Research note

NO_x g/km and PN #/km exhaust emissions from UK passenger cars.

A preliminary analysis of published DfT / DVSA Vehicle Market Surveillance Unit RDE 'on road' exhaust emissions data (2019 – 2023).

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The analysis described in this research note is furnished "as is". Whilst reasonable efforts have been made to ensure accuracy, no warranty is provided whatsoever. The author will not be held responsible for any loss, damage or inconvenience caused as a result of any inaccuracy or error.

1. Introduction

The UK Department for Transport (DfT) and its agency the Driver and Vehicle Standards Agency (DVSA) has a market surveillance unit, which inspects vehicles to make sure they meet safety and environmental standards. Since 2017, the Vehicle Market Surveillance Unit (VMSU) has carried out exhaust emissions tests (laboratory, test track, and on-road) annually on a representative selection of the most popular vehicle types used on UK roads.

https://www.gov.uk/government/collections/dvsa-vehicle-market-surveillance-unit

The DVSA test vehicles to make sure they conform to European emission standards (as adopted in GB legislation). While the published VMSU annual reports present aggregate emission results for pollutants with legislated limit values (such as NO_x and particle number per km) over the total RDE (real driving emissions) 'on road' drive cycle, the published data permit far more detailed analysis.

The published RDE 'on road' exhaust emission data are of potential value to the research community to help inform analysis of 'real world' NO_x and PN emissions, encompassing factors such as variation in ambient temperature, highway gradient, road type and traffic conditions.

This analysis utilises the RDE 'on road' exhaust emissions data from the datasets published by DVSA on their website. The analysis in this research note has been limited to petrol and diesel passenger cars of Euro class 6d-temp and Euro class 6d. The analysis excludes passenger cars identified by DVSA as either plug-in hybrid electric vehicles (PHEV) or self-charging hybrid vehicles.

The analysis provides insights into the 'on road' NO_x and PN emissions performance of the vehicles tested, and facilitates comparison between RDE 'on road' emission rates, published WLTP values, and emission rate assumptions in tools such as DEFRA's Emissions Factors Toolkit.

Table 1 presents the EU emissions standards and conformity factors for passenger cars (category M1), applicable in this analysis. Conformity factors recognise uncertainty in the RDE PEMS measurements using on-vehicle equipment, when compared to laboratory measurements in more controlled conditions, i.e. conformity factors allow margins to account for the additional measurement uncertainty of on-board systems relative to standard laboratory equipment, for NO_x and particle number emissions. For example, with reference to Table 1, the legally acceptable not-to-exceed (NTE) NO_x g/km value for a Euro 6d-temp diesel car is 0.080 x 2.1 = 0.168 g/km.

Table 1: EU emissions standards and conformity factors for passenger cars (category M1)

Emissions standard	**Fuel type**	**NO_x limit value (g/km)**	**NO_x conformity factor**	**PN# limit value (#/km)**	**PN# conformity factor**
Euro 6d-temp	Diesel	0.080	2.1	6.0×10^{11}	1.5
Euro 6d	Diesel	0.080	1.43	6.0×10^{11}	1.5
Euro 6d-temp	Petrol	0.060	2.1	6.0×10^{11}	1.5
Euro 6d	Petrol	0.060	1.43	6.0×10^{11}	1.5

N.B. PN #/km limit values for petrol cars are only applicable for vehicles using DI engines.

2. Data processing

The RDE 'on road' data published by DVSA were collected using Portable Emissions Measurement System (PEMS) equipment. Each test measures exhaust emissions while the vehicle is being driven on public roads for between 1.5 and 2 hours over a specified test route. The routes included urban, rural and motorway driving, and tests were carried out during daytime in normal traffic conditions. The routes utilised by DVSA in years 2019 to 2023 are illustrated in Appendix A.

Most of the RDE 'on road' data published by DVSA is at 1Hz frequency, although some data files were found to be at 10Hz frequency. 10Hz data were aggregated to 1Hz prior to analysis.

This analysis utilised the EMROAD version 6 utility developed by the European Commission Joint Research Centre (JRC). The mass of the exhaust gas component (in this case NO_x) is calculated using:

$$m_{gas,i} = u_{gas} \cdot c_{gas,i} \cdot q_{mew,i}$$

where:

$m_{gas,i}$ is the mass of the exhaust component "gas" [g/s]

u_{gas} is the ratio of the density of the exhaust component "gas" and the overall density of the exhaust

$c_{gas,i}$ is the measured concentration of the exhaust component "gas" in the exhaust [ppm]

$q_{mew,i}$ is the measured exhaust mass flow rate [kg/s]

gas is the respective component

i is the number of the measurement.

Table 2 presents the list of diesel passenger cars included in the analysis (29 vehicles, 34 tests), documenting relevant parameters such as Euro class, engine capacity, maximum power output, and the mean ambient temperature of the RDE 'on road' test. Table 3 presents the list of petrol passenger cars (41 vehicles, 43 tests).

Figures 1 and 2 illustrate the RDE 'on road' and WLTP drive cycles respectively, for information.

Table 2: Diesel passenger cars included in DfT/DVSA RDE 'on road' PEMS tests (Euro 6d-temp & Euro 6d only)

DVSA test year	Manufacturer	Model	Fuel type	Engine cc	Euro class	kW	Ambient Temp °C
2021	BMW	3 Series 320d (2020MY) auto	Diesel	1995	6d-temp	140	13
2022	Ford	Focus (2020MY) manual	Diesel	1995	6d-temp	110	15
2020	Ford	Kuga (2019MY) manual (Run 1)	Diesel	1997	6d-temp	132	24
2020	Ford	Kuga (2019MY) manual (Run 2)	Diesel	1997	6d-temp	132	20
2019	Honda	Civic EX i-Dtec (2018MY) man. (Run 1)	Diesel	1597	6d-temp	88	14
2019	Honda	Civic EX i-Dtec (2018MY) man. (Run 2)	Diesel	1597	6d-temp	88	21
2022	Hyundai	Tucson (2020MY) manual	Diesel	1598	6d-temp	85	13
2021	Jaguar	F Pace (2020MY) auto	Diesel	1999	6d-temp	177	11
2022	Jeep	Wrangler (2019MY) auto	Diesel	2143	6d-temp	147	4
2020	Kia	Sportage (2018MY) manual	Diesel	1598	6d-temp	100	16
2019	Land Rover	Discovery SD4 (2018MY) auto (Run 1)	Diesel	1999	6d-temp	177	4
2019	Land Rover	Discovery SD4 (2018MY) auto (Run 2)	Diesel	1999	6d-temp	177	19
2021	Mercedes-Benz	A Class (2020MY) auto	Diesel	1461	6d-temp	85	7
2021	Mercedes-Benz	E Class E220 D AMG (2019MY)	Diesel	1950	6d-temp	143	11
2019	Nissan	Qashqai (2018MY) manual	Diesel	1461	6d-temp		10
2021	Peugeot	3008 (2020MY) auto	Diesel	1499	6d-temp		14
2019	Range Rover	Velar (2018MY) auto (Run 1)	Diesel	2993	6d-temp	221	6
2019	Range Rover	Velar (2018MY) auto (Run 2)	Diesel	2993	6d-temp	221	20
2020	Renault	Kadjar (2019MY) manual	Diesel	1461	6d-temp	85	12
2021	Skoda	Octavia (2020MY) manual	Diesel	1598	6d-temp	85	9
2020	Toyota	Land Cruiser (2019MY) auto	Diesel	2755	6d-temp	130	22
2020	Vauxhall	Astra Sri VX Line CDTi (2018MY) man.	Diesel	1598	6d-temp	100	16
2020	Vauxhall	Grandland X (2019MY) manual	Diesel	1499	6d-temp	96	17
2021	Vauxhall	Insignia (2019MY) manual	Diesel	1956	6d-temp	125	16
2021	Volvo	V90 (2020MY) auto	Diesel	1969	6d-temp		25
2020	Volvo	XC60 (2019MY) auto	Diesel	1969	6d-temp	173	17
2023	Audi	Q5 (2021MY) auto	Diesel	1968	6d	100	10
2022	BMW	X5 (2021MY) auto	Diesel	2993	6d	210	9
2022	Ford	Galaxy (2021MY) auto (Run 1)	Diesel	1995	6d	110	23
2022	Ford	Galaxy (2021MY) auto (Run 2)	Diesel	1995	6d	110	17
2023	Ford	Tourneo Custom (2022MY) auto	Diesel	1995	6d	125	9
2022	Mercedes-Benz	GLC (2019MY) auto	Diesel	1950	6d	143	12
2022	Volkswagen	Passat (2021MY) auto	Diesel	1968	6d	110	14
2023	Volkswagen	Tiguan (2021MY) auto	Diesel	1968	6d	110	8

Table 3: Petrol passenger cars included in DfT/DVSA RDE 'on road' PEMS tests (Euro 6d-temp & Euro 6d only)

DVSA test year	Manufacturer	Model	Fuel type	Engine cc	Euro class	kW	Ambient Temp °C
2019	BMW	118i Sport (2018MY) manual	Petrol	1499	6d-temp	100	11
2021	Ford	Fiesta (2019MY) manual	Petrol	998	6d-temp	92	12
2021	Ford	Focus (2020MY) auto	Petrol	999	6d-temp	92	10
2020	Hyundai	i20 (2019MY) auto	Petrol	1248	6d-temp	61.8	14
2020	Jaguar	XE R-Sport (2019MY) auto	Petrol	1997	6d-temp	147	7
2021	Kia	Sportage (2020MY) auto	Petrol	1591	6d-temp		20
2020	Kia	XCeed (2019MY) manual	Petrol	998	6d-temp	88.3	17
2020	Mazda	CX5 (2019MY) manual	Petrol	1998	6d-temp	121	13
2020	Mercedes-Benz	A180 Sport (2019MY) auto	Petrol	1332	6d-temp	100	9
2021	Mini	Countryman Cooper S(2019MY) man.	Petrol	1998	6d-temp	141	14
2021	Mitsubishi	Eclipse Cross (2019MY) manual	Petrol	1499	6d-temp		14
2022	Nissan	Juke (2020MY) auto	Petrol	999	6d-temp	86	13
2021	Nissan	Qashqai (2020MY) auto	Petrol	1332	6d-temp	117	14
2020	Peugeot	2008 auto	Petrol	1191	6d-temp		27
2022	Range Rover	Sport SVR (2020MY) auto	Petrol	4999	6d-temp	432	13
2021	Renault	Captur (2020MY) manual	Petrol	1332	6d-temp		15
2021	Renault	Clio (2020MY) manual	Petrol	999	6d-temp		7
2022	Subaru	Outback (2019MY) auto	Petrol	2498	6d-temp	114	9
2021	Vauxhall	Mokka (2018MY) auto	Petrol	1364	6d-temp		26
2021	Volkswagen	Golf Life TSI (2020MY) manual	Petrol	1498	6d-temp	96	15
2022	Volkswagen	Polo (2019MY) manual	Petrol	999	6d-temp	59	12
2019	Volvo	V40 manual	Petrol	1969	6d-temp		12
2023	Aston Martin	DB11 (2022MY) auto	Petrol	3982	6d	393.5	3
2023	Audi	A1 (2022MY) auto	Petrol	999	6d	81	5
2022	Citroen	C5 (2020MY) auto	Petrol	1199	6d	96	13
2023	CUPRA	Ateca (2022MY) auto	Petrol	1984	6d	221	7
2022	Dacia	Sandero (2021MY) manual	Petrol	999	6d	74	12
2022	Fiat	500 (2021MY) manual	Petrol	999	6d	51.5	25
2023	Ford	Puma MEHV (2020MY) manual	Petrol	999	6d	91.9	8
2022	Honda	Civic (2021MY) manual	Petrol	998	6d	93	15
2023	Hyundai	Tucson (2021MY) manual (Run 1)	Petrol	1598	6d	110	18
2023	Hyundai	Tucson (2021MY) manual (Run 2)	Petrol	1598	6d	110	15
2023	Maserati	Levante (2022MY) auto	Petrol	1995	6d	243	2
2022	Mazda	3 (2020MY) manual (Run 1)	Petrol	1998	6d	132	13
2022	Mazda	3 (2020MY) manual (Run 2)	Petrol	1998	6d	132	10
2023	Mercedes Benz	A Class (2022MY) auto	Petrol	1332	6d	120	9
2023	Mini	Cooper (2022MY) manual	Petrol	1499	6d	100	9
2023	Porsche	Macan (2022MY) auto	Petrol	1984	6d	195	11
2021	Suzuki	Vitara (2020MY) manual	Petrol	1373	6d	95	15
2021	Toyota	Aygo (2019MY) manual	Petrol	998	6d	53	8
2021	Vauxhall	Corsa (2020MY) manual	Petrol	1199	6d	74	10
2022	Volkswagen	Tiguan (2021MY) auto	Petrol	1498	6d	110	8
2023	Volvo	XC40 MEHV (2021MY) auto	Petrol	1969	6d	145	3

