EMISSIONS ANALYTICS

Transport & Environment

Plug-in hybrid RDE testing

27 October 2020

report

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When it comes to the pursuit for improved air quality, we believe in the power of clarity, transparency and integrity. With real-world data we can meet emissions challenges – instilling trust and confidence in our industry partners and public.

It’s with our commitment and independence we are able to make a significant contribution toward positive change and to achieve enduring results.

Contents

Executive summary

Testing was of the three test vehicles was successfully completed on the 24 August 2020.

The largest gap between official type-approval data and real-world emissions data was recorded in the BMW X5 PHEV; officially recorded as emitting 32.0 g/km of CO_2 on the WLTP combined cycle. Emissions analytics testing revealed that in its most efficient configuration (full battery, starting in EV only mode) the X5 produced 42.3 g/km of CO_2 over the combined cycle. When driven with only the internal combustion engine (ICE), to recharge a depleted battery, the X5 produced 384.6 g/km of CO_2 over the same cycle, nine times more than what was emitted in its most efficient configuration.

The gap between most and least efficient CO_2 performance for the Volvo XC60 and Mitsubishi Outlander PHEVs was 130.3 g/km on both vehicles, compared to the gap of 342.3 g/km on the X5.

The XC60 official WLTP CO_2 result is 71 g/km and the Outlander is 46 g/km. At its most efficient (Reverse phase order) the XC60 recorded a result of 115.3 g/km, the Outlander 85.8 g/km (EV mode); at its least efficient, the XC60 recorded a result of 241.8 g/km (Charging mode) and the Outlander 216.1 g/km (Charging mode).

Background

Currently CO_2, pollutant emissions and electric range figures of plug-in hybrid electric vehicles (PHEV) determined at type-approval do not necessarily reflect the on-road performance of these vehicles. Environmental NGO Transport & Environment (T&E) was looking for RDE testing (both inside and outside of RDE test boundaries) on PHEV cars in order to investigate their emissions performance, fuel and electric consumption as well as electric-only range under real world driving conditions.

The main aim of the project was to investigate the size of the gap between official type-approval data and independent on-road testing for a range of PHEV vehicles.

With this project, T&E together with German NGO Deutsche Umwelthilfe e.V. (DUH) aim to inform the public about the existing gap between actual fuel consumption figures and official manufacturer data for passenger cars.

Objective

The project has been initiated to test PHEV vehicles with the latest engine, battery and aftertreatment technology.

This was completed through use of a portable emissions measurement system (PEMS) to collect real-world emissions data for the following gases:

- Carbon dioxide (CO_2)
- Carbon monoxide (CO)
- Nitric oxide (NO)
- Nitrogen dioxide (NO_2)
- Nitrogen oxides (NO_x = NO + NO_2)

In addition, real-time electricity consumption was recorded using a battery clamp fitted across the positive and negative terminals of the PHEV battery.

Test dates

Testing was successfully completed between 11 July 2020 and 24 August 2020.

Test vehicles

PHEV vehicles with the latest engine, battery and aftertreatment technology were the focus of this testing project. Therefore, the vehicles used for testing were WLTP type-approved Euro 6d-temp or 6d vehicles only. The specification put forward by T&E asked for three PHEV vehicles that met the Euro 6d-temp standard; the test vehicles acquired by Emissions Analytics for this purpose are shown below:

Manufacturer	Model	VRM	Model Year	Engine Size (litres)	Regulatory Stage	Odometer (miles)
Volvo	XC60	BX68 SFF	2018	2.0	Euro 6d-TEMP-EVAP (WLTP)	16,512
BMW	X5	BX20 MHK	2020	3.0	Euro 6d-TEMP-EVAP-ISC (WLTP)	3,972
Mitsubishi	Outlander	WP68 XSK	2018	2.4	Euro 6d-TEMP-EVAP (WLTP)	32,672

Test equipment

Gaseous emissions

A SEMTECH-LDV from Sensors, Inc was used to measure gaseous emissions. A flow tube was mounted on the exterior of the vehicle at the end of the tailpipe to measure total flow independently of the vehicle's systems.

The analyser measures CO, CO_2, NO and NO_2 gases and works in conjunction with a conditioning system to analyse conditioned sampled gases. The gas module incorporates Non-Dispersive Ultraviolet (NDUV) and Non-Dispersive Infrared (NDIR) benches.

Further details can be found at: http://www.sensors-inc.com/Products/SEMTECH/LDV.

Particle emissions

For particles, a Sensors' Condensation Particle Number (CPN) was used. It uses a heated line to deliver a sample to the catalytic volatile particle remover, which then dilutes the aerosol, and counts the particles by butanol condensation. Measurements are taken continuously to allow second-by-second data acquisition during real-world PEMS testing.

Further details can be located at: http://www.sensors-inc.com/Products/SEMTECH/CPN.

Power consumption measurement

Measurement of the test vehicles' battery state of charge was conducted using a 1,000-amp CT6846 battery clamp produced by Hioki Corporation.

High-accuracy sensors use the "zero flux method" as the measurement principle. High-frequency currents are detected with the winding (CT method), and DC to low frequency currents are detected using a "flux gate."

Flux gate detection has outstanding linear properties and maintains high precision even at low current levels.

The flux gate component, used in DC detection, has an extremely small offset in a wide range of temperatures due to its operating principle and therefore achieves high precision and superior stability, making it ideal for measurements that require high accuracy.

Full details on the accuracy of the CT6846 can be found in Appendix 1.

Setup methodology

The same setup methodology was applied to each of the test vehicles to ensure the installation of the PEMS and battery clamp was consistent. The methodology for use of the battery clamp to measure electricity consumption has been adapted from Argonne National Laboratory, https://www.anl.gov.

After receiving each test vehicle, an inspection was carried out to ensure its safe working condition, this included fueling up the vehicle using the same forecourt grade of unleaded fuel.

Following on from this, the vehicle was then weighed empty and then fitted with the PEMS (SEMTECH-LDV and CPN) into the boot of the vehicle. Batteries to power the PEMS were loaded into the footwells of the passenger seats, and the GPS and climate probe were mounted to the exterior of the vehicle. The heated sample lines were then connected to the PEMS and fixed to the exterior of the vehicle via the rear passenger window. At this point, the exhaust flow meter was installed to the rear of the vehicle, with a sealed connection to the tailpipe created, primarily using metallic tubes. The heated sample lines were then connected to the exhaust flow meter.

The battery clamp was fitted to measure the current and voltage being drawn from the PHEV battery (Figure 1 below). This proved to be challenging, in part, due to the size of the clamps and getting them fitted into a confined area. The main power cables for the vehicles were very well shielded and close to the bodywork and so some minor manipulation of the cabling was required in order to securely locate the clamps.

Finally, the clamp was then connected via a data connection to the PEMS, alongside a CAN connection to provide engine data. Battery state of charge information was not available on any of the vehicles, this is quite standard as vehicle manufacturers do not need to supply this information via the OBD port.

With the vehicle setup, checks were carried out to ensure the exhaust system was sealed and that there were no leaks within the PEMS system. The vehicle was then left overnight so that a cold start test could be initiated the following morning.

Figure 1 - Battery clamp installed on a test vehicle

Test conditioning

The following conditioning, in order of occurrence, were applied to the test vehicles pre and post-test:

Pre-test

- Vehicle fueled to a full-tank with standard forecourt unleaded fuel.
- Tyre pressures and tread depths checked pre-test.
- Test vehicle weight recorded with PEMS loaded but no occupants on board.
- Overnight soak of at least 12 hours inside the Emissions Analytics workshop.
- Vehicle charging would take place overnight if applicable for the following day of testing.
- An OBD fault code reader was connected to check for any warnings.
- Battery clamp readings were checked following a full charge of the PHEV battery to ensure accurate readings.
- Zero and span calibration of the analysers conducted.

Post-test

- Zero and span calibration of the analysers conducted.
- Integrity of data checked to ensure successful capture.
- Test vehicle weight recorded with PEMS loaded but no occupants on board.
- An OBD fault code reader was connected to check for any warnings.
- Tyre pressures checked post-test.
- Test vehicle placed on charge (if applicable) to check total amount of electricity replenished following on from the test.

Equipment calibration

Span and zero calibrations of the gaseous measurement equipment were performed at the start and end of each cycle of tests to monitor and prevent analyser drift. The zero calibration

was performed with pure nitrogen, followed by the span calibration against gas bottles of known concentrations supplied by Air Liquide.

Details of the span values can be found in Appendix 2.

The equipment had current certificates of calibration compliance for the linearity of the analyser and flow tube, from Sensors. Details can be found in Appendix 3.

Test methodology

The distance of the RDE test was sufficient to determine the electric only range of all vehicles tested on one RDE test.

For the RDE compliant tests (RDE4 Regulation 2018/1832), distance shares for the urban cycle were between 29% and 44%; for rural and motorway cycles, 23% and 43%; altitude difference between the start and end point was not exceeding 100 meters; cumulative altitude gain was below 1200m per 100km on urban and total trip.

The trip started with the urban portion of at least 16km which was driven on urban roads with a speed limit of 60 km/h or less, followed by the rural (speed between 60 and 90 km/h) and the motorway (speed over 90 km/h). During the motorway section, the vehicle's velocity was kept above 100 km/h for at least 5 minutes.

In order to minimize the effects on the results, the driver and their driving style was the same for every test independently from the selected driving mode.

The battery current was measured during all RDE tests using a clamp-on transducer, separate from any vehicle system. Air conditioning/heating, infotainment, sat-nav and lights were switched on during all tests and used in a manner typical of everyday use. Air conditioning was kept at 19 degrees Celsius, fan speed medium with the radio on and lights set to 'Auto'. The degree of auxiliary use, e.g. the air conditioning temperature, was kept constant between vehicles and recorded in the test report.

The following test plan was used:

Test Number	Test Mode	RDE Compliant	Route	Cold Start
1	EV only mode	Y	RDE	Y
2	ICE only	Y	RDE	Y
3	Battery charging mode	Y	RDE	Y
4	Dynamic/altitude	N	Dynamic/altitude	Y
5	Reverse route	N	Reverse	Y
6	Max payload	Y	RDE	Y

Test 1 – EV only mode

Determine the electric only range.
The vehicle started with a battery at the maximum state of charge, and the EV only mode was selected by the driver at the beginning of the test, upon vehicle ignition. Once the battery was depleted the test continued in the default mode selected by the vehicle until the end of the RDE test route.
The startup sequence for the XC60 involved throttle position briefly hitting 50% before returning to 0%, as a result of this, the ICE engaged briefly on startup.

Vehicle mode selected:
BMW X5 – EV Mode
Volvo XC60 – EV Mode
Mitsubishi Outlander – EV Mode

Test 2 – ICE only

Determine the emissions when battery is not charged.

The vehicle started the test with its battery at the minimum state of charge allowable by the system. At the beginning of the test the driver selected the ICE only mode. While the energy stored in the battery may fluctuate during the test, on average, a neutral state of charge was maintained. The vehicles stayed in the chosen mode for the duration of the test.

For the X5 the Battery Hold mode was the closest approximation to an ICE only mode. The battery hold was set at the minimum level of 30% which meant that during the initial part of the test the battery was charging until it reached the 30% level. The X5 Battery Hold mode is activated using a separate button, distinct from the mode selection. It allows setting the percentage of battery charge the vehicle should maintain in the range 30-100%. For comparison, when the vehicle was started from low battery, the predominant, default mode is hybrid. In this case, a similar period of charging was observed; this would likely be to a 30% battery level, although the details are undocumented.

Vehicle mode selected:
BMW X5 - Battery Hold set to 30% (minimum allowed)
Volvo XC60 – Power Mode
Mitsubishi Outlander - Battery Save

Test 3 – Battery charging mode

Determine the emissions when battery is being charged by ICE.
The vehicle started the test with a battery that was at the minimum state of charge allowable by the system. At the beginning of the test the driver selected the battery charging mode, once the battery was charged the test continued in the mode selected by the vehicle.

Vehicle mode selected:
BMW X5 – Battery Hold set to 100%
Volvo XC60 – Hybrid Battery Charge
Mitsubishi Outlander – Charge Mode

Test 4 – Dynamic/altitude

The first non-compliant RDE route focused on driving the vehicle more dynamically and included greater positive cumulative altitude gain (>1,200 m/100km) than allowed by the current RDE regulation. The test route included a share of urban, rural and motorway driving.

Vehicle mode selected:
BMW X5 – EV Mode
Volvo XC60 – EV Mode
Mitsubishi Outlander – EV Mode

Test 5 – Reverse route

The vehicle was tested in reverse RDE order (extra urban, rural then urban). The vehicle started the journey with only a short urban drive followed by high speed driving on the motorway until the battery was depleted. The test then continued on the motorway for ~5km before transitioning back to a mixture of urban and rural driving.

Vehicle mode selected:
BMW X5 – EV Mode
Volvo XC60 – EV Mode
Mitsubishi Outlander – EV Mode

Test 6 – Max payload

Determine the electric only range under maximum payload.
The vehicle started with a battery at the maximum state of charge, and ballast was loaded into the vehicle to bring it to its max permissible payload. EV only mode was selected by the driver at the beginning of the test, upon vehicle ignition. Once the battery was depleted the test continued in the default mode selected by the vehicle until the end of the RDE test route.

Vehicle mode selected:
BMW X5 – EV Mode
Volvo XC60 – EV Mode
Mitsubishi Outlander – EV Mode

Vehicle ballast added:
BMW X5 – 750 kg
Volvo XC60 – 550 kg
Mitsubishi Outlander – 475 kg

Test routes

EV-only range was determined as the distance travelled between the start of the RDE test and when the engine first turned on (RPM signal was detected by the equipment).

Small differences in trip length for all routes were caused by road closures, diversions, and detours caused by road repair work. Specifically, for the reverse phase order route, there are larger differences caused by the requirement to exhaust the battery on the motorway section. As the vehicle batteries were of different sizes, the distance driven on the motorway section of this route also varied.

RDE route

	Duration minutes	Distance km	Speed km/h	Altitude m	Relative Positive Acceleration m/s^2	V*Apos @ 95th Percentile m^2/s^3	Cumulative Positive Elevation Gain m/100km
Overall	107.1	92.1	51.6	109.4	0.14	14.77	544
Cold Start	4.3	1.5	20.4	n/a	0.18	6.49	n/a
Urban	68.0	36.3	32.1	n/a	0.18	11.35	391
Rural	23.8	29.1	73.3	n/a	0.12	16.73	n/a
Motorway	15.3	26.7	104.6	n/a	0.11	20.08	n/a

Note: these are the average values across all tests run on this route.

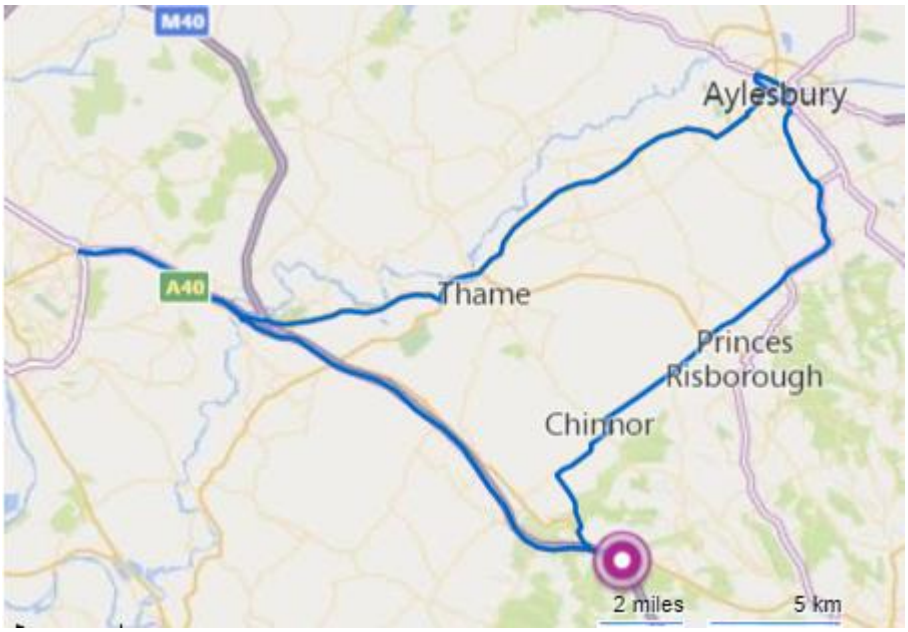


Figure 1 - RDE route (complete cycle)

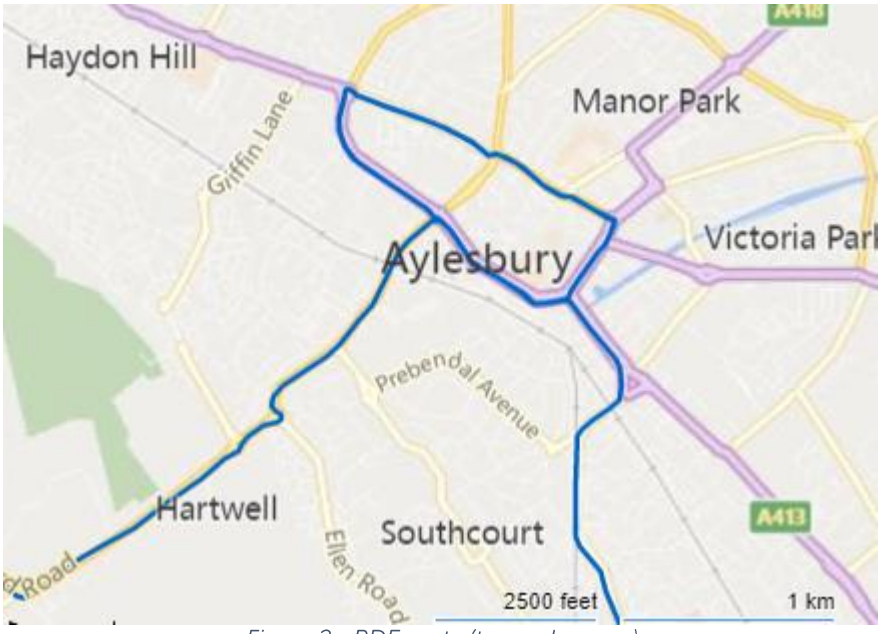
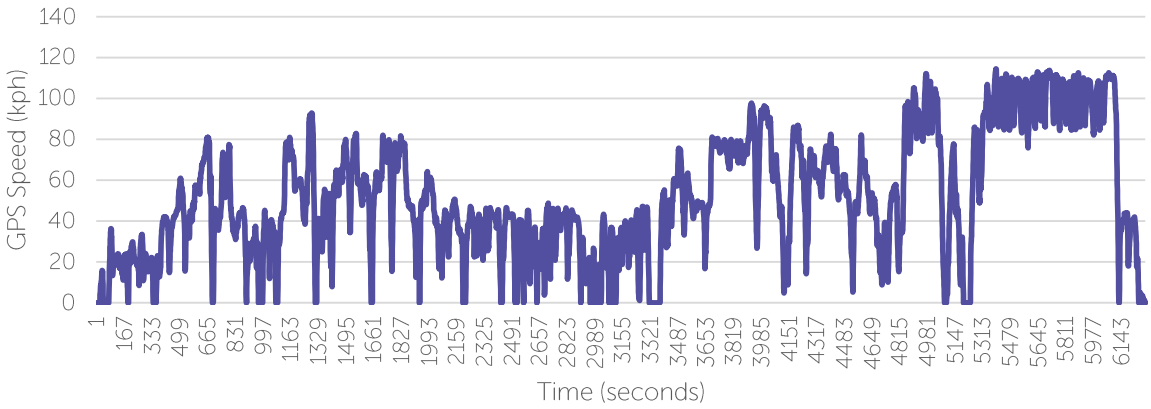


Figure 2 - RDE route (town close-up)



Dynamic/altitude route

	Duration minutes	Distance km	Speed km/h	Altitude m	Relative Positive Acceleration m/s^2	V*Apos @ 95th Percentile m^2/s^3	Cumulative Positive Elevation Gain m/100km
Overall	113.0	99.5	52.9	148.4	0.20	26.68	1276
Cold Start	5.0	1.8	21.6	n/a	0.19	8.26	n/a
Urban	74.2	43.5	35.2	n/a	0.25	21.80	1695
Rural	21.5	25.9	72.2	n/a	0.21	32.18	n/a
Motorway	17.3	30.2	104.7	n/a	0.12	33.99	n/a

Note: these are the average values across all tests run on this route.

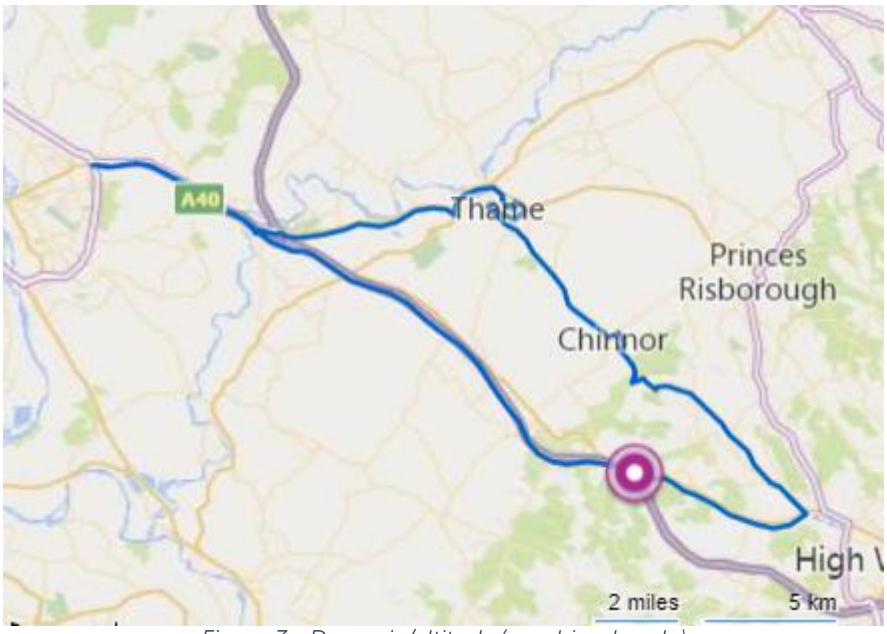


Figure 3 - Dynamic/altitude (combined cycle)

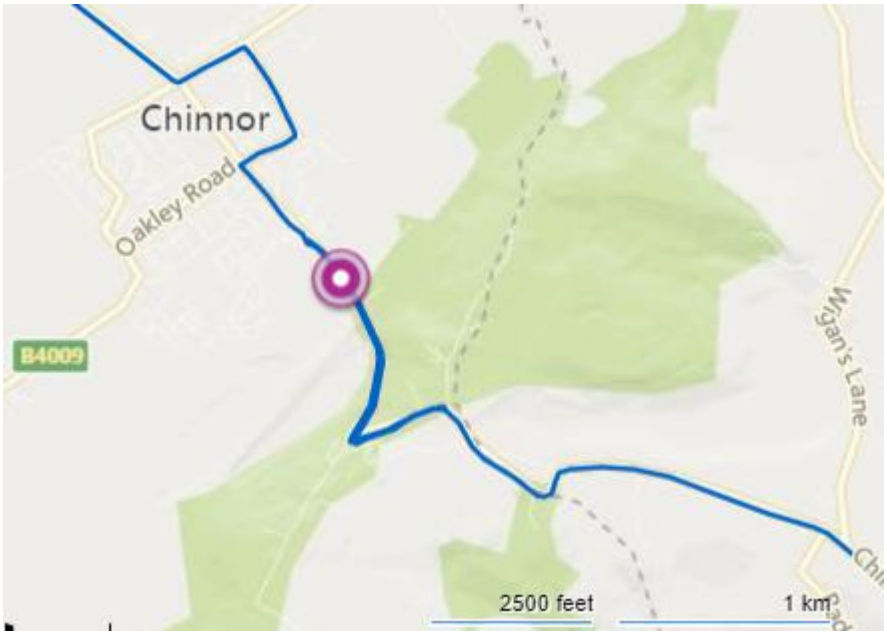
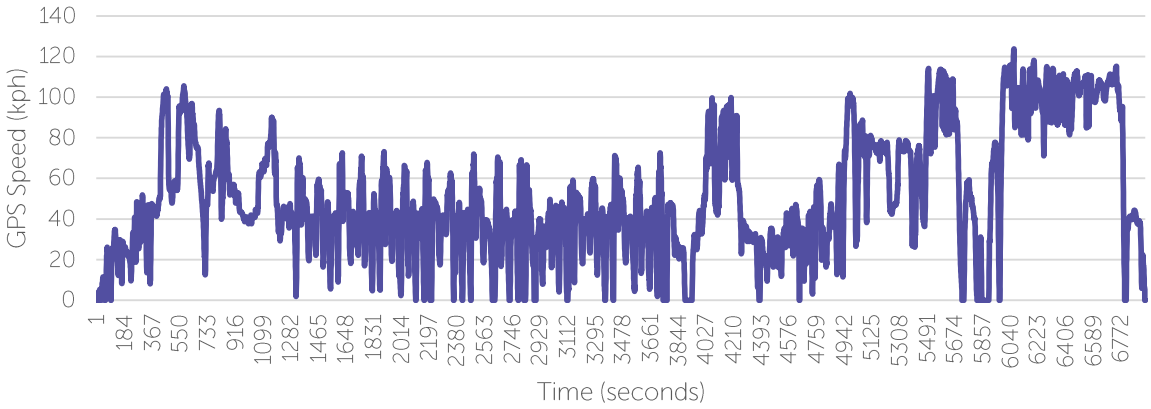


Figure 4 - Dynamic/altitude (elevation section, repeated multiple times)



Reverse phase order route

	Duration	Distance	Speed	Altitude	Relative Positive Acceleration	V*Apos @ 95th Percentile	Cumulative Positive Elevation Gain
	minutes	km	km/h	m	m/s^2	m^2/s^3	m/100km
Overall	90.4	99.6	65.9	132.0	0.11	15.58	703
Cold Start	5.0	2.0	24.4	n/a	0.21	9.54	n/a
Urban	41.3	23.3	34.0	n/a	0.20	13.83	641
Rural	20.7	25.6	74.3	n/a	0.13	18.63	n/a
Motorway	28.4	50.6	106.6	n/a	0.05	16.54	n/a

Note: these are the average values across all tests run on this route.

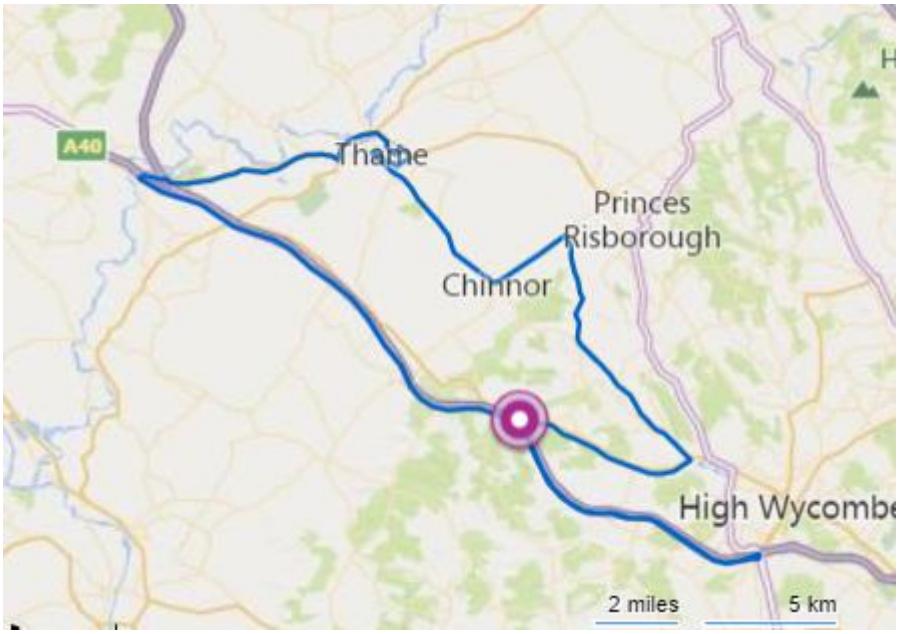
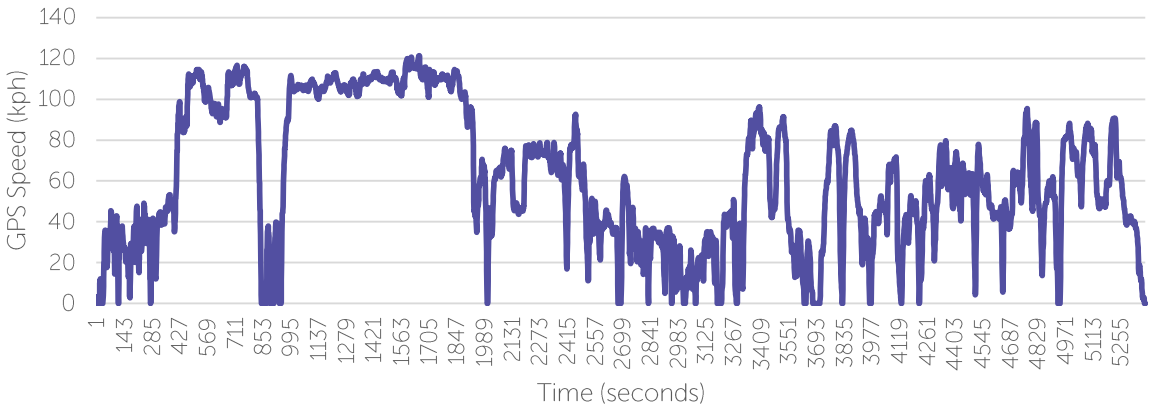


Figure 5 - Reverse route



Test vehicles

All vehicles were hired through third-parties for Emissions Analytics.

BMW X5 PHEV

BMW X5 prior to test commencement

Manufacturer	Model	VRM	Model Year	Regulatory Stage	Battery Size (kWh)
BMW	X5	BX20 MHK	2020	Euro 6d-TEMP-EVAP-ISC (WLTP)	24.00

VIN	Engine Size (litres)	Fuel	Drivetrain	Power (bhp)	Derivative
WBATA62030LE47415	3.0	Gasoline	AWD	394	XDrive 45E M PHEV

WLTP Electric Energy Consumption	WLTP Electric Range
249 Wh/km	81 km

Pre-test odometer (miles)	Post-test odometer (miles)
3,264	4,027

Tyre information

Front

Manufacturer	Model	Width	Aspect Ratio	Rim diameter
Continental	Premium Contact 6	275 mm	35%	22 inch

Rear

Manufacturer	Model	Width	Aspect Ratio	Rim diameter
Continental	Premium Contact 6	315 mm	30%	22 inch

	Front Left	Front Right	Rear Left	Rear Right
Tyre pressure (psi)	32.0	32.0	32.0	32.0

	Front Left	Front Right	Rear Left	Rear Right
Tread depth (mm)	8.0	8.0	8.0	8.0

Emissions information

WLTP Urban	WLTP Suburban	WLTP Rural	WLTP Motorway
N/A	N/A	N/A	N/A

WLTP Combined FE	WLTP Combined CO_2
1.4 l/100km	32.0 g/km

Volvo XC60 PHEV

Volvo XC60 undergoing pre-test calibration

Manufacturer	Model	VRM	Model Year	Regulatory Stage	Battery Size (kWh)
Volvo	XC60	BX68 SFF	2018	Euro 6d-TEMP-EVAP (WLTP)	10.40

VIN	Engine Size (litres)	Fuel	Drivetrain	Power (bhp)	Derivative
YV1UZBMTDK1249230	2.0	Gasoline	AWD	384	R Design Pro T8 PHEV

WLTP Electric Energy Consumption	WLTP Electric Range
160 Wh/km	35 km

Pre-test odometer (miles)	Post-test odometer (miles)
15,915	16,556

Tyre information

Front

Manufacturer	Model	Width	Aspect Ratio	Rim diameter
Pirelli	P Zero	255 mm	40%	21 inch

Rear

Manufacturer	Model	Width	Aspect Ratio	Rim diameter
Pirelli	P Zero	255 mm	40%	21 inch

	Front Left	Front Right	Rear Left	Rear Right
Tyre pressure (psi)	34.0	34.0	34.0	34.0

	Front Left	Front Right	Rear Left	Rear Right
Tread depth (mm)	6.0	7.0	6.0	6.0

Emissions information

WLTP Urban	WLTP Suburban	WLTP Rural	WLTP Motorway
8.6 l/100km	6.8 l/100km	6.4 l/100km	8.3 l/100km

WLTP Combined FE	WLTP Combined CO_2
3.5 l/100km	71.0 g/km

Mitsubishi Outlander PHEV

Mitsubishi Outlander prior to test commencement

Manufacturer	Model	VRM	Model Year	Regulatory Stage	Battery Size (kWh)
Mitsubishi	Outlander	WP68 XSK	2018	Euro 6d-TEMP-EVAP (WLTP)	13.80

VIN	Engine Size (litres)	Fuel	Drivetrain	Power (bhp)	Derivative
JMAXDGG3WKZ004557	2.4	Gasoline	AWD	206	5H PHEV

WLTP Electric Energy Consumption	WLTP Electric Range
169 Wh/km	45 km

Pre-test odometer (miles)	Post-test odometer (miles)
30,506	32,729

Tyre information

Front

Manufacturer	Model	Width	Aspect Ratio	Rim diameter
Yokohama	Blueearth E60	225 mm	55%	18 inch

Rear

Manufacturer	Model	Width	Aspect Ratio	Rim diameter
Yokohama	Blueearth E60	225 mm	55%	18 inch

	Front Left	Front Right	Rear Left	Rear Right
Tyre pressure (psi)	36.0	36.0	38.0	38.0

	Front Left	Front Right	Rear Left	Rear Right
Tread depth (mm)	6.0	6.0	7.0	7.0

Emissions information

WLTP Urban	WLTP Suburban	WLTP Rural	WLTP Motorway
N/A	N/A	N/A	N/A

WLTP Combined FE	WLTP Combined CO_2
2.0 l/100km	46.0 g/km

Vehicle charging

The benefits of fast charging are clear for the Mitsubishi Outlander, but it is the only vehicle that supports the CHAdeMO technology.

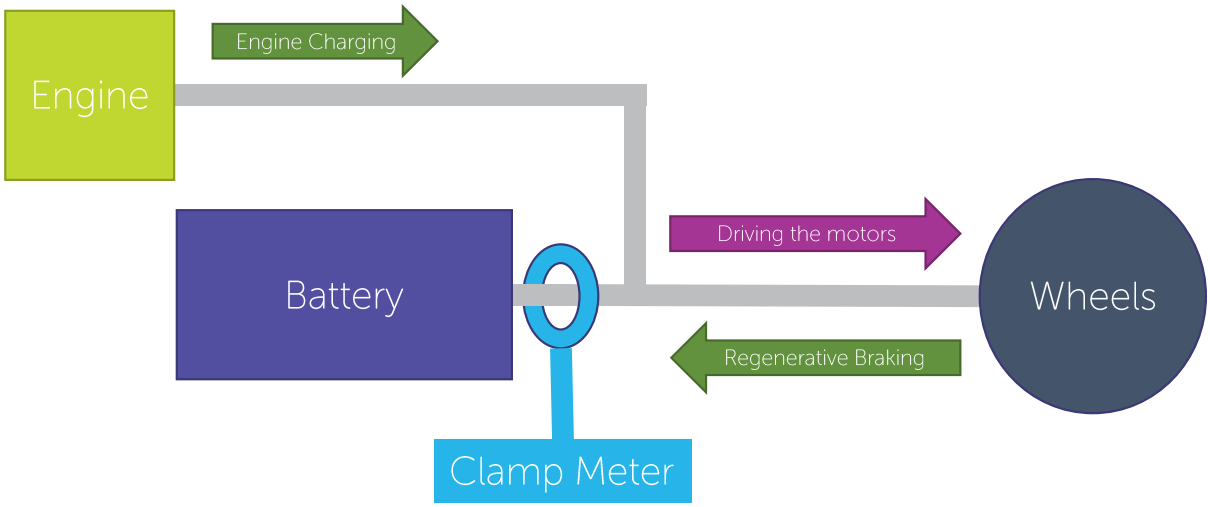
Charging Point	Average Power	BMW X5	Volvo XC60	Mitsubishi Outlander
Wall Plug	2.3 kW	11h15m	5h15m	5h45m
1-phase 16A	3.7 kW	7 hours	3h15m	3h30m
Fast charging CHAdeMO (50 kW DC)	15 kW	n/a	n/a	32m

Information sourced from the EV database (https://ev-database.uk/), an independent resource that uses a blend of official and real-world data.

Vehicle battery wiring

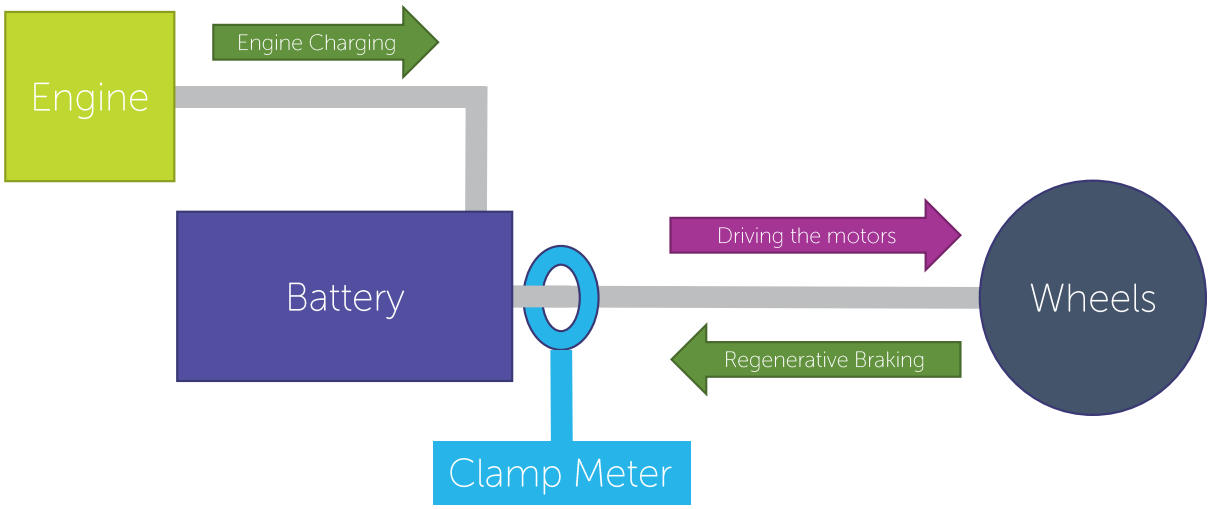
BMW X5

The BMW has a single connection the main battery for both the engine charging and the motors to the wheels. With our single clamp meter, we were able to capture current flow from engine charging, driving the motors, and regenerative braking.



Mitsubishi Outlander 5H and Volvo XC60

These vehicles have separate connections to the main battery for the engine charging and the motors to the wheels. With our single clamp meter, we were able to capture current flow from driving the motors and regenerative braking. We were not able to capture the engine charging.



Electricity consumption

After driving the vehicles for these tests, we have the following observations regarding the battery usage.

The vehicles inform you when you have selected a specific mode, or when it switches between modes, for example from EV to Normal. The reverse is also true, when running on ICE (No battery charge) the vehicle will switch to EV when there is a nominal charge in the battery and the demand is low (crawling traffic or just pulling off from a stop).

In EV mode the vehicles behaved similarly – exclusively running on battery until an internal preset state of charge is reached after which they switch to hybrid mode. However, in hybrid mode we see some differences.

Both the BMW X5 and Volvo XC60 behaved like traditional hybrid vehicles with the engine being used partially to charge the battery and partially to drive the wheels.

However, regardless of the driving mode, the Mitsubishi Outlander behaved mostly like an electric vehicle that carries around an engine to charge the battery. It rarely used the engine to drive the wheels and instead powered the wheels almost exclusively from battery and used the engine to charge the battery as needed.

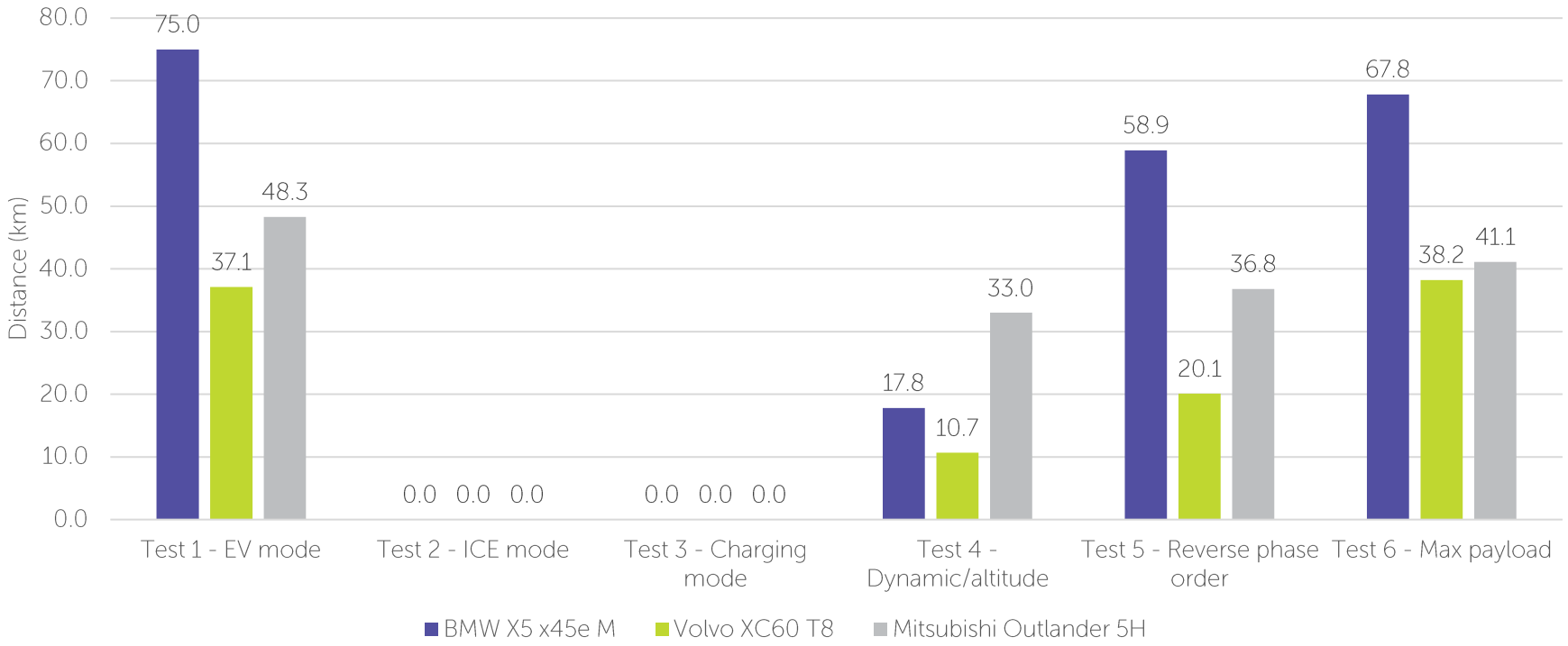
These observations coupled with the information regarding the battery wiring and what was recorded by the clamp meter provide an understanding of the electricity consumption results presented later in this document.

Climatic Conditions

	Ambient Temperature °C	Ambient Pressure mbar	Relative Humidity %
BMW X5 x45e M			
Test 1 - EV mode	22.5	1007	43
Test 2 - ICE mode	19.0	1016	45
Test 3 - Charging mode	20.0	1017	82
Test 4 - Dynamic/altitude	23.0	1017	38
Test 5 - Reverse phase order	25.0	1016	82
Test 6 - Max payload	19.0	1013	90
Volvo XC60 T8			
Test 1 - EV mode	23.0	1012	73
Test 2 - ICE mode	17.0	1003	94
Test 3 - Charging mode	18.0	1008	78
Test 4 - Dynamic/altitude	16.0	1015	92
Test 5 - Reverse phase order	19.0	1003	66
Test 6 - Max payload	19.0	1009	76
Mitsubishi Outlander 5H			
Test 1 - EV mode	22.0	1009	53
Test 2 - ICE mode	19.0	1016	63
Test 3 - Charging mode	17.1	1009	58
Test 4 - Dynamic/altitude	20.1	995	39
Test 5 - Reverse phase order	19.4	998	41
Test 6 - Max payload	18.7	997	72

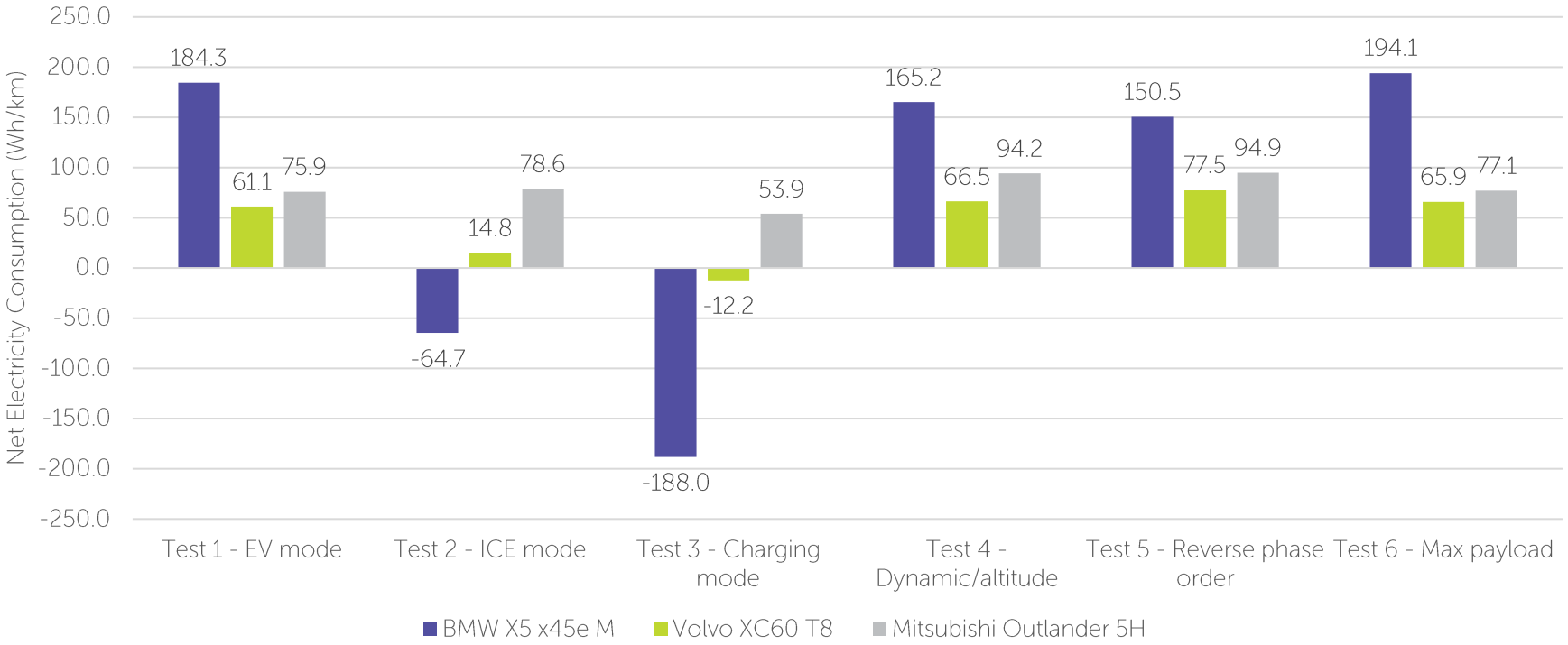
Charts

Initial electric-only range



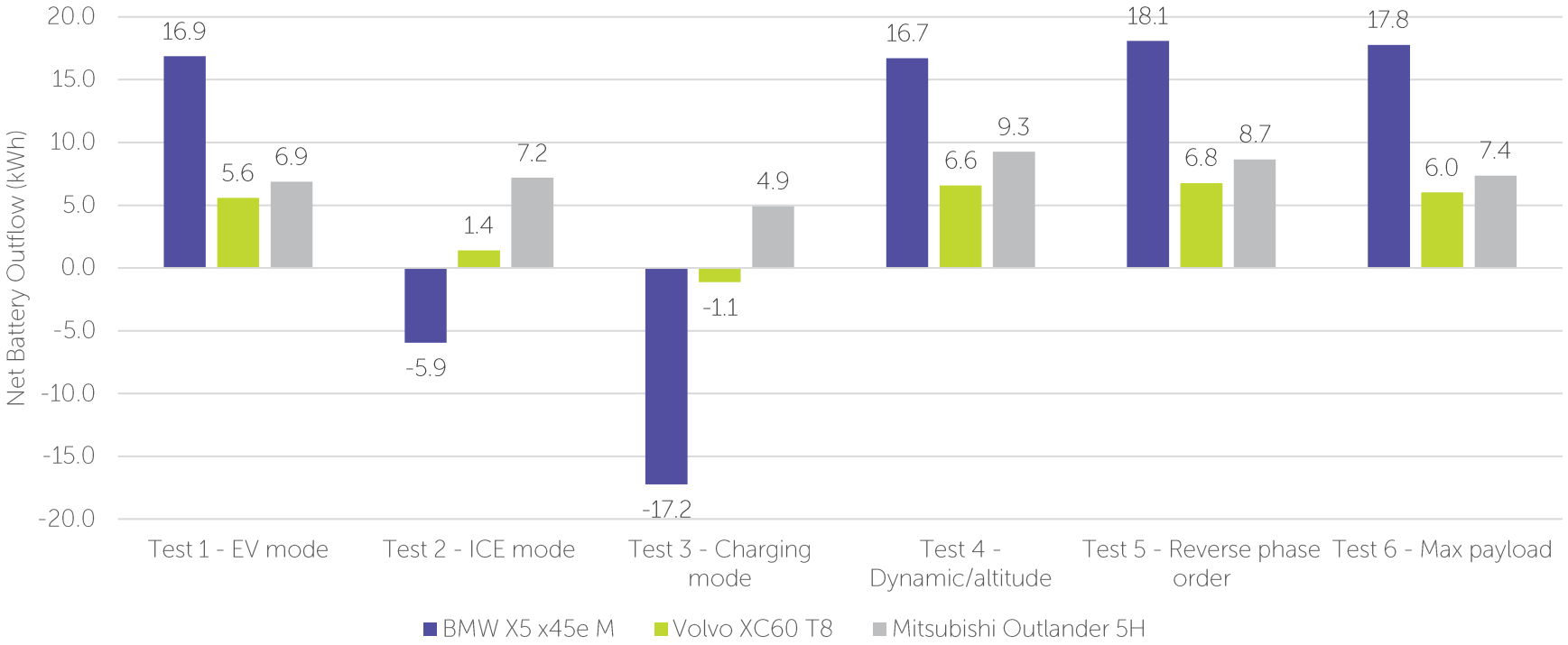
Electricity consumption

Electricity consumption is the electrical energy flowing out of the high voltage battery to drive the wheels, net of the inflows from regenerative braking and engine charging. The value is expressed in watt hours per km. A negative value indicates there was a net inflow to the battery. Note that we were only able to measure engine charging on the BMW X5.



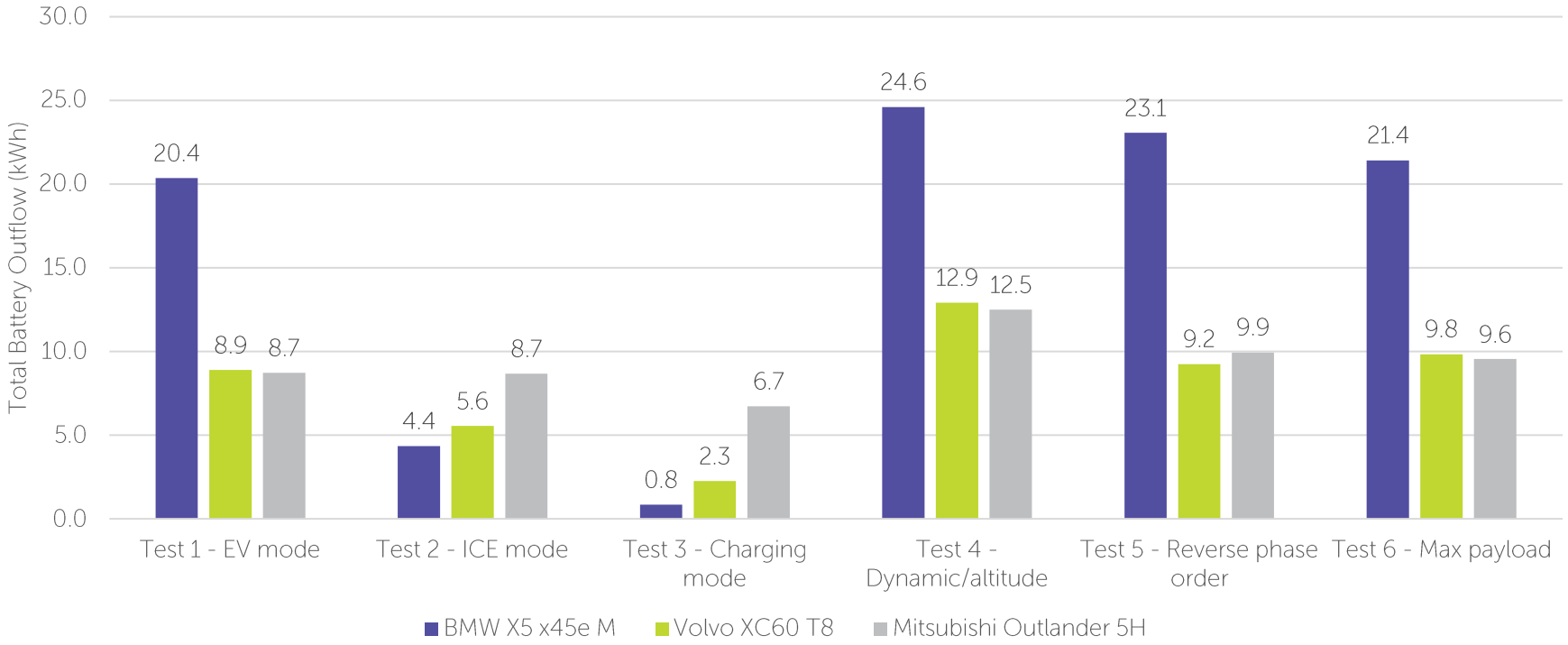
Total electricity consumption

Total electricity consumption is the electrical energy flowing out of the high voltage battery to drive the wheels, net of the inflows from regenerative braking and engine charging. The value is expressed in kilowatt hours. A negative value indicates there was a net inflow to the battery. Note that we were only able to measure engine charging on the BMW X5.

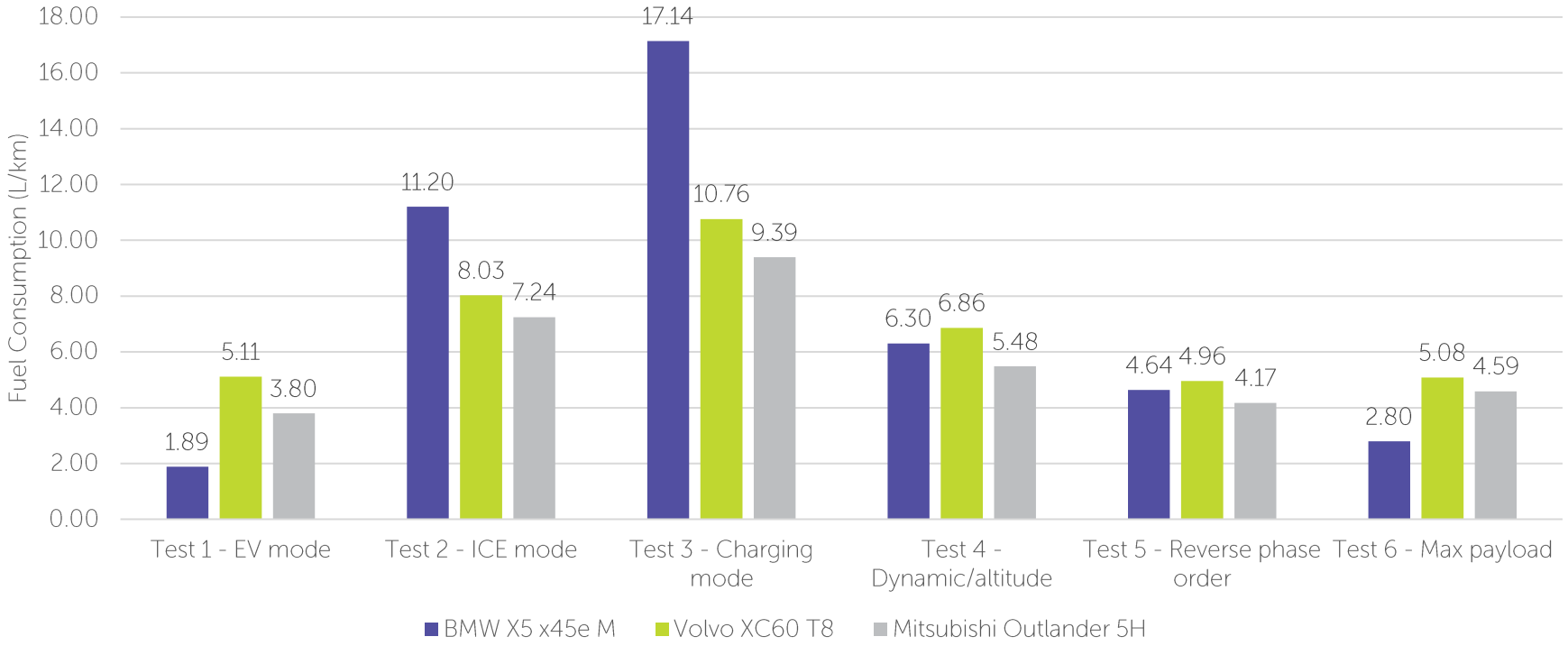


Total battery usage

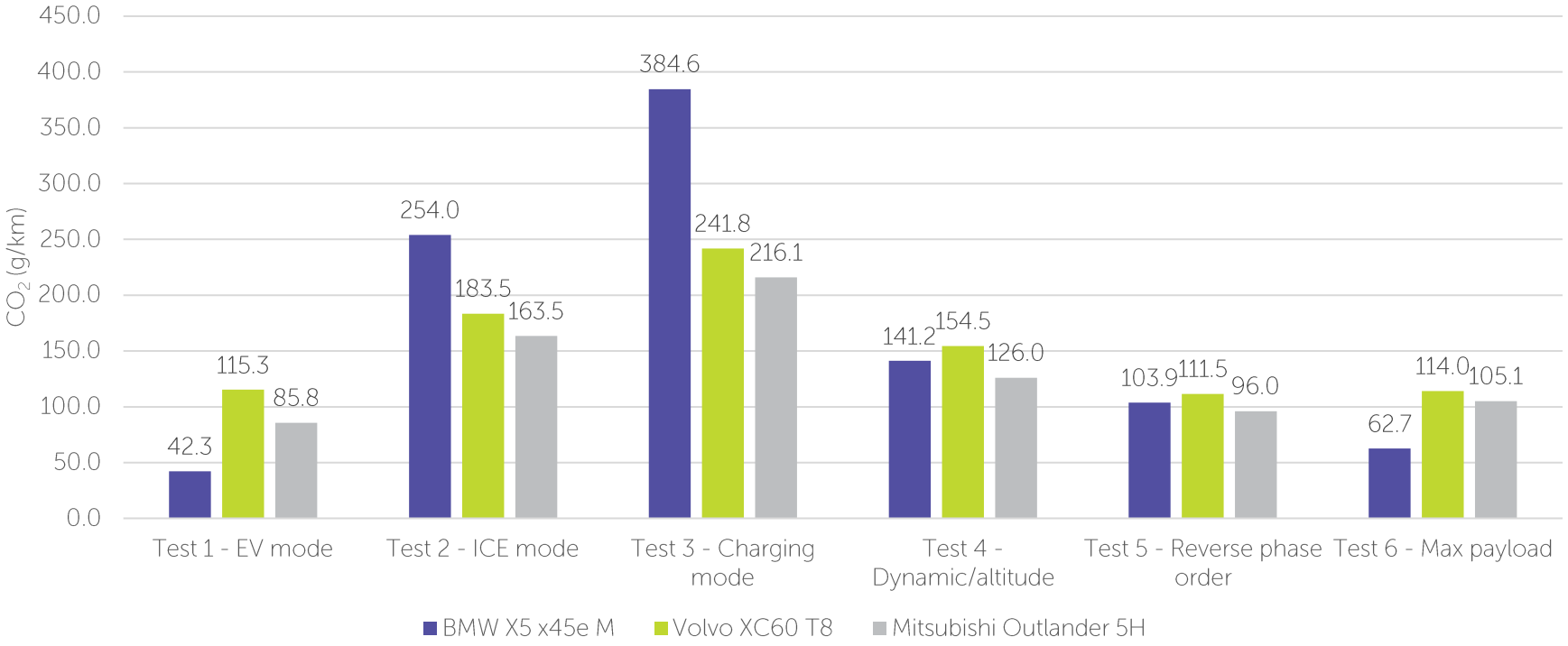
Total battery usage is the electrical energy flowing out of the high voltage battery to drive the wheels. The value is expressed in kilowatt hours.



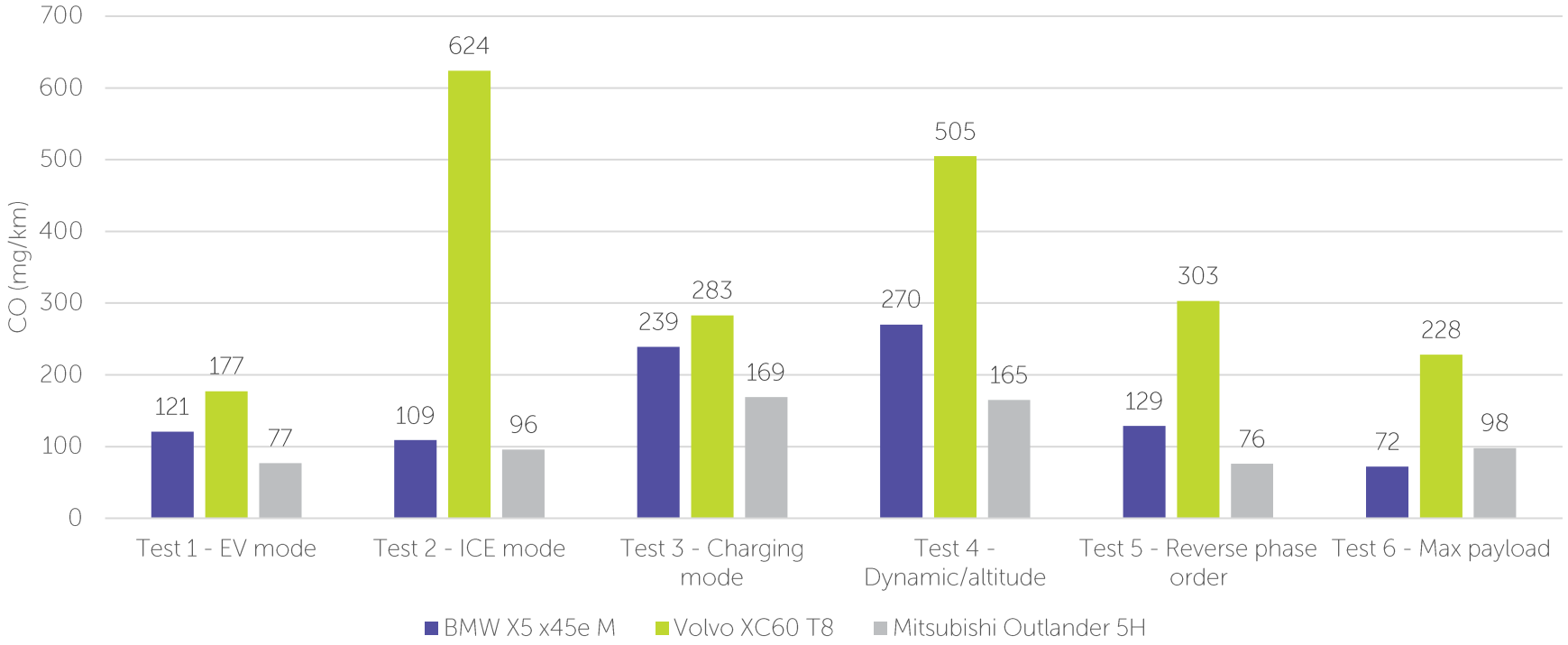
Fuel consumption



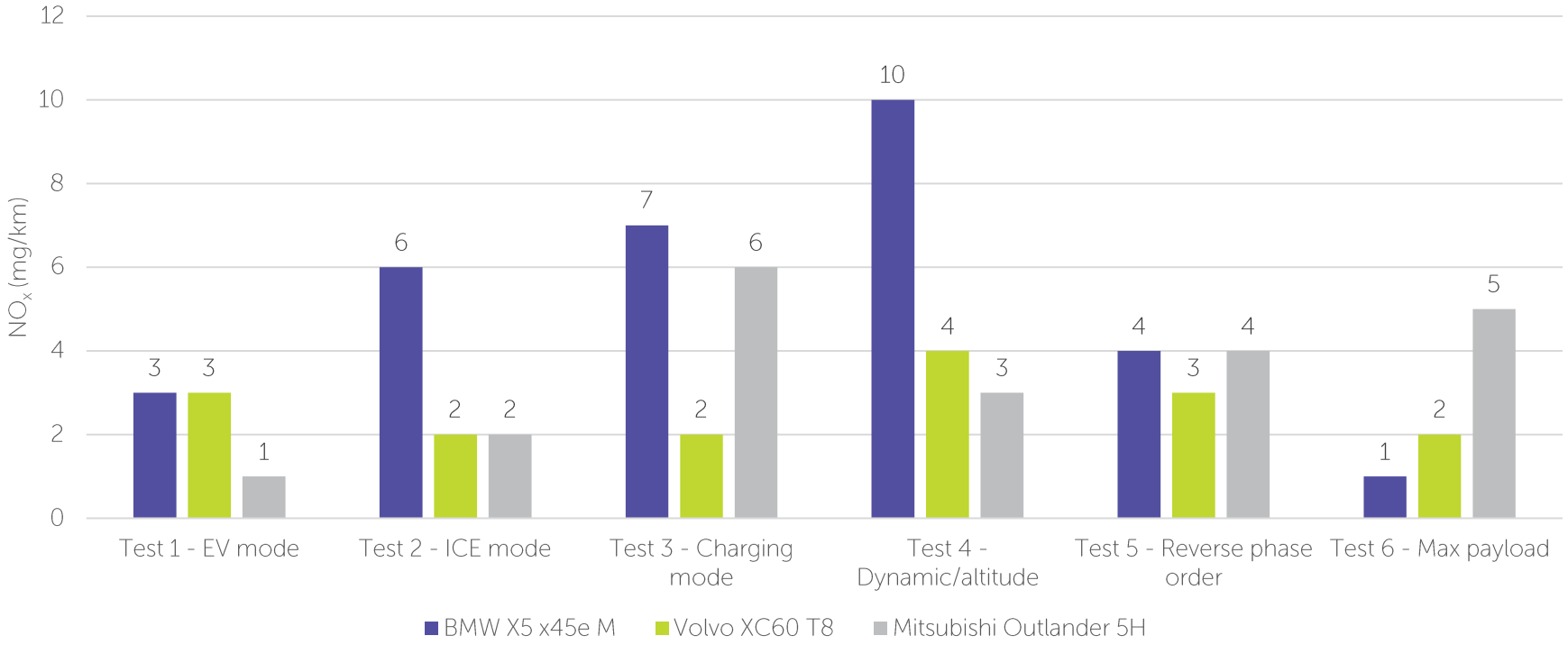
Carbon dioxide (CO_2)



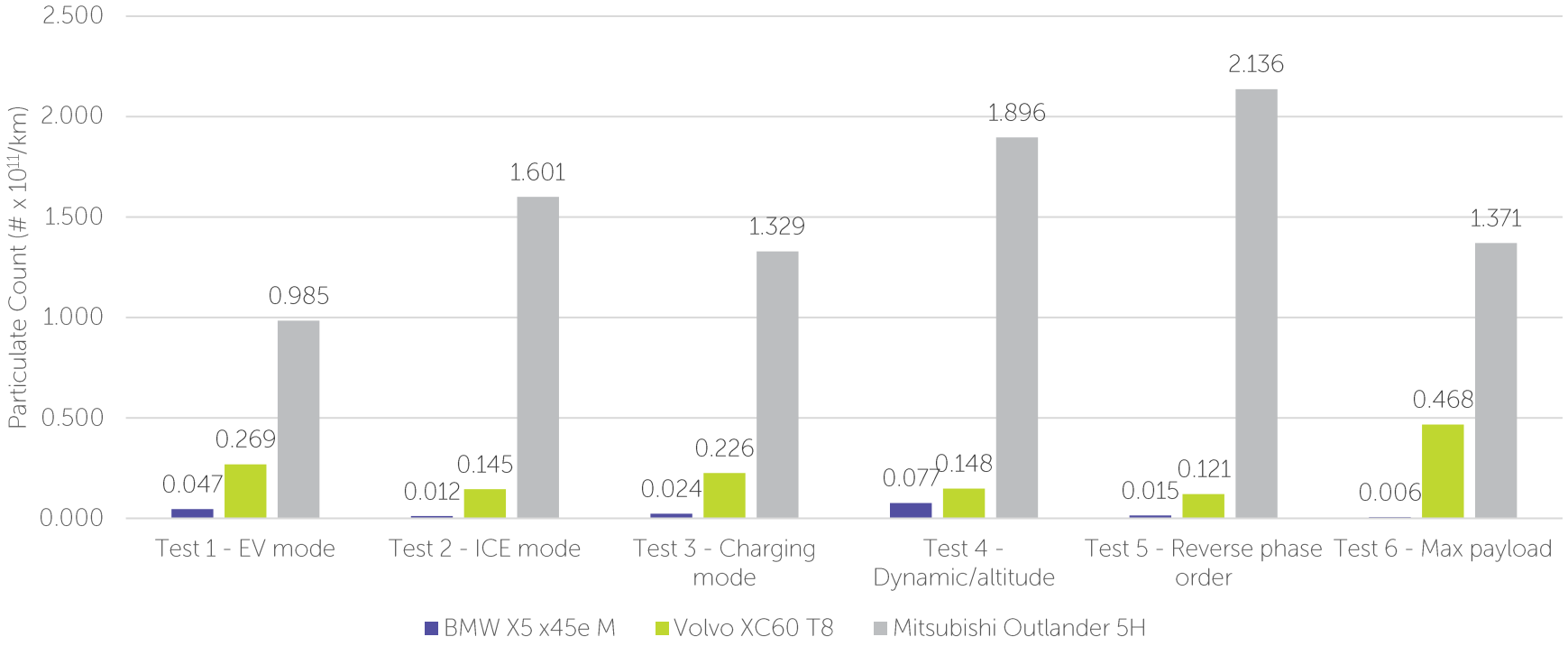
Carbon monoxide (CO)



Nitrogen oxides (NO_x)

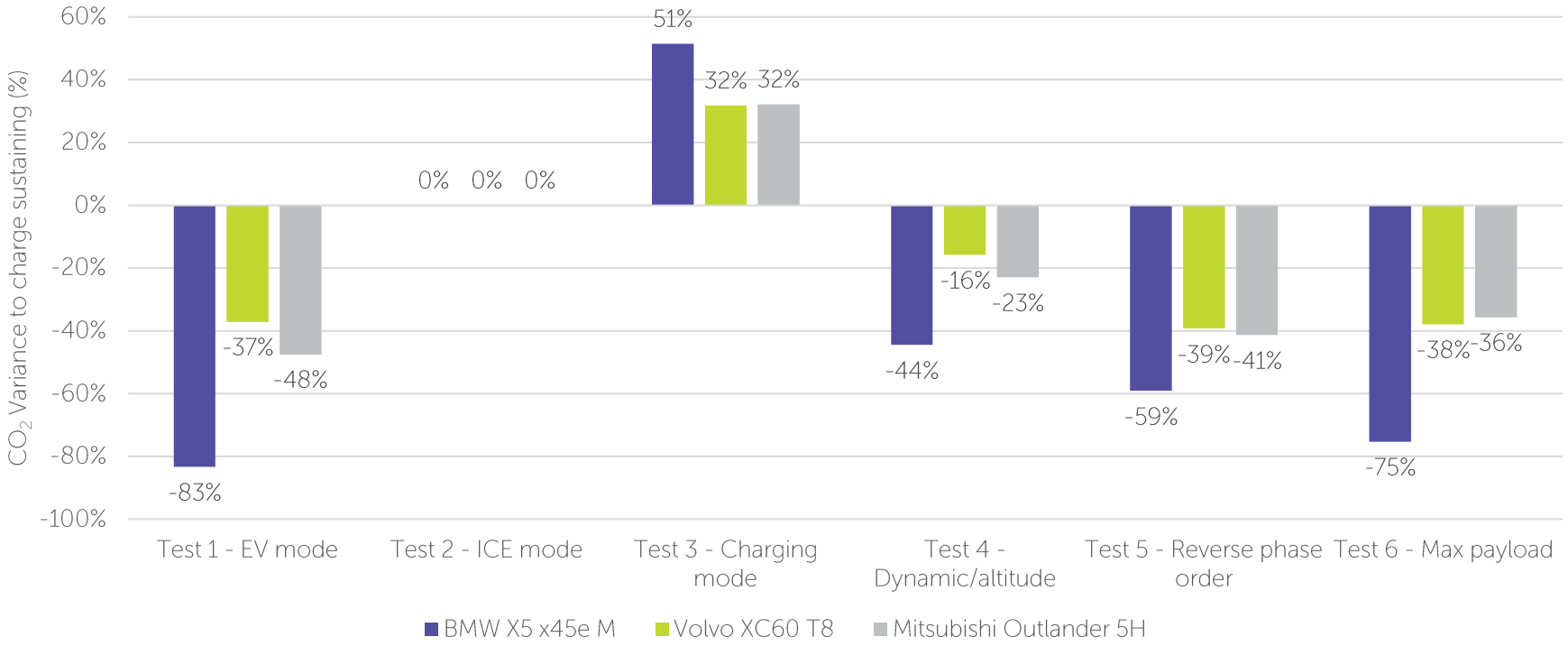


Particulates



CO_2 savings

This chart shows the CO_2 variance between each test as compared to the ICE-only test (charge sustaining). For the charging test more CO_2 is emitted but for all others there are significant savings.



Results

Route summary - Overall

Overall	RDE Compliant	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Electric-only Range km
BMW X5 x45e M						
Test 1 - EV mode	Yes	102.2	91.6	53.8	119.4	75.0
Test 2 - ICE mode	Yes	108.0	91.8	51.0	116.3	0.0
Test 3 - Charging mode	Yes	107.9	91.6	50.9	117.6	0.0
Test 4 - Dynamic/altitude	No	113.4	101.2	53.6	122.3	17.8
Test 5 - Reverse phase order	No	101.2	120.2	71.2	120.0	58.9
Test 6 - Max payload	Yes	104.7	91.5	52.5	114.2	67.8
Volvo XC60 T8						
Test 1 - EV mode	Yes	105.7	91.6	52.0	116.5	37.1
Test 2 - ICE mode	Yes	119.2	94.9	47.8	119.4	0.0
Test 3 - Charging mode	Yes	102.1	91.5	53.8	114.4	0.0
Test 4 - Dynamic/altitude	No	110.3	99.1	53.9	118.9	10.7
Test 5 - Reverse phase order	No	80.3	87.3	65.3	115.0	20.1
Test 6 - Max payload	Yes	107.8	91.5	50.9	115.7	38.2
Mitsubishi Outlander 5H						
Test 1 - EV mode	Yes	104.4	90.5	52.0	114.4	48.3
Test 2 - ICE mode	Yes	104.8	91.5	52.4	114.2	0.0
Test 3 - Charging mode	Yes	109.0	91.3	50.2	113.6	0.0
Test 4 - Dynamic/altitude	No	115.4	98.3	51.1	123.7	33.0
Test 5 - Reverse phase order	No	89.6	91.2	61.1	121.3	36.8
Test 6 - Max payload	Yes	109.7	95.5	52.2	120.8	41.1

Emissions summary – Overall - Raw

	FE	FC	CO_2	CO	NO_x	PN	Electricity Consumption	Total Electricity Consumed	Battery Usage	Total Battery Usage
	MPG	L/100km	g/km	mg/km	mg/km	#x10^{11}/km	Wh/km	kWh	Wh/km	kWh
BMW X5 x45e M										
Test 1 - EV mode	149.2	1.89	42.3	121	3	0.047	184.3	16.88	222.4	20.37
Test 2 - ICE mode	25.2	11.20	254.0	109	6	0.012	-64.7	-5.94	47.5	4.36
Test 3 - Charging mode	16.5	17.14	384.6	239	7	0.024	-188.0	-17.22	9.3	0.85
Test 4 - Dynamic/altitude	44.9	6.30	141.2	270	10	0.077	165.2	16.72	243.2	24.61
Test 5 - Reverse phase order	60.9	4.64	103.9	129	4	0.015	150.5	18.10	191.9	23.07
Test 6 - Max payload	100.9	2.80	62.7	72	1	0.006	194.1	17.76	234.0	21.41
Volvo XC60 T8										
Test 1 - EV mode	55.3	5.11	115.3	177	3	0.269	61.1	5.59	97.1	8.89
Test 2 - ICE mode	35.2	8.03	183.5	624	2	0.145	14.8	1.40	58.5	5.55
Test 3 - Charging mode	26.3	10.76	241.8	283	2	0.226	-12.2	-1.12	24.7	2.26
Test 4 - Dynamic/altitude	41.2	6.86	154.5	505	4	0.148	66.5	6.58	130.4	12.92
Test 5 - Reverse phase order	57.0	4.96	111.5	303	3	0.121	77.5	6.77	106.0	9.25
Test 6 - Max payload	55.7	5.08	114.0	228	2	0.468	65.9	6.02	107.5	9.84
Mitsubishi Outlander 5H										
Test 1 - EV mode	74.4	3.80	85.8	77	1	0.985	75.9	6.87	96.5	8.73
Test 2 - ICE mode	39.0	7.24	163.5	96	2	1.601	78.6	7.19	94.9	8.68
Test 3 - Charging mode	30.1	9.39	216.1	169	6	1.329	53.9	4.92	73.7	6.73
Test 4 - Dynamic/altitude	51.5	5.48	126.0	165	3	1.896	94.2	9.26	127.3	12.51
Test 5 - Reverse phase order	67.8	4.17	96.0	76	4	2.136	94.9	8.65	109.0	9.94
Test 6 - Max payload	61.5	4.59	105.1	98	5	1.371	77.1	7.37	100.0	9.55

Emissions summary – Overall – EMROAD

	CO - Total mg/km	NO_x - Total mg/km	PN - Total #x10^{11}/km	CO - Urban mg/km	NO_x - Urban mg/km	PN - Urban #x10^{11}/km
BMW X5 x45e M						
Test 1 - EV mode	51	1	0.024	0	0	0.003
Test 2 - ICE mode	109	6	0.012	75	7	0.013
Test 3 - Charging mode	182	5	0.018	159	5	0.025
Test 4 - Dynamic/altitude	239	9	0.067	155	6	0.049
Test 5 - Reverse phase order	129	4	0.015	131	1	0.015
Test 6 - Max payload	72	1	0.006	0	0	0.000
Volvo XC60 T8						
Test 1 - EV mode	180	3	0.283	88	2	0.307
Test 2 - ICE mode	488	2	0.133	439	1	0.129
Test 3 - Charging mode	284	2	0.228	243	1	0.174
Test 4 - Dynamic/altitude	365	3	0.110	328	1	0.050
Test 5 - Reverse phase order	298	3	0.119	437	1	0.053
Test 6 - Max payload	228	2	0.468	108	2	0.630
Mitsubishi Outlander 5H						
Test 1 - EV mode	77	1	0.985	11	0	0.274
Test 2 - ICE mode	85	2	1.419	47	2	0.874
Test 3 - Charging mode	183	5	1.353	124	4	0.687
Test 4 - Dynamic/altitude	147	3	1.695	58	2	1.097
Test 5 - Reverse phase order	75	4	2.107	13	2	0.547
Test 6 - Max payload	96	5	1.347	9	1	0.377

Note: Please see Appendix 4 for more explanation of the EMROAD calculations.

Route summary – Cold start

Cold start is defined as the part of the test where the coolant temperature is between 70% and 100% of the coolant temperature mean, for at least 5 minutes, up to a maximum of 20 minutes, provided that the coolant temp started below the 70% threshold. Cold start was included during the urban cycle.

	RDE Compliant	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
BMW X5 x45e M						
Test 1 - EV mode	Yes	5.0	2.1	25.4	43.8	2.3%
Test 2 - ICE mode	Yes	3.0	1.0	21.0	34.8	1.1%
Test 3 - Charging mode	Yes	3.5	1.1	18.8	33.3	1.2%
Test 4 - Dynamic/altitude	No	5.0	2.0	23.5	38.1	1.9%
Test 5 - Reverse phase order	No	5.0	2.1	24.6	41.0	1.7%
Test 6 - Max payload	Yes	5.0	2.0	23.6	36.0	2.2%
Volvo XC60 T8						
Test 1 - EV mode	Yes	5.0	1.7	20.6	36.5	1.9%
Test 2 - ICE mode	Yes	2.5	0.9	22.1	38.1	1.0%
Test 3 - Charging mode	Yes	2.5	0.8	19.6	34.8	0.9%
Test 4 - Dynamic/altitude	No	5.0	1.7	19.8	32.8	1.7%
Test 5 - Reverse phase order	No	5.0	1.9	22.3	38.8	2.1%
Test 6 - Max payload	Yes	5.0	1.6	19.2	35.6	1.8%
Mitsubishi Outlander 5H						
Test 1 - EV mode	Yes	5.0	1.5	17.6	36.4	1.6%
Test 2 - ICE mode	Yes	5.0	1.5	17.7	34.1	1.6%
Test 3 - Charging mode	Yes	5.0	1.3	16.0	34.1	1.5%
Test 4 - Dynamic/altitude	No	5.0	1.8	21.5	51.8	1.8%
Test 5 - Reverse phase order	No	5.0	2.2	26.2	49.1	2.4%
Test 6 - Max payload	Yes	5.0	1.9	23.3	54.2	2.0%

Emissions summary – Cold start – Raw

	FE	FC	CO_2	CO	NO_x	PN	Electricity Consumption	Total Electricity Consumed	Battery Usage	Total Battery Usage
	MPG	L/100km	g/km	mg/km	mg/km	#x10^{11}/km	Wh/km	kWh	Wh/km	kWh
BMW X5 x45e M										
Test 1 - EV mode	5324.1	0.05	0.1	1	0	0.003	278.7	0.59	309.5	0.65
Test 2 - ICE mode	9.4	30.14	681.7	1136	178	0.093	-248.5	-0.26	50.0	0.05
Test 3 - Charging mode	9.3	30.46	682.4	1136	141	0.114	-203.1	-0.22	63.6	0.07
Test 4 - Dynamic/altitude	5004.7	0.06	0.1	0	0	0.004	354.3	0.69	365.0	0.73
Test 5 - Reverse phase order	n/a	0.00	0.0	0	0	0.001	342.0	0.70	347.6	0.73
Test 6 - Max payload	n/a	0.00	0.0	0	0	0.000	303.5	0.60	325.0	0.65
Volvo XC60 T8										
Test 1 - EV mode	38.8	7.29	161.7	1047	57	9.924	132.6	0.23	152.9	0.26
Test 2 - ICE mode	12.1	23.40	536.1	1113	87	6.987	61.4	0.06	122.2	0.11
Test 3 - Charging mode	8.5	33.27	749.7	570	31	2.692	-0.3	0.00	25.0	0.02
Test 4 - Dynamic/altitude	n/a	0.00	0.0	0	0	0.000	191.0	0.32	211.8	0.36
Test 5 - Reverse phase order	1707.8	0.17	1.3	10	1	0.006	181.7	0.34	205.3	0.39
Test 6 - Max payload	1642.3	0.17	0.6	0	1	0.007	215.0	0.34	243.8	0.39
Mitsubishi Outlander 5H										
Test 1 - EV mode	n/a	0.00	0.0	0	0	0.000	116.5	0.17	120.0	0.18
Test 2 - ICE mode	34.6	8.17	183.0	1106	38	4.063	146.9	0.22	160.0	0.24
Test 3 - Charging mode	26.6	10.61	241.3	1444	43	12.392	240.9	0.32	246.2	0.32
Test 4 - Dynamic/altitude	n/a	0.00	0.2	1	0	0.001	122.9	0.22	138.9	0.25
Test 5 - Reverse phase order	n/a	0.00	0.0	0	0	0.001	132.1	0.29	163.6	0.36
Test 6 - Max payload	4829.3	0.06	0.2	2	2	0.002	184.5	0.36	205.3	0.39

Route summary – Urban

	RDE Compliant	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
BMW X5 x45e M						
Test 1 - EV mode	Yes	63.7	36.0	33.9	59.9	39.3%
Test 2 - ICE mode	Yes	68.4	34.7	30.5	59.9	37.8%
Test 3 - Charging mode	Yes	69.5	36.3	31.3	59.9	39.6%
Test 4 - Dynamic/altitude	No	74.4	45.1	36.4	59.9	44.5%
Test 5 - Reverse phase order	No	41.2	23.8	34.7	59.9	19.8%
Test 6 - Max payload	Yes	67.9	38.0	33.6	59.9	41.5%
Volvo XC60 T8						
Test 1 - EV mode	Yes	65.1	33.4	30.8	59.9	36.5%
Test 2 - ICE mode	Yes	80.0	40.6	30.4	59.9	42.8%
Test 3 - Charging mode	Yes	63.9	35.8	33.6	59.9	39.1%
Test 4 - Dynamic/altitude	No	69.7	40.9	35.2	59.9	41.3%
Test 5 - Reverse phase order	No	37.0	21.5	34.7	59.9	24.6%
Test 6 - Max payload	Yes	68.9	36.3	31.6	59.9	39.7%
Mitsubishi Outlander 5H						
Test 1 - EV mode	Yes	66.1	36.2	32.9	59.9	40.0%
Test 2 - ICE mode	Yes	64.5	35.0	32.5	59.9	38.2%
Test 3 - Charging mode	Yes	68.2	34.5	30.4	59.9	37.8%
Test 4 - Dynamic/altitude	No	78.5	44.4	34.0	59.9	45.2%
Test 5 - Reverse phase order	No	45.6	24.8	32.6	59.9	27.1%
Test 6 - Max payload	Yes	69.9	39.0	33.5	59.9	40.8%

Emissions summary – Urban – Raw

	FE	FC	CO_2	CO	NO_x	PN	Electricity Consumption	Total Electricity Consumed	Battery Usage	Total Battery Usage
	MPG	L/100km	g/km	mg/km	mg/km	#x10^{11}/km	Wh/km	kWh	Wh/km	kWh
BMW X5 x45e M										
Test 1 - EV mode	5484.6	0.05	0.4	1	0	0.005	233.3	8.39	287.8	10.36
Test 2 - ICE mode	23.0	12.28	278.4	111	10	0.019	-94.9	-3.29	109.5	3.80
Test 3 - Charging mode	13.5	20.94	470.0	254	9	0.040	-280.2	-10.16	22.3	0.81
Test 4 - Dynamic/altitude	72.0	3.93	87.5	265	11	0.086	310.0	13.97	398.2	17.96
Test 5 - Reverse phase order	37.1	7.61	170.5	175	1	0.021	124.8	2.97	229.8	5.47
Test 6 - Max payload	7382.6	0.04	0.9	0	0	0.000	254.2	9.66	316.6	12.03
Volvo XC60 T8										
Test 1 - EV mode	126.2	2.24	52.6	150	2	0.515	119.4	3.99	182.6	6.10
Test 2 - ICE mode	38.3	7.37	168.3	898	2	0.206	34.1	1.38	103.0	4.18
Test 3 - Charging mode	21.5	13.12	295.2	343	2	0.246	-30.1	-1.08	39.4	1.41
Test 4 - Dynamic/altitude	49.1	5.76	129.7	754	3	0.107	104.9	4.29	219.1	8.96
Test 5 - Reverse phase order	48.4	5.83	130.3	688	1	0.083	49.6	1.06	118.1	2.54
Test 6 - Max payload	155.8	1.81	40.5	169	2	0.984	111.4	4.04	186.5	6.77
Mitsubishi Outlander 5H										
Test 1 - EV mode	397.1	0.71	16.1	14	0	0.356	103.6	3.75	127.9	4.63
Test 2 - ICE mode	56.1	5.04	113.8	70	3	1.316	101.6	3.55	130.6	4.57
Test 3 - Charging mode	22.9	12.31	283.2	202	4	0.911	90.0	3.11	119.7	4.13
Test 4 - Dynamic/altitude	85.5	3.30	75.6	98	2	1.843	129.4	5.75	174.5	7.75
Test 5 - Reverse phase order	59.5	4.74	109.5	19	3	0.786	116.9	2.90	145.6	3.61
Test 6 - Max payload	427.2	0.66	14.5	10	2	0.387	107.1	4.17	138.2	5.39

Route summary – Rural

	RDE Compliant	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
BMW X5 x45e M						
Test 1 - EV mode	Yes	23.2	28.5	73.7	89.8	31.1%
Test 2 - ICE mode	Yes	23.9	29.2	73.4	89.9	31.8%
Test 3 - Charging mode	Yes	22.7	27.5	72.9	89.9	30.1%
Test 4 - Dynamic/altitude	No	21.6	25.5	70.8	89.9	25.2%
Test 5 - Reverse phase order	No	21.3	26.1	73.7	89.9	21.7%
Test 6 - Max payload	Yes	21.5	26.1	72.9	89.9	28.5%
Volvo XC60 T8						
Test 1 - EV mode	Yes	25.0	30.9	74.2	89.9	33.7%
Test 2 - ICE mode	Yes	24.2	29.4	72.7	89.9	30.9%
Test 3 - Charging mode	Yes	21.6	26.8	74.3	89.9	29.3%
Test 4 - Dynamic/altitude	No	23.6	28.3	71.9	89.9	28.6%
Test 5 - Reverse phase order	No	19.7	24.9	75.8	89.9	28.5%
Test 6 - Max payload	Yes	24.2	29.2	72.3	89.9	31.9%
Mitsubishi Outlander 5H						
Test 1 - EV mode	Yes	23.4	28.7	73.8	89.9	31.8%
Test 2 - ICE mode	Yes	25.6	30.6	71.8	89.9	33.5%
Test 3 - Charging mode	Yes	26.2	31.9	73.1	89.9	35.0%
Test 4 - Dynamic/altitude	No	19.4	23.9	73.9	89.9	24.3%
Test 5 - Reverse phase order	No	21.1	25.9	73.6	89.9	28.4%
Test 6 - Max payload	Yes	24.5	30.3	74.2	89.9	31.8%

Emissions summary – Rural – Raw

	FE	FC	CO_2	CO	NO_x	PN	Electricity Consumption	Total Electricity Consumed	Battery Usage	Total Battery Usage
	MPG	L/100km	g/km	mg/km	mg/km	#x10^{11}/km	Wh/km	kWh	Wh/km	kWh
BMW X5 x45e M										
Test 1 - EV mode	4433.6	0.06	1.1	0	0	0.003	194.3	5.53	220.0	6.27
Test 2 - ICE mode	26.5	10.67	241.9	105	3	0.008	-83.2	-2.43	7.2	0.21
Test 3 - Charging mode	19.7	14.35	321.9	180	5	0.013	-166.5	-4.58	0.4	0.01
Test 4 - Dynamic/altitude	41.7	6.78	152.1	190	9	0.134	54.2	1.38	166.7	4.25
Test 5 - Reverse phase order	26.1	10.81	241.9	380	14	0.042	26.9	0.70	81.6	2.13
Test 6 - Max payload	1026.1	0.28	6.2	4	0	0.000	217.7	5.68	245.6	6.41
Volvo XC60 T8										
Test 1 - EV mode	72.1	3.92	87.7	180	2	0.117	48.8	1.51	74.8	2.31
Test 2 - ICE mode	41.6	6.79	155.4	399	1	0.026	-0.8	-0.02	29.6	0.87
Test 3 - Charging mode	33.4	8.46	190.1	260	1	0.127	-9.2	-0.25	14.9	0.40
Test 4 - Dynamic/altitude	45.2	6.25	140.7	402	7	0.283	57.2	1.62	109.9	3.11
Test 5 - Reverse phase order	33.0	8.55	192.4	387	4	0.087	12.0	0.30	40.6	1.01
Test 6 - Max payload	65.7	4.30	96.5	252	0	0.106	69.0	2.01	91.4	2.67
Mitsubishi Outlander 5H										
Test 1 - EV mode	101.2	2.79	63.0	78	2	0.758	77.8	2.24	96.9	2.78
Test 2 - ICE mode	37.6	7.51	169.8	69	1	1.170	76.5	2.34	87.6	2.68
Test 3 - Charging mode	41.0	6.89	158.7	103	5	0.978	39.2	1.25	57.4	1.83
Test 4 - Dynamic/altitude	57.3	4.93	113.3	165	2	1.026	92.9	2.22	128.5	3.07
Test 5 - Reverse phase order	38.9	7.26	167.5	50	3	0.992	59.6	1.54	74.1	1.92
Test 6 - Max payload	64.7	4.36	100.0	152	4	1.668	76.2	2.31	95.0	2.88

Route summary – Motorway

	RDE Compliant	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
BMW X5 x45e M						
Test 1 - EV mode	Yes	15.4	27.1	106.1	119.4	29.6%
Test 2 - ICE mode	Yes	15.7	27.9	106.8	116.3	30.4%
Test 3 - Charging mode	Yes	15.8	27.8	105.9	117.6	30.4%
Test 4 - Dynamic/altitude	No	17.4	30.7	105.8	122.3	30.4%
Test 5 - Reverse phase order	No	38.8	70.3	108.7	120.0	58.5%
Test 6 - Max payload	Yes	15.3	27.4	107.3	114.2	29.9%
Volvo XC60 T8						
Test 1 - EV mode	Yes	15.7	27.3	104.7	116.5	29.8%
Test 2 - ICE mode	Yes	14.9	25.0	100.4	119.4	26.3%
Test 3 - Charging mode	Yes	16.6	29.0	104.9	114.4	31.7%
Test 4 - Dynamic/altitude	No	17.0	29.9	105.7	118.9	30.2%
Test 5 - Reverse phase order	No	23.5	41.0	104.6	115.0	47.0%
Test 6 - Max payload	Yes	14.7	26.0	106.6	115.7	28.5%
Mitsubishi Outlander 5H						
Test 1 - EV mode	Yes	15.0	25.5	102.1	114.4	28.2%
Test 2 - ICE mode	Yes	14.7	25.9	105.7	114.2	28.3%
Test 3 - Charging mode	Yes	14.6	24.9	102.1	113.6	27.2%
Test 4 - Dynamic/altitude	No	17.5	30.0	102.5	123.7	30.5%
Test 5 - Reverse phase order	No	22.9	40.6	106.5	121.3	44.5%
Test 6 - Max payload	Yes	15.2	26.2	103.2	120.8	27.4%

Emissions summary – Motorway – Raw

	FE	FC	CO_2	CO	NO_x	PN	Electricity Consumption	Total Electricity Consumed	Battery Usage	Total Battery Usage
	MPG	L/100km	g/km	mg/km	mg/km	#x10^{11}/km	Wh/km	kWh	Wh/km	kWh
BMW X5 x45e M										
Test 1 - EV mode	45.2	6.25	141.1	406	10	0.148	109.1	2.96	138.0	3.74
Test 2 - ICE mode	27.1	10.41	236.2	110	2	0.006	-7.8	-0.22	12.2	0.34
Test 3 - Charging mode	18.9	14.94	335.2	277	7	0.014	-89.2	-2.48	1.1	0.03
Test 4 - Dynamic/altitude	30.1	9.38	210.8	344	9	0.018	44.6	1.37	78.2	2.40
Test 5 - Reverse phase order	210.3	1.34	30.1	20	1	0.003	205.2	14.43	220.1	15.47
Test 6 - Max payload	31.3	9.04	202.6	237	4	0.019	88.1	2.41	108.8	2.98
Volvo XC60 T8										
Test 1 - EV mode	28.4	9.96	223.0	208	4	0.139	3.7	0.10	17.6	0.48
Test 2 - ICE mode	26.8	10.53	241.3	444	3	0.184	1.7	0.04	20.0	0.50
Test 3 - Charging mode	28.4	9.95	223.5	228	3	0.294	7.0	0.20	15.9	0.46
Test 4 - Dynamic/altitude	31.5	8.96	201.5	264	2	0.076	22.5	0.67	28.4	0.85
Test 5 - Reverse phase order	121.4	2.33	52.5	50	4	0.161	131.7	5.40	139.0	5.70
Test 6 - Max payload	26.9	10.49	236.0	282	3	0.152	-1.2	-0.03	15.4	0.40
Mitsubishi Outlander 5H										
Test 1 - EV mode	30.3	9.32	210.4	166	2	2.134	34.5	0.88	51.4	1.31
Test 2 - ICE mode	28.6	9.88	223.0	162	2	2.498	50.0	1.29	55.2	1.43
Test 3 - Charging mode	33.1	8.55	196.6	209	8	2.360	22.8	0.57	30.5	0.76
Test 4 - Dynamic/altitude	30.9	9.16	210.9	264	3	2.670	43.1	1.29	56.3	1.69
Test 5 - Reverse phase order	153.4	1.84	42.3	128	4	3.687	103.9	4.22	108.6	4.41
Test 6 - Max payload	26.4	10.71	246.2	166	11	2.494	33.7	0.88	48.9	1.28

Individual test results

Vehicle 1 – BMW X5 x45e M – Test 1 – EV mode

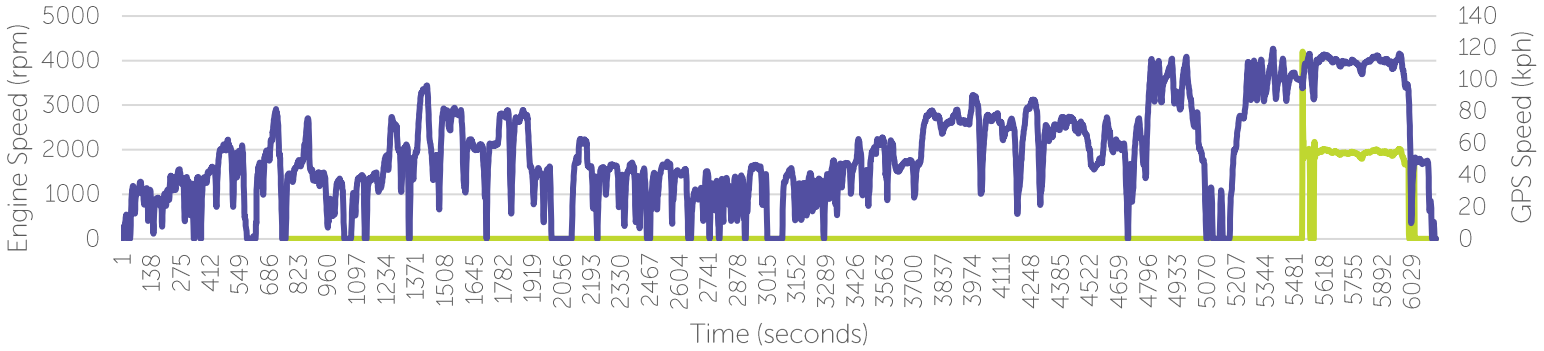
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	102.2	91.6	53.8	119.4	100.0%
Cold Start	5.0	2.1	25.4	43.8	1.6%
Urban	63.7	36.0	33.9	59.9	40.0%
Rural	23.2	28.5	73.7	89.8	31.8%
Motorway	15.4	27.1	106.1	119.4	28.2%

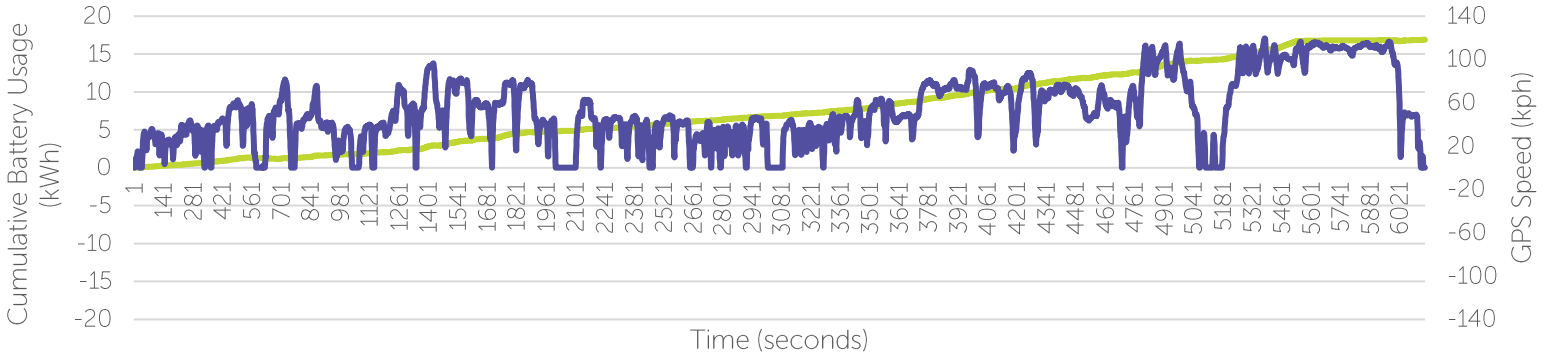
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	149.2	1.89	42.3	121	3	0.047	184.3	16.88	222.4	20.37
Cold Start	5324.1	0.05	0.1	1	0	0.003	278.7	0.59	309.5	0.65
Urban	5484.6	0.05	0.4	1	0	0.005	233.3	8.39	287.8	10.36
Rural	4433.6	0.06	1.1	0	0	0.003	194.3	5.53	220.0	6.27
Motorway	45.2	6.25	141.1	406	10	0.148	109.1	2.96	138.0	3.74

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 1 – BMW X5 x45e M – Test 2 – ICE mode

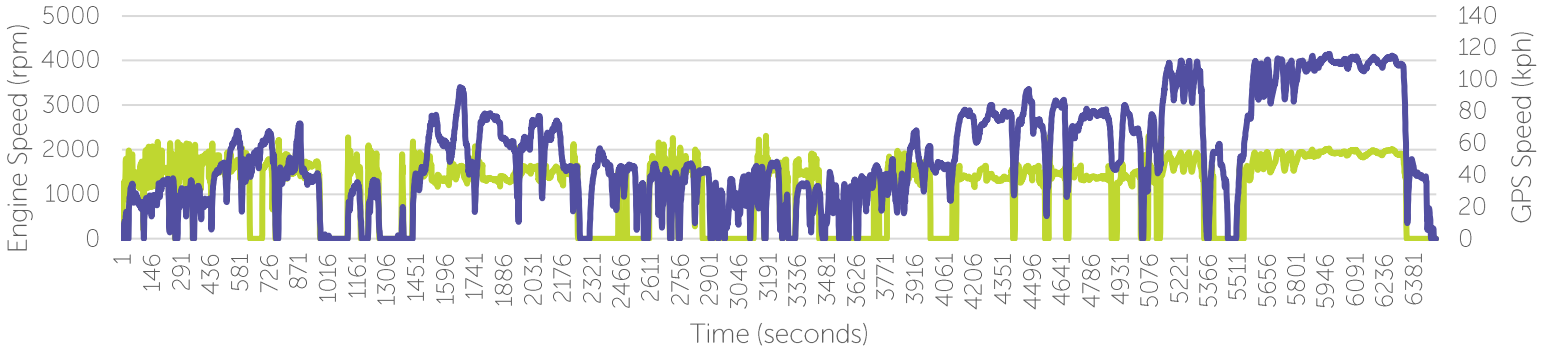
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	108.0	91.8	51.0	116.3	100.0%
Cold Start	3.0	1.0	21.0	34.8	1.1%
Urban	68.4	34.7	30.5	59.9	37.8%
Rural	23.9	29.2	73.4	89.9	31.8%
Motorway	15.7	27.9	106.8	116.3	30.4%

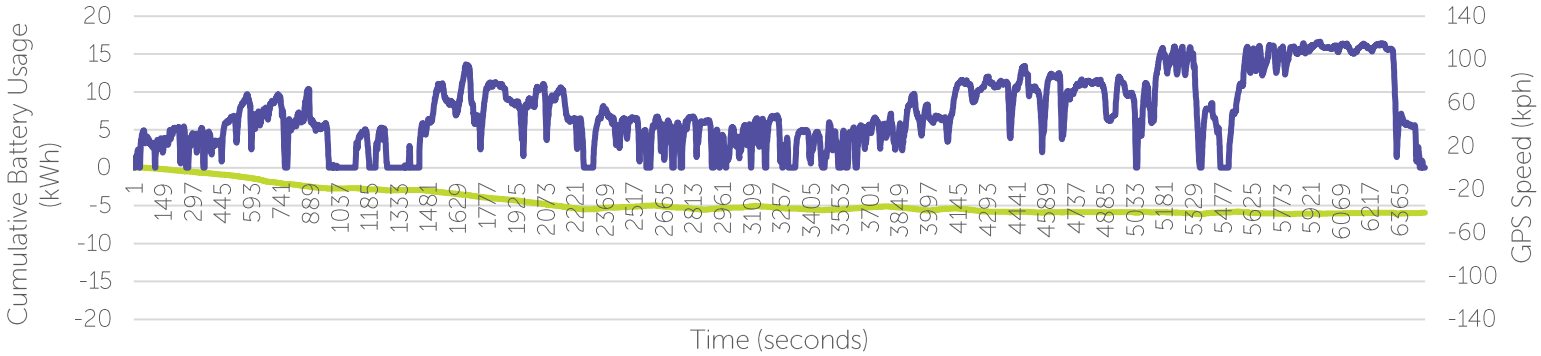
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	25.2	11.20	254.0	109	6	0.012	-64.7	-5.94	45.9	4.36
Cold Start	9.4	30.14	681.7	1136	178	0.093	-248.5	-0.26	50.0	0.05
Urban	23.0	12.28	278.4	111	10	0.019	-94.9	-3.29	109.5	3.80
Rural	26.5	10.67	241.9	105	3	0.008	-83.2	-2.43	7.2	0.21
Motorway	27.1	10.41	236.2	110	2	0.006	-7.8	-0.22	12.2	0.34

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 1 – BMW X5 x45e M – Test 3 – Charging mode

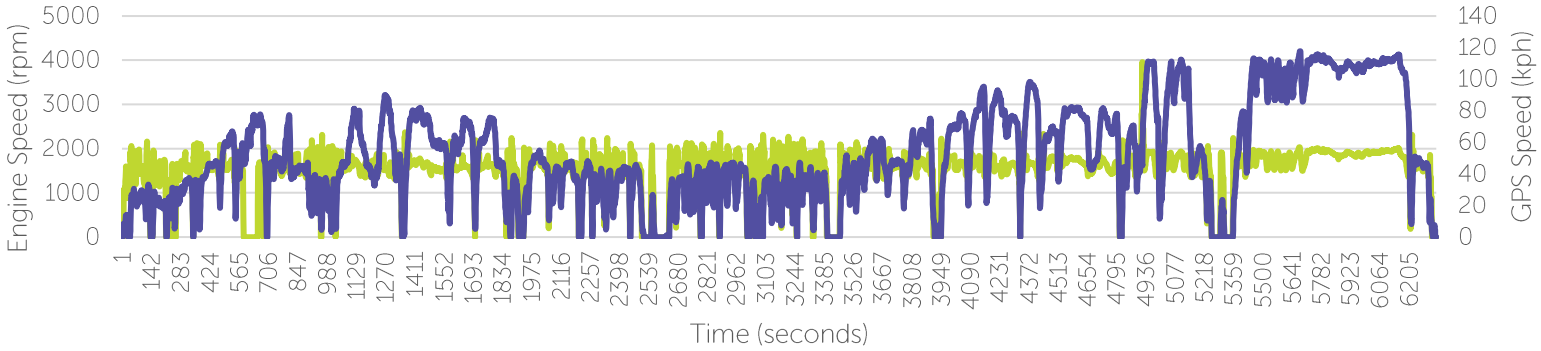
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	107.9	91.6	50.9	117.6	100.0%
Cold Start	3.5	1.1	18.8	33.3	1.2%
Urban	69.5	36.3	31.3	59.9	39.6%
Rural	22.7	27.5	72.9	89.9	30.1%
Motorway	15.8	27.8	105.9	117.6	30.4%

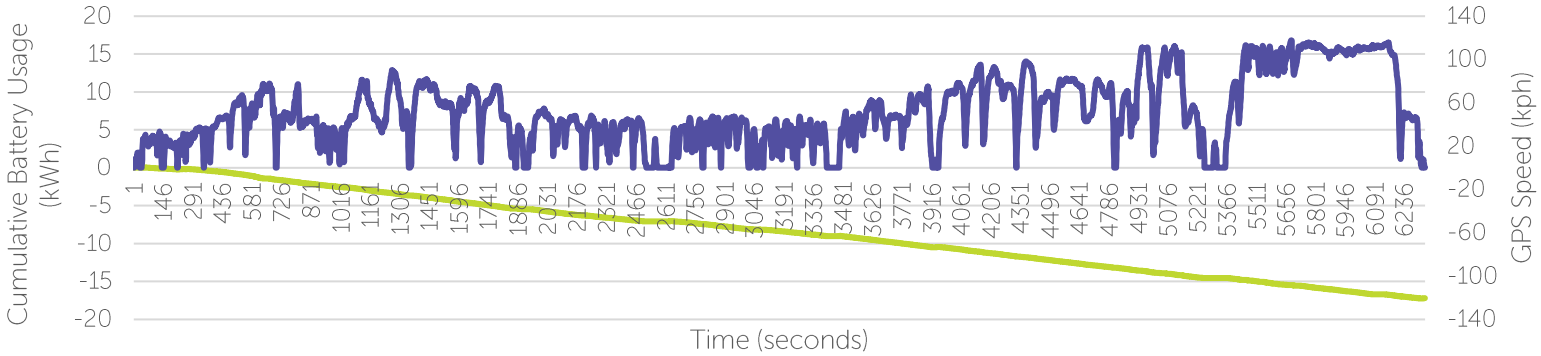
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	16.5	17.14	384.6	239	7	0.024	-188.0	-17.22	9.3	0.85
Cold Start	9.3	30.46	682.4	1136	141	0.114	-203.1	-0.22	63.6	0.07
Urban	13.5	20.94	470.0	254	9	0.040	-280.2	-10.16	22.3	0.81
Rural	19.7	14.35	321.9	180	5	0.013	-166.5	-4.58	0.4	0.01
Motorway	18.9	14.94	335.2	277	7	0.014	-89.2	-2.48	1.1	0.03

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 1 – BMW X5 x45e M – Test 4 – Dynamic/altitude

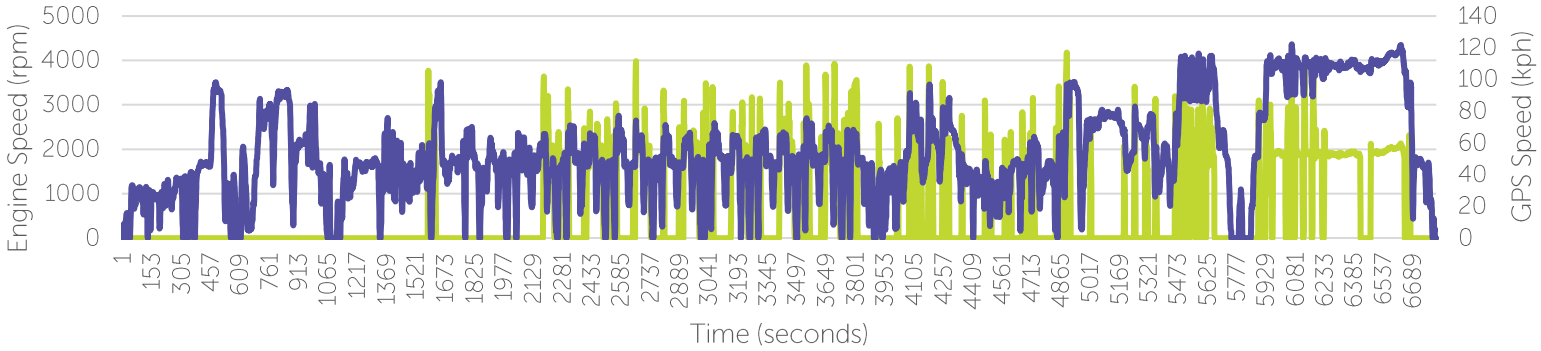
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	113.4	101.2	53.6	122.3	100.0%
Cold Start	5.0	2.0	23.5	38.1	1.9%
Urban	74.4	45.1	36.4	59.9	44.5%
Rural	21.6	25.5	70.8	89.9	25.2%
Motorway	17.4	30.7	105.8	122.3	30.4%

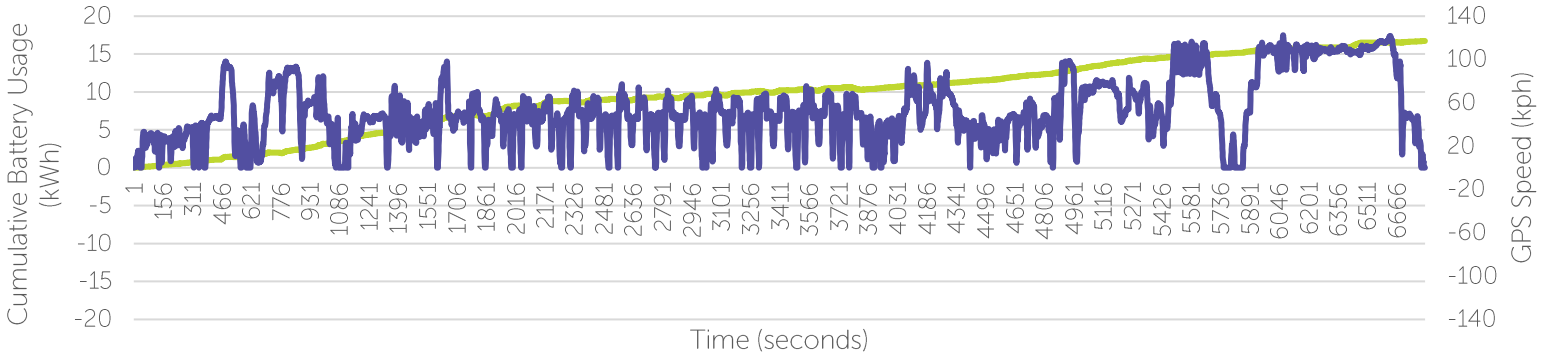
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	44.9	6.30	141.2	270	10	0.077	165.2	16.72	248.3	24.61
Cold Start	5004.7	0.06	0.1	0	0	0.004	354.3	0.69	365.0	0.73
Urban	72.0	3.93	87.5	265	11	0.086	310.0	13.97	398.2	17.96
Rural	41.7	6.78	152.1	190	9	0.134	54.2	1.38	166.7	4.25
Motorway	30.1	9.38	210.8	344	9	0.018	44.6	1.37	78.2	2.40

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 1 – BMW X5 x45e M – Test 5 – Reverse phase order

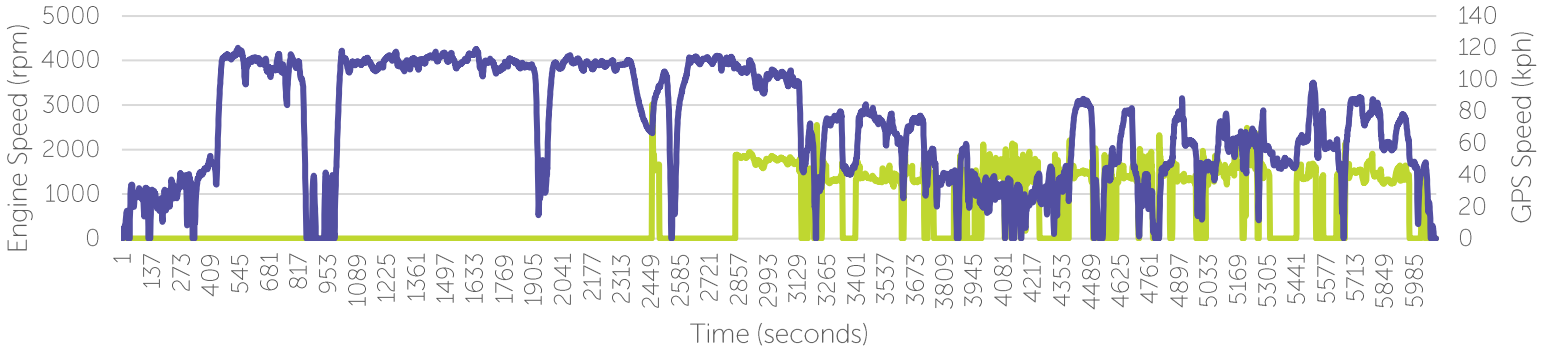
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	101.2	120.2	71.2	120.0	100.0%
Cold Start	5.0	2.1	24.6	41.0	1.7%
Urban	41.2	23.8	34.7	59.9	19.8%
Rural	21.3	26.1	73.7	89.9	21.7%
Motorway	38.8	70.3	108.7	120.0	58.5%

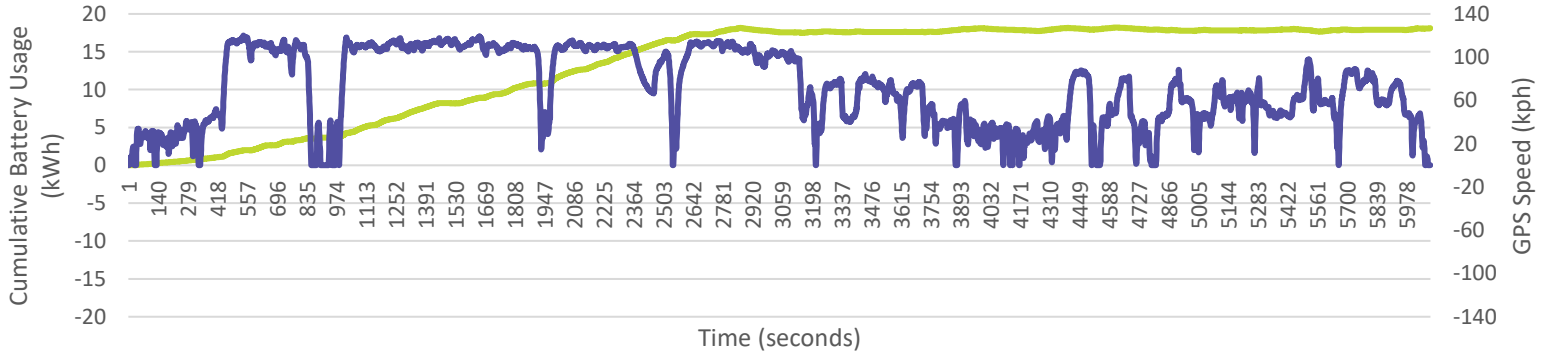
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	60.9	4.64	103.9	129	4	0.015	150.5	18.10	264.3	23.07
Cold Start	n/a	0.00	0.0	0	0	0.001	342.0	0.70	347.6	0.73
Urban	37.1	7.61	170.5	175	1	0.021	124.8	2.97	229.8	5.47
Rural	26.1	10.81	241.9	380	14	0.042	26.9	0.70	81.6	2.13
Motorway	210.3	1.34	30.1	20	1	0.003	205.2	14.43	220.1	15.47

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 1 – BMW X5 x45e M – Test 6 – Max payload

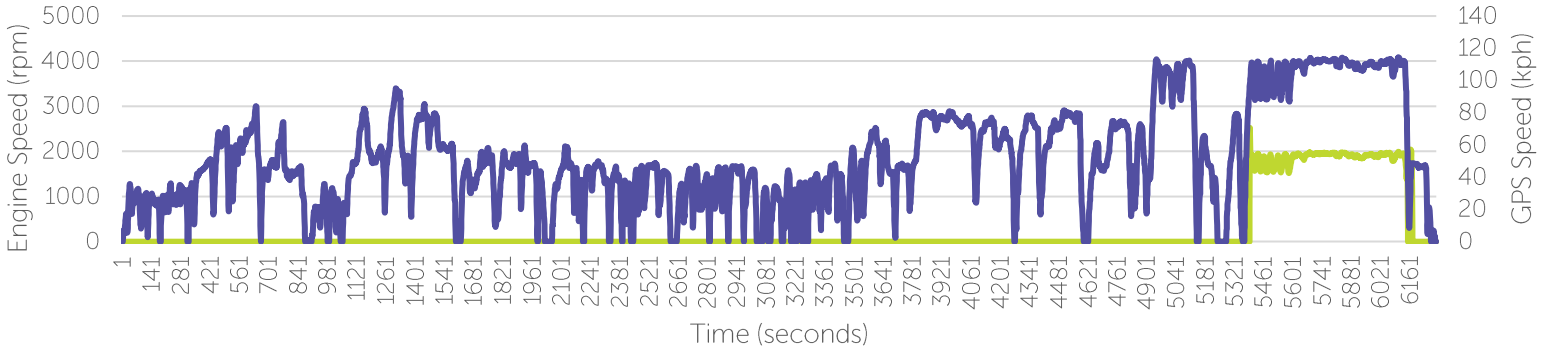
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	104.7	91.5	52.5	114.2	100.0%
Cold Start	5.0	2.0	23.6	36.0	2.2%
Urban	67.9	38.0	33.6	59.9	41.5%
Rural	21.5	26.1	72.9	89.9	28.5%
Motorway	15.3	27.4	107.3	114.2	29.9%

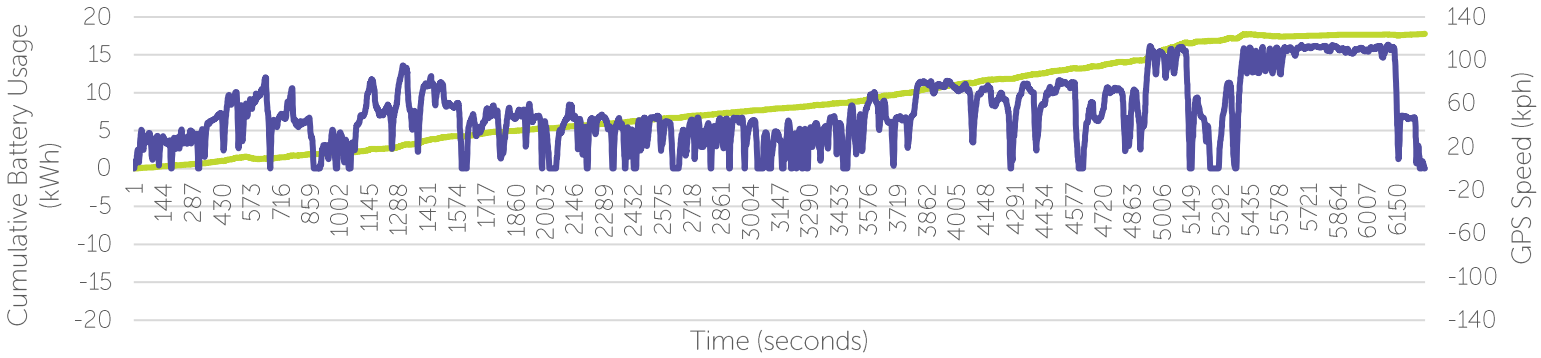
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	100.9	2.80	62.7	72	1	0.006	194.1	17.76	234.0	21.41
Cold Start	n/a	0.00	0.0	0	0	0.000	303.5	0.60	325.0	0.65
Urban	7382.6	0.04	0.9	0	0	0.000	254.2	9.66	316.6	12.03
Rural	1026.1	0.28	6.2	4	0	0.000	217.7	5.68	245.6	6.41
Motorway	31.3	9.04	202.6	237	4	0.019	88.1	2.41	108.8	2.98

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 2 – Volvo XC60 T8 – Test 1 – EV mode

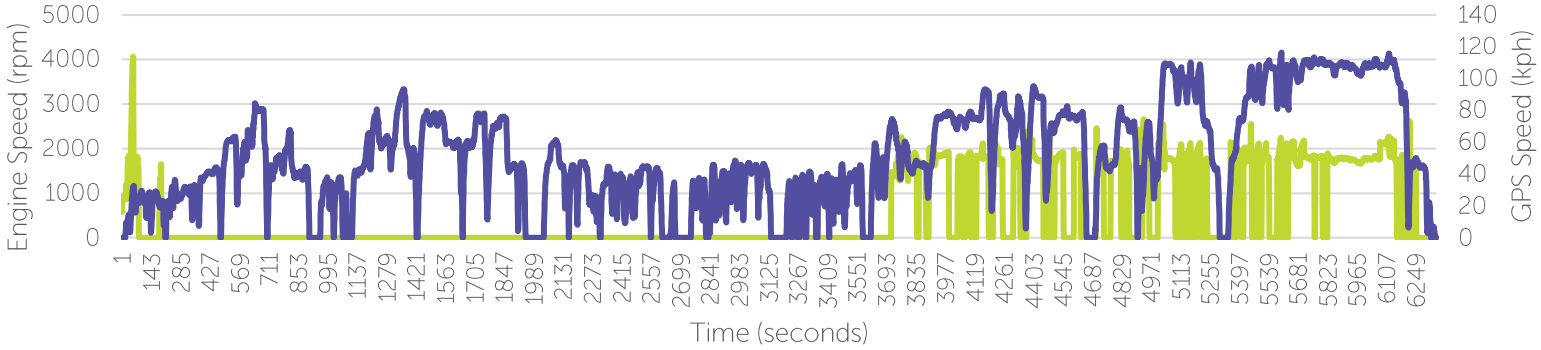
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	105.7	91.6	52.0	116.5	100.0%
Cold Start	5.0	1.7	20.6	36.5	1.9%
Urban	65.1	33.4	30.8	59.9	36.5%
Rural	25.0	30.9	74.2	89.9	33.7%
Motorway	15.7	27.3	104.7	116.5	29.8%

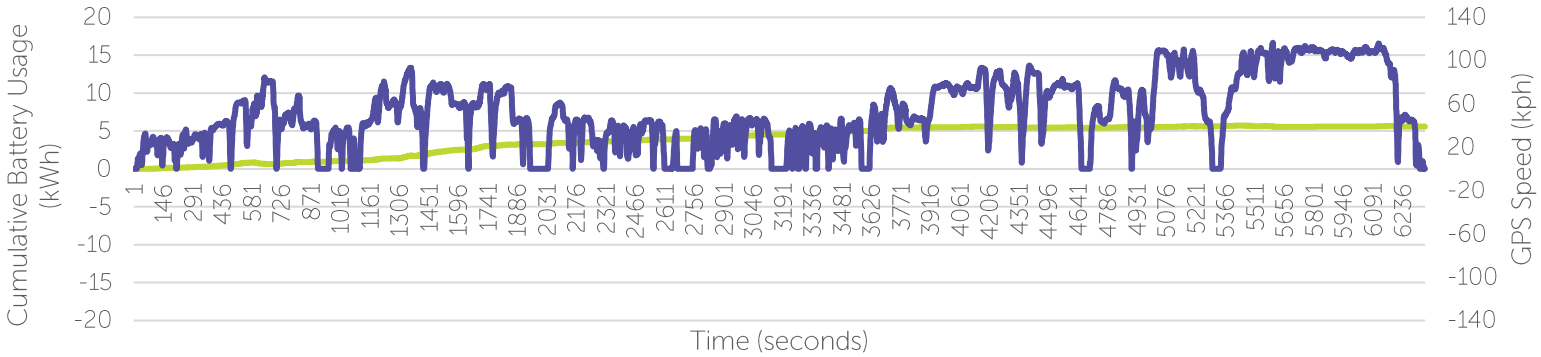
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	55.3	5.11	115.3	177	3	0.269	61.1	5.59	97.1	8.89
Cold Start	38.8	7.29	161.7	1047	57	9.924	132.6	0.23	152.9	0.26
Urban	126.2	2.24	52.6	150	2	0.515	119.4	3.99	182.6	6.10
Rural	72.1	3.92	87.7	180	2	0.117	48.8	1.51	74.8	2.31
Motorway	28.4	9.96	223.0	208	4	0.139	3.7	0.10	17.6	0.48

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 2 – Volvo XC60 T8 – Test 2 – ICE mode

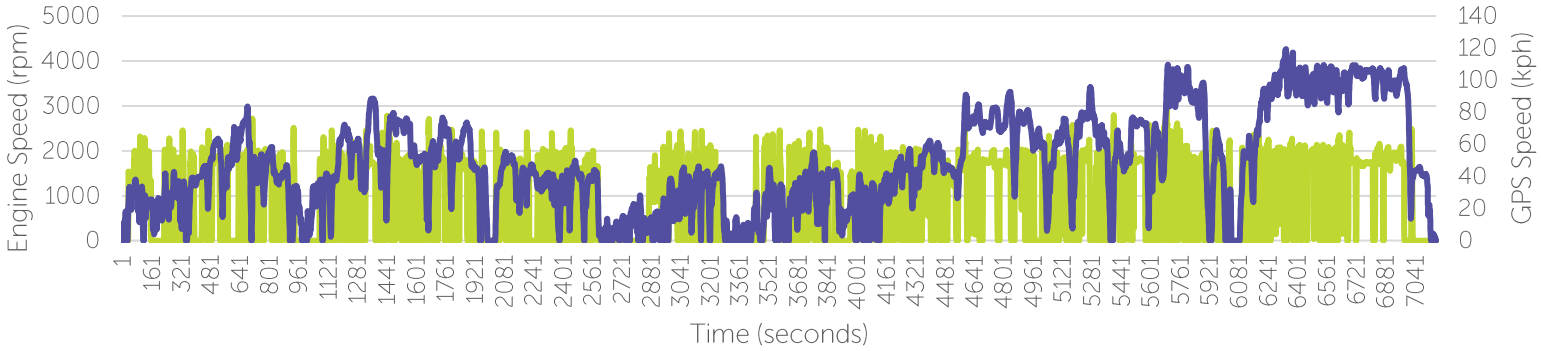
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	119.2	94.9	47.8	119.4	100.0%
Cold Start	2.5	0.9	22.1	38.1	1.0%
Urban	80.0	40.6	30.4	59.9	42.8%
Rural	24.2	29.4	72.7	89.9	30.9%
Motorway	14.9	25.0	100.4	119.4	26.3%

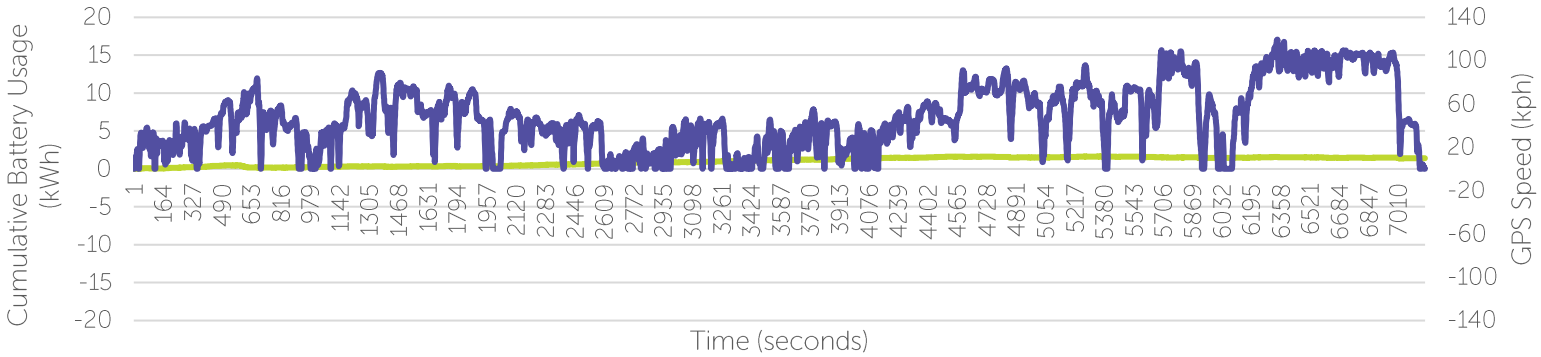
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	35.2	8.03	183.5	624	2	0.145	14.8	1.40	58.5	5.55
Cold Start	12.1	23.40	536.1	1113	87	6.987	61.4	0.06	122.2	0.11
Urban	38.3	7.37	168.3	898	2	0.206	34.1	1.38	103.0	4.18
Rural	41.6	6.79	155.4	399	1	0.026	-0.8	-0.02	29.6	0.87
Motorway	26.8	10.53	241.3	444	3	0.184	1.7	0.04	20.0	0.50

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 2 – Volvo XC60 T8 – Test 3 – Charging mode

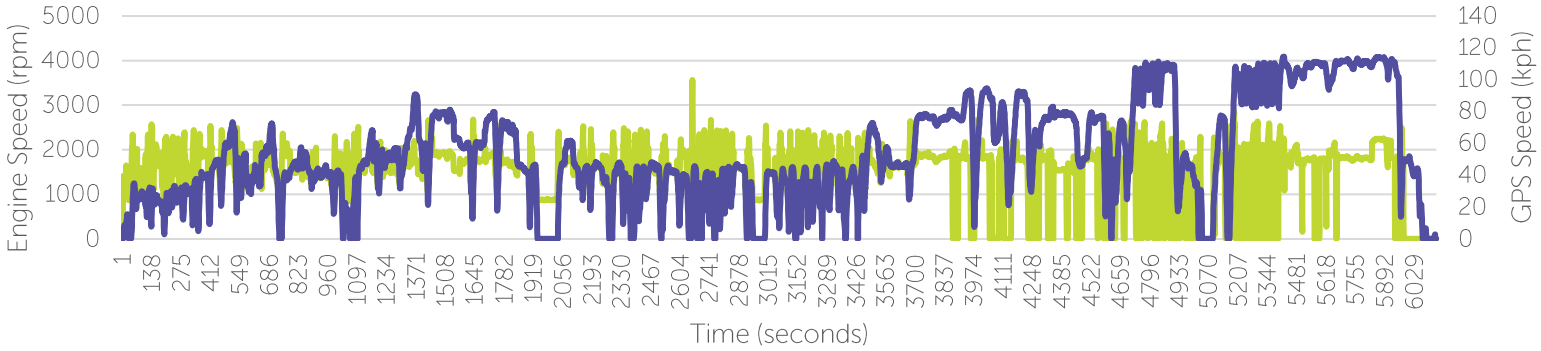
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	102.1	91.5	53.8	114.4	100.0%
Cold Start	2.5	0.8	19.6	34.8	0.9%
Urban	63.9	35.8	33.6	59.9	39.1%
Rural	21.6	26.8	74.3	89.9	29.3%
Motorway	16.6	29.0	104.9	114.4	31.7%

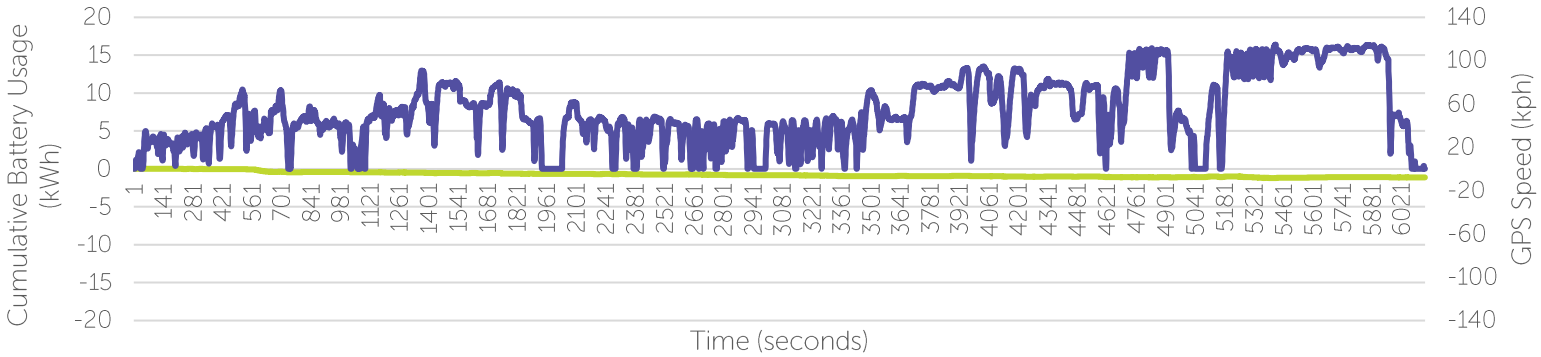
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	26.3	10.76	241.8	283	2	0.226	-12.2	-1.12	24.7	2.26
Cold Start	8.5	33.27	749.7	570	31	2.692	-0.3	0.00	25.0	0.02
Urban	21.5	13.12	295.2	343	2	0.246	-30.1	-1.08	39.4	1.41
Rural	33.4	8.46	190.1	260	1	0.127	-9.2	-0.25	14.9	0.40
Motorway	28.4	9.95	223.5	228	3	0.294	7.0	0.20	15.9	0.46

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 2 – Volvo XC60 T8 – Test 4 – Dynamic/altitude

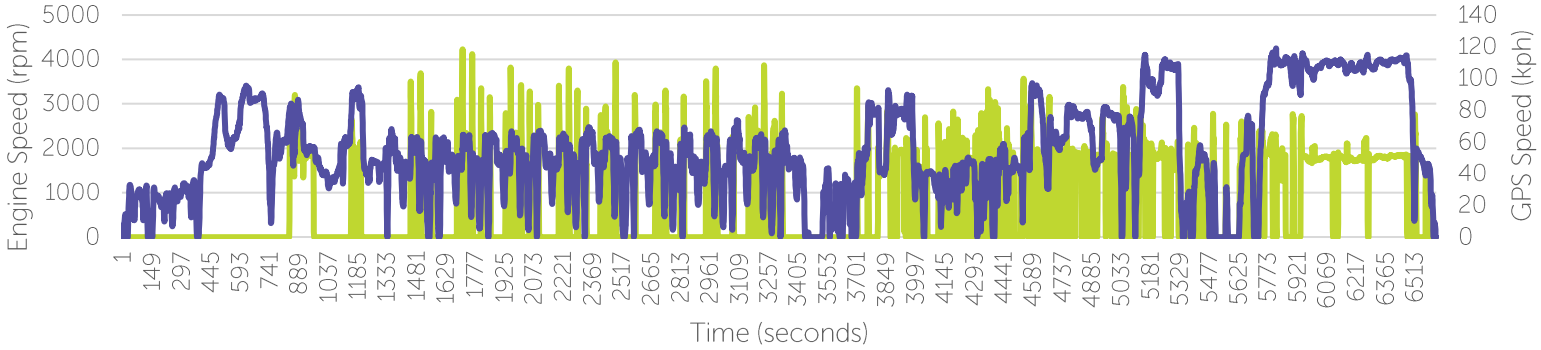
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	110.3	99.1	53.9	118.9	100.0%
Cold Start	5.0	1.7	19.8	32.8	1.7%
Urban	69.7	40.9	35.2	59.9	41.3%
Rural	23.6	28.3	71.9	89.9	28.6%
Motorway	17.0	29.9	105.7	118.9	30.2%

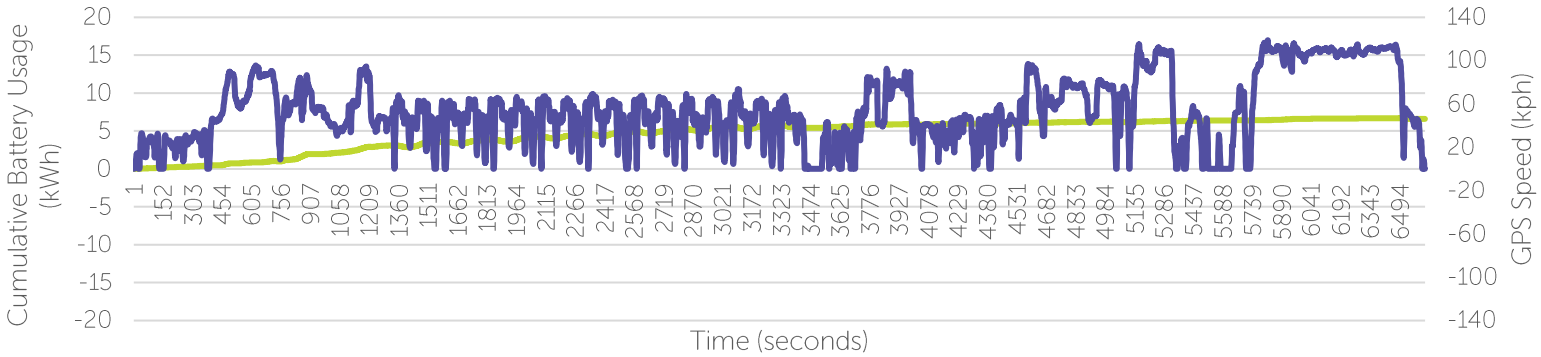
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	41.2	6.86	154.5	505	4	0.148	66.5	6.58	130.4	12.92
Cold Start	n/a	0.00	0.0	0	0	0.000	191.0	0.32	211.8	0.36
Urban	49.1	5.76	129.7	754	3	0.107	104.9	4.29	219.1	8.96
Rural	45.2	6.25	140.7	402	7	0.283	57.2	1.62	109.9	3.11
Motorway	31.5	8.96	201.5	264	2	0.076	22.5	0.67	28.4	0.85

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 2 – Volvo XC60 T8 – Test 5 – Reverse phase order

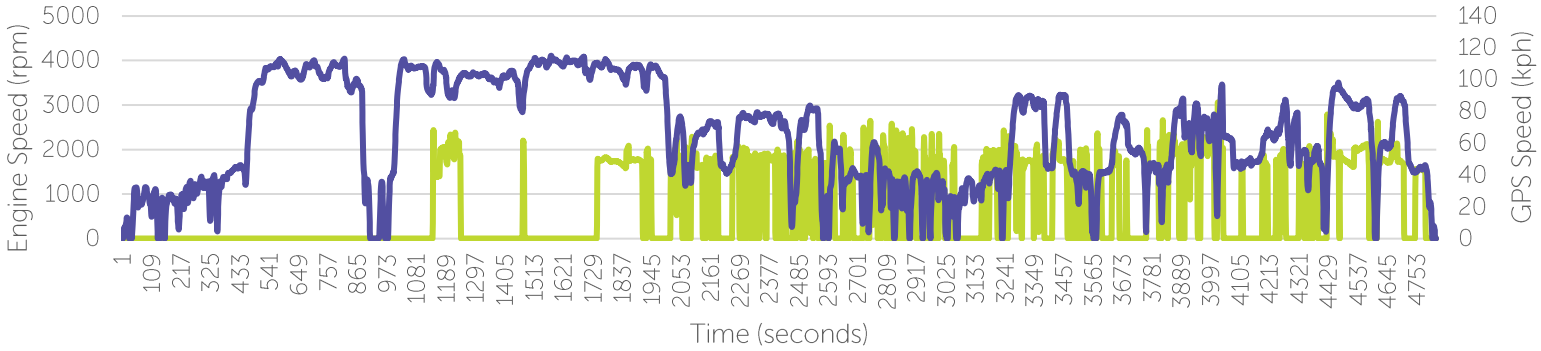
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	80.3	87.3	65.3	115.0	100.0%
Cold Start	5.0	1.9	22.3	38.8	2.1%
Urban	37.0	21.5	34.7	59.9	24.6%
Rural	19.7	24.9	75.8	89.9	28.5%
Motorway	23.5	41.0	104.6	115.0	47.0%

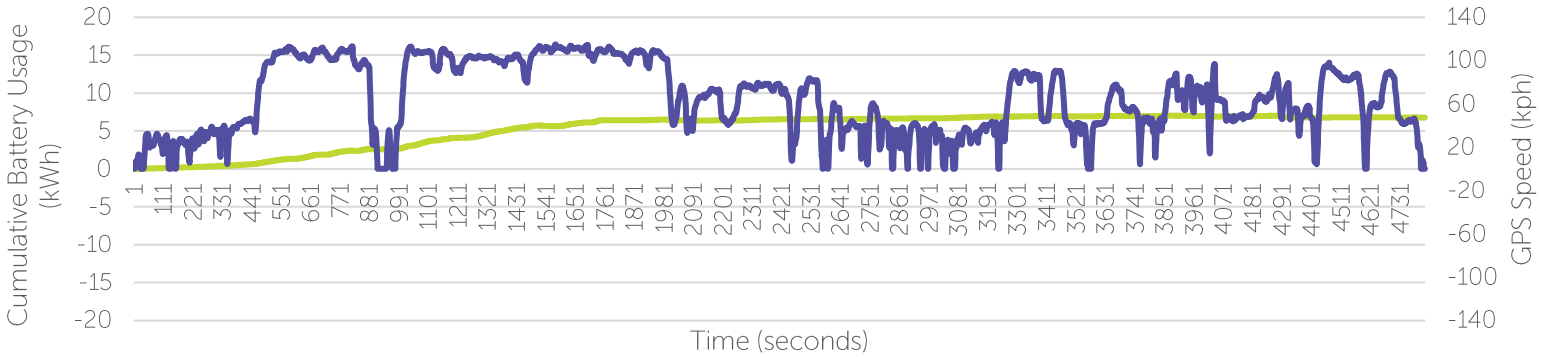
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	57.0	4.96	111.5	303	3	0.121	77.5	6.77	106.0	9.25
Cold Start	1707.8	0.17	1.3	10	1	0.006	181.7	0.34	205.3	0.39
Urban	48.4	5.83	130.3	688	1	0.083	49.6	1.06	118.1	2.54
Rural	33.0	8.55	192.4	387	4	0.087	12.0	0.30	40.6	1.01
Motorway	121.4	2.33	52.5	50	4	0.161	131.7	5.40	139.0	5.70

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 2 – Volvo XC60 T8 – Test 6 – Max payload

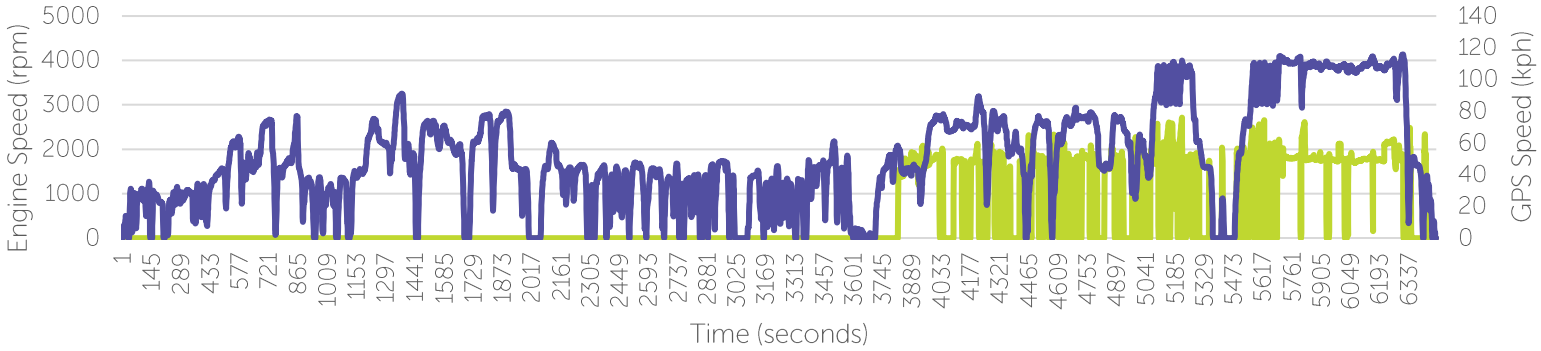
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	107.8	91.5	50.9	115.7	100.0%
Cold Start	5.0	1.6	19.2	35.6	1.8%
Urban	68.9	36.3	31.6	59.9	39.7%
Rural	24.2	29.2	72.3	89.9	31.9%
Motorway	14.7	26.0	106.6	115.7	28.5%

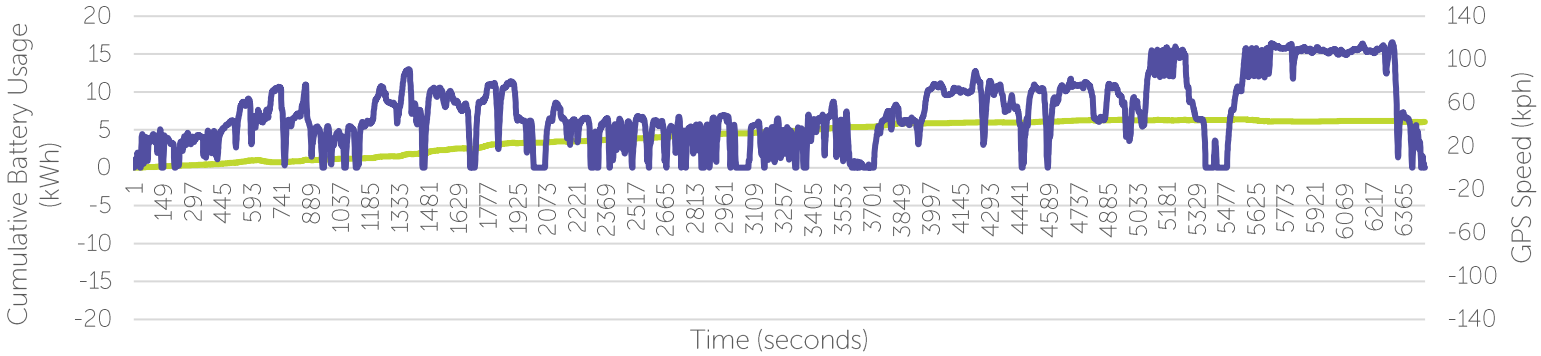
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	55.7	5.08	114.0	228	2	0.468	65.9	6.02	107.5	9.84
Cold Start	1642.3	0.17	0.6	0	1	0.007	215.0	0.34	243.8	0.39
Urban	155.8	1.81	40.5	169	2	0.984	111.4	4.04	186.5	6.77
Rural	65.7	4.30	96.5	252	0	0.106	69.0	2.01	91.4	2.67
Motorway	26.9	10.49	236.0	282	3	0.152	-1.2	-0.03	15.4	0.40

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 3 – Mitsubishi Outlander 5H – Test 1 – EV mode

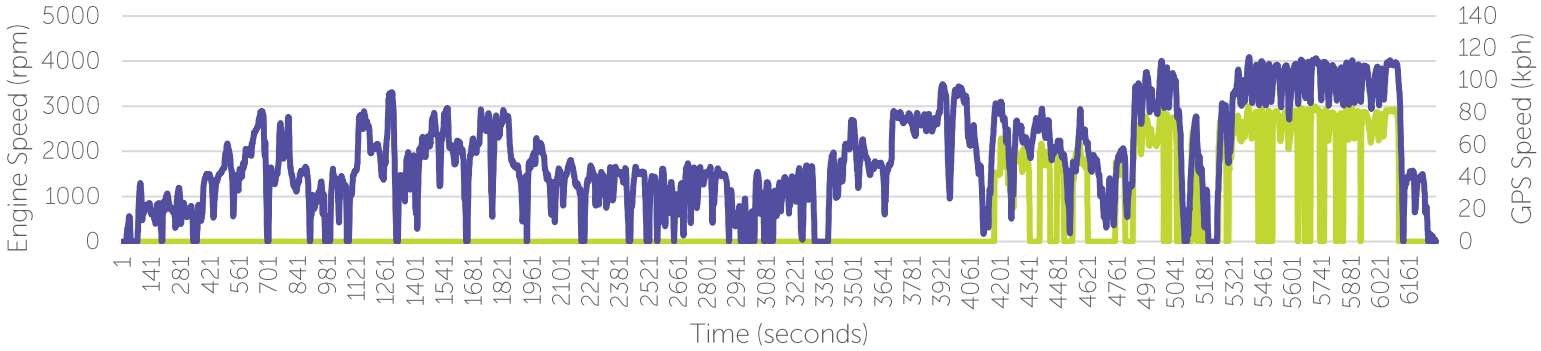
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	104.4	90.5	52.0	114.4	100.0%
Cold Start	5.0	1.5	17.6	36.4	1.6%
Urban	66.1	36.2	32.9	59.9	40.0%
Rural	23.4	28.7	73.8	89.9	31.8%
Motorway	15.0	25.5	102.1	114.4	28.2%

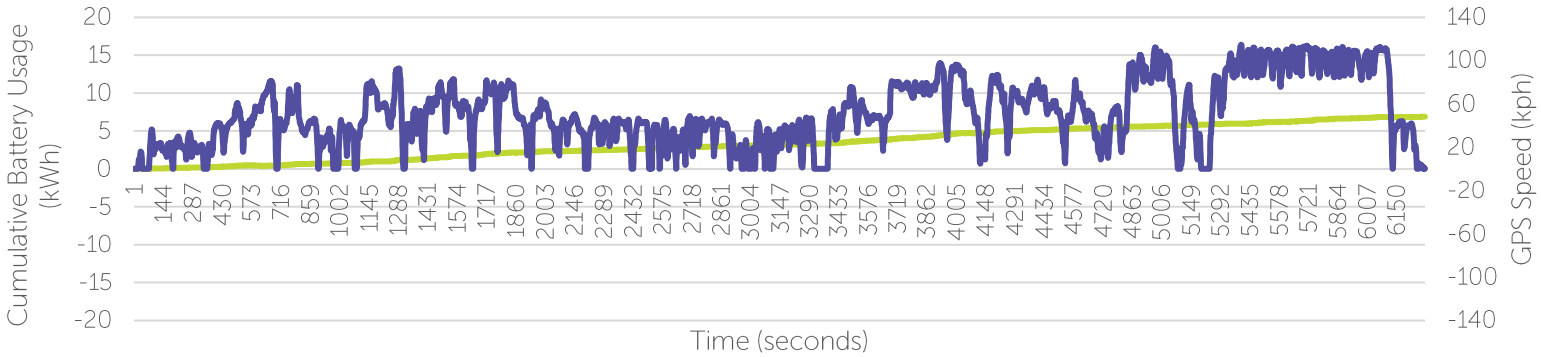
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	74.4	3.80	85.8	77	1	0.985	75.9	6.87	96.5	8.73
Cold Start	n/a	0.00	0.0	0	0	0.000	116.5	0.17	120.0	0.18
Urban	397.1	0.71	16.1	14	0	0.356	103.6	3.75	127.9	4.63
Rural	101.2	2.79	63.0	78	2	0.758	77.8	2.24	96.9	2.78
Motorway	30.3	9.32	210.4	166	2	2.134	34.5	0.88	51.4	1.31

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 3 – Mitsubishi Outlander 5H – Test 2 – ICE mode

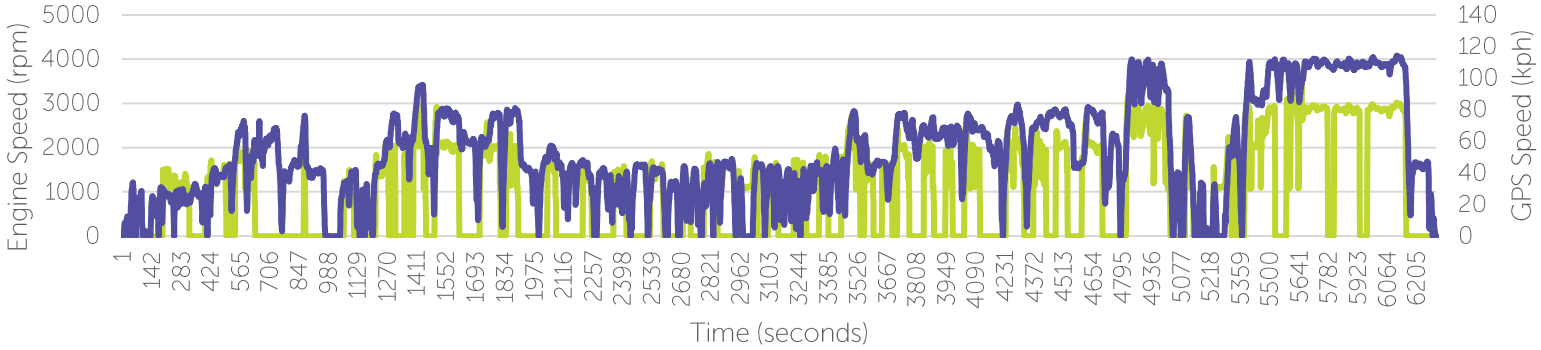
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	104.8	91.5	52.4	114.2	100.0%
Cold Start	5.0	1.5	17.7	34.1	1.6%
Urban	64.5	35.0	32.5	59.9	38.2%
Rural	25.6	30.6	71.8	89.9	33.5%
Motorway	14.7	25.9	105.7	114.2	28.3%

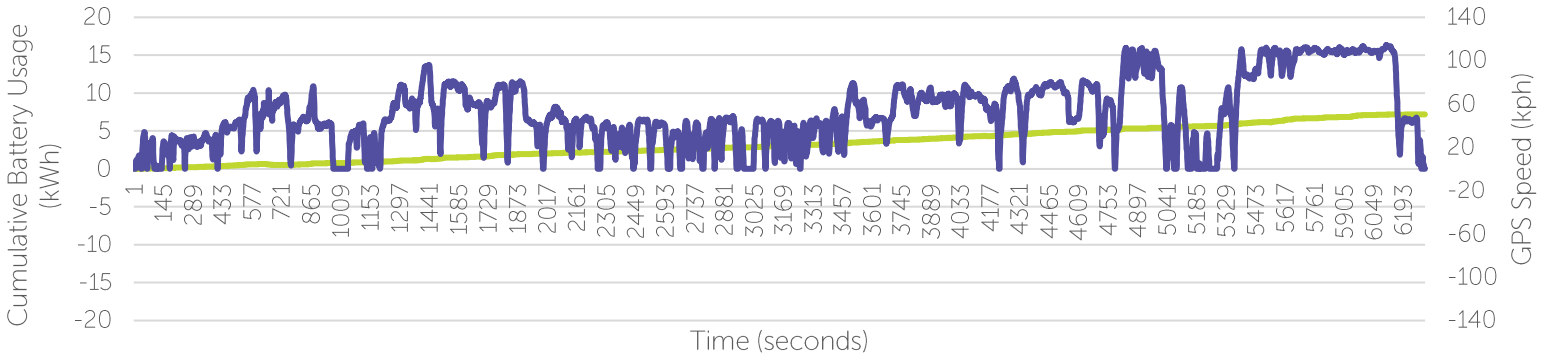
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	39.0	7.24	163.5	96	2	1.601	78.6	7.19	94.9	8.68
Cold Start	34.6	8.17	183.0	1106	38	4.063	146.9	0.22	160.0	0.24
Urban	56.1	5.04	113.8	70	3	1.316	101.6	3.55	130.6	4.57
Rural	37.6	7.51	169.8	69	1	1.170	76.5	2.34	87.6	2.68
Motorway	28.6	9.88	223.0	162	2	2.498	50.0	1.29	55.2	1.43

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 3 – Mitsubishi Outlander 5H – Test 3 – Charging mode

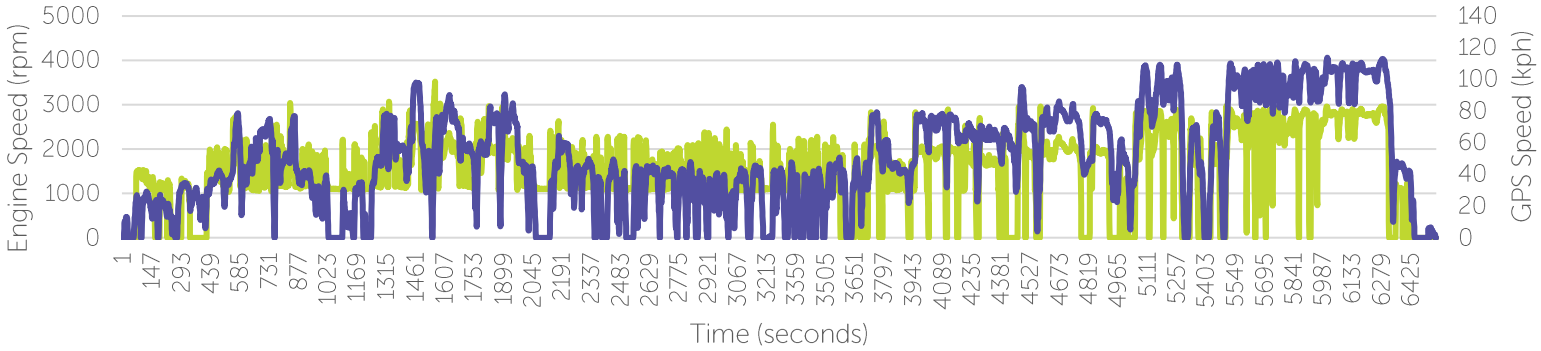
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	109.0	91.3	50.2	113.6	100.0%
Cold Start	5.0	1.3	16.0	34.1	1.5%
Urban	68.2	34.5	30.4	59.9	37.8%
Rural	26.2	31.9	73.1	89.9	35.0%
Motorway	14.6	24.9	102.1	113.6	27.2%

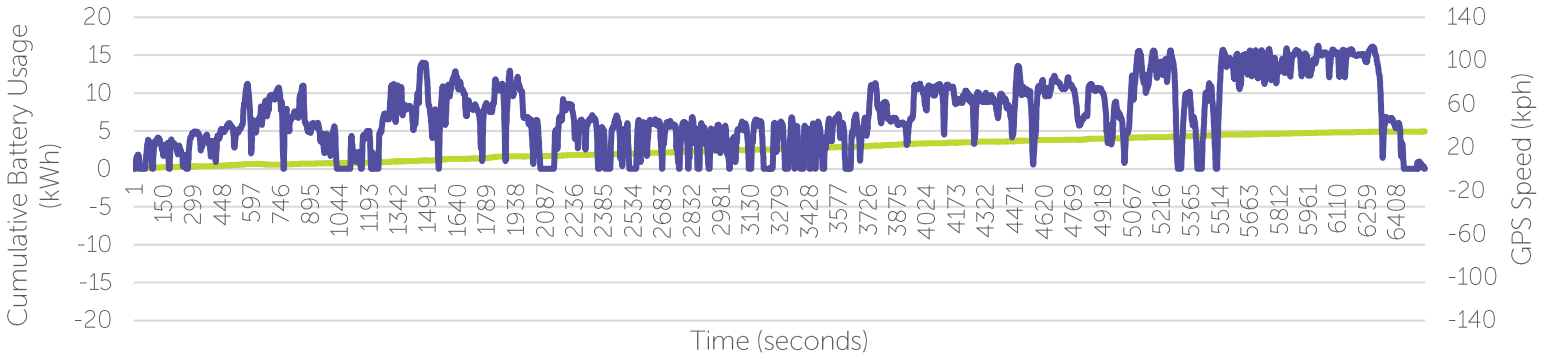
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	30.1	9.39	216.1	169	6	1.329	53.9	4.92	73.7	6.73
Cold Start	26.6	10.61	241.3	1444	43	12.392	240.9	0.32	246.2	0.32
Urban	22.9	12.31	283.2	202	4	0.911	90.0	3.11	119.7	4.13
Rural	41.0	6.89	158.7	103	5	0.978	39.2	1.25	57.4	1.83
Motorway	33.1	8.55	196.6	209	8	2.360	22.8	0.57	30.5	0.76

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 3 – Mitsubishi Outlander 5H – Test 4 – Dynamic/altitude

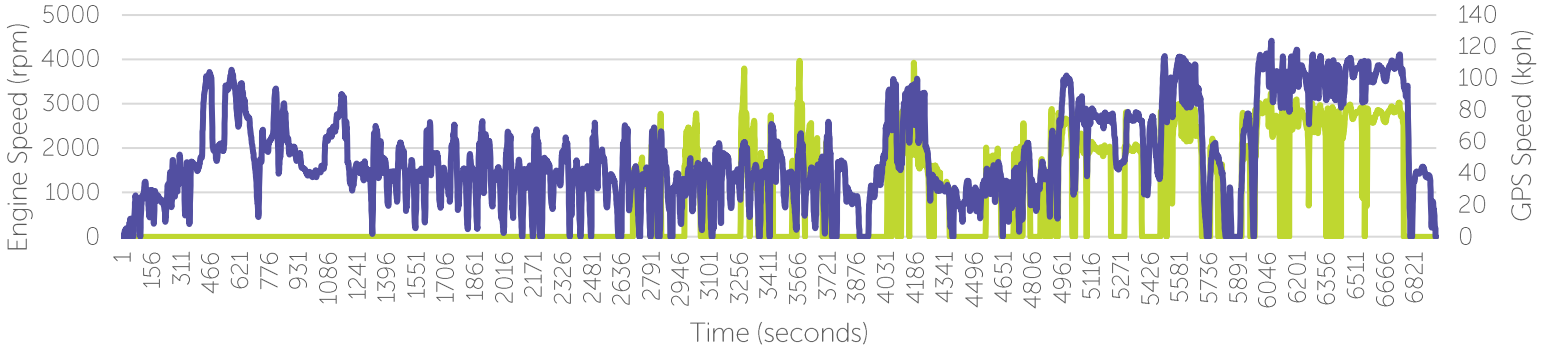
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	115.4	98.3	51.1	123.7	100.0%
Cold Start	5.0	1.8	21.5	51.8	1.8%
Urban	78.5	44.4	34.0	59.9	45.2%
Rural	19.4	23.9	73.9	89.9	24.3%
Motorway	17.5	30.0	102.5	123.7	30.5%

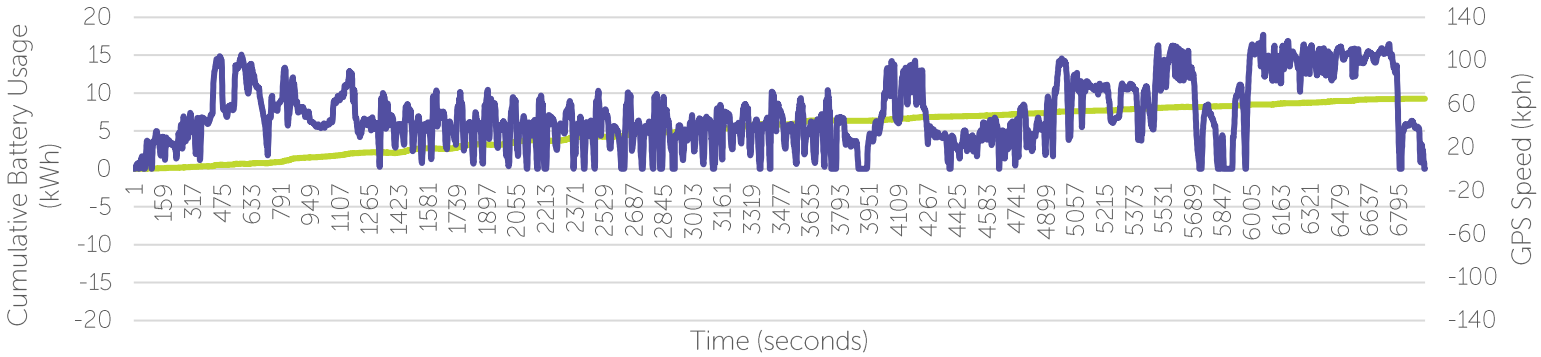
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	51.5	5.48	126.0	165	3	1.896	94.2	9.26	127.3	12.51
Cold Start	n/a	0.00	0.2	1	0	0.001	122.9	0.22	138.9	0.25
Urban	85.5	3.30	75.6	98	2	1.843	129.4	5.75	174.5	7.75
Rural	57.3	4.93	113.3	165	2	1.026	92.9	2.22	128.5	3.07
Motorway	30.9	9.16	210.9	264	3	2.670	43.1	1.29	56.3	1.69

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 3 – Mitsubishi Outlander 5H – Test 5 – Reverse phase order

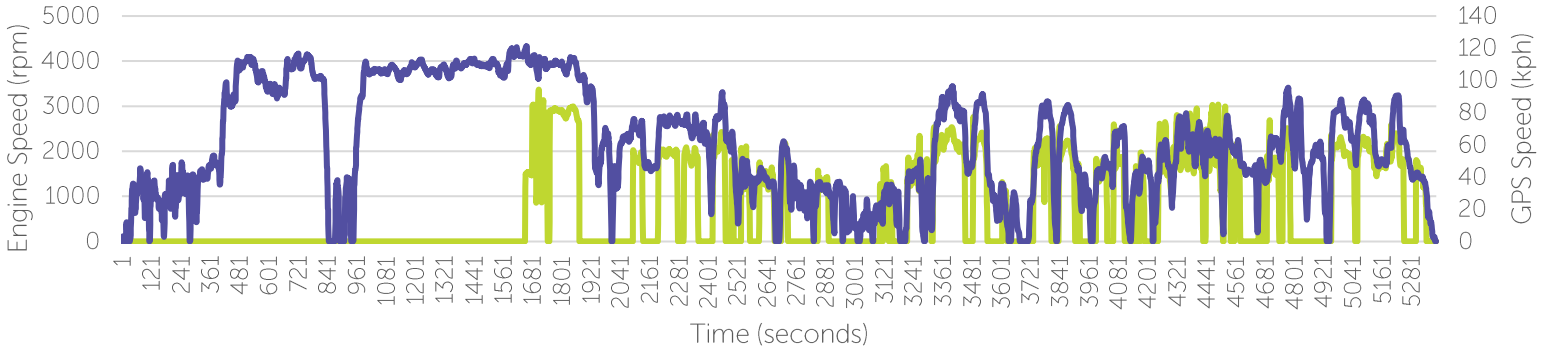
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	89.6	91.2	61.1	121.3	100.0%
Cold Start	5.0	2.2	26.2	49.1	2.4%
Urban	45.6	24.8	32.6	59.9	27.1%
Rural	21.1	25.9	73.6	89.9	28.4%
Motorway	22.9	40.6	106.5	121.3	44.5%

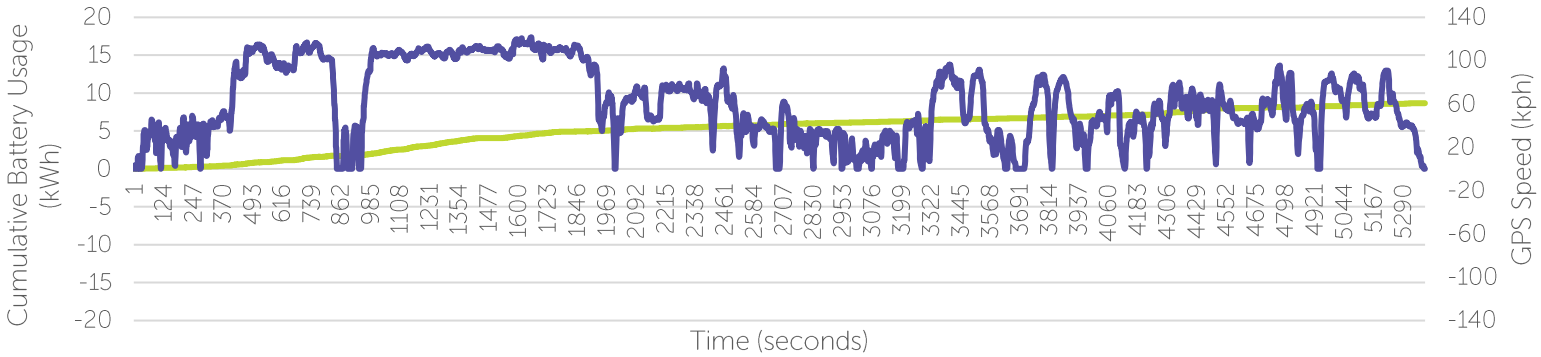
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	67.8	4.17	96.0	76	4	2.136	94.9	8.65	109.0	9.94
Cold Start	n/a	0.00	0.0	0	0	0.001	132.1	0.29	163.6	0.36
Urban	59.5	4.74	109.5	19	3	0.786	116.9	2.90	145.6	3.61
Rural	38.9	7.26	167.5	50	3	0.992	59.6	1.54	74.1	1.92
Motorway	153.4	1.84	42.3	128	4	3.687	103.9	4.22	108.6	4.41

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Vehicle 3 – Mitsubishi Outlander 5H – Test 6 – Max payload

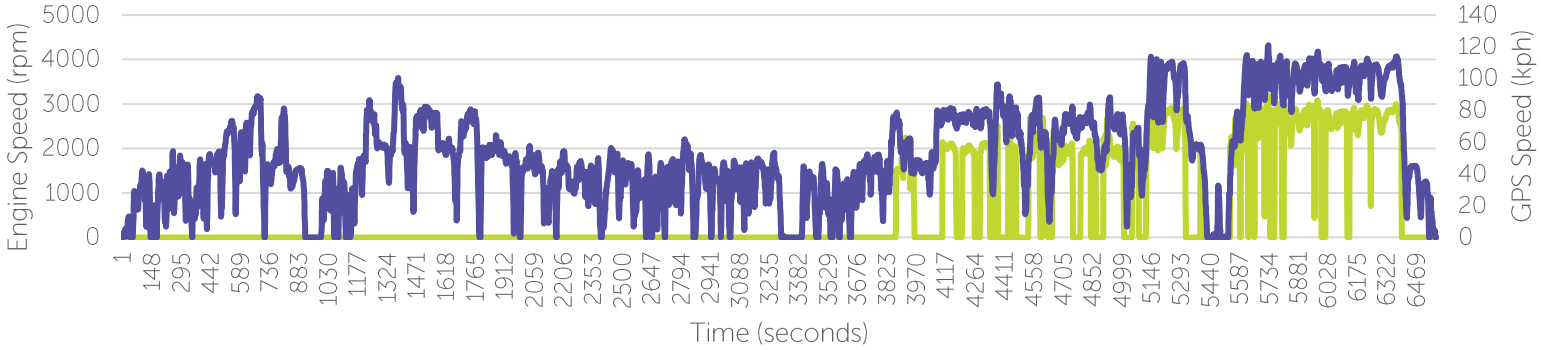
Route summary

	Duration minutes	Distance km	Speed km/h	Max Speed km/h	Distance Share %
Overall	109.7	95.5	52.2	120.8	100.0%
Cold Start	5.0	1.9	23.3	54.2	2.0%
Urban	69.9	39.0	33.5	59.9	40.8%
Rural	24.5	30.3	74.2	89.9	31.8%
Motorway	15.2	26.2	103.2	120.8	27.4%

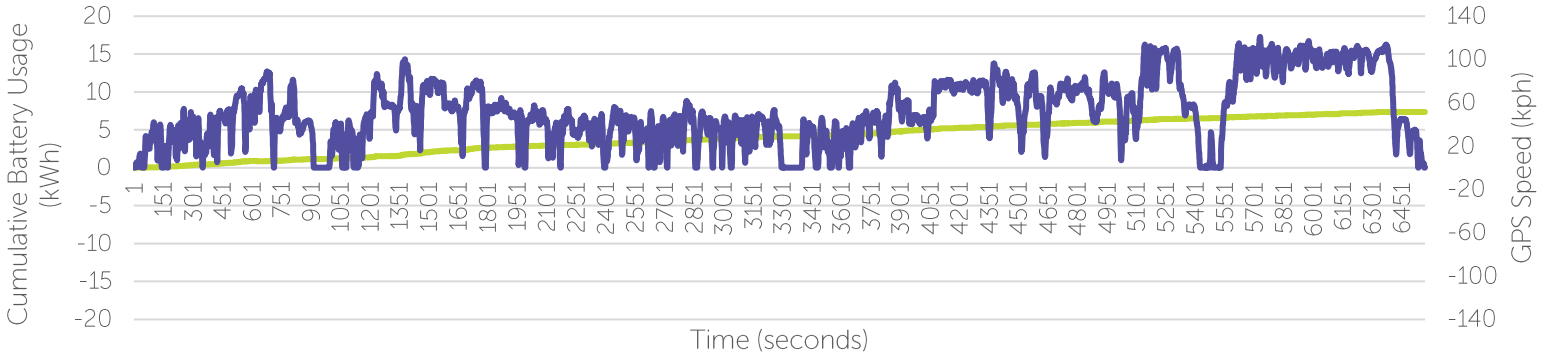
Emissions summary

	FE MPG	FC L/100km	CO_2 g/km	CO mg/km	NO_x mg/km	PN #x10^{11}/km	Electricity Consumption Wh/km	Total Electricity Consumed kWh	Battery Usage Wh/km	Total Battery Usage kWh
Overall	61.5	4.59	105.1	98	5	1.371	77.1	7.37	100.0	9.55
Cold Start	4829.3	0.06	0.2	2	2	0.002	184.5	0.36	205.3	0.39
Urban	427.2	0.66	14.5	10	2	0.387	107.1	4.17	138.2	5.39
Rural	64.7	4.36	100.0	152	4	1.668	76.2	2.31	95.0	2.88
Motorway	26.4	10.71	246.2	166	11	2.494	33.7	0.88	48.9	1.28

Engine speed vs GPS speed



Cumulative battery usage vs GPS speed



Conclusion

The three plug-in hybrid vehicles were successfully tested for emissions and battery usage on the various routes, using a variety of driving modes to provide a comprehensive evaluation of their performance compared to official figures.

With regards to emissions, the BMW X5 PHEV showed the greatest variance between official and real-world CO_2. The Volvo XC60 and the Mitsubishi Outlander still exceeded their stated CO_2 output with the smallest gap being the Outlander at 86% more CO_2 produced per km than advertised.

One notable difference between the test vehicles is how they choose to utilise the engine when driven in the default hybrid mode. Both the BMW X5 and Volvo XC60 use the engine in a similar way to regular hybrid vehicles, partially charging the high voltage battery, and partially driving the wheels. The Mitsubishi Outlander 5H however, avoids driving the wheels with the engine except under very demanding conditions. Instead it used the engine almost exclusively to charge the high voltage battery, and the wheels were almost always powered by the battery.

Appendix 1 – Battery clamp specification

Frequency	Amplitude	Phase
DC	±0.3% rdg. ±0.02% f.s.	–
DC < f ≤ 100 Hz	±0.3% rdg. ±0.01% f.s.	±0.1°
100 Hz < f ≤ 500 Hz	±0.5% rdg. ±0.02% f.s.	±0.2°
500 Hz < f ≤ 1 kHz	±1.0% rdg. ±0.02% f.s.	±0.5°
1 kHz < f ≤ 5 kHz	±2.0% rdg. ±0.02% f.s.	±1.5°
5 kHz < f ≤ 10 kHz	±5.0% rdg. ±0.05% f.s.	±2.0°
10 kHz < f ≤ 20 kHz	±30.0% rdg. ±0.10% f.s.	±10.0°

CT6846-05 1000 A AC/DC
Output connector: ME15W

Temperature and humidity range for 0°C to 40°C (32°F to 104°F), 80% RH or less guaranteed accuracy

Effect of temperature:
In ranges from -40°C to 0°C (-40°F to 32°F) and 40°C to 85°C (104°F to 185°F)
Amplitude sensitivity: ±0.01% rdg./°C or less
Offset voltage: ±0.005% f.s./°C or less
Effect of common mode 0.05% f.s. or less (1000 Vrms, DC to 100 Hz) voltage

Magnetic susceptibility:
150 mA or less (Scaled value, after input of 1000 A DC)

Effect of conductor position:
±0.2% rdg. or less (1000 A input, 50 Hz / 60 Hz, wire with outer diameter of 30 mm)

Effect of external:
150 mA or less magnetic field (Scaled value, in a DC and 60 Hz magnetic field of 400 A/m)

Output voltage:
2 mV/A (= 2 V / 1000 A) Offset adjustable range = ±2 mV

Output impedance:
50 Ω

Output connector:
CT6846: HIOKI PL23
CT6846-05: HIOKI ME15W
Operating temperature:
-40°C to 85°C (-40°F to 185°F), 80% RH or less (no condensation) and humidity range

Supply voltage:
±11 V to ±15 V

Supply capacity:
±300 mA or less

Rated power:
7 VA or less

Dimensions:
238 mm (9.37 in) W x 116 mm (4.57 in) H x 35 mm (1.38 in) D

Mass:
990 g (34.9 oz)

Further details can be found at: https://www.hioki.com/en/products/.

Appendix 2 – Calibration values

Channel	Unit	Value
CO	ppm	1296
CO_2	%	15.99
O_2	%	20.9
HC	ppm	2010
NO	ppm	1762
NO_2	ppm	195
THC	ppm	244.2

Appendix 3 – Calibration certificates

LDV1

Sensors Europe GmbH
Feldheider Str. 60
40699 Erkrath - Germany

Certificate No.	SE-LC-19-066
Test date:	9-Oct-19
Expiration date:	8-Oct-20

SEMTECH LDV LINEARITY CERTIFICATE

This document certifies that the PEMS listed below meets the linearization requirements listed in RDE 1832/2018 Appendix 2, Part 3.2. Linearization testing was performed using procedures specified in RDE Part 3.4 with gas standards traceable to the National Institute of Standards (NIST). The PEMS listed below is in compliance with UN/ECE regulations provided that emissions testing is performed within 1 year from the test date listed on this document.

SEMTECH LDV Instrument information:

LDV GAS Module S/N:	L15128720
NDIR Analyzer S/N:	K15127108
NDUV Analyzer S/N:	L15128602
Software Version:	18.06C
Customer	Emissions Analytics

RDE 1832/2018 Linearity Regulation Acceptance Criteria:

Appx.2 - 3.2 Table 1	Intercept	Slope a_1	SEE	R^2
Gas Analyzers	≤0.5% max	0.99 ≤ slope ≤ 1.01	≤1% max	≥ 0.998

Traceability of Gas Standards

Gas Bottle Description	Supplier	Cylinder #	Analytical Accuracy	Expiration Date
CO - 1.18%	Westfalen AG	27600502615223	±1.00%	Aug-20
CO2 - 15.9%	Westfalen AG	27600502615223	±1.00%	Aug-20
NO - 2540ppm	Westfalen AG	27600502615223	±1.00%	Aug-20
NO2 - 900ppm	Westfalen AG	27600504841934	±2.00%	Feb-20

Gas Divider Traceability

Model:	S/N:	Calibration Date:	Calibration Due date:	Certificate number:
HORIBA SGD-710C	UDHH9DDD	25-Mar-19	24-Mar-20	DAkkS 13976

Technician: O. Brüggemann Date: 9-Oct-19

Q.A.: Date: 10-Oct-19

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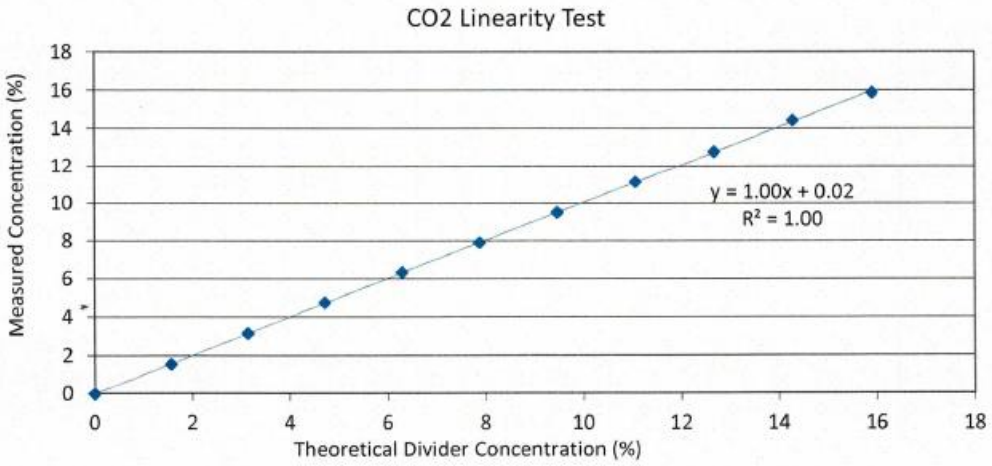
CO_2 Linearity Test Results:

Appx.2 - 3.2 Table 1	Intercept	Slope a_1	SEE	R^2
CO2 - 15.9%	0.104	1.01	0.326	1
Criteria	≤0.5% max	0.99 ≤ slope ≤ 1.01	≤1% max	≥ 0.998
Status	Pass	Pass	Pass	Pass

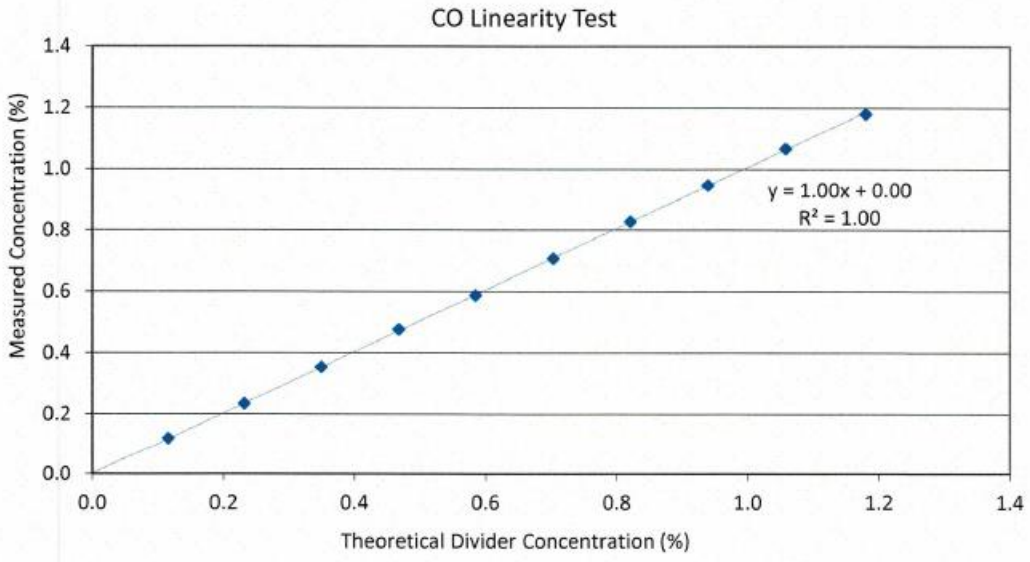
Linearity Data				
Divider (%)	Measured (%)	Full Scal Error (%)	Relative Error of reading (%)	Status
0.00	0.00	-0.01	0.00	Pass
1.56	1.57	0.08	0.91	Pass
3.12	3.17	0.29	1.65	Pass
4.71	4.77	0.37	1.40	Pass
6.30	6.35	0.30	0.86	Pass
7.88	7.91	0.20	0.47	Pass
9.48	9.52	0.22	0.41	Pass
11.06	11.15	0.51	0.82	Pass
12.66	12.79	0.74	1.06	Pass
14.26	14.44	1.04	1.31	Pass
15.90	15.89	-0.06	-0.07	Pass
0.00	0.01	0.06	0.00	Pass



CO Linearity Test Results:

Appx.2 - 3.2 Table 1	Intercept	Slope a_1	SEE	R^2
CO - 1.18%	0.113	1.00	0.270	1.000
Criteria	≤0.5% max	0.99 ≤ slope ≤ 1.01	≤1% max	≥ 0.998
Status	Pass	Pass	Pass	Pass

Linearity Data				
Divider (%)	Measured (%)	Full Scal Error (%)	Relative Error of reading (%)	Status
0.000	-0.001	-0.02	0.00	Pass
0.116	0.119	0.04	3.08	Pass
0.232	0.234	0.03	0.94	Pass
0.349	0.353	0.05	1.14	Pass
0.467	0.475	0.10	1.72	Pass
0.585	0.587	0.03	0.43	Pass
0.704	0.705	0.02	0.19	Pass
0.821	0.827	0.07	0.70	Pass
0.939	0.947	0.09	0.77	Pass
1.058	1.066	0.10	0.76	Pass
1.180	1.180	0.00	-0.01	Pass
0.000	-0.001	-0.02	0.00	Pass



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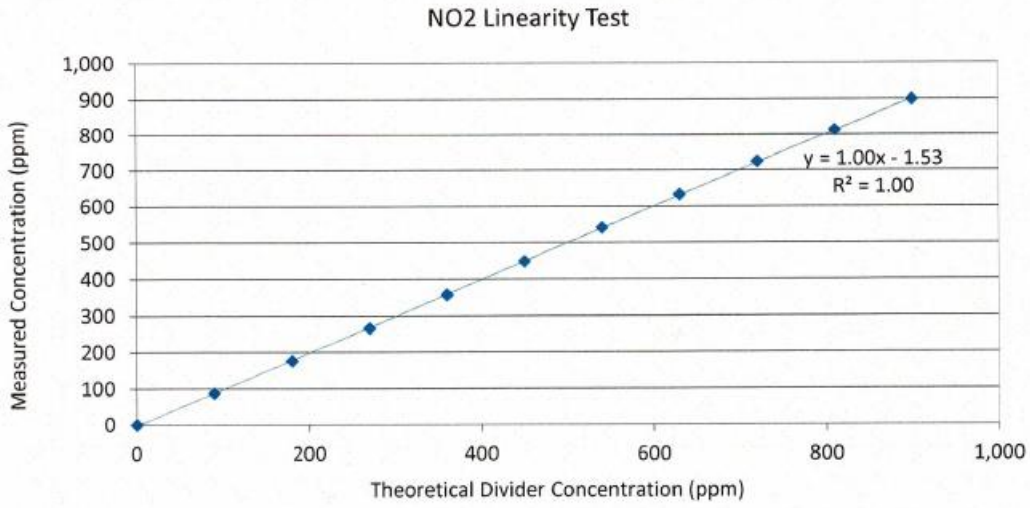
NO_2 Linearity Test Results:

Appx.2 - 3.2 Table 1	Intercept	Slope a_1	SEE	R^2
NO2 - 900ppm	-0.185	1.01	0.256	1.000
Criteria	≤0.5% max	0.99 ≤ slope ≤ 1.01	≤1% max	≥ 0.998
Status	Pass	Pass	Pass	Pass

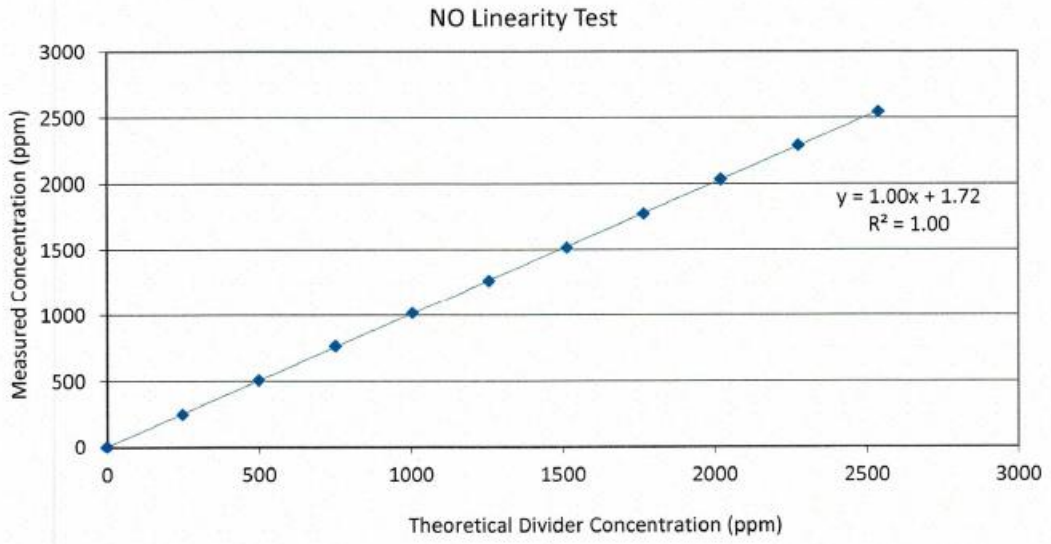
Linearity Data				
Divider (ppm)	Measured (ppm)	Full Scal Error (%)	Relative Error of reading (%)	Status
0.0	0.0	0.00	0.00	Pass
89.8	88.3	-0.15	-1.67	Pass
179.6	177.6	-0.20	-1.10	Pass
270.1	267.4	-0.27	-1.01	Pass
360.6	358.2	-0.24	-0.67	Pass
450.3	449.6	-0.07	-0.15	Pass
540.9	541.8	0.09	0.17	Pass
629.8	633.3	0.34	0.55	Pass
719.2	724.3	0.51	0.71	Pass
808.6	813.8	0.52	0.65	Pass
900.0	900.2	0.02	0.02	Pass
0.0	0.8	0.08	0.00	Pass



NO Linearity Test Results:

Appx.2 - 3.2 Table 1	Intercept	Slope a_1	SEE	R^2
NO - 2540ppm	0.068	1.00	0.191	1.000
Criteria	≤0.5% max	0.99 ≤ slope ≤ 1.01	≤1% max	≥ 0.998
Status	Pass	Pass	Pass	Pass

Linearity Data				
Divider (ppm)	Measured (ppm)	Full Scal Error (%)	Relative Error of reading (%)	Status
0.0	0.0	0.00	0.00	Pass
249.1	246.8	-0.08	-0.91	Pass
498.9	506.0	0.24	1.42	Pass
752.0	762.9	0.36	1.45	Pass
1006.0	1013.7	0.26	0.77	Pass
1258.5	1260.1	0.06	0.13	Pass
1514.7	1512.7	-0.07	-0.13	Pass
1767.1	1768.8	0.06	0.10	Pass
2021.8	2030.0	0.27	0.40	Pass
2277.5	2290.0	0.42	0.55	Pass
2540.0	2544.2	0.14	0.16	Pass
0.0	0.7	0.02	0.00	Pass



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LDV4

Sensors Europe GmbH
Feldheider Str. 60
40699 Erkrath - Germany

Certificate No.	SE-LC-19-61
Test date:	19-Sep-19
Expiration date:	18-Sep-20

SEMTECH LDV LINEARITY CERTIFICATE

This document certifies that the PEMS listed below meets the linearization requirements listed in RDE 1832/2018 Appendix 2, Part 3.2. Linearization testing was performed using procedures specified in RDE Part 3.4 with gas standards traceable to the National Institute of Standards (NIST). The PEMS listed below is in compliance with UN/ECE regulations provided that emissions testing is performed within 1 year from the test date listed on this document.

SEMTECH LDV Instrument information:

LDV GAS Module S/N: D16131431
NDIR Analyzer S/N: A16126748
NDUV Analyzer S/N: E14115575
Software Version: 18.06C
Customer Emissions Analytics

RDE 1832/2018 Linearity Regulation Acceptance Criteria:

Appx.2 - 3.2 Table 1	Intercept	Slope a_1	SEE	R^2
Gas Analyzers	≤0.5% max	0.99 ≤ slope ≤ 1.01	≤1% max	≥ 0.998

Traceability of Gas Standards

Gas Bottle Description	Supplier	Cylinder #	Analytical Accuracy	Expiration Date
CO - 1.18%	Westfalen AG	27600502615223	±1.00%	Aug-20
CO2 - 15.9%	Westfalen AG	27600502615223	±1.00%	Aug-20
NO - 2540ppm	Westfalen AG	27600502615223	±1.00%	Aug-20
NO2 - 900ppm	Westfalen AG	27600504841934	±2.00%	Feb-20

Gas Divider Traceability

Model:	S/N:	Calibration Date:	Calibration Due date:	Certificate number:
HORIBA SGD-710C	UDHH9DDD	25-Mar-19	24-Mar-20	DAkkS 13976

Technician: O. Brüggemann Date: 19-Sep-19

Q.A.: R. [illegible] Date: 19-Sep-19

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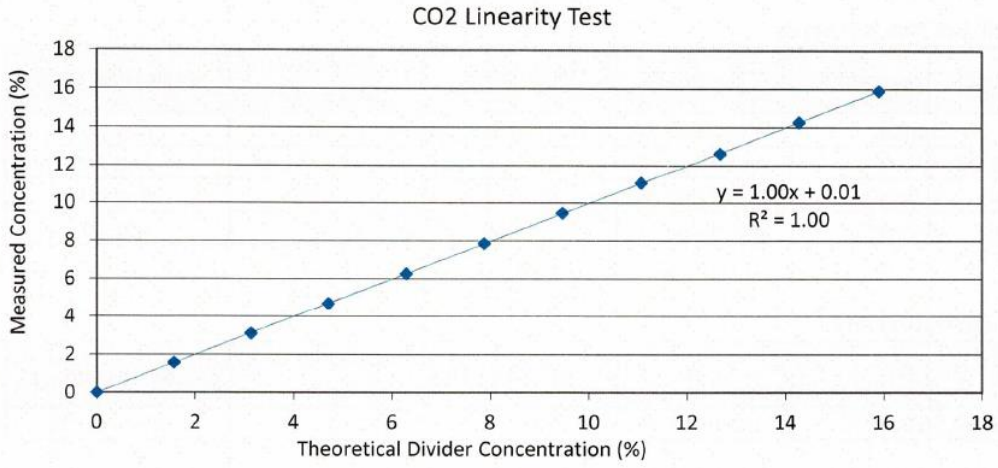
CO_2 Linearity Test Results:

Appx.2 - 3.2 Table 1	Intercept	Slope a_1	SEE	R^2
CO2 - 15.9%	0.060	1.00	0.060	1
Criteria	≤0.5% max	0.99 ≤ slope ≤ 1.01	≤1% max	≥ 0.998
Status	Pass	Pass	Pass	Pass

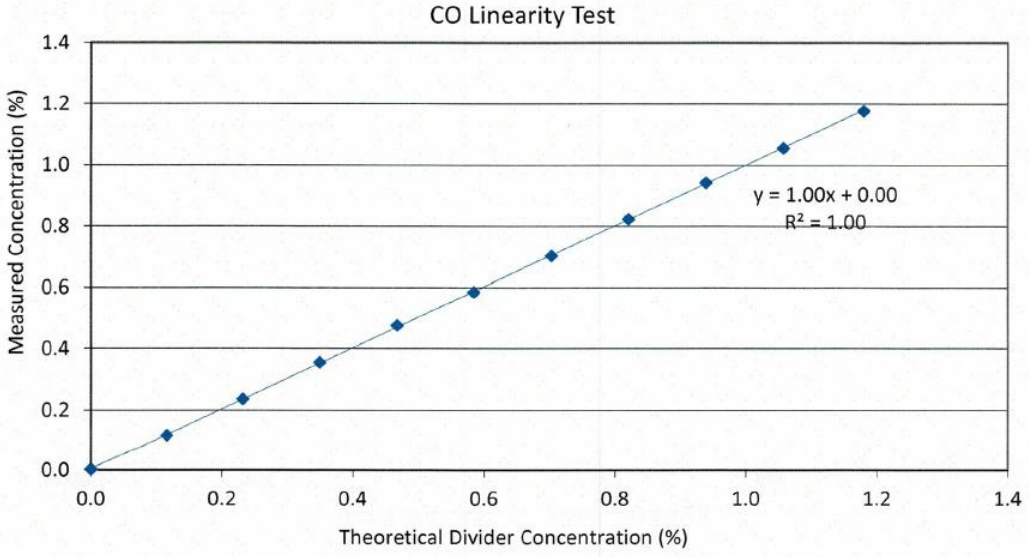
Linearity Data				
Divider (%)	Measured (%)	Full Scal Error (%)	Relative Error of reading (%)	Status
0.00	0.00	0.03	0.00	Pass
1.56	1.58	0.11	1.29	Pass
3.12	3.14	0.07	0.40	Pass
4.71	4.71	0.03	0.10	Pass
6.30	6.31	0.07	0.20	Pass
7.88	7.91	0.20	0.46	Pass
9.48	9.50	0.13	0.24	Pass
11.06	11.09	0.15	0.25	Pass
12.66	12.67	0.07	0.10	Pass
14.26	14.30	0.23	0.30	Pass
15.90	15.93	0.16	0.19	Pass
0.00	0.01	0.07	0.00	Pass



CO Linearity Test Results:

Appx.2 - 3.2 Table 1	Intercept	Slope a_1	SEE	R^2
CO - 1.18%	0.270	1.00	0.270	1.000
Criteria	≤0.5% max	0.99 ≤ slope ≤ 1.01	≤1% max	≥ 0.998
Status	Pass	Pass	Pass	Pass

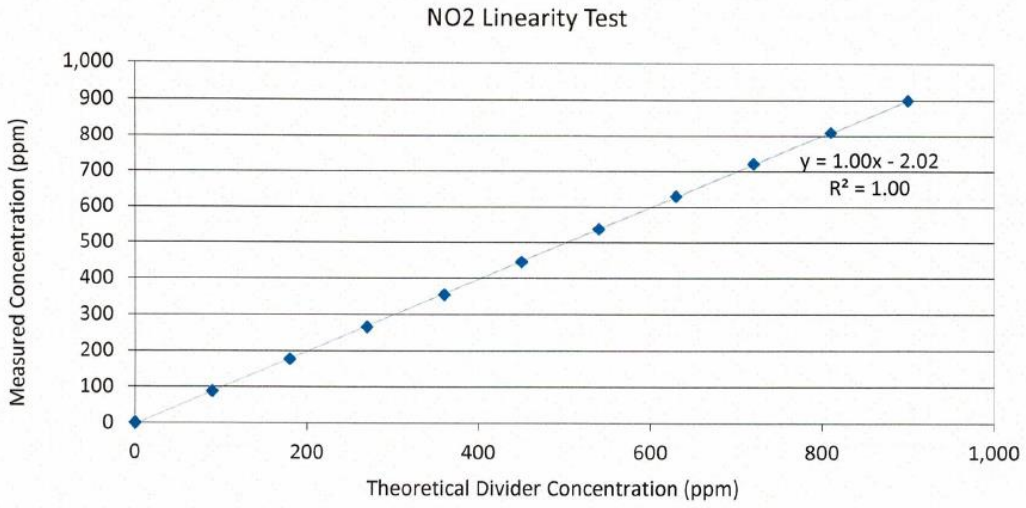
Linearity Data				
Divider (%)	Measured (%)	Full Scal Error (%)	Relative Error of reading (%)	Status
0.000	0.001	0.01	0.00	Pass
0.116	0.117	0.01	0.96	Pass
0.232	0.235	0.04	1.55	Pass
0.349	0.355	0.07	1.56	Pass
0.467	0.475	0.10	1.73	Pass
0.585	0.585	0.00	-0.01	Pass
0.704	0.703	-0.01	-0.14	Pass
0.821	0.824	0.03	0.34	Pass
0.939	0.942	0.04	0.34	Pass
1.058	1.056	-0.03	-0.20	Pass
1.180	1.176	-0.05	-0.31	Pass
0.000	0.001	0.01	0.00	Pass



NO_2 Linearity Test Results:

Appx.2 - 3.2 Table 1	Intercept	Slope a_1	SEE	R^2
NO2 - 900ppm	-0.239	1.00	0.286	1.000
Criteria	≤0.5% max	0.99 ≤ slope ≤ 1.01	≤1% max	≥ 0.998
Status	Pass	Pass	Pass	Pass

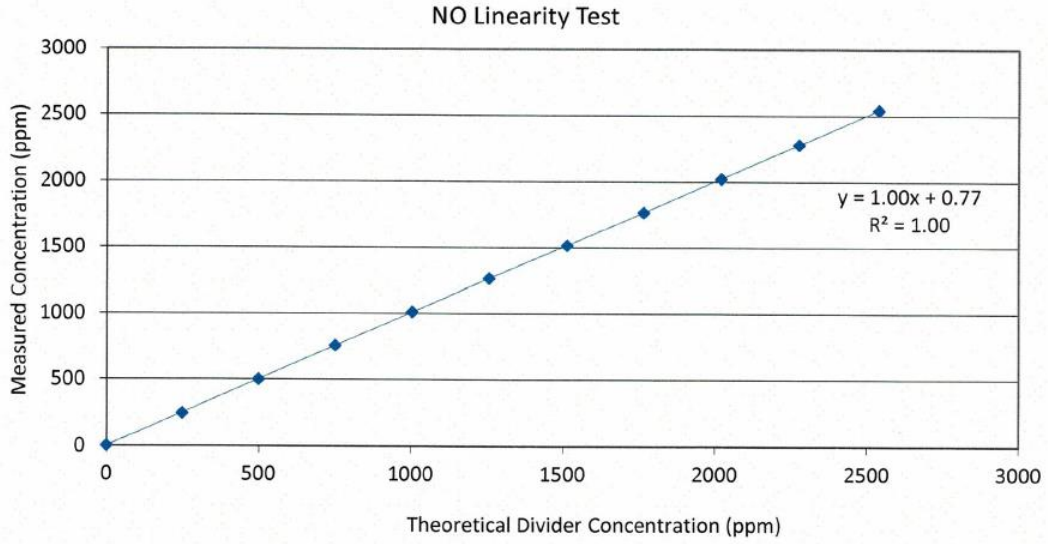
Linearity Data				
Divider (ppm)	Measured (ppm)	Full Scal Error (%)	Relative Error of reading (%)	Status
0.0	0.4	0.04	0.00	Pass
89.8	87.8	-0.20	-2.22	Pass
179.6	177.0	-0.26	-1.43	Pass
270.1	266.2	-0.39	-1.46	Pass
360.6	356.2	-0.44	-1.22	Pass
450.3	447.6	-0.27	-0.60	Pass
540.9	539.8	-0.11	-0.20	Pass
629.8	632.0	0.22	0.35	Pass
719.2	722.9	0.37	0.51	Pass
808.6	812.0	0.35	0.43	Pass
900.0	901.4	0.14	0.16	Pass
0.0	1.4	0.14	0.00	Pass



NO Linearity Test Results:

Appx.2 - 3.2 Table 1	Intercept	Slope a_1	SEE	R^2
NO - 2540ppm	0.030	1.00	0.067	1.000
Criteria	≤0.5% max	0.99 ≤ slope ≤ 1.01	≤1% max	≥ 0.998
Status	Pass	Pass	Pass	Pass

Linearity Data				
Divider (ppm)	Measured (ppm)	Full Scal Error (%)	Relative Error of reading (%)	Status
0.0	-0.2	-0.01	0.00	Pass
249.1	247.8	-0.04	-0.53	Pass
498.9	500.7	0.06	0.35	Pass
752.0	755.6	0.12	0.48	Pass
1006.0	1009.6	0.12	0.36	Pass
1258.5	1261.9	0.12	0.27	Pass
1514.7	1516.3	0.05	0.11	Pass
1767.1	1770.5	0.11	0.19	Pass
2021.8	2022.6	0.03	0.04	Pass
2277.5	2281.7	0.14	0.18	Pass
2540.0	2541.0	0.03	0.04	Pass
0.0	0.2	0.01	0.00	Pass



CPN1

CPN Maintenance Report

Case No: 5726 14 January 2020

6. Outgoing Quality Check:

- Outgoing check after maintenance operation:

Diagnostics Parameter	Value	Criteria (new)	Pass/Fail
PND1 pump pressure [kPa]	180	180±5	☒ Pass ☐Fail
PND2 pump pressure [kPa]	181	180±5	☒ Pass ☐Fail
CPC pump pressure [kPa]	73,3	setpoint ±5	☒ Pass ☐Fail
PND1 duty cycle [%]	38	60±25	☒ Pass ☐Fail
PND2 duty cycle [%]	41	60±25	☒ Pass ☐Fail
CPC duty cycle [%]	37	50±20	☒ Pass ☐Fail
Purge duty cycle [%]	48	55±15	☒ Pass ☐Fail
PND1 dilution ratio	27.2	30±10:1	☒ Pass ☐Fail
PND2 low dilution ratio	38.3	50±20:1	☒ Pass ☐Fail
PND1 sample dp [kPa]	2.8	2<dp<5	☒ Pass ☐Fail
PND2 sample dp on high dilution ratio [kPa]	0.43	>0.3kPa	☒ Pass ☐Fail
Condenser temperature [°C]	14.9	15±1	☒ Pass ☐Fail
Heatsink temperature [°C]	30.9	36±8	☒ Pass ☐Fail
Block temperature [°C]	40.1	40±1	☒ Pass ☐Fail
Board temperature [°C]	36.5	35±15	☒ Pass ☐Fail
Tank temperature [°C]	38	38±1	☒ Pass ☐Fail
Catalyst temperature [°C]	294	300±10	☒ Pass ☐Fail
CPC sample flow [ccm]	60	set-point ±5	☒ Pass ☐Fail
Comp. offset	0.48	0.4 ±0.1	☒ Pass ☐Fail
Zero Check TP conc.[#/cm³]	0	<5000	☒ Pass ☐Fail
Zero Drift TP conc. [#/cm³] after 4 hrs	0	<5000	☒ Pass ☐Fail

- Leak check:passed
  Hepa filter is attached for 2 minutes to check for the leak.

Detector conc. beginning of Test (#/cm³)	*Detector conc. after 2 min Test (#/cm³)*	*Criteria: <1 #/cm³*
1	*0*	*Pass*

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CPN Maintenance Report

Case No: 6504 27 May 2020

6. Outgoing Quality Check:

- Outgoing check after maintenance operation:

Diagnostics Parameter	Value	Criteria (new)	Pass/Fail
PND1 pump pressure [kPa]	180	180±5	☒ Pass ☐Fail
PND2 pump pressure [kPa]	180	180±5	☒ Pass ☐Fail
CPC pump pressure [kPa]	73	setpoint ±5	☒ Pass ☐Fail
PND1 duty cycle [%]	42	60±20	☒ Pass ☐Fail
PND2 duty cycle [%]	40	60±20	☒ Pass ☐Fail
CPC duty cycle [%]	35	50±20	☒ Pass ☐Fail
Purge duty cycle [%]	41	55±15	☒ Pass ☐Fail
PND1 dilution ratio	27	30±10:1	☒ Pass ☐Fail
PND2 low dilution ratio	42	50±20:1	☒ Pass ☐Fail
PND1 sample dp [kPa]	3	2<dp<5	☒ Pass ☐Fail
PND2 sample dp on high dilution ratio [kPa]	0.37	>0.3kPa	☒ Pass ☐Fail
Condenser temperature [°C]	15	15±1	☒ Pass ☐Fail
Heatsink temperature [°C]	32.5	36±8	☒ Pass ☐Fail
Block temperature [°C]	40.0	40±1	☒ Pass ☐Fail
Board temperature [°C]	38.5	35±15	☒ Pass ☐Fail
Tank temperature [°C]	38	38±1	☒ Pass ☐Fail
Catalyst temperature [°C]	298	300±10	☒ Pass ☐Fail
CPC sample flow [ccm]	54	set-point ±5	☒ Pass ☐Fail
Comp. offset	0.42	0.4 ±0.1	☒ Pass ☐Fail
Zero Check TP conc.[#/cm³]	0	<5000	☒ Pass ☐Fail
Zero Drift TP conc. [#/cm³] after 4 hrs		<5000	☐ Pass ☐Fail

- Leak check:
  Hepa filter is attached for 2 minutes to check for the leak.

Detector conc. beginning of Test (#/cm³)	*Detector conc. after 2 min Test (#/cm³)*	*Criteria: <1 #/cm³*
0.25	*0*	*Pass*

Sensors Europe GmbH • Feldheider Str.60 • D-40699 Erkrath FON: +49 (0) 2104 14188-12 • FAX: +49 (0) 2104 14188-14 MAIL: SemtechSupport@sensors-europe.eu• WEB: www.sensors-inc.com

Appendix 4 – EMROAD calculations and settings

Moving Average Window (MAW) calculation

To calculate the Moving Average Window (MAW) emissions and verify test validity, the EMROAD software requires various values take from the official WLTP figures. Additionally, for plug-in hybrids, values for the charge sustaining WLTP tests are also required. Only some of these values were available on the Certificate of Conformity for the various vehicles and so we made some additional assumptions and derivations as detailed below.

Reference CO_2 mass

The reference CO_2 mass is half the mass of CO_2 emitted during the type approval WLTP cycle. For all vehicles tested here the Certificate of Conformity only shows the weighted combined WLTP CO_2 in g/km. We derive the mass of CO_2 by multiplying the CO_2 in g/km by the fixed distance of the WLTP cycle (23.266 km) and dividing by 1000 to convert to kg. The final equation is:

Reference CO_2 mass (kg) = 0.5 * WLTP CO_2 (g/km) * 23.266 (km) / 1000 (g/kg)

Reference cycle CO_2

The reference cycle CO_2 is the weighted combined WLTP CO_2 in g/km from the Certificate of Conformity.

OVC-HEV charge sustaining CO_2

This value is required for plug-in hybrids and is the CO_2 in g/km taken from the charge sustaining WLTP test. It is our understanding that this value should be taken from the non-weighted combined WLTP field in section 49.4 on the Certificate of Conformity. However only the Volvo XC60 provided this value. For the BMW X5 the value was obtained direct from the manufacturer. For the Mitsubishi Outlander we used the overall CO_2 from the charge-sustaining test of this project.

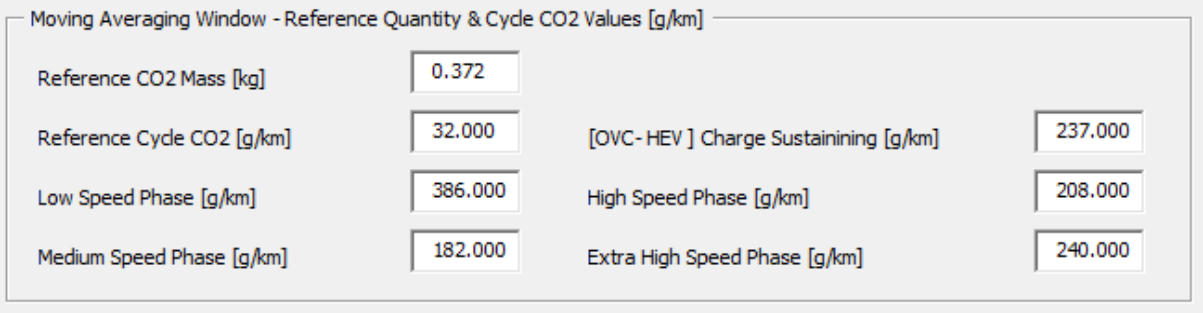
Phase CO_2

It is our understanding that these values should be taken from the charge sustaining WLTP test and are recorded as the Low/Medium/High/Very High WLTP fields in section 49.4 on the Certificate of Conformity. However only the Volvo XC60 provided these values. For the BMW X5 the value was obtained direct from the manufacturer. For the Mitsubishi Outlander we used the overall CO_2 from the charge-sustaining test of this project.

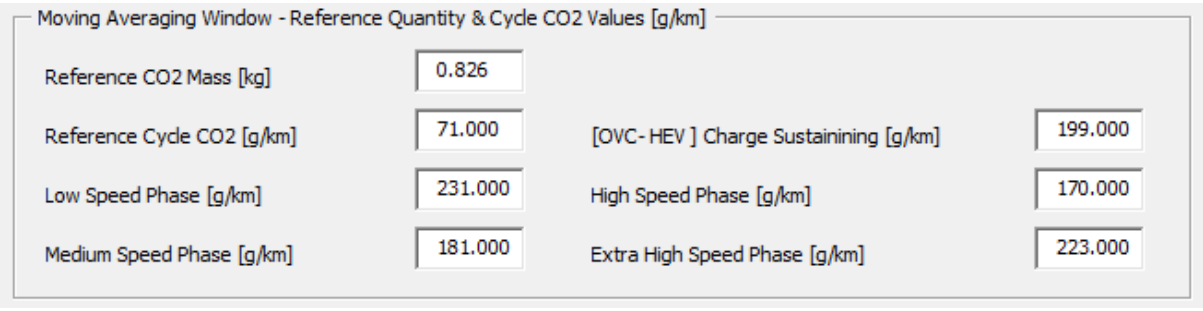
Vehicle settings

The below images show the MAW settings used for the EMROAD calculations for each of the three vehicles.

BMW X5 x45e M



Volvo XC60 T8



Mitsubishi Outlander 5H