions factors to equivalent DfT vehicle category emissions factors for second-by-second speed based analysis.

Vehicle	Ratio
Compact saloon: DfT R005	0.89
Family Euro 2 Petrol : DfT R010	1.36
Small family : DfT R012	0.67
Prestige saloon : DfT R019	3.71
Mini saloon : DfT R026	1.84
Family Euro 2 Diesel : DfT R031	1.06
MPV : DfT R040	2.05
SUV/4x4: DfT R040	3.16

It is clear from the disparate ratios that there is much variation according to where the test vehicle sits within the DfT category (closer to top or bottom of the range). Graphs of the emissions test data for a selection of vehicles are shown in Figure 10 to **Error! Reference source not found.**. DfT emissions curves for NO_X are shown alongside the TfL test data.

NO_X emissions from the TfL test data showed much more scatter than the CO_2 emissions data and for some vehicles no clear trend was apparent with vehicle speed. For vehicles where a trend was apparent NO_X emissions displayed a similar pattern to CO_2 emissions – emissions factors were highest at low vehicle speeds and decreased with increasing vehicle speed up to between 40 km/h and 50 km/h. The weaker correlation between NO_X emissions factors and vehicle speeds than that seen for CO_2 emissions factors is likely to be a consequence of the lower concentrations of NO_X in the exhaust gas and the relative complexity of the chemical reactions that leads to the formation of NO_X during the fuel combustion process. However, it is significant that the petrol vehicles are emitting less NOx than the DfT curve suggests, whilst diesel cars emit more.

Figure 10 Variation of measured NOx emission factors and average vehicle speed (second-by-second) – Compact Saloon and DfT category R005.