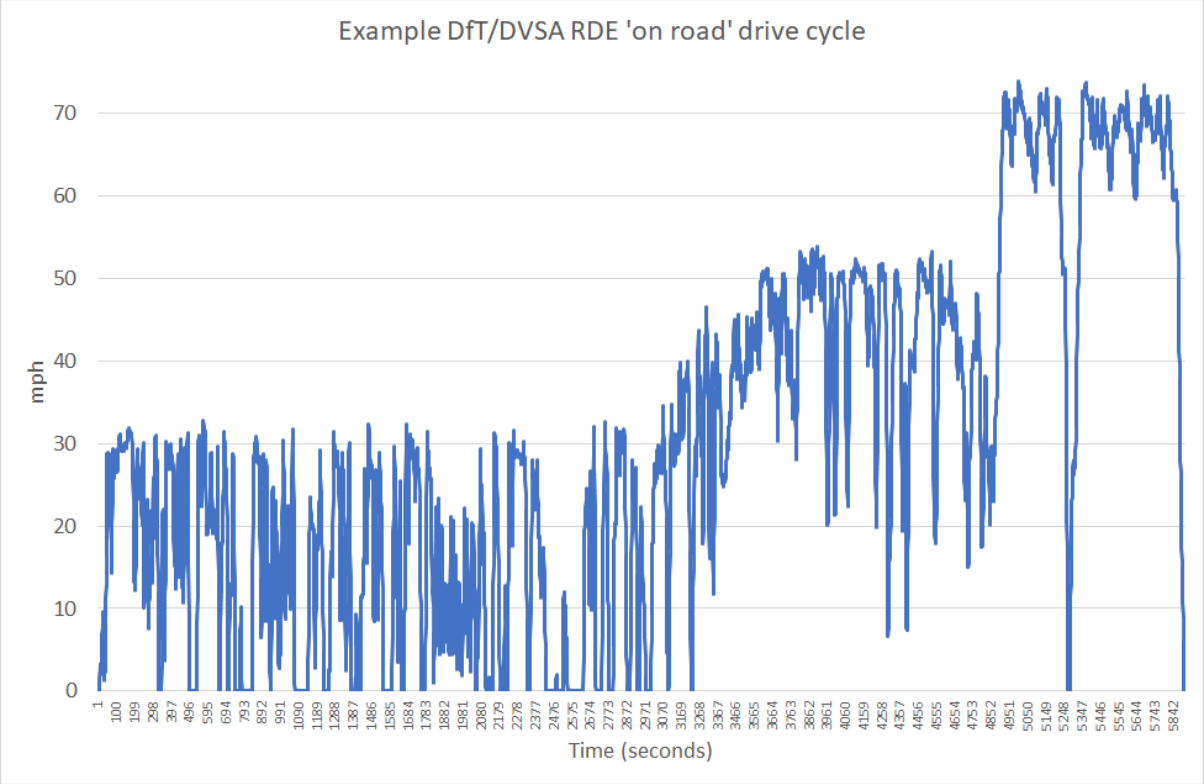

Figure 1: Example DfT/DVSA RDE 'on road' drive cycle

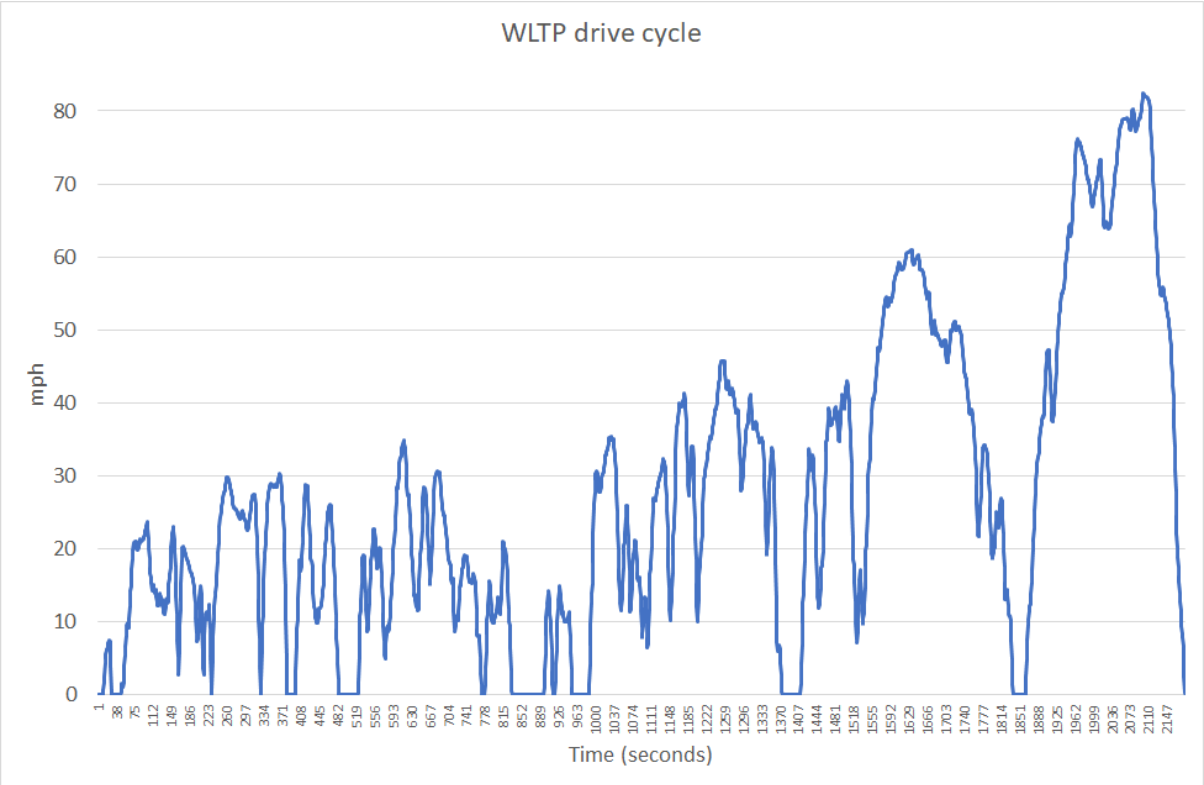

Figure 2: WLTP drive cycle

3. Aggregate RDE 'on-road' drive cycle results by road type

3.1 RDE 'on road' NO_x mg/km values – Diesel cars Euro 6d-temp

Table 4: RDE 'on road' PEMS test NO_x mg/km – Diesel cars (Euro 6d-temp)

Vehicle	Complete test	Urban	Rural	Motorway
Honda Civic 1597cc manual 88kW Run 1	223	310	269	80
Honda Civic 1597cc manual 88kW Run 2	110	88	168	100
Ford Kuga 1997cc manual 132Kw Run 2	89	90	74	98
Range Rover Velar 2993cc auto 221kW Run 1	84	80	44	134
Kia Sportage 1598cc manual 100kW	77	155	59	9
Jeep Wrangler 2143cc auto 147kW	75	154	25	35
Nissan Qashqai 1461cc manual	62	42	44	109
Range Rover Velar 2993cc auto 221kW Run 2	56	92	38	38
Ford Kuga 1997cc manual 132Kw Run 1	48	52	43	49
BMW 3 series 1995cc auto 140kW	43	119	10	2
Land Rover Discovery SD4 auto 177kW Run 1	39	76	26	6
Renault Kadjar 1461cc manual 85kW	39	47	18	51
Vauxhall Grandland X 1499cc manual 96kW	36	80	35	7
Vauxhall Insignia 1956cc manual 125kW	30	59	23	4
Peugeot 3008 1499cc auto	29	60	25	11
Hyundai Tucson 1598cc manual 85kW	28	57	18	2
Jaguar F Pace 1999cc auto 177kW	27	66	11	6
Land Rover Discovery SD4 auto 177kW Run 2	26	45	12	19
Mercedes A class 1461cc auto 85kW	26	33	28	15
Ford Focus 1995cc manual 110kW	13	33	5	0
Toyota Land Cruiser 2755cc auto 130kW	11	38	0	3
Skoda Octavia 1598cc manual 85kW	10	26	3	1
Vauxhall Astra 1598cc manual 100kW	10	26	5	3
Volvo V90 1969cc auto	8	23	0	0
Mercedes E class 1950cc auto 143kW	8	23	1	0
Volvo XC60 1969cc auto 173kW	6	19	1	2

It can be seen from Table 4 that the Honda Civic (Run 1 highlighted) exceeded the NTE NO_x value of 168 mg/km. Following discussions with the manufacturer and a second RDE test (Run 2), DVSA concluded in their 2019 report that: *"Although results of our testing are not sufficient to conclude non-compliance of this vehicle type against NO_x conformity factors, we believe that variability in emissions performance presents a risk of non-compliance that should be carefully considered as part of the manufacturer's ongoing in-service conformity obligations. Therefore, we have written to the granting type approval authority for this vehicle to ensure that these results are considered as part of ongoing discussions of compliance with Honda."*

3.2 RDE 'on road' NO_x mg/km values – Diesel cars Euro 6d

Table 5: RDE 'on road' PEMS test NO_x mg/km – Diesel cars (Euro 6d)

Vehicle	Complete test	Urban	Rural	Motorway
BMW X5 2993cc auto 210 kW	14	35	6	0
Ford Galaxy 1995cc auto 110kW Run 1	13	17	4	20
Ford Tourneo Custom 1995cc auto 125kW	12	31	1	2
VW Tiguan 1968cc auto 110kW	9	24	1	1
Audi Q5 1968cc auto 100kW	9	23	1	1
VW Passat 1968cc auto 110kW	8	19	3	2
Mercedes GLC 1950cc auto 143kW	6	15	0	1
Ford Galaxy 1995cc auto 110kW Run 2	5	14	0	0

All vehicles within the sample were observed to be within the legislated 'not-to-exceed' NO_x value of 114.4 mg/km.

3.3 RDE 'on road' NO_x mg/km values – Petrol cars Euro 6d-temp

Table 6: RDE 'on road' PEMS test NO_x mg/km – Petrol cars (Euro 6d-temp)

Vehicle	Complete test	Urban	Rural	Motorway
Subaru Outback 2498cc auto 114kW	31	30	35	29
Renault Captur 1332cc manual	30	71	11	1
Nissan Juke 999cc auto 86kW	27	39	14	25
Mini Countryman Cooper S 1998cc man. 141kW	25	21	16	36
VW Golf Life TSI 1498cc manual 96kW	20	47	13	4
Vauxhall Mokka 1364cc auto	17	13	23	16
Nissan Qashqai 1332cc auto 117kW	16	37	5	5
Kia XCeed 998cc manual 88.3kW	15	24	6	17
Mazda CX5 1998cc manual 121kW	14	40	6	3
Jaguar XE R-Sport 1997cc auto 147kW	13	17	17	5
Ford Fiesta 998cc manual 92kW	13	28	7	5
Mercedes A180 Sport 1332cc auto 100kW	13	19	7	12
Renault Clio 999cc manual	12	24	10	1
Peugeot 2008 1191cc auto	12	22	4	10
Range Rover Sport SVR 4999cc auto 432kW	10	16	7	6
VW Polo 999cc manual 59kW	10	17	3	8
Kia Sportage 1591cc auto	9	18	8	1
Ford Focus 999cc auto 92kW	8	17	6	2
Hyundai i20 1248cc auto 61.8kW	7	10	4	8
Volvo V40 1969cc manual	7	12	4	5
Mitsubishi Eclipse Cross 1499cc manual	3	9	0	0
BMW 118i Sport 1499cc manual 100kW	1	3	0	0

All vehicles within the sample were observed to be within the legislated 'not-to-exceed' NO_x value of 126 mg/km.

3.4 RDE 'on road' NO_x mg/km values – Petrol cars Euro 6d

Table 7: RDE 'on road' PEMS test NO_x mg/km – Petrol cars (Euro 6d)

Vehicle	Complete test	Urban	Rural	Motorway
Hyundai Tucson 1598cc manual 110kW Run 2	26	52	18	7
Hyundai Tucson 1598cc manual 110kW Run 1	25	61	10	5
Dacia Sandero 999cc manual 74kW	17	34	6	9
Ford Puma 999cc manual 91.9kW	16	27	10	10
Toyota Aygo 998cc manual 53kW	16	39	9	2
Fiat 500 999cc manual 51.5kW	15	25	8	8
Mazda 3 1998cc manual 132kW Run 1	14	13	22	9
Mazda 3 1998cc manual 132kW Run 2	14	15	17	10
Mercedes A class 1332cc auto 120kW	12	32	3	1
Citroen C5 1199cc auto 96kW	9	14	5	8
Aston Martin DB11 3982cc auto 393.5kW	9	17	5	4
Porsche Macan 1984cc auto 195kW	8	21	2	1
Mini Cooper 1499cc manual 100kW	8	12	6	6
Suzuki Vitara 1373cc manual 95kW	8	18	5	0
Audi A1 999cc auto 81Kw	7	21	1	0
VW Tiguan 1498cc auto 110kW	7	15	2	2
CUPRA Ateca 1984cc auto 221kW	7	16	2	1
Volvo XC40 1969cc auto 145kW	6	14	2	2
Vauxhall Corsa 1199cc manual 74kW	6	15	2	0
Honda Civic 998cc manual 93kW	5	12	1	1
Maserati Levante 1995cc auto 243kW	4	10	0	1

All vehicles within the sample were observed to be within the legislated 'not-to-exceed' NO_x value of 85.8 mg/km.

3.5 RDE 'on road' PN #/km values – Diesel cars Euro 6d-temp

Table 8: RDE 'on road' PEMS test PN #/km – Diesel cars (Euro 6d-temp)

Vehicle	Complete test	Urban	Rural	Motorway
Range Rover Velar 2993cc auto 221kW Run 1	1.8E+12	1.6E+12	1.2E+12	2.8E+12
Nissan Qashqai 1461cc manual	4.2E+11	2.1E+11	2.8E+11	8.6E+11
Jeep Wrangler 2143cc auto 147kW	1.1E+11	3.0E+11	2.3E+09	7.5E+09
Land Rover Discovery SD4 auto 177kW Run 1	8.3E+10	4.0E+10	1.5E+11	6.1E+10
Mercedes A class 1461cc auto 85kW	6.6E+10	7.8E+10	5.3E+10	6.8E+10
Toyota Land Cruiser 2755cc auto 130kW	3.9E+10	1.3E+11	2.5E+09	5.0E+09
Peugeot 3008 1499cc auto	3.7E+10	4.6E+10	3.3E+10	3.4E+10
Jaguar F Pace 1999cc auto 177kW	2.7E+10	6.3E+10	1.2E+10	7.8E+09
Honda Civic 1597cc manual 88kW Run 2	2.2E+10	6.3E+10	8.9E+08	5.9E+08
Kia Sportage 1598cc manual 100kW	2.1E+10	1.7E+10	1.9E+10	2.8E+10
Ford Kuga 1997cc manual 132Kw Run 2	1.4E+10	1.8E+10	2.3E+10	4.8E+09
Mercedes E class 1950cc auto 143kW	9.5E+09	2.3E+10	3.9E+09	1.4E+09
Honda Civic 1597cc manual 88kW Run 1	7.6E+09	2.1E+10	1.1E+08	7.7E+07
Land Rover Discovery SD4 auto 177kW Run 2	7.3E+09	9.7E+09	5.7E+09	6.4E+09
Range Rover Velar 2993cc auto 221kW Run 2	4.4E+09	5.1E+09	5.3E+09	2.6E+09
Hyundai Tucson 1598cc manual 85kW	2.6E+09	5.2E+09	6.6E+08	1.4E+09
Renault Kadjar 1461cc manual 85kW	2.5E+09	3.9E+09	3.8E+07	3.6E+09
Vauxhall Grandland X 1499cc manual 96kW	2.2E+09	4.3E+09	2.4E+09	6.8E+08
Ford Focus 1995cc manual 110kW	1.9E+09	3.5E+09	5.9E+08	1.3E+09
Vauxhall Astra 1598cc manual 100kW	1.5E+09	1.2E+09	1.9E+09	1.5E+09
Ford Kuga 1997cc manual 132Kw Run 1	1.4E+09	9.2E+08	8.6E+08	2.1E+09
Volvo XC60 1969cc auto 173kW	1.3E+09	1.5E+09	1.0E+09	1.4E+09
BMW 3 series 1995cc auto 140kW	6.7E+08	2.8E+08	9.4E+08	7.8E+08
Vauxhall Insignia 1956cc manual 125kW	4.8E+08	5.2E+08	5.4E+08	3.8E+08
Skoda Octavia 1598cc manual 85kW	9.2E+07	2.6E+08	3.9E+06	8.0E+06
Volvo V90 1969cc auto	5.1E+07	1.2E+08	1.2E+07	1.5E+07

It can be seen from Table 8 that the Range Rover Velar (Run 1 highlighted) exceeded the NTE PN# value of 9.0 x 10^{11} #/km. DVSA stated in their 2019 report that: *"Our analysis showed the vehicle experienced a diesel particulate filter (DPF) regeneration event during the first RDE test, which is likely to have accounted for the increase in PN.*

For RDE certified vehicles it is recommended within the relevant regulations to repeat the RDE test if a regeneration event is suspected. On repeating the RDE test, the PN results were much improved and were comfortably within the legal limit".

3.6 RDE 'on road' PN #/km values – Diesel cars Euro 6d

Table 9: RDE 'on road' PEMS test PN #/km – Diesel cars (Euro 6d)

Vehicle	Complete test	Urban	Rural	Motorway
Ford Galaxy 1995cc auto 110kW Run 1	2.4E+11	4.3E+11	1.5E+11	6.1E+10
Ford Tourneo Custom 1995cc auto 125kW	8.2E+10	2.4E+11	1.8E+08	1.0E+08
BMW X5 2993cc auto 210 kW	5.6E+10	1.2E+11	1.2E+10	2.9E+10
Ford Galaxy 1995cc auto 110kW Run 2	1.4E+10	2.0E+10	1.7E+10	2.2E+09
Audi Q5 1968cc auto 100kW	5.2E+09	8.0E+09	4.9E+09	2.7E+09
VW Passat 1968cc auto 110kW	4.4E+09	1.1E+10	6.7E+08	9.8E+08
VW Tiguan 1968cc auto 110kW	2.9E+09	6.6E+09	6.0E+08	9.4E+08
Mercedes GLC 1950cc auto 143kW	3.7E+08	9.7E+08	8.5E+06	6.7E+06

All vehicles within the sample were observed to be within the legislated 'not-to-exceed' PN# value of 9.0×10^{11} #/km.

3.7 RDE 'on road' PN #/km values – Petrol cars Euro 6d-temp

Table 10: RDE 'on road' PEMS test PN #/km – Petrol cars (Euro 6d-temp)

Vehicle	Complete test	Urban	Rural	Motorway
Vauxhall Mokka 1364cc auto	5.7E+11	9.7E+11	4.1E+11	3.7E+11
Renault Clio 999cc manual	5.0E+11	1.1E+12	3.0E+11	9.1E+10
Subaru Outback 2498cc auto 114kW	2.9E+11	6.6E+11	2.9E+10	1.1E+11
VW Polo 999cc manual 59kW	1.7E+11	3.5E+11	5.7E+10	6.6E+10
Nissan Juke 999cc auto 86kW	1.5E+11	1.1E+11	1.1E+11	2.5E+11
Kia Sportage 1591cc auto	1.5E+11	1.7E+11	2.3E+11	4.2E+10
Mazda CX5 1998cc manual 121kW	1.2E+11	2.9E+11	4.5E+10	6.7E+10
Ford Fiesta 998cc manual 92kW	1.2E+11	1.4E+11	1.1E+11	1.1E+11
Kia XCeed 998cc manual 88.3kW	1.0E+11	2.0E+11	5.4E+10	7.2E+10
Peugeot 2008 1191cc auto	9.3E+10	2.1E+11	4.2E+10	4.5E+10
Volvo V40 1969cc manual	6.3E+10	1.6E+11	1.3E+10	5.3E+09
Hyundai i20 1248cc auto 61.8kW	5.5E+10	1.5E+11	3.4E+10	1.3E+10
Mercedes A180 Sport 1332cc auto 100kW	4.6E+10	9.9E+10	5.8E+09	3.8E+10
Range Rover Sport SVR 4999cc auto 432kW	4.0E+10	8.8E+10	1.1E+10	1.3E+10
Ford Focus 999cc auto 92kW	3.4E+10	6.2E+10	2.3E+10	1.4E+10
VW Golf Life TSI 1498cc manual 96kW	3.3E+10	4.6E+10	3.6E+10	2.0E+10
Mitsubishi Eclipse Cross 1499cc manual	2.6E+10	3.8E+10	1.9E+10	1.9E+10
Renault Captur 1332cc manual	1.3E+10	2.6E+10	8.1E+09	4.1E+09
Nissan Qashqai 1332cc auto 117kW	6.3E+09	1.6E+10	2.0E+09	1.1E+09
Mini Countryman Cooper S 1998cc 141kW	4.9E+09	5.5E+09	3.9E+09	5.3E+09
Jaguar XE R-Sport 1997cc auto 147kW	2.0E+09	4.9E+09	8.0E+08	4.7E+08
BMW 118i Sport 1499cc manual 100kW	2.2E+08	4.0E+08	1.4E+08	7.3E+07

All vehicles within the sample were observed to be within the legislated 'not-to-exceed' PN# value of 9.0×10^{11} #/km for the complete RDE drive cycle, although the Vauxhall Mokka and Renault Clio did exceed this value for the 'urban' element of the test.

3.8 RDE 'on road' PN #/km values – Petrol cars Euro 6d

Table 11: RDE 'on road' PEMS test PN #/km – Petrol cars (Euro 6d)

Vehicle	Complete test	Urban	Rural	Motorway
Hyundai Tucson 1598cc manual 110kW Run 1	2.5E+11	4.6E+11	1.1E+11	1.8E+11
Toyota Aygo 998cc manual 53kW	2.3E+11	3.4E+11	1.1E+11	2.6E+11
Vauxhall Corsa 1199cc manual 74kW	2.0E+11	3.0E+11	1.3E+11	1.7E+11
Hyundai Tucson 1598cc manual 110kW Run 2	1.7E+11	1.1E+11	1.7E+11	2.2E+11
Mercedes A class 1332cc auto 120kW	1.4E+11	3.6E+11	2.6E+10	4.9E+10
Honda Civic 998cc manual 93kW	1.0E+11	1.9E+11	4.8E+10	5.3E+10
Audi A1 999cc auto 81Kw	1.0E+11	1.5E+11	9.7E+10	6.1E+10
Suzuki Vitara 1373cc manual 95kW	8.8E+10	8.2E+10	6.3E+10	1.2E+11
Aston Martin DB11 3982cc auto 393.5kW	7.0E+10	1.5E+11	2.8E+10	2.7E+10
Volvo XC40 1969cc auto 145kW	6.7E+10	1.7E+11	1.7E+10	1.7E+10
Fiat 500 999cc manual 51.5kW	5.7E+10	1.3E+11	1.2E+10	1.5E+10
Citroen C5 1199cc auto 96kW	5.6E+10	7.9E+10	3.5E+10	4.8E+10
VW Tiguan 1498cc auto 110kW	4.6E+10	7.0E+10	2.8E+10	3.0E+10
Mazda 3 1998cc manual 132kW Run 2	3.7E+10	8.1E+10	7.3E+09	1.5E+10
Mazda 3 1998cc manual 132kW Run 1	3.6E+10	7.5E+10	6.3E+09	1.5E+10
Ford Puma 999cc manual 91.9kW	3.3E+10	4.2E+10	3.3E+10	2.2E+10
CUPRA Ateca 1984cc auto 221kW	1.4E+10	3.5E+10	2.5E+09	3.4E+09
Dacia Sandero 999cc manual 74kW	1.4E+10	3.1E+10	4.8E+09	2.4E+09
Maserati Levante 1995cc auto 243kW	1.3E+10	3.1E+10	1.8E+09	3.2E+09
Mini Cooper 1499cc manual 100kW	1.1E+10	2.5E+10	4.9E+09	3.0E+09
Porsche Macan 1984cc auto 195kW	9.4E+09	1.7E+10	5.2E+09	5.5E+09

All vehicles within the sample were observed to be within the legislated 'not-to-exceed' PN# value of 9.0×10^{11} #/km.

4. Relationship between RDE 'on-road' exhaust emissions and vehicle speed by vehicle

The RDE 'on-road' PEMS data were processed to analyse the relationships between exhaust emissions and vehicle speed. For presentational purposes, the instantaneous 1Hz emissions data were aggregated to 5 mph 'bins' between 10mph and 70mph, and the mean value within each bin presented for each individual vehicle, fuel type and Euro standard. This analysis helps to highlight any 'outliers' or anomalies in the data, which may not be immediately apparent from the aggregate drive cycle results presented in Section 3.

It can be expected that higher rates of exhaust emissions of NO_x and particulate matter may occur under positive acceleration and other high engine load events (e.g. positive gradient). Figure 3 presents the mean positive velocity * acceleration (m^2/s^3) which highlights systematically higher levels of engine load in the ranges 35 to 40mph, and also at 55 to 60mph, and 60 to 65mph. This is consistent by fuel type and Euro emissions standard, and is a characteristic of the on-road drive cycles utilised by DVSA. For example, there is positive acceleration in the transition from the rural element of the drive cycle (between 37mph and 56mph) to the motorway element of the drive cycle (above 56mph) as speed increases (see Figure 1).

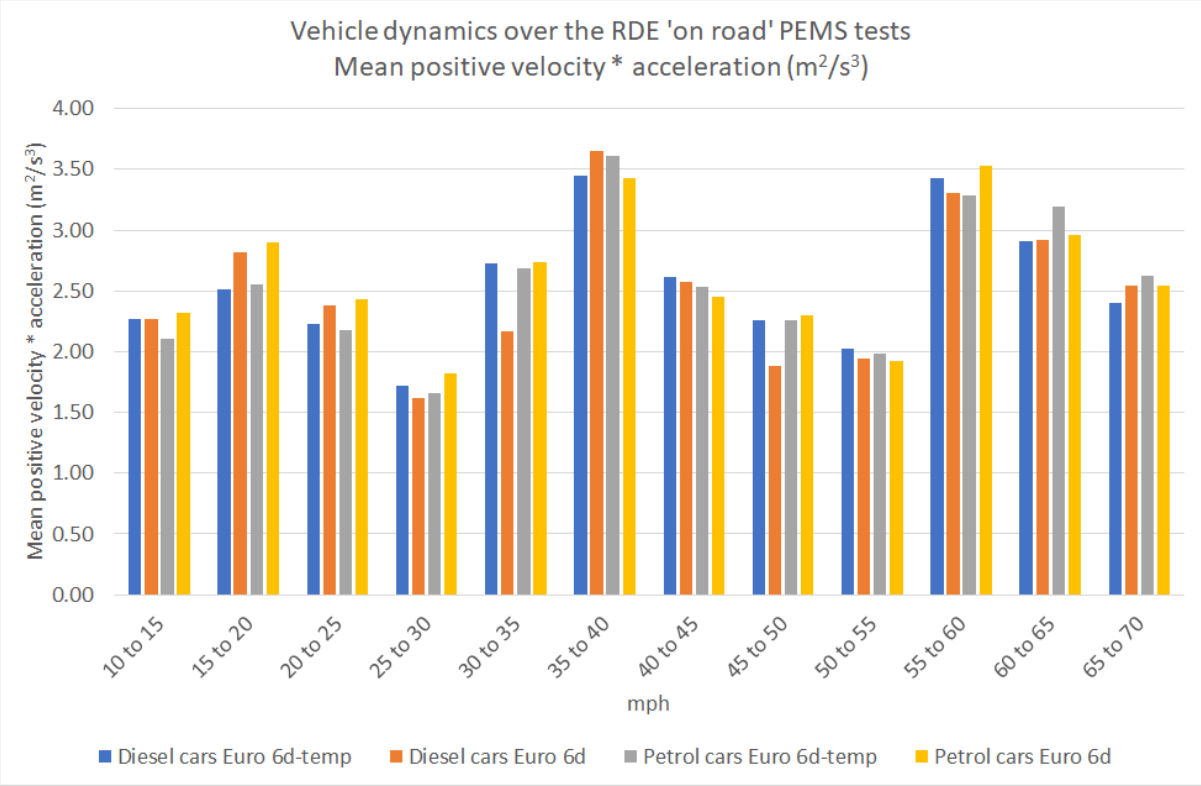

*Figure 3: Vehicle dynamics over the RDE 'on-road' PEMS tests. Mean positive velocity * acceleration (m^2/s^3) by speed bin*

4.1 Euro 6d-temp diesel cars

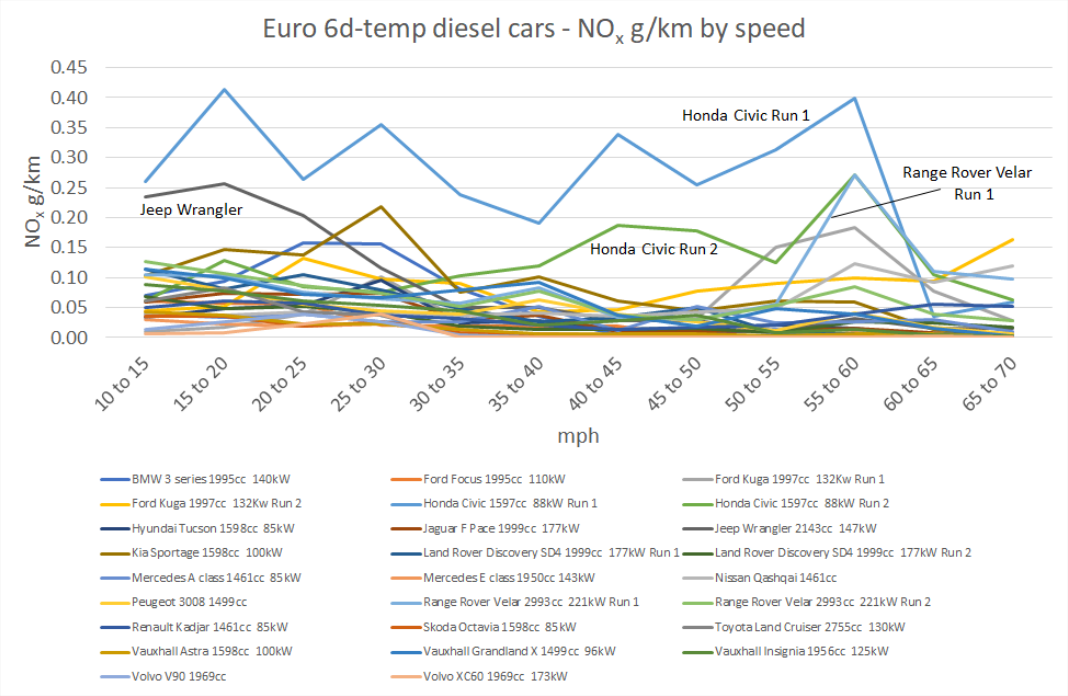

Figure 4: RDE NO_x g/km by speed – Euro 6d-temp diesel cars

Figure 4 confirms the high levels of NO_x from the Honda Civic (Run 1) seen in Table 4. NO_x emissions from the Honda Civic (Run 2) are still high relative to most other vehicles in the sample. Localised elevated emissions are also seen for the Jeep Wrangler and Range Rover Velar (Run 1).

