SPaTS Task 1-650 – Review of updates to emission curves for non-conventional ICE and ultra-low emission vehicles

Task in: Production of updated emission curves for NTM and WebTAG

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Glossary of abbreviations

ANPR	Automatic Number Plate Recognition
BEV	Battery Electric Vehicle
CI	Compression Ignition
COPERT	Software tool for calculating pollutant emissions from road transport
DfT	UK Department for Transport
ERMES	European Research on Mobile Emission Sources
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GSR	Gas Substitution Rate
HBEFA	HandBook of Emission Factors
HDV	Heavy Duty Vehicle (both HGVs and buses/coaches)
HEV	Hybrid Electric Vehicle
HGV	Heavy Goods Vehicle
ICE	Internal Combustion Engine
ITS Leeds	Institute of Transport Studies at Leeds University
LDV	Light duty vehicle (both passenger cars and LGV, see below)
LGV	Light Goods Vehicle
NAEI	National Atmospheric Emissions Inventory
NTM	National Transport Model
PC	Passenger cars
PEMS	Portable Emissions Monitoring Systems
PHEM	Technical University of Graz’s vehicle and powertrain simulation model
PHEV	Plug-in Hybrid Electric Vehicle
PM	Particulate matter
SI	Spark Ignition
TfL	Transport for London
TRL	Transport Research Laboratory
UF	Utility factor
ULEV	Ultra-Low Emission Vehicle
VCA	Vehicle Certification Agency
VERSIT	Instantaneous traffic emissions model developed by TNO
WebTAG	DfT Web-based Transport Analysis Guidance
WLTC	Worldwide harmonised Light vehicles Test Cycle
WLTP	Worldwide harmonised Light vehicles Test Procedure

1 Introduction

1.1 Overview

DfT require an update to the speed-emission factor and fuel consumption curves in a specified format for use in the NTM and WebTAG consistent with the exhaust emission factors in the European COPERT 5 model, now used in the compilation of the UK's National Atmospheric Emissions Inventory (NAEI) on behalf of Defra and BEIS (http://naei.beis.gov.uk/) and in national air quality modelling under the MAAQ contract for Defra. This includes modelling that underpinned the UK's Plans for reducing roadside nitrogen dioxide concentrations. The update to these speed-emission curves has been reported separately.

The updated emission curves provided for the NTM and WebTAG are restricted to vehicles running on conventional petrol and diesel engines. In this separate project we revisit evidence on speed-emission curves for non-conventional Internal Combustion Engine (ICE) and other ultra-low emission (ULEV) vehicles developed by Ricardo in 2015 in a report "*Speed emission/energy curves for ultra-low emission vehicles*". This project comprises a short scoping study that will examine whether there is sufficient new evidence to merit revisiting and possibly updating the emission curves for these vehicles. The conclusions from this provides DfT with the basis for a fuller discussion to decide whether an update of the 2015 curves is appropriate.

1.2 Scope and overview of the methodology

The vehicles and technologies which are covered by the project are shown in Table 1. For each vehicle/technology type except buses, speed emission/energy curves were previously developed for fuel or energy use, and CO_2, NOx and PM_{10} emissions.

Table 1 Low Emission Vehicles in scope for this review

Vehicle Type	Fuel/Technology Type
Cars	Petrol Hybrid Electric Vehicle (Petrol HEV) Diesel Hybrid Electric Vehicle (Diesel HEV) Petrol Plug-in Hybrid Electric Vehicle (Petrol PHEV) Diesel Plug-in Hybrid Electric Vehicle (Diesel PHEV) Battery Electric Vehicle (BEV) Fuel Cell Electric Vehicle (FCEV)
Light Goods Vehicles	Petrol Hybrid Electric Vehicle Diesel Hybrid Electric Vehicle Petrol Plug-in Hybrid Electric Vehicle Diesel Plug-in Hybrid Electric Vehicle Battery Electric Vehicle Fuel Cell Electric Vehicle
Rigid Heavy Goods Vehicles	Biomethane/ Natural Gas Vehicle Dual Fuel Diesel & Biomethane/ Natural Gas Vehicle Battery Electric Vehicle (3.5t -12t GVW only)

Vehicle Type	Fuel/Technology Type
Articulated Heavy Goods vehicles	Biomethane/ Natural Gas Vehicle Dual Fuel Diesel & Biomethane/ Natural Gas Vehicle
Buses **(not included in the original 2015 review)**	Biomethane/ Natural Gas Vehicle Hybrid buses Battery Electric buses Fuel Cell Electric buses

Buses are a new vehicle type introduced in this study because of their increasing importance, although they were not within the scope of the 2015 study.

This report starts with a résumé of the data and methodologies used in the earlier 2015 report, using summary data Tables 5, 6 and 7 of the earlier report. From these a complete list of key data sources that were used is drawn up, and coloured to highlight those sources where significant new evidence has become available. The new evidence for these sources is then systematically discussed in the following chapters with Chapter 3 covering light duty vehicles, and Chapter 4 covering heavy duty vehicles, including buses.

2 Résumé of data and method tables used in the original report

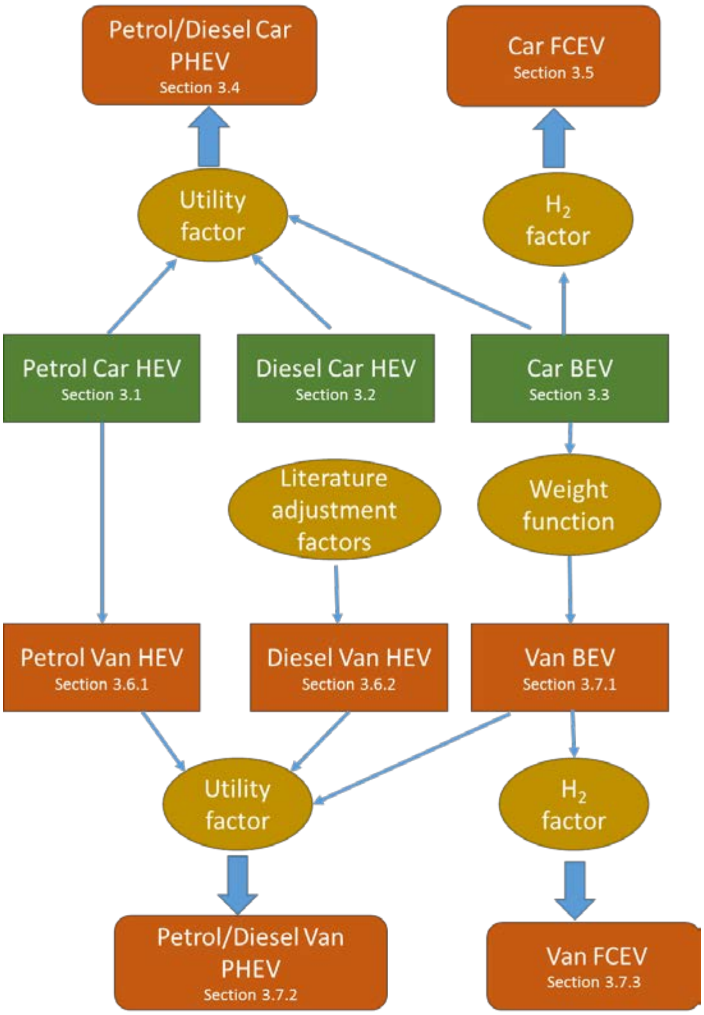
2.1 Overview of the core data sources

For the original study a number of data sources were used to assess, derive and validate the emissions curves reported. The key data sources cover:

- Existing emissions models
- Manufacturers' type approval data
- Literature results on real world emissions
- Simulation data using the PHEM model
- PEMS data from vehicle tests in the UK

In terms of quantities of data for different vehicle categories, the 2015 study used the speed related emission factor curves for some ULEV for which there were considerable data, to derive the speed related emission factor curves for others. Figure 1 below summarises these relationships for light duty vehicles.