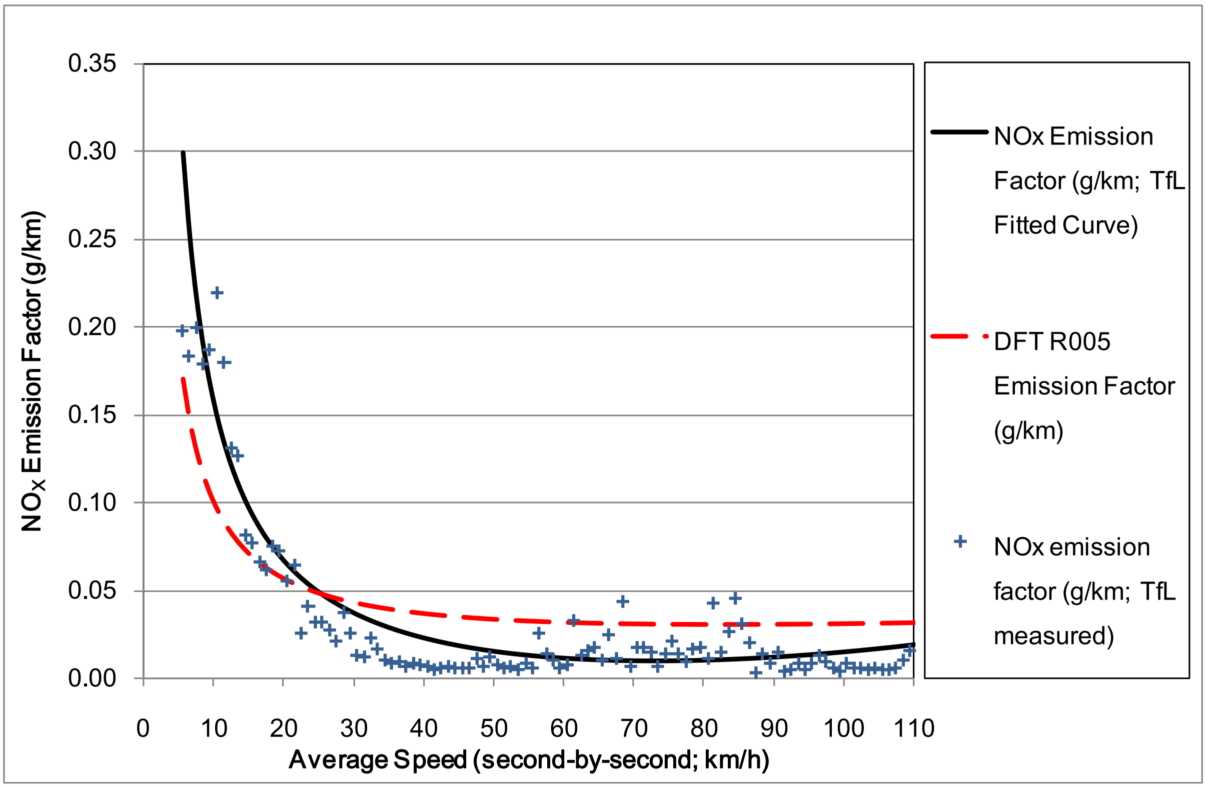
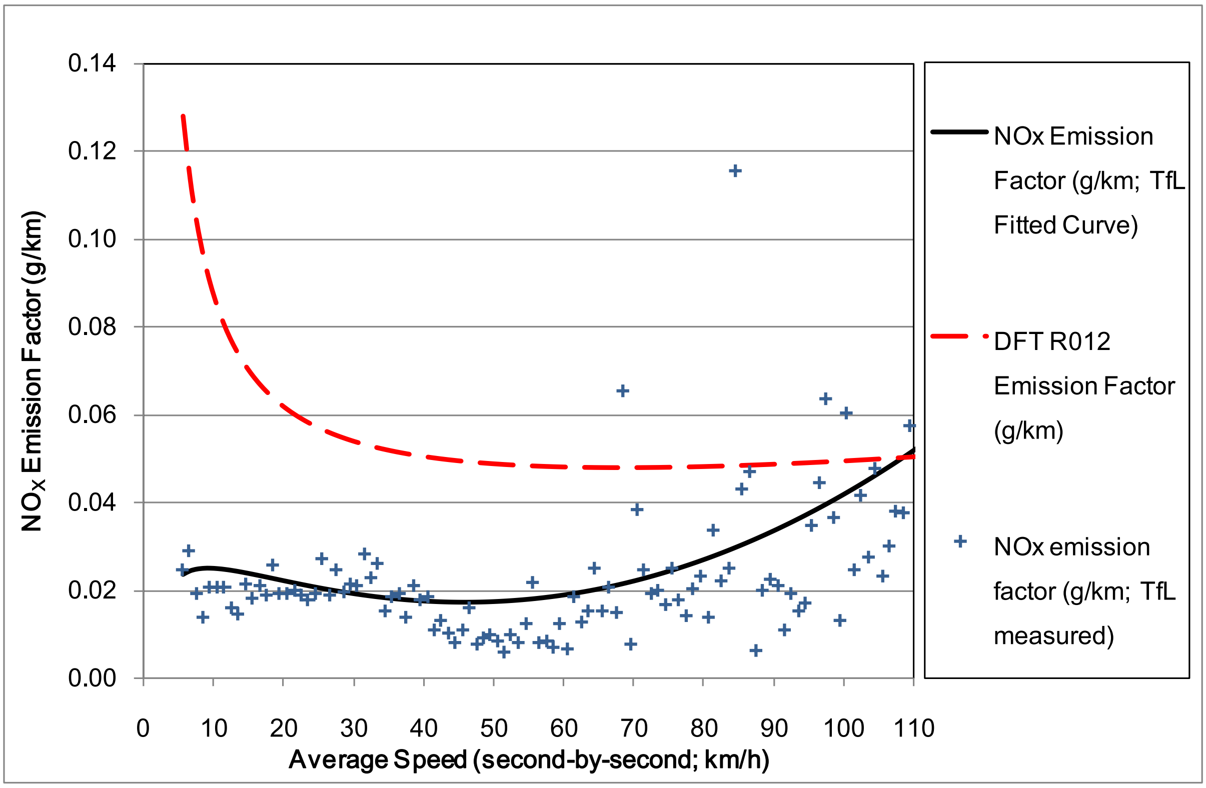


Figure 1 Variation of measured NOx emission factors and average vehicle speed (second-by-second) – Small family Saloon and DfT category R012.



Calculated NO_X emissions factors for the Compact Saloon were highest at 5-6 km/h and decreased with increasing speed up to around 40 km/h. At speeds greater than 40 km/h the NO_X emissions factors for the Compact Saloon remained approximately constant. In comparison to DfT predictions the NO_X emissions for the Compact Saloon were similar up to 25 km/h after which the emissions tended to be lower than DfT values. The NO_X emissions factors for the Euro 2 Petrol Family Saloon and Small Family Saloon displayed a less clear variation with speed and showed a considerable amount of scatter. Despite the scatter in the data the Euro 2 Petrol Family Saloon emissions factors were similar to the equivalent DfT category estimates. NO_X emissions for the Small Family Saloon were lower than DfT predictions. Calculated NO_X emissions factors for the Premium Sports Saloon followed a similar trend to the Small Family Saloon but values were typically higher than DfT emissions factors.

Figure 2 Variation of measured NOx emission factors and average vehicle speed (second-by-second) – Euro 2 Diesel family Saloon and DfT category R031,

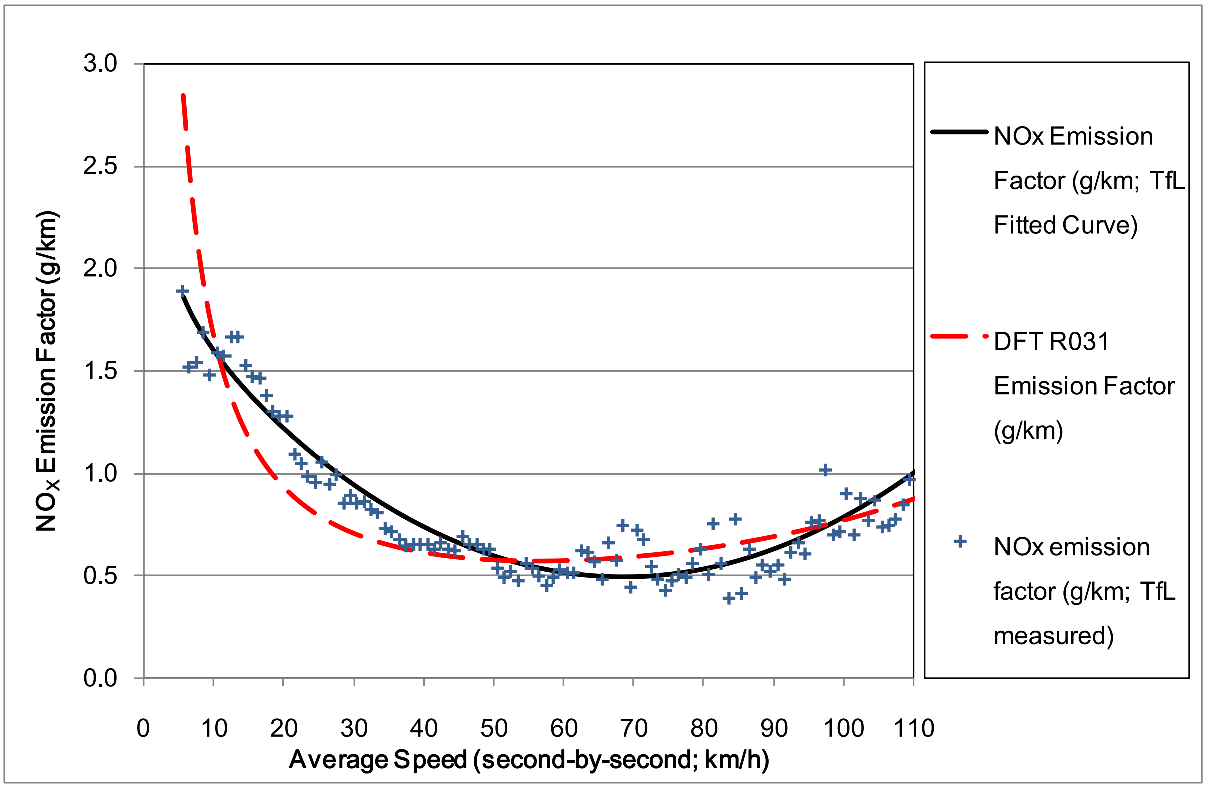


Figure 12 is an example of the NO_x performance of the diesel vehicles tested. The diesel vehicles tended to show a clearer trend between NO_X emissions factors and vehicle speed. Up to around 50 km/h NO_X emissions factors for the Mini Saloon, Euro 2 Diesel Family Saloon, SUV and the vans (all diesel) decreased with increasing speed. At speeds above 50 km/h individual vehicles appeared to behave differently. For example, the Mini Saloon, Euro 2 Diesel family Saloon and Diesel Van (Euro 4) displayed an increase in emissions with increasing speed above 70 km/h, whereas NO_X emissions from the SUV and Diesel Van (Euro 2) showed much less pronounced increases at higher speeds. All diesel vehicles tested by

TfL had higher NO_X emissions factors than the corresponding DfT category estimates especially at the lower end of the speed range.

6. Impact of vehicle ancillary equipment use on emissions

Significantly, given the level of ancillary equipment fitted to modern vehicles, the DfT emissions functions for CO_2 do not allow for the use of ancillary equipment (such as air conditioning, in-car entertainment, lights etc.)[ii]. In the TfL vehicle testing some ancillaries were switched on to better reflect real-world driving conditions. Air conditioning (where fitted) was set to its mid-point temperature setting, radios were turned on and daytime running lights (where fitted) were turned on. To account for the use of ancillaries an 'uplift' factor for CO_2 emissions factors of 15 per cent for passenger cars is quoted by Defra [iii]. CO_2 emissions factors using the DfT functions were recalculated applying this 15 per cent uplift factor to all values and the emissions speed curves re-plotted. The uplifted curves were then compared against the TfL emissions speed curves. The results for the Small Family Saloon and Supermini Saloon are shown in **Error! Reference source not found.** and **Error! Reference source not found.**.

The results for the Small Family Saloon (figure 13) indicate that the application of the 15 per cent "uplift" factor brought the DfT emissions factors predictions into close alignment with the TfL fitted curve for this vehicle. This may indicate that part of the observed difference between the TfL test data and the DfT predictions are attributable to the use of ancillaries in the TfL vehicle tests. At lower vehicle speeds the TfL emissions speed curve still resulted in slightly higher emissions than DfT equivalent predictions. The Euro 2 Petrol and Diesel Family Saloons showed the same pattern after the uplift of DfT figures by 15 per cent.

The fitted emissions speed curve for the Supermini Saloon (figure 14) remained higher than the equivalent DfT category curve at all vehicle speeds even after 15 per cent uplift. This could indicate that fuel consumption (and hence CO_2 emissions) are more greatly affected by the use of ancillaries than other test vehicles. It may also be an indication that the smallest diesel vehicles are inadequately characterised in the DfT emissions factors database. Comparing the Supermini Saloon fitted curve against vehicle category R033 {Diesel Car Euro 4 (less than 2.5 tonnes; 1400-2000 cc)} produced a much closer alignment, particularly after uplift of the DfT curve by 15 per cent.

The effect of the 15 per cent uplift on the ratio between the TfL fitted emissions curves and the equivalent DfT category (uplifted by 15 per cent) is shown in **Error! Reference source not found.**. As expected the 15 per cent uplift resulted in a lowering of the ratios of the TfL predicted emissions factors to the DfT predicted values.

Table 13 Ratios of CO_2 fitted polynomial emissions factors to equivalent DfT vehicle category emissions factors after 15 per cent uplift for road link-speed analysis.

Vehicle	Ratio	Difference
Compact saloon: DfT R005	0.73	-0.08
Family Euro 2 Petrol : DfT R010	1.07	-0.13
Small family : DfT R012	1.01	-0.11
Prestige saloon : DfT R019	1.21	-0.14
Mini saloon : DfT R026	1.29	-0.13
Family Euro 2 Diesel : DfT R031	1.00	-0.10
MPV : DfT R040	1.03	-0.09
SUV/4x4: DfT R040	1.23	-0.12

Figure 13 TfL emissions factors (fitted polynomial) and DfT emissions factors for CO_2 uplifted by 15 per cent - small family saloon and DfT category R012.

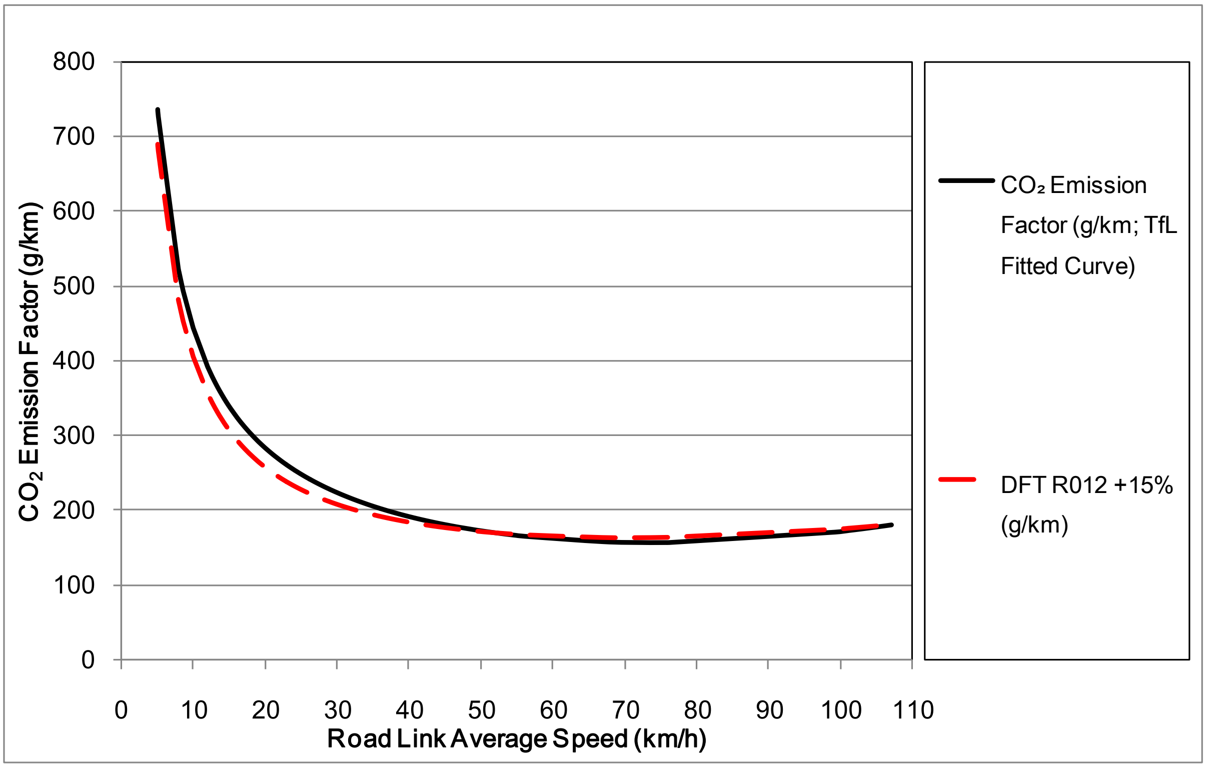
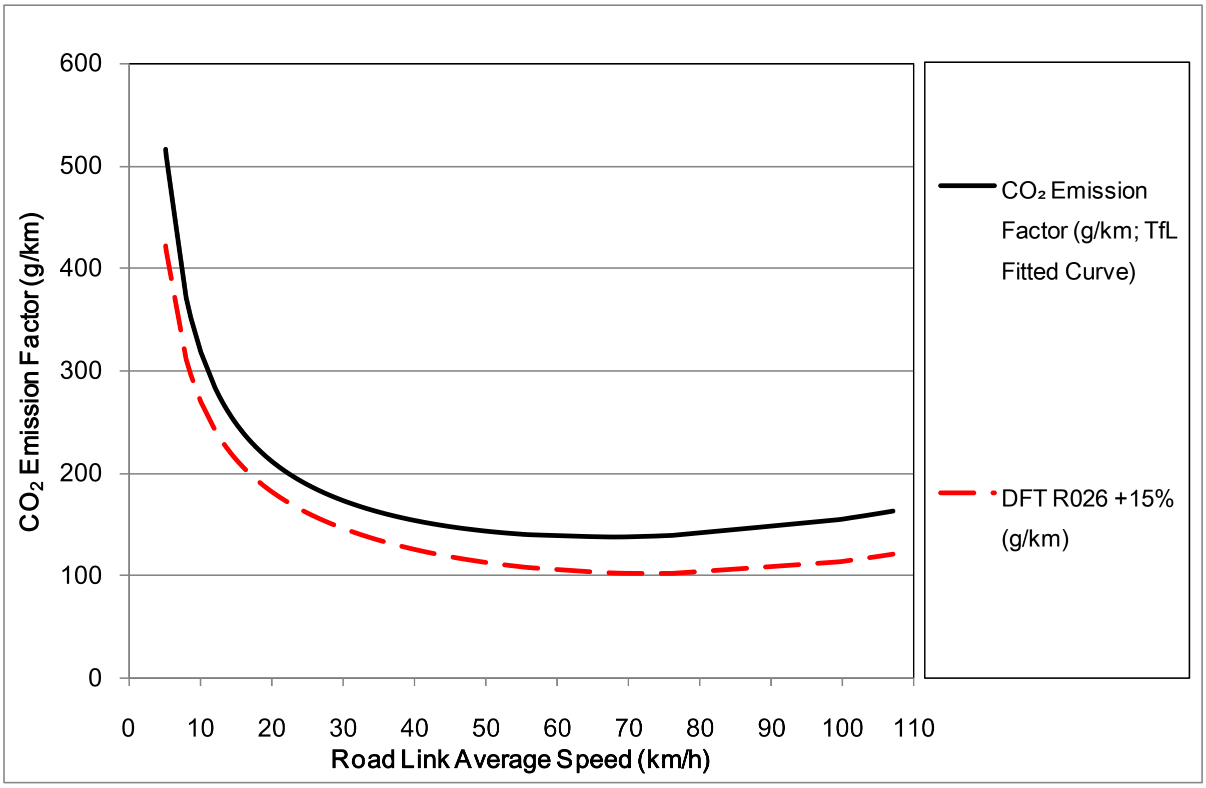


Figure 14 TfL emissions factors (fitted polynomial) and DfT emissions factors for CO_2 uplifted by 15 per cent - supermini and DfT category R026



