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# Support for the in-service verification of CO2 emissions of new light- and heavy-duty vehicles

Final report

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Unit B.3 — Mobility (I): Road
*Contact: Filip FRANCOIS*

*E-mail:* *EC-CO2-LDV-IMPLEMENTATION@ec.europa.eu*
*Filip.FRANCOIS@ec.europa.eu*

*European Commission*
*B-1049 Brussels*

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# Support for the in-service verification of $CO_2$ emissions of new light- and heavy-duty vehicles

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## Final Report

19 January 2023

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# Executive Summary

This is the final report of the study "Support for the in-service verification of $CO_2$ emissions of new light- and heavy-duty vehicles", aiming to provide the technical support to the Commission for the development of the relevant requirements for the In-Service Verification (ISV) of $CO_2$ emissions of new light- and heavy-duty vehicles.

The current study analysed and developed various elements and procedures for the ISV of $CO_2$ emissions of new LDV and HDV as foreseen in Regulations (EU) 2019/631 (Article 13 and Article 7(9)) and 2019/1242 (Article 13 and Article 9). The aim of such procedures shall be to verify the correspondence of the certified $CO_2$ emissions with the performance of vehicles in-service on the same type-approval procedure, as well as to detect strategies aiming at artificially improving $CO_2$ emissions during Type Approval (TA).

Initially in this context, a screening of the relevant existing regulations was conducted, covering legislations from both the EU and other areas of the world (US, China, Japan, South Korea, India). The target was to identify elements and procedures of those legislations that could be useful for the ISV of $CO_2$ emissions. To that aim, and after analysing the various regulations, some useful elements, from both EU and non-EU regulations, were isolated and were further used as input to the development of the actual ISV procedures.

In the next step, the main guiding principles of the ISV procedure were developed, considering different verification options (testing and simulation), and covering all the main elements of the procedure, such as vehicle categories, responsible parties and funding of the procedure, family criteria, sample share and frequency, risk assessment, vehicle selection, sample size, quality assurance, deviations, statistical procedures, corrections, reporting. The main principles developed in this task, together with the useful elements retrieved in existing regulations, were used as inputs in the development of the actual methods that could be used in the $CO_2$ ISV procedure.

After making the general outline of the ISV procedure, the actual methodologies were developed, covering three main elements:

i. Verification procedure for the road load test results
ii. Verification procedure for the chassis-dynamometer test results
iii. Procedures for detecting strategies aiming at an artificial improvement of the vehicle $CO_2$ performance in the type approval

Two approaches were examined, as follows:

1. "parallel" approach, where each one of the above elements (i-iii) practically runs independently
2. "sequential" approach, where the above elements (i-iii) run in order – element [ii] depends on element [i], while the procedure may integrate some indicative flags for element [iii]

The advantages and disadvantages of each approach were evaluated. However, independently of the followed approach, the actual methodologies for the verification of road-load and $CO_2$ emissions are the same and practically replicate the type-approval procedure. The evaluation is made on the family level and the decision is made according to a statistical procedure, applying pass/fail criteria, similar to the CoP procedure. For the evaluation of the statistical procedure, indicative results have been produced, showing the pass rate for various combinations of the statistical parameters.

After the testing activities of the ISV procedure and according to the outcome of the decision based on the statistical procedure, the necessary corrections shall be applied. Different cases have been identified here, depending on the pass or fail of the road load (RL, or equivalently the cycle energy demand

(CED)) and $CO_2$ emissions. In all cases, an updated value of $CO_2$ emissions is determined, while in case of fail of the RL, then RL coefficients are also corrected to ensure consistency of the values reported on the CoC.

# Abbreviations and acronyms

| | |
|---|---|
| 2WD/4WD | 2 / 4 Wheel Drive |
| ADAC | Allgemeiner Deutscher Automobil-Club (German motoring association) |
| AdBlue (or DEF) | Diesel Exhaust Fluid; aqueous urea solution for SCR |
| AES | Alternative Emissions Strategy |
| ATCT | Ambient Temperature Correction Test |
| BAB130 | Bundesautobahn 130 kph; motorway test cycle for vehicle dyno |
| CED | Cycle Energy Demand |
| CF | Conformity Factor |
| $CO_2$ | Carbon Dioxide |
| $CO_2$MPAS | $CO_2$ Model for PAssenger and commercial vehicles Simulation (JRC tool) |
| CoP | Conformity of Production |
| CoC | Certificate of Conformity |
| E5, E10, E85 | Biofuel blends of 5%, 10%, 85%, in gasoline |
| EC | European Commission |
| ECU | Engine Control Unit |
| EEA | European Environmental Agency |
| EU | European Union |
| FC | Fuel Consumption |
| GPS | Global Positioning System, as used for satellite navigation |
| HEV | Hybrid Electric Vehicle |
| HDE | Heavy Duty Engine |
| HDV | Heavy Duty Vehicle |
| ICE | Internal Combustion Engine |
| ISC | In Service Conformity |
| ISV | In Service Verification |
| JRC | Joint Research Centre |
| LCV | Light Commercial Vehicle |
| LDV | Light duty vehicle |
| MaS | Market Surveillance |
| MIL | Malfunction Indicator Light – OBD warning on dash |
| NEDC | New European Driving Cycle |
| NGO | Non-Governmental Organization |
| NOVC-HEV | Non-Off Vehicle Charging Hybrid Electric vehicle |
| NTE | Not To Exceed |
| NVH | Noise, vibration, and harshness (of a vehicle) |
| OBD | On Board Diagnostics |
| OBFCM | On-Board Fuel and/or energy Consumption Monitoring |
| OEM | Original Equipment Manufacturer |
| OTA | Over the Air |
| OVC-HEV | Off Vehicle Charging (plug-in) Hybrid Electric vehicle (PHEV) |
| PEMS | Portable Emission Measurement System |
| PHEV | Plug-in Hybrid Electric Vehicle |
| PM | Particle Mass |
| PN | Particle Number |

| | |
|---|---|
| PTI | Periodical Technical Inspection |
| RDE | Real Drive Emissions |
| RL | Road Load |
| RON | Research Octane Number – measure of gasoline resistance to knock |
| RRC | Rolling Resistance Coefficient |
| RTS50 / RTS95 | Randomised Standard Test (for vehicle dyno) at 50th and 95th percentile– intended to represent medium and upper limits of driving dynamics |
| RW | Real World |
| SCR | Selective Catalytic Reduction |
| SIM | Subscriber Identification Module |
| TA | Type Approval |
| TAA | Type Approval Authority |
| TPMS | Tyre Pressure Monitoring System |
| VDOP | Variable Displacement Oil Pump |
| VECTO | Vehicle Energy Consumption calculation Tool |
| VIN | Vehicle Identification Number |
| VTP | Verification Testing Procedure |
| WLTC/WLTP | Worldwide harmonised Light vehicle Test Cycle/Procedure |

# 1 Introduction

## 1.1 Background

This is the final report of the study "Support for the in-service verification of $CO_2$ emissions of new light- and heavy-duty vehicles", aiming to provide the technical support to the Commission for the development of the relevant requirements for the in-service verification (ISV) of $CO_2$ emissions of new light- and heavy-duty vehicles.

Determination of the official fuel consumption and $CO_2$ emissions in the EU is currently realized based on Regulation (EU) 2017/1151 (WLTP) for light-duty vehicles (LDV) and Regulation (EU) 2017/2400 (VECTO) for heavy-duty vehicles (HDV). In the case of LDV the fuel consumption and $CO_2$ emissions are determined via laboratory tests performed on a chassis dynamometer. Vehicle driving resistance is simulated by the chassis dynamometer according to a polynomial equation, which expresses the resistance force (aerodynamic drag and rolling resistance) as a function of the vehicle velocity, known as the "Road Load (RL)". The RL function (or the coefficients of the polynomial) is determined experimentally with a coast-down test (or equivalent), prior to the chassis dynamometer test. For HDV, $CO_2$ emissions are certified using the Vehicle Energy Consumption calculation Tool (VECTO). This tool takes into account the characteristics of the components, separate technical units and vehicle systems that have an impact on the $CO_2$ emissions and fuel consumption, such as the engine, the gearbox, the axles, the tyres etc.

The $CO_2$ emissions standards are defined with the Regulations (EU) 2019/631 and 2019/1242 for LDV and HDV, respectively. Both regulations contain provisions for the in-service verification of $CO_2$ emissions (Article 13). For LDV, $CO_2$ emissions are recorded in the Certificate of Conformity (CoC) and are verified by manufacturers on the production line as part of the Conformity of Production (CoP) procedure. However, a procedure for the verification of the $CO_2$ emissions of vehicles in-service is not yet in place. For HDV, a Verification Testing Procedure (VTP) is included in Regulation (EU) 2017/2400 at production/TA stage, but an in-service verification procedure is not yet in place. The VTP consists of an on-road test carried-out by the manufacturer and verified by the type-approval authority (TAA) with the application of VECTO. Such a methodology, that combines experimental testing and VECTO simulation for fuel consumption may be used as a reference methodology for the development of the ISV procedure.

## 1.2 Objectives of the study

The current project aims at assisting the Commission (DG CLIMA) in developing the guiding principles and detailed procedures for the in-service verification of $CO_2$ emissions of new LDV and HDV as foreseen in Regulations (EU) 2019/631 (Article 13 and Article 7(9)) and 2019/1242 (Article 13 and Article 9). The aim of such procedures shall be to verify the correspondence of the certified $CO_2$ emissions with the performance of vehicles in-service on the same type-approval procedure, as well as to detect strategies aiming at artificially improving $CO_2$ emissions during type approval (TA).

Specifically, the scope of assignment comprises the following major components:

- Task 1: Initial mapping of the relevant existing regulations that contain useful provisions for in-service verification of $CO_2$ emissions, for both LDV and HDV.
- Task 2: Setting the guiding principles and overarching criteria to be considered in the procedure for the in-service verification of $CO_2$ emissions for LDV.
- Task 3: This task consists of the following sub-tasks:

  - Elaboration of possible approaches allowing TAAs to verify the actual road-load of LDV and the corresponding $CO_2$ emissions of WLTP.
  - Elaboration of detailed verification procedure of the results of WLTP chassis-dynamometer testing
  - Development of a methodology for the detection of strategies aiming at artificially improving $CO_2$ emissions of LDV during the type-approval test.
- Task 4: Development of a methodology for correcting the average specific $CO_2$ emissions, in case that deviations are found between certified and in-service values or if strategies aiming at artificially improving $CO_2$ emissions during the type-approval test are detected.

The following chapters present the results of the work that has been carried out in the context of this study, concluding to a number of proposals by CLOVE. The final selection of the actual procedures and specific parameters should be done by the Commission as part of the implementing act.

# 2 Task 1: Mapping of relevant existing legislative provisions (LDV and HDV)

## 2.1 Introduction

As basis for the following tasks, a summary overview of existing regulations with relevance for verifying and correcting in-service vehicle's $CO_2$ emissions was elaborated. The main focus was to analyse which of the provisions in the regulations:

- can support an in-service verification (ISV) procedure for $CO_2$ emissions of LDVs
- are relevant for the correction of the fleet specific $CO_2$ values in case of deviations found during the in-service verification procedure for LDVs and HDVs
- may be a barrier for one of the aforementioned objectives.

Provisions from relevant EU regulations on test and evaluation procedures, data access and responsibilities that might be used as elements of the $CO_2$ in-service verification were identified. Moreover, relevant non-EU regulations were looked at. In particular, the following aspects are considered:

- Vehicle test procedures concerning the recording of fuel consumption and/or $CO_2$ mass flows.
- Accuracy demands defined for the measurement equipment (mainly for speed, torque, rpm, $CO_2$ and fuel flow).
- Operation modes covered, measures to be recorded and access rights to the test data for:
    - Chassis dyno (LDV) and engine test stand procedures (HDE),
    - On-board test procedures.
- Provisions and responsibilities for vehicle selections for CoP, MaS, ISC and RDE.
- Responsibilities for the tests, for the evaluation and for the storage of test data (including instantaneous measured data).
- Existing methods and tools to simulate $CO_2$ emissions (i.e. $CO_2$MPAS and VECTO) and information on model uncertainties.
- Existing pass/fail criteria for $CO_2$ and fuel flow as well as for criteria pollutants.
- Provisions for adaptive emission control strategies allowed[1].

A summary of relevant regulations identified and recommendations for Tasks 2, 3 and 4 is given in the following subchapters.

## 2.2 Relevant EU LDV and HDV regulations

### 2.2.1 Relevant LDV regulations

a) TA Framework Regulation

This Regulation aims to describe the procedures that shall be followed during the TA of the light duty vehicles. The regulation describes all the steps, the processes, the technical details and the provisions regarding the preparation and the certification test that is conducted during the TA. Furthermore, the regulation lays down the provisions and requirements for the placing on the market of all new

[1] E.g. the combustion control from a diesel car depends on the temperature level of the coolant and of the after-treatment system. Cold after-treatment systems need active heating from the engine while an optimal SCR temperature allows higher raw exhaust NOx levels and thus better fuel efficiency settings. Such control algorithms result in variable fuel efficiencies at a given engine operation point, which may be an issue in task 3. Also, the AES (Auxiliary Emission Strategy) provisions in RDE may be relevant for task 3.

vehicles, systems, components and separate technical units. In addition, it includes the requirements for the market surveillance of the vehicles and their parts and equipment.

b) The regulations related to the TA framework are: EU Regulations 2017/1151, 2017/1152, 2017/1153, 2017/1154, 2017/2400, 2018/858, 2018/1832, 2019/318)

c) General elements from emission type approval regulation (WLTP)

The test procedures for the determination of $CO_2$ and criteria pollutant emissions ($NO_x$, CO, HC, PM, PN) for the emission type approval of new LDV are set out in the Regulation (EU) 2017/1151 and its amendments. In the so-called Type 1 test the vehicle is measured in the WLTC cycle on the chassis dyno with cold start of the engine at 23 °C ambient temperature. The dyno is programmed to simulate the road load (RL) of the vehicle, which may be determined by various procedures (coast-down test, torque meter method, wind tunnel), as described in Regulation (EU) 2017/1151.

In the WLTP tests, within a $CO_2$ interpolation family (vehicles with same internal combustion engine, operation strategy of all $CO_2$ emission influencing components within the powertrain, same transmission type etc.), the vehicle H (producing the highest cycle energy) shall be measured. In addition, the vehicle L (producing the lowest cycle energy and which must not differ more than 30 g/km or 20% of the g $CO_2$/km from vehicle H, whichever value is the lower) can be measured. In selecting the test vehicles, the manufacturer and approval authority shall agree which vehicle models are representative for the H and the L vehicle in the $CO_2$ interpolation family. For each new manufactured and registered vehicle, the $CO_2$ emissions are interpolated based on the vehicle H and vehicle L emission values of the interpolation family. The $CO_2$ emissions of each vehicle can be found on the CoC.

For the WLTP-chassis dyno test the auxiliary devices (like e.g., air conditioning) are switched off or deactivated unless their operation is required to run the vehicle. For type approval, the vehicle shall have been run-in and driven between 3,000 and 15,000 km before the WLTP test.

Additional to the 23°C ambient temperature test, one vehicle per ambient temperature correction test (ATCT) family shall also be measured at 14 °C to determine the $CO_2$ emissions under such temperature conditions. For all other vehicles of the ATCT family, the $CO_2$ values can be calculated based on the correction factor between 23 °C and 14 °C of the tested vehicle.

In case of the existence of an Auxiliary Emission Strategy (AES), the manufacturer is obliged to provide an extended documentation package, as described in Appendix 3a of Annex I to Regulation 2017/1151. Such documentation is mandatory for the TAA so that they are able to assess the use of the AES taking into account the prohibition of defeat devices.

d) Real Driving Emissions and PEMS

Beside the WLTP chassis dyno test, the emission type approval procedures, starting from EURO 6c, also demand on-road emission tests in real driving emissions (RDE) patterns, applying portable emission measurement systems (PEMS). The RDE tests are performed directly after soaking at ambient temperatures down to -7 °C for EURO 6d vehicles.

For RDE tests the air conditioning system or other auxiliary devices shall be operated in a way which corresponds to their use at real driving on the road.

With Regulations (EU) 2017/1154 and 2018/1832 ("RDE package" 3 and 4, respectively) RDE provisions have been completed in the WLTP Regulation (EU) 2017/1151. For RDE tests, emission limits for the pollutants $NO_x$ and PN apply and an ISC procedure for RDE is set out. The $CO_2$ emission values determined during RDE tests are used in a weighting function for the pollutants to correct RDE tests with different driving styles. According to Regulation (EU) 2017/1151 the permissible g $CO_2$ /km tolerance of the PEMS result in the WLTP test is ±10 g/km or 10 % of the laboratory reference, whichever is larger.

WLTP and RDE type approval tests are carried out by the manufacturer with the presence of the type approval authority. Type approval authorities can delegate the supervision to the technical services.

e) CoP provisions

Conformity of Production (CoP) basic principles and provisions are set out in the TA framework Regulation (EU) 2018/858 (Article 31 and Annex IV). The detailed procedures are set out in Annex I, paragraph 4 of Regulation (EU) 2017/1151. The manufacturer shall check the conformity of production for $CO_2$ emissions and criterion pollutants by testing the vehicle according to a WLTP type 1 test. The frequency of CoP testing shall be based on a risk assessment methodology, for the type 1 test with a minimum frequency of one per 5 000 vehicles produced per interpolation family or once per year, whichever comes first.

For $CO_2$ emissions, the CoP-limit value shall be the value determined by the manufacturer for the selected vehicle in accordance with the interpolation methodology. When checking the conformity of production for $CO_2$, the vehicle manufacturer may use a fixed evolution coefficient (EvC) of 0.98 to the measured $CO_2$ values at new CoP vehicles. As alternative, he may determine his own EvC by measurements, where the EvC function is fitted as natural logarithmic curve. All the conformity of production tests may be conducted with commercial fuel.

The $CO_2$ emissions verification for conformity of production of OVC-HEVs shall be tested according to the charge-sustaining WLTP test.

One important aspect of the CoP procedure is the statistical evaluation of the tests results for the decision of the pass or fail for the CoP family. The statistical method is based on a sequential sampling approach and the parameter that is evaluated is the average from the ratio of tested $CO_2$ over the declared $CO_2$. The calculated average value is compared to a lower and upper limit defined according to Paragraph 4 of Appendix 1 to ANNEX 1 of (EU) Regulation 2017/1151. The main parameter that affects the definition of the limits is the bias or A factor, that is 1.01 for the CoP procedure in case of $CO_2$ emissions. The minimum number of tests is three while the tests consecutively increase until a pass or fail decision is reached.

f) In-Service Conformity testing of pollutants (ISC)

The in-service conformity measures shall confirm the functionality of the pollution control devices during the normal useful life of the vehicles under normal conditions of use according to Article 9 and Annex II resp. of Regulation (EU) 2017/1151. The manufacturer shall perform ISC testing for criterion pollutants among others for the WLTP type 1 and type 6 test and at least for all in-service conformity-families. The manufacturer may also perform RDE tests for all or part of the in-service conformity families.

The type approval authority shall check an appropriate number of in-service conformity families each year. Accredited laboratories or technical services may perform checks on any number of in-service conformity families each year. With respect to a correct vehicle selection there are a couple of general requirements to be fulfilled. For example, a vehicle shall not be selected for testing if the information stored in the on-board computer shows that the vehicle has operated after a fault code was stored and a relatively prompt repair was not carried out. Also, vehicles should not be used for in-service verification if e.g. the vehicle is not registered in EU, was adapted or used for racing / motor sports, any unauthorised devices were installed or used with wrong fuel type / non-commercially available EU-quality fuel. The vehicle shall have been in-service for at least 15 000 km or 6 months, whichever the later, and for no more than 100 000 km or 5 years, whichever the sooner. There shall be a maintenance record to show that the vehicle has been properly maintained. The manufacturer shall not be obliged to carry out an audit if the annual sales of that vehicle type are less than 5 000 across EU. Test results shall not be multiplied by deterioration factors. Additional details regarding the proposal for the vehicle selection and the conditions of the vehicles used for in-service verification are presented in Section 3.11.

A statistical approach is used for the evaluation of the In-service conformity and the decision on the compliance of the PEMS family with the declared emission values. The method applied is based on a sequential sampling. In contrast to the statistical approach used for the CoP, during ISC the emissions from the test of the individual vehicle is compared to the limit. If it is below then it is considered as a pass, while in case that exceeds the limit it is considered as a fail. The cumulative number of pass and fail determines the decision for the whole family, a pass or fail, or the continuation of the testing, in case of undefined. The guiding principles for the sample size are also mentioned in Section 3.12.

g) Market Surveillance (MaS)

In Chapter II (Article 6 and 8) of Regulation (EU) 2018/858 the requirements for market surveillance (MaS) of vehicles, systems, components and separate technical units that are subject to approval are laid down. Market surveillance means the activities carried out and measures taken by the market surveillance authorities to ensure that vehicles comply with the requirements set out in the regulations (incl. on emissions). MaS tests may include WLTP and RDE tests.

Regulation (EU) 2018/858 provides the means for ensuring that, in the case of deviations, remedial measures are taken by the manufacturer, and that in the case of non-compliance, the European Commission is able to impose administrative fines. The framework also acknowledges the importance of third parties being allowed to perform independent testing of vehicles and having access to necessary data.

The relevance of MaS with $CO_2$ emissions ISV procedure is described in Section 4.4.

h) Real-world fuel consumption

Regulation (EU) 2018/1832 requires new passenger cars and light commercial vehicles to be equipped with on-board fuel consumption monitoring (OBFCM) devices from 2021 on. These shall be used to determine the fuel and/or electric energy real-world consumption of vehicles used on the road. The monitored lifetime values are stored on board.

The manufacturer shall ensure that, at type approval, the accuracy of the OBFCM device, is ±5%.

According to Regulation (EU) 2019/631 the European Commission shall regularly collect the OBFCM data . The procedures to monitor and report the relevant data are set out in Regulation (EU) 2021/392.

i) WLTP-NEDC Correlation Exercise ($CO_2$MPAS simulation tool)

Until 2020, the $CO_2$ emission targets for new light-duty vehicles were based on the NEDC test procedures. To convert the WLTP-based test results to the equivalent NEDC-based values, the software $CO_2$MPAS (https://co2mpas.io/) was developed at the Joint Research Centre (JRC)[2]. $CO_2$MPAS is a longitudinal-dynamics backward-simulation programme in order to determine NEDC-based $CO_2$ and fuel-consumption values of passenger cars and light commercial vehicles from physically measured WLTP-based ones.

The following input is needed for $CO_2$MPAS to run:

- Vehicle, engine and gearbox parameters

[2] Supported as well from the contract "Simulation and testing of light duty vehicles with a view to ensuring the correlation of $CO_2$ emission values measured on NEDC and WLTP" and its follow-up activities.

- WLTP and NEDC road-load parameters
- $CO_2$ emission levels measured during laboratory testing for each of the WLTP cycle phases (low, medium, high, extra-high)
- The manufacturer declared WLTP $CO_2$ value ($WLTP_{declared}$) and NEDC $CO_2$ value ($NEDC_{declared}$)

The input data for $CO_2$MPAS from type approval is stored in the DICE database at the JRC which is continuously updated.

The capabilities of $CO_2$MPAS simulation tool are not limited to the prediction of the NEDC $CO_2$ emissions using WLTP test data as input. The simulation tool is able to predict the $CO_2$ emissions of WLTP with different vehicle set-up, e.g. RLs and mass, tyre size, etc. In addition, it is possible to use the $CO_2$MPAS for the prediction of the real-world $CO_2$ emissions performance using the WLTP input data found in the official $CO_2$MPAS input file (dataset stored in DICE database). A methodology for the determination of real word $CO_2$ emissions using WLTP data or the opposite is presented in Annex IV – Simulation approach for WLTP/Real World $CO_2$ emissions determination. The methodology is based on the fact that the vehicle parameters are available from the official data recorded in DICE, while the calibration of the vehicle would be achieved using either WLTP or RDE/real-world test data. The analysis presented in Annex IV – Simulation approach for WLTP/Real World $CO_2$ emissions determination showed that both options (prediction of real-world $CO_2$ using WLTP data or vice versa) provide result that have a deviation, from the actual measured $CO_2$ emissions, lower than 5%.

For the adaptation of EU Regulation 2017/1151, and the certification and monitoring procedures (443/2009, 510/2011, 2017/1152 and 2017/1153) the $CO_2$MPAS simulation tool was used to estimate the $CO_2$ emissions of vehicles undergoing NEDC testing based on the emissions produced in WLTP testing during type-approval. To that aim a series of input data concerning the vehicle specifications and the test data were recorded and stored also to the DICE database. As an extend of this data storage at the DICE database, the provisions of EU Regulation 2021/392[3] foresee the collection of real-world data from OEMs (Article 9) and from member states (Article 10), along with the test data from WLTP TA testing (Article 14). Particularly Article 14 of the EU Regulation 2021/392 TAA shall ensure that data from each Type 1 test that is performed according with Annex XXI to Regulation (EU) 2017/1151 are recorded and uploaded to the Commission server. The detailed list of data that shall be recorded according to Article 14 of the EU Regulation 2021/392 are described in Table 2 of the Annex of the regulation. The dataset that is be recorded would be sufficient to create the $CO_2$MPAS simulation input files that could be used for the determination of WLTP and/or real-world $CO_2$ emission performance, following a methodology described in Annex IV – Simulation approach for WLTP/Real World $CO_2$ emissions determination.

### 2.2.2 Access to data and reporting formats for LDV tests in Europe

a) Data exchange formats for technical parameters

According to Regulation (EU) 2017/1151, Annex IIIA, Appendix 8, emission values as well as any other relevant parameters shall be reported and exchanged (between the measurement systems and the data evaluation software) as a csv-formatted data file. Intermediate and final RDE results shall be reported and exchanged after the completion of the data evaluation.

b) RDE test data as an example for a way of publicly available data access

RDE test data can be made available on two ways:

[3] EUR-Lex - 32021R0392 - EN - EUR-Lex (europa.eu)

i. any interested party can request the technical report from the manufacturer, according to Regulation (EU) 2017/1151, Annex IIIA, paragraph 3.1.3.3

ii. publicly available websites, either from individual manufacturers or the central website of ACEA: https://www.acea.be/publications/article/access-to-euro-6-rde-monitoring-data.

c) Exchange of CoP test reports between TAAs and European Commission

The approval authority which has granted type-approval may at any time verify the conformity of production in each production facility. The Approval Authority shall report the results of all audit checks and physical tests performed on verifying conformity of the manufacturers and store it for a period of minimum 10 years. These reports should be available for other type approval authorities and the European Commission on request.

d) Electronic platform for exchange of in-service conformity (ISC) results

For the in-service conformity the manufacturer shall report to the granting type approval authority all results of the in-service conformity testing using an electronic platform. The electronic platform shall be set up by European Commission to exchange data. Defined test data shall be accessible to the public in an electronic form free of charge.

e) Set-up of an electronic platform.

According to paragraph 5.9 of Part B to Annex II of Regulation (EU) 2017/1151 the Commission "shall set up an electronic platform in order to facilitate the exchange of data between on the one side, the manufacturers, accredited labs or technical services and on the other side the granting type approval authority and the taking of the decision on the sample fail or pass". This database will also contain for each vehicle type, variant and version the information regarding the relevant family identifiers, including the interpolation family.

### 2.2.3 Relevant EU regulations for HDV

a) $CO_2$ certification of HDV

According to Regulation (EU) 2017/2400 for each produced HDV the specific fuel consumption and $CO_2$ emissions are calculated with a standardised simulation tool (VECTO), using certified input data for relevant components of the vehicles (engine, transmission, axle, tires, air drag, mass and auxiliary technologies). The $CO_2$ emissions calculated are recorded in the customer information file (CIF) according to Regulation (EU) 2017/2400. More detailed information on vehicle components, certification information and simulation results are given in the Manufacturer Record File (MRF), which is accessible for type approval authorities and the Commission on request. Information relevant for the HDV fleet $CO_2$ monitoring is provided by the manufacturers for all HDVs, for which Regulation 2017/2400 is applicable (Regulation (EU) 2019/956).

b) OBFCM and VTP: monitoring vehicle's real-world actual fuel consumption and verification of TA values

Regulation (EU) 2019/1242 requires the Commission to develop procedures needed for the assessment of the real-world representativeness of the $CO_2$ emissions calculated according to regulation 2017/2400 and "for collecting and processing fuel and energy consumption data required for making such assessments and to ensure the public availability of such data, whilst providing for the protection of any personal data." The procedures to implement this provision are currently under development and is considering the option of extending the "Verification Test Procedure – VTP" to an ISV procedure.

The VTP, introduced with Regulation (EU) 2019/318, verifies the compliance of single HDVs with the certified component data in a CoP procedure by on-board measurements in real driving situations. The VTP is defined in Annex Xa of Regulation (EU) 2017/2400 (as amended by Regulation (EU) 2019/318).

In the VTP test the vehicle is driven in real traffic and fuel flow, engine speed and torque and speed at the driven axles is measured. The simulation tool VECTO is used to simulate the $CO_2$ emissions for this test cycle using the certified component data as input. The ratio of measured and simulated $CO_2$ emissions shows the deviations caused in total from possible deviations of the input data, from the measurement inaccuracies and from model uncertainties.

According to Regulation (EU) 2017/2400, the $CO_2$ values are simulated for the entire vehicle in the abovementioned settings and cycles. The main input data into the simulation tool (VECTO) used for the $CO_2$ declaration of the vehicle is based on well-defined certification tests of the engine, transmission, axles, tires, air drag coefficient and weight. Components with less relevance, i.e. mainly auxiliaries with power demand, are represented as generic data depending on technology levels. Furthermore, all control algorithms, such as gear shift manoeuvres, driver assistance systems etc. are reflected as generic controllers in the software to have a stable and not too complicated certification system.

The OEM of the base vehicle is responsible for the declaration of the vehicles $CO_2$ values[4]. Since the OEM of the tractor is not responsible for the trailers used later in real operation and the chassis OEM is not responsible for the design of the body mounted in case of multistage certification processes, bodies and trailers are represented by generic data for mass and tires and are defined by generic dimensions for the air drag test.

c) Elements of CoP-, ISC and MaS-testing of criterion pollutants

For HDV, the criterion pollutants ($NO_x$, CO, HC, PM, PN) are tested based on Regulation (EU) No 595/2009 and 582/2011 and their amendments. The provisions in these regulations and their amendments cover tests for type approval, CoP, ISC and market surveillance (MaS). For HDVs the engine is type approved for criterion pollutants and type approved engines can be mounted in various vehicles. Type approval tests include engine tests in WHSC, WHTC and NTE as well as on-board emission tests in real driving using PEMS equipment. For type approval, the on-board test has to be done for a vehicle using the parent engine of an engine family in type approval.

With the introduction of on-board emission tests with EURO VI, the conformity to the emission limits is also tested for engines already mounted in HDVs. The relevant unit to meet are the NTE limits in [g/kWh] during the test. The NTE is calculated from the engine type approval limits and a Conformity Factor (CF). The CFs are 1.5 for gaseous exhaust components and 1.63 for PN for EURO VI E. The evaluation is using the "Moving average Window, MAW" method, which divides the test into MAWs with the length of a WHTC work. Then MAWs below a power threshold of 10% of the rated power are excluded and the 90 percentile of the remaining windows has to be below the NTE limit. Further criterions to check for valid PEMS test conditions are then applied. This method is related to the WHTC test but does not test low load, short and cold trips emission behaviour very well.

CoP for criterion pollutants is based on engine tests at the end of the production line while ISC and MaS use on-board tests in real driving similar to the type approval on-board tests, but with a broader range of allowed vehicle loading (10% to 100% in ISC and 50%-60% in type approval).

Also, $CO_2$ is recorded during the on-board tests. The accuracy demands in the PEMS tests are less demanding than in the VTP test for $CO_2$. ISC tests demand for engine torque and speed from OBD signals an accuracy of +/- 5%. In addition, the $CO_2$-measurement via PEMS has most likely uncertainties in the range of 5% since analysers are allowed for +/-3% of the reading and the mass flow meter adds further uncertainties. The VTP test demands accuracies better than 0.2% for engine speed, 0.4% for wheel torque and 1% for fuel flow. Higher accuracies were introduced in the VTP to

[4] For buses also multistage processes shall be covered in an upcoming amendment of Regulation 2017/2400 to provide also results for the completed buses, since results with generic bodies only do not provide reliable information to bus-customers.

allow for meaningful thresholds for pass/fail criterion for $CO_2$ (maximum 7.5% deviation between measured and simulated $CO_2$ values allowed).

ISC tests for criteria pollutants are performed by the OEM on a minimum of 3 engines per pollutant engine family, repeated every 2 years over useful life[5]. ISC is based on on-board emission tests using PEMS equipment. In several updates the valid ISC test conditions cover from EURO VI E on also cold starts and Moving Average Windows (MAWs) down to an average of 10% of the rated power (Regulation (EU) 2019/1939.

The VTP test as CoP test is also run by the OEM, but only for 1 to 5 vehicles per year, depending on the number of HDVs produced (5 tests if more than 100 000 HDVs are produced per year). For ISC tests vehicles above 25 000 km odometer reading have to be selected, for VTP tests less than 15 000km must be chosen since CoP tests are assigned to new components only.

Due to many different boundary conditions, current ISC provisions cannot be applied to VTP tests.

Market Surveillance (MaS) testing for criterion pollutants of HD engines can be conducted by Member States based on the ISC test provisions. If failures of engines are detected in MaS, the type approval granting authority shall be informed which then has to contact the manufacturer.

### 2.2.4 Access to data and reporting formats for HDV tests in Europe

To allow independent VTP tests and to enable a comparison with values certified or declared by the manufacturers, all necessary data needs to be accessible to the involved parties. Regulation (EU) 2018/858 provides a framework for the data access and defines steps for online data exchange. However, it seems not to be defined, that input data for VECTO simulations of HDVs are also candidates for online data exchange according to this regulation, since this data is not part of the contents of the certificate of conformity and of the EU type-approval certificate. Article 15 of Regulation (EU) 2018/858 however defines access to authorities to data needed to demonstrate CoP. Since the VTP test is defined in Regulation (EU) 2017/2400 as a CoP test, one may argue that also VECTO input data is concerned, not only the VTP results.

Relevant data structures currently defined and (partly) available to 3rd parties are summarised below.

For the $CO_2$ declaration and the VTP test according to Regulations (EU) 2017/2400 and 2019/318 following data is produced and available as standardised files:

- Input Information File: contains all data needed to run the simulation tool VECTO for a HDV. The file is recorded at the OEM. Access to others seems not to be explicitly defined in a regulation. A VTP test without the input information file is not possible.
- Manufacturer record file: contains details of the simulation and results. The file is recorded at the OEM and shall be available to the approval authority and the Commission at their request. Other parties have yet no access. This file is needed to verify if the components of the vehicle are in line with the ones used for the simulation and to check the integrity of the input files with the VECTO hashing tool (also Input Information File and Customer Information File are needed for this full check).
- Customer Information File: information on the vehicle and results from the $CO_2$ simulation. The file is available together with each sold vehicle.

[5] Useful life is 300,000 km for vehicles of class M3, N2, N3<16t and 700,000 km for vehicles of class N3>16t.

- A test report on the VTP tests from each OEM is sent on a yearly basis to the approval authority. The report is accessible to the Commission and approval authorities of the other Member States upon request.
- For each vehicle, the certificate of conformity or an individual approval certificate is available, including an imprint of the cryptographic hash of the manufacturer's records file and of the customer information file. The hashes can be used to check the validity of the files in course of the VTP using the VECTO Hashing Tool.
- For each $CO_2$ relevant component that has been certified in test procedures according to Regulation (EU) 2017/2400, a certificate on $CO_2$ emissions and fuel consumption related properties exists, with imprinted certificate number and hash of the input file for the simulation tool produced from the certification tests. For each component also the CoP results from tests at the OEM have to be reported annually to the type approval authority. The Commission has access to this information on request. The certificates are relevant if the components of a vehicle shall be compared with the ones used in the Input Information File.
- The data from the central register for HDV data on vehicles $CO_2$ results and new registrations organised by the Commission and managed by the European Environment Agency. The data is public available.

Following reports and information are relevant for $CO_2$ verification and are produced and available as standardised files from criterion pollutant testing according to Regulations (EU) 595/2009 and 582/2011 and its amendments:

- From EURO VI on, the OEMs have to provide unrestricted access to vehicle OBD information. This information is relevant e.g. for access to engine speed and power signals if needed.
- Technical reports from the ISC test results are submitted to the granting type approval authorities. Also instantaneously recorded data, such as vehicle speed, engine speed, engine torque and $CO_2$ and fuel mass flow are included in the report according to point 10 in Annex II of Regulation 582/2011.
- An AES (Auxiliary Emission Strategies) documentation package: a documentation package that fully explains any element of design which affects emissions. This includes also the description of any condition(s) under which the strategies and devices will not operate as they do during testing for Type Approval. The document has to be provided to the type approval authorities.

## 2.3 LDV and HDV regulations of non-European countries

In this section, the regulatory framework of non-European countries is examined. The primary aim is to collect information relevant to the in-service verification of $CO_2$ emissions for LDV and HDV. For this reason, it was crucial to identify regions with an active and evolving vehicle automotive emissions regulation framework, from which best cases and examples can be extracted. Based on this principle, five regions were identified for further study, namely USA, China, Japan, South Korea and India.

In order to collect the necessary information a number of sources were used, including:

- Reports and presentations with comparisons of regulations in different regions, such as relevant reports from EC-funded studies, non-governmental organisations, and different independent organisations.
- Scientific papers comparing and critically reviewing effectiveness and limits of regulations.
- Booklets and electronic databases with summaries of emission limits and regulations worldwide, curated by experts.
- Official government sites and reports.

In-service conformity programs are well established all around the world, but the main focus is away from greenhouse gas emissions. Most compliance and enforcement programs do not extend to $CO_2$ verification except for the USA program. Nevertheless, useful practices for the creation of a $CO_2$ in-use surveillance program may be found by reviewing these compliance and enforcement programs, even if this is not their primary goal. Useful information includes:

- The authority responsible for applying the existing compliance and enforcement program.
- The type of tests that are already being conducted and could possibly be extended to measuring $CO_2$ emissions and fuel consumption during the vehicle's useful life.
- The criteria used to determine in-use compliance.
- The guidelines for selecting vehicles for in-use compliance testing.
- Systems for collecting vehicle data and measurement results, from OEMs and testing authorities.

### 2.3.1 United States LDV regulations

In 2012, the environmental protection agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) issued the Corporate Average Fuel Economy (CAFE) standards. These refer to all LDVs with model years (MY) 2017-2025. EPA oversees testing, collects and processes test data, and performs calculations to determine compliance with CAFE standards. In general, EPA is responsible for addressing greenhouse gas emissions while NHTSA addresses fuel economy, while this is measured and calculated by the EPA. Manufacturers demonstrate compliance on a fleet average basis at the end of each MY.

The applied enforcement and compliance program ensure compliance with clean air, vehicle emissions and vehicle fuel economy standards. Both the EPA and OEMs are part of this program and their responsibilities are described briefly in Figure 1.

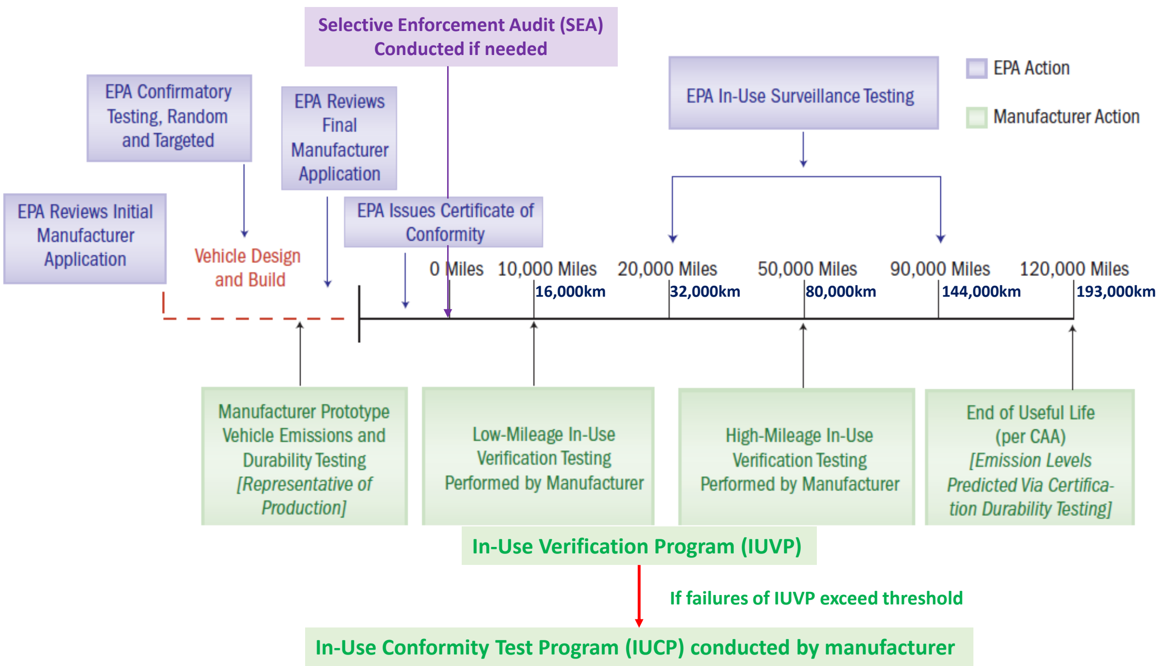


**Figure 1:** Compliance schedule for light-duty vehicles (Source: EPA 2007 Progress Report-Vehicle and Engine Compliance Activities. Oct. 2008).

The compliance and enforcement program for LDVs consists of:

1. Pre-production certification
2. Confirmatory testing
3. Selective enforcement audit (SEA)
4. In-use surveillance
5. In-use verification program (IUVP)
6. Recall in case of noncompliance
7. Warranties and defect reporting

The pre-production certification is performed by the manufacturers and aims at supporting the certificate of conformity (CoC) application. For confirmatory testing, manufacturers are requested to test every engine or vehicle family under the following driving cycles **(ICCT 2017)**:

- The Federal Test Procedure (FTP) which is representative of urban driving. It consists of 3 phases as shown in Figure 2 and is conducted under ambient temperature of 20-30°C.
- Highway Fuel Economy Test Cycle (HWFET).
- US06 which represents more aggressive driving, with high speeds and accelerations.
- SC03 represents engine load from the use of air conditioning, when the vehicle is tested under high ambient temperature (35°C).
- Cold FTP which is identical to FTP conducted under low ambient temperature (-6.7°C).

HWFET, US06 and SC03 velocity profiles are presented in Figure 3. These 5 driving cycles (FTP, HWFET, US06, SC03, Cold FTP) constitute the 5-cycle test, which is also used for the purpose of fuel economy labelling.

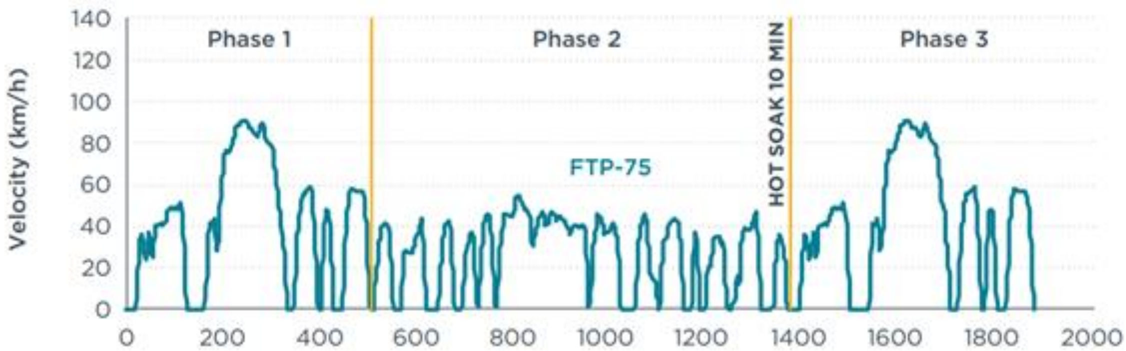


**Figure 2:** FTP velocity profile (ICCT 2017).

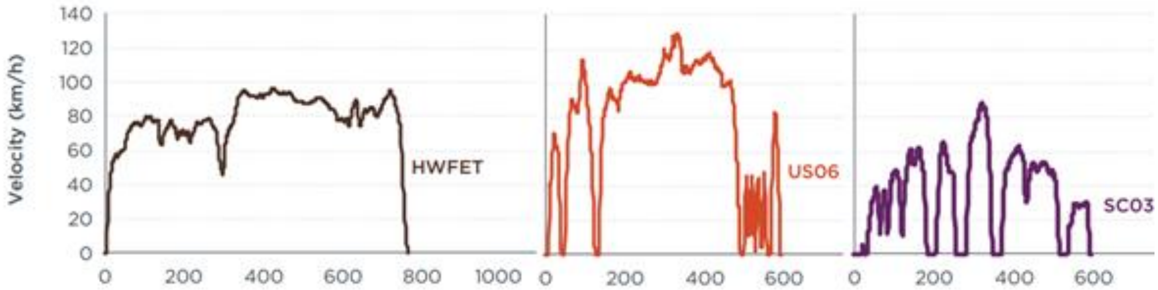


**Figure 3:** HWFET, US06, SC03 velocity profiles (ICCT 2017).

EPA also performs confirmatory tests, at engines that have been targeted for various reasons or randomly. If an engine or vehicle succeeds in confirmatory testing, it can be produced and enter the market. In the recent years, EPA conducted confirmatory testing on 15% of the selected test groups, where 10% were selected randomly and the rest 5% were targeted test groups.

a) Selective Enforcement Audit (SEA) at production start

Under the SEA program, EPA can request to test a vehicle from the assembly line, without prior notice. SEA aims at identifying cases where the produced vehicles deviate from the already certified prototype. Except SEA, which is the most formal type, there are other types of field audits: record inspection, emission laboratory audit, test monitoring and assembly line audit. SEA testing depends on the sales of the engine or vehicle family that is examined. Based on the test sample, there are pass/fail criteria. An engine or vehicle family succeeds in SEA testing, when a number of final deteriorated test results, does not exceed the corresponding permitted regulated limit, for the different pollutants. If a family fails, EPA suspends the certificate of conformity for this family. No SEAs have been conducted in the recent years, but EPA retains the right to do so, if there are indications of fraud or improper testing by the manufacturer.

b) Verification of products’ compliance with CoC – EV-CIS

EPA has developed a system for collecting and verifying data from manufacturers, the Engine and Vehicles – Compliance Information System (EV-CIS). In EV-CIS, vehicle and engine manufacturers submit all the required data for the issuance of the Certificate of Conformity. Manufacturers are also obliged to submit reports to EPA, regarding any found defects, even if these do not increase emission levels. A defect that leads to increased emission levels could possibly lead to a recall. Recalls can be issued when EPA determines that a number of vehicles or engines do not meet emission standards even when they are properly used and maintained. The manufacturer is responsible for taking any actions necessary for repairing or modifying the customers’ vehicles or engines. Information systems of this kind could also be used to adjust the calculation of the OEMs average emissions, in case deviations would be found or strategies that artificially improve $CO_2$ emissions.

c) Surveillance program for vehicles in-service and provisions to check for CO2 emissions- IUVP

The in-use compliance program is responsible for tracking the vehicles’ emissions performance during their useful life. Tests are mainly conducted by the manufacturers, by running the IUVP for vehicles of both low-mileage (16 000 km) and high-mileage (80 000 km). Manufacturers test a number of vehicles at their own expenses, which depends on the overall sales and the mileage group. IUVP is successfully passed if the average emissions are lower than the corresponding emission standard multiplied by 1.3 and 50% or more of the vehicles do not exceed the emission standard. If the testing sample fails to comply, the manufacturer must conduct IUCP testing where at least 10 vehicles are tested under similar conditions to confirmatory testing. If a significant number of vehicle emissions exceed the regulated limit, the IUCP test is failed and this could lead to a recall.

In order to check for compliance with the in-use $CO_2$ emission values, the FTP and the HWFET are run for each vehicle. The weighted average of the two, 55% of FTP result and 45% of the highway result, is compared to the $CO_2$ value used for the calculation of fleet average $CO_2$ multiplied by 1.1. The in-use $CO_2$ emission standard is 10% higher to account for issues of production and test-to-test variability. A possible failure could come either from a faulty vehicle component or inaccurate $CO_2$ emissions reporting when the vehicle was originally tested. In the first case, the faulty component would also affect the emissions of other pollutants and the vehicle would possibly not comply with multiple standards. No deterioration factor is applied to the results, as $CO_2$ emissions rarely deteriorate during the vehicle’s useful life.

In March 2020, EPA and NHTSA finalized the Safer Affordable Fuel-Efficient (SAFE) vehicle rule which sets stringency of $CO_2$ and fuel economy standards, by 1.5% each year for LDVs with MYs 2021-2026, which is more relaxed than the 2012 standards (5% per year).

d) Vehicle selection

The criteria for vehicle selection for the in-use surveillance are multiple. They are based on the data gathered from manufacturers, defect reports, inspection and maintenance (I/M) programs and certification test results. Also, testing may be focused on vehicles or engines implementing newer technologies or vehicle models that have failed IUVP testing. Finally, some vehicles are selected randomly or based on any other reason that may suggest incompliance. In-use compliance testing and certification testing follow the same testing procedures, for LDVs.

### 2.3.2 China LDV regulations

From the conducted literature review, no in-use compliance program for $CO_2$ emissions or fuel consumption was found to be applied in China. However, a short description of the China 6 enforcement and compliance program is presented below, as useful elements for the creation of an in-use $CO_2$ verification procedure could be identified.

The China 6 standard was released by the Ministry of Environmental Protection on December 2016 and took effect in July 2020, for all light duty vehicles. The NEDC was replaced with the Worldwide Harmonized Light Vehicle Test Cycle (WLTC) and the WLTP. The compliance program under the China 6 standard consists of tests run by both manufacturers and regulatory agencies. An overview of all the actions required is presented in Figure 4.

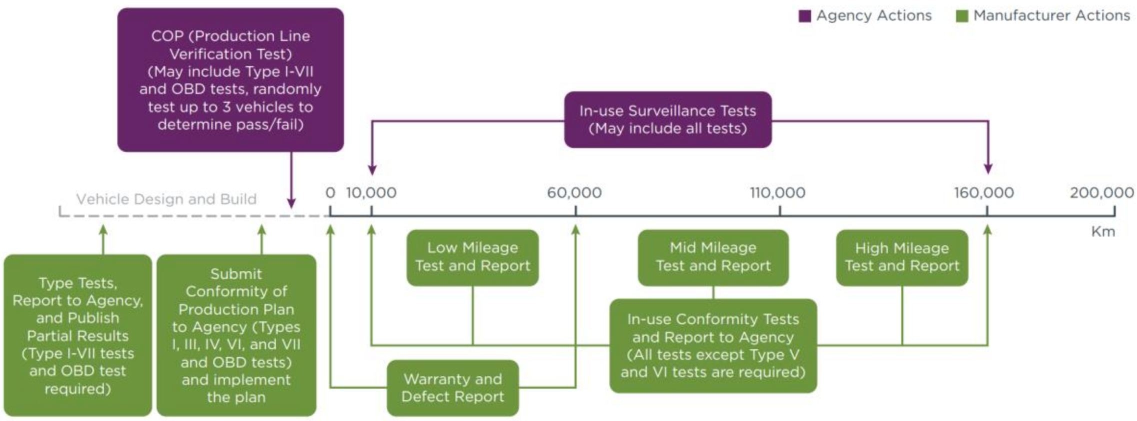


**Figure 4:** Overview of China 6 compliance program (ICCT 2017).

Manufacturers are required to conduct type tests, which replaced TA testing, and report the results to the regulatory agency. Type tests consist of Type I to Type VII tests, which are briefly described in Table 1. Manufacturers are also required to run CoP and in-use testing of vehicles at low (10 000-60 000 km), medium (60 000-110 000 km) and high (110 000-160 000 km) mileage and report the results to regulatory agencies. Random CoP and in-use surveillance tests are also conducted by regulatory agencies, in order to verify the manufacturers' test results. Some of these type tests could possibly be used in the creation of a procedure that checks compliance of the in-use $CO_2$ emissions.

**Table 1:** Description of China 6 type tests

| Type test | Description |
|---|---|
| Type I | Exhaust emissions test after a cold start at normal ambient temperature. |
| Type II | Real-driving emissions (RDE) test. |
| Type III | Crankcase pollutants emissions test. |
| Type IV | Evaporative emissions test. |
| Type V | Pollution-control devices durability test. |
| Type VI | CO, THC, and $NO_x$ emissions test after a cold start at low ambient temperature. |
| Type VII | Refuelling evaporative emissions test |

Additionally, emission limits and test procedures for loaded and unloaded I/M tests are set. Loaded I/M tests are usually conducted in regions with acute air pollution and limits are set based on the local situation. Loaded I/M tests include simplified, short driving cycles (ASM2540, ASM5025) as shown in Figure 5 and transient driving cycles (IG195). Vehicles with high I/M failure rate could be possibly selected for confirmatory testing. I/M tests are conducted by vehicle test centres approved by the Public Security Bureau.

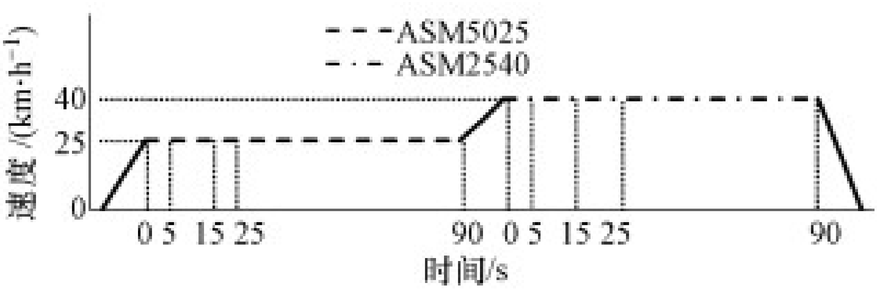


**Figure 5:** ASM2540 and ASM5025 velocity profiles.

### 2.3.3 Japan, South Korea and India LDV regulations

In most cases Japan closely follows EU or US policies when it comes to automotive emission regulations. This is also true in the case of in-service $CO_2$ emissions of LDVs, as a procedure dedicated to check for in-use compliance was not identified. This extends to South Korea and India too, where an in-use compliance program for $CO_2$ emissions is not in place yet. Nonetheless, a description of the enforcement and compliance programs that are already applied in these regions can provide useful insight.

a) Japan

In Japan, TA is based on WLTP, which was introduced in October 2018, after some adjustments to better represent driving conditions. Additional cycles include JC08 (Figure 6) which is representative of congested urban and urban expressway traffic conditions and is used for fuel economy determination. An overview of the vehicle compliance program of Japan is shown in Figure 7.

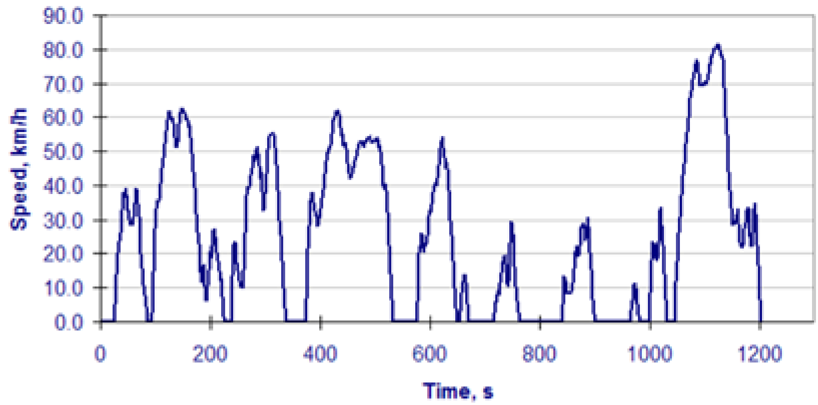


**Figure 6:** JC08 driving cycle (DieselNet).

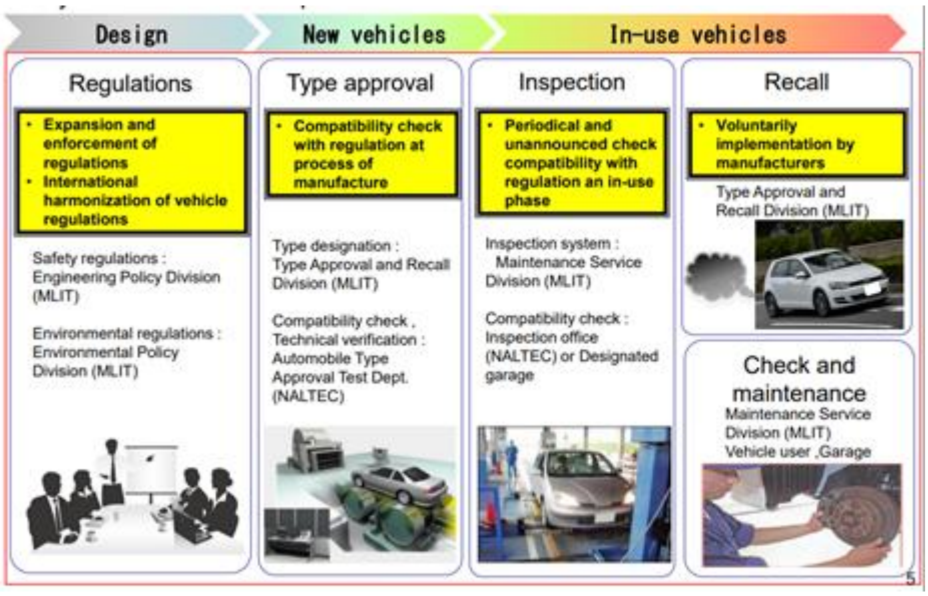


**Figure 7:** Overview of vehicle compliance program in Japan (Nobutoshi HORIE, 2017)

The TA procedure is applied to both imported and domestically produced vehicles. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is responsible for inspecting a sample of vehicles and the quality-control system of the manufacturers and also completing the TA process within two months. Regarding imported vehicles, MLIT conducts certification inspections overseas and also accepts test results from specific foreign institutes. MLIT tests about five models and 20 vehicles, for in-use compliance every year. Also, vehicle users are required to perform annual and two-year checks, performed by approved garages.

b) South Korea

In South Korea CoP testing is conducted on about 100 vehicles yearly on a chassis dynamometer. Additionally, manufacturers are required to perform tests and report the results to the regulatory agency. Regarding in-use testing, the regulatory agency will typically test five properly maintained vehicles per test group for in-use testing. If the average level of any pollutant emitted by the tested vehicles exceeds the regulated standards, the test group fails the test. If the manufacturer does not agree with the results, the regulatory agency will test 10 more properly maintained vehicles of the same test group and determines noncompliance, if the average level of any emitted pollutant exceeds applicable standards for these 10 vehicles. The vehicle selection is based on manufacturer's test results report. Manufacturers are also required to report if they receive more than 40 defect repair requests for the same part of the same vehicle sold in the same year or if the ratio of number of requests for repair to annual sales is more than 2%. Additionally, MLIT is responsible for running tests in order to check for compliance of the vehicle's road load. The vehicle's road load is acceptable if the difference between the road load specified by the manufacturer and the in-use road load is not greater than 15%.

c) India

On February, 2016, the Indian Ministry of Road Transport and Highways (MoRTH) announced the draft proposal of Bharat Stage (BS) VI emission standards. These refer to both LDV and HDV as well as to L-category vehicles. BS VI introduced provisions for in-service conformity test requirements for LDVs using PEMS.

### 2.3.4 United States HDV regulations

a) Enforcement and compliance program

HDV enforcement and compliance program is similar to the LDV program, where both EPA and OEMs are responsible for its application. In the case of HDVs, there is a $CO_2$ verification procedure based on a simulation software similar to VECTO. Required actions occur in pre-production, during production and in-use and the main elements are described in Figure 8.

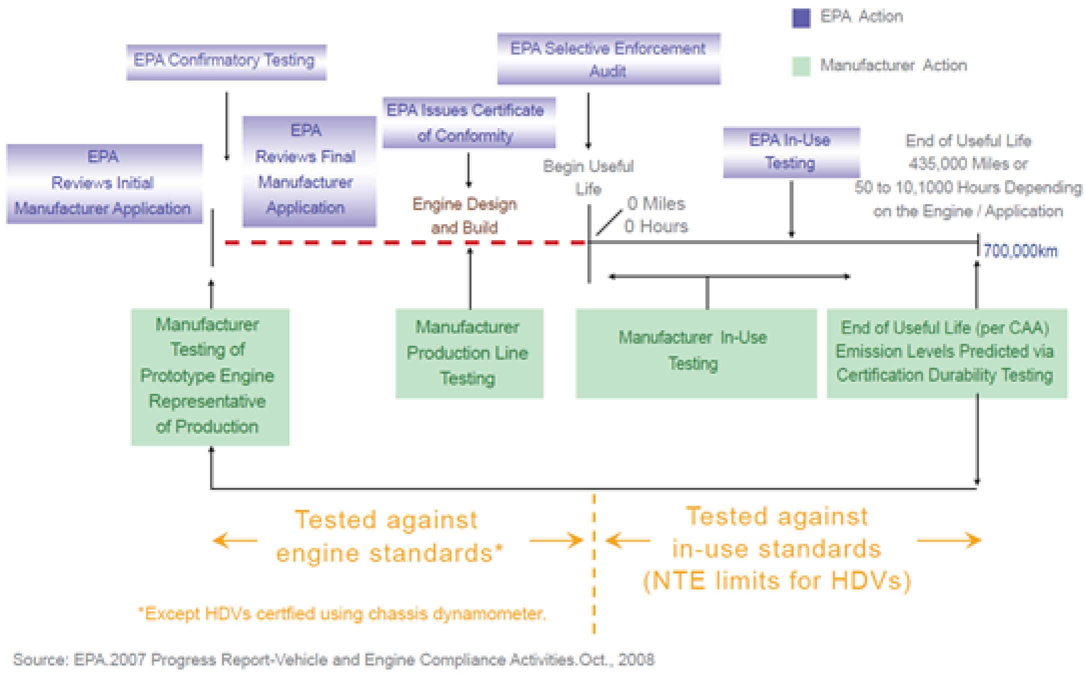


**Figure 8:** Compliance Schedule for Certain Heavy-Duty Highway and Nonroad Engines.

The compliance and enforcement program consists of:

1. Pre-production certification
2. Confirmatory testing
3. SEA

4. Manufacturer production line testing
5. In-use testing
6. Warranties and defect reporting

Even though the enforcement and compliance program is similar between LDVs and HDVs, actual testing is quite different. For LDVs the testing methods are the same for certification and in-use testing. In the case of HDVs, certification is based mainly on engine testing instead of chassis dynamometer tests of the whole vehicle. Also, manufacturer production line testing is rarely conducted as it is quite costly to remove the engine from the vehicle.

b) Certification

Certification is based on FTP transient**,** which is an engine dynamometer cycle. Normalized torque and speed values are presented in Figure 9. Additional testing includes:

- Supplemental Emissions Test (SET), which ensures that emissions are controlled during steady-state.
- Not-To-Exceed (NTE) testing, which includes driving within a predefined control area, which includes both steady-state and transient conditions, under various ambient conditions.

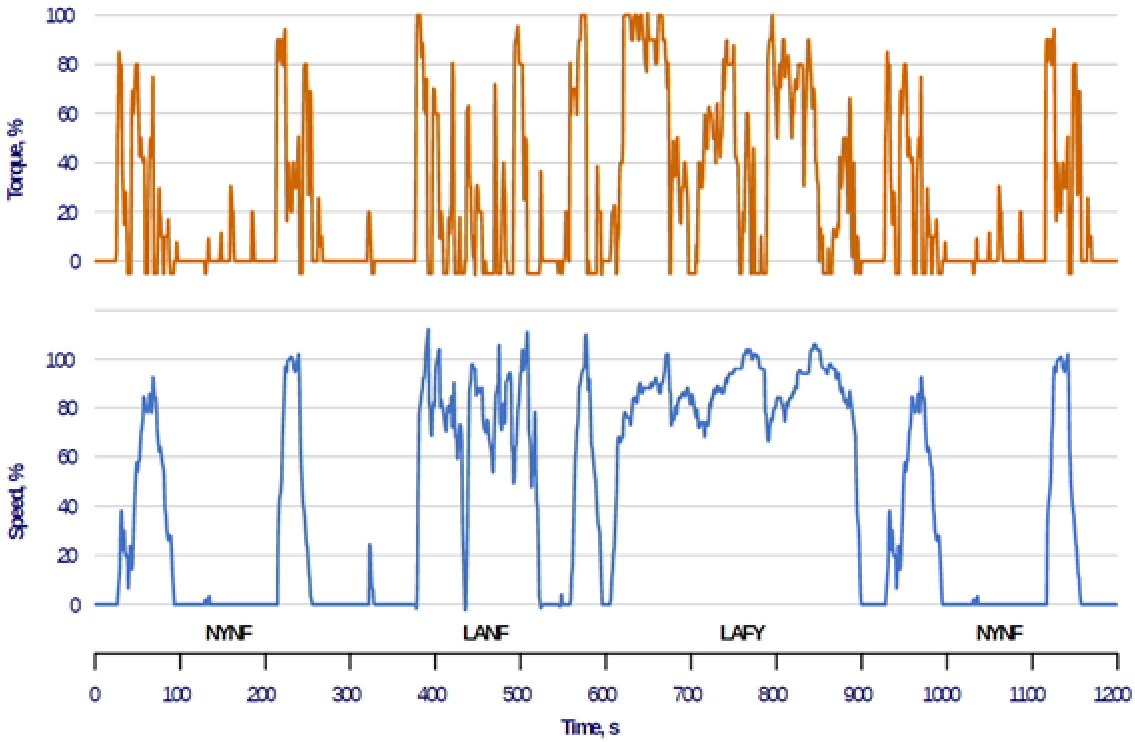


**Figure 9:** Normalized Torque and Speed of HDV FTP transient cycle (DieselNet).

c) In-use testing program

The in-use testing program was designed in collaboration with the California Air Resources Board (CARB) and it is performed by EPA, CARB and OEMs. Testing is usually conducted using portable emissions measurement systems (PEMS). Compliance is determined against NTE limits, which in general are 1.25-1.5 higher than the FTP standards. Current legislative framework requires in-use testing of compression ignition engines from the manufacturers without mandating the in-use testing of spark ignition engines.

Additionally, EPA applies a surveillance program to check compliance for vehicles near the end of their useful life. The engine is removed from the vehicles and it is tested in an engine dynamometer and with PEMS.

d) Use of GEM Simulation model to estimate $CO_2$-emissions of HDV

In most cases, heavy duty engines are offered in multiple combinations of transmissions and body style. This is one of the reasons that engine dynamometer testing is the preferred method for TA tests, which is suitable for measuring most pollutant emissions, but not for fuel economy and $CO_2$ emissions. Chassis dynamometer testing would be required, but this it is rather costly. On the other hand, simulation software is low cost and can accurately predict fuel economy and $CO_2$ emissions under various operating conditions. Greenhouse Emission Model (GEM) is a vehicle simulation model, developed in the US and it is used to estimate $CO_2$ emissions and fuel consumption of HDV. GEM is used by OEMs to demonstrate compliance for US greenhouse gas emissions and fuel efficiency standards set by EPA and NHTSA. GEM is similar to VECTO and it was built with similar purposes.

GEM (phase 2 version) is available for free download from EPA's website. The necessary input parameters for GEM are provided using .csv files. An example of these files is shown in Figure 10. Separate .csv files are required for engine and transmission data. Also, a comparison of the necessary input data between VECTO and GEM is presented in Figure 11.

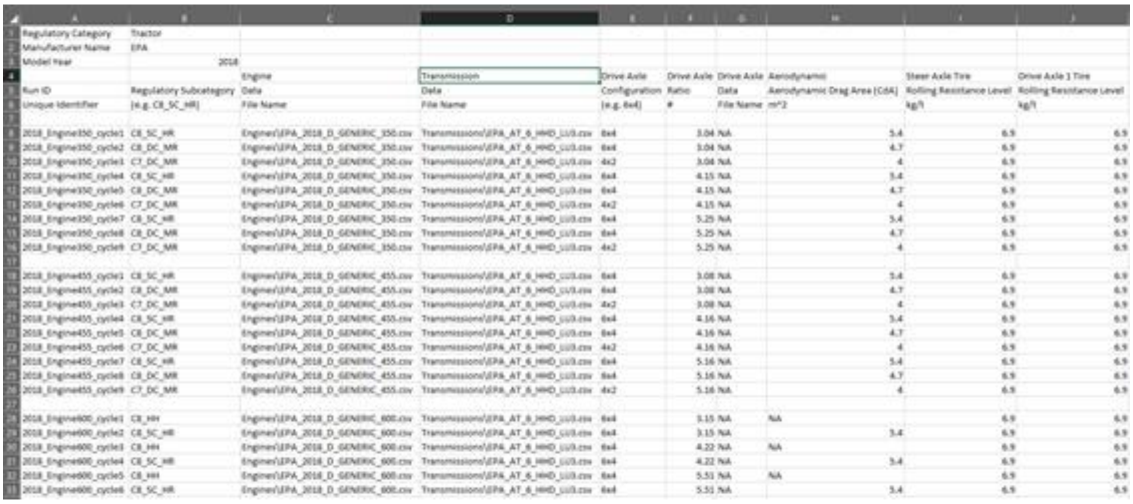

**Figure 10:** Screenshot of .csv files used as input to GEM.

| Component | VECTO Input | GEM Input |
|---|---|---|
| Engine | Displacement, idle speed, fuel consumption map, full load torque curve, motoring friction curve, **brake-specific fuel consumption over the Worldwide Harmonized Transient Cycle (WHTC)** | Displacement, idle speed, fuel consumption map, full load torque curve, motoring friction curve, **fuel consumption over the ARB Transient Drive Cycle for 9 different vehicle configurations** |
| Transmission | Transmission type, gear ratios, **torque loss map as a function of torque and speed** for each gear, maximum torque and speed per gear | Transmission type, gear ratios, and maximum torque per gear. **Optional: Power loss map** as a function of torque and speed for each gear |
| Axle | Axle ratio and **torque loss map as a function of torque and speed** | Axle ratio<br>**Optional: Power loss map** as a function of torque and speed |
| Aerodynamic drag | Air drag area as determined during the **constant speed procedure.** For rigid trucks, a standard box is used. For tractors, a standard trailer is used. | Air drag area as determined by the **coastdown methodology.** Standard trailers are used for tractor modeling. |
| Tires | Tire dimensions, **rolling resistance coefficient (Crr),** and load applied during the rolling resistance test for each axle | **Rolling resistance coefficient (Crr)** for each axle, and drive tire revolutions per mile |
| Vehicle | **Curb vehicle weight,** gross vehicle weight rating, and axle configuration | **Vehicle weight reduction** (sum of standardized weight reductions per component), vehicle regulatory subcategory (e.g., Class 8, sleeper cabin, high roof), and axle configuration |
| Other | **Auxiliaries:** Technology used for the following auxiliaries: cooling fan, steering system, electric system, pneumatic system, A/C system (whether it is present or not), and power take-off | **Off-cycle technologies:** Improvements through the application of the following technologies: Speed-limiter, neutral-idle, intelligent controls, accessory load reduction, extended idle reduction, tire pressure system, and other technologies. |

**Figure 11:** Input comparison between VECTO and GEM (ICCT 2018).

The necessary input data are listed below:

1. Engine
    - Engine full load torque curve
    - Parent engine full load torque curve
    - Engine motoring torque curve
    - Engine idle fuel map
    - Engine fuel map
2. Transmission
    - Gear ratio
    - Input torque limit
3. Drive axle configuration
4. Drive Axle Ratio
5. Aerodynamic Drag Area (CdA)
6. Steer Axle Tire Rolling Resistance Level
7. Drive Axle 1 Tire Rolling Resistance Level
8. Drive Axle 2 Tire Rolling Resistance Level
9. Loaded Tire Size
10. Technology improvements
    - Vehicle Speed Limiter
    - Weight Reduction
    - Neutral-Idle
    - Intelligent Controls
    - Accessory Load
    - Extended Idle Reduction
    - Tire Pressure System
    - Other

Simulation results are also recorded in .csv files, which are identical to the input .csv files, with additional columns for $CO_2$ emissions and fuel consumption values. An instant of the results file is shown in Figure 12.

| Technolog | Technolog | Technology Improvement | | | | | |
|---|---|---|---|---|---|---|---|
| Accessory | Tire Pressi | Other | Date/Tim | GEM CO2 Emissions | GEM Consumption | FEL CO2 Emissions | FEL Consumption |
| % | % | % | YYYY_MM | g CO2/ton-mile | gal/1000 ton-mile | g CO2/ton-mile | gal/1000 ton-mile |
| | | | | | | | |
| 0 | 0 | 0 | 2020-070: | 222.0614119 | 21.81349822 | 222 | 21.8075 |
| 0 | 0 | 0 | 2020-070: | 284.345287 | 27.93175708 | 284 | 27.8978 |
| 0 | 0 | 0 | 2020-070: | 454.7105 | 44.66704322 | 455 | 44.6955 |
| 0 | 0 | 0 | 2020-070: | 361.3490975 | 35.49598207 | 361 | 35.4617 |
| 0 | 0 | 0 | 2020-070: | 353.0790532 | 34.68360051 | 353 | 34.6758 |
| 0 | 0 | 0 | 2020-070: | 425.4534148 | 47.87368232 | 425 | 47.8227 |
| 0 | 0 | 0 | 2020-070: | 223.155649 | 21.92098713 | 223 | 21.9057 |
| 0 | 0 | 0 | 2020-070: | 361.3490975 | 35.49598207 | 361 | 35.4617 |
| | | | | | | | |
| 0 | 0 | 0 | 2020-070: | 318.3891503 | 31.27594797 | 318 | 31.2377 |
| 0 | 0 | 0 | 2020-070: | 316.3808801 | 31.07867192 | 316 | 31.0413 |
| 0 | 0 | 0 | 2020-070: | 319.6701413 | 31.40178206 | 320 | 31.4342 |
| 0 | 0 | 0 | 2020-070: | 310.986531 | 30.54877515 | 311 | 30.5501 |
| 0 | 0 | 0 | 2020-070: | 216.6907536 | 21.28592864 | 217 | 21.3163 |
| 0 | 0 | 0 | 2020-070: | 238.2142984 | 23.40022578 | 238 | 23.3792 |
| 0 | 0 | 0 | 2020-070: | 316.1164549 | 31.05269694 | 316 | 31.0413 |
| | | | | | | | |
| 0 | 0 | 0 | 2020-070: | 246.1558575 | 24.18033964 | 246 | 24.165 |

**Figure 12:** Screenshot of GEM output .csv files.

### 2.3.5 China HDV regulations

a) Enforcement and Compliance Program

No in-use compliance program for $CO_2$ emissions or fuel consumption was found to be applied in China for HDV as well, but a short review of the enforcement and compliance program could provide interesting findings.

China's air pollution prevention and control law includes the legislative framework for controlling vehicle's emissions. It prohibits the production, import and selling of any vehicle that exceeds the regulated limits. If non-conforming vehicles are discovered, they can be confiscated, but it is not clearly specified which agency is responsible for this action. The Ministry of Ecology and Environment (MEE), on June 2018, released China VI which is the latest update for emission standards. According to China VI both regulatory agencies and manufacturers are part of the compliance program, which is briefly described in Figure 13.

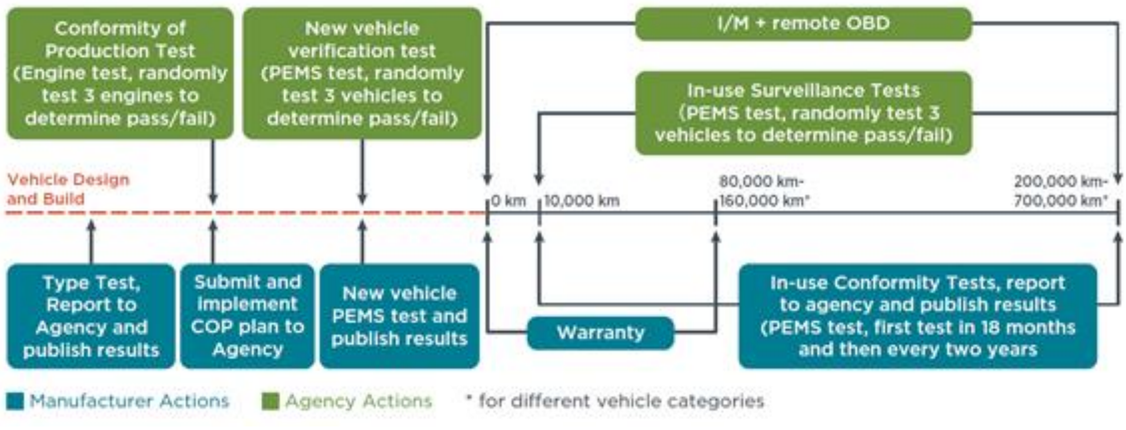


**Figure 13:** China compliance program for HDV (ICCT 2018).

b) Vehicle Certification

In China VI, TA tests are replaced by type tests where manufacturers test and certify their new vehicles. Type tests are performed under the World Harmonized Transient Cycle (WHTC) and World Harmonized Stationary Cycle (WHSC). Also, manufacturers perform CoP tests and new vehicle inspection, where newly produced vehicles are tested using PEMS.

Additionally, HDV are required to meet fuel consumption standards. For the calculation of fuel consumption, all base models are tested on a chassis dynamometer, under the World Transient Vehicle Cycle (WTVC), which is a variant of World Harmonized Vehicle Cycle (WHVC). Models that are similar to the base model on features that affect fuel consumption can be tested with a chassis dynamometer or a simulation model. Vehicle fuel consumption during CoP testing can be up to 6% higher than levels in the vehicle used for certification. This increase takes into account any potential chassis dynamometer measurement errors.

c) In-Service Tests

In-service tests are run using PEMS, with a sample of 3-10 engines or vehicles from each engine or vehicle family. The first in-service test is conducted 18 months after the vehicle's registration and every two years for every engine or vehicle family. Test results are reported to the regulatory agency and published by the manufacturers.

For all these tests performed by manufacturers, MEE retains the authority to run verification tests. CoP verification is conducted by performing engine tests as well as OBD and ECU tests on three random engines. The engine family fails, if one engine emission results exceed the regulated limits by 10 % or if the average emissions of the tested engines are higher than the limits or if one of the three tested engines fail the ECU or OBD check.

For the first 10.000 km the vehicle is considered new and it is tested for new vehicle verification test. In-use surveillance tests are similar to new vehicle verification tests, but it is performed to vehicles with mileage above 10.000 km. New vehicle and in-use surveillance tests are performed using PEMS and includes OBD and NOx control checks.

I/M testing is also performed for HDV and includes lug-down testing, which is used to check for smoke emissions under loaded conditions. Lug-down tests require the vehicle to operate at wide open throttle while driving with a velocity over 70km/h on a chassis dynamometer. When the vehicle reaches its maximum velocity, the dynamometer's load is gradually increased in order to achieve the vehicle's maximum velocity under maximum power.

Moreover, China VI-b standards for HDVs include the recording of key engine and operation information as vehicles operate on the road. Although the technical details of the approach are not finalized yet, real-time recordings of the engine, together with speed, location and other signals are recorded in real time. The engine signals include load, fuel flow, NOx emissions, etc. Therefore, on-board fuel consumption is recorded, is collected over the cloud and is made available to authorities. It is not yet known how this will be used to verify declared fuel consumption and $CO_2$ but it evidently provides an interesting technical approach.

### 2.3.6 Japan, South Korea and India HDV regulations

The compliance and enforcement programs of Japan, South Korea and India include in-use compliance procedures, but they do not extend to greenhouse gas emissions or fuel consumption. Again, a short description of these programs is provided as these procedures could be implemented in the formation of an in-service $CO_2$ verification method in the EU.

The Japanese enforcement and compliance program for HDV is similar to the LDV program. Japan adopted the WHTC and WHSC test cycles. However, contrary to EU, Japan employs chassis dynamometer tests for HDV. Japan has also introduced the JE05 which is used for fuel economy estimation from buses and freight vehicles and is demonstrated in Figure 14. The test cycle has three parts: urban, downtown (congested urban with lower speeds and increased idling) and motorway.

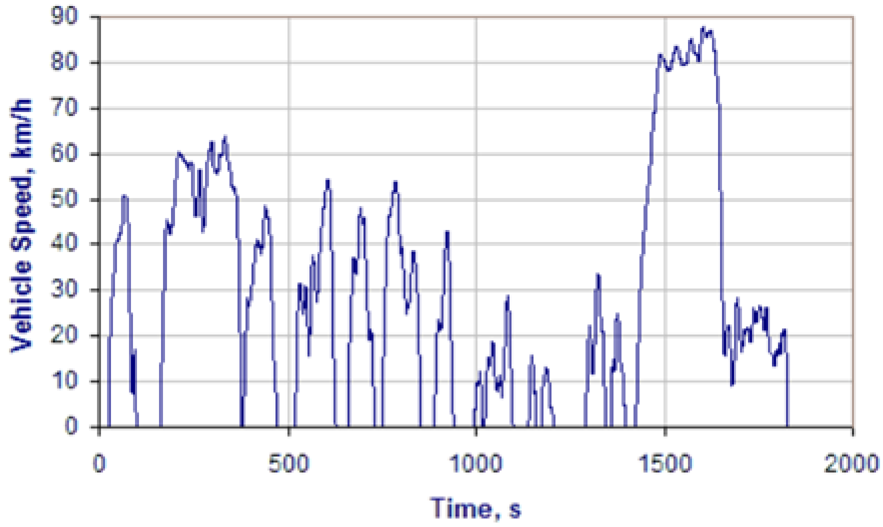


**Figure 14:** JE05 test cycle (DieselNet).

The compliance and enforcement program for HDV in South Korea is similar to this for LDV. The WHSC and WHTC are used for TA and also CoP testing is conducted using PEMS.

In India, BS VI vehicle emission standard refers to both LDVs and HDVs. Again, the WHSC and WHTC are used for type approval. Additionally, off-cycles emissions testing and in-service conformity testing using PEMS are required.

## 2.4 Elements from existing regulations to be further considered for developing In-Service Verification of $CO_2$

This section provides a short summary of the useful elements of existing regulations that could be used in the in-service verification procedure of $CO_2$. However, the development of the relevant procedure is made in the following tasks (Task 2 sets out the guiding principles and Task 3 describes the actual methods).

### 2.4.1 Elements from EU Regulations for LDV

For the verification of the type approved test values, WLTP $CO_2$ emission results, road load test results, as well as RDE tests data can potentially be used (the latter as a first indication or as input to a possible simulation concept). Beside the PEMS data from manufacturers, measurements of in-service vehicles in the context of ISC and market surveillance activities can be used.

Results from road load tests and WLTP type 1 test from TA can be compared directly with the respective results from the ISV tests. The impact of deviations in the road load data on resulting $CO_2$ emissions may be assessed by a calculation of the total positive work at the vehicle wheels (i.e. recalculation of the Cycle Energy Demand – CED) using equations of longitudinal dynamics with the different road load parameters. As alternative also a more comprehensive simulation tool like $CO_2$MPAS may be used.

The direct comparison of the $CO_2$ emissions from WLTP type 1 test on a chassis dyno and on-road tests is not very meaningful due to different vehicle mass, driving resistances, operating conditions etc. Therefore, a simulation tool could support the verification, where the model could be calibrated with the one set of data (WLTP Type 1 test or on-road test) and calculate the other. Such approach could be also used for the identification of artificial strategies to improve $CO_2$ emissions performance.

This simulation concept, which is also mentioned in section 3.3 and described in detail in Annex IV – Simulation approach for WLTP/Real World $CO_2$ emissions determination, may be useful considering following points:

- $CO_2$MPAS may be used as simulation tool. Since $CO_2$MPAS is a longitudinal-dynamics backward-simulation tool for calculating vehicle's $CO_2$ emissions, this tool is suitable to simulate WLTP-chassis dyno tests and on-road tests. $CO_2$MPAS includes also modules to simulate vehicles with hybrid electric architectures. Instructions for installation and usage is available on the website: https://co2mpas.io/. According to the available description of $CO_2$MPAS, the simulation tool could support besides NEDC and WTLC cycles also on-road tests with arbitrary driving patterns. The input data for $CO_2$MPAS from type approval is stored in the DICE database at JRC. This database could be a relevant source for a simulation-based verification method. Furthermore, in the regulation no information is available, how long the $CO_2$MPAS tool will be supported after the transition phase from NEDC to WLTP.
- The test data from manufacturer (which should include instantaneous RDE test results and the WLTP vehicle settings) could be requested by any interested party according to Regulation (EU) 2017/1151, Annex IIIA, chapter 3.1.3.3.
- To extend the on-road data for the comparison with WLTP, RDE tests from market surveillance activities according to the Regulation (EU) 2018/858 can be included. Access to detailed test results needs to be provided in a structured and efficient way for all sources.
- For a simple test set up, instead of the $CO_2$ mass flow from a PEMS test also the fuel consumption in the test trip may be gained from the OBFCM interface if it is available.

The usability of OBFCM data on vehicle fleet level needs further analysis. A recalculation of all data provided by OBFCM using a detailed simulation tool like $CO_2$MPAS may not be a viable option. Simple correction functions for distributions e.g. of average speed, temperatures, trip length etc. may lead to sufficient accuracies to compare with type approved $CO_2$ values. Since the OBFCM data are only available from 2021 onwards, on-road tests for the near-term developments of a regulation for $CO_2$ verification seems more promising. Certainly, for long term developments also the OBFCM data shall be considered. Aspects from the current TA regulation considered in the following tasks are listed below:

- To simulate on-road tests for the comparison with WLTP test, vehicle data from the on-road measurements are necessary (e.g. on-road test mass, road loads, activated auxiliaries etc.). To set up generic correction functions for the road load values gained from type approval coast down and those to be expected in real driving, road load measurements according to Regulation (EU) 2017/1151 should be performed and be extended to include also side wind, PEMS equipment and different tire conditions (mainly different tread depth). For these measurements it should be taken into account, that as post-processing an air resistance correction, a rolling resistance correction, a wind correction and test mass correction (if measurements deviate from the standard) should be considered as described in the Regulation (EU) 2017/1151.
- For the WLTP type approval test, the test vehicle shall have been run-in and driven between 3,000 and 15,000 km. When checking the conformity of production for $CO_2$, the vehicle manufacturer may use an evolution coefficient multiply all values of $CO_2$ measured at zero km. For the in-service conformity the test vehicle shall have been in service for at least 15 000 km or 6 months, whichever the later, and for no more than 100 000 km or 5 years, whichever the sooner.
- The ISC and CoP procedures may provide significant input to the development of the ISV procedure. The methodology followed during the ISC and CoP, the testing sequence and the test procedures followed and the statistical evaluation applied to the two procedures, can serve as basis for the ISV procedure. Furthermore, ISC and CoP may potentially provide test data and input at the application of the ISV.

### 2.4.2 Elements from Regulations of non-European countries for LDV and HDV

There are a few useful practices identified in regulations of non-European countries that could be a possible source of inspiration for in-service $CO_2$ verification of LDV and HDV. In the US, there is already a procedure in force for checking compliance of in-use $CO_2$ emissions for LDV, by using the FTP and HWFET test cycles. FTP and HWFET are part of the 5-cycles test which is used for confirmatory and in-use testing of other pollutants. Additional test cycles used in other regions for TA or for determining fuel economy are the China 6 type tests and JC08 test cycle in Japan.

On EU level this would correspond to a verification using the WLTP test. Since we cannot exclude, that vehicle operation is changed if a chassis dyno test is detected by the ECU, the options discussed in chapter 2.2.2 using RDE tests in addition or instead of chassis dyno thus seem to have additional value.

Finally, the US information system EV-CIS, is a practice that could be used to adjust the calculation of the OEMs average emissions, in case deviations would be found or strategies that artificially improve $CO_2$ emissions. Also, this could be a source of input data for possible verification through simulation software, similar to $CO_2$MPAS.

Regarding HDV, apart from chassis dynamometer testing (Japan), simulation software is also used for the determination of fuel economy (US). This is a similar practice to the use of VECTO, which is already in force in the EU. In China, the recording and storage of real-time fuel consumption data reported by the engine may also provide the basis for fuel consumption verification.

The options described for EU based on the VTP (chapter 2.2.3) seem to be more advanced in terms of verification on single vehicle level. Options to use OBFCM data should look on the Chinese methods.

Table 2 and Table 3 show an overview of details from existing regulations of non-European countries, which could be a basis for in-service verification of $CO_2$.

**Table 2:** Procedures identified as possible inspiration for in-service $CO_2$ verification of LDV based on existing non-EU regulations

| Region | Procedures |
|---|---|
| **US** | • Use test results of FTP and HWFET test cycles to check for in-use $CO_2$ emissions compliance.<br>• EV-CIS: information system for collecting and verifying data from manufacturers. |
| **China** | • China 6 type tests. |
| **Japan** | • JC08 cycle, used to determine fuel economy. |
| **South Korea** | • No specific information found. |
| **India** | • No specific information found. |

**Table 3:** Procedures identified as possible basis for in-service $CO_2$ verification of HDV based on existing regulations

| Region | Procedures identified as possible basis |
|---|---|
| **US** | • Testing conditions and driving cycles of FTP, SET and NTE tests. |
| **China** | • In-use surveillance testing using PEMS.<br>• Real-time recording of fuel consumption, together with other signals. |
| **Japan** | • Chassis dynamometer tests.<br>• JE05 test cycle, used for fuel economy determination. |
| **South Korea** | • No specific information found. |
| **India** | • No specific information found. |

# 3 Task 2 – Guiding principles and criteria for in-service verification of $CO_2$ emissions (LDV)

## 3.1 Introduction – Starting point for the overall ISV procedure

The objective of the ISV is to check the $CO_2$ emission value on the CoC for which it is needed to repeat a Type 1 test. On the other hand, the ISV procedure should detect strategies that artificially reduce the $CO_2$ during such a test, but in fact those strategies will be active again during a repeated test. Therefore, these objectives cannot be met by just one testing option, so complementing approaches will be needed. In this section we will identify which approaches are available and analyse to what extent they are fit to serve either of these objectives.

Considering that the testing options needed for the ISV procedure are expensive and time-consuming, a layered approach is recommended, starting from the level of the risk assessment up until a full test. The basic idea is to escalate to the next level if a certain threshold is exceeded. Such an approach is expected to make the ISV procedure cost-effective, as full tests would only be conducted on those vehicles that have the highest potential to show a deviation in the test.

## 3.2 Scope and understanding of this task

Under Task 2 of this study, support is provided to the Commission in preparing the delegated act referred to in Article 13 of Regulation (EU) 2019/631[6]. That act shall set out the guiding principles and criteria for defining the in-service verification procedures for $CO_2$ including the methodologies to be used to detect strategies to artificially improve the vehicles' $CO_2$ performance in the type approval test.

This shall ensure:

- that the $CO_2$ emissions recorded in the certificates of conformity correspond to those from vehicles in-service as determined in accordance with Regulation (EU) 2017/1151;
- that strategies used to artificially improve the vehicles' $CO_2$ performance in the type approval test, -either at mechanical component, vehicle or control-software level, e.g. gear shift strategies, which are not driveable on the road- can be detected.

While the development of these guiding principles and criteria are primarily intended for an ISV procedure for LDV, an indication will be provided as to whether the same guiding principles would also apply for HDV. This is addressed separately in Annex I – Guiding principles for HDVs. For those elements where HDVs would require a different approach, this has only been flagged and not worked out in detail.

The following elements clarify our basic understanding of this task:

1. The first objective of the ISV procedure is "*that the $CO_2$ emissions recorded in the certificates of conformity correspond to those from vehicles in-service as determined in accordance with Regulation (EU) 2017/1151*" (Article 13 of Regulation (EU) 2019/631). This is understood as a comparison between the $CO_2$ emissions on the CoC and the $CO_2$ emissions measured at an in-service vehicle on a type approval test. This will be further clarified under point 4.
2. The second objective is "that strategies used to artificially improve the vehicles' $CO_2$ performance in the type approval test […] can be detected". This could refer to strategies by the manufacturer to systematically apply the best-case conditions towards low $CO_2$ emissions during the type approval test (in other words to exploit test flexibilities) and/or to control strategies built into the vehicle to actively reduce $CO_2$ during the type approval test. It is

[6] EUR-Lex - 02019R0631-20211202 - EN - EUR-Lex (europa.eu)

assumed that the latter interpretation applies here, since the effect of choosing favourable test conditions will be covered by the first objective. However, a comparison of $CO_2$ emissions at the level of the type approval test will not be sufficient to achieve the second objective: by repeating the type approval test, any strategy that is designed to influence the $CO_2$ performance will be active during the ISV test as well. This means that fully achieving both objectives into one ISV test is effectively not possible without one or the other being compromised. Therefore, the detection of such strategies will need a separate approach.

3. There is quite some experience available from ad hoc in-service verification programmes in the past. Usually, when a deviation in emission performance was found, the explanation provided by the manufacturer was that this would be caused by a wrong setting or by a specific test condition which was different at type approval. To make the ISV procedure effective, the burden of proof should be reversed: it should be the manufacturer's responsibility to explain why the declared value is lower than the result of a valid ISV test meeting all requirements of the WLTP, without necessarily mimicking the exact same conditions under which the type approval test was performed. The general principle should be that the WLTP test can be executed without instructions from the manufacturer with respect to test conditions or vehicle adjustments (except for general instructions, for example how to set a vehicle dyno mode or to evaluate an on-board signal).
4. Even if the ISV test would aim to exactly repeat the type approval test and try to copy all relevant vehicle and test conditions, there will always be deviations that cannot be eliminated (e.g. due to test-to-test variability). Therefore, in the comparison between the measured ISV $CO_2$ value and the CoC value a certain tolerance might need to be taken into account. As a starting point, only justified differences between the type approval test and the ISV should be accounted for in this tolerance. Any strategies applied during the type approval process to systematically lower the $CO_2$ emissions should not be rewarded.
5. For the legal robustness of the ISV procedure, the same test protocol as used for the type approval should be the core of the procedure. Vehicle simulation, however, could play a useful role in various stages of the protocol. The use of vehicle simulations may reduce the test burden and therefore the cost implications to the industry, but may also help to improve the effectiveness of ISV. This will be further explained in the next paragraph.
6. The main requirement from Article 13 of Regulation (EU) 2019/631 for the in-service verification is to verify correspondence with the $CO_2$ emissions on the CoC of the vehicles. For OVC-HEVs, the electric range is a parameter that impacts the utility factor (UF) which is needed to calculate the UF-weighted $CO_2$ value on the basis of $CO_2$ results from a "charge sustaining" and a "charge depleting" test in accordance with the WLTP protocol. This electric range generally depends on the useable battery capacity and the vehicle's energy consumption in electric mode. Both these parameters may be different for in-service vehicles compared to the CoC value. This means that a check of the electric range of OVC-HEVs is in principle necessary to enable in-service verification of the UF-weighted CoC $CO_2$ result. As a proxy, screening of the electric range would be possible by measuring the electric energy consumption and considering the useable battery capacity. The electric energy consumption and the electric range of PEVs are not covered by this study. However, it could make sense to address electric range and electric energy consumption as formal parameters for verification in the future. It is expected that the majority of test protocols developed for ISV of $CO_2$ emissions are equally applicable to these parameters. Concerning the (statistical) evaluation procedures, however, care should be taken in order to account for the battery aging and the subsequent deterioration of the electric range.

## 3.3 Considerations on the possible role of vehicle simulation

As part of developing guiding principles for the ISV procedure, it is useful to explore the role that vehicle simulation could have in the context of various stages of the ISV procedure. The first question is whether and how simulations can be used as tools to support the process of carrying out ISV.

It is acknowledged that there are powerful simulation instruments that have good capabilities in predicting the $CO_2$ emissions. Such tools can be calibrated on measurement results from laboratory tests as well as on-road testing and monitoring. The latter include results obtained from RDE tests. This means that simulation tools can be used to translate results from a type approval test towards any kind of on-road test performed on an in-service vehicle. This allows for a direct comparison between measured and calculated $CO_2$ emission values. Such comparisons may provide indications of the extent to which the WLTP $CO_2$ emission of in-service vehicles are consistent with the emission value on the CoC. In the risk assessment phase, simulations might therefore be helpful in evaluating available data on in-service vehicles and pointing out which vehicle types should be selected for the ISV testing (see paragraph 3.10).

In addition, simulations can be used to gain insight in the sensitivity of $CO_2$ emissions on the WLTP to variations in test conditions within the boundaries prescribed by the WLTP protocol. In the testing phase this may be helpful in reducing the number of tests needed to detect a possible deviation with sufficient statistical significance.

Simulations can also be useful in later stages of the ISV procedure, specifically the evaluation of test results by the GTAA or the evaluation by the European Commission of ISV results reported by GTAAs. Discrepancies detected between measured and simulated $CO_2$ emissions may provide indications for the application of strategies to artificially improve the vehicles' $CO_2$ performance in the type approval test.

A next question is whether results from simulations could serve as evidence, perhaps even the sole evidence, upon which a decision concerning a deviation of the In-Service $CO_2$ value from the CoC value can be based. Here, the following considerations apply:

- In principle, vehicle simulation can be the source of the $CO_2$ emission value that is attributed to vehicles in the context of $CO_2$ regulation and associated regulatory requirements and procedures. This is the case for heavy duty vehicles, where the VECTO simulation tool is the basis for determining $CO_2$ emissions as part of the type approval, for lack of a practicable whole vehicle test. As part of the CoP requirements under the $CO_2$ regulation for HD vehicles a procedure has already been developed in which the measured on-road $CO_2$ emissions is the output of VECTO simulations which are based on inputs from physical on-road tests performed on a sample of production vehicles. For ISV of HDVs a similar approach is conceivable[7].
- For light duty vehicles, the CoC $CO_2$ value is derived from a (set of) physical test(s). In accordance with the WLTP protocol, an actual vehicle is tested on a chassis dynamometer, using driving resistance settings derived from a physical road load test. The purpose of ISV is to verify (i.e. confirm or falsify) whether the $CO_2$ emissions of in-service vehicles, determined by using the same test procedure as used for type approval testing, correspond with the CoC value. Article 13(1) of Regulation (EU) 2019/631 requires that the determination of the $CO_2$ emissions of vehicles in-service shall be done "in accordance with Regulation (EU) 2017/1151", i.e. in accordance with the WLTP protocol as also used for type approval.
- Vehicle simulations alone may only provide convincing evidence for a deviation of the in-service $CO_2$ value from the CoC value, if it can be proven that the inaccuracies of the simulation tool are significantly smaller than the observed deviation. The accuracy of the simulation tool is defined by the extent to which the tool is able to reproduce the outcome of chassis dynamometer tests performed on the vehicle that is simulated. Results from simulations may deviate from actual test results because component modules are insufficiently accurately modelled or calibrated. And vehicles may even contain new technologies for which there are not yet applicable simulation tools. In general, the accuracy of a simulation model can only be proven by comparison of its predictions with the results of extensive physical tests. Developing a model with sufficient accuracy in general requires inputs from component tests to accurately calibrate individual component modules, and comparison of model outputs with vehicle test results for calibration of the complete model. This makes it questionable that using simulation results as the basis for formal decisions on deviations will reduce the test burden involved in

[7] See Appendix 1 for further considerations on ISV procedures for HDV.

ISV. An additional complexity would be that it is difficult to define common procedures and requirements for tests that are needed to develop and validate simulation tools for this purpose.
- A further aspect of the accuracy of simulations relates to the impact of differences between the driving conditions during the (on-road) measurements which are used as input to the simulation and the conditions during the WLTP test (e.g. road inclination, weather conditions and road surface). Corrections applied for these differences can never be completely accurate, even if all relevant parameters are recorded. Therefore, if the ISV would be based on vehicle simulations a wider tolerance will be required in addition to the extra tolerance related to the accuracy of the model itself.
- Basing the ISV outcome on simulation only would thus put a large burden of proof for the accuracy of the simulation tool on the GTAA performing the ISV. When deviations would be established on the basis of simulation results, this will inevitably lead to disputes between the manufacturer and the GTAA performing the ISV. The willingness of manufacturers to accept results of simulations by the GTAA could be improved by allowing the GTAA to use information provided by the manufacturer for developing or calibrating the simulation. This, however, is undesirable from the point of view of effectiveness and credibility of the ISV regulation.

Based on the above considerations it is concluded that vehicle simulation software may play an important supporting role in the ISV procedure, but there are limitations to its applicability in providing evidence upon which decisions with respect to deviations can be based.

## 3.4 Approach for developing ISV procedures

In-service conformity procedures for emissions of pollutants from light-duty vehicles based on chassis dyno testing are set out in Annex II of Regulation (EU) 2017/1151[8] (EU WLTP). They were last amended and extended by RDE testing with portable emission measurement through Regulation (EU) 2018/1832[9]. Annex I of the EU WLTP Regulation sets out procedures for verifying that newly produced vehicles comply with the approved type (CoP testing).

As presented in Task 1, the ISC and CoP procedures may serve well as a basis for the $CO_2$ in-service verification procedure to be developed, in particular on the following points:

- ➔ The ISC procedures consist of a Type 1 test and an RDE approach for the verification of pollutant emissions of in-service light duty vehicles. In Annex II, procedures are described for risk-based assessment, follow-up protocols, vehicle procurement, quality control, statistics, outlier treatment, reporting and responsible parties. The RDE element of the ISC procedure will be further referred to as RDE ISC[10]. Particularly, the statistical methodology (which is based on sequential sampling approach) for the evaluation of ISC test results may serve as a starting point for the ISV statistical approach.
- ➔ The WLTP CoP procedures in Regulation (EU) 2017/1151[8] and the CoP annex of the new UN Regulation on Worldwide harmonized Light vehicles Test Procedure (UNR 154)[11] contain elements for the verification of $CO_2$ emissions of production vehicles, providing further insight and evidence on the current state of $CO_2$ testing. This will be further referred to as WLTP CoP. Besides the CO2 emissions testing, the CoP procedure incudes a pass/fail statistical approach that can be proved helpful for the design of the statistical approach of the ISV procedure (analyzed in Section 6.6).

Therefore, the definition of the guiding principles and criteria for the $CO_2$ in-service verification procedures for light-duty vehicles will take the ISC approach and the WLTP CoP approach as the prime basis. This is complemented by the output of Task 1, which delivers in-depth information on existing

[8] EUR-Lex - 02017R1151-20200125 - EN - EUR-Lex (europa.eu)
[9] https://eur-lex.europa.eu/legal-content/NL/TXT/?uri=CELEX%3A32018R1832
[10] Aside from the RDE test there is also a Type 1 test included in the ISC procedure in EU WLTP, however this is considered less relevant for the ISV procedure because this is tested under the responsibility of the manufacturer.
[11] Refer to documents ECE/TRANS/WP.29/2020/77 and ECE/TRANS/WP.29/2020/92 and their 01 series of amendments ECE/TRANS/WP.29/2020/78 and ECE/TRANS/WP.29/2020/93 which can be found at https://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/gen2020.html

pass/fail criteria, their applications, lessons learned from heavy-duty legislation and similar legislation in other regions.

The guiding principles and criteria will be developed as follows:

The first step is to select the relevant general elements identified from the ISC and WLTP CoP procedures and assess their suitability for the $CO_2$ ISV procedure. This is combined with the output from Task 1 to compile a list of elements from the existing regulations that can be used for the guiding principles and criteria.

The next step is to identify the options to fill in these elements, discuss what the benefits and drawbacks may be and, where possible, provide recommendations. For this process an important input is the outcome and lessons learned from the project "$CO_2$ in-service conformity test campaign and methodology development for light-duty vehicles" for DG CLIMA[12]. Some examples of the insights emerging from that project are:

- ➔ Vehicles put on the road do not necessarily match all characteristics specified in the CoC. A lot of vehicles have different tyres and rims and many other deviations can be observed. Vehicle owners may adapt the vehicle.
- ➔ The availability of information in the CoC is limited, which in many cases makes it difficult to verify how vehicles compare with their original state at type approval (e.g. concerning the original bodywork, missing wheel/tyre dimensions and actual tyre rolling resistance coefficient).

This step will qualitatively address elements such as:

- ➔ Transparency of type approval data and relevant information needed for the ISV test
- ➔ Types of tests to be performed and the possible role of vehicle simulation tools
- ➔ Frequency and scope of tests and/or vehicle simulations
- ➔ Risk assessment methodology
- ➔ Statistical procedures: e.g. pass/fail criteria, treatment of outliers
- ➔ State of selected vehicles compared to the CoC
- ➔ Availability of all data necessary for proper comparison; which information to be collected from the manufacturer for testing
- ➔ Remedial measures and appeal process, burden of proof in case of disputed results
- ➔ How to account for 'natural' differences between a test environment and real-world conditions (correction factors, other options)

## 3.5 Elements of the ISV procedure

The EU legislation on ISC and WLTP CoP covers a multitude of procedural aspects, ranging from general ones such as responsibilities for the parties involved, to very specific issues such as the pass/fail criteria. For the development of the ISV procedure, we have identified the following main elements. Some of these elements may fit into the delegated act as foreseen in Article 13 of Regulation (EU) 2019/631, while others might be more relevant for the implementing act setting out the detailed ISV procedures.

1. Objectives of ISV testing; Which tests are performed, and the parameters to be measured
2. Responsible parties; Define the responsibility for each party involved
3. Funding of ISV test activities
4. Family criteria for ISV test; Define an ISV family to reduce testing burden
5. Minimum sample share and frequency; Share and frequency of vehicle families to be tested
6. Risk assessment methodology; Methods to improve the selection process and increase cost-effectiveness of the implementation of the regulation
7. Test vehicle selection, acquisition and preparation

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[12] Refer to TNO-report 2020 R11122 "Final report - $CO_2$ In-Service Verification test campaign and methodology development for light-duty vehicles", J.A. van den Meiracker et al., DG CLIMA, 17 August 2020.

8. Minimum and maximum sample size for the ISV test;
9. Scope of necessary type approval data and their secure exchange
10. Quality assurance method; Accreditation of testing laboratories
11. Test fuel;
12. Road load setting;
13. Corrections; Additional correction factors such as Ki , ATCT, and RCB
14. Type of tests for ISV
15. Tolerance; Reference value and allowed deviation from type approval results
16. Pass/fail evaluation criteria statistics
17. Outliers; How to deal with large deviations
18. Adjustment of CoC values for ISV family; Consequences in the case that a fail decision is reached
19. Reporting

These elements will be addressed separately in the following paragraphs.

Other elements identified in ISC and WLTP CoP are not seen as applicable to the ISV procedure such as the minimum check interval by TAA and the run-in procedure (including the evolution coefficient). These are addressed separately in paragraph 3.22.

### 3.5.1 Objectives of ISV testing

As indicated in Article 13(1) of Regulation (EU) 2019/631[13] the first objective of the ISV procedure is to compare the $CO_2$ emissions on the CoC with the $CO_2$ emissions measured at an in-service vehicle on a type approval WLTP test. The comparison of $CO_2$ emissions is fundamentally different from the objective of the on-road RDE ISC test, where pollutant emissions may not exceed a certain limit in various driving situations and ambient conditions. For $CO_2$ there is no such limit value. The reference against which the ISV value is to be compared is the $CO_2$ emission value on the CoC, which is interpolated from the values declared for vehicle High and Low that are verified at type approval. If on-road RDE testing were to be used for ISV testing of $CO_2$ emissions, there would be a lot of unknown variables in the on-road tests which have an influence on the $CO_2$ emissions (e.g. driver behaviour, vehicle load, road inclination, weather conditions and road surface etc.). Making general assumptions for these unknown conditions would make the results rather inaccurate, consequently elevating the tolerance to such an extent that the verification would become totally ineffective. This makes the RDE ISC unfit to serve as the testing procedure for ISV[14]. Therefore, the basis of the ISV will be formed by the type approval Type 1 test procedure (WLTP).

In paragraph 3.10 we will investigate the possibility to use the data from the type approval tests as input to simulate the expected WLTP $CO_2$ emission for the on-road RDE ISC tests and use the comparison as a basis for the risk assessment. The testing methodology for the ISV procedure itself will be worked out in detail in paragraph 3.17.

The second main purpose of the ISV testing is to detect strategies that artificially decrease $CO_2$ emissions during the type approval test. As outlined under point 2 in Section 3, this will require a separate approach since the type 1 type approval test itself is not fit for detecting such strategies. This approach should not be based on a specific well-defined vehicle test because such a test can be detected and targeted to lower the CO2 emissions by specific strategies. Instead, methods should be applied that can indicate the existence of such strategies and reveal the mechanisms behind them. By focusing on these mechanisms and performing for example dedicated on-road tests, it could be proven that the

[13] EUR-Lex - 02019R0631-20211202 - EN - EUR-Lex (europa.eu)
[14] Note that that the allowed tolerance for measurement of $CO_2$ by a PEMS system on a WLTC is rather wide: ± 10 g/km or 10% of the laboratory reference, whichever is greater. According to the JRC, the state-of-the-art PEMS systems are capable to determine $CO_2$ emissions within half of that tolerance. Reducing that tolerance in EU WLTP will make these results more reliable for the risk assessment procedure, refer to paragraph 3.10.

behaviour of the vehicle in the type approval test is not representative for real-life driving conditions and that this leads to an artificial improvement of the $CO_2$ emissions. This approach will be further detailed in paragraph 3.17.

Determining the $CO_2$ emission value on the WLTP Type 1 test during the type approval process contains two main elements: first, the determination of the road load of the vehicle, and secondly the measurement of the $CO_2$ emissions on the chassis dynamometer which is set to the measured target road load. The road load has a large influence on the measured $CO_2$ levels and the ISV should therefore not be limited to the WLTP chassis dynamometer test, but also cover the road load determination.

## 3.6 Parties involved

As set out in Article 13 of Regulation (EU) 2019/631, the overall responsibility for the ISV lies with the Granting Type Approval Authority (GTAA). When a GTAA formally determines a deviation, it has the responsibility to ensure that the original CoC value is adjusted and to report the deviation to the European Commission. It is up to the Commission to take that deviation into account when determining the average specific $CO_2$ emissions of a manufacturer.

Various other parties can contribute to the process of ISV, for example by providing information to the GTAA that can be used in the risk assessment or other steps of the ISV. These parties include **other TAAs, Market Surveillance Authorities (MSAs) and Independent Third Parties (ITPs)**.

The role for the **manufacturer** in the ISV procedure is limited to provide information requested by the GTAA and to correct the CoC value if a deviation has been determined.

As part of the type approval process the GTAA has already received or access to all vehicle-related information that is needed to enable proper execution of the ISV tests. The manufacturer will be informed by the GTAA on the outcome of ISV testing. The roles and responsibilities of the various parties in relation to the various steps in the ISV procedure, and the associated flows of information, are depicted in Figure 15.

Other TAAs, MSAs and ITPs may contribute to the risk assessment and vehicle selection process performed by the GTAA by providing data to the GTAA in particular where this would provide indications of (a risk of) possible deviations. Such data may be derived from e.g. vehicle inspections, RDE-tests, on-road emission and fuel consumption monitoring programmes as well as coast down or chassis dynamometer tests performed for other purposes than ISV testing.

Other TAAs, MSAs and ITPs may also decide to hire a TS to carry out their own tests in accordance with the ISV test protocols. If such tests provide results that challenge the validity of the CoC value of the vehicle, they may submit these results to the GTAA. It is recommended that GTAAs are obliged to evaluate that information. Provided that the conditions and execution of the independent tests can be sufficiently validated against the ISV and WLTP protocols and are found to comply with those, it would be recommended that the GTAA will start its own procedure for the ISV family in question. An issue with the possible validity of independently performed tests in accordance with the ISV test protocols is that in general information from the manufacturer is needed to correctly perform the tests. The GTAA will have this information as it is needed for performing type approval. At present, manufacturers and GTAAs have no obligation to provide such information to third parties. There are also good reasons to prevent that such information becomes public. Procedures needed to disable safety features of the vehicle, which are e.g. needed to allow chassis dynamometer testing, lead to dangerous situations when applied by unauthorised persons to vehicles on the road. It is recommended to include an obligation for GTAAs to provide such information upon request to technical services or other accredited test laboratories. For this purpose, there should be an accreditation procedure put in place, preferably consistent to the requirements for third parties in Article 13 of Regulation (EU) 2018/858. This will be described in detail in paragraph 3.13 and 3.14. To safeguard the confidentiality of the submitted information it is recommended that this information is only provided directly to the technical service or accredited test laboratory, without it being disclosed to the ITP.

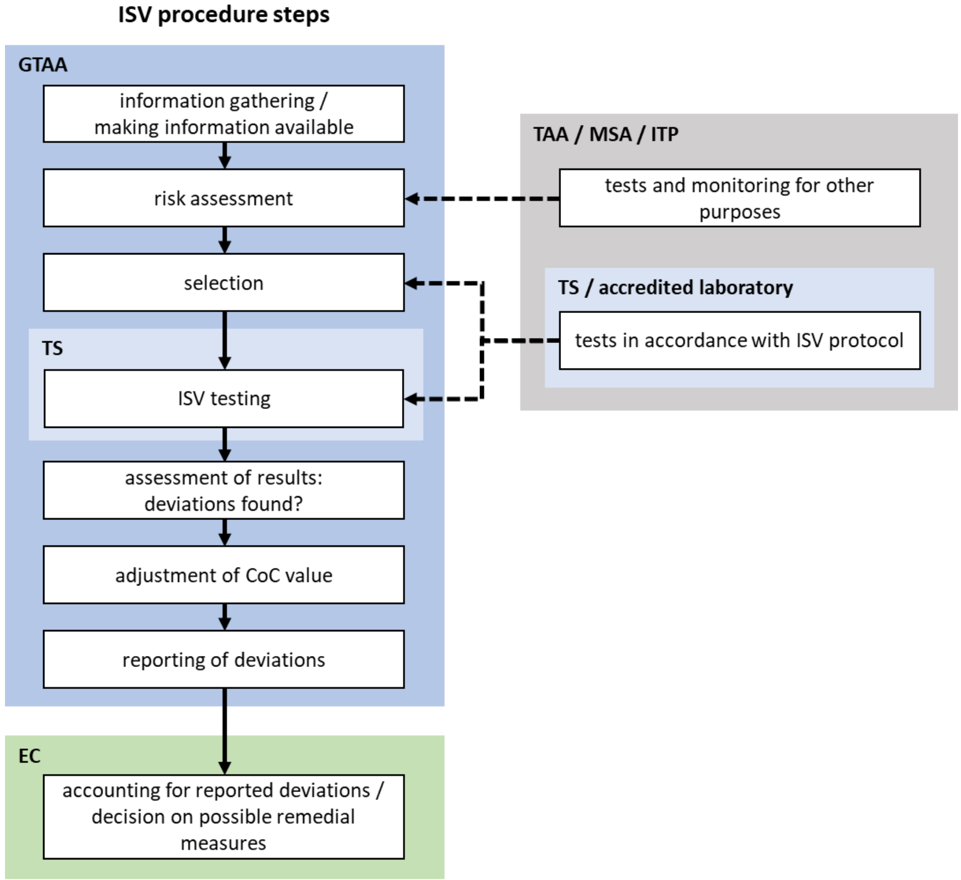


**Figure 15:** Overview of roles and responsibilities for the parties involved in the ISV procedure and associated flows of information (the role of the involved parties shown is not necessarily exhaustive especially as regards the EC)

In this way MSAs or ITPs wishing to perform ISV test programmes could do so by contracting an accredited TS or other accredited test laboratory, and GTAAs are informed of the interest of ITPs to perform tests that may be relevant in the context of their ISV obligation.

For the provisions for data availability and accreditation Article 13(10) of Regulation (EU) 2018/858 could be used as a basis.

Effective execution of the ISV procedure by a GTAA requires that the tests are performed in such a way that they constitute an attempt to falsify the applicability of the CoC value for in-service vehicles. This involves assessing the impacts of differences between in-service vehicles and the vehicle(s) used for type approval testing, but also the impacts of variations in test conditions within the boundaries of the WLTP procedure. The test conditions in the ISV testing may thus be different from the ones used in the type approval test as long as they are within the accepted bandwidth of the test procedure. This not only includes variation of test conditions in the road load determination and chassis dynamometer test, but also using another TS to carry out the test. The latter also helps to avoid a possible conflict of interest associated with the chance that the GTAA might need to put into question its own prior approval. Involving a different TS, and allowing other organisations (TAAs, MSA and ITPs) to contribute information, further enhances the robustness of the procedure and credibility of the ISV results. From that perspective it is therefore recommended that:

- ISV testing is not carried out by the manufacturer;
- the GTAA facilitates independent testing by a technical service or other accredited laboratory by providing upon request the vehicle-specific technical information needed to perform the ISV tests;
- the GTAA involves a different technical service to perform the actual ISV tests than the technical service involved in the execution of the type approval test.
- the GTAA is obliged to evaluate test results provided by ITPs which challenge the validity of the CoC value;

## 3.7 Funding of ISV test activities

The costs for the ISC testing of pollutant emissions are covered by fees that the GTAA charges to the manufacturer, refer to Regulation (EU) 2018/1832, Annex II Part B, par. 5.5. These fees are based on the number of ISC tests that have to be performed, which is related to the sample share and number of test vehicles per sample.

For the ISV procedure a similar funding system is recommended.

## 3.8 Family criteria for ISV test

In order to reduce the testing burden, it is suggested to define 'ISV families'. If a vehicle within such family is verified, the final decision based on the ISV findings for that vehicle should be valid for all vehicles within that family and the consequences of such findings should be applied accordingly.

There are many vehicle families already defined within WLTP. Specifically, for the purpose of ISV testing the interpolation family seems best qualified as family definition since the declared $CO_2$ emission on the CoC is based on the interpolation line. The interpolation family criteria can be found in par. 5.6 of Annex XXI to Regulation (EU) 2017/1151. Vehicles which do not belong to an interpolation family and are part of a family defined on the basis of a vehicle high should also be tested for the ISV.

In some cases, different interpolation families will have (almost) the same $CO_2$ emission performance, for example:

- Interpolation families that are technically identical but only differ by the brand name;
- Technically identical vehicles which are type approved as M1 and N1 category vehicles;
- Interpolation families with identical engines yet having different power ratings

If for these specific cases the argument of equivalency is made plausible, the TAA may allow the same type approval test results to be used for different interpolation families, thereby accepting a 'child' family to be based on the interpolation line of a 'parent' family. This is not an existing concept in WLTP, but a common practice for TAAs. Such a parent/child approach is recommended to be allowed as a valid grouping option for the ISV family. Based on an estimation by the JRC this grouping is expected to lead to a 20% reduction in ISV families.

Taking the ISC family -which effectively is the same as the PEMS test family for Type 1 testing- as a basis for grouping would offer even more potential for reducing the number of tests. However, the ISC family is not suitable as a basis for the ISV family since different interpolation families are merged into one ISC family.

Finally, it is recommended that the vehicles in the sample lot are different in terms of mass, tyre rolling resistance and aerodynamic drag in order to cover the broader CO2 range of vehicles included in the ISV family. How these different vehicles will be evaluated will be explained in paragraph 3.19 and the method for determining the adjustment of the CoC value in the case of a CO2 deviation is the subject of paragraph 3.21.

## 3.9 Minimum sample share and frequency

Defining the minimum share of ISV families to be sampled should ensure an optimal cost-effectiveness: the additional test burden of the $CO_2$ verification should be as low as possible, yet the effect should be such that it achieves a sufficiently high level of confidence in the confirmation of the type approval CO2 emissions.

In EU WLTP it is required that the manufacturer performs ISC and CoP testing on at least one sample for every single ISC and CoP family. The RDE ISC requires that RDE testing is performed by the GTAA on a minimum of 5% of the ISC families per manufacturer per year, refer to (EU) 2018/1832, Annex II Part B, par. 5.4. Unlike ISC, which checks the in-service emission performance of pollutants for vehicles with mileage between 15,000 km and 100,000 kilometres, the ISV will verify the $CO_2$ value recorded in the CoC. Therefore, it would be appropriate and preferable that ISV testing can be initiated soon after market introduction of the ISV family. This will be addressed in paragraph 3.11.

In order to find a balance between the test burden and the effectiveness of the ISV procedure, it is recommended to take a similar approach as for the RDE ISC, i.e. a random spot check. In this case a certain minimum sample share (e.g. 5%) of the ISV families per manufacturer per year would be tested. An exception or exemption could be allowed for small-volume manufacturers[15]. With this, the instrument of ISV may still be very effective, provided it is

a) ensured that the selection of vehicles has a random component, and
b) the consequences for an ISV vehicle family that was found to fail are sufficiently severe.

The element of the selection process will be further explored in paragraphs 3.10 and the consequences of detecting a deviation in paragraph 3.21.

With a minimum sample share of 5%, according to an estimation by the JRC, the ISV tests would cover 75-100 ISV families in Europe annually. The costs per vehicle will depend on the choices made for the composition of the ISV test procedure. As a reference, according to Article 8(2) of Regulation (EU)2018/858 market surveillance authorities of Member States are required to perform verification tests on a minimum of one vehicle per 40,000 new registrations. Considering a volume of about 15 million new car registrations in Europe, this means that about 375 vehicles are checked annually. With an assumed average sample size of five vehicle per ISV family, a minimum sample share of 5% translates into 375 – 500 vehicles per year, which is the same order of magnitude.

Within the above-mentioned constraints, a first attempt to provide an estimation on the costs will be made, which consists of the following:

- Vehicle rent, transport to/from owner to test track/test laboratory and insurance: ~2.5 k€
- Chassis dynamometer WLTP test including preparation, instrumentation and reporting: ~3 k€
- Road load test, including track rent, preparation, instrumentation and reporting: ~3 k€
- Management, organisation and communication, including full test report: ~1.5 k€

The costs of these activities are roughly estimated and may vary significantly depending on the travelled distances to and from test locations, type of vehicle (rent price), need for tyre replacement and whether test facilities are owned by the testing body or not. Based on these figures, a complete ISV test (including road load and a WLTP test on the chassis dynamometer) would cost around 10 k€. Assuming

[15] In the context of the $CO_2$ legislation small-volume manufacturers are defined as "manufacturers responsible for fewer than 1 000 new passenger cars and new light commercial vehicles registered annually in the Union"

an average sample size per ISV family of 5 vehicles, the total amount per verification is 50 k€. As will be explained later in paragraph 3.17, there will be possibilities to improve the cost-efficiency of ISV testing by adding screening tests and focussing on either the road load or the chassis dynamometer test. If the testing can be limited to either the road load or the chassis dynamometer test, costs would be reduced to 35 k€. To test the estimated 75-100 ISV families per year, the associated costs would range between 2.6 and 5 million euro.

Instead of having a fixed minimum sample share, it would be even more efficient as well as effective to make this number dependent on the results. If an ISV family sample is found to have a statistically significant deviation leading to a fail decision, the minimum sample share of the manufacturer concerned could be increased. This could be a relative increase (e.g. increasing the minimum of 5% by 1% for each fail) or an absolute increase (e.g. adding two ISV families for each fail). Similarly, a consecutive number of ISV family passes of the same manufacturer could lead to a reduction of the minimum sample share. Such a mechanism can be very effective to limit the minimum sample share yet having a sufficient leverage to create an effective verification instrument.

In EU WLTP the ISC check is not mandatory if the annual sales within an ISC family are below 5000 units. For ISC families which are produced in high numbers, the number of sample lots per ISC family increases to one per 100,000 annual sold vehicles per family with a maximum of 3 sample lots. The underlying reason for this increase is that pollutants may deteriorate rapidly due to durability issues of the emission control systems. A different approach is foreseen for the ISV procedure because the $CO_2$ emissions remain fairly stable after the run-in period. There is more added value in testing other ISV families than in testing more sample lots of the same family. At the same time, it is recommended that those ISV families which are produced in high numbers should receive a higher chance of being selected while low volume families could be selected less frequently. This will be explored more in detail in paragraph 3.10 on risk assessment.

For the sample frequency another approach is foreseen than the ISC requirement, which states that the time period between two consecutive checks should not exceed 24 months. As outlined above, there is not much added value in repeating ISV checks on the same family since $CO_2$ emissions are less susceptible to deterioration issues than pollutants. Hence the requirement might better be reversed: an ISV family that has been checked cannot be selected again within a period of 24 months.

## 3.10 Risk assessment methodology

As explained in the previous paragraph a 100% coverage of the ISV families by surveillance measures is not feasible. Consequently, there needs to be a selection process in place. This could simply be developed as a completely random process, which would give every ISV family the same chance of being picked. However, the verification process can be made more effective if an element can be added which increases the chance of selecting an ISV family that has a higher probability to show a significant CO2 deviation. This also allows for a lower minimum share of families to be tested, thus increasing the cost-effectiveness of the instrument[16]. A risk assessment strategy should improve the selection process such that it becomes a smart selection rather than a random one.

From the perspective of European $CO_2$ targets the risk of in-service vehicles exceeding the CoC $CO_2$ value is that the effectiveness of these targets is undermined. The main parameters contributing to this underperformance are the amount of deviation from the CoC ($\Delta CO2$), the amount of vehicle

[16] The scope of the ISV includes OVC-HEVs hence the risk assessment for this category should also include discrepancies in energy consumption and/or electric range. The risk assessment strategy outlined in this paragraph for $CO_2$ emission deviations is also applicable to these parameters.

registrations N for that ISV vehicle family and the average annual mileage of vehicles in the family. The risk assessment should therefore be based on these three parameters[17]. While N is a known parameter from the registration database and the annual mileage will be reported together with the OBFCM dataflow -although there may be a delay in the information becoming available- the $\Delta CO_2$ remains unknown until the ISV procedure has taken place. Therefore, the risk assessment needs to be based on predictions for the $\Delta CO_2$ by analysing information sources which may indicate that certain ISV families have a higher potential for deviations than others.

The following sources are identified for this purpose:

- ➔ **Results of earlier ISV tests**, particularly looking at manufacturers which have a record of deviations for one or more ISV families in the recent past (note that there might also be a mechanism put in place to increase the minimum percentage of ISV families to check, see paragraph 3.9)
- ➔ **Statistical analysis of information in the DICE database**: The $CO_2$MPAS correlation tool was developed by the JRC to support the transition to the new WLTP testing protocol and to support Correlation Implementing Regulations (EU) 2017/1152 (vans) and (EU) 2017/1153 (passenger cars). DICE is the JRC server where all $CO_2$MPAS encrypted files were submitted to. These files contain all necessary WLTP input data and $CO_2$MPAS simulation results for every interpolation family. Only persons appointed by TAAs can encrypt the type approval files and submit them to the DICE database. Since 2021, the obligation to provide these data to the Commission (JRC) continued under Regulation (EU) 2021/392. The database offers possibilities for statistical analysis of the ISV families: by making a comparison of vehicles with similar $CO_2$ relevant characteristics, vehicles could be identified which have lower than average $CO_2$ emissions. A deeper analysis into the road load relevant characteristics might reveal if this deviation is more likely to be related to the road load determination or to the WLTP chassis dynamometer test.
- ➔ **Data from the on-road RDE ISC test[18]** could be predicted by a simulation model which is calibrated by feeding data from the WLTP type approval test. The predicted $CO_2$ emissions can then be compared against the measured on-road results. A good candidate for this approach is the $CO_2$MPAS model or a similar model specifically dedicated to the task of ISV verification. If the deviation between predicted and measured $CO_2$ is significantly to the high side (at least beyond a tolerance reflecting the expected inaccuracy of the simulation model) that is a good indicator for selecting the ISV family corresponding to the vehicle that was tested for RDE ISC.
- ➔ The Commission is collecting **data on the real-world $CO_2$ emissions and fuel or energy consumption** of passenger cars and light commercial vehicles using OBFCM devices, starting with new vehicles registered in 2021. Analysing these data against the CoC $CO_2$ emissions will reveal the gap between real-life driving and type approval, and this gap could be used as an indicator. This analysis should also involve harmonisation of the data to correct for differences between the type approval test and real-life conditions, e.g. related to different driving profiles and the use of auxiliaries. A statistical analysis of the gap may pinpoint those ISV families that have a higher risk of showing a significant deviation on the ISV test. Such an analysis should be based on comparing vehicle models that have similar $CO_2$ emission relevant characteristics and vehicle use[19].
- ➔ The GTAA has access to the CoP results. The ratio between the average measured $CO_2$ emissions within a CoP family and the declared $CO_2$ emissions may prove to be a valuable indicator; a ratio which is close to 1 indicates that there is little safety margin, hence a higher probability that an ISV check may reveal a deviation.

[17]

[18] These data can be requested by any interested party according to Regulation (EU) 2017/1151, Annex IIIA, chapter 3.1.3.3**Error! Bookmark not defined.**

[19] Note that evaluation of the gap might need some further evaluation into the vehicle use. For example, vehicles that are frequently used for towing trailers will show a larger gap. Similarly, sports cars and 4WD vehicles may also show higher than average $CO_2$ emission gaps. Such vehicles should be filtered out from the OBFCM based risk assessment. This does not mean they should never be selected for verification, only that the selection should not be based on an OBFCM analysis. Also note that the CO¬2 emissions of OVC-HEVs are closely related to the share between EV and ICE operation, so the OBFCM data will have no relevance for this vehicle category unless the actual utility factor is known.

- ➔ $CO_2$ emission deviations found for vehicles from verification testing performed by ITPs or MSAs.
- ➔ Any other available information source that may indicate a higher $CO_2$ emission, ranging from consumer complaints on fuel consumption to electronic platforms for collecting fuel efficiency data of car owners (e.g. Spritmonitor.de). The testing campaigns conducted for updating emission databases and models (such as the HBEFA emission database[20]) may also be a valuable source of information.

The selection process should ideally be based on a combination of sources. Additionally, the predictive potential may be different for these sources, or only apply to certain vehicle categories.

To factor these different sources/methods into the selection strategy, one of the following approaches could be followed:

1. For each of the sources available, the ISV families are ranked for their risk score and a fixed distribution share is applied, i.e. x% of the selection is based on the ISV families showing the highest risk scores according to method 1, y% is based on the ISV families showing the highest risk scores according to method 2, etc.
2. For each of the sources available the ISV families are ranked, and the risk score rankings are summed to arrive at a total risk score. The selection is then based on the ISV families showing the highest total risk score[21].
3. Further to the previous approach, the selection strategy can be made even more effective by adding a weighting factor to the different sources, indicating their predictive potential (i.e. the confidence) to identify vehicles which show a significant deviation on the ISV procedure. The total risk score is calculated by multiplying the individual risk scores by the weighting factors and calculating the sum as a total risk score. Of course, the predictive potential of different sources and the weighting factors that they should receive can only be evaluated after the procedure is already in place.

As indicated, the second element for the risk assessment is based on the number of vehicle registrations. Vehicle families with a high production volume should therefore have an increased chance of being selected. Approaches 2 and 3 are particularly suitable for this, as the production volume might be used as a weighting factor in the overall risk score. The main source for the vehicle registrations in Europe is the database of the European Environmental Agency (EEA). The only drawback is that the information included in that database arrives with some delay, generally provisional data become available 6-8 months after the sales-year closes. It should be investigated if there are means to make earlier predictions, e.g. based on the registrations of previous years.

Whatever kind of intelligent selection strategy is applied, it is highly recommended that a small but significant share of the ISV families to be selected (for example 20%) is chosen completely randomly. The principle behind this recommendation is that there should always be a finite possibility that any ISV family can be selected for the verification procedure.

In this paragraph we have identified a lot of possibilities to develop an effective risk assessment and selection strategy. However, for the regulations that cover the ISV procedure it may not be necessary to describe the risk assessment procedure in such detail. Since the GTAA will be the responsible party for the selection process, it is not required to specify how their selection process is actually taking place. Furthermore, the advantage of not revealing the selection strategy is twofold:

1. the GTAAs can optimize their strategy if better information sources become available without contradicting the regulation, and
2. Manufacturers have no possibility to anticipate the selection strategy.

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[20] Refer to https://www.hbefa.net/e/index.html

[21] Note that not all vehicles may have a score according to all sources/methods. In this case the scores should be ranked relative to the average baseline, and vehicles for which there is no information available the score is assumed at '1'. This is to avoid that only vehicles are selected for which multiple information sources are available. In other words, if a certain information source is not available for an ISV family, this should not decrease or increase its chance of being selected.

In this case, the only requirement that should be included is that the granting type approval authority is responsible for selection of the ISV families, and that this selection process shall be based on a risk assessment methodology consistent with the international standard ISO 31000[22]. This is similar to the requirements on ISC in EU WLTP (refer to paragraph 4 in Part B to Annex II on initial risk assessment and paragraph 3.7).

On the other hand, it could also be argued that the selection process needs to be transparent, and is following a well-defined procedure with clear evaluation criteria, especially if manufacturers have to bear the financial burden for testing ISV vehicles.

## 3.11 Test vehicle selection, acquisition and preparation

Once the selection for a particular ISV family has been made, the next step for the GTAA, will be to acquire in-service vehicles for testing. For a TAA that has access to the national vehicle registration database this should not be very complicated. As mentioned in Task 1, according to paragraph 5.9 of Part B to Annex II of Regulation (EU) 2017/1151 the Commission an electronic platform is planned to be created, with aim to facilitate the exchange of data (vehicles'/families' technical specifications, test data, etc.) between, OEMs, accredited labs or technical services and on the GTAAs/TAAs. The information found in the database could be very helpful for acquiring vehicles for the ISV, although the connection from a particular vehicle to a vehicle owner is shielded by privacy legislation and therefore needs a dedicated approach. The in-service vehicles to be tested need to fulfil basic requirements in order to be suitable for testing. Following the provisions of ISC, the test vehicle shall not be selected for testing if the information stored in the computer shows that the vehicle has operated after a fault code was stored and a relatively prompt repair was not carried out. Also, vehicles should not be used for in-service verification if e.g. the vehicle is not registered in EU, was adapted or used for racing / motor sports, any unauthorised devices were installed or used with wrong fuel type/ non-commercially available EU-quality fuel. The vehicle shall have been in service for at least 15,000 km or 6 months, whichever the later, and for no more than 100,000 km or 5 years, whichever the sooner. There shall be a maintenance record to show that the vehicle has been properly maintained. Ideally, ISV testing should commence earlier, for early detection of deviating CoC values and to ensure the vehicle is in the original state. Preferably, the ISV test takes place before the first service interval and after a run-in period (see details below).

Further requirements are listed in paragraph 5.7 of Annex II Part B, and detailed selection and exclusion criteria are defined in Appendix 1 to Annex II of Regulation (EU) 2017/1151. Based on this table, a possible checklist that can be used during vehicle selection for ISV is included in Annex III – Check list for vehicle inspection prior to ISV testing.

This may provide a good basis as vehicle selection criteria for ISV, but there are three items which need further attention:

a) Since the ISV also covers the road load determination, the specific run-in requirements need particular consideration:
   - ➔ For the road load determination, the run-in requirement is specified as 10,000 to 80,000 km, with a manufacturer option to start at a minimum of 3000 km (refer to paragraph 4.2.1.8.1. of Sub-annex 4 to Annex XXI of Regulation (EU) 2017/1151):
   - ➔ For the Type 1 test the run-in requirement is 3000 to 15,000 km (refer to paragraph 2.3.3. of Sub-annex 6 to Annex XXI of Regulation (EU) 2017/1151)

b) Appendix 1 to Annex II does not set specific requirements on tyres. However, for the checking of the road load this is an important item. According to par. 4.2.2.2. of Sub-annex 4 to Annex XXI on the road load determination the tyres on the test vehicle shall:
   - (a) Not be older than 2 years after the production date;
   - (b) Not be specially conditioned or treated (e.g. heated or artificially aged), with the exception of grinding in the original shape of the tread;
   - (c) Be run-in on a road for at least 200 km before road load determination;

[22] ISO 31000:2018 — Risk Management— Principles and guidelines

- (d) Have a constant tread depth before the test between 100 and 80 per cent of the original tread depth at any point over the full tread width of the tyre.

c) It is essential that the CoC state is achieved for the in-service vehicle since any difference may potentially lead to a change in the measured $CO_2$ emissions.

Furthermore, to ensure that the tested vehicle is in a normal state and not tuned towards low test results, an independent party must be able to execute a WLTP test without detailed manufacturer instructions. The vehicle must be made suitable to perform in the same manner in the WLTP test as in normal use. Consequently, manufacturer instructions for testing should be limited and simple. At the same time, the testing body has the responsibility to bring the vehicle into the same state as indicated on the CoC. This means that original parts need to be used, aftermarket options installed on the vehicle exterior by the vehicle owner (e.g. a roofrack) are removed and that tyres are fitted in accordance with the CoC specifications. When the vehicle is fitted with other tyres, an option is to make a road load correction based on the ratio of the rolling resistance coefficients (RRC). If this option will work without compromising the accuracy of the ISV test needs to be evaluated in practice.

Looking at the run-in distances specified above it would be safe to select 15,000 km as the minimum distance for an ISV vehicle. A TNO study on the run-in effect on $CO_2$ of new vehicles proved that this effect is limited and insignificant beyond 3,000 km[23]. It should also be noted that in the WLTP CoP the fixed run-in factor (or evolution coefficient EvC) on $CO_2$ for a new vehicle is 2%, of which the largest effect may be expected during the first 1,000 kilometres. From this information a minimum distance well below 15,000 km is justifiable. However, the minimum distance should not be chosen below 3,000 km unless a run-in factor is applied. As a reference, the in-service verification procedures in the US and China apply a minimum driven distance for test vehicles of respectively 16,000 and 10,000 km.

The requirement of the tyre tread depth is quite critical, they may be worn below 80 per cent of the original tread depth well before the vehicle has reached 15,000 km. This needs further attention as it would not be preferable to test vehicles on different tyres than the ones that were fitted by the manufacturer. The obvious solution would be to (temporarily) fit new tyres of the same label class and dimensions as on the CoC, but that is a somewhat costly option which would require additional breaking in of the tyres. Alternatively, a correction algorithm could be developed to correct for tyres that have less than 80% of tread depth.

Concludingly, the minimum run-in distance is proposed to be selected in the range of 5,000 to 10,000 km. It should be noted that the minimum run-in distance is more relevant for road load testing than for chassis dynamometer testing because the dyno setting procedure will eliminate some of the run-in effects within the driveline.

## 3.12 Minimum and maximum sample size for the ISV test

According to paragraph 5.10.1 of Part B to Annex II to Regulation (EU) 2017/1151, the minimum sample size for a pass result for the ISC procedure is three vehicles, and the maximum cumulative sample size is ten vehicles for the Type 1 and RDE tests. For the CoP procedure in EU WLTP, the minimum sample size is three and the maximum is sixteen (see paragraph 4.2.3. in Annex I).

From a practical point of view, the same minimum and maximum sample size as in ISC is recommended for the ISV procedure. Anything less than three vehicles in the sample would jeopardise obtaining a credible result, while more than ten vehicles in the sample would lead to a too high test burden and associated costs. To avoid undue test burden, the statistical procedure should even be such that only in a limited number of cases 10 vehicles are needed. Normally, the standard statistical procedures based on acceptable confidence levels will lead to a forced decision at the maximum number of tests. It is also recommended that different vehicle models and variants within the same ISV family are included in the sample lot.

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[23] Refer to TNO report TNO 2015 R11766, "Run-in fuel consumption from Travelcard Nederland BV fuel-pass data", N.Ligterink, December 2015, http://publications.tno.nl/publication/34619575/Gg3L7a/TNO-2015-R11766.pdf

Note that there is also a link between the maximum sample size and the evaluation method applied to the test results for in-service vehicles within the sample. For example, if the tolerance and pass/fail criteria are chosen very strict, or if no provisions are included for dealing with outliers, there might be a need for more vehicles in the sample to arrive at a sufficient confidence level. This will be further addressed in Task 3.

## 3.13 Scope of necessary type approval data and their secure exchange

The type approval data contains commercially sensitive data and is therefore largely confidential, for example on specific control strategies (e.g. for grill shutters) or how to engage the dyno mode. For the GTAA in charge of the ISV procedure there is no problem to retrieve all the necessary type approval information for the risk assessment and to perform the ISV checking.

As mentioned in previous sections, paragraph 5.9 of (EU) 2018/1832 states that the Commission will set up an electronic platform to facilitate the exchange of information related to vehicle TA within OEMs, technical centres and TAAs. To further extend the usage of such a database, all the information could be accessible to the public in an electronic form, free of charge. However, the database at its current form contains useful information to execute the ISV test, but not all of the required information such as how to engage the vehicle dyno mode. In addition, most of the type approval information can also be retrieved from the DICE server at the JRC, which contains most of the necessary data to perform and validate a type approval[24].

In the case that another party as the GTAA performs tests in accordance with the ISV protocol, the transfer of the necessary data should be organised in such a way that the confidentiality can be assured (see also paragraph 3.6). The position that has been created through Regulation (EU) 2018/858 for MSAs in Europe could open the possibility to securely transmit the necessary data to the MSA. However, the situation is quite different for an ITP. In the current system of type approval, they have no formal position and therefore have no access to the type approval data. Following the recommendation in paragraph 3.6 this could be solved by submitting the necessary information only to the TS or accredited laboratory which performs the tests for the ITP. In this way the information will not be disclosed to the ITP itself, thereby avoiding the risk that the information is used for other purposes.

Finally, it is important to note here that currently the information in the DICE database is mainly oriented towards the Type 1 test on the chassis dynamometer. The scope of the ISV also includes the road load determination procedure, but the test data included in the type approval file is limited to only the results of that test procedure, not the detailed road load test report as indicated in Appendix 8b to Annex 1 of EU-WLTP. After the ISV procedure has been defined, it should be checked if there is a need to extend the data file with specific data on the road load tests. For example, if it can be demonstrated that certain conditions during the road load determination lead to consistently lower road load results (e.g. the ambient temperature or crosswind velocity) these conditions could be used as an indicator for the risk assessment.

## 3.14 Quality assurance method

Since the consequences of the ISV checking may be severe for a manufacturer, it is evident that the quality of the testing activities needs to be assured to a standard beyond any doubt.

In par. 5.1 to Part B of Annex II of the EU WLTP it is stated for ISC testing that "inspection bodies and laboratories performing ISC checks, that are not a designated technical service, shall be accredited according to EN ISO/IEC 17020:2012 and EN ISO/IEC 17025:2017 for the ISC procedure". The GTAA also has the authority to witness the testing. The text of this paragraph could also fit well to serve as an accreditation for laboratories that are engaging in ISV testing.

[24] Refer to Table 4 in Annex I to the Inception report for an overview of these data

## 3.15 Test fuel

In EU WLTP vehicles are tested during type approval on reference fuel in accordance with the specifications in Annex IX. Based on these tests, the declared values for $CO_2$ emissions are confirmed and included in the CoC[25]. However, the requirements on CoP testing state that a commercial fuel shall be used. Only at the request of the manufacturer, CoP tests may be conducted on reference fuel. It should be noted that reference fuel has a required high polyaromatic hydrocarbon content, and therefore a high $CO_2$/MJ ratio. Market fuels, in particular synthetic fuels, can have lower $CO_2$/MJ, reducing the $CO_2$ emissions by up to 3%, based on the range of aromatic content allowed in market fuels[26]. The energy content of the fuel has an effect on the fuel consumption, but not on the $CO_2$ emissions.

For the ISV checking the following advantages can be listed for the use of standard fuel:

- ➔ Synergies with the CoP procedure, for which commercial fuel shall be used, although on the manufacturer's request, reference fuel may be also used.
- ➔ More preparation is needed for the in-service vehicles by draining the fuel tank and additional driving to empty the fuel lines and for the engine ECU to adapt to the different fuel composition.
- ➔ The price of reference fuel is roughly 3 times higher than the price of commercial fuel. However, if a fuel quality analysis would be a must for the commercial fuel, this advantage disappears.

On the other hand, there are also arguments that favour the use of reference fuel:

- ➔ The boundaries of the fuel quality are closer, leading to a higher reproducibility. The maximum $CO_2$ deviation between the extremes of reference fuel qualities is limited to only 0.7%[27]. This means that any other $CO_2$ deviation can be directly linked to the vehicle or effects of test conditions.
- ➔ The systematic lower $CO_2$ emission and the higher spread for a vehicle running on market fuel compromises the tolerance for the ISV procedure, possibly increasing the share of 'false negatives'. Refer to paragraph 3.18. for the tolerance.

Therefore, reference fuel is the option leading to the highest accuracy and reproducibility, while market fuel would be the more pragmatic option. Therefore, no clear recommendation can be given at this point, the Commission should decide which arguments have a higher weight.

## 3.16 Corrections

The $CO_2$ emission value from a type approval test is not simply the result of the measurement on the chassis dynamometer test. There may be a number of correction factors being applied to the test result, in particular:

- ➔ Target speed and distance correction;
- ➔ RCB correction, to correct for an imbalance in the battery state-of-charge;
- ➔ Ki correction for vehicles equipped with periodically regenerating systems;
- ➔ ATCT correction, to correct for the difference between test temperature and the regional ambient temperature.

The latter two use correction factors which are vehicle family specific, and are determined by a dedicated test procedure in the EU WLTP. The effect on the $CO_2$ emission value of an erroneous correction factor may be significant. However, checking the validity of these correction factors is a costly and time-consuming process, involving at least a number of chassis dynamometer tests. For example, the Family Correction Factor (FCF) for the ATCT correction is based on the ratio of measured $CO_2$ emissions at the normal test cell temperature of 23°C and at the regional temperature of 14°C.

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[25] Refer to paragraph 4.2.4.2. of Annex I in EU WLTP
[26] Refer to EN228
[27] Refer to TNO report 2020 R10138 "Petrol fuel and blending ethanol analyses", N. Ligterink, January 2020, https://repository.tudelft.nl/view/tno/uuid%3A175399b6-b38f-48be-936a-9d4f12a874b8

For that reason, it would be recommended that a screening check is added to the ISV procedure to evaluate if the correction factor is rational, particularly in those cases where the correction is significant. This screening could be developed as a credibility check on the DICE database, e.g. by an intercomparison analysis of the correction coefficients for similar vehicle families. Alternatively, this analysis may be added to the risk assessment procedure, to pinpoint ISV families with unrealistic correction factors. In the case that this screening leads to a suspicion on an erroneous correction factor, the testing body should investigate this in more detail. If necessary, this investigation may include challenging the correction factor experimentally by repeating the relevant WLTP test procedure.

Special attention should be given to the RCB correction. The EU WLTP specifies that the RCB is only corrected if the electric energy change of the battery exceeds a threshold which is equal to 0.5 % of the energy of the consumed fuel during the test (criterion c in Annex XXI Sub-Annex 6, Appendix 2 and Sub-Annex 8, Appendix 2). This discontinuity may lead to small deviations, especially if the type approval vehicle is just below the threshold while the ISV vehicle just exceeds it, or vice versa. Therefore, it is recommended that if the RCB at the type approval is below the threshold criterion c, the CoC $CO_2$ value is corrected for the measured RCB anyway. By applying the RCB correction to the all vehicles tested in the sample, the $CO_2$ results are not biased by this discontinuity and therefore become better comparable[28].

Note that the RCB correction for OVC-HEVs is vehicle family specific, as this includes the charge balance of the traction battery (REESS). For this vehicle category the influence of the RCB correction on the $CO_2$ emission and energy consumption can be significant so this should therefore deserve attention in the screening check by comparing the correction factor against a baseline for similar vehicles.

## 3.17 Type of tests for ISV

The risk assessment as described in Section 3.10 can be seen as a first step of this process, i.e. to select those ISV families for checking that have a higher than average risk of having a deviation of the CO2 emissions. The ISV checking procedure could then proceed at the following three levels:

a) **Screening methods**
These are methods that can be executed from the desk, without actually performing any testing activities, for example performing a comparative analysis to detect outliers in the CoC values.

b) **Screening tests**
Tests that cost much less test effort than a full test, but whose results can be used as an indicator to trigger a full test, for example checking a specific value of the CoC by a simple test.

c) **Full test**
If the results from the screening method and screening test indicate that the vehicle is likely to show a deviation, the full test will be done to arrive at a final pass or fail decision. In the case of road load determination, this means that the road load deviation needs to be translated into an equivalent $CO_2$ emission deviation.

The threshold values should be selected carefully, in particular to avoid false negative tests, i.e. vehicles which eventually might fail the full test yet are undetected during the screening phase.

If an ISV family is found to fail the $CO_2$ emission value on the CoC, this can be the result of either a deviation in the road load test result or a deviation in the chassis dynamometer test or both. If the screening methods and/or screening tests are able to point out for which of these two aspects a vehicle family is likely to show a significant deviation, the testing effort may be reduced by focusing on this aspect alone. For example, if a screening check of the reported boundary conditions and on the gear shift points of the type approval Type 1 test suggests that the vehicle is most likely to deviate on the chassis dynamometer test, the testing burden can be reduced by skipping the road load test and use the road load coefficients of the CoC instead. Therefore, it is recommended that the ISV procedure is

[28] Please note that in the UNR WLTP5 this discontinuity has been removed for ICE vehicles.

split into these two components which can then be evaluated separately by a pass/fail procedure. As a consequence, this would require that an exceedance of the road load is translated into an equivalent $CO_2$ deviation, and that separate threshold limits are applied. The separated approach will also enable MSA and ITP to focus on either the road load checking or the $CO_2$ emission from the chassis dynamometer test, for example if they have a particular interest or only testing facilities available for one of these components.

In the following paragraphs we will identify which options exist for checking the road load and for checking the $CO_2$ emissions separately. Whether these testing options are actually suitable and what kind of accuracy can be achieved will be investigated in more detail in Task 3.

Road load determination options

1) ***Screening methods***
The road load coefficient f0 can be checked against the tyre rolling resistance coefficient (RRC). If the RRC is significantly higher than f0¬ this might indicate that there is an issue with the road load of the vehicle. This comparison can be realized by all the involved parties (GTAAs, technical centres, technical services, etc.) which would have the CoC of the vehicle. Besides the screening at the level of f0, an initial check could be realized at the level of coast down results and TA RL along with the track and test conditions during coast down. Unfortunately, currently there is no type approval data collected in the DICE database on the road load determination other than the final results. If the dataset were to be extended with information on the test track, ambient temperature, tyre pressure and wind conditions, this could possibly be employed as a screening indicator. For example, if it is found that the coast down results of a particular test track show a consistently lower road load than other tracks, that information can be used to trigger a screening test for vehicles that were type approved at that track.
2) ***Screening tests***
The following methods are identified as options for screening the road load coefficient f0:
   - ➔ The vehicle is towed at a low constant speed of e.g. 20 km/h on a flat road. By measuring the average towing force during this test, the road load coefficient f0 can be derived by assuming that the CoC values for f1 and f2 are correct. At low velocity, the effects of air drag and wind are less significant anyway so this assumption will only have a limited influence. The f0 coefficient can be compared against the tyre rolling resistance coefficient value.
   - ➔ The vehicle is rolled at low speed from a slope of roughly 2% and the speed profile is measured. From this speed profile the f0 coefficient can be derived. Alternatively, the vehicle is pushed forward at a constant power, e.g. 1 kW/ton, and the speed profile is measured.
   - ➔ Instead of a full road load determination test, the vehicle is tested only on one pair of coast downs and the results are evaluated. Alternatively, the coast down criteria (e.g. test track requirements, wind speeds, measurement accuracy etc.) are relaxed if that makes the testing easier, especially when ambient conditions are not favourable for testing. Even though this does not lead to a valid test, it may be sufficient to serve as a screening check.

   Data from an on-road test could be analysed and calculated back into an estimated road load by a modelling approach (e.g. $CO_2$MPAS). These data could be sourced from the ISC testing activities or be measured specifically for the purpose of a screening test. As explained in paragraph 3.5.1 this calculation involves a number of assumptions, so it is expected that the inherent uncertainties of such measurements (e.g. road inclination, weather conditions and road surface) will make it challenging to accurately determine the road load on the basis of on-road data. Nevertheless, this option will be further explored in 5.3.1.2.
3) ***Full test***
For the full test, the road load determination procedure is executed in accordance with Sub-annex 4 to Annex XXI of the EU WLTP by adding coast down run pairs until the statistical precision requirement has been satisfied. To establish a pass/fail decision for the test vehicle, the road load deviation should be translated into an equivalent cycle energy demand. This can be achieved by calculating the CED according to the provisions of the Paragraph 5, of Sub-

Annex 7 to Annex XXI of EU Regulation 2017/1151. The evaluation of for the correspondence between TA and ISV RL would be realized by comparing the calculated CED of both RLs. It is important to state that test mass during ISV RL determination should be the same as TA to avoid any deviations in CED coming from the different test mass.
An alternative is to use a simulation (e.g. the $CO_2$MPAS model) to perform the calculation of the CED.

4) ***Detecting strategies to artificially improve the $CO_2$ emission during the type approval test***
During the road load determination procedure, the driveline of the vehicle is decoupled from the wheels, so it is impossible to influence the coast-down by any strategy in the driveline. If there are any non-reproducible forces (e.g. due to electric motors which are directly coupled to the wheels) the manufacturer has to ensure that there is a 'vehicle coast down mode' present and active to allow reproducible coast down testing. This vehicle coast down mode needs to be approved separately. Note that the information on how the engage vehicle coast down mode needs to be available for the ISV check on road load.
There is only a limited number of ways in which a manufacturer is able to apply strategies which will have an effect during the coast down runs. Of course, a manufacturer may optimise the test vehicle for coast down testing, but such optimisations would not be present during an independent ISV check performed by the TAA. There are two possible strategies for a manufacturer to artificially reduce the road load:
    1. To use the vehicle coast down mode as a trigger for an alternative strategy, for example a hybrid vehicle that would use electric energy to increase the coast down times. However, the vehicle coast down mode needs to be approved by the TAA, and they will be particularly interested to check any electric energy flows in the case that there are electric motors in the driveline that cannot be disconnected from the wheels.
    2. The application of movable aerodynamic options such as automatic grill shutters. Their behaviour might be not reproducible or even be very different between a coast down test and in normal driving situations on the road. In the case that there are doubts about the behaviour, the testing body may decide to perform on-road tests to check the normal behaviour. By manually overriding the automatic system and reflect the normal use during coast down, the effect on the road load could be established.

Therefore, there are no specific tests available that would detect possible strategies to artificially lower the road load test results, but there is a possibility to monitor the vehicle control system to evaluate if it behaves during coast-down testing in a way that is representative for real-life conditions on the road.

<u>Chassis dynamometer testing</u>

1) Screening methods

There are possibilities for screening the plausibility of the $CO_2$ emission value on the CoC by focussing on the detailed type approval data stored in the DICE database. This could consist for example of a check on the correct calculation of the gear shift points and an evaluation if favourable conditions -yet within the allowed bandwidth- have been used during the chassis dynamometer test (e.g. an average test cell temperature well above the setpoint of 23 °C but within the tolerance of +5°C). This screening exercise could be performed as an automated process, resulting in a score to indicate if the $CO_2$ emission value is likely to be significantly influenced. Based on that score it is then decided to escalate to the next verification level. Alternatively, such an automated checking process could also be added as an element to the risk assessment procedure, meaning that this check is done for every vehicle in the DICE database.

2) Screening tests

For the purpose of screening, there is a possibility to use data from an on-road test, and calculate it back by normalisation into an estimated $CO_2$ emission performance on a WLTP test, e.g. by using the $CO_2$MPAS model. These data could be sourced from the RDE ISC testing activities or be measured specifically for the purpose of this screening test.

3) Full Type 1 tests

For the full test, the $CO_2$ emissions are determined according to the provisions for TA testing in Article 9 of EU WLTP. For vehicles with a combustion engine (ICEs) this means that a Type 1 test is performed to check the $CO_2$ emissions.

4) Issues of the $CO_2$ verification for OVC-HEV

For the OVC-HEV category, the $CO_2$ emissions are determined according to the provisions for CoP testing in Article 9 of EU WLTP. The verification requirements in EU WLTP CoP are limited to the charge-sustaining $CO_2$ emissions and energy consumption, so the electric range verification is excluded. This was done to reduce the testing burden because the charge-depleting Type 1 test can be costly and time consuming while the charge-sustaining $CO_2$ value has more relation to the on-road $CO_2$ emissions than the charge-depleting $CO_2$ value.

For verifying the energy consumption of OVC-HEV in-service, the UNR WLTP CoP procedure would provide a good basis. This procedure requires a charge-depleting test in addition to check the electric energy consumption (but not the electric range). If the vehicle has no engine start in the first cycle, the charge-depleting test can be reduced to a verification only on that first cycle. As a consequence, the so-called 'adjustment factor' would be needed for the evaluation of the reduced charge-depleting test, this is the ratio between the average energy consumption and the energy consumption in the first cycle. This parameter is determined at type approval but not listed on the CoC. For the GTAA the adjustment factor would be known, as this is required to evaluate the CoP test results.

For verifying the electric range (EAER) of the OVC-HEV in-service, there are two options identified:

- ➔ perform a full charge depleting test, or
- ➔ determine the usable battery energy and calculate the electric range by using the energy consumption.

Either one of these options could come in addition to the charge-sustaining test.

5) Detecting strategies to artificially improve the $CO_2$ emission during the type approval test

Even though it is explicitly forbidden by Article 13(5) of Regulation (EU) 2018/858 to incorporate strategies or other means that alter the performance exhibited during test procedures in such a way that they do not comply with that Regulation when operating under conditions that can reasonably be expected in normal operation, a vehicle potentially has a multitude of signals to detect that it is being tested on a chassis dynamometer, e.g. engagement of the vehicle dyno mode, signals of the ABS sensors on the non-rotating axle (on a 2WD chassis dynamometer), loss of GPS signal, no steering input, ambient temperature, the speed profile, etc. If the vehicle adapts its control strategy to reduce $CO_2$ emissions during the test, such a strategy remains undetected if a repetition of the WLTP chassis dynamometer test is conducted. Therefore, an alternative method is needed for the detection of such strategies (relevant methods are analysed in Task 3.3).

Investigations into irrational strategies are costly and time consuming, so it is important that only those vehicles are targeted which have a high probability to apply such strategies. A good indicator to test for irrational strategies is when the risk assessment showed a large potential for a $CO_2$ deviation, while the road load and chassis dynamometer ISV test did not show any deviation.

## 3.18 Deviations

The reference value of the ISV test is the $CO_2$ emission value recorded on the CoC. When comparing the results of the ISV test to that $CO_2$ value, there are a number of influencing factors which have to be taken into account, in particular:

a) The ISV vehicle selected for the verification is not the same as the type approval vehicle due to production variance, maintenance condition, mileage (run-in), tyres mounted and their condition, wheel alignment, aftermarket options, etc. Any differences between the state of these vehicles may potentially lead to a change in the $CO_2$ emissions. This should be prevented as far as possible by bringing the ISV vehicle into the same state as the type approval vehicle.

b) Variations in the $CO_2$ emissions may result from the fact that the WLTP offers a bandwidth in testing conditions, alternative measurement procedures and manufacturer options.
c) Test-to-test variations in the $CO_2$ emissions may occur as a result of uncontrolled variations in the WLTP test procedure and repeatability issues of the measurement equipment. The accuracy with which a laboratory can execute tests will follow from repeated tests performed on the same vehicle.
d) Differences which occur in the ISV testing due to a lack of data on the execution of the type approval test, for example the CoC only offers limited data.

The ISV procedure needs to take into account those influencing factors that the manufacturer cannot be held responsible for. Without any acceptable deviations to the declared value, there is a possibility that an ISV vehicle would be concluded to fail while in reality it only suffered from a variation during the test. This is referred to as an 'unjustified fail decision' or a 'false negative and can be seen as an unfair risk to the manufacturer. However, a too wide acceptable deviation could cause an 'unjustified pass decision' or 'false positive' and can be seen as creating an unfair risk of undermining the effectiveness of the legislation.

This clearly shows that the determination of an appropriate acceptable deviation needs a well-balanced approach and is seen as a crucial element of the ISV procedure. A careful analysis is needed to discern between legitimate and inadmissible variations. The basic principle for this analysis should be that any correctly executed WLTP test is a valid test. An acceptable deviation for ISV testing which includes all possible variations in $CO_2$ emissions in the WLTP as uncertainties would implicitly accept that manufacturers systematically test towards the lower end of the full bandwidth associated with allowed variations in test conditions and measurement uncertainties. However, this should not be considered appropriate.

The recommended approach is therefore to carefully consider all the possible influencing factors, and analyse these in detail to determine:

1) Are there possibilities to mitigate these influencing factors, e.g. by setting strict criteria for selecting test vehicles, setting additional requirements to vehicle preparation, improving the data transparency or applying correction methods? The influencing factors mentioned under a) and d) might be eliminated completely by such mitigation measures.
2) Are these differences considered to be the responsibility of the manufacturer, or accepted as natural or test-to-test variations of the test result? In the latter case, they should be accounted for in the acceptable deviation.
3) For those influencing factors that should be considered in the acceptable deviation: what is their effect in terms of an offset and/or variance?

The basis for the analysis under point 2, is that the manufacturer cannot be held accountable for anything beyond his control or his responsibility. For example, the average tyre pressure variation with the ambient temperature variation during coast-down testing can be seen as a natural variation, however pressurizing the tyres systematically at the coldest moment of the day to benefit from the higher pressure at daytime would not be an acceptable practice.

At the same time, an important principle is that all variations in the test results must be taken into account by the manufacturer in setting an appropriate declared value if they originate from e.g.:

- ➔ variations due to the use of different test tracks,
- ➔ different ways in which the test can be executed within the specifications of the WLTP, or
- ➔ variations in test conditions that are not corrected for in the elaboration of test results.

These 'natural' variations are not an uncertainty or spread, but an inherent and accepted bandwidth of which the impacts on the measured $CO_2$ value can be known and which the manufacturer should therefore take into consideration in the declaration of the $CO_2$ value.

Effectively this means that the only variations which should be taken into account in the acceptable deviation are the normal variations between repeat tests on the same vehicle. These can be expressed as a 'base margin'.

Most of the influencing factors as described under b) should not be considered in the acceptable deviation, aside from maybe a few where the distinction between natural and normal variation is not clear, e.g. the wind corrections for the road load determination. Nevertheless, it can be useful to have insight in the magnitude of these natural variations. Vehicle simulation models, such as the $CO_2$MPAS tool, may prove very useful to quantify the effect on $CO_2$ emissions from natural variations, see also paragraph 3.3.

After all the influencing factors have been identified, analysed and where necessary quantified, the next step is to combine these into one value. This value is not simply the sum of the maximum possible deviations, but the result of a statistical procedure to combine the offsets and variations into one value at a predetermined confidence level. This confidence level is not only based on the actual value of the acceptable deviation, but also connected to the sample size, pass/fail statistics and outlier management. These elements will be addressed in the next paragraphs, and further detailed in Task 3.

The WLTP test procedures for road load determination and for $CO_2$ emission measurement on the chassis dynamometer have their own specific influencing factors. Therefore, it is clear that this analysis needs to be done separately for both procedures.

Quantifying the acceptable deviation for the road load determination should preferably be defined as a relative variation of the energy demand; for a particular ISV family these relative changes of the cycle energy demand can be converted to equivalent $CO_2$ emission deviation through the interpolation line of the ISV family.

## 3.19 Pass/fail evaluation criteria statistics

If the $CO_2$ emissions from the tested vehicles for ISV are concluded to show a significant deviation from the $CO_2$ value on the CoC, this will lead to an adjustment of the CoC, a recalculation of the reported fleet average $CO_2$ emissions of the manufacturer and possibly additional enforcement measures. Since the consequences of such a fail decision can be severe for a manufacturer, there needs to be a clear statistical approach in place for the evaluation of the ISV test results leading to such a decision. The most straightforward way to achieve a high confidence level is to test a large number of vehicles for every checked ISV family. However, the associated costs for testing a large sample are high. Also, it may not always be necessary to test a large sample. For example, if nine vehicles have been tested and found to be well within the tolerance, there is hardly any added value in testing a tenth. But if five vehicles are just outside the tolerance and four are just inside, the result of the tenth vehicle will be relevant to make a final decision. This is where the pass/fail statistics may prove useful. The decision on a pass or fail is made on the basis of the number of tested vehicles and their results. If a predefined confidence level on a final decision has been reached, the sample does not need to be expanded any further.

In the WTLP Regulation there are two pass/fail statistics (see Section 2.2.1) that might be potential candidates for the ISV procedure:

1. The ISC procedure evaluates the results on a single vehicle level for a sample size between 3 and 10. If the pollutant emissions of a tested vehicle are below the respective pollutant limit it is considered to pass, else it is a fail. The number of passes and fails in a sample is counted,

and a decision chart determines whether the sample is considered to pass, to fail, or if it is undecided. In the latter case, another vehicle is added to the sample. This is repeated until a final pass or fail decision can be drawn. If the sample size reaches ten vehicles, at least five passes are needed for a sample pass decision. Note that the ISC procedure only applies to pollutant emissions, not to $CO_2$ emissions and energy consumption.

2. The EU WLTP CoP procedure[29] evaluates the results on the basis of the sample mean and variance for a sample size of 3 to 16 vehicles. An upper and a lower boundary are defined: if the sample mean is above the upper limit, the sample fails; is it below the lower limit, it passes. A sample mean between the limits means that the decision is not conclusive and another vehicle is added to the sample. The upper and lower limits are a function of the variance, and they converge as the sample size increases. After 16 vehicles a decision is forced. $CO_2$ emissions and energy consumption results are normalised by dividing these by their respective type approval values.

From the view of statistics, the concept of ISC testing, where pollutant emissions have to stay below a certain limit value, is fundamentally different from the concept of CoP (for $CO_2$) where the measured result is compared against a declared value instead of a limit and, in the case of a fail, the magnitude of the observed deviation is an output of the procedure. This makes the approach of the CoP procedure more suitable for ISV testing, particularly because the measured results in terms of deviation and variance play a central role in the final decision. This is a clear advantage over the ISC procedure, where a pass/fail decision at individual vehicle level ignores the deviation amount by which the vehicle passes or fails. The amount of deviation is also very relevant for the consequence of a fail decision, i.e. the adjustment of the CoC value, so that is another reason to favour the CoP approach. Additionally, the mean value of all vehicles tested has the closest relation with the fleet average target and should therefore be the basis for the evaluation.

For the CoP procedure of the EU WLTP, a statistical method was developed which primarily aimed at evaluating pollutant emissions, generally showing a much larger spread in outcomes than $CO_2$ emissions. In the case of particulate mass emissions this can vary between 0.0 to 4.5 mg/km. The same pass/fail methodology is also applied to (normalised) $CO_2$ emissions. However, $CO_2$ emissions have a much lower spread in test results, normally within a few g/km between repeated tests. Therefore, the margin of error based on the spread in results was estimated to be very small. This leads to the situation that an early pass or fail decision is reached, typically after the first three tests. Research showed that if more tests were added to the sample this decision could change in both directions, leading to roughly equal fractions of false positives and false negatives on the basis of three tests only[30].

The pass/fail statistics will be further explored in Task 3 in section 5.3.7.

## 3.20 Outliers

As indicated in the previous paragraph, the $CO_2$ emissions have a low spread in test results and the pass/fail evaluation should be based on the mean value of the tested vehicles in the sample. Now, if for some unknown reason one of these tests shows a result which is considerably higher than the others, a lot of additional test results will be needed to compensate for this one outlier. Consequently, it may be difficult to arrive at a pass decision. Such outlier results may be due to unrepresentative behaviour of the vehicle during the test but could also be the result of a procedural error that was overlooked. Another possibility is that the vehicle is equipped with a regenerative exhaust aftertreatment system which went into a regeneration phase during the test, in such cases the test

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[29] Refer to Section 4 of Annex I to Regulation 2017/1151 and the relevant statistical method in Appendices 1 and 2 to that Annex.

[30] Refer to the discussion paper "Evaluation of alternative statistical procedures for the evaluation of in-service conformity emissions tests under the real-driving emissions (RDE) regulation" by V. Franco*, Z. Kregar, P. Dilara https://circabc.europa.eu/sd/a/a911941e-7f27-4f50-b3ef-62ee75e0ef48/ISC_statistics_paper_final.pdf

should be void. If the source of the outlier result cannot be established, an approach will be needed on how to deal with that result to avoid that it would dominate the final pass/fail decision. Without such an approach, the tolerance for the test evaluation would need to be widened.

One approach to reduce the effects of outliers is double testing of each vehicle. If the lowest of the two rest results of each vehicle is used in the subsequent statistical procedure, this would avoid the risk of a unjust fail decision due to occasional deviations in the test execution.

Another approach is to apply an outlier analysis. For this we have to define what should be considered as an outlier result. As a first indication on the basis of test experience, we recommend that any result which deviates more than the average deviation between official and real world ("real world gap") from the CoC value should be treated as an outlier. For this outlier the test is repeated at least three times on the same vehicle. If repeated tests demonstrate that the outlying result is an isolated observation, the outlier may be discarded in the statistical evaluation. However, if the outlying result is confirmed by at least one of the repeated tests and there are no indications found that the tests were not performed correctly, the average of the tests for that vehicle should be included in the statistical evaluation. In the case that there are two or more vehicles in the sample showing an outlier result (based on at least three tests per vehicle), this should lead to a fail decision even if the sample would still pass.

The double testing option minimises the influence of test execution for all vehicles tested while at the same time it provides an indication of the quality of the test lab. However, it doubles the test effort and therefore is a costly option. The advantage of the outlier analysis approach is that it only takes effect when there is an apparent need to.

## 3.21 Adjustment of CoC value

In the WLTP CoP procedure, the pass/fail evaluation is based on a relative $CO_2$ value, i.e. the measured $CO_2$ emissions divided by the CoC value. This relative number is also proposed to be applied for ISV, which makes it possible to compare the performance of all tested vehicles within the ISV family, even if they have different CoC values. While the performance can be evaluated in a relative sense, the absolute deviation of the ISV family -which may be relevant for correcting the fleet average $CO_2$- is not available. Instead, a good proxy for the absolute deviation is obtained by applying the average measured relative deviation to the CoC interpolation line of the IP family. Adjusting the specific CoC value and consequently the fleet average $CO_2$ is then based on this relative deviation.

Indications for deviations from the CoC value may already be detected at the coast down test. Therefore, it was recommended that in addition to a pass/fail procedure for the $CO_2$ result from the chassis dynamometer test there is also a separate pass/fail procedure in place for the results of road load determination. The road load deviation could be evaluated on the basis of the equivalent $CO_2$ emission following from the difference in cycle energy.

When the deviation has been determined as being statistically significant, the following options (that could be the options for the OEM and/or the GTAA o to apply the corrections after the ISV results) are possible:

a) The manufacturer accepts the $CO_2$ value determined by the ISV procedure as new declared value by shifting the interpolation line upwards for the entire IP family (for chassis dynamometer test deviations) or entire road load family (for road load deviations) based on the average deviation, without taking the base margin into account.
b) The manufacturer motivates another plausible change to the interpolation line which explains the ISV results and re-declares a higher interpolation line. After the shift of the interpolation line, the actual ISV test results (without taking the base margin into account) should be on or below the new interpolation line.

c) In response to the change in the declared values (a or b) the GTAA starts a broad investigation into the declared values of the manufacturer, similar to the procedure for ISC in the case of a failed compliance test. The investigation should search for the source of the deviation and extend to all vehicle models that use the same technologies or test practices that may have caused the deviation. This investigation may include an analysis of the CoP results in the case of a chassis dynamometer-based $CO_2$ deviation.

Adjusting the CoC value and the fleet average $CO_2$ emissions can be seen as the minimum consequence of a failed ISV family. There may be a need to implement further consequences to add weight to the procedure, especially if the chances of a fail decision are slim. Therefore, the criteria for sample share and consequential measures need to be considered in relation to each other.

There are three options identified for additional enforcement:

- ➔ Publicly reporting the name of the manufacturer and the vehicle model concerned.
- ➔ Financial penalties, proportional to the number of vehicles produced in the ISV family and by the level of exceedance.
- ➔ Increasing the minimum sample share for those manufacturers who have an ISV family that was found to fail.

Although detecting a defeat strategy may be proved challenging, in the case that vehicles were found to apply a strategy to artificially reduce $CO_2$ during the type approval test, the logical consequence should be that this strategy is removed from the control software by a recall of all vehicles produced in the ISV family and that the vehicle is re-certified to an appropriate declared value. On top of that, additional enforcement mechanisms should be applied. In addition, it should be investigated by the GTAA if similar strategies have been applied to other ISV families of this manufacturer. The consequences for applying an artificial $CO_2$ reducing strategy during type approval should be more severe than those for finding a $CO_2$ deviation because the potential consequences for real-world $CO_2$ emissions are higher and it costs more effort to detect such a strategy.

## 3.22 Excluded elements

The following elements, which are covered in ISC and/or WLTP CoP are not considered applicable to the ISV procedure for the reasons set out below.

<u>Minimum check interval by TAA</u>

The testing activities for CoP and ISC are normally performed by the manufacturer. The role of the TAA in these procedures is limited to an annual audit on the results and by witnessing the tests at their request. For the CoP procedure in EU WLTP there is a specific requirement that at least once per three years the TAA will verify the conformity of the production by a physical test. Since the ISV testing will be executed under the responsibility of the GTAA and specifically not by the manufacturer, there is no need to introduce a check interval by the TAA.

<u>Run-in procedure and evolution coefficient</u>

The in-service vehicles selected for the ISV are already run-in on the road to a certain degree. To avoid that the run-in may need to be accounted for in the evaluation procedure, the recommended approach is to select vehicles on the basis of a minimum mileage. If this minimum is set appropriately, no run-in effects have to be considered (see also paragraph 3.11). Hence, there is no need to include a test procedure to determine an evolution coefficient for ISV (as is the case for the CoP procedure), nor is there any need for fixed evolution coefficients.

## 3.23 Summary and recommendations

During the development of the guiding principles and criteria for the LDV ISV procedure, a number of recommendations were provided, as summarised below:

- The scope of the ISV includes both the road load determination and the Type 1 test on the chassis dynamometer. However, the detailed information in the DICE database is oriented towards only the Type 1 test results on the chassis dynamometer of vehicle high and where applicable of vehicle low, but not the information on the road-load measurements. After the ISV procedure has been defined it should be checked if there is a need to extend the data file with specific data on the road load tests.
- Only the GTAA can come to the conclusion of a failing ISV family. Findings by a MSA or an ITP should be confirmed by the GTAA, e.g. on the basis of a confirmation ISV test and/or an in-depth investigation. All the necessary information needed to perform a valid WLTP test should be made available to any party involved in ISV checking. Results from any correctly executed ISV test should be accepted as valid. This builds on the principle that the manufacturer should take the 'natural' variations into account for setting an appropriate declared value.
- The RCB correction is applied for the ISV, even if the RCB is below the threshold criterion. By applying the RCB correction to the vehicles tested in the sample, the $CO_2$ results are not biased by this discontinuity and therefore become more comparable.
- Vehicles should perform on the type approval test in a way that is representative for their performance and behaviour in normal use. The operation of auxiliaries, including adjustable grills and energy consuming devices during the test must match the operation of these auxiliaries under normal use conditions. If systematic and unexplained deviations are found, these should be compensated in the $CO_2$ test result.
- Adjustment of the CoC $CO_2$ value in the case of a fail decision can be done on the basis of the average relative $CO_2$ deviation. A good proxy for the absolute deviation could be obtained by applying the average measured relative deviation to the CoC interpolation line of the IP family.
- In the case of a fail decision additional enforcement measures may be necessary to create sufficient leverage for the legislator, e.g. publicly reporting vehicles that have found to fail the ISV, financial penalties, and/or an increase of the minimum sample share.
- Results of the ISV tests are published on a central electronic platform, indicating which ISV families have been checked, whether they passed or failed and -in the case of a failure- the adjustment of the CoC value. This information can be helpful for the vehicle selection and risk assessment in future ISV test activities and to avoid double testing of the same ISV families. Therefore, this platform should be preferably be publicly accessible. A similar system is already in place for RDE ISC, which could be used as a blueprint.

The burden of proof for deviations found lies on the manufacturer rather than the type approval authority carrying out the In-Service Verification. The manufacturer should also ensure that issues which lead to deviating results are avoided or reported.

Considering that the testing options needed for the ISV procedure are expensive and time-consuming, a layered approach could be recommended starting from the level of a simple screening method up until a full test. The basic idea is to escalate to the next level if a threshold is exceeded. Such an approach is expected to make the ISV procedure more cost-effective, as full tests would only be conducted on those vehicles that have the highest potential to show a deviation in the test. Two possible options for the ISV procedure are described in Task 3.

# 4 Task 3 – Elaborate detailed procedures for in-service verification of $CO_2$ emissions (LDV)

This chapter outlines two possible approaches for the detailed ISV procedure.

## 4.1 Parallel approach for the in-service verification procedure

The in-service verification of the RL and the $CO_2$ emissions of an ISV family could be based on a parallel approach as illustrated in Figure 16. The main idea for the parallel approach is that parallel testing of RL (determination of ISV RL) and for $CO_2$ emissions (WLTP tests on chassis dynamometer) would be realized. For the RL verification, the 1st step would be the selection of the RL family that will undergo the RL verification process. The second step would be the selection of the vehicles that will be tested for the in-service RL determination. The decision for the compliance between in-service and TA (for the whole RL family) would be based on the test results from the vehicles tested and a pass/fail statistical approach. The ratio of measured over TA CED, calculated for the WLTP using the respective RLs, needs to be within the margins defined by the statistical method and will determine the final decision.

Similarly, for the $CO_2$ emissions verification, the starting point would be the selection of the IP family that is to be examined. The vehicles selected would be tested under WLTC following the Type 1 test procedure. The goal of the $CO_2$ emissions verification procedure is to evaluate the correspondence of the TA and in-service $CO_2$ emissions. This means that the complete IP line needs to be verified, consequently there are two possible ways to achieve this. The first method is to select the minimum number of physical vehicles and perform several WLTC tests using the RLs found in the range of the IP line. With that way it would be possible to verify the correspondence of the $CO_2$ emissions calculated with the IP line and the test results. The second method is to test individual vehicles from the IP family (with different RLs) until the pass/fail are fulfilled.

The third activity that would take place in parallel with the RL and $CO_2$ emissions testing, is the investigation of artificial strategies that may have been used for improving the $CO_2$ emissions performance. Selected vehicles would undergo specific tests, targeted to reveal artificial strategies, while also ISV ($CO_2$ and RL) results would be evaluated.

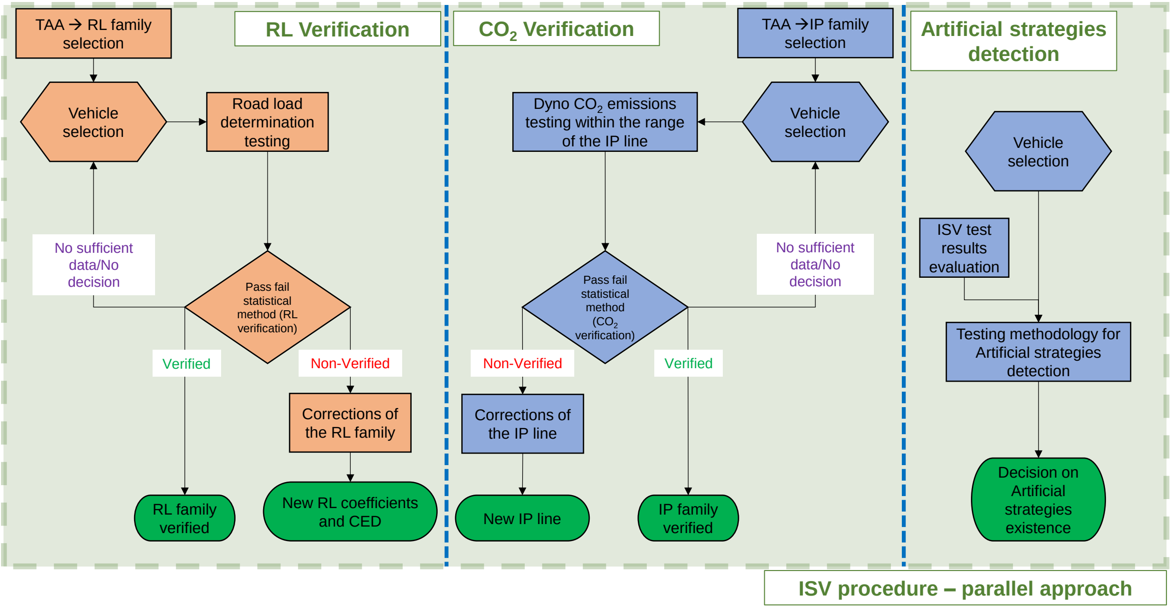



**Figure 16:** ISV procedure flowchart with RL and $CO_2$ interpolation line correction process

## 4.2 Sequential approach for the in-service verification procedure

A second approach for the complete ISV procedure and the corrections of the RL and the $CO_2$ emissions is presented in Figure 17. For this approach the ISV procedure of a family starts with the RL testing and verification. The following chassis dynamometer testing that follows, is based on the outcome of the RL verification, as regards the RL coefficients that would be used. The requirement for applying the necessary corrections is the completion of the different steps of the ISV procedure and the decision on the pass or fail for the RL and the $CO_2$ emissions. The developed methodology covers two cases:

- ➔ 1st case: RL pass the statistical approach, $CO_2$ fails the statistical approach (paragraph 8.2.1)
- ➔ 2nd case: RL fails the statistical approach, $CO_2$ fails the statistical approach (paragraph 8.2.3)
- ➔ 3rd case: RL fails the statistical approach, $CO_2$ pass the statistical approach.

It should be highlighted that the third case raises a flag for further investigation, particularly for examining the existence of a strategy that improves artificially the CO2 emissions performance. Figure 17 presents an overview of the proposed methodology, with the various steps of Task 3 and Task 4.

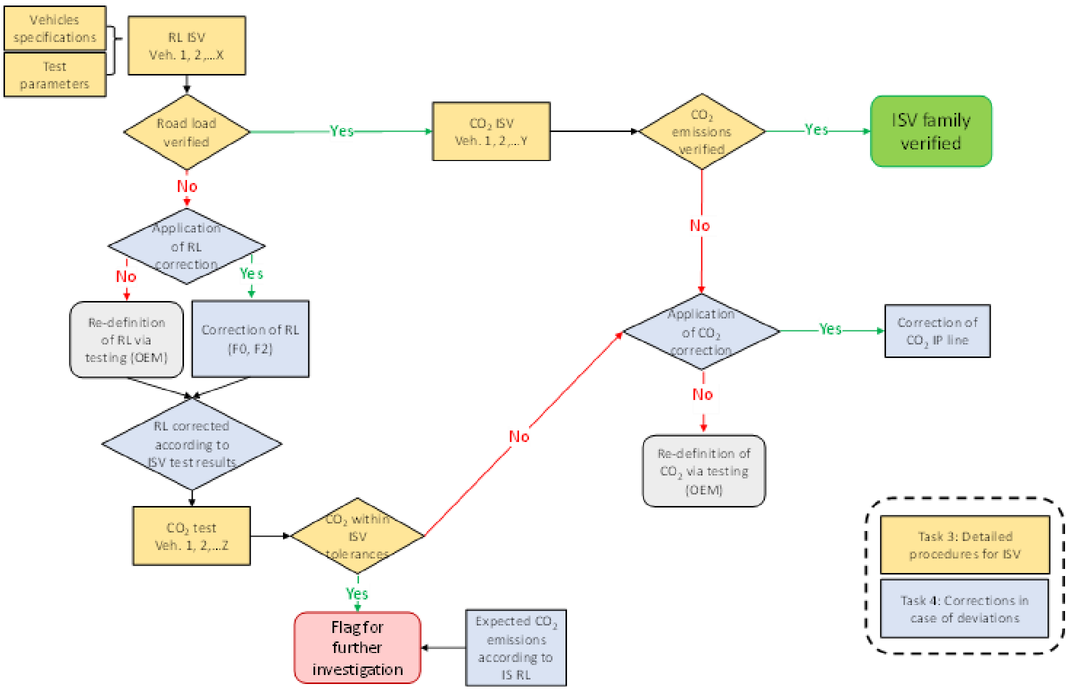



**Figure 17:** Schematic description of the sequential approach for the in-service verification procedure

1. The in-service verification (ISV) procedure begins with the road load testing:
   b. The RL is verified. Then proceed to $CO_2$ ISV testing using the CoC RL.
      i. If $CO_2$ emissions are verified, then the ISV procedure concludes there is no deviation.
      ii. If $CO_2$ emissions are not verified, then a correction must be applied.
         - the deviations found in ISV testing are applied and the $CO_2$ IP line is corrected.
   c. The RL is not verified. Before proceeding to any $CO_2$ emissions testing, RL must be corrected.
      i. ISV RL is applied to chassis dynamometer testing
2. With the corrected RL, $CO_2$ emissions testing is performed:
   a. If $CO_2$ emissions are within the ISV tolerances, this could possibly be a flag for further investigation, particularly for targeted testing towards examining the existence of a strategy that improves artificially the $CO_2$ emissions performance. A useful input here is the expected $CO_2$ emissions according to the in-service RL that can be determined by calculation (using $CO_2$MPAS).
   b. If $CO_2$ emissions are not within the ISV tolerances, then the relevant correction shall be applied.

the deviations found in ISV testing are applied and the $CO_2$ IP line is corrected

## 4.3 Evaluation of the two approaches for the ISV procedure

Both approaches presented a series of advantages and disadvantages that are highlighted in Table 4, which summarises the pros and cons of each option.

The maximum number of vehicles that needs to be tested for RL verification and dyno tests is the same in both cases. However, the two approaches eventually differ in the total test burden. In the parallel approach, not all vehicles tested for RL verification should be tested on the chassis-dyno and vice versa. This also means that vehicle sourcing could be proved simpler since the independent verification of RL and $CO_2$ emissions can be split among all the involved parties. Also, the $CO_2$ emissions verification demands lower effort for vehicle preparation as the necessary number of $CO_2$ emissions tests to reach a conclusion can be covered with fewer vehicles.  However, testing on the chassis dynamometer a higher number of vehicles could help to avoid any systematic error or bias from individual vehicles. Regarding the corrections, and particularly for the case of non-verified RL, an experimental determination of the $CO_2$ emissions is foreseen in the sequential approach, while in the parallel one the $CO_2$ re-determination would be based on a computational method.

It is important to state that the procedure to detect artificial strategies would run in parallel to the verification procedure, regardless of the approach (parallel or sequential). However, for the sequential approach there is a possibility to integrate a flag for further investigation for defeat devices.

**Table 4:** Pros and cons of each approach for the verification procedure

| Approach | Pros | Cons |
|---|---|---|
| Parallel | • Independent verification of RL and $CO_2$ emissions<br>• Work allocation to all the different involved parties<br>• Reduced vehicles sourcing burden, particularly for $CO_2$ emissions testing<br>• Reduced test burden in terms of preparation (e.g. vehicle installation on the dyno) in case of using different RL settings for the same test vehicle | • No indication/flag for further investigation (i.e., defeat devices detection) |
| Sequential | • RL and $CO_2$ emissions verification is based on multiple vehicles (e.g. max. sample of 10 vehicles) → avoid systematic error by using different RL settings for a single vehicle<br>• Possibility to integrate a flag for defeat devices present at $CO_2$ testing in the case of non-verified RL<br>• $CO_2$ emissions for vehicles with non-verified RL determined via CDM testing | • Increased vehicle sourcing burden<br>• Increased test burden → all vehicles used in RL verification should be tested for $CO_2$ emissions and the other way around |

## 4.4 Proposal for the detailed ISV procedure

A possible overall ISV procedure is described in

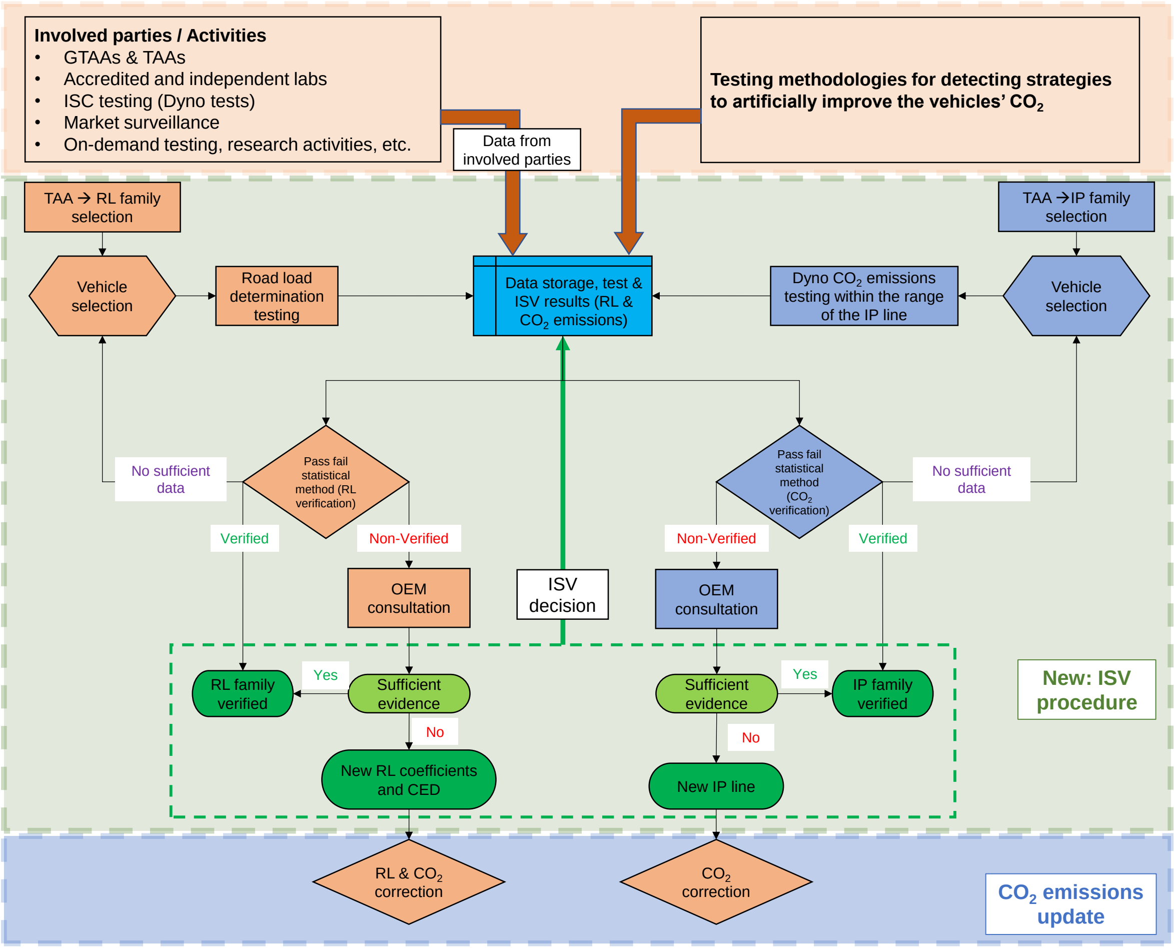



Figure 18. A database could include all relevant information regarding the RL and IP families of each manufacturer and could be the base of the possible ISV procedure. . This could be built on the DICE database of the European Commission, further expanded with ISV data, including the test results from the different sources and involved parties. That said, WLTP test results along with the RL determination results reported from the GTAAs or TAAs, the accredited and/or independent laboratories, the dyno testing from ISC activities, the market surveillance tests or results from research activities and on-demand testing, would be available to the TAAs. The TAA would be responsible to evaluate the data that concern the families (RL and/or $CO_2$ families) selected for ISV testing. The TAA would request or perform additional testing until it obtains sufficient data (fulfil the requirements of the pass/fail method) to reach a conclusion on the verification. Verification of RL and $CO_2$ emissions would be two parallel procedures, the results of which are combined at the level of the RL and $CO_2$ emissions corrections for the non-verified families.

For the verification of the RL, the in-service CED would be determined with the in-service RL that is measured during the RL determination test (this data could be potentially be already available in the database). Measured and TA RL is compared on the basis of the calculated CED under WLTC. The conclusion on the pass or fail is made with the statistical approach. If the statistical evaluation, based on the available data, leads to a conclusion, the pass or fail would be determined for the whole RL family. In case that additional testing would be needed, then targeted tests with additional vehicles would be performed.

Similarly, the pass or fail decision in terms of the $CO_2$ emissions would be based on the test data found in the main database, that come from the involved parties (TAA, accredited laboratories, etc). Again, in case of no sufficient data additional testing shall be conducted. As also mentioned in previous paragraphs, the target of the $CO_2$ verification would be to check the correspondence of the TA interpolation line with the in-service measured $CO_2$ emissions. This would be realized via testing different RLs from all the range in the $CO_2$ family.

Corrections in $CO_2$ emissions and RL would be realized in the end of the verification of both $CO_2$ and RL. The different combinations for the corrections are analysed below. The corrections that would be applied to the respective families, based on the ISV procedure decision, are:

- Case 1: Correction of the $CO_2$ emissions (IP line) (for the complete $CO_2$ family) in case that $CO_2$ fails the statistical approach, and RL passes the statistical approach (paragraph 8.2.1)
- Case 2: Correction of the RLs and CED (for the complete RL family) in case that RL fails the statistical approach, and $CO_2$ emissions pass the statistical approach. For this case the $CO_2$ emissions for the vehicles of the non-verified RL family are recalculated using the verified IP line and the increased CED
- Case 3: Both RL and $CO_2$ emissions IP line are updated, new IP and CED are defined for the family that fails in terms of both RL and $CO_2$.

The outcome of the statistical procedure would be communicated to the OEM, while the application of the proposed corrections may be decided after OEM consultation. Before making the final decision, the OEM would be requested to provide sufficient evidence that would justify the deviations found and that a correspondence between the TA and the ISV values still exists.

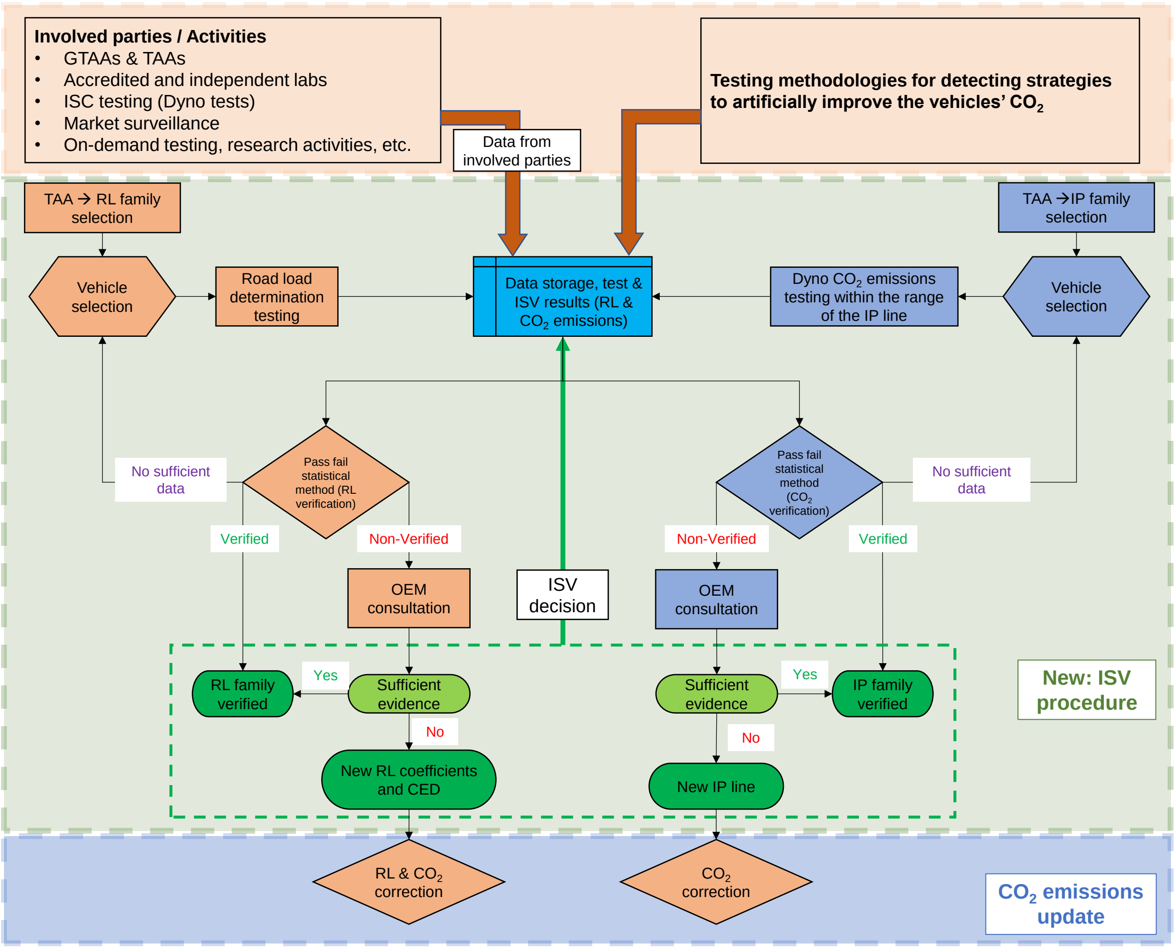



**Figure 18:** Flowchart of a possible ISV procedure

# 5 Task 3 – Elaborate detailed procedures for in-service verification of $CO_2$ emissions (LDV) – Sub-Task 3.1: Road load determination

## 5.1 Requirements and objectives

The ISV procedure consists of two main activities, the verification of the Road Load (RL) and the $CO_2$ emissions determined on the chassis-dynamometer during type-approval. In the following paragraphs the procedure for the ISV RL determination is presented. Furthermore, a sequence of steps is investigated to verify whether the RL of the in-service vehicle corresponds to the one determined during official testing. Target is to evaluate the factors that influence the determination of the RL and the impact on cycle energy demand. Based on the findings, a methodology for in-service RL verification is proposed.

## 5.2 In-service Road Load verification procedure – proposed methodology

The in-service RL verification overall procedure is schematically presented in Figure 19. The main goal of the proposed methodology is to identify the correspondence of the in-service RL with the one reported in the CoC. The evaluation is explicitly based on an experimental approach, and on the determination (via testing) of the in-service RL.

Starting point for the whole procedure is the selection of the vehicles (from a RL family) that would be tested. Prior to the performance of the RL determination test, an inspection of the test vehicle would be performed. The aim is to ensure that the selected vehicle is well maintained and that no retrofit parts are fitted. A possible check list that can be used for the pre-test check is included in Annex III – Check list for vehicle inspection prior to ISV testing, and it is a modified version of the check list, included in Appendix 1 of Annex II of Regulation (EU) 2017/1151, that is used during the ISC. The second step would be the preparation of the vehicle for the RL determination test. As it will be analysed in a following section, mass of test vehicles would need to be adjusted to the CoC test mass. This is applicable to the on-road determination methodologies (coast down and torque meter methods). The following step is the determination of the in-service RL, using one of the methodologies foreseen by the Regulation (EU) 2017/1151. The applicable RL determination tests are the coast down method, the torque meter method and the wind tunnel method. Finally, the cycle energy demand (CED) over a complete WLTC using the in-service RL is calculated and compared to the respective CED using the CoC RLs. The final decision over the verification of the family would be made with a pass/fail methodology that is based on the total/sufficient number of tested vehicles. In case that no decision can be made, additional vehicles would be tested.

The in-service RL verification procedure would be applied to a RL family, from which individual vehicles are to be tested.

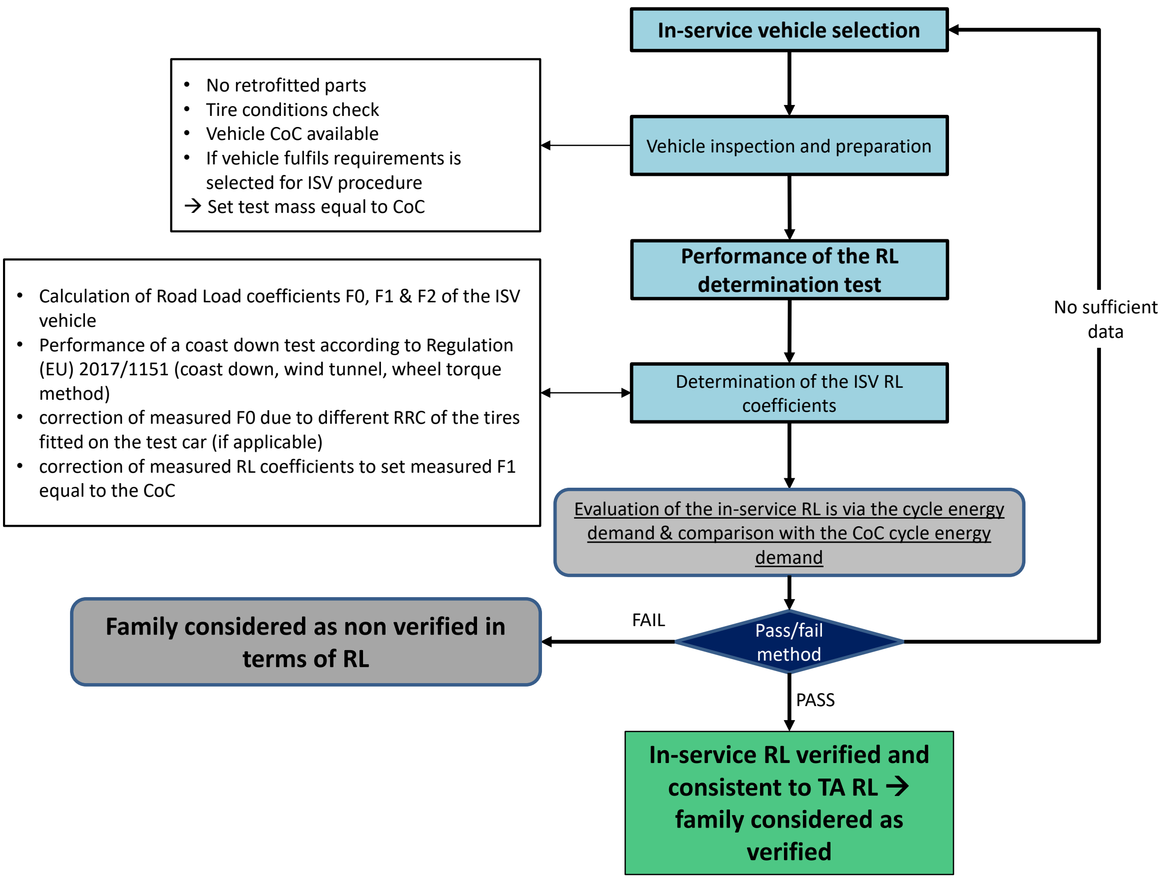



**Figure 19:** Flowchart of the proposed in-service RL verification procedure

## 5.3 Road load determination methods

As mentioned above, the determination of the in-service RL would be based on an experimental approach. According to regulation (EU) 2017/1151, Annex XXI, Sub-Annex 4, three test methods for Road Load determination along to a calculation method are described:

- The on-road coast down test method
- The on-road torque meter test method
- The wind tunnel test method

For the ISV procedure, all of the aforementioned RL determination options is proposed to be applicable. The most convenient method would be selected by the involved parties, i.e. the TAAs or the 3rd parties/ accredited laboratories.

The following paragraphs present the different tests that could be applied during the ISV procedure for the RL determination. Furthermore, a description of the RL correction due to different tyres is presented. The precision of each methodology is also evaluated to determine the minimum acceptable deviation within the tests. To further investigate the acceptable margins for the comparison of the cycle energy demand, in the following paragraphs an analysis that is based on experimental data is presented.

## 5.3.1 Road Load determination method

### 5.3.1.1 Road Load determination via the coast down method

The first on-road method to measure the vehicle road load is the coast down method described in paragraph 4.3, Sub-annex 4 of Annex XXI of Regulation (EU) 2017/1151. During coast down test the vehicle is accelerated to high velocity (e.g., 135-140 km/h) and left to decelerate. From the measured velocity and the deceleration time the total resistance force is calculated. The coast down method can be considered as the simplest approach to measure the vehicle's RL. However, the road standards limit the possible sites that a cost down can be performed. Even though this means that a test track would be needed, access to such test facilities may be easy for TAAs or 3rd parties (accredited laboratories and technical centers).

According to Regulation (EU) 2017/1151, the surface of the road where the coast-down test is performed shall be flat (the longitudinal slope shall not exceed ±1%). If desired to allow a larger selection of test tracks with more than ±1% gradient, the gradient from an individual test track may be corrected using simple physical relations. So far, no regulation was found in which such a correction is described. A study already conducted in TUG[31], which dealt with road gradient corrections, showed accurate results and is available. Regulation (EU) 2017/1151 also specifies that on WLTP the auxiliary devices shall be switched off or deactivated unless their operation is required. For on-road trips auxiliaries may be activated. This should also be considered for the verification. In the following paragraphs the coast down test results of 16 vehicle are analyzed and compared to the CoC RLs.

### 5.3.1.2 Road Load determination via the torque meter method

The second on-road method to measure the vehicle road load is the torque meter method described in paragraph 4.4, Sub-annex 4 of Annex XXI of Regulation 2017/1151. Torque meters are installed on the drive wheels and velocity is recorded, while wind speed is taken into account (e.g., using an on-board anemometry or a with stationary anemometry). The vehicle is driven at a series of specific constant reference velocity points (e.g. high and low velocities) and for specific time duration (s) at a straight road without steering while the wheel torque is measured. For the post-processing, corrections are applied for vehicle velocity, air flow data and torque sensors' error.

A similar method is applied for heavy-duty vehicles for the determination of the RL under steady state speed test EU Regulation 2017/2400. A methodology for constant speed measurements with heavy-duty vehicles on a test track using torque meters is also described by Fontaras et al. (2014). A methodology for determination of driving resistance curve of light-duty vehicles is proposed by Komnos et al. (2020). The study describes an experimental approach of a simple on-road test and the use of torque meters targeted to the calculation of road load. Torque sensors are installed on the wheels and are calibrated prior to the test. During the on-road testing, the velocity of the vehicle was kept constant whenever possible, and these constant speed segments are extracted from the data. From the obtained data of torque on wheels and speed, power on wheels is determined and the RL is calculated. Although this procedure does not strictly follow the provisions of the regulation for the torque meter method, it is an example of an on-road testing procedure. Applied for a high number of vehicles it can be proved effective for a screening methodology.

Vehicle instrumentation could increase the effort of the RL determination, particularly for individual vehicles, since a custom hub for adapting the torque meter is needed. Such a method can be applied

[31] Master thesis of L. Lohnauer entitled "Einfluss von Anbauteilen und Umgebungsbedingungen auf Real Drive Emission Ergebnisse", 2019.

from 3rd parties easier because a test with torque meters can be performed to public roads (Komnos et al. (2020)). However, for official testing, a test track may be required.

Finally, the torque meter method could be more efficient (compared to coast down) in case of a large-scale testing with the same vehicle model, testing a high number of vehicles (e.g. for screening). In addition, the selection of the torque meter method could lead to an ISV approach that is similar to the HDVs.

#### 5.3.1.3 Road Load determination via the wind tunnel method

The wind tunnel method is a RL determination procedure that is based on laboratory tests at a wind tunnel and a chassis dynamometer. The compete procedure of the RL determination is described in paragraph 6 of Sub-annex 4, Annex XXI of Regulation 2017/1151. The main disadvantage of this RL determination method is the lack of test facilities, that are limited only to the OEMs' own facilities. This means that ISV RL determination with the wind tunnel method may increase the demand on the existing facilities. Although this method is not recommended, it could be applicable for the ISV procedure and selected by the responsible TAAs.

#### 5.3.1.4 Calculation of the vehicle RL based on the default equations from paragraph 5.2 Sub Annex 4, EU Regulation 1151/2017

In the WLTP regulation foresees a methodology for RL calculation based on default equations, that use the vehicle test mass, width and height. The formulas for the calculation of $f_0$ and $f_2$ RL coefficients are (1) and (2), where TM is the test mass of the vehicle, while in this case the $f_1$ is set to zero.

$$\boldsymbol{f_0 = 0.140 \times TM} \tag{1}$$

$$\boldsymbol{f_2 = \left(2.8 \times 10^{-6} \times TM\right) + (0.0170 \times width \times height)} \tag{2}$$

To identify the applicability of the method, the RL of eight vehicles was calculated using the above equations and the values for test mass, width and height mentioned in the CoC. Using the calculated RL coefficients, the CED over WLTC was calculated and compared with the respective CED calculated using the CoC RLs. The comparison of the CED presented in Figure 20 reveals that the CED derived with the calculated RLs is approximately 30% higher than the CED calculated with the CoC RL. This deviation in CED is explained by the particularly high resistance force that results of the calculated RL coefficients. An indicative example of the resistance curves from Vehicles 1, 3 and 5 is presented in Figure 21. In the comparison of the resistance curves it becomes obvious that the calculation of RL coefficients leads to an overestimation of the driving resistance.

This method should not be considered appropriate for the in-service RL verification procedure nor for the screening process, since it tends to overestimate the vehicles' RL, compared to the RL determined using the coast-down method. Furthermore, for the vehicles that the official RL coefficients were calculated with this method, the verification needs to be explicitly realized with an experimental method.

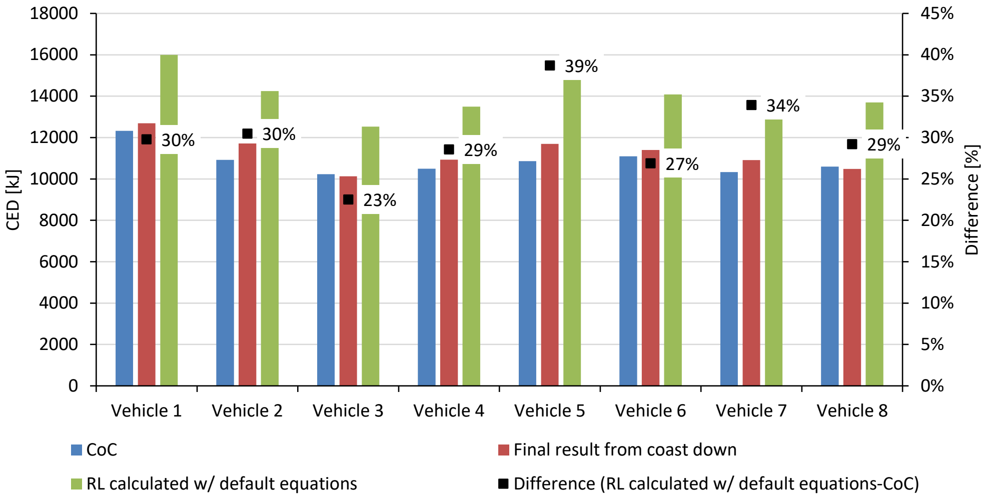
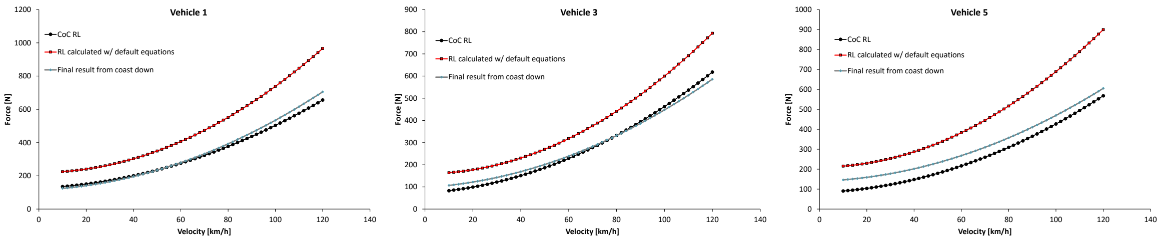



**Figure 20:** Comparison of the CED from calculated RL with equations (7) and (8), with CED from the CoC and ISV RLs




| RL coefficients | CoC | RL calculated w/ default equations | Difference |
|---|---|---|---|
| F0 [N] | 126.7 | 219.8 | 73.5% |
| F1 [N/km/h] | 0.559 | 0 | -100.0% |
| F2 [N/(km/h)^2] | 0.0321 | 0.0518 | 61.5% |
| Mass [kg] | 1570 | 1570 | |
| WLTP energy [kJ] | 12325.21 | 15996.12 | 29.8% |

| RL coefficients | CoC | RL calculated w/ default equations | Difference |
|---|---|---|---|
| F0 [N] | 73.36295 | 159.74 | 117.7% |
| F1 [N/km/h] | 0.63691 | 0 | -100.0% |
| F2 [N/(km/h)^2] | 0.032518 | 0.0440 | 35.3% |
| Mass [kg] | 1141 | 1141 | |
| WLTP energy [kJ] | 10225.36 | 12529.63 | 22.5% |

| RL coefficients | CoC | RL calculated w/ default equations | Difference |
|---|---|---|---|
| F0 [N] | 83.5 | 210.42 | 152.0% |
| F1 [N/km/h] | 0.4 | 0 | -100.0% |
| F2 [N/(km/h)^2] | 0.03031 | 0.0479 | 58.0% |
| Mass [kg] | 1503 | 1503 | |
| WLTP energy [kJ] | 10859.26 | 15064.71 | 38.7% |

**Figure 21:** Example of the resistance curve derived from the calculated RL coefficients compared to CoC and ISV resistance curves

### 5.3.2 Determination of the vehicle test mass

The vehicle test mass is defined in paragraph 3.2.25 of Annex XXI of Regulation (EU) 2017/1151 and needs to be determined prior to the execution of the coast down test. The average test mass before and after the coast down shall be determined by vehicle weighing (paragraph 4.2.1.6 of Sub-Annex 4, Regulation (EU) 2017/1151). For the needs of the ISV procedure the vehicle mass at the start of the coast down test shall be equal to the test mass reported in the CoC. Test mass[32] is defined as the sum of the actual mass[33] of the vehicle, plus 25kg, plus the mass representative of the vehicle load[34] i.e. +15% of max. payload in case of M category vehicles (passenger cars) and +28% of max. payload for N category vehicles (LCVs).

### 5.3.3 ISV test vehicle tyre conditions

During type approval tyre conditions of the test vehicle shall comply with the requirements of paragraph 4.2.2.2 of Sub-annex 4 to Annex XXI to Regulation (EU) 2017/1151.

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[32] Paragraph 3.2.25. of Annex XXI of Commission Regulation (EU) 2017/1151
[33] Paragraph 3.2.24. of Annex XXI of Commission Regulation (EU) 2017/1151
[34] Paragraph 3.2.26. of Annex XXI of Commission Regulation (EU) 2017/1151

During the ISV vehicle preparation for the coast down test, a tire inspection should be undertaken. The parameters that should at least be reported are:

- Tire RRC label
- Tread depth
- Date of production

Practically speaking, for the ISV tests it would be very difficult to fit exactly the same tyres as were used during the TA. Different options could be considered to deal with this issue.

One option is to fit the test vehicle with new tyres with the same RRC class as indicated in the CoC. with an appropriate running-in. This is considered a high-cost solution, since the minimum cost for a set of new tyres is higher than 200-300 € depending on the tyre size and specifications, cost that is additional for each to the testing cost. Furthermore, cost may be increased in case of the tyres' conditioning (if needed). This increased cost would not be applicable in the case that the TAA have available sets of tyres. In addition, the same set of tyres could be used for more than one vehicle of the ISV family in case this solution is applicable (the different test cars have the same tyre size and type).

A second, cheaper option is to allow that the ISV vehicle is fitted with tyres and rims of the same dimensions as reported in the CoC. and the RRC class may deviate than the one reported in the CoC. The tyre tread depth and RRC class should then be reported with the ISV road load test results. In other words, for this option, the tyres will remain the same as fitted by the owner/rental company, etc. Of course, in case that the fitted tyres are extremely worn (putting in question also the safety), a replacement with new tyres should be required. It is recommended that the minimum accepted tyre tread is 50%. In this case the

Finally, the tyre pressure shall be checked and adjusted to comply with the provisions of the paragraph 4.2.2.3 of Sub-annex 4 to Annex XXI to Regulation (EU) 2017/1151. The aim would be that the tyre pressure shall be within the recommendations of the OEM so that any deviations due to tyre inflation is minimized.

### 5.3.4 Correction of the RL coefficients due to different tyre RRC class

During the RL determination testing, it would be possible that the test vehicle is fitted with tyres that have different rolling resistance coefficient (RRC) than the one mentioned in the CoC. In the case that the tyres fitted on the test vehicle will have a different RRC class than the one recorded in the CoC, this will directly lead to a difference in RL. To compensate the difference in RRC, the measured F0 will need to be recalculated based on the difference between actual RRC of the tyres fitted and the CoC values. There are two possible methods that can be applied for the correction of the F0 coefficient. The first method is based on the correction of the measured F0, while the second is based on the recalculation of the CoC F0 using the F0 interpolation line and the RRC of the tyres fitted on the test vehicle.

The method makes use of the equation (3) that is derived from the road load calculation method of an individual vehicle of a road load matrix family as described in paragraph 5.1.1.1 of Sub-annex 4 to Annex XXI Regulation (EU) 2017/1151. In the case that the test mass is equal to the CoC test mass then the equation can be simplified to equation (4). With the RRC of the ISV vehicle known, it is possible to normalize/correct the measured F0 Road Load coefficient with the CoC reported tire efficiency class so that RLs (measured and CoC) are directly comparable. Considering the measured RL as the reference values, the formula for calculating the F0 of an individual vehicle returns the F0 coefficient of the tested vehicle as if it was fitted with tires that have CoC RRC.

$$F_0 = max\left(\left(0.05 \cdot f_{0,m} + 0.95 \cdot \left(f_{0,m} \cdot \frac{TM_{CoC}}{TM} + \frac{RR_{CoC} - RR_m}{1000} \cdot 9.81 * TM_{CoC}\right)\right), \left(0.2 \cdot f_{0,m} + 0.8 \cdot \left(f_{0,m} \cdot \frac{TM_{CoC}}{TM} + \frac{RR_{CoC} - RR_m}{1000} \cdot 9.81 * TM_{CoC}\right)\right)\right) \quad (3)$$

$$F_0 = max\left(\left(0.05 \cdot f_{0,m} + 0.95 \cdot \left(f_{0,m} + \frac{RR_{CoC} - RR_m}{1000} \cdot 9.81 * TM_{CoC}\right)\right), \left(0.2 \cdot f_{0,m} + 0.8 \cdot \left(f_{0,m} + \frac{RR_{CoC} - RR_m}{1000} \cdot 9.81 * TM_{CoC}\right)\right)\right) \quad (4)$$

Where:

| | |
|---|---|
| $f_{0,m}$ | Constant road load coefficient of the ISV vehicle derived from the coast down test [N] |
| $TM_{CoC}$ | Test mass of the vehicle as reported in the CoC [kg] |
| $TM$ | Test mass of the ISV vehicle with which the coast down test was performed [kg] |
| $RR_{CoC}$ | Rolling resistance from the CoC (efficiency class of the tires) [kg/tonne] |
| $RR_m$ | Rolling resistance of the ISV car derived from the measurements [kg/tonne] |

The second method is based on calculation of the road load coefficients for individual vehicles of a road load interpolation family. For the tested vehicle, the official F0 is recalculated using the RRC of the tires fitted, using equation (5). That way, the measured in-service RL is compared to the expected official RL for the given vehicle. This equation is included in paragraph 3.2.3.2.2.4. of Sub-annex 7 to Annex XXI Regulation (EU) 2017/1151. For this correction approach, the information regarding the vehicles high and low are needed to complete the calculations.

$$F_0 = f_{0,H} - \Delta f_0 \frac{(TM_H \times RR_H - TM_{ind} \times RR_{ind})}{(TM_H \times RR_H - TM_L \times RR_L)} \quad (5)$$

where:

| | |
|---|---|
| $F_0$ | Constant road load coefficient of the ISV vehicle calculated from the RRC (RR) of the tires fitted on the ISV vehicle [N] |
| $TM_H$ | Test mass of the vehicle high [kg] |
| $TM_L$ | Test mass of the vehicle low [kg] |
| $TM_{ind}$ | Test mass of the individual vehicle (ISV vehicle) [kg] |
| $RR_H$ | Rolling resistance of the vehicle high [kg/tonne] |
| $RR_L$ | Rolling resistance of the vehicle low [kg/tonne] |
| $RR_{ind}$ | Rolling resistance of the individual vehicle (ISV vehicle) of the tires fitted [kg/tonne] |

$\Delta f_0 = f_{0,H} - f_{0,L}$

In case that the RRC of the tyres fitted on the test vehicle is not known, then it would be possible to estimate/calculate the actual RRC. The description of possible test methods to determine the RRC can be found in Annex II – Methodologies for RRC determination of the in-service test vehicle.

### 5.3.5 Evaluation of the measured RL and comparison with the TA data

#### 5.3.5.1 Coast down method

The ISV proposed procedure is based on the comparison of the CED that is calculated with the CoC and the measured in-service RL. To investigate the deviations between the measured and CoC RLs a dataset of 16 vehicles was analysed. The main specifications of the vehicles are presented in Table 5. Vehicles 1-8, 15 and 16 were tested by CLOVE on an empty public road (dead end auxiliary route without traffic) that is suitable for coast down tests. Vehicles 9-14 were tested at the IDIADA and LOMMEL proving grounds in the context of a previous study conducted by TNO (all data and results were taken from the TNO report35). During the coast down test the test mass for vehicles 15 and 16 was equal to the CoC the test mass.

The RL derived by a coast down test is compared with the CoC RL primarily in terms of CED over WLTC, the metric that is used to evaluate the correspondence between ISV and CoC RLs. For the needs of the investigation presented in the report and to cover additional alternatives, the results of the coast down test and the CoC are also compared in terms of the RL coefficients and driving resistance at specific velocity points. The aim of the following analysis was to evaluate the deviations (between CoC and in-service RLs) of CED that can be observed in state-of-art (Euro 6) vehicles. For vehicles 1-8 may have been different than the CoC test mass. To compensate that, the RL derived from the tests, particularly the F0 coefficients, were adjusted to the CoC test mass. For vehicles 9-14, although test mass was close to the CoC test mass, for consistency the F0 was also adjusted to the exact value of the CoC test mass.

[35] TNO report 2020 R11122 "Final report - $CO_2$ In-Service Verification test campaign and methodology development for light-duty vehicles", J.A. van den Meiracker et al., DG CLIMA, 17 August 2020.

**Table 5:** Vehicle specifications

| Vehicle | Fuel Type/Powertrain type | Engine displacement [l] | Official WLTP test mass [kg] | Body type/segment | Euro standard |
|---|---|---|---|---|---|
| **Vehicle 1** | Petrol/Hybrid | 1.8 | 1570 | SUV | Euro 6d-ISC |
| **Vehicle 2** | CNG | 1.0 | 1380 | Hatchback/B-segment | Euro 6d-TEMP-EVAP |
| **Vehicle 3** | CNG | 1.0 | 1141 | Hatchback/A-segment | Euro 6d-TEMP |
| **Vehicle 4** | Petrol | 1.4 | 1242 | Hatchback/A-segment | Euro 6d-TEMP |
| **Vehicle 5** | Diesel | 1.6 | 1503 | Hatchback/C-segment | Euro 6d-TEMP |
| **Vehicle 6** | Petrol | 1.0 | 1311 | Hatchback/B-segment | Euro 6d-TEMP |
| **Vehicle 7** | Diesel | 1.5 | 1298 | Hatchback/B-segment | Euro 6d-ISC |
| **Vehicle 8** | Petrol | 1.0 | 1270 | Hatchback/B-segment | Euro 6d-TEMP-EVAP-ISC |
| **Vehicle 9** | Diesel | 2.0 | 2058 | SUV | Euro 6d-TEMP |
| **Vehicle 10** | Diesel | 2.0 | 2021 | SUV | Euro 6d-TEMP |
| **Vehicle 11** | Diesel | 2.0 | 2018 | SUV | Euro 6d-TEMP |
| **Vehicle 12** | Petrol | 1.0 | 1313 | Hatchback/B-segment | Euro 6d-TEMP |
| **Vehicle 13** | Petrol | 1.0 | 1312 | Hatchback/B-segment | Euro 6d-TEMP |
| **Vehicle 14** | Petrol | 1.0 | 1325 | Hatchback/B-segment | Euro 6d-TEMP |
| **Vehicle 15** | Petrol | 1.5 | 1224 | Hatchback/B-segment | Euro 6d-ISC-FCM |
| **Vehicle 16** | Diesel | 1.6 | 1523 | Hatchback/C-segment | Euro 6d-ISC-FCM |

The primary parameter that is used to evaluate the correspondence between the measured and TA RL for the 16 vehicles is the cycle energy demand (CED) over the WLTC. Using the test mass and the RL coefficients the CED is calculated according to Paragraph 5 of Sub-Annex 7 to Annex XXI of Regulation (EU) 2017/1151. Calculating the energy demand does not require any additional input regarding the vehicle technical specifications. Furthermore, the comparison of CED is a robust methodology since not very sensitive to the deviations of RL coefficient (in following graphs it can be observed that RL coefficients present high deviations, that are not significant when CED is calculated).

For the 16 vehicles the CED is calculated with both the measured and TA RLs, and the percentage difference is calculated as $\frac{CED_{ISV}-CED_{TA}}{CED_{TA}}100$. Positive difference means that the CED calculated with the measured RLs is higher than the CED calculated with the TA RLs. The calculated difference for the 16 vehicles is presented in Figure 22. The calculated difference does not exceed 11% while most of the vehicles present a difference that is between 3% and 6%. Four vehicles have deviation that is between -1% and -5% meaning that there is a good correspondence between measured and TA RL. The average deviation of the positive values is 5%.

An alternative way to express the deviation of CED is the ratio of CED calculated with measured RL and the CED calculated with TA RL, i.e. $\frac{CED_{ISV}}{CED_{TA}}$. This expression may be more useful for the application of the pass/fail methodology that is similar to the CO2 CoP statistical approach. The calculated ratio is presented in Figure 23. When the ratio is higher than 1 (>1) it means that CED from measured RL is higher that the respective CED from TA RL. As for the percentage difference, the average ratio of the CED derived from measured RL and the CED derived from TA RL for the cases that are >1 is 1.05. Taking into account the deviation from all the vehicles, the average deviation is calculated at 2% with a standard deviation of 4% or expressed as a ratio between ISV and CoC the average is 1.02 with a standard deviation of 0.04.

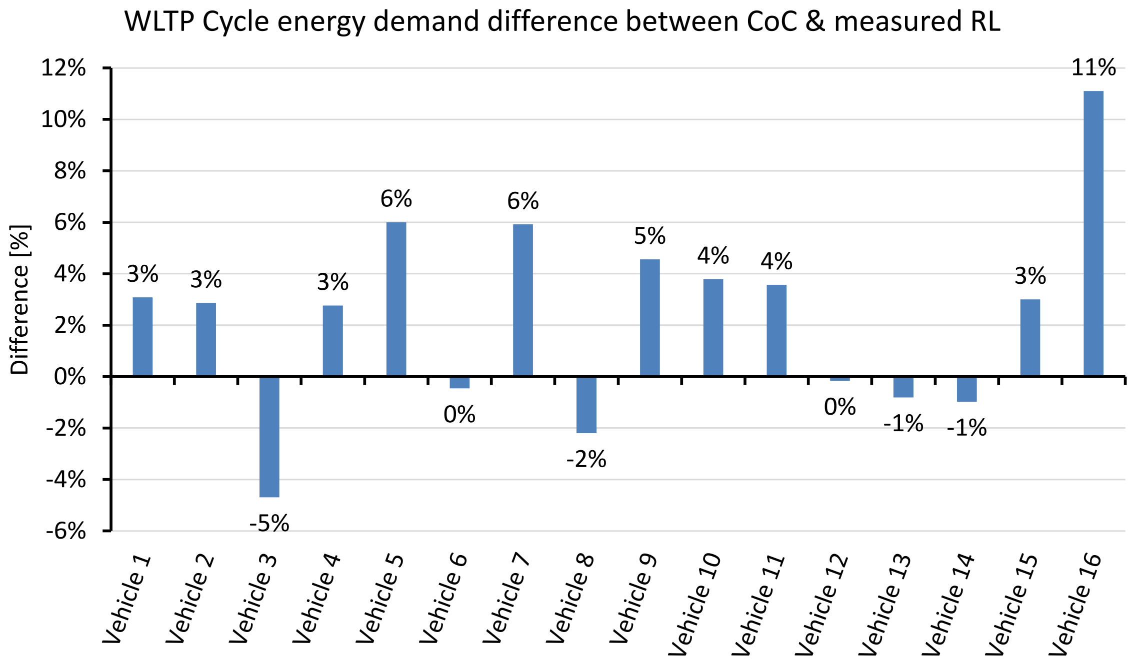



**Figure 22:** WLTP Cycle energy demand difference between CoC & measured road loads, positive difference indicates that the CED from measured RL is higher than the one calculated with CoC RL

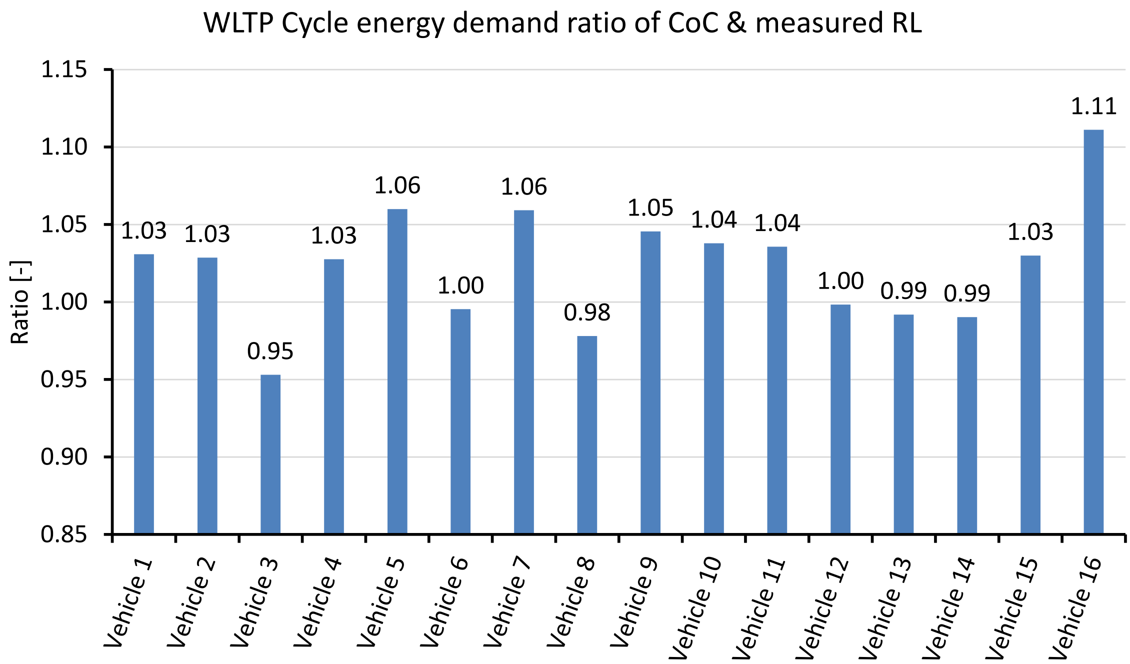



**Figure 23:** WLTP Cycle energy demand ratio of CoC & measured road loads, ratio higher than 1 (>1) indicates that the CED from measured RL is higher than the one calculated with CoC RL

Previously it was mentioned that comparison of CED is the most robust method, a conclusion that is based on the observations from the direct comparison of RL coefficients and the resistance force. Figure 24 presents the comparison of the RL coefficients between measured and TA, the percentage difