

CO₂ g/km exhaust emissions from UK passenger vehicles.

PHEV (Plug-in Hybrid Electric Vehicles) and Self Charging Hybrid passenger cars.

A preliminary analysis of published DfT / DVSA Vehicle Market Surveillance Unit RDE 'on road' exhaust emissions data (2020 – 2024).

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Disclaimer

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 document emission results for pollutants with legislated limit values (such as NO_x, CO, and particle number per km), CO₂ g/km results over the RDE (real driving emissions) 'on road' drive cycle are not systematically reported. In European legislation, CO₂ g/km emissions limits are specified in terms of annual specific emission targets for each manufacturer based on EU fleet-wide targets, taking into account the mix of its registered new vehicles. Since 2021, these specific CO₂ emission targets are based on the Worldwide Harmonised Light Vehicle Test Procedure (WLTP) laboratory test cycle. The CO₂ g/km values published for each new passenger car are WLTP values.

However, the RDE 'on road' CO₂ g/km values are of potential value to the research community to help inform analysis of 'real world' carbon 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 passenger cars identified by DVSA as either plug-in hybrid electric vehicles (PHEV) or self-charging hybrid electric vehicles of Euro class 6d-temp and Euro class 6d. CO₂ g/km emissions values from conventional (non-hybrid) petrol and diesel passenger cars were reported in October 2024 (see <https://www.glynrhys-tyler.com/publications.html>).

The analysis provides insights into the 'on road' CO₂ 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.

2. Data processing

The RDE 'on road' data published by DVSA were collected using Portable Emissions Measuring 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 2020 to 2024 are illustrated in Appendix A.

This analysis utilised the EMROAD version 6.06 (B1) utility developed by the European Commission Joint Research Centre (JRC). The mass of the exhaust gas component (in this case CO₂) is calculated using:

$$m_{\text{gas},i} = U_{\text{gas}} \cdot C_{\text{gas},i} \cdot q_{\text{mew},i}$$

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 1 presents the list of petrol PHEV passenger cars included in the analysis (17 vehicles), documenting relevant parameters such as Euro class, engine capacity, maximum power output, and the mean ambient temperature of the RDE ‘on road’ test. Note that each PHEV vehicle was subjected to two ‘on-road’ RDE tests:

- **Charge depleting** RDE ‘on-road’ test from a cold start (where power for vehicle propulsion is primarily dependent on the vehicle battery pack);
- **Charge sustaining** RDE ‘on-road’ test from a hot start (where power for vehicle propulsion is primarily dependent on the internal combustion engine).

In practice, when the minimum battery state of charge is reached, or battery charge is insufficient to provide the required power, the PHEV powertrain control system automatically switches from charge depleting to charge sustaining mode, and activates the internal combustion engine (ICE).

Table 2 presents the list of petrol self-charging hybrid passenger cars in the analysis (10 vehicles).

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

Table 1: Petrol PHEV passenger cars included in DfT/DVSA RDE ‘on road’ PEMS tests (Euro 6d-temp & Euro 6d only), as reported by DfT/DVSA

DVSA test year	Manufacturer	Model	Engine cc	Euro class	kW	Mean Ambient Temp °C	
						Charge depleting	Charge sustaining
2020	BMW	530e (2018MY) auto	1998	6d-temp		11	21.5
2020	Mitsubishi	Outlander (2019MY) auto	2360	6d-temp	99	13.2	17.5
2020	Volvo	XC90 (2019MY) auto	1969	6d-temp	223	13.8	13.8
2022	Audi	A3 (2021MY) auto	1395	6d		13.2	14.9
2022	Kia	Niro (2021MY) auto	1580	6d		19.7	21.7
2022	Kia	Niro (2021MY) auto Run 2	1580	6d			22.4
2022	Peugeot	508 (2021MY) auto	1598	6d		12	8.3
2023	BMW	330e xDrive (2022MY) auto	1998	6d	135 ICE / 80 EM	12.6	15.6
2023	Mercedes Benz	E300 (2020MY) auto	1950	6d-temp	143 ICE / 90 EM	11.7	17.1
2023	Porsche	Cayenne (2022MY) auto	2995	6d	250 ICE / 100 EM	5.7	6.9
2023	Range Rover	Vogue P400E (2021MY) auto	1997	6d	221 ICE / 105 EM	9.9	14.7
2023	Volvo	XC40 (2022MY) auto	1477	6d	132 ICE / 60 EM	14	16.8
2024	Bentley	Bentayga (2021MY) auto	2995	6d	250 ICE / 94 EM	18.6	20.5
2024	Ford	Kuga (2022MY) auto	2488	6d	112 ICE / 42.4 EM	18.8	20
2024	MG	HS (2022MY) auto	1490	6d	119 ICE / 35 EM	7.4	7.2
2024	Skoda	Octavia (2023MY) auto	1395	6d	110 ICE / 55 EM	8	10.6
2024	Suzuki	Across (2023MY) auto	2487	6d	136 ICE / 40 EM	18	22.1
2024	Vauxhall	Astra (2022MY) auto	1598	6d	110 ICE / 40 EM	12.4	13.5

Note: ICE = Internal combustion engine; EM = Electric motor

Table 2: Petrol self-charging hybrid passenger cars included in DfT/DVSA RDE 'on road' PEMS tests (Euro 6d-temp & Euro 6d only), as reported by DfT/DVSA

DVSA test year	Manufacturer	Model	Engine cc	Euro class	kW	Mean Ambient Temp °C
2020	Lexus	NX300h (2019MY) CVT cold start	2494	6d-temp	114	13.6
2020	Lexus	NX300h (2019MY) CVT hot start	2494	6d-temp	114	20.1
2020	Toyota	Yaris (2019MY) CVT cold start	1497	6d-temp	54	10.3
2020	Toyota	Yaris (2019MY) CVT hot start	1497	6d-temp	54	12
2022	Hyundai	IONIQ (2021MY) auto cold start	1580	6d-temp	77.2	8.6
2022	Toyota	C-HR (2021MY) auto cold start	1798	6d	72	8.1
2022	Toyota	C-HR (2021MY) auto hot start	1798	6d	72	3
2023	Honda	Jazz (2021MY) CVT	1498	6d	72	12.5
2023	Toyota	Corolla (2021MY) CVT	1798	6d	72	11.9
2024	Lexus	RX450 (2022MY) CVT	3456	6d	193 ICE/ 123 EM	9.8
2024	Renault	Arkana (2023MY) auto	1598	6d	69 ICE / 36 EM	4
2024	Renault	Clio (2023MY) auto	1598	6d	69 ICE / 51 EM	11.3
2024	Suzuki	Swift (2023MY) auto	1197	6d	61 ICE / 1.94 EM	6.7

Note: ICE = Internal combustion engine; EM = Electric motor; CVT = Continuously variable transmission