Figure 1 Relationship between data sources and ULEV light duty vehicle categories for curve fitting

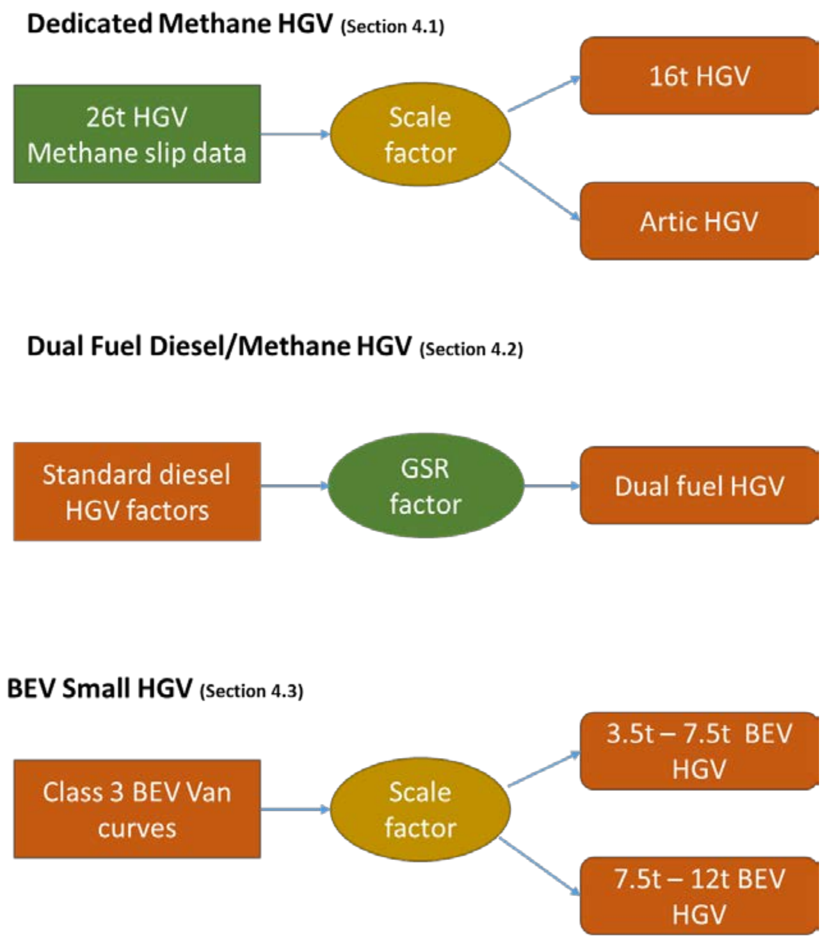


This shows that for LDV the primary data sources were for petrol and diesel HEV and BEV cars. (The section numbers refer to subsections in the original 2015 report.) In the figure:

- Green cells denote core technologies for which a substantial quantity of emissions data existed and which comprise the starting data from which other emission factors are extrapolated;
- Red cells denote technologies whose emissions performance was extrapolated from the core technologies;
- Mustard coloured circles contain key factors/assumptions involved in the extrapolations.

Figure 2 summarises what data sources were used for heavy duty vehicles. (The section numbers refer to subsections in the original 2015 report.) It shows that for HDV there is much less primary data than was the case for LDV and curves for BEV vans were used to estimate energy curves for small HGVs. We cite some studies Ricardo undertook on methane fuelled vehicles for the DfT. The gas substitution rate (GSR), i.e. the amount of diesel substituted by methane, is the other primary input parameter determining the emissions from dual fuel diesel/methane HGV.

Figure 2 Relationship between data sources and ULEV heavy duty vehicle categories for curve fitting



Legend: green is new data, mustard is scaling factors, orange are derived emission curves.

In more detail, the following two tables summarise the methodology used to generate the speed related emission functions for light duty vehicles. An analogous table for HDVs is given in Table 4.

Table 2 Summary of curve generation for cars (Table 5 of 2015 study)

	Petrol HEV	Diesel HEV	BEV	Petrol PHEV	Diesel PHEV	Fuel Cell EV
NOx						
Curve data	PHEM data for HEV and ICE, normalised to COPERT	PEMS data COPERT scaling for Euro 6	N/A	Extrapolated from HEV and BEV data using utility factor	Extrapolated from HEV and BEV data using utility factor	N/A
Validation data	PEMS data Manufacturers' data	Manufacturers' data	N/A	Manufacturers' data	Manufacturers' data	N/A
Vehicle categories	1 vehicle size Euro 5 and 6	1 vehicle size Euro 5 and 6	N/A	1 vehicle size 3 utility factors Euro 6	1 vehicle size 3 utility factors Euro 6	N/A
PM						
Curve data	No data, assume HEV same as COPERT ICE	No data, assume HEV same as COPERT ICE	N/A	Extrapolated from HEV and BEV data using utility factor	Extrapolated from HEV and BEV data using utility factor	N/A
Validation data	None	None	N/A	Manufacturers' data	Manufacturers' data	N/A
Vehicle categories	1 vehicle size Euro 5 and 6	1 vehicle size Euro 5 and 6	N/A	1 vehicle size 3 utility factors Euro 6	1 vehicle size 3 utility factors Euro 6	N/A
CO_2/Energy						
Curve data	PHEM data for HEV and ICE, normalised to TRL factors	PEMS data TRL data for scaling to Euro 6	PHEM data Single speed curve	Extrapolated from HEV and BEV data using utility factor	Extrapolated from HEV and BEV data using utility factor	Extrapolated from BEV using H_2 conversion factor based on manufactures data.
Validation data	PEMS data Manufacturers' data	Manufacturers' data	Manufacturers' data	Manufacturers' data	Manufacturers' data	None
Vehicle categories	3 vehicle sizes, same as COPERT Euro 5 and 6	1 vehicle size Euro 5 and 6	3 vehicle sizes, scaled based on mass	3 vehicle sizes related to HEV/BEV sizes 3 utility factors Euro 6	3 vehicle sizes related to BEV sizes 3 utility factors Euro 6	1 vehicle size

Table 3 Summary of curve generation for vans (Table 6 of 2015 study)