7. An examination of the NO_x and NO_2 ratio over London Drive Cycles

Nitrogen present in atmospheric air is generally inert, but under the high temperature and pressure conditions within the combustion chamber of an internal combustion engine, the nitrogen present tends to oxidise to form oxides of nitrogen, known as NO_x. This process also occurs with other forms of combustion, such as domestic and industrial heating processes. NO_x is made up of three main constituent gases, nitrogen monoxide (NO), nitrogen dioxide (NO_2) and nitrous oxide (N_2O). Because of the nature of combustion, compression ignition (diesel) engines tend to create more NO_x than spark ignition (petrol) engines although both types produce NO_x. This is because diesel engines are "lean-burn" meaning that they run at less than stoichiometric air/fuel ratio. This means that there is excess oxygen present in the combustion chamber which allows for additional NO_x formation. Consequently the feature of diesel engines that makes them emit less carbon dioxide (CO2), has the unhappy side-effect of increased NO_x emissions. Additionally, certain exhaust after-treatment systems utilise a catalytic action which further modifies the speciation of the NO_x, increasing the NO_2 fraction.

NO_2 is of particular interest to TfL and other authorities since it is an irritant associated with respiratory ailments and early deaths among people with respiratory illness. Transport and local authorities have a statutory duty to control atmospheric concentrations of NO_2.

Measurements of roadside nitrogen dioxide (NO_2) concentrations in London have caused some uncertainty because, despite the reducing legislated limits for total NO_x in vehicle exhausts, the measured levels at roadside locations has tended to plateau, and is no longer reducing as projections have suggested.

Roadside emissions findings

Measurement of emissions at the roadside and kerbside both within London and elsewhere has revealed a general trend of reducing total NO_x over the years from 1998 to 2007. (Data is less certain outside London). However, the levels of NO_2 within the total measured NO_x have, in general, not reduced, with some sites seeing an increase. [iv] Historically in London, it has been seen that the levels of primary NO_2 (that is, NO_2 emitted from the vehicle exhaust rather than converted afterwards) has grown from around 5 per cent in 1996 to around 20 per cent in 2009.[v] This has given rise to review of the previously held assumption that 5 per cent was appropriate for both light and heavy vehicle primary NO_2 fractions. Based upon UK and international measurement programmes it is now generally considered that the fleet average primary NO_2 emissions are in the range 8 – 40 per cent. This increase is explained largely by the increasing proportion of diesel engines and the prevalence of oxidation catalysts. During the same timeframe, PM_{10} reduction has received greater priority, to good effect, although total NO_x has been reduced. Table 19 shows the ranges of primary NO_2 ratio assumed for each vehicle type (light duty vehicles only) arising from various measurement programmes.

Table 19 Assumed ranges for primary NO_2 emissions from vehicle types included in this study.

Vehicle type	Euro standard	Fuel type	Primary NO_2 ratio
Light duty	3	Petrol	2 – 10 %
Light duty	3	Diesel	20 – 70 %
London taxi	3	Diesel	7%
Light commercial vehicle	3	Diesel	22 – 38 %

Heavy Duty vehicles are considered separately and have NO_2 performances very dependent on vehicle specification (eg use of SCR or EGR for NO_x control, use of DOC or catalytic DPF for PM control).

TfL test results

The results discussed here are illustrated in table 20, firstly in grammes per kilometre and then in percentage form in table 21. The proportion of primary NO_2 in total NO_x emissions is important because it may be a determinant of human exposure to NO_2 in dense urban areas, where people are exposed to the primary NO_2 prior to the formation of any secondary NO_2 through photo-chemical reaction and before any dispersion has been able to take place.

This is important because in order to comply with the Euro standards, many motor manufacturers have employed exhaust after-treatment systems. This may consist of a 3-way catalytic convertor for petrol engines and a diesel oxidation catalyst (DOC) for diesel engines. For Euro 5 compliance in particular, the diesel oxidation catalyst is supplemented by a diesel particulate filter (DPF) to lower tailpipe emissions of particulate matter to adequate levels. Some manufacturers have used DPF s at Euro 4.

Certain DOC and DPF systems utilise a precious metal catalytic coating in order to function. Platinum is commonly used for this purpose. These coatings tend to cause some of the NO within the total NOx to oxidise forming NO_2. It should be remembered that this does not increase the total amount of NOx in the exhaust, but it does increase the proportion which is NO_2. This addition to the primary NO_2 produced during combustion may have a significant effect on the resultant NO_2 concentrations at the roadside. The vehicle test data being reviewed here is intended to illustrate those vehicle types emitting high ratios of primary NO_2 within the total NOx.

Table 20 Nitrogen dioxide (NO_2) emissions in g/km.

	Cold start urban g/km	Warm start urban g/km	Cold start suburban g/km	Warm start suburban g/km	Warm start M-way g/km
	NO_2	NO_2	NO_2	NO_2	NO_2
	Compact saloon petrol				
Freeflow	0.002	0.005	0.001	0.003	0
AM Peak	0.009	0.007	0.004	0.001	0.001
Interpeak	0.005	0.004	0.001	0.003	0
	MPV diesel				
Freeflow	0.312	0	0.206	0.254	0.374
AM Peak	0.322	0	0.322	0.345	0.353
Interpeak	0.386	0	0.295	0.319	0.351
	SUV diesel				
Freeflow	0.298	0.673	0.374	0.547	0.468
AM Peak	0.716	1.107	0.451	0.879	0.622
Interpeak	0.594	0	0.421	0.534	0.566
	Family saloon Euro 2 diesel				
Freeflow	0.056	0.094	0	0.013	0.068
AM Peak	0.154	0.122	0	0.011	0.069
Interpeak	0.145	0.129	0.009	0.034	0.082

Table 21 Nitrogen dioxide (NO_2) emissions as a percentage of total NOx.

	Cold start urban	Warm start urban	Cold start suburban	Warm start suburban	Warm start M-way
	Nox:NO_2	Nox:NO_2	Nox:NO_2	Nox:NO_2	Nox:NO_2
	Compact saloon petrol				
Freeflow	5.12%	29.67%	7.50%	23.19%	6.10%
AM Peak	27.51%	10.52%	6.03%	2.40%	5.59%
Interpeak	10.45%	7.73%	5.00%	51.27%	2.32%
	MPV diesel				
Freeflow	52.45%	0.00%	50.88%	63.72%	44.40%
AM Peak	53.01%	0.00%	52.21%	56.52%	35.87%
Interpeak	52.03%	0.00%	47.40%	51.41%	42.81%
	SUV diesel				
Freeflow	43.66%	53.26%	56.18%	65.10%	54.77%
AM Peak	59.64%	52.65%	53.67%	61.89%	57.73%
Interpeak	49.10%	0.00%	49.78%	55.68%	58.39%
	Family saloon Euro 2 diesel				
Freeflow	6.62%	10.95%	0.00%	2.42%	8.58%
AM Peak	13.04%	10.29%	0.00%	1.27%	8.32%
Interpeak	11.47%	10.45%	1.14%	4.59%	10.33%

NOx: NO_2 ratio – conclusions from the TfL tests.

It can be concluded from these test results that, for London, the 5 per cent assumed ratio for NO_2 discussed in the DEFRA report, *Trends in Primary Nitrogen Dioxide in the UK*, is too generalised and too low. Petrol cars tested for this study revealed an average NO_2 ratio of 5 per cent. The diesels, particularly Euro 4 cars using exhaust after treatment, have much higher NO_2 ratios with an average of 28 per cent but with individual vehicles recording up to 60 per cent in some cases.

The overall average proportion of NO_2 within the total NOx for all vehicles tested was 17.96 per cent. This compares well with the 18 per cent assumed in the DEFRA report.

What does seem to be clear is that primary NO_2 is increasing as a proportion of total NOx, but the mass emission is still small and is not sufficient to produce the concentrations which are being measured. This is largely secondary NO_2 created through photo-chemical reaction. For this reason, it will be necessary to pursue a range of measures to control the NO_2 concentrations. Although reductions in total NO emissions are still valid as a means to control NO_2.

References

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[iv] Trends in Primary Nitrogen Dioxide in the UK. Published by DEFRA and prepared by the Air Quality Expert Group, 2007.

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