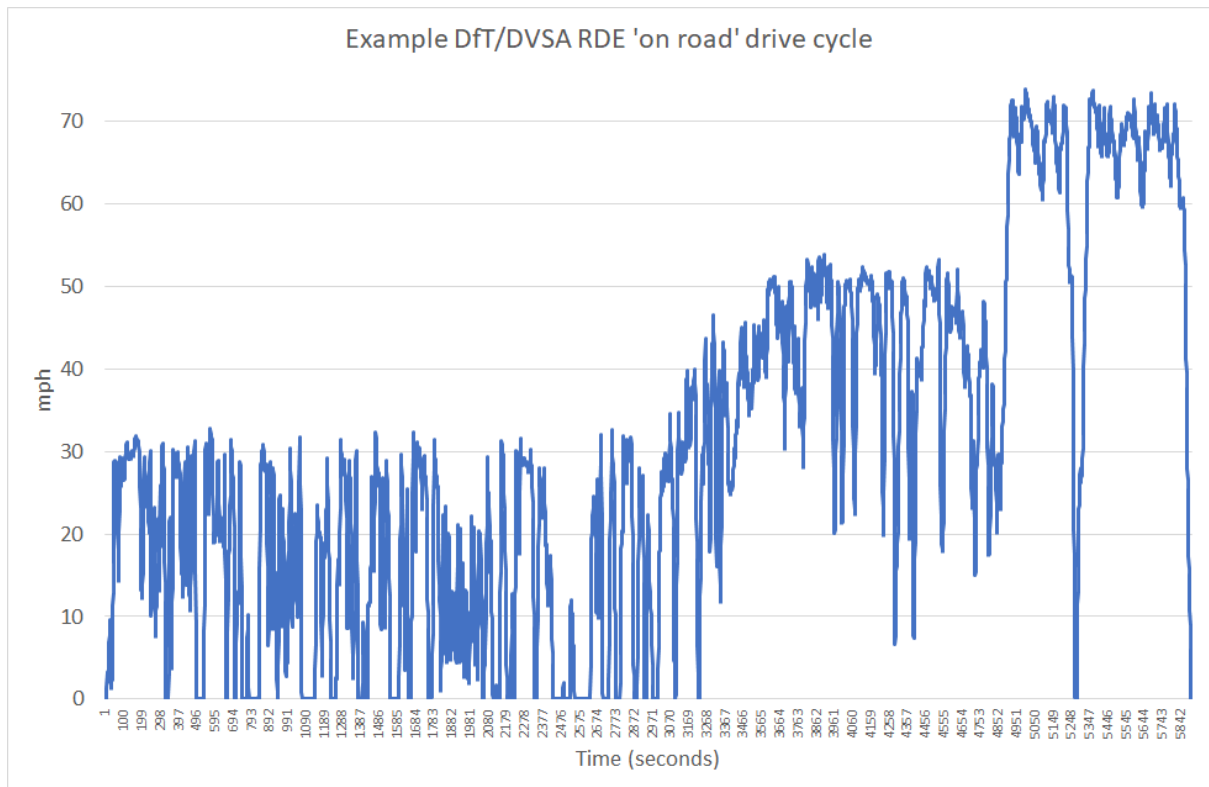


Figure 1: Example DfT/DVSA RDE 'on road' drive cycle

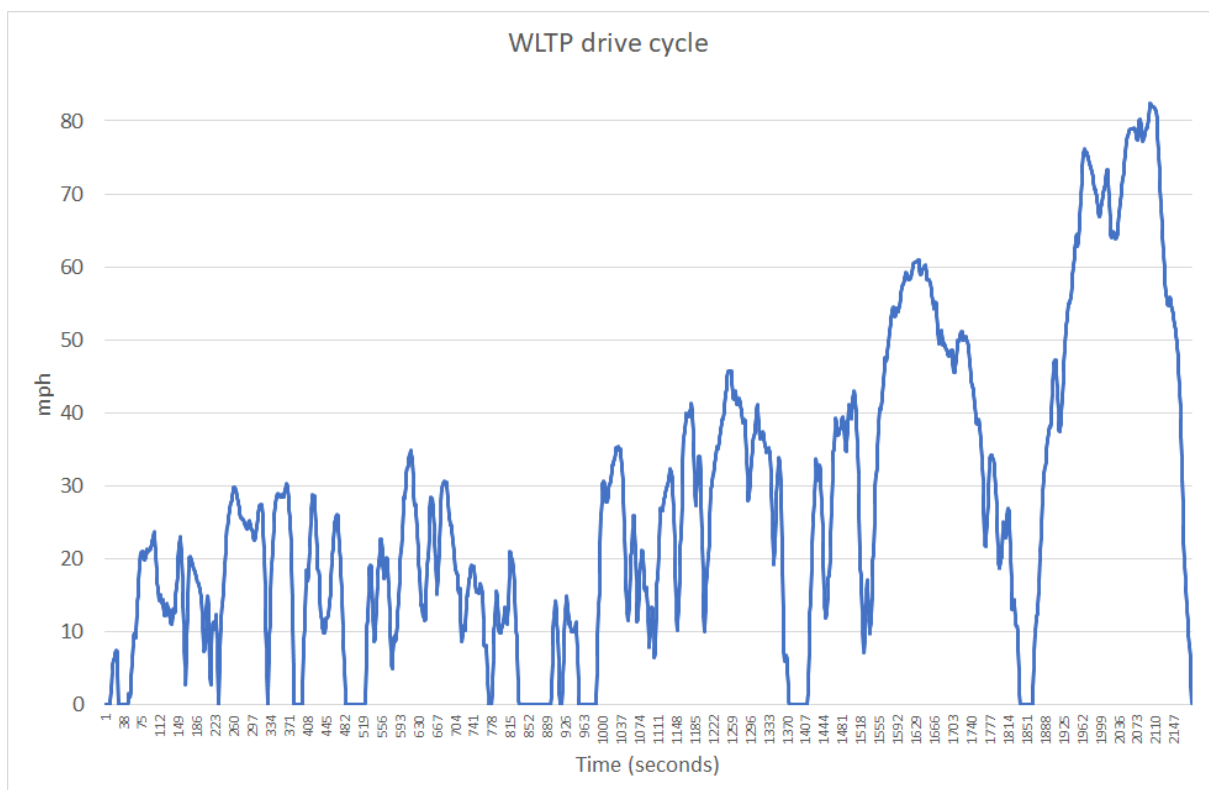


Figure 2: WLTP drive cycle

3. Results

3.1 RDE 'on road' CO₂ g/km values – Petrol PHEV cars

Tables 3 and 4 present the aggregate CO₂ g/km results for the PHEV vehicles tested, by road type, and for the complete test. Table 3 presents the results for the charge depleting tests, and Table 4 presents the results for the charge sustaining tests.

Figures 3 to 6 inclusive illustrate the results for the complete tests, and each road type, comparing charge depleting with charge sustaining. As is perhaps to be expected, the largest differences in CO₂ g/km emissions between charge depleting and charge sustaining modes are to be seen in the urban road type in Figure 4, and to a lesser extent in the rural road type in Figure 5. Figure 6 demonstrates that the differences in CO₂ g/km between the two modes of operation on the motorway road type are negligible for the majority of vehicles tested.

The pattern of results for the three PHEV vehicles tested by DVSA in 2020 (see Table 1) appear to be inconsistent with PHEV tests carried out by DVSA in 2022, 2023, and 2024, which may indicate inconsistencies in the testing regimes between these two cohorts of vehicles.

Figures 7 to 10 inclusive present the same data, but in the form of scatter plots, plotting charge depleting CO₂ g/km versus charge sustaining CO₂ g/km results. As a benchmark, the median CO₂ g/km values for conventional (non-hybrid) Euro 6d-temp and Euro 6d petrol cars from DVSA PEMS tests have been overlaid as a black dashed line, for each road type respectively. It is notable that:

- For the **motorway road type** (see Figure 10), 11 of the 17 PHEV vehicles tested (65%) have higher CO₂ g/km emission rates than the median CO₂ g/km value for conventional (non-hybrid) petrol cars tested by DVSA, both in charge depleting and charge sustaining modes;
- For the **rural road type** (see Figure 9), 5 of the 17 PHEV vehicles tested (29%) have higher CO₂ g/km emission rates than the median CO₂ g/km value for conventional (non-hybrid) petrol cars tested by DVSA, both in charge depleting and charge sustaining modes. Considering charge sustaining mode only, 11 of the 17 PHEV vehicles tested (65%) have higher CO₂ g/km emission rates than the median CO₂ g/km value for conventional (non-hybrid) petrol cars tested by DVSA.
- For the **urban road type** (see Figure 8), in charge sustaining mode, 5 of the 17 PHEV vehicles tested (29%) have higher CO₂ g/km emission rates than the median CO₂ g/km value for conventional (non-hybrid) petrol cars tested by DVSA.
- For the **complete RDE 'on-road' drive cycle test** (see Figure 7), in charge sustaining mode, 8 of the 17 PHEV vehicles tested (47%) have higher CO₂ g/km emission rates than the median CO₂ g/km value for conventional (non-hybrid) petrol cars tested by DVSA.

It may be concluded that if the majority of vehicle mileage is driven on motorways, there is little (CO₂ g/km) benefit in choosing a PHEV car over a conventional (non-hybrid) petrol car. Indeed, there may be a disbenefit of driving a PHEV car, depending on vehicle specification. The test results also indicate that for urban and rural road types, the state of battery charge (charge depleting versus charge sustaining) is a significant issue for CO₂ g/km emissions. Hence, driver behaviour in terms of frequency of battery charging is an important consideration when assessing environmental performance of PHEV cars.

Table 3: RDE 'on road' PEMS test CO₂ g/km – Petrol PHEV charge depleting

Vehicle	Complete test	Urban	Rural	Motorway
Volvo XC90 (2019MY)	164	122	169	203
BMW 530e iPerformance (2018MY)	152	95	189	173
Porsche Cayenne (2022MY)	146	46	180	215
Range Rover Vogue P400E (2021MY)	145	143	71	218
Bentley Bentayga (2021MY)	137	61	149	204
Mitsubishi Outlander (2019MY)	129	34	151	209
MG HS (2022MY)	91	42	42	185
BMW 330e xDrive (2022MY)	88	17	100	150
Volvo XC40 (2022MY)	87	10	74	180
Mercedes E300 (2020MY)	81	25	96	135
Skoda Octavia (2023MY)	81	24	67	153
Vauxhall Astra (2022MY)	79	13	76	152
Peugeot 508 (2021MY)	74	13	77	131
Audi A3 (2021MY)	58	14	26	115
Ford Kuga (2022MY)	51	10	22	124
Kia Niro (2021MY)	45	5	9	122
Suzuki Across (2023MY)	22	0	0	68

Table 4: RDE 'on road' PEMS test CO₂ g/km – Petrol PHEV charge sustaining

Vehicle	Complete test	Urban	Rural	Motorway
Bentley Bentayga (2021MY)	247	316	213	202
Range Rover Vogue P400E (2021MY)	243	295	217	218
Porsche Cayenne (2022MY)	230	283	212	195
MG HS (2022MY)	202	232	178	195
BMW 330e xDrive (2022MY)	184	240	164	148
Volvo XC40 (2022MY)	171	191	158	162
Volvo XC90 (2019MY)	166	107	183	209
Vauxhall Astra (2022MY)	161	187	142	151
Skoda Octavia (2023MY)	151	182	128	142
Peugeot 508 (2021MY)	150	186	139	125
Mercedes E300 (2020MY)	143	154	135	137
BMW 530e iPerformance (2018MY)	130	50	173	177
Mitsubishi Outlander (2019MY)	125	37	138	200
Suzuki Across (2023MY)	125	133	121	119
Audi A3 (2021MY)	123	141	125	110
Ford Kuga (2022MY)	123	121	121	127
Kia Niro (2021MY) Run 1	119	130	112	114
Kia Niro (2021MY) Run 2	110	112	96	119

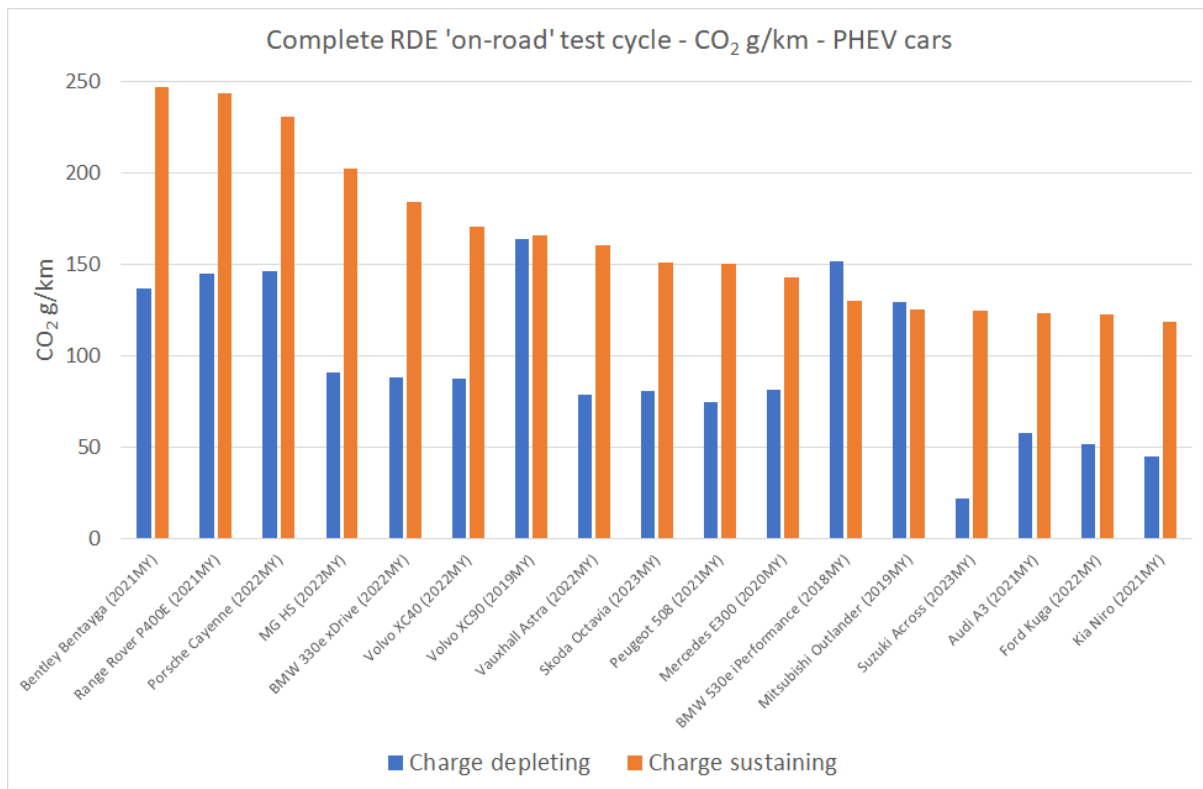


Figure 3: RDE 'on road' PEMS test CO₂ g/km – Petrol PHEV – Complete test cycle

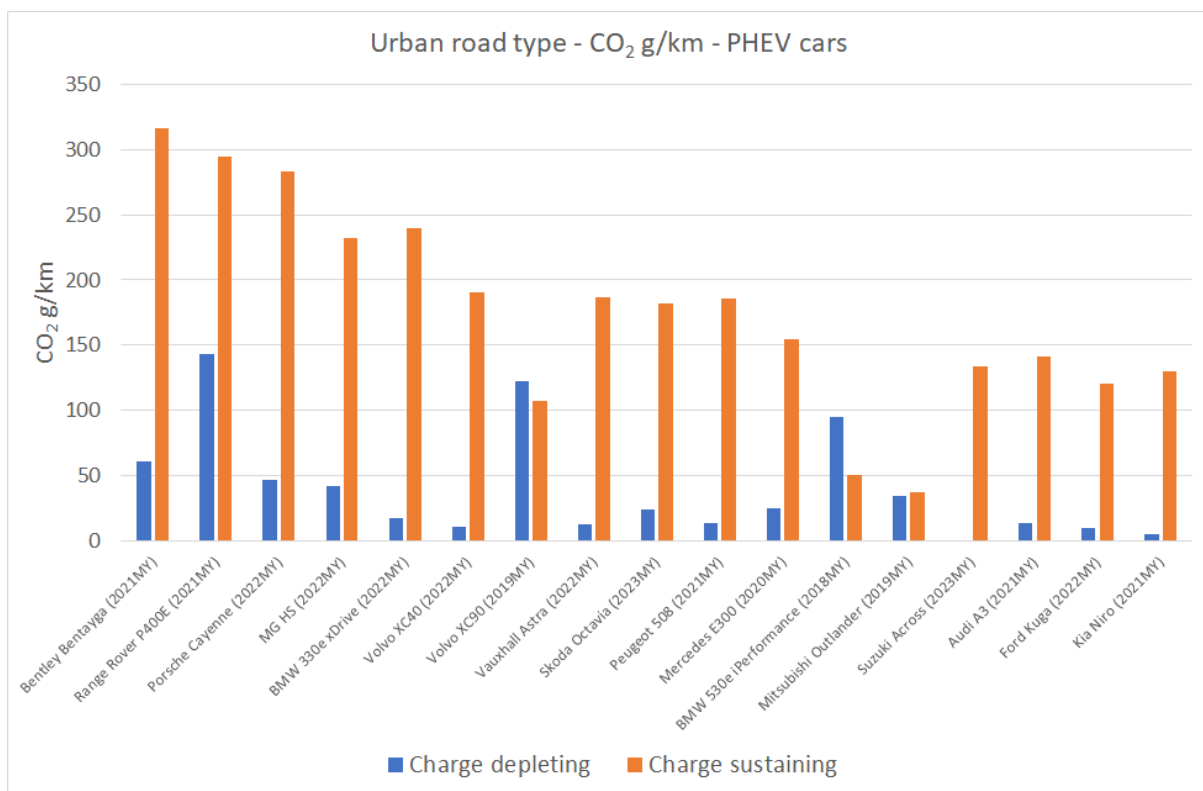


Figure 4: RDE 'on road' PEMS test CO₂ g/km – Petrol PHEV – Urban

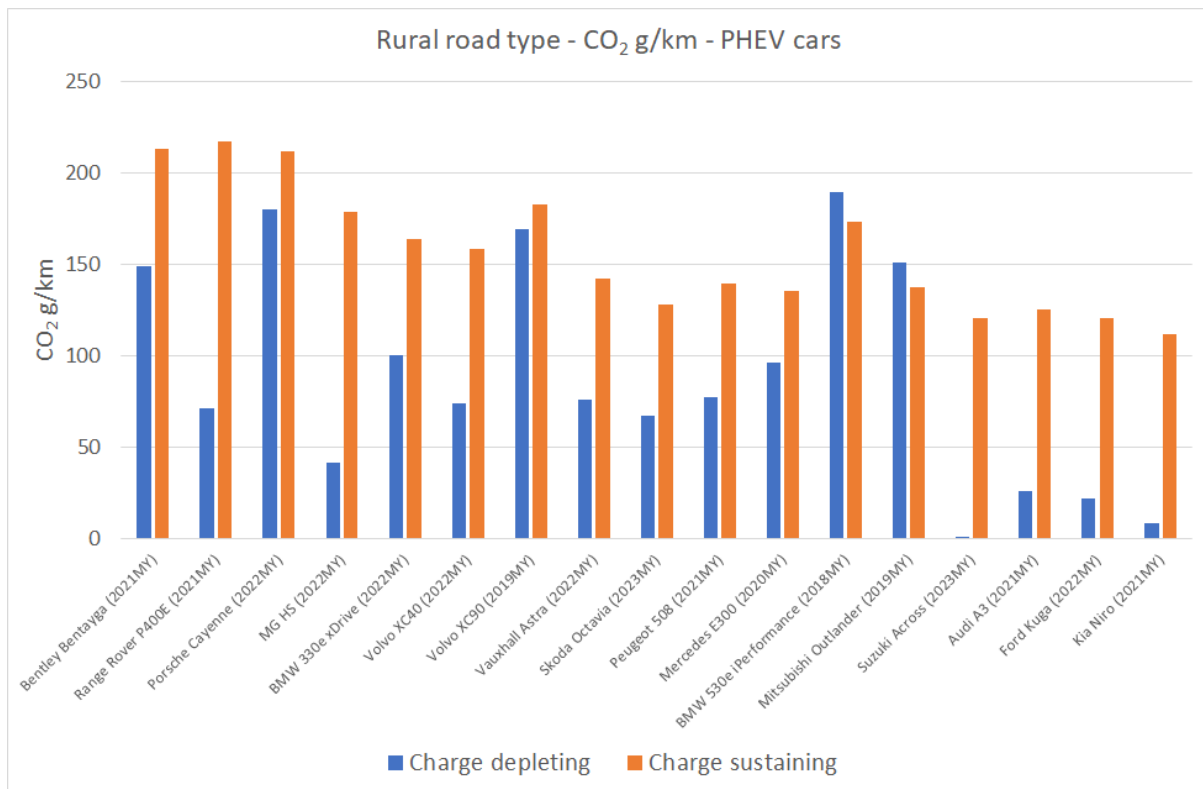


Figure 5: RDE 'on road' PEMS test CO₂ g/km – Petrol PHEV – Rural

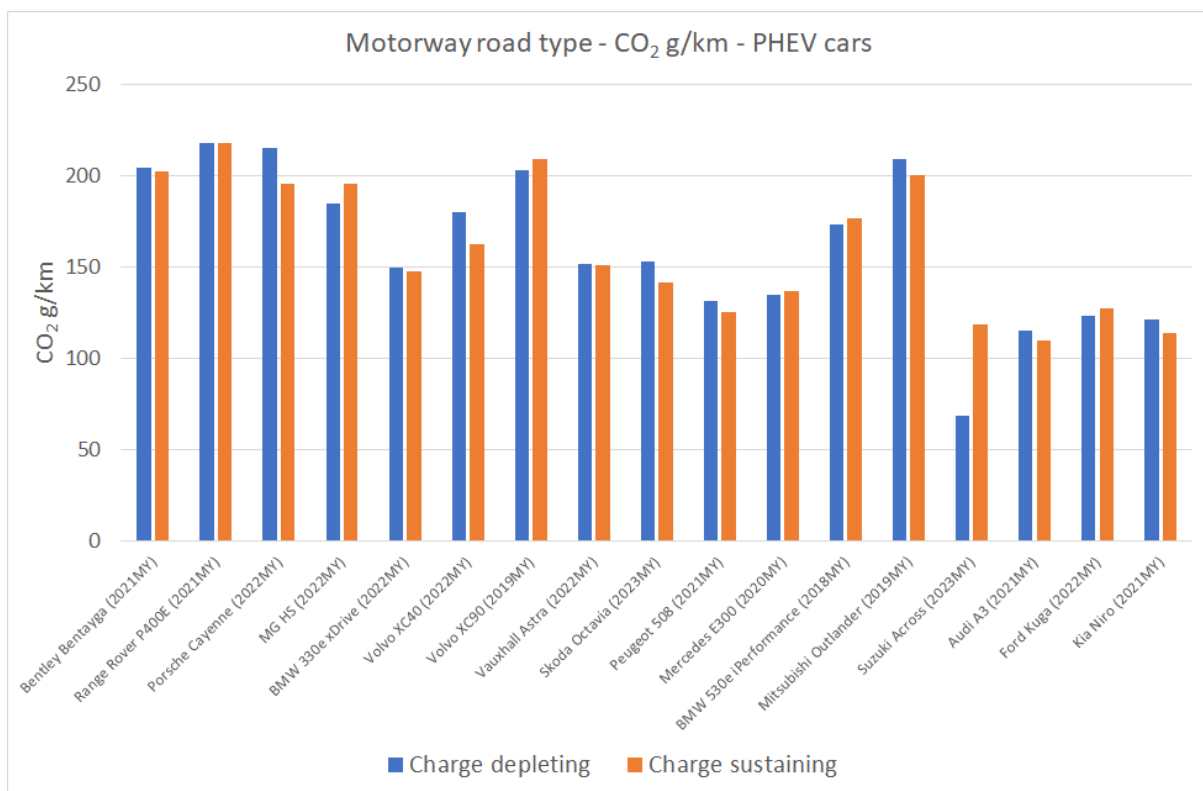


Figure 6: RDE 'on road' PEMS test CO₂ g/km – Petrol PHEV – Motorway

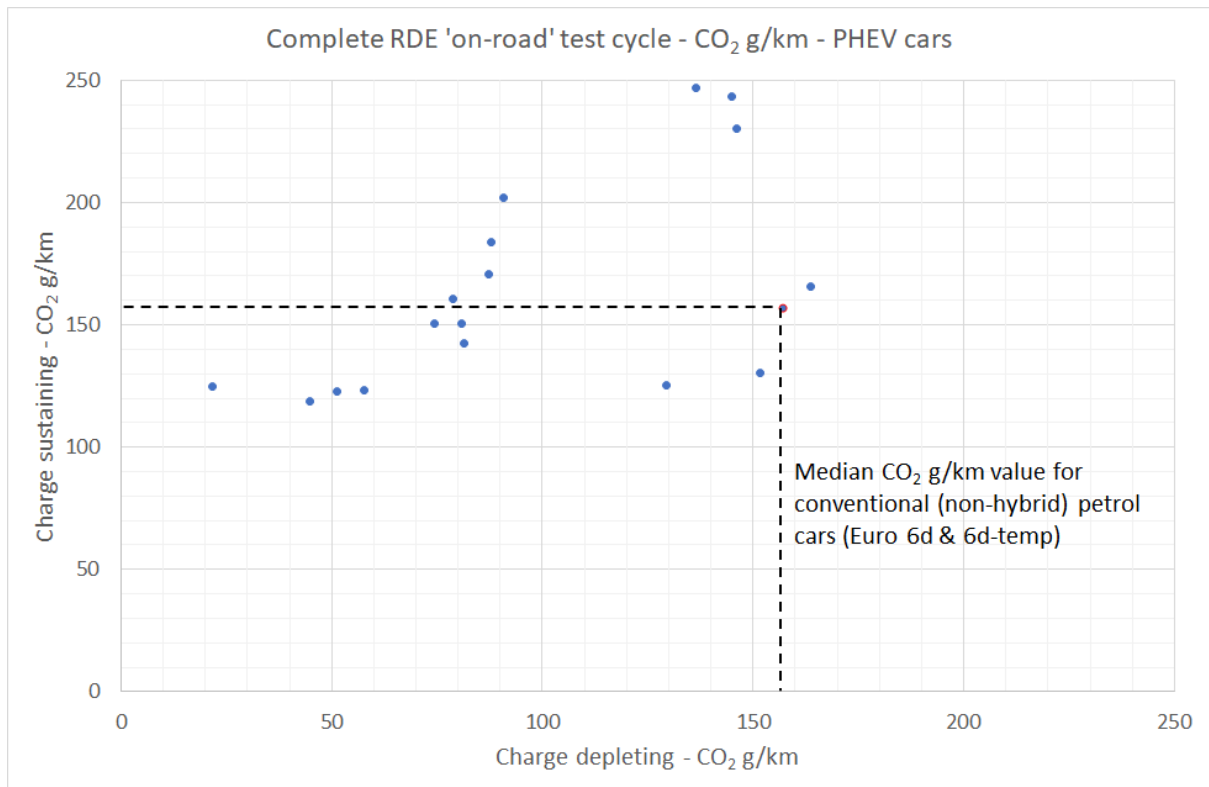


Figure 7: RDE 'on road' PEMS test CO₂ g/km – Petrol PHEV – Complete cycle. Scatter plot of charge depleting vs charge sustaining by vehicle.

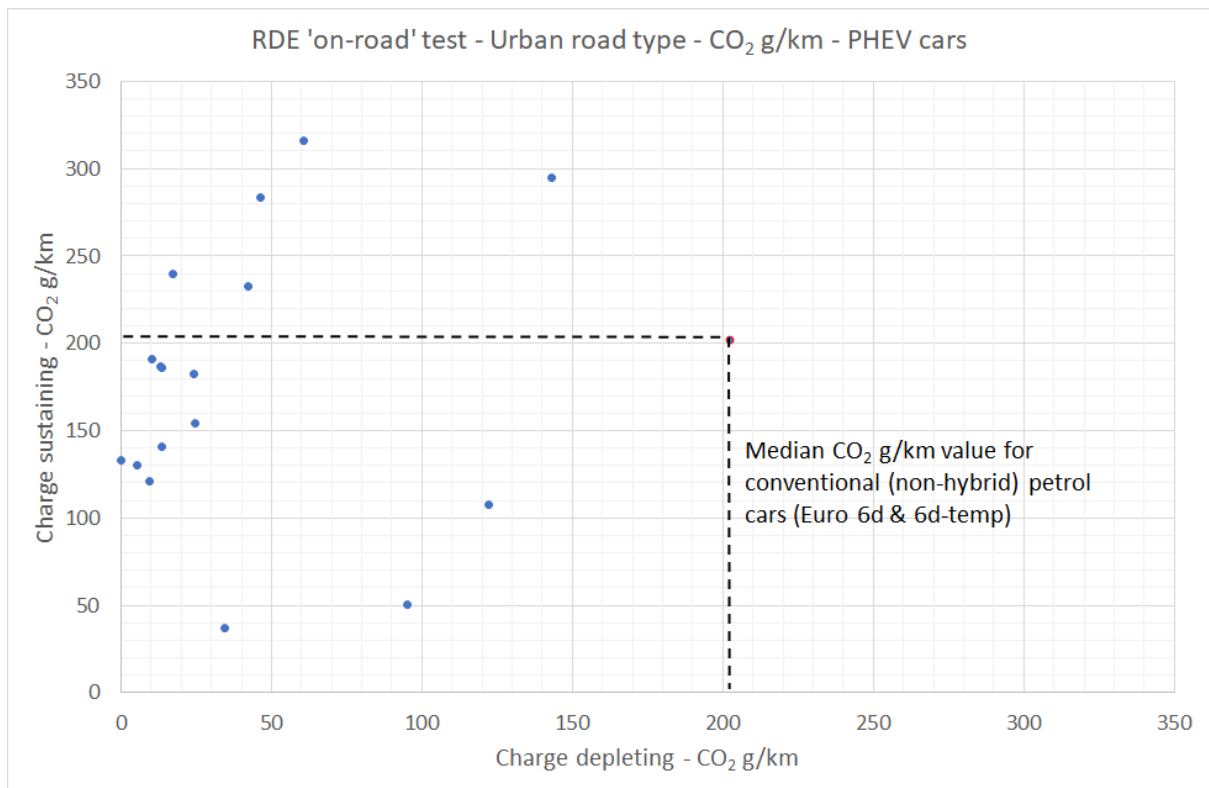


Figure 8: RDE 'on road' PEMS test CO₂ g/km – Petrol PHEV – Urban component. Scatter plot of charge depleting vs charge sustaining by vehicle.

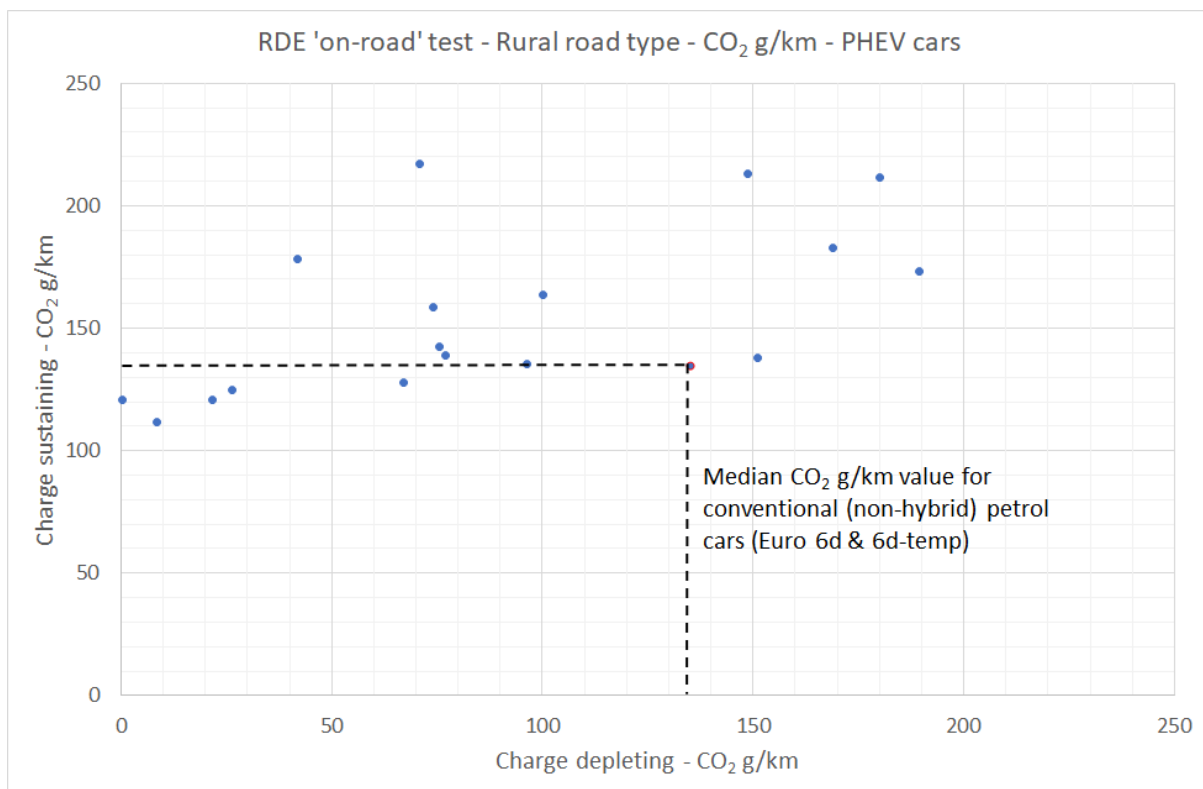


Figure 9: RDE 'on road' PEMS test CO₂ g/km – Petrol PHEV – Rural component. Scatter plot of charge depleting vs charge sustaining by vehicle.

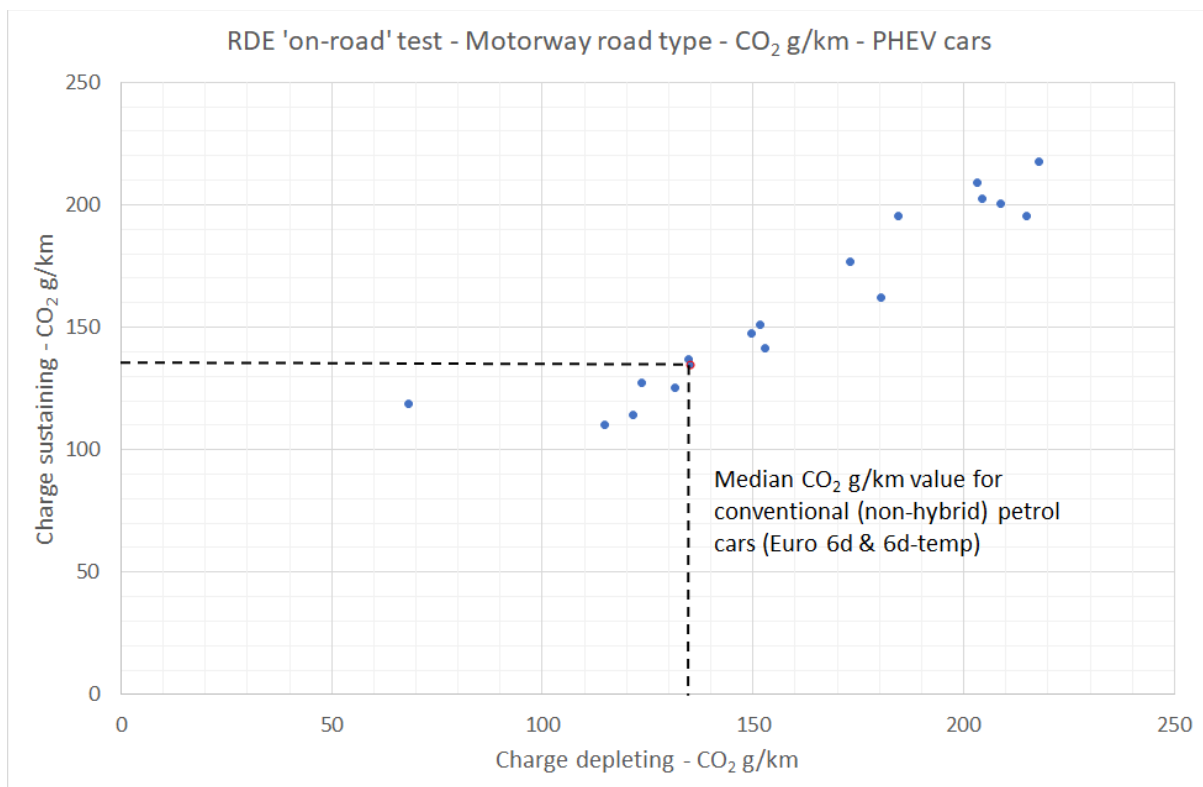


Figure 10: RDE 'on road' PEMS test CO₂ g/km – Petrol PHEV – Motorway component. Scatter plot of charge depleting vs charge sustaining by vehicle.

3.2 RDE 'on road' CO₂ g/km values – Petrol self-charging hybrid cars

Table 5 presents the CO₂ g/km values for the sample of petrol self-charging hybrid cars, by road type. Figure 11 illustrates the same data graphically.

Figures 12 to 15 inclusive present the data by individual road type. On each of these graphs, the median CO₂ g/km value for conventional (non-hybrid) petrol cars (Euro 6d-temp & Euro 6d) has been annotated as a black dashed line, as a benchmark.

Over the total drive cycle (Figure 12, and the urban element (Figure 13),) it can be seen that all of the tested self-charging hybrid vehicles are at or below the comparator CO₂ g/km value for conventional (non-hybrid) petrol vehicles, with only one exception. Generally speaking, the CO₂ g/km exhaust emissions from the self-charging hybrid cars are significantly lower than the median CO₂ g/km value for conventional (non-hybrid) petrol cars, over the urban road type (Figure 13).

The differences in CO₂ g/km exhaust emissions between self-charging hybrid and conventional petrol cars over the rural and motorway road types are smaller. Over the motorway road type in particular (Figure 15), the CO₂ g/km emissions from 6 of the 13 RDE 'on-road' tests are higher than the median CO₂ g/km value for conventional (non-hybrid) petrol cars. However, based on the available sample, the differences in emissions performance between self-charging hybrid cars and the median conventional petrol car value tend to be smaller than the differences observed between some PHEV cars and the median conventional petrol car value.

It would therefore appear that if self-charging hybrid electric vehicles are used predominantly on urban and rural road types, the CO₂ g/km benefits over conventional petrol cars are more reliable, and not so reliant on driver behaviour. On motorway road types, the differences in environmental performance are less clear cut.

Table 5: RDE 'on road' PEMS test CO₂ g/km – Petrol Self-charging hybrids

Vehicle	Complete test	Urban	Rural	Motorway
Lexus RX450 (2022MY)	192	212	180	184
Lexus NX300h (2019MY) cold start	158	145	154	175
Lexus NX300h (2019MY) hot start	158	131	156	186
Suzuki Swift (2023MY)	136	171	106	127
Renault Arkana (2023MY)	135	133	130	143
Toyota C-HR (2021MY) cold start	122	127	118	121
Renault Clio (2023MY)	121	113	132	117
Toyota Yaris (2019MY) hot start	115	96	105	142
Toyota Yaris (2019MY) cold start	114	96	106	140
Toyota C-HR (2021MY) hot start	114	118	107	118
Toyota Corolla (2021MY)	109	114	99	114
Hyundai IONIQ (2021MY) cold start	108	113	102	108
Honda Jazz (2021MY)	103	91	102	116

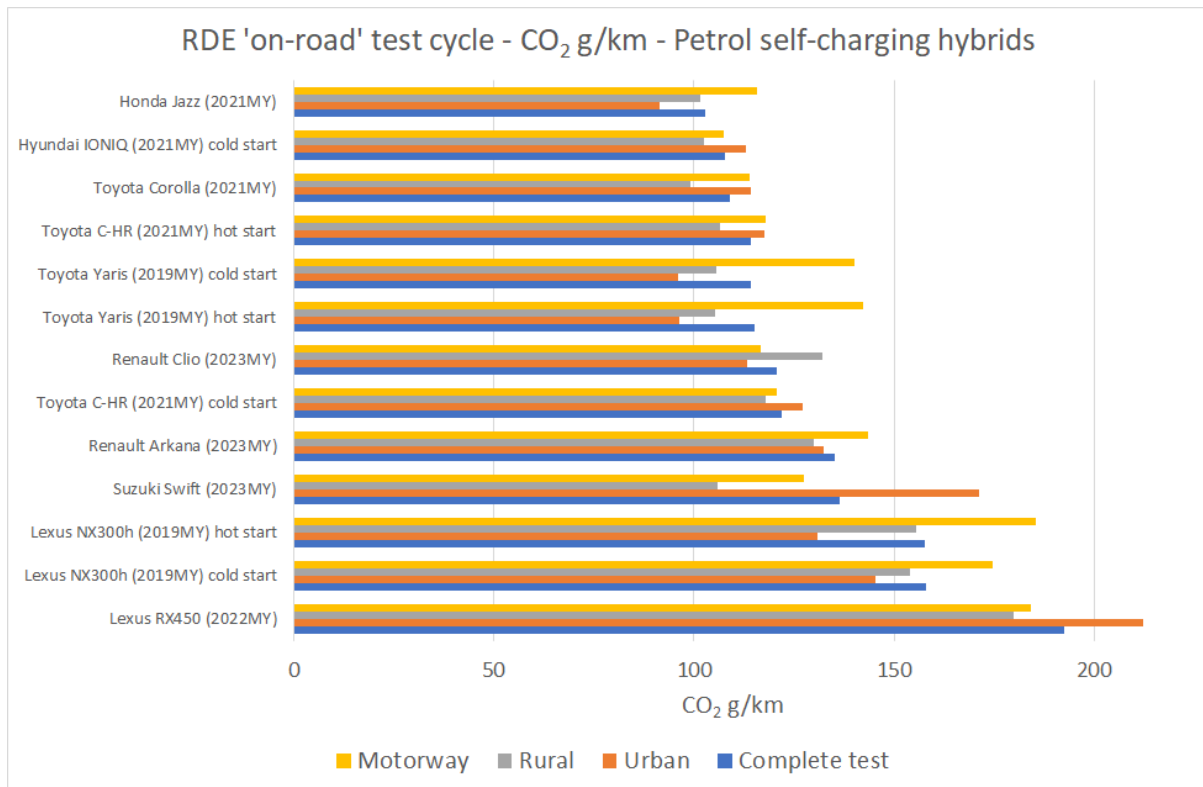


Figure 11: RDE 'on road' PEMS test CO₂ g/km – Petrol self-charging hybrid cars

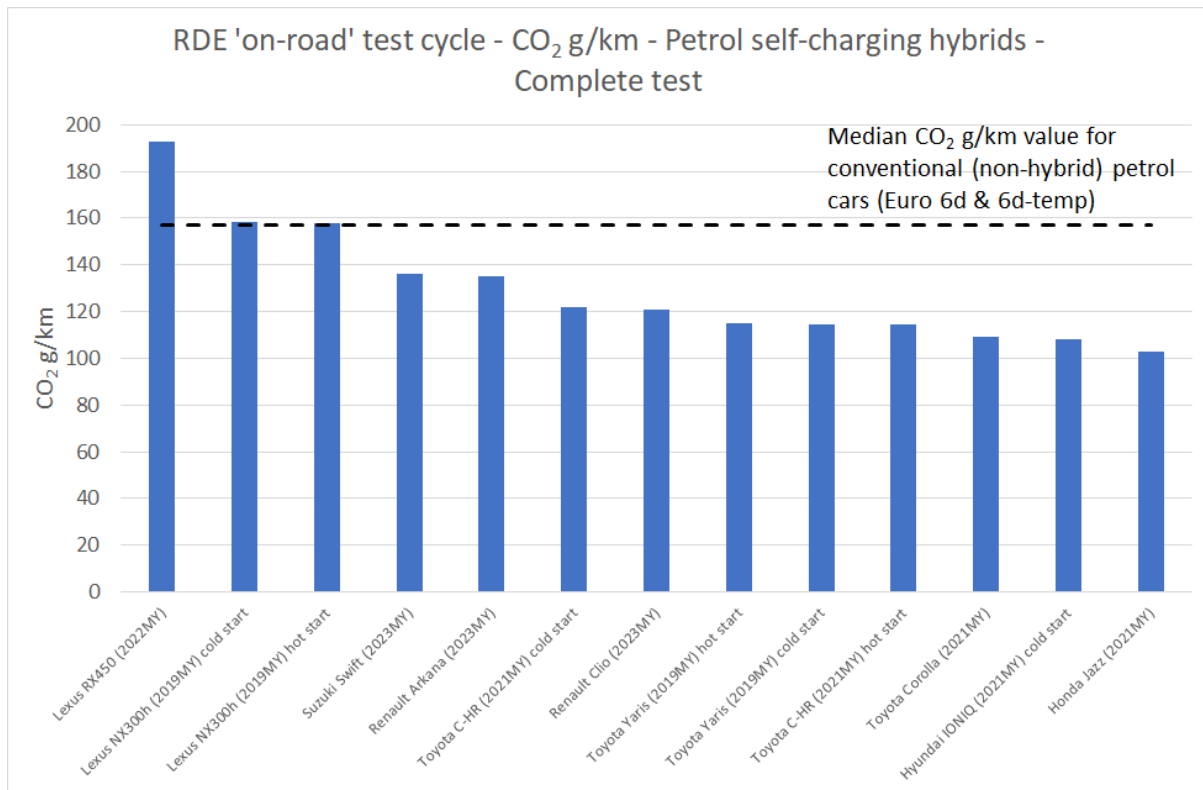


Figure 12: RDE 'on road' PEMS test CO₂ g/km – Petrol self-charging hybrid cars – Complete test cycle

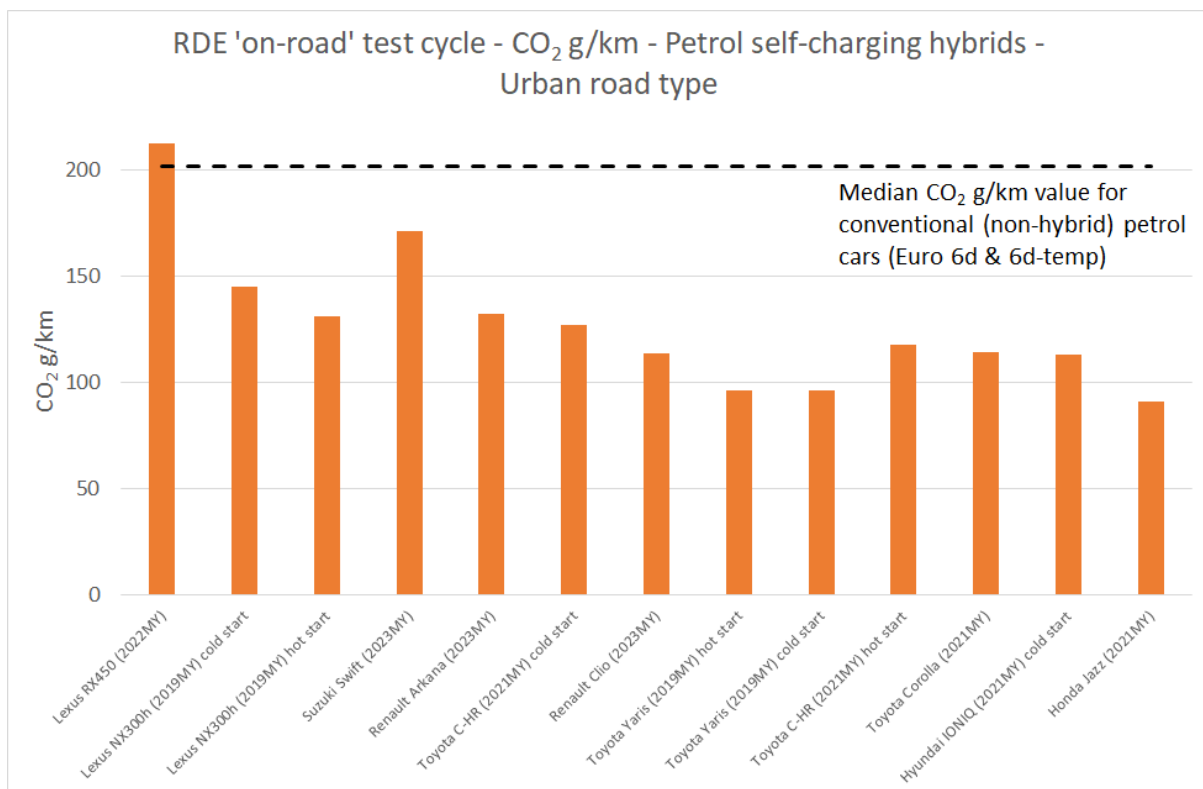


Figure 13: RDE 'on road' PEMS test CO₂ g/km – Petrol self-charging hybrid cars – Urban

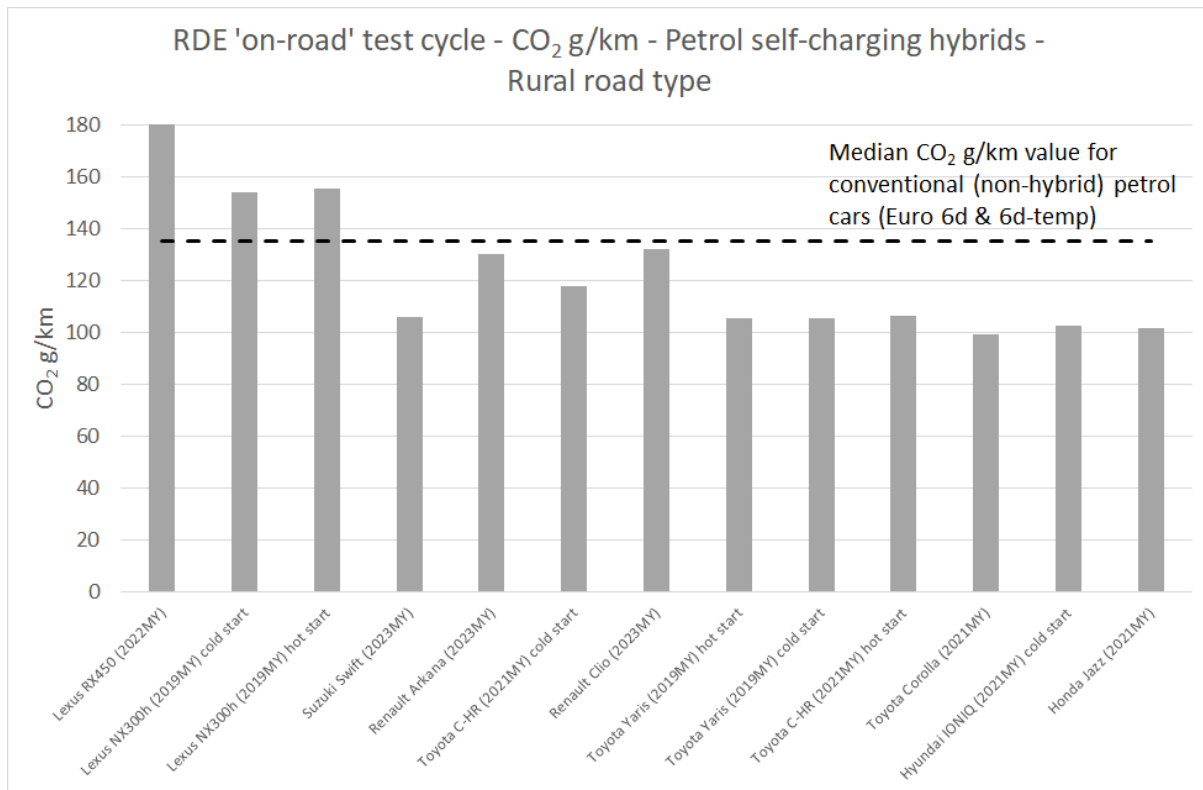


Figure 14: RDE 'on road' PEMS test CO₂ g/km – Petrol self-charging hybrid cars – Rural

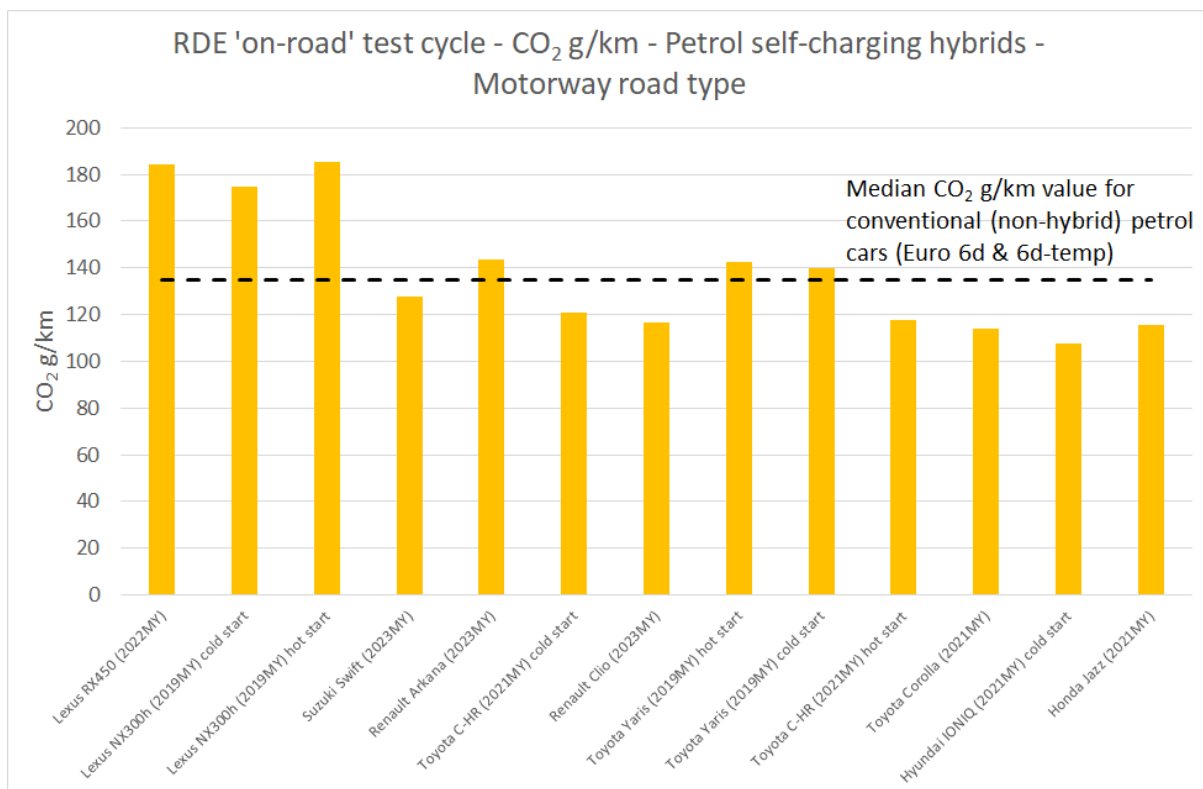


Figure 15: RDE 'on road' PEMS test CO₂ g/km – Petrol self-charging hybrid cars – Motorway

4. Comparison of RDE 'on road' PEMS and DEFRA's Emissions Factors Toolkit v13.1

CO₂ g/km values were abstracted from DEFRA's Emissions Factors Toolkit v13.1 (EFT), separately for PHEV petrol cars and self-charging petrol cars. The balance between Euro 6d-temp and Euro 6d cars was set in EFT to be equivalent to the DfT/DVSA sample of hybrid 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 two groups of vehicles.

Figures 16 and 17 present the comparison of the mean RDE 'on-road' PEMS and EFT v13.1 CO₂ g/km values, for PHEV petrol cars and self-charging hybrid petrol cars respectively. The data are presented by 5mph speed bin between 10mph and 70mph.

Figure 16 presents mean RDE 'on-road' PEMS data for both charge depleting and charge sustaining modes separately. A mean has been calculated from the entire aggregate sample of 17 vehicles. Defra's Emissions Factors Toolkit v 13.1 only provides a single aggregate value for PHEV cars; EFT does not explicitly distinguish between charge depleting and charge sustaining modes.

To make a detailed comparison between the two data sources, it would be necessary to know what assumptions regarding PHEV driver charging behaviour had been incorporated within EFT, and the relative proportions of charge depleting and charge sustaining operation assumed within EFT. This information is not currently available. However, it is possible to observe from Figure 16 that, between 40mph and 65mph, the EFT estimate of CO₂ g/km emissions is higher than either the charge depleting or charge sustaining values derived from the DfT/DVSA PEMS survey data.

Figure 17 presents the comparison of the mean RDE 'on-road' PEMS and EFT v13.1 CO₂ g/km values, for self-charging hybrid petrol cars. It can be seen that, above 15mph, the EFT estimate of CO₂ g/km is on average about 20% higher than the values derived from the DfT/DVSA PEMS survey data.

When making such comparisons, the limited sample size (number of vehicles) of the DfT/DVSA PEMS survey data should be kept in mind, and results interpreted accordingly.

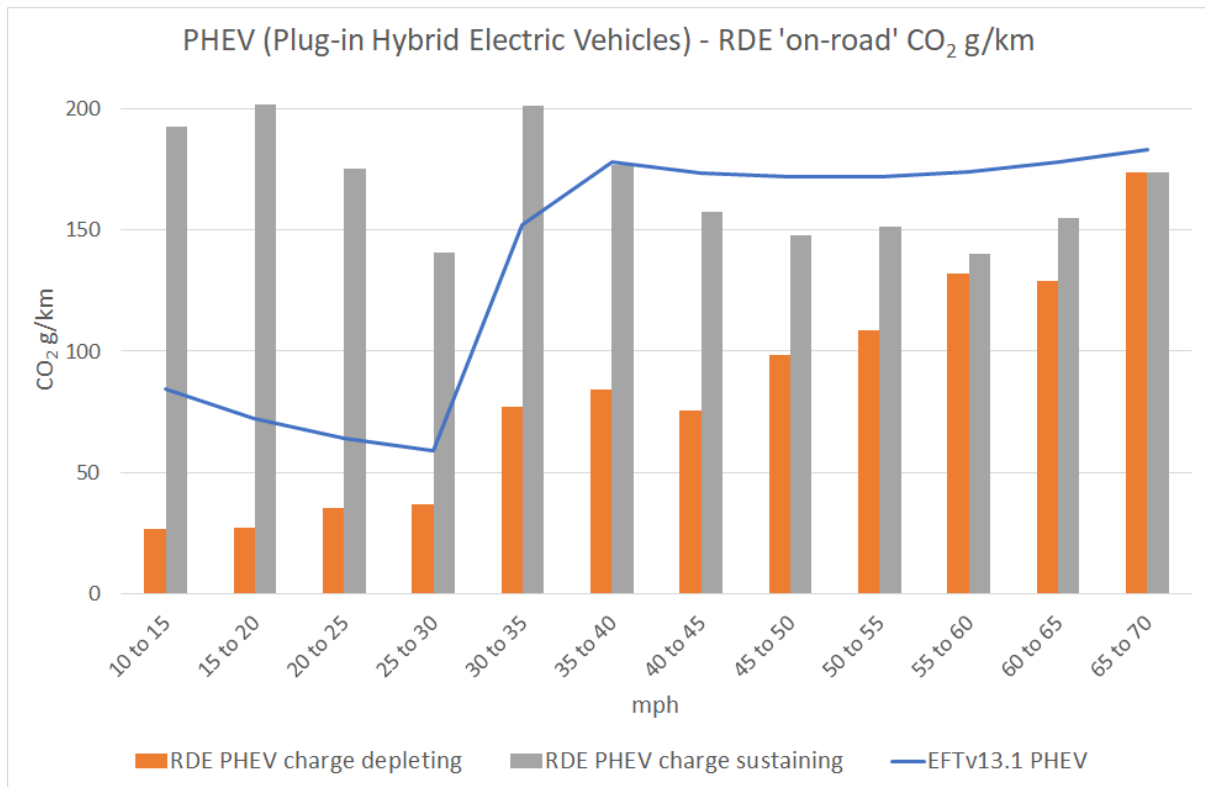


Figure 16: Comparison of RDE 'on-road' PEMS and EFT v13.1 – PHEV petrol cars

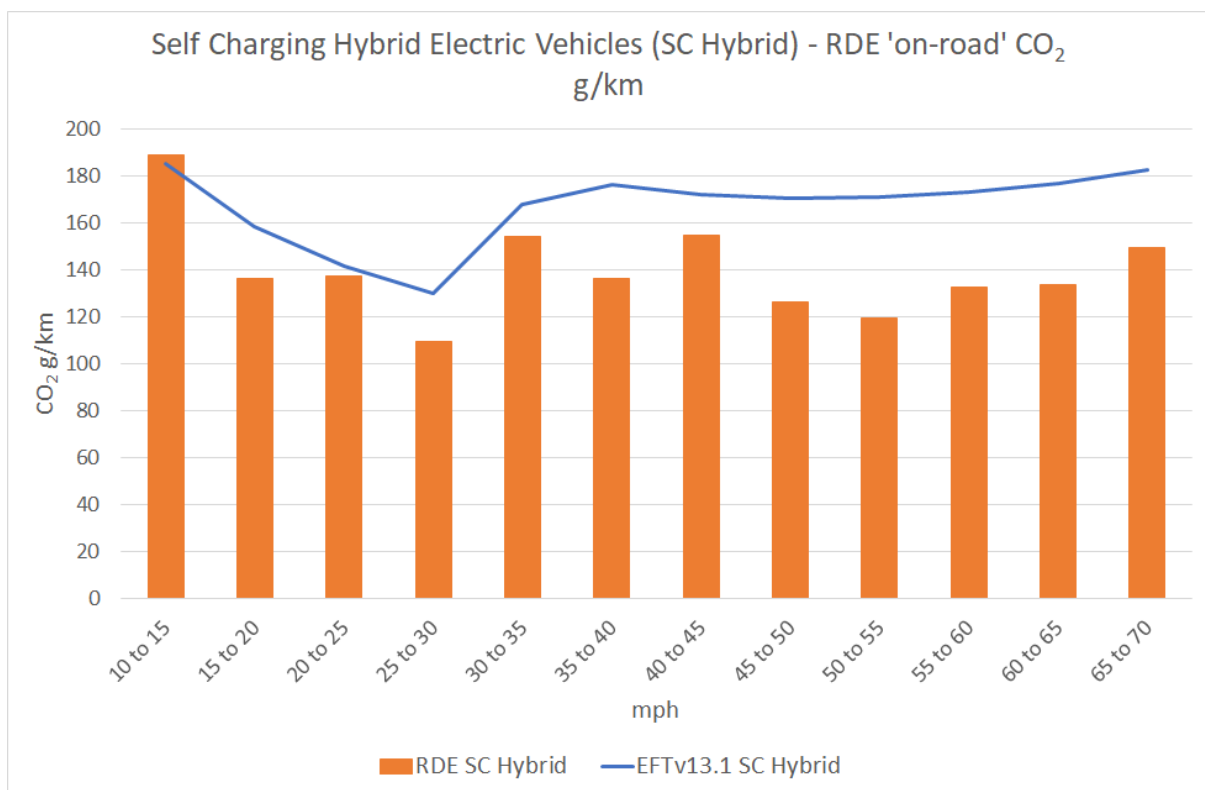


Figure 17: Comparison of RDE 'on-road' PEMS and EFT v13.1 – Self-charging hybrid petrol cars

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

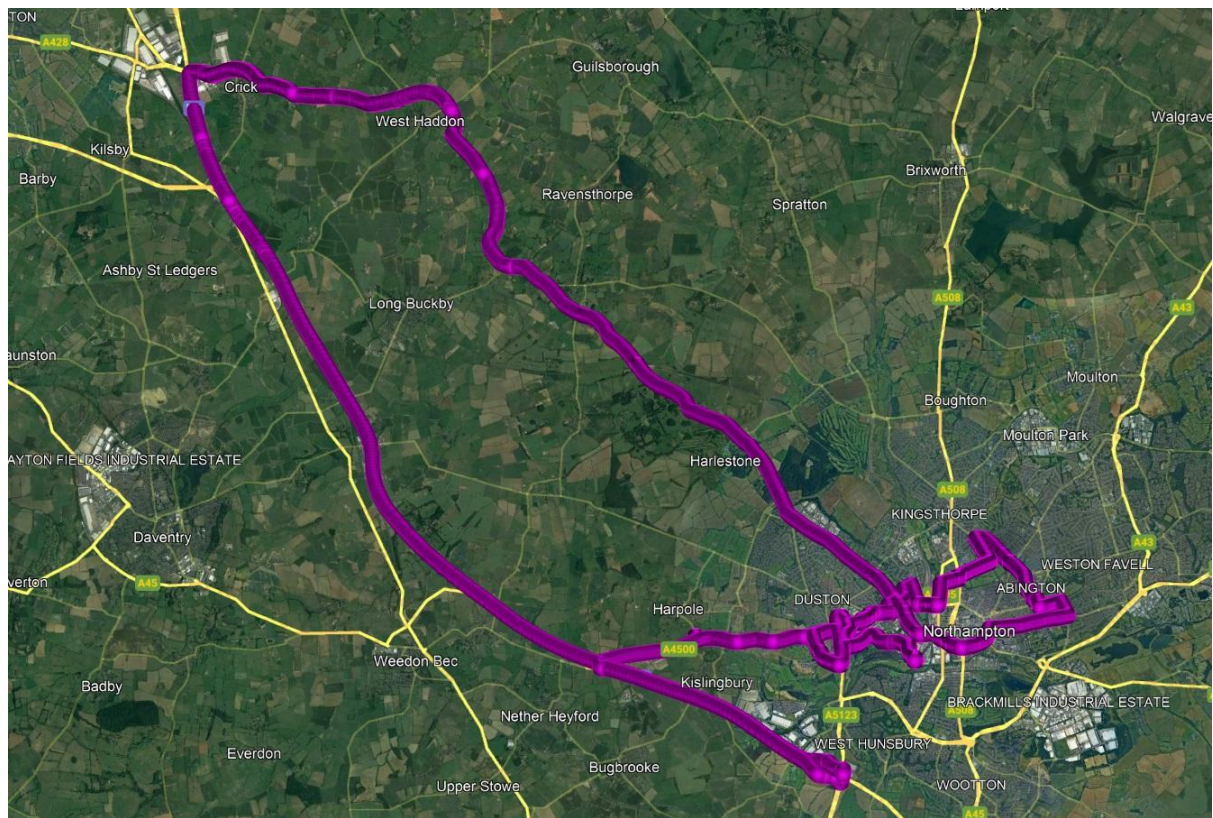


Figure A1: Survey year 2020 & 2021 – Northampton urban area and M1, A428 west of Northampton

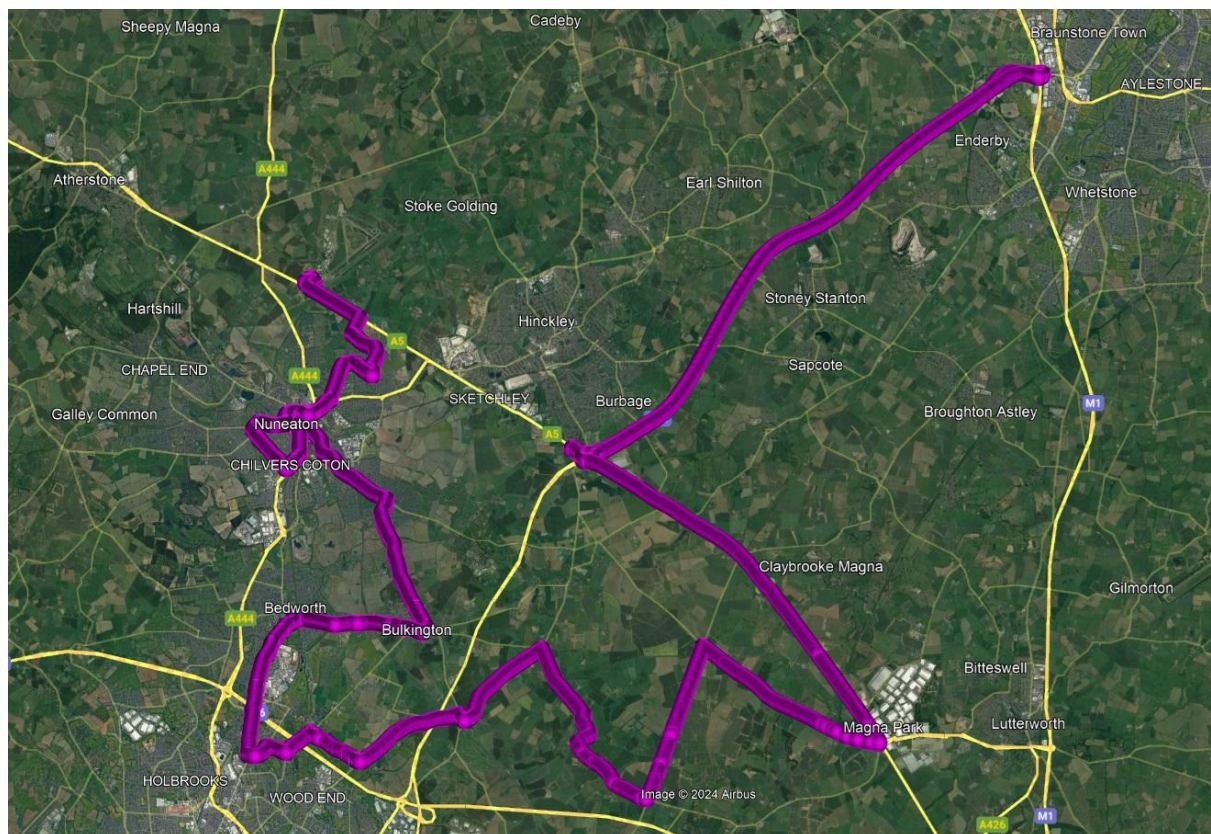


Figure A2: Survey year 2022 – Nuneaton, M69, A5 north of Coventry

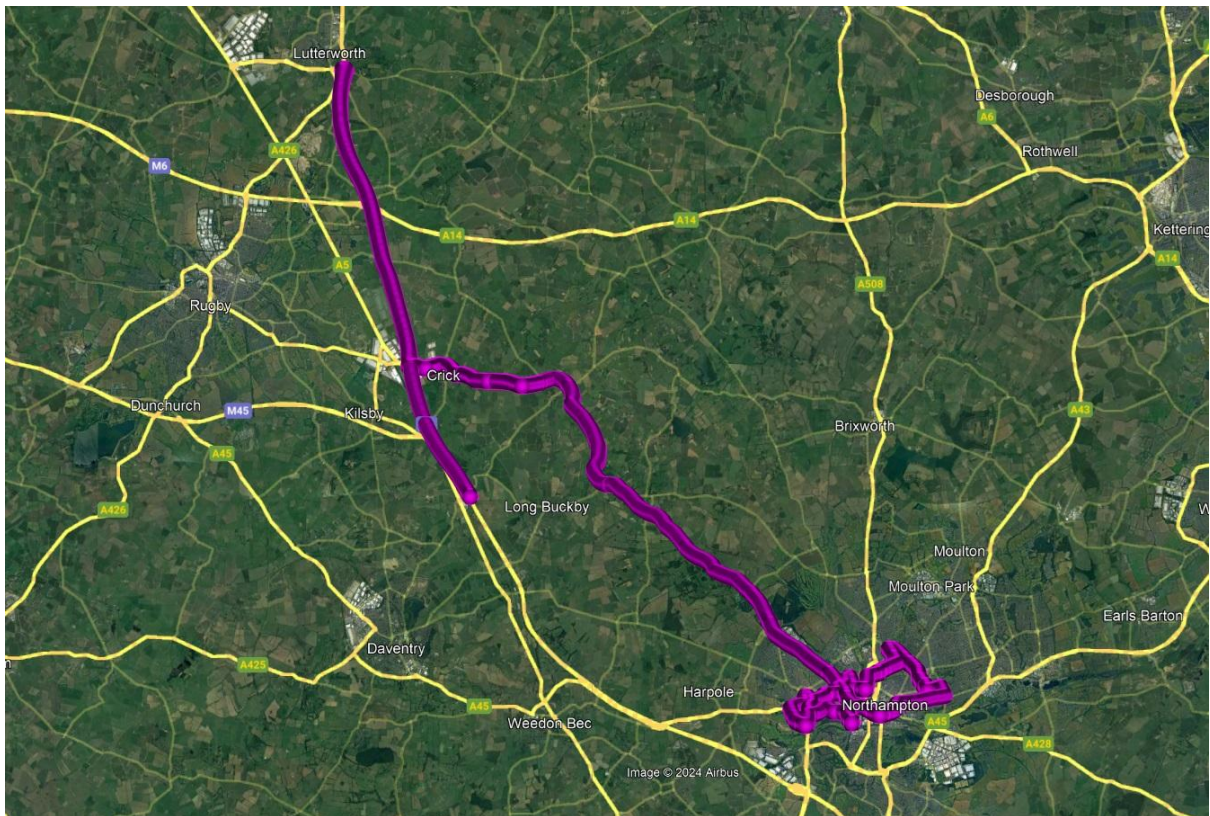


Figure A3: Survey year 2023 & 2024– Northampton urban area and A428, M1 to Lutterworth