	Petrol HEV	Diesel HEV	BEV	Petrol PHEV	Diesel PHEV	Fuel cell EV
NOx						
Curve data	Same as car petrol HEV	Scaled to diesel car using same ratio as ICE diesel to van from TRL data	N/A	Same as car petrol PHEV	Extrapolated from HEV and BEV data using utility factor	N/A
Validation data	None	None	N/A	None	None	N/A
Vehicle categories	1 size Euro 6	3 sizes Euro 6	N/A	1 size 3 utility factors Euro 6	3 sizes 3 utility factors Euro 6	N/A
PM						
Curve data	Same as car petrol HEV	Scaled to diesel car using same ratio as ICE diesel to van from TRL data	N/A	Same as car petrol PHEV	Extrapolated from HEV and BEV data using utility factor	N/A
Validation data	None	None	N/A	None	None	N/A
Vehicle categories	1 size Euro 6	3 sizes Euro 6	N/A	1 size 3 utility factors Euro 6	3 sizes 3 utility factors Euro 6	N/A
CO_2/Energy						
Curve data	Same as car petrol HEV	Scaled to diesel car using same ratio as ICE diesel to van from TRL data	Scaled to car HEV by weight	Same as car petrol PHEV	Extrapolated from HEV and BEV data using utility factor	Extrapolated from BEV using H_2 conversion factor based on manufactures data
Validation data	None	None	Manufacturers' data	None	None	None
Vehicle categories	1 size Euro 6	3 sizes Euro 6	3 sizes	1 size 3 utility factors Euro 6	3 sizes 3 utility factors Euro 6	3 sizes

Table 4 Summary curve generation for HGVs (Table 7 of 2015 study)

	Dedicated gas-fuelled rigid HGV	Dedicated gas-fuelled artic HGV	Dual fuel rigid HGV	Dual fuel artic HGV	Electric rigid HGV
NOx					
Curve data	Test data from DfT Methane slip project	Extrapolate from dedicated rigid HGV	Infer from test data from DfT methane slip project and low carbon truck trial	Infer from test data from DfT methane slip project and low carbon truck trial	N/A
Validation data	Existing Ricardo-AEA non-speed dependent emission factors	Existing Ricardo-AEA non-speed dependent emission factors	Literature	Literature	N/A
Vehicle categories	2 rigid truck GVWs Euro V and Euro VI	Single articulated truck GVW Euro V and Euro VI	2 rigid truck GVW Euro V and Euro VI	2 rigid truck GVW Euro V and Euro VI	N/A
PM					
Curve data	Existing Ricardo-AEA non-speed dependent emission factors	Extrapolate from dedicated rigid HGV	Same as existing ICE diesel curve	Same as existing ICE diesel curve	N/A
Validation data	None	Existing Ricardo-AEA non-speed dependent emission factors	Literature	Literature	N/A
Vehicle categories	2 rigid truck GVWs Euro V and Euro VI	Single articulated truck GVW Euro V and Euro VI	2 rigid truck GVW Euro V and Euro VI	2 rigid truck GVW Euro V and Euro VI	N/A
CO_2/Energy					
Curve data	Test data from DfT Methane slip project	Extrapolate from dedicated rigid HGV	Infer from test data from DfT methane slip project and low carbon truck trial	Infer from test data from DfT methane slip project and low carbon truck trial	Extrapolate from Class 3 BEV van
Validation data	Existing Ricardo-AEA non-speed dependent emission factors	Existing Ricardo-AEA non-speed dependent emission factors	Literature	Literature	Literature
Vehicle categories	2 rigid truck GVWs	Single articulated truck GVW	2 rigid truck GVW	Single articulated truck GVW	2 rigid truck GVWs

2.2 Summary of key data sources used

For the original study the key data sources used to assess, derive and validate the emissions curves reported are summarised in Table 5. The right-hand column indicates where new data are available in relation to each data source since the 2015 study was undertaken.

Table 5 Key data sources used to assess, derive and validate the emissions curves in the 2015 study

For light duty vehicles

Data type	Data source	Availability of new data
Models	COPERT 4 (v10/11)	Moderate new data
	Handbook of Emission Factors (HB EFA) v3.1	Revised
	Passenger and Heavy duty Emissions Model (PHEM	No new data
	Other hybrid vehicle simulation models	Moderate new data
Manufacturers data	VCA new car CO_2 and emissions database	Much new data
	PEMS measurements including for RDE	Much new data
Other studies	Utility Factor	Much new data
	TRL factors	No new data
	Quantification of real driving emissions (RDE)	Much new data
	Independently gathered emissions data	Much new data[1]

For heavy duty vehicles

Data type	Data source	Availability of new data
Research studies	DfT Methane slip test data	No new data
	Existing Ricardo non-speed dependent emission factors	Revised
	Dedicated rigid HGV PM & NOx emission factors	Revised
	Low carbon truck trial	Moderate new data
	Literature	Moderate new data

[1] These data include real driving emissions testing and remote sensing

3 LDV - Detailed consideration of data available

3.1 Emission models

3.1.1 COPERT

The 2015 study used COPERT 4 (v10/11) for normalising or scaling NOx and PM emissions rates from petrol and diesel hybrid vehicles available from other sources. These emissions curves were then used to derive analogous emission factors for hybrid light commercial vehicles and for plug-in versions of both car and van PHEVs (see Figure 1).

The COPERT road transport hot emission factors database is available as an Excel file. The latest version is COPERT version 5.2.0, which was published in August 2018[2]. The only LDV ULEV category in Table 1 for which emission factors are available are petrol HEVs (as was the case for the earlier review). However, emission factors for NOx for these hybrids are likely to have been changed.

The "EMISIA SA COPERT Versions" site lists the following changes between since COPERT 4 (v10/11) that are pertinent to this study[3]:

COPERT Version	Publication date	Updates pertinent to this study
COPERT v 4.11.4	September 2016	New PC Euro 6 2020+ and LDV Euro 6 2021+ vehicle category Updated NOx emission factors for PC Diesel & LDV Diesel, Euro6 and on. PC Diesel post Euro 6 LDV Diesel post Euro 5
COPERT v 5.0.1039	September 2016	Updated NOx emission factors for PC Diesel & LDV Diesel, Euro 6 and on.
COPERT v 5.0.1067	October 2016	Corrected NOx hot emission parameters for PC Diesel Medium
COPERT v 5.2.0	August 2018	Little change pertinent to this study

The 2013 guidebook (which gives the emission factors for hybrids used in COPERT 4 (v10) gives emission factors for a single vehicle category (hybrid petrol passenger cars < 1.6 litres) and gives NOx emissions for urban, rural and highway roads. Examination of the COPERT 5.2 emission factors indicates that there are 52 vehicle categories (Euro standard, vehicle type, fuel technology) and speed functions are expressed as a polynomial for, amongst other species, NOx and fuel/energy consumption.

[2] COPERT Emission Factor database available from: https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-i-1/view

[3] For details of changes to COPERT see the site: https://www.emisia.com/utilities/copert/versions/

However, although there are a large number of vehicle categories listed, many of the coefficients are the same, i.e. the same polynomial emission factors cover a range of vehicle categories. Notwithstanding, it is clear that the COPERT factors for HEVs have been updated.

In their list of future plans, EMISIA say the next expected update is due in December 2018, and among the planned changes are "an update of alternatively fuelled vehicles (LPG, CNG, hybrids, electric). However, this update has not yet happened (as of February 2019)

3.1.2 Swiss-German-Austrian Handbook of Emission Factors (HBEFA)

The 2015 study used some data from the Swiss-German-Austrian Handbook of Emission Factors (HBEFA 3.1). The current version was updated to HBEFA 3.3 on 25th April 2017.

3.1.3 PHEM and other Vehicle simulation models

The NOx, PM and CO_2/energy emission curves for petrol HEVs in the 2015 study were generated from a petrol HEV PHEM model run specifically for the project. This has not been added to.

However, more sophisticated HEV models have been developed. For example, Ricardo have an HEV vehicle simulator. Recent research activities have developed and validated this model.

Also, another key model from the ERMES (European Research on Mobile Emissions) group is TNO's VERSIT+ model.

3.2 Manufacturers' data

3.2.1 VCA new vehicle emissions database

The 2015 study used the 2013 VCA database of car fuel and CO_2 emissions data. The latest version of this database now available was published in August 2017 (no 2018 data are available yet). The numbers of the different ULEV vehicle categories in the databases are summarised in Table 6.

Table 6: Vehicles categorised by fuel type and technology

	Data available in 2013 database	Data available in 2017 database	Change	
Passenger cars				
Petrol HEV	22 models	82 models	+ 270%	
Petrol PHEV	6 models	45 models	+ 650%	
Diesel HEV	6 models	3 models	- 50%	Peugeot & Citroen models no longer available
Diesel PHEV	1 model	3 models	+ 300%	
EVs	12 models	30 models	+ 150%	
Vans				
Petrol HEV	None	None		
Petrol PHEV	None	1 model		
Diesel HEV	few	None		
Diesel PHEV	None	None		
EVs	13 models	4 models		

Large increases in the numbers of available petrol HEV and PHEV, and of BEV models have occurred. However, not only do there remain very few diesel HEV and PHEV in the database, but the numbers of available models have reduced. **This leads to the important recommendation that hybrid diesel vehicles should be de-emphasised, and arguably should be removed from the emission factors supplied because fleet numbers will be minimal.**

For the petrol HEV and PHEV, their type approval CO_2 values are in the public domain and could be analysed to obtain current/updates average emissions over the whole regulatory cycle. The data therefore does not provide speed related information but could be used to update/ scale the previously derived curves.

It is noted that no analogous 2018 database has yet been published. In part this may be caused by changes in the light duty type approval process.

3.2.2 Change in type approval process

At the time of the 2015 study the VCA published two sets of data because light duty vehicles could be type approved to meet either Euro 5 or Euro 6b emissions standards. The driving cycle for both these emission standards was the NEDC.

More recently new emissions standards have come into force, as summarised below for passenger cars and N1 Class 1 vans. Implementation dates for large N1 vans, Classes 2 and 3 are 12 months later.

Implementation date	PM and NOx emission standards	Driving cycle	Other changes	Implications for emission factors+
1/9/2015	All vehicles to meet Euro 6b	NEDC		Baseline values
1/9/2017	All new models cars and N1 class 1 vans to meet Euro 6d-Temp	WLTP	RDE becomes mandatory	Certification CO_2 figures will change
1/9/2018	All vehicles registered to be type approved to Euro 6c	NEDC		Baseline values
1/9/2019	All vehicles registered to be type approved to Euro 6d-Temp	WLTC	RDE becomes mandatory	Certification CO_2 figures will change even for old models

The NEDC comprises two driven components and data for a whole vehicle type were given for the two phases, and for their distance weighted average.

Vehicle certification using WLTP involves four driven components, and each vehicle registered will be given its own CO_2 emission factor averaged over the whole WLTC, calculated from the vehicle's configuration (based on its weight, tyres fitted, air drag) and extrapolated from the extremes for the vehicle's type approval family.

It is not known how VCA will report these data.

For the annual monitoring of CO_2 emissions from passenger cars (and vans) undertaken by the EEA, the database from vehicle registrations is changing from grouping vehicle registrations according to their "type" and recording how many of each vehicle type were registered, to recording individually each vehicle registered.

The reporting of "Vehicles registered in 2015: final data[4]" comprises around 440,000 rows of data and is a 73 MB uncompressed file. For the 2017 data, vehicles are registered following certification using the NEDC and WLTP regulations. The 2017 provisional data (volume 15 of the series) is 1,700 MB uncompressed file that will not load into Excel because it contains more than 1,000,000 rows of data. (It is estimated to contain around 6 million rows of data. The number of columns has also been expanded to include key WLTP certification data, e.g. vehicle family identification number and WLTP test mass (rather than mass in running order) and CO_2 emissions measured over the WLTC.

Communications with the EEA indicate that for the 2019 database, where all registrations are recorded using the WLTP regulation, the database will comprise around 15 million rows of data.

Therefore, relative to the 2015 study, vehicle certification recording of the Type 1 test of WLTP is generating much new data on CO_2 emissions/energy consumption. This will include test data for HEV and PHEV models, over the WLTP, that were not previously available. However, it may not be trivial to extract these data and use it to develop new speed-emission curves.

3.3 Utility factor

For PHEVs their driving can be sub-divided into the fraction driven using mains derived electricity, for which there are no tailpipe emissions, but there is an electric energy requirement, and the fraction where the vehicle behaves like a conventional hybrid vehicle. The utility factor (UF) weights the consumption in each driving mode according to a modelled consumer behaviour that is based on travel survey data. Widely used standardized methods are the European ECE R101 method and the US SAE J2841 method. The emission factor curves reported in the 2015 study came from the weighting of these two emission factor curves using this function, shown in Figure 3.

EC regulations and the VCA use a very simple UF calculated as follows:

UF = electric range/(electric range +25km)

This gives the simple curve shown in Figure 3 where the proportion of electric only operation increases as the electric range increases.

Since 2015 further evidence has been amassed on the "real world" ratio of the driving using the two modes. The Miles Consultancy has been highlighting discrepancies between the VCA figure and the real world performance of some PHEVs. This was also reported by LowCVP, and made the UK national headlines in November 2018[5]. In extreme cases this involved PHEVs that were never charged with mains electricity.

Two suggested alternatives have been provided by (chronologically) the International Council on Clean Transportation, and the Joint Research Council of the European Commission[6]. The latter paper is entitled: ""Alternative utility factor versus the SAE J2841 standard method for PHEV and BEV applications" was published on 30th September 2018, and is available in the journal Transport Policy.