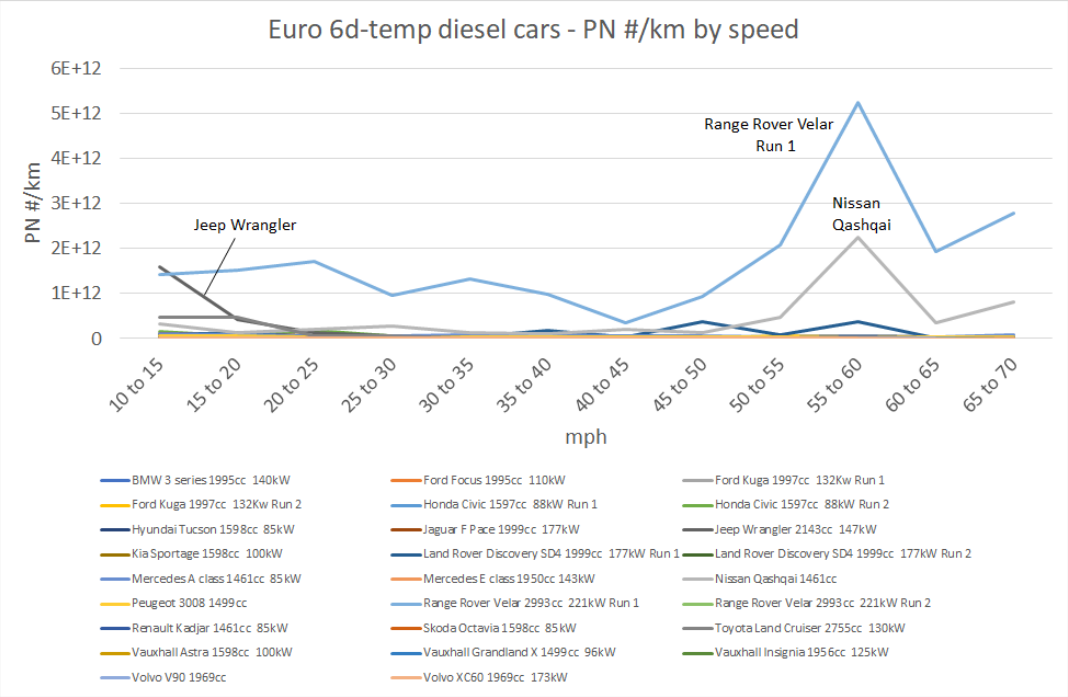

Figure 5: RDE PN #/km by speed – Euro 6d-temp diesel cars

Figure 5 confirms the high levels of PN# from the Range Rover Velar (Run 1) seen in Table 8. Localised elevated emissions are also seen for the Jeep Wrangler and Nissan Qashqai.

4.2 Euro 6d diesel cars

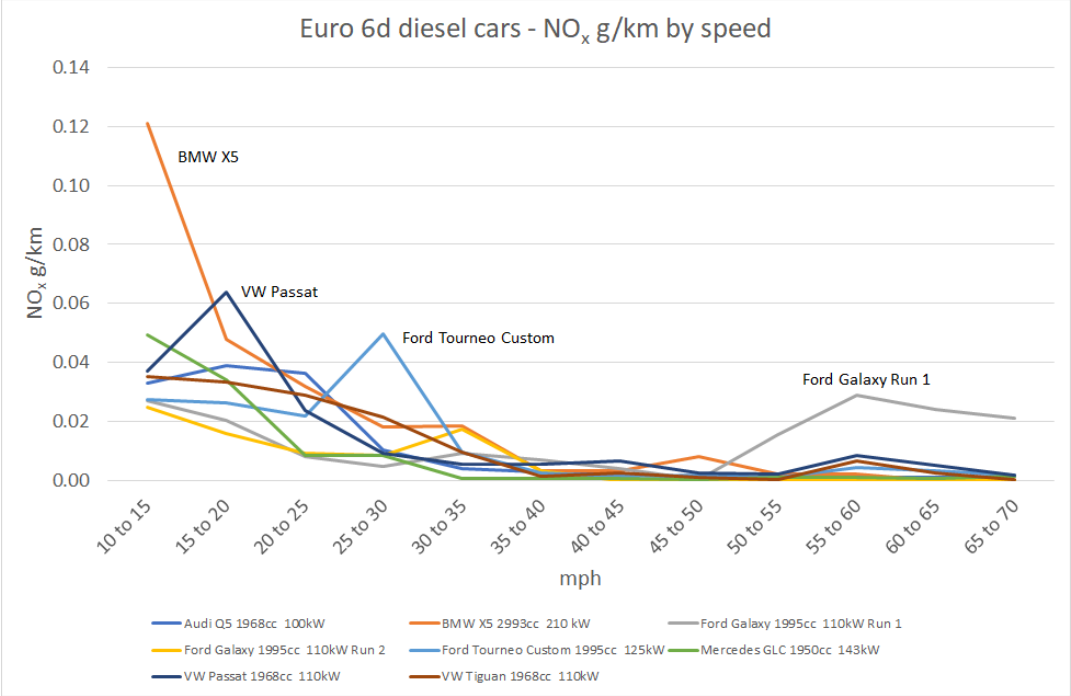

Figure 6: RDE NO_x g/km by speed – Euro 6d diesel cars

For Euro 6d diesel cars, higher NO_x emissions tend to be associated with 'urban' operation (below 37mph), although the Ford Galaxy (Run 1) does exhibit relatively higher emissions above 50mph.

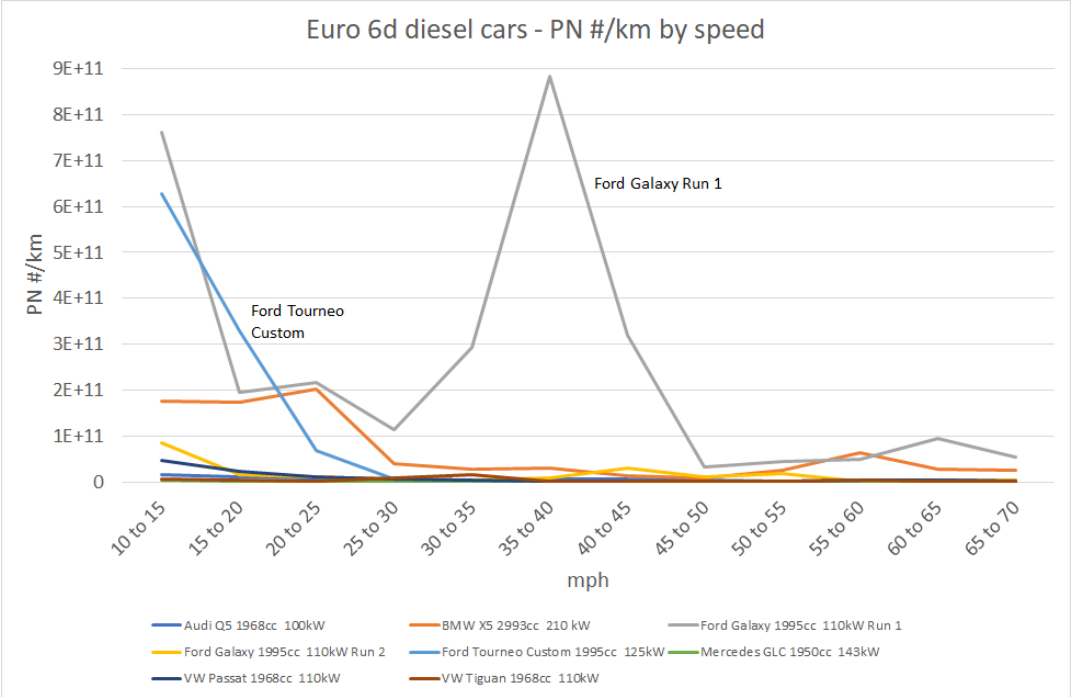

Figure 7: RDE PN #/km by speed – Euro 6d diesel cars

Whilst all Euro 6d diesel cars were compliant with the PN# 'not-to-exceed' value of 9.0 x 10^{11} over the total RDE drive cycle (see Table 9), localised elevated values are observed for the Ford Galaxy (Run 1) and Ford Tourneo Custom.

4.3 Euro 6d-temp petrol cars

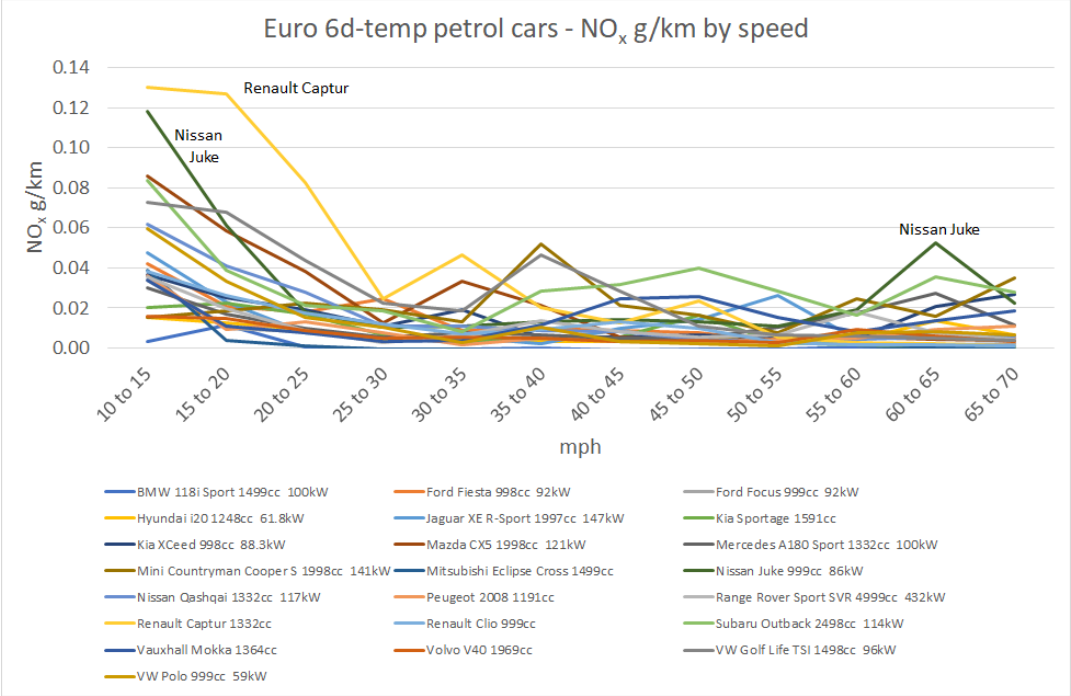

Figure 8: RDE NO_x g/km by speed – Euro 6d-temp petrol cars

For the sample of Euro 6d-temp petrol cars, higher NO_x emissions tend to be associated with lower speed operation (below 30mph). Above 30mph, mean NO_x g/km values are below 60mg/km.

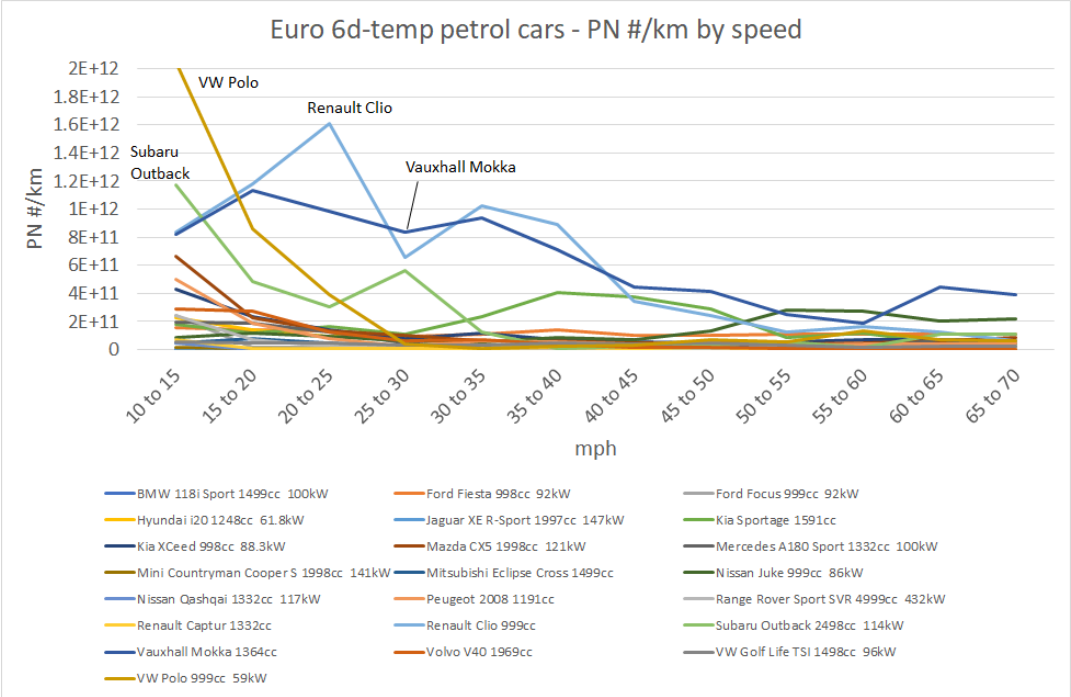

Figure 9: RDE PN #/km by speed – Euro 6d-temp petrol cars

Elevated levels of PN #/km are observed below 40mph for a number of vehicles within the sample, including the Renault Clio, Vauxhall Mokka, and Volkswagen Polo.

4.4 Euro 6d petrol cars

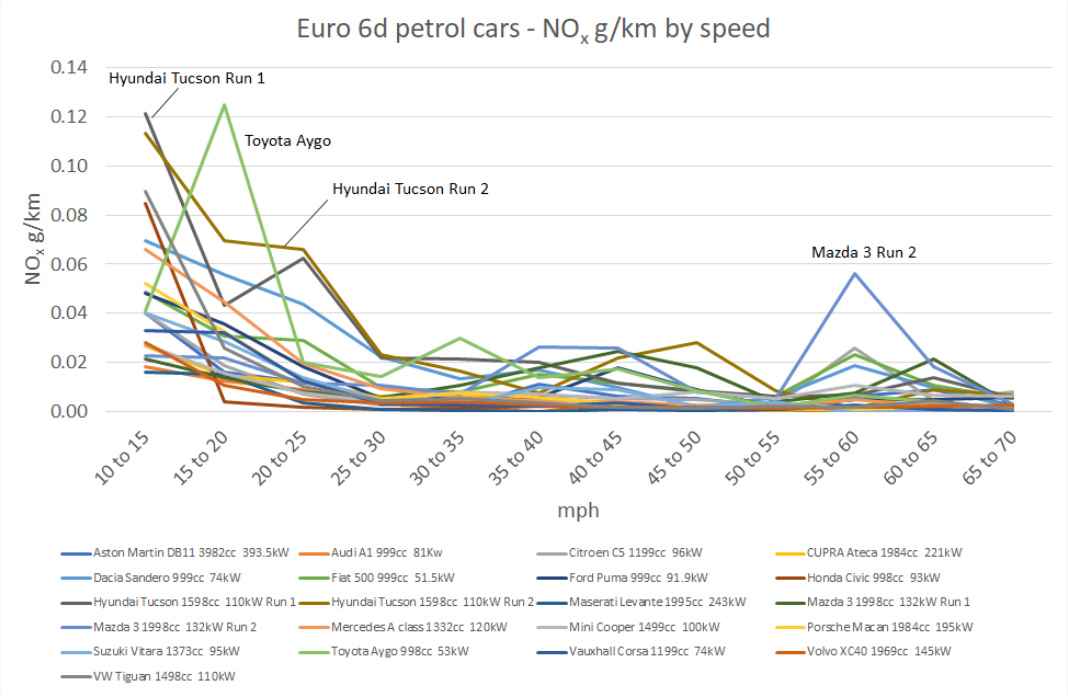

Figure 10: RDE NO_x g/km by speed – Euro 6d-temp petrol cars

For the sample of Euro 6d petrol cars, higher NO_x emissions again tend to be associated with lower speed operation (below 30mph). Above 30mph, mean NO_x g/km values are below 40mg/km, with the exception of the Mazda 3 (Run 2).

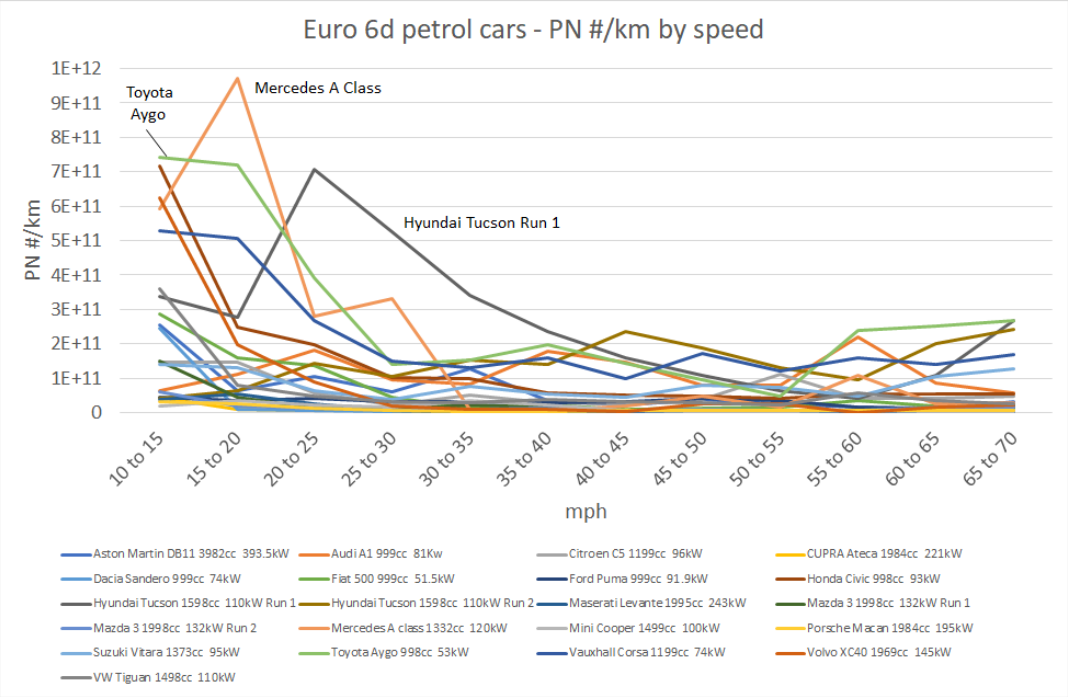

Figure 11: RDE PN #/km by speed – Euro 6d petrol cars

Elevated levels of PN #/km are observed below 40mph for a number of vehicles within the sample, including the Toyota Aygo, Mercedes A Class, and Hyundai Tucson (Run 1).

5. Comparison of RDE 'on road' PEMS NO_x g/km and DEFRA's Emissions Factors Toolkit v12.1

NO_x g/km values were abstracted from DEFRA's Emissions Factors Toolkit v12.1 (EFT), separately for Euro 6d-temp diesel cars, Euro 6d diesel cars, Euro 6d-temp petrol cars, and Euro 6d petrol cars.

https://laqm.defra.gov.uk/air-quality/air-quality-assessment/emissions-factors-toolkit/

The default proportions of vehicles by engine size in EFT were adjusted to be consistent with the available DfT/DVSA dataset for each of the four groups of vehicles, as presented in Table 12.

Table 12: Adjusted proportions of vehicles by engine size applied in EFT

	<1400 cc	**1400-2000cc**	**>2000 cc**
Euro 6d-temp diesel car	0	0.86	0.14
Euro 6d diesel car	0	0.86	0.14
Euro 6d-temp petrol car	0.55	0.36	0.09
Euro 6d petrol car	0.53	0.42	0.05

For the purpose of the comparison of the RDE 'on-road' PEMS and EFT v12.1 NO_x g/km values, the Honda Civic 1597cc 88kW Run 1 (Euro 6d-temp) data were excluded from the comparison. The test was not compliant with the legislated 'not-to-exceed' value, but DVSA accepted that their testing was not sufficient to conclude non-compliance of this vehicle type against NO_x conformity factors, after a second RDE test (Run 2) was conducted and was found compliant. Therefore, the Honda Civic 1597cc 88kW Run 2 (Euro 6d-temp) data have been included in the comparison with EFT.

Figures 12 to 15 present the comparison of the mean RDE 'on-road' PEMS and EFT v12.1 NO_x mg/km values by 5mph speed bin between 10mph and 70mph. Some notable differences between the two data sources are apparent.

With reference to Figure 12 (Euro 6d-temp diesel cars), it can be seen that up to 30mph the NO_x mg/km values from PEMS and EFT are not dissimilar. Above 30mph, the 'on-road' RDE values are lower than the EFT values, with the exception of the 55 to 60mph speed range, where there is a spike in the RDE NO_x value. Referring back to Figure 4 which presents the NO_x g/km data for the individual vehicles, and Figure 3 (vehicle dynamics), this spike in the RDE data appears to be associated with a subset of vehicles (including the Range Rover Velar Run 1, Honda Civic Run 2, Ford Kuga Run 1, and Nissan Qashqai) when operating under higher levels of acceleration, in the transition from 'rural' to 'motorway' operation, which is a characteristic of the 'on-road' RDE drive cycle utilised by DVSA.

However, with reference to Figures 13, 14, and 15 (Euro 6d diesel, Euro 6d-temp petrol, & Euro 6d petrol respectively), the 'on-road' RDE NO_x mg/km values are all significantly lower than the equivalent values obtained from DEFRA's Emissions Factors Toolkit v12.1. It should be noted that the PEMS sample size for Euro 6d diesel vehicles (7 vehicles, 8 PEMS tests) is small, so the results should be interpreted accordingly. However, the sample sizes for Euro 6d-temp petrol cars (22 vehicles), and Euro 6d petrol cars (19 vehicles, 21 PEMS tests) are larger and therefore more reliable.

Further research is required to understand the reasons for the observed differences between the DVSA 'on-road' RDE NO_x data collected using PEMS instrumentation, and DEFRA's Emissions Factors Toolkit v12.1. Such large differences may have a significant impact on highway scheme evaluation if they are demonstrated to be reliable.

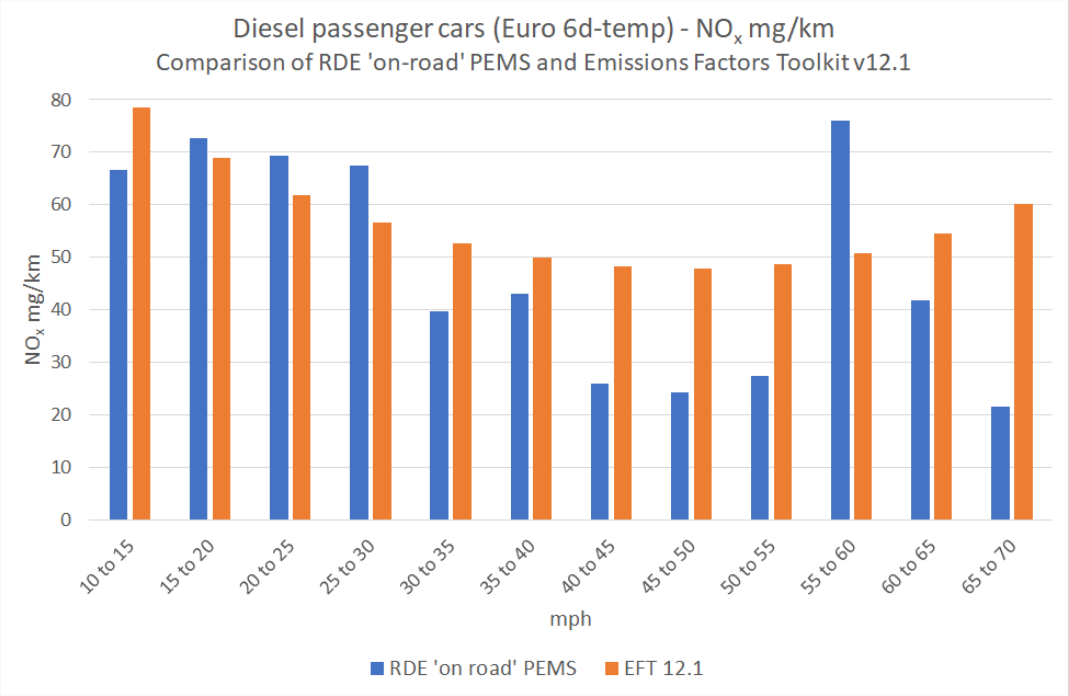

Figure 12: NO_x mg/km - Comparison of RDE 'on-road' PEMS and EFT v12.1 – Euro 6d-temp diesel cars

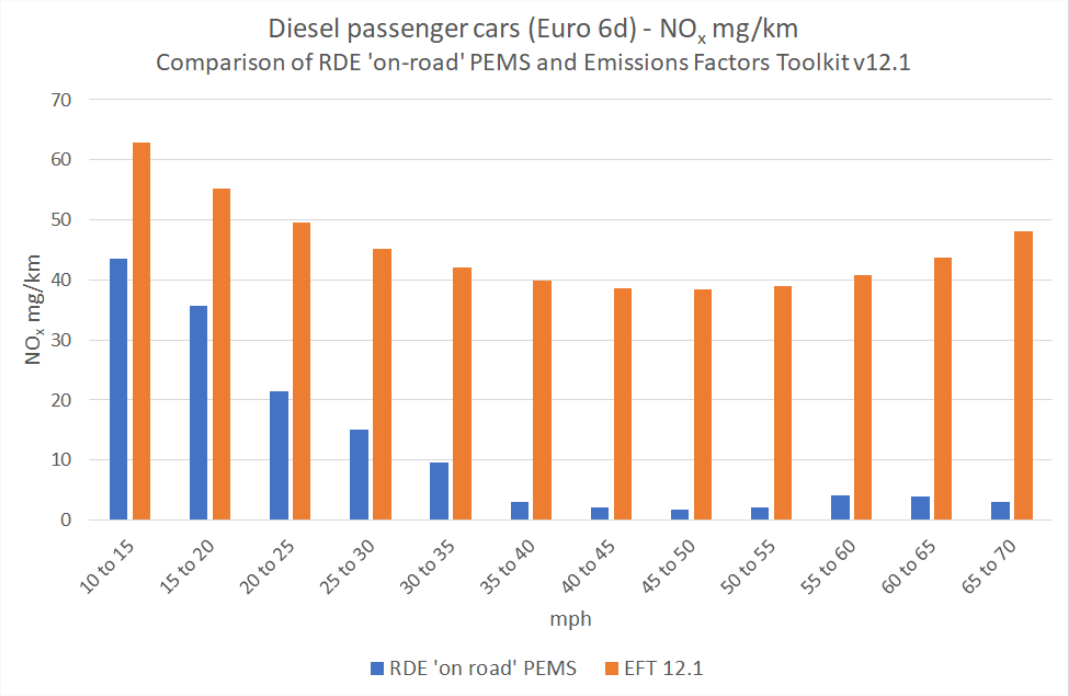

Figure 13: NO_x mg/km - Comparison of RDE 'on-road' PEMS and EFT v12.1 – Euro 6d diesel cars

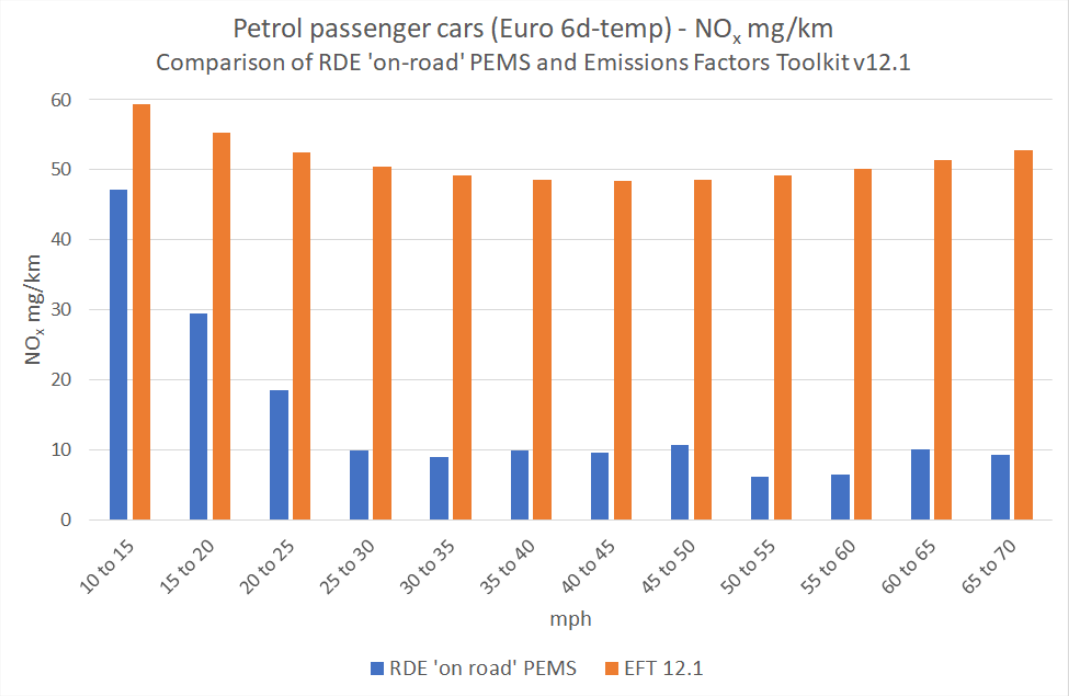

Figure 14: NO_x mg/km - Comparison of RDE 'on-road' PEMS and EFT v12.1 – Euro 6d-temp petrol cars

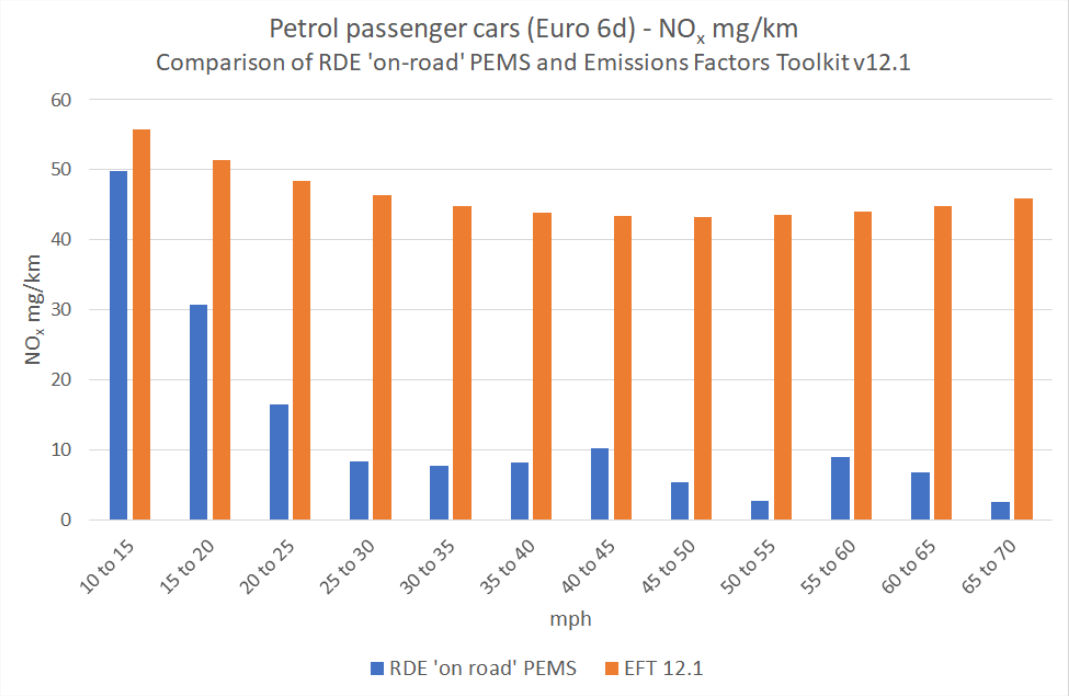

Figure 15: NO_x mg/km - Comparison of RDE 'on-road' PEMS and EFT v12.1 – Euro 6d petrol cars

6. Relationship between RDE 'on-road' PEMS exhaust emissions and Vehicle Specific Power (VSP)

Vehicle Specific Power (VSP) is a commonly used metric of engine load, with units of kW / tonne. VSP is a function of tyre rolling resistance, aerodynamic drag, highway gradient and acceleration. Allowances are also made for vehicle transmission efficiency, and additional engine load due to vehicle auxiliary systems (such as air conditioning). VSP values are calculated for each 1Hz data observation.

In this analysis, highway gradient has been estimated from changes in the GPS altitude data, with localised smoothing applied to mitigate any abrupt second by second step changes. The quality of GPS altitude data (and indeed latitude / longitude position data) is dependent on factors such as the number of satellites visible by the PEMS instrument at any particular time.

Table 13 presents the assumed kerb weight of the sample of vehicles for the calculation of VSP. A value of 150kg was added to the assumed kerb weight of the vehicle to represent the driver and instrumentation.

A preliminary analysis has been carried out to explore the relationships between VSP and NO_x g/km emissions, and between VSP and PN #/km.

For the purpose of the VSP analysis of NO_x data, the Honda Civic 1597cc 88kW Run 1 (Euro 6d-temp) data were excluded from the comparison. The test was not compliant with the legislated 'not-to-exceed' value, but DVSA accepted that their testing was not sufficient to conclude non-compliance of this vehicle type against NO_x conformity factors, after a second RDE test (Run 2) was conducted and was found compliant. Therefore, the Honda Civic 1597cc 88kW Run 2 (Euro 6d-temp) data have been included in the analysis.

Similarly, for the purpose of the VSP analysis of PN# data, the Range Rover Velar 2993cc 221kW Run 1 (Euro 6d-temp) data were excluded from the analysis. DVSA's analysis showed *"the vehicle experienced a diesel particulate filter (DPF) regeneration event during the first RDE test, which is likely to have accounted for the increase in PN. For RDE certified vehicles it is recommended within the relevant regulations to repeat the RDE test if a regeneration event is suspected. On repeating the RDE test, the PN results were much improved and were comfortably within the legal limit".* The VSP analysis includes the Range Rover Velar 2993cc 221kW Run 2 (Euro 6d-temp) data.

Table 13: Assumed kerb weight of passenger cars for VSP calculations

DVSA test year	Manufacturer	Model	Fuel type	Engine cc	Euro class	Kerb weight kg
2021	BMW	3 Series 320d (2020MY) auto	Diesel	1995	6d-temp	1455
2022	Ford	Focus (2020MY) manual	Diesel	1995	6d-temp	1418
2020	Ford	Kuga (2019MY) manual	Diesel	1997	6d-temp	1627
2019	Honda	Civic EX i-Dtec (2018MY) manual	Diesel	1597	6d-temp	1342
2022	Hyundai	Tucson (2020MY) manual	Diesel	1598	6d-temp	1507
2021	Jaguar	F Pace (2020MY) auto	Diesel	1999	6d-temp	1805
2022	Jeep	Wrangler (2019MY) auto	Diesel	2143	6d-temp	1845
2020	Kia	Sportage (2018MY) manual	Diesel	1598	6d-temp	1454
2019	Land Rover	Discovery SD4 (2018MY) auto	Diesel	1999	6d-temp	2109
2021	Mercedes-Benz	A Class (2020MY) auto	Diesel	1461	6d-temp	1445
2021	Mercedes-Benz	E Class E220 D AMG (2019MY)	Diesel	1950	6d-temp	1715
2019	Nissan	Qashqai (2018MY) manual	Diesel	1461	6d-temp	1365
2021	Peugeot	3008 (2020MY) auto	Diesel	1499	6d-temp	1430
2019	Range Rover	Velar (2018MY) auto	Diesel	2993	6d-temp	2029
2020	Renault	Kadjar (2019MY) manual	Diesel	1461	6d-temp	1428
2021	Skoda	Octavia (2020MY) manual	Diesel	1598	6d-temp	1273
2020	Toyota	Land Cruiser (2019MY) auto	Diesel	2755	6d-temp	2180
2020	Vauxhall	Astra Sri VX Line Nav CDTi (2018MY) manual	Diesel	1598	6d-temp	1275
2020	Vauxhall	Grandland X (2019MY) manual	Diesel	1499	6d-temp	1373
2021	Vauxhall	Insignia (2019MY) manual	Diesel	1956	6d-temp	1582
2021	Volvo	V90 (2020MY) auto	Diesel	1969	6d-temp	1722
2020	Volvo	XC60 (2019MY) auto	Diesel	1969	6d-temp	1873
2023	Audi	Q5 (2021MY) auto	Diesel	1968	6d	1805
2022	BMW	X5 (2021MY) auto	Diesel	2993	6d	2190
2022	Ford	Galaxy (2021MY) auto	Diesel	1995	6d	1760
2023	Ford	Tourneo Custom (2022MY) auto	Diesel	1995	6d	2093
2022	Mercedes-Benz	GLC (2019MY) auto	Diesel	1950	6d	1845
2022	Volkswagen	Passat (2021MY) auto	Diesel	1968	6d	1426
2023	Volkswagen	Tiguan (2021MY) auto	Diesel	1968	6d	1650
2019	BMW	118i Sport (2018MY) manual	Petrol	1499	6d-temp	1300
2021	Ford	Fiesta (2019MY) manual	Petrol	998	6d-temp	1163
2021	Ford	Focus (2020MY) auto	Petrol	999	6d-temp	1296
2020	Hyundai	i20 (2019MY) auto	Petrol	1248	6d-temp	1158
2020	Jaguar	XE R-Sport (2019MY) auto	Petrol	1997	6d-temp	1540
2021	Kia	Sportage (2020MY) auto	Petrol	1591	6d-temp	1490
2020	Kia	XCeed (2019MY) manual	Petrol	998	6d-temp	1393
2020	Mazda	CX5 (2019MY) manual	Petrol	1998	6d-temp	1573
2020	Mercedes-Benz	A180 Sport (2019MY) auto	Petrol	1332	6d-temp	1395
2021	Mini	Countryman Cooper S(2019MY) manual	Petrol	1998	6d-temp	1450
2021	Mitsubishi	Eclipse Cross (2019MY) manual	Petrol	1499	6d-temp	1425
2022	Nissan	Juke (2020MY) auto	Petrol	999	6d-temp	1207
2021	Nissan	Qashqai (2020MY) auto	Petrol	1332	6d-temp	1315
2020	Peugeot	2008 auto	Petrol	1191	6d-temp	1190
2022	Range Rover	Sport SVR (2020MY) auto	Petrol	4999	6d-temp	2323
2021	Renault	Captur (2020MY) manual	Petrol	1332	6d-temp	1180
2021	Renault	Clio (2020MY) manual	Petrol	999	6d-temp	1174
2022	Subaru	Outback (2019MY) auto	Petrol	2498	6d-temp	1621
2021	Vauxhall	Mokka (2018MY) auto	Petrol	1364	6d-temp	1394
2021	Volkswagen	Golf Life TSI (2020MY) manual	Petrol	1498	6d-temp	1231
2022	Volkswagen	Polo (2019MY) manual	Petrol	999	6d-temp	1068
2019	Volvo	V40 manual	Petrol	1969	6d-temp	1390
2023	Aston Martin	DB11 (2022MY) auto	Petrol	3982	6d	1770
2023	Audi	A1 (2022MY) auto	Petrol	999	6d	1130
2022	Citroen	C5 (2020MY) auto	Petrol	1199	6d	1430
2023	CUPRA	Ateca (2022MY) auto	Petrol	1984	6d	1553
2022	Dacia	Sandero (2021MY) manual	Petrol	999	6d	1061
2022	Fiat	500 (2021MY) manual	Petrol	999	6d	980
2023	Ford	Puma MEHV (2020MY) manual	Petrol	999	6d	1244
2022	Honda	Civic (2021MY) manual	Petrol	998	6d	1275
2023	Hyundai	Tucson (2021MY) manual	Petrol	1598	6d	1425
2023	Maserati	Levante (2022MY) auto	Petrol	1995	6d	2090
2022	Mazda	3 (2020MY) manual	Petrol	1998	6d	1411
2023	Mercedes-Benz	A Class (2022MY) auto	Petrol	1332	6d	1375
2023	Mini	Cooper (2022MY) manual	Petrol	1499	6d	1320
2023	Porsche	Macan (2022MY) auto	Petrol	1984	6d	1865
2021	Suzuki	Vitara (2020MY) manual	Petrol	1373	6d	1205
2021	Toyota	Aygo (2019MY) manual	Petrol	998	6d	840
2021	Vauxhall	Corsa (2020MY) manual	Petrol	1199	6d	1090
2022	Volkswagen	Tiguan (2021MY) auto	Petrol	1498	6d	1461
2023	Volvo	XC40 MEHV (2021MY) auto	Petrol	1969	6d	1640

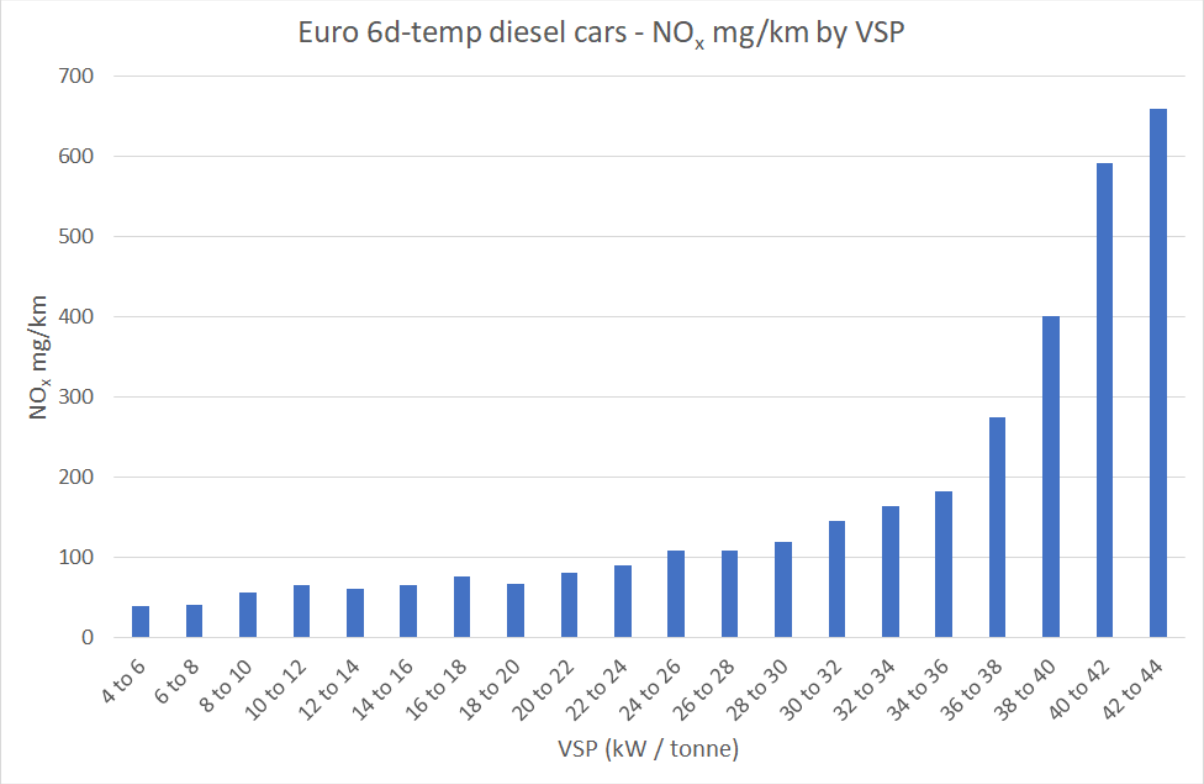

Figure 16: Relationship between NO_x mg/km and VSP – Euro 6d-temp diesel cars

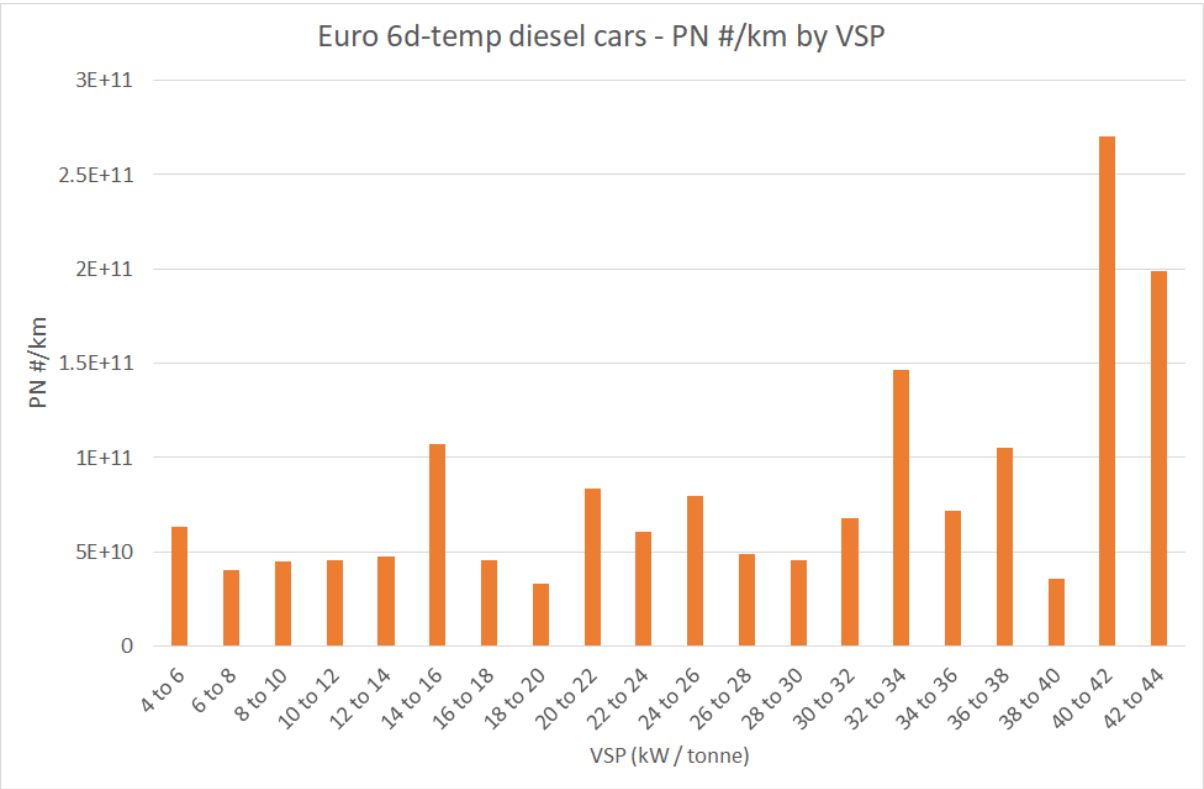

Figure 17: Relationship between PN #/km and VSP – Euro 6d-temp diesel cars

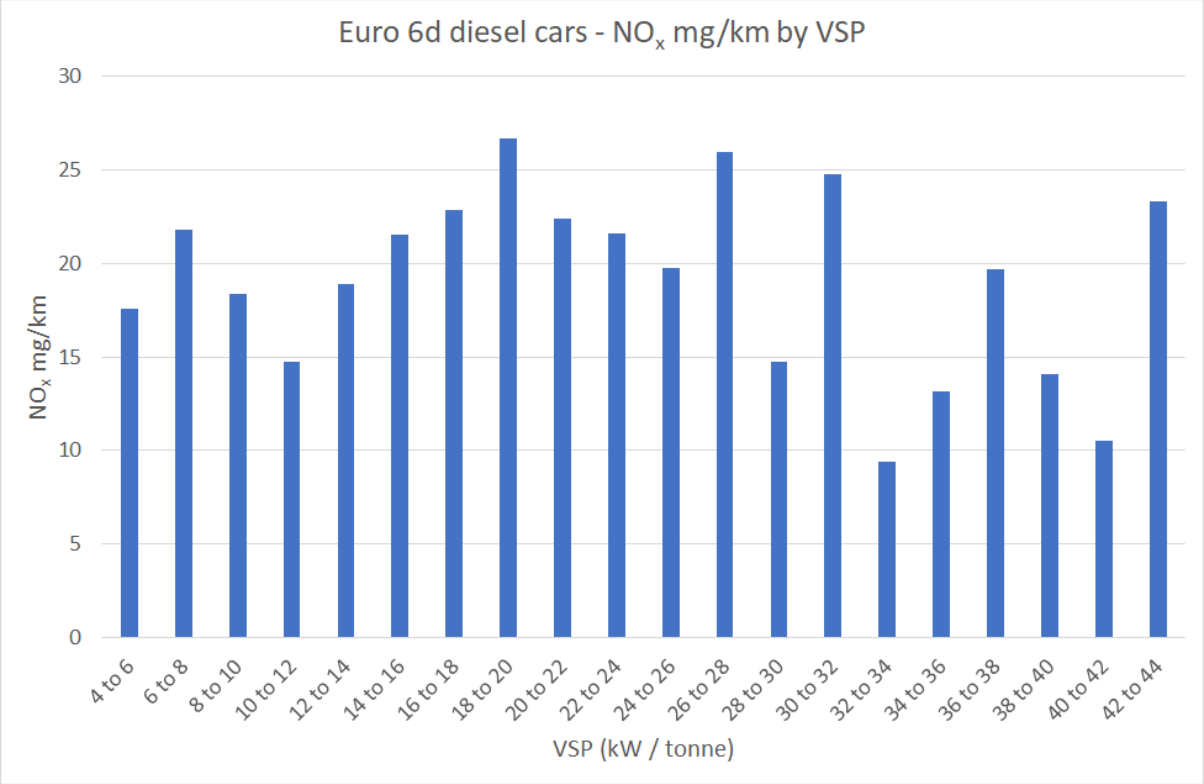

Figure 18: Relationship between NO_x mg/km and VSP – Euro 6d diesel cars

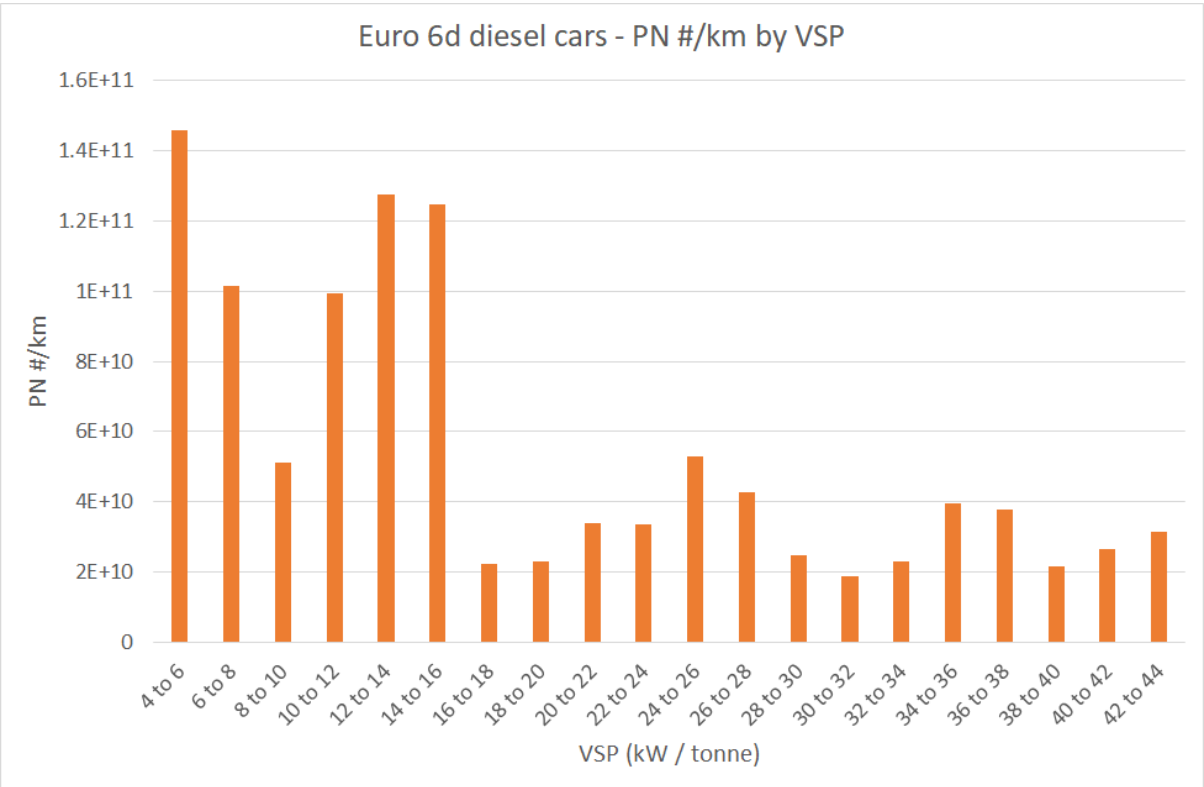

Figure 19: Relationship between PN #/km and VSP – Euro 6d diesel cars

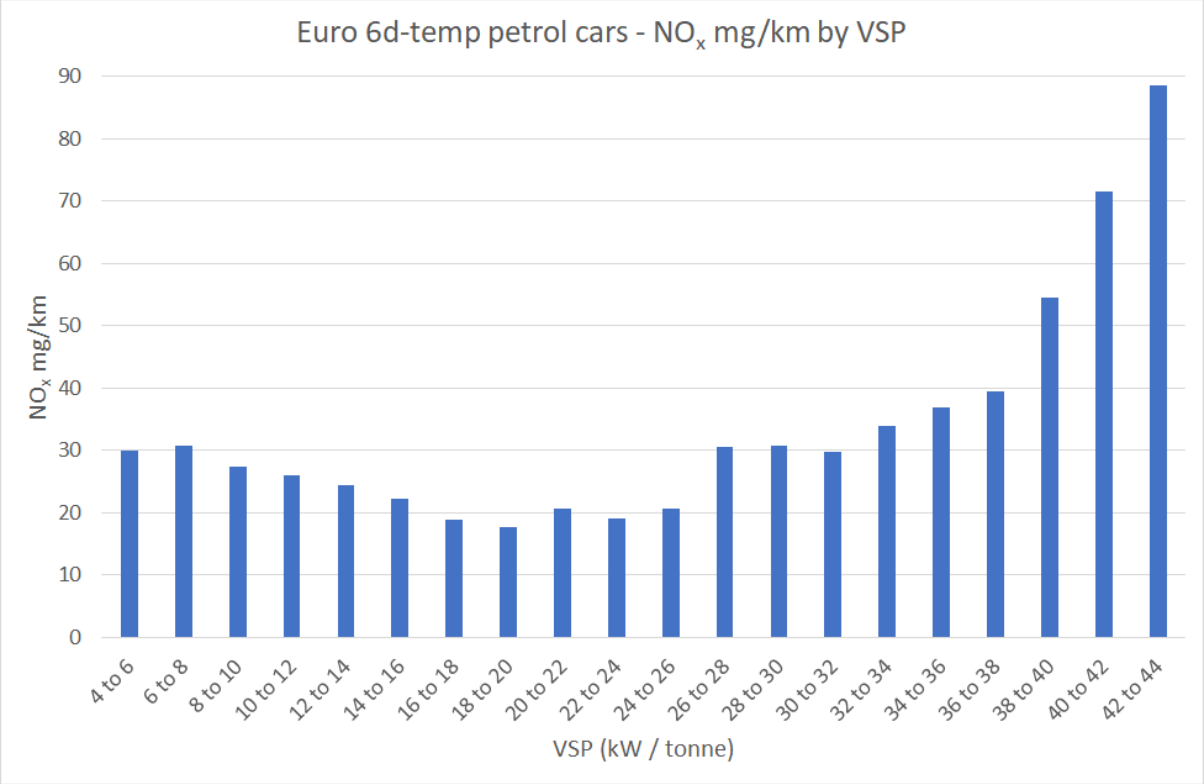

Figure 20: Relationship between NO_x mg/km and VSP – Euro 6d-temp petrol cars

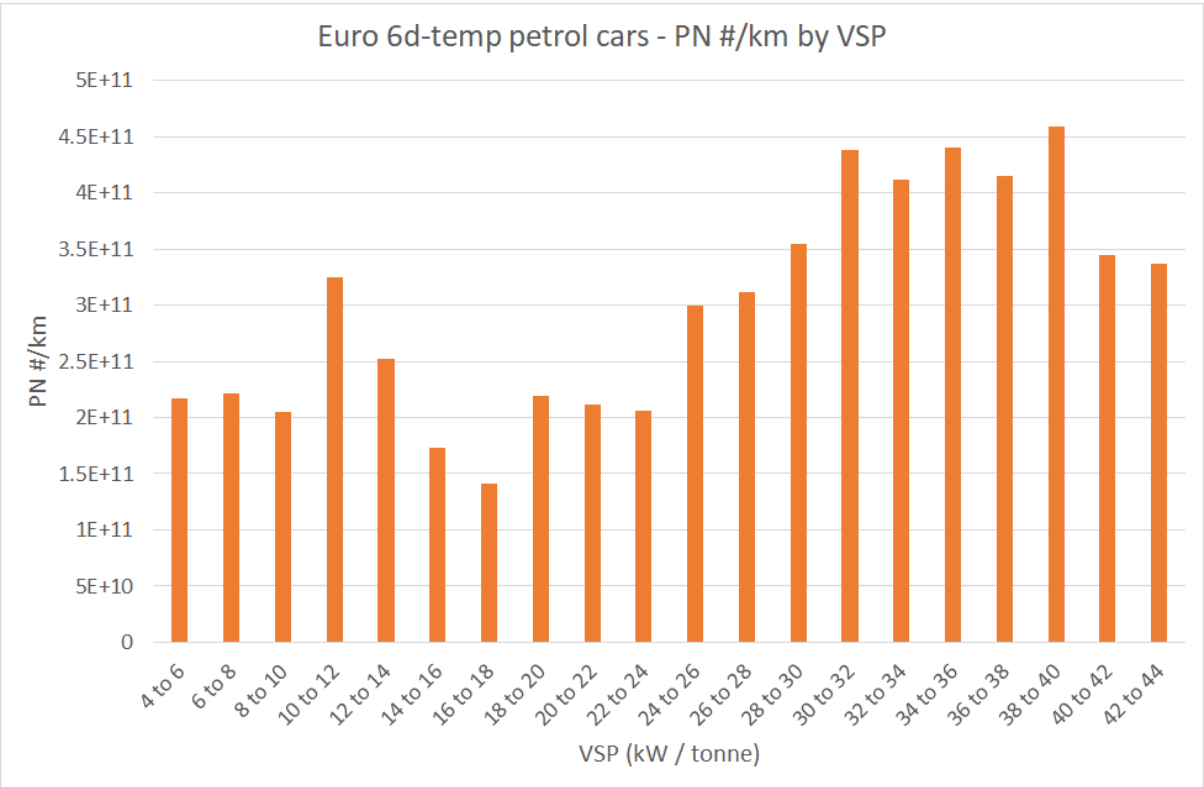

Figure 21: Relationship between PN #/km and VSP – Euro 6d-temp petrol cars

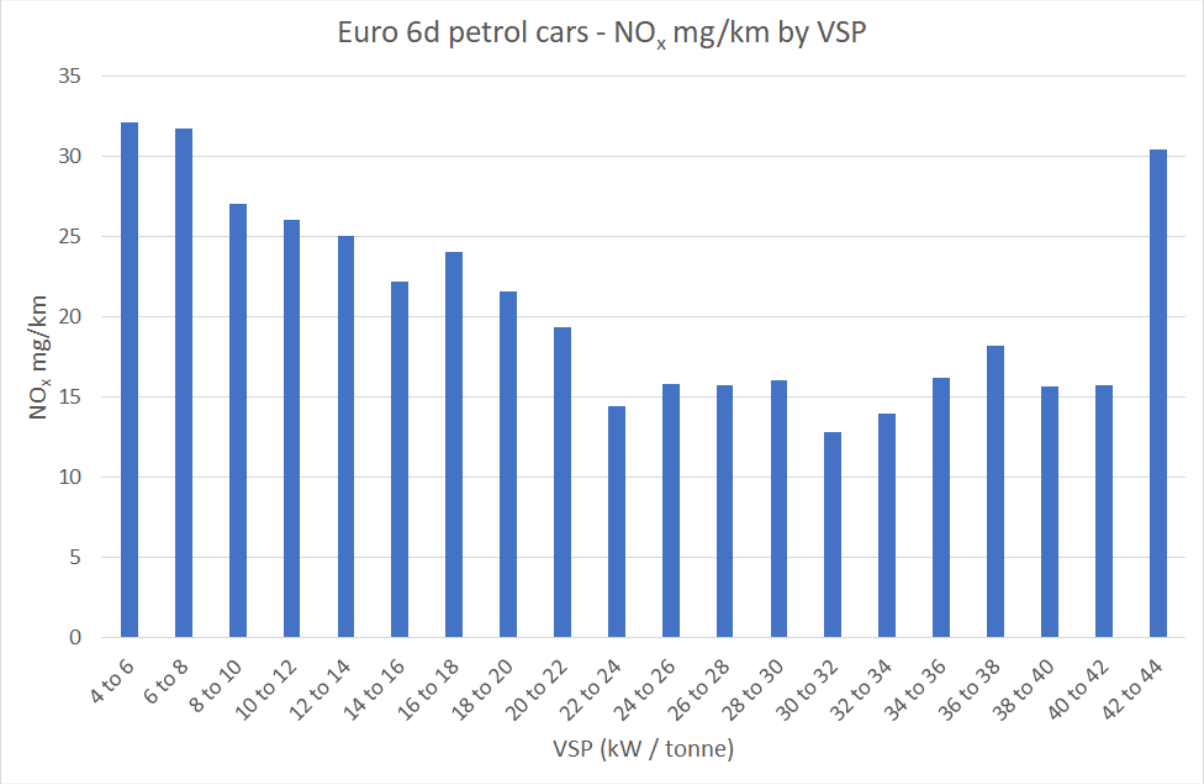

Figure 22: Relationship between NO_x mg/km and VSP – Euro 6d petrol cars

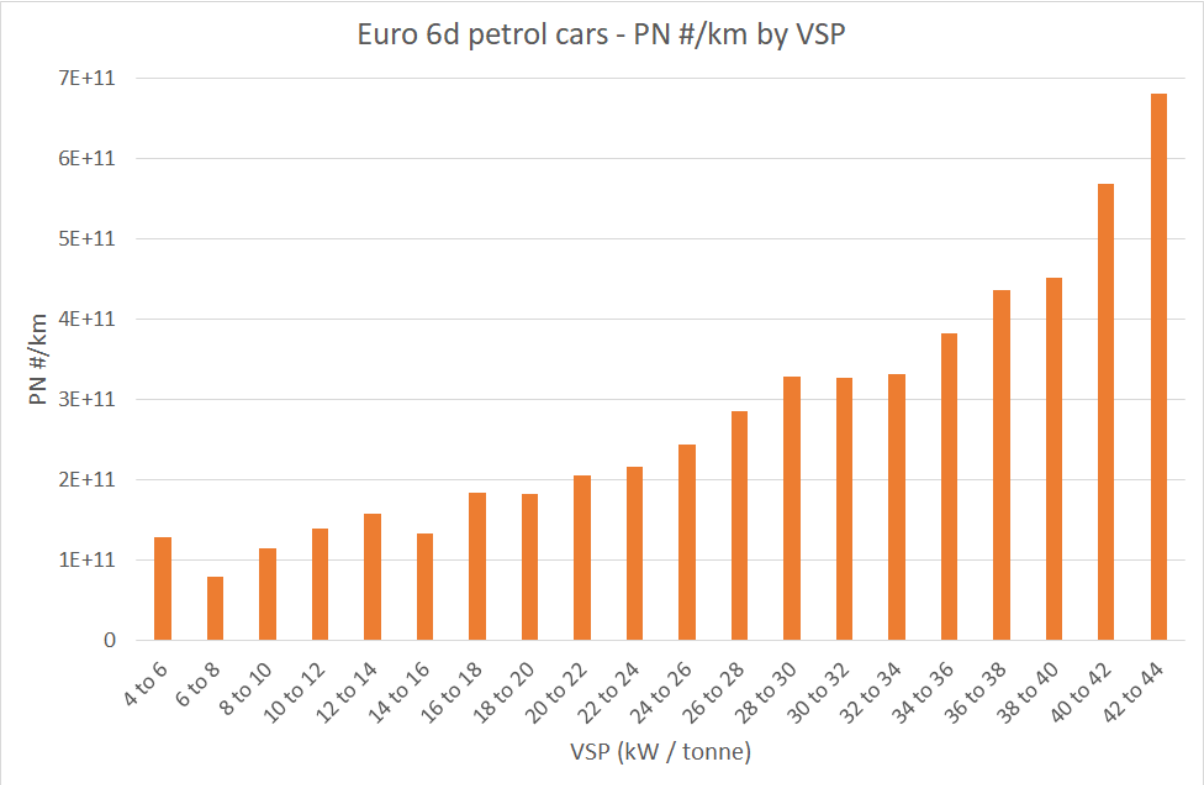

Figure 23: Relationship between PN #/km and VSP – Euro 6d petrol cars

Appendix A – DfT / DVSA RDE 'on road' PEMS survey routes

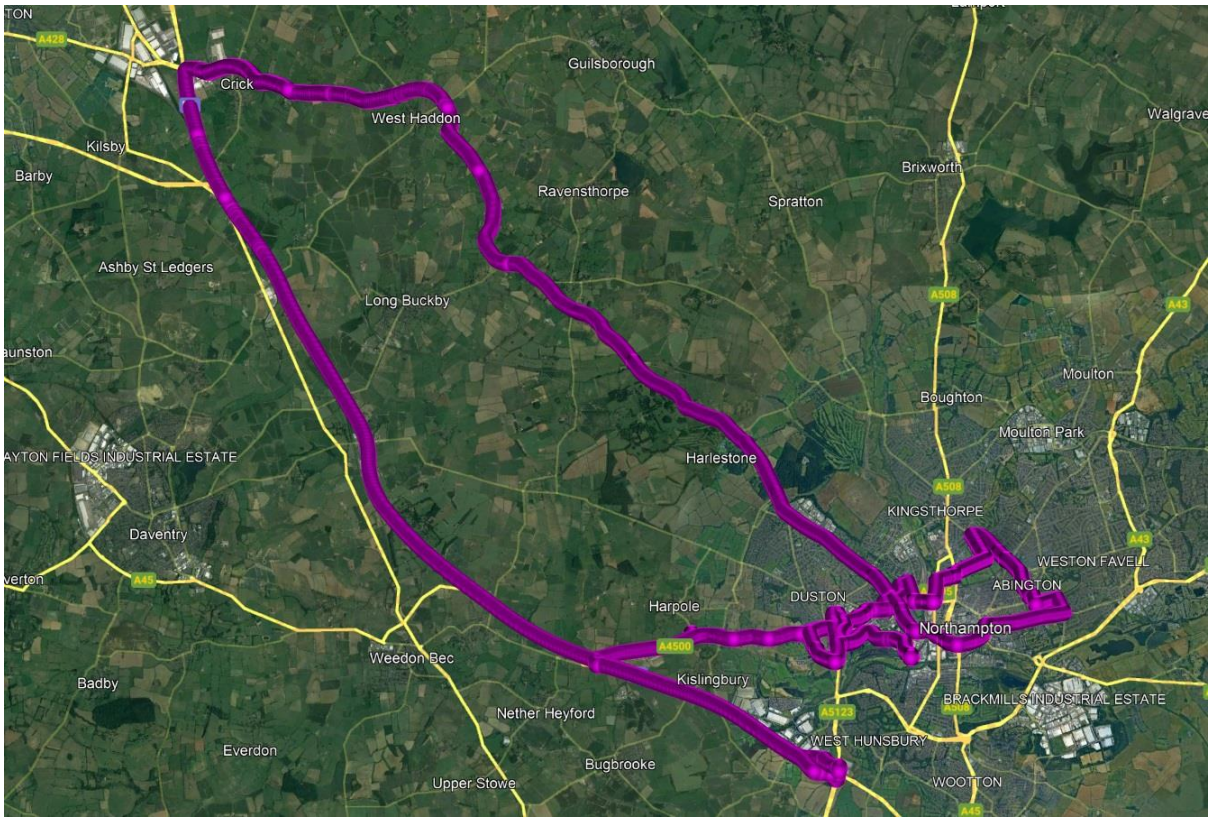

Figure A1: Survey year 2019, 2020 & 2021 – Northampton urban area and M1, A428 west of Northampton

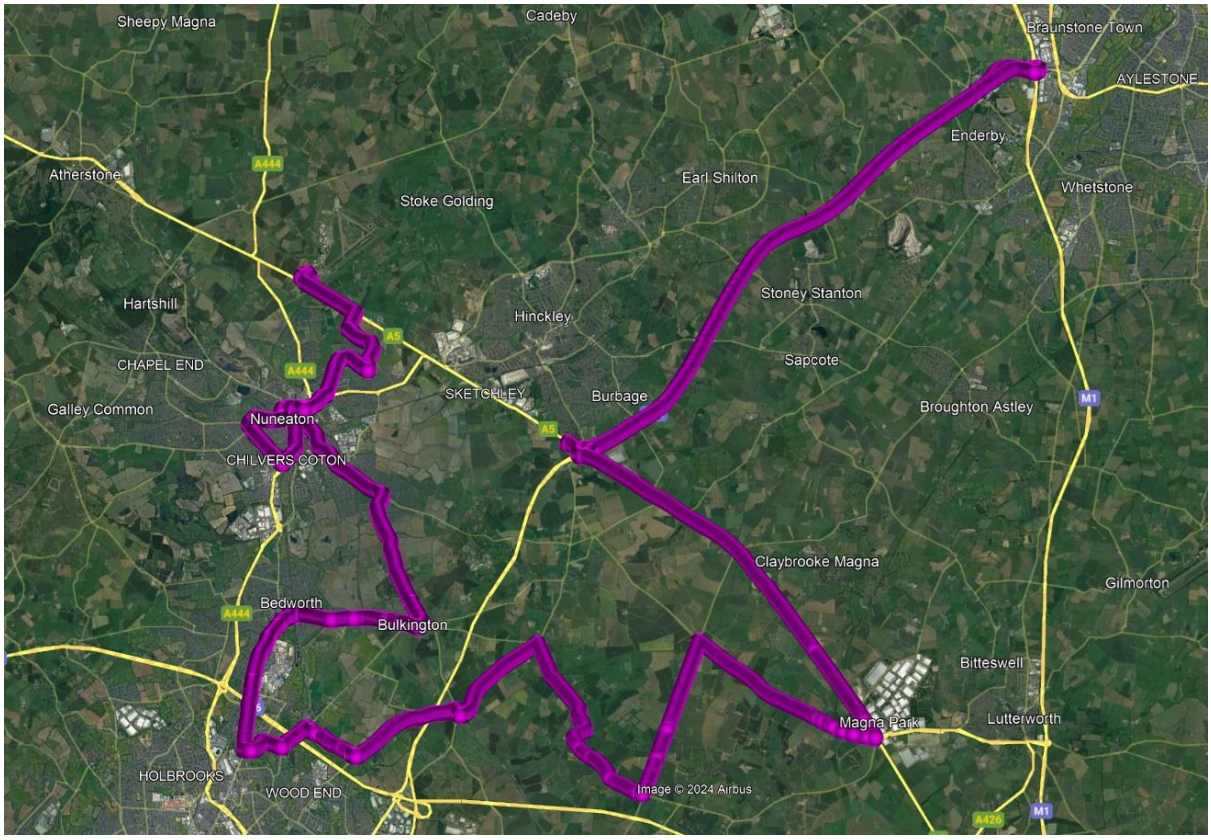

Figure A2: Survey year 2022 – Nuneaton, M69, A5 north of Coventry

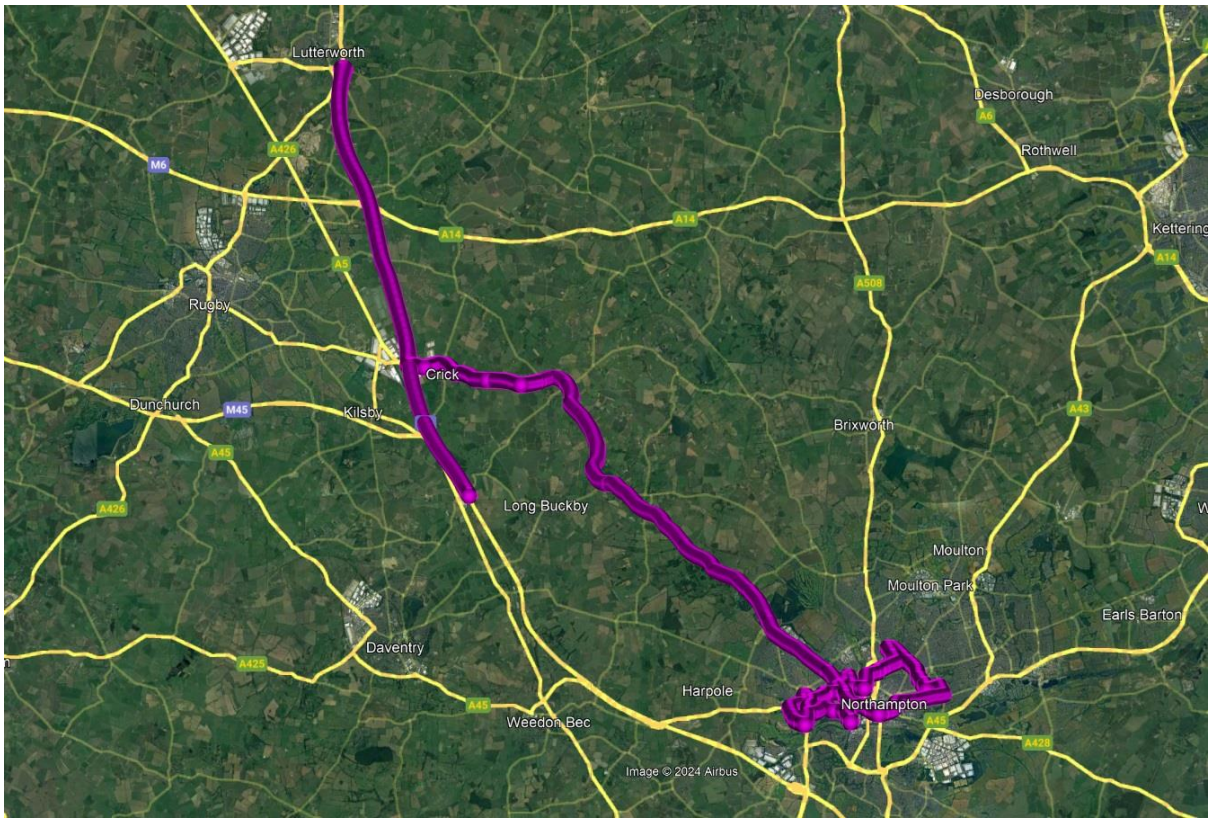

Figure A3: Survey year 2023 – Northampton urban area and A428, M1 to Lutterworth