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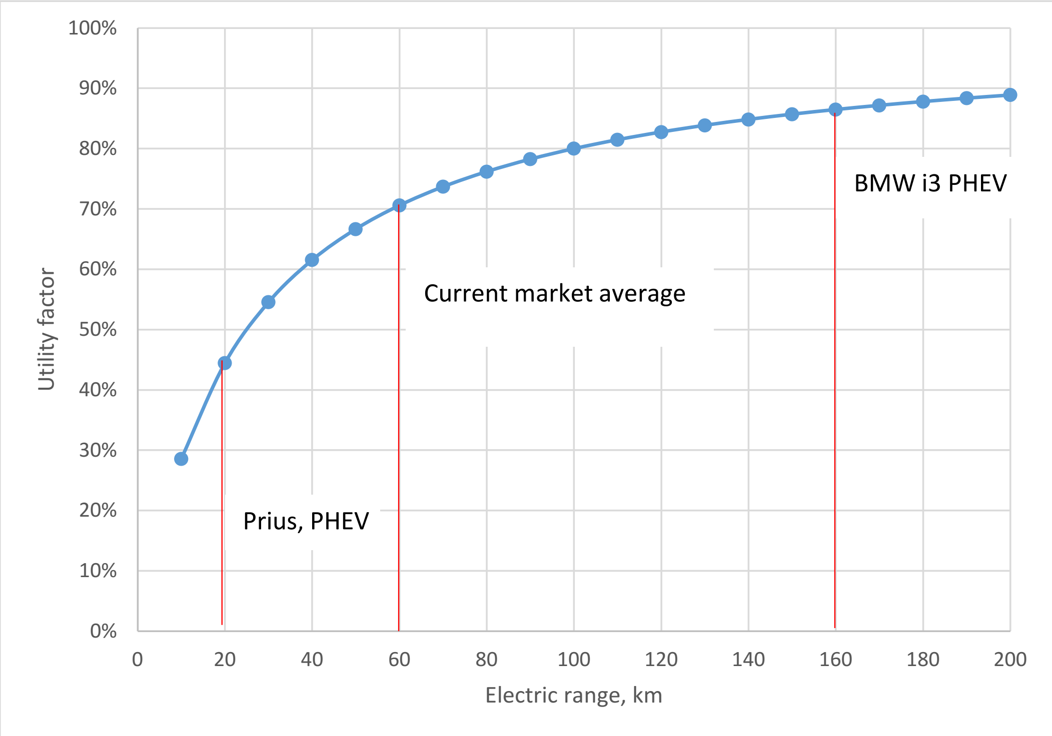
[4] This is in the EEA Report: "Monitoring of CO2 emissions from passenger cars:Data 2015: final data (Volume 12 in this series of reports)

[5] Original story available from Miles Consultancy blog https://themilesconsultancy.com/new-analysis-plug-hybrid-car-mpg-emissions-expected-spark-debate-suitability-fleet-operation/ with further highlighting by LowCVP https://www.lowcvp.org.uk/news,fleet-operator-consultancy-finds-plugin-hybrid-vehicles-are-not-efficient-for-all-types-of-operation_3706.htm, and then BBC news https://www.bbc.co.uk/news/business-46152853?intlink_from_url=https://www.bbc.co.uk/news/topics/cljev49lzr4t/electric-cars&link_location=live-reporting-story

[6] ICCT paper available from: https://www.theicct.org/sites/default/files/publications/EU-PHEV_ICCT-Briefing-Paper_280717_vF.pdf , and EC JRC paper study published in Transport Policy, **68,** (2018) 80 – 97.

Figure 3 Utility factors as a function of electric range



This new evidence and these considerations make a strong case for reviewing the nature of this function. This would impact the emissions curves for all PHEVs (diesel and petrol, both cars and vans).

3.4 Independently gathered emissions data

Measurement studies

There are three types of measurement studies that have been carried out:

- Laboratory tests using a chassis dynamometer and real world drive cycles, which is the traditional testing approach;
- Portable Emissions Monitoring Systems (PEMS) where emissions tests are carried out on vehicles in real traffic situations;
- Remote sensing data that uses a static beam projected across a road to analyse tailpipe emissions from passing vehicles.

3.4.1 Laboratory testing

These are chassis dynamometer tests using full emissions characterisation. The changes in light duty vehicle type approval processes have meant much recent laboratory emissions testing has been undertaken. Communications with test houses indicate they are over-subscribed with demands for their services outstripping supply. Therefore, there will be much recent laboratory testing undertaken, including for the new ULEV vehicles, as highlighted in Table 6.

A key question for generating emissions curves for ULEVs is its accessibility. It is anticipated that anonymised data, in terms of the modal emissions from the chassis dynamometer tests, of ULEVs with representative emissions over the whole cycle, could be obtained and analysed to generate updated emissions curves. (This would need to be done in such a way so as to maintain client confidentiality.)

3.4.2 PHEM simulation data and PEMS data from Emission Analytics

These were important sources of data for the original, 2015 study. **However, no new data have been purchased nor analysed since that study.**

3.4.3 RDE measurements using PEMS

PEMS data are collected on vehicles operating in real traffic on the road. Whilst they are less repeatable than laboratory tests and will have less detail in terms of emissions monitored, they are a very useful source of data indicating what the performance of technologies might be on the road.

The changes in light duty vehicles type approval regulations (Section 3.2.2), and specifically the introduction of Euro 6d-temp mandates the augmenting of the traditional chassis dynamometer testing (the Type 1 emissions test) with real driving emissions (RDE). Implementation dates are 1/9/2017 for new models and for all new passenger cars and N1 Class 1 vans such testing will be required from 1/9/2019. The regulations specify that the on-the-road driving emissions should be measured on a second-by-second basis, using PEMS (that meet various accuracy and precision specifications).

The important consequence for this work is that much more modal emissions data are being collected from ULEVs. Also, the regulations require that such data are publicly available. This provides a rich source of new data from which speed related emission factors for NOx can be derived. However, further work would need to be carried out to establish exactly what data on ULEVs are available and how this data could be used to generate new emission curves.

3.4.4 Remote sensing data

Remote sensing allows the collection of emissions data from vehicles as they pass a fixed monitoring point on a road. It is effectively a snap shot of emissions at one location and is matched with automatic number plate recognition (ANPR) data to link emissions to vehicles. It is a good way of collecting emission data from a very large sample of vehicles, albeit under one traffic situation, and is being used to characterise emissions from local traffic. A disadvantage of the technique is that it does not measure absolute emission factors, but ratios in pollutant emissions relative to CO_2. However, since CO_2 emission factors are relatively well understood, the technique provides a useful way of showing the range of factors for a given technology and comparing real world pollutant emissions for a range of technologies under a given traffic situation. Some studies have been used to show the ratio in NO_2/NO_x emissions for different technologies, potentially useful for this project.

The 2015 study discussed a number of studies using this approach undertaken by Kings College in London and the Institute of Transport Studies at Leeds University (ITS Leeds). Within these studies a few LEV's were captured and provide a small but useful snapshot of the emissions of these vehicles operating on the road.

Since the 2015 study Ricardo Energy & Environment have been undertaking remote sensing measurements using the AccuScan RSD 5000 system provided to Ricardo by OPUS RSE. In total over 350,000 measurements have been made. This includes around 100,000 valid vehicle emissions measurements in London as part of The Real Urban Emissions Initiative (TRUE) which seeks to supply cities with data regarding the real-world emissions of their car fleets and equip them with technical information that can be used for strategic decision-making. The TRUE initiative was established by the International Council on Clean Transportation along with the FIA Foundation, Global NCAP, Emissions Analytics, Transport and Environment and the C40 Cities. The database includes emissions from hybrids, and potentially PHEVs and would be available for Ricardo to use to develop or adjust existing emission curves for these vehicle types. Its analysis could provide comparative emissions data, e.g. comparing emissions from Euro 6b petrol hybrids with their non-hybrid counterparts.

4 HDV - Detailed consideration of data available

4.1 Overview

Vehicle categories for which speed related emission functions were generated in the 2015 study are given in Table 1. This is expanded in Table 5 where the availability of new data sources is reviewed in the final column. Generally, whilst some new data have become available there have not been major studies adding to this. So for HDV, this review of evidential data available for generating emission factor curves is structured by considering the ultra-low emission HDV available in the current fleet. This defines the potential need for such curves. The subsections below give further details on a vehicle category by vehicle category basis.

Because some ULEV vehicle categories, i.e. buses, are now more widely in service, even though they were not considered in the earlier study, Table 7 is expanded to include them.

Table 7 HGV technology categories

Vehicle fuel	Vehicle type	Emission-curves that were generated in 2015 study
	Trucks	
Dedicated methane	Rigid 16 and 26 t	CO_2, NOx and PM
	Articulated	CO_2, NOx and PM
Diesel/methane dual fuel	Rigid 16 and 26 t	CO_2, NOx and PM
	Articulated	CO_2, NOx and PM
Battery electric truck	Rigid 3.5 – 7.5 t	Energy
	Rigid 7.5 – 12 t	Energy
	Buses	
Hybrid	City buses	Not included in earlier study
Dedicated methane	City buses	Not included in earlier study
Battery electric buses	City buses	Not included in earlier study
Fuel cell buses	City buses	Not included in earlier study

4.2 Significance of various ultra-low emission HDV in the fleet

4.2.1 Dedicated methane fuelled HGV

A LowCVP study on the “Emissions testing of Gas Powered Commercial Vehicles”, has been completed and published in January 2017. The overall view of this study, and consultation with the relatively recently formed LowCVP's Commercial Vehicle Working Group, recommends that the Government: “should continue to support the development of gas vehicle infrastructure and *gas-powered vehicles,*

***particularly dedicated gas**, while increasing the supply of low carbon/renewable methane as a sustainable transport fuel in order to realize these benefits.*"[7]

This study does contain some emissions data which are available to Ricardo and could be added to the evidence base included in the generation of emission curves.

In terms of penetration into the fleet, unlike diesel/methane dual fuelled HGV, see the section below, where penetration into the fleet has stalled/reversed, dedicated methane fuelled HGV continue to be seen as viable. There are large commercial attractions because of the differential in tax between the fuel duty on diesel and methane (around £0.40 per taxed unit when VAT is included).

Iveco, who claim to be the methane engine leaders and Scania have both relatively recently announced 13 litre dedicated methane engines, of 345 kW and 300 kW peak power, respectively[8]

In addition to the largest power units described above, smaller dedicated methane fuelled engines appropriate to powering buses are being manufactured. These are considered in further detail in sub-section 4.2.4.

4.2.2 Diesel/methane dual fuelled HGV

Dual fuel methane/diesel vehicles retain the existing diesel compression ignition (CI) engine but run using a combination of diesel and methane gas fuels. The diesel provides the ignition source because it auto-ignites, but some (to most) of the power stroke's energy comes from the combustion of methane. The amount of diesel substituted by methane is called the gas substitution ratio (GSR) and depends on the duty cycle of the vehicle. The need to have some diesel present to provide the ignition source means that under low power conditions little gas is used. Overall the emissions of dual fuel methane/diesel vehicles are much more similar to their diesel counterparts than the dedicated SI methane vehicles discussed above.

The attraction of dual fuel vehicles is that the basic engine remains unaltered, and in the absence of methane refuelling infrastructure, the vehicle can revert to being a standard diesel vehicle. The principal challenge is adjusting the methane fuelling over the engine's operational envelop to ensure drivability, but at the same time to meet the Euro VI emission standards, including limits on methane slip for dual fuel vehicles.

For dual fuel vehicles, in 2015 there had been very little data. However, data generated by the Low Carbon Truck Demonstration Trial and a LowCVP project on the "Emissions testing of Gas Powered Commercial Vehicles, has since been published. However, most of the vehicles studies were Euro V compliant after-market conversions.

Summarising the key features about the diesel/methane dual fuelled trucks are:

- Most diesel/methane dual fuelled trucks that have been placed on the road were aftermarket conversions;
- The two largest companies involved were Clean Air Power, and Hardstaffs;

[7] See LowCVP report on "Emissions testing of gas-powered commercial vehicles", study for DfT, published January 2017, available from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/581859/emissions-testing-of-gas-powered-commercial-vehicles.pdf

[8] See, for example https://www.iveco.com/uk/products/pages/gas-engine-stralis-natural-power-truck.aspx and https://www.scania.com/global/en/home/experience-scania/news-and-events/events/2017/latest-gas-engine-designed-for-long-distance-transport.html

- Clean Air Power went into voluntary liquidation in Sept 2015, and was sold to Vayon Holdings Ltd;
- Harstaff too were bought by Vayon Holdings Ltd in Sept 2015;
- Vayon closed Clean Air Power https://www.greencarcongress.com/2016/04/20160405-vayoncap.html ;
- Vayon Hardstaffs creditors meeting occurred in Nov 2016 as Hardstaffs too ceased trading: https://www.thegazette.co.uk/notice/2638898.

Consequently, the principal suppliers of dual fuel vehicles have ceased trading since 2015. There are other companies who undertake aftermarket conversions, modifying pure diesel engines to be dual fuelled (e.g. Prins and G-Volution) but our research has not indicated there are any vehicles that meet Euro VI emissions standards on the market.

With regards to vehicle OEMs, rather than aftermarket conversions, Volvo do appear to have a product[9].

The overall conclusion from this review of evidence regarding diesel/methane dual fuel trucks is that these vehicles are not being used in significant numbers, and there is no clear route to market, so currently there is no reason to seek to update the emission curves.

Similarly, it is also noted that there do not appear to be diesel/methane dual fuel buses, and so there is no recommendation that emission curves are generated for this vehicle category.

4.2.3 Battery electric and hydrogen fuelled HGV

We are not aware of major significant additional data becoming available for this group of ULEV trucks. Moreover, DfT's "Road to zero" report summarises the current position in its appendices, stating that for both 18 tonne HGV (Figure A4) and 44 tonne HGV (Figure A5) *"Electric and hydrogen trucks are not yet market ready, but would offer the most significant GHG and pollutant emission reductions."*. Therefore, at present it is not suggested that energy consumption (or emissions) data are estimated from available evidence as an immediate priority.

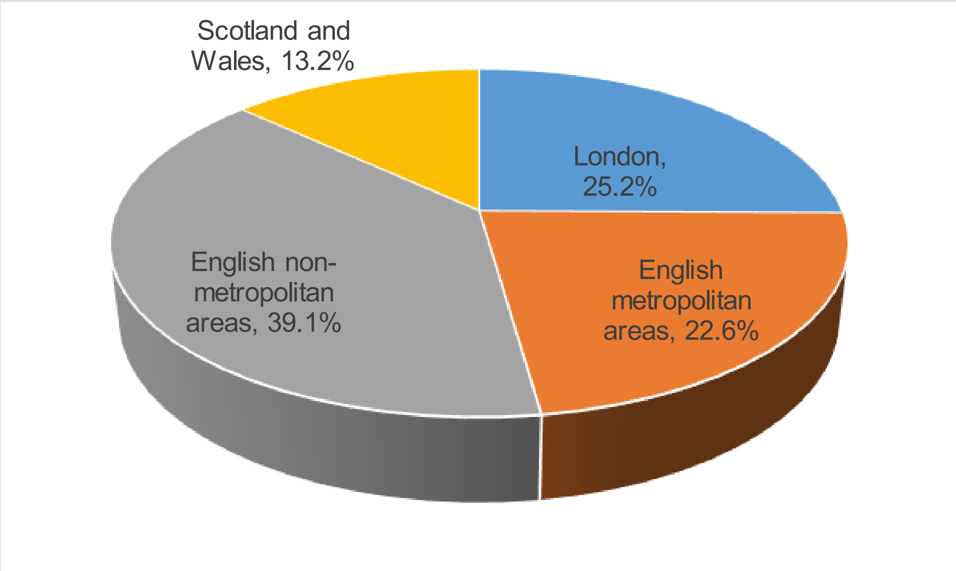
4.2.4 Ultra-low emission buses (hybrids, battery electric, methane and hydrogen)

DfT statistics (December 2017) indicate there are around 40,300 buses and coaches in Great Britain, with around 35,000 in England[10]. This is shown in Figure 4. Around 10,150 of these are in London (25.2% of the overall total, and 29% of the English total). The DfT statistics do not publish data on the powertrains used for these vehicles.

[9] Information on Volvo dual fuel product from https://dieselnet.com/news/2017/10volvo.php

[10] DfT bus statistics taken from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/666759/annual-bus-statistics-year-ending-march-2017.pdf with further detailed analysis coming from https://www.gov.uk/government/statistical-data-sets/bus06-vehicle-stocks-technology-and-equipment#table-bus0602

Figure 4 Numbers of buses and coaches in Great Britain



Transport for London (TfL) operate around 9,550 of London's buses. The powertrain of these include hybrids, electrics and 8 hydrogen buses, see Figure 5[11]. This shows how around 30% are hybrid buses, and electric buses are approaching 1% of the fleet. The NAEI already uses data provided by TfL on the proportions of hybrid buses in the fleet and the reductions in emissions they lead to relative to conventional diesel buses. These are based on emissions measured over a London bus test cycle. TfL do not operate any methane fuelled buses.

However, a brief survey of the literature indicates that other operators and areas are increasingly using ULEV buses. Specific examples include:

- One of the UK's biggest national bus operators, Arriva, has invested in a new fleet of 174 hybrid buses, with the help of grants from OLEV, the government's Office for Low Emission Vehicles[12].
- Both Merseytravel and Transport for London were beneficiaries under the £30 million Low Emission Bus Scheme, allowing 123 of the new Volvo diesel-electric hybrid buses to enter service in London, while a further 51 will operate on selected routes around Merseyside[12].
- Oxford bus company have recently added 14 brand new hybrid buses which are the very first of a new design by Alexander Dennis (who built the bodies for the 200-series Scanias). They are the first "Euro VI" buses for service in Oxford, and also the first roll-out of the Gyrodrive hybrid power system. (Williams engineering KERS system). This takes the number of hybrids in the Oxford Bus Company's fleet to 83 out of a fleet of 182 buses and coaches (45.6%)[13].

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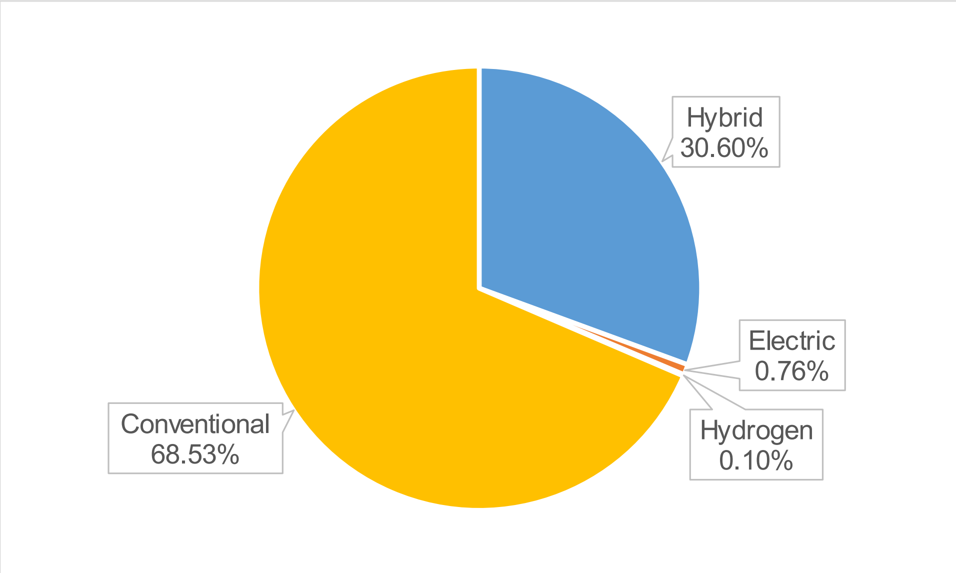
[11] Data taken from 2017 source: https://data.london.gov.uk/dataset/number-buses-type-bus-london Non-corroborated data indicates that current non-conventional powertrain fraction has continued to increase

[12] See SMMT announcement: https://www.smmt.co.uk/2017/01/major-uk-operator-invests-in-new-hybrid-bus-fleet/

[13] For announcement about latest additions to Oxford Bus Company's fleet see https://www.oxfordbus.co.uk/hybrids/. Statistics taken from October 2018 fleet list, downloaded from https://assets.goaheadbus.com/media/cms_page_media/72/Oxford%20Bus%20Group%20Current%20Fleet%20List.pdf

Figure 5 Powertrain types for TfL's buses in London



Scope in terms of

- The other major operator in Oxford city, Stagecoach, has a lower percentage of hybrids, although that is in the context of a larger fraction of their fleet being coaches that shuttle between Oxford and London[14].
- Reading has adopted a different approach with over half its fleet being ULEV buses, including 31 hybrid buses, and 57 methane fuelled vehicles. These are more than half their total fleet of 168 buses[15]. Bids for the provision of methane fuelled buses came from Scania and MAN – indicating companies with commercially available methane buses at the time of tendering.

The above references emphasise the importance of ULEV buses in terms of their penetration into the fleet. Combined with these rapid increases in numbers, there has been a rapid collection of data regarding their use. TfL in particular have invested considerable resources into quantifying the environmental impact of the bus powertrain options they use. Detailed measurement campaigns, principally undertaken in collaboration with the VTEC facility at Millbrook Proving Ground, and published high level overviews[16]. Another example are case studies published following the introduction of new vehicles (e.g. Reading indicating that their methane fuelled buses lead to a 30 – 50% reduction in NOx emissions relative to comparable diesel technologies)[17]. Together these indicate that there is already a strong body of emissions evidence that is available on which emissions curves could be based.

Conversations with these operators indicate that they are willing to share, up to a point, data that could be used to generate new emission curves, which, at the same time, promotes their use of these ULEVs. Further avenues for potentially acquiring data include LowCVP's Bus Working Group, and the OLEV Low Emission Bus scheme where £30 million has been allocated to low emission buses. As for chassis laboratory testing of LDVs, provided that customer confidentiality is preserved, recently collected data could be used for generating new emission curves for these important ULEVs that operate in urban areas.

[14] For Stagecoach's Oxford fleet list see: http://www.ukbuses.co.uk/fleet/stagecoachoxfordshire.pdf

[15] Data taken from Reading Buses website: https://www.reading-buses.co.uk/about-us

[16] See for example a presentation by F Coyle on "Cutting carbon from the London bus fleet", https://www.lowcvp.org.uk/assets/presentations/Transport%20for%20London%20-%20Finn%20Coyle.pdf

[17] See for example http://www.clean-fleets.eu/fileadmin/files/documents/Publications/Reading_CleanFleets_CaseStudy.pdf

5 Conclusions

In this project we revisit the evidence used to develop speed-emission curves for non-conventional Internal Combustion Engine (ICE) vehicles, completed by Ricardo in 2015 in a report to DfT “Speed emission/energy curves for ultra-low emission vehicles”. This project comprises a short scoping study that examines whether there is sufficient new evidence to merit revisiting and possibly updating the emission curves for these vehicles.

5.1.1 Recommendations for LDV

Key sources of data, and how they have changed since the 2015 published study, are summarised in Table 5. The recommendation regarding what could be undertaken, based on this analysis, is:

1. Revisiting the CO_2 emissions/energy consumption based on most recent data within VCA new car CO_2 database for petrol and diesel HEV and BEV passenger cars. (foundational data as shown in Figure 1). This data is in the public domain and whilst it does not provide speed related information, it could be used to update/ scale the previously derived curves.
2. Potentially augmenting/checking conclusions from 1 (above) by assessing what data is available within the annual monitoring of CO_2 emissions from passenger cars (and vans) published by the EEA, using the new WLTP reporting format. Like the VCA data, this data is in the public domain but the format of the information has changes markedly, and it is somewhat unknown as to what data can be extracted and analysed.
3. Revisiting the “utility factors” used to obtain emission curves from PHEVs (both cars and vans) from HEV curves based on information from JRC. This is based on public domain research papers, i.e. is accessible information.
4. Remote sensing – examination of new Ricardo Energy & Environment database, especially for validation of NOx emissions curves for light duty ULEVs. Because these are our data they are accessible.
5. Investigating the accessibility of data gathered for “Real driving emissions” testing, with emissions monitored by PEMS. A potentially rich source of new modal data. However, it is not known how accessible these data may be.
6. Checking whether emission factors within COPERT 5.2.0 for ULEV categories have changed markedly for PM, NOx or energy from those use from COPERT 4 (v10/11). This, like the following item, is based on public domain information and emission factors.
7. Keeping a watching brief on next release of COPERT because indications are an update “of alternatively fuelled vehicles (LPG, CNG, hybrids, electric)” is planned.
8. De-emphasising the importance of diesel HEV and PHEV (and arguably removing these vehicle categories from the emission factors supplied because fleet numbers will be minimal).

Additional recommendations are the consideration of the disaggregating of petrol HEV into different powertrain architectures – e.g. parallel and series HEV. This is because the different powertrain types (e.g. the Electric London taxi, and BMW i3 series hybrids may well have markedly different emission curves relative to parallel hybrids, e.g. from Toyota and Lexus.

5.1.2 Recommendations for HDV

For heavy duty vehicles, the details of Chapter 4 lead to the following two key recommendations:

a) Dual fuel vehicles should be de-emphasised – since anticipated future vehicle numbers are expected to be very low;
b) ULEV buses should be included. These include: hybrids, dedicated methane/natural gas, battery electric and (hydrogen) fuel cell buses. Data are potentially available from bus fleet

operators, LowCVP and OLEV but customer and vehicle confidentiality would need to be preserved during the analysis of the data to generate new speed emission factors.

5.2 Priorities of recommendations

The preceding sections gave a systematic review of the recommendations for LDV and HDV, summarising the preceding chapters in the order the vehicle categories were considered. It does not provide any prioritisation of the options. The following tables do this by ordering the ten recommendations of the previous sections in order of decreasing strength, i.e with the highest priority recommendations given first. The prioritisation is largely based on accessibility of data, the benefits that pursuing the recommendations will bring and any effort required for further data analysis.

Recommendations regarding light duty vehicles in order of decreasing prioritisation

	Recommendation	Key information sources /availability	Prioritised recommendation
3	Revisiting the “utility factors” used to obtain emission curves from PHEVs (both cars and vans)	Public domain information from JRC publication	No dependencies – all public domain – worth pursuing
6	Checking whether emission factors within COPERT 5.2.0 for ULEV categories have changed markedly for PM, NOx or energy from those use from COPERT 4 (v10/11).	Compare COPERT 4 & COPERT 5 – for energy, NOx & PM (all publically available	No dependencies – all public domain – worth pursuing
b	ULEV buses should be included, specifically hybrids, dedicated methane/natural gas, battery electric and (hydrogen) fuel cell buses.	We have data we use for projections studies COPERT has data for urban CNG vehicles TfL are generally keen to publicise their ULEV buses emission characteristics	No dependencies – all public domain – worth pursuing
8	De-emphasising the importance of diesel HEV and PHEV (and arguably removing these vehicle categories from the emission factors supplied because fleet numbers will be minimal)	Based reductions in number of models available as evidenced in VCA new car CO_2 database (publically available)	No dependencies – all public domain – worth pursuing
1	Revisiting the CO_2 emissions/energy consumption based on most recent data within VCA new car CO_2 database for petrol and diesel HEV and BEV passenger cars.	VCA new car CO_2 database (publically available)	No dependencies – all public domain – worth pursuing
2	Looking at EEA WLTP data for latest years registrations to see if NEDC – WLTP causes marked changes	Uses EEA	No dependencies – all public domain – worth pursuing
7	Keeping a watching brief on next release of COPERT because indications are an update “of alternatively fuelled vehicles (LPG, CNG, hybrids, electric)” is planned	Would use publically available information	Minimal effort required. Can only be done once next COPERT is released

4	Remote sensing – examination of new Ricardo Energy & Environment database, especially for validation of NOx emissions curves for light duty ULEVs.	Database within Ricardo Energy & Environment's control	Possibility it does not reveal new useful emission factors
5	Investigating the accessibility of data gathered for "Real driving emissions" testing, with emissions monitored by PEMS. A potentially rich source of new modal data. However, it is not known how accessible these data may be.	This would not use data currently in the public domain	Probably not worth pursuing currently, but this data will increasingly become available

Recommendations regarding ULEVs that are not significant in the fleet, and for which we now recommend emissions functions are both not required, and are unreliable

	Recommendation	Prioritised recommendation
a	Dual fuel (diesel/methane) HDVs vehicles should be de-emphasised	Do nothing further
8	Diesel hybrid light duty vehicles should also be de-emphasised, see for example scarce number of models from Table 6	Do nothing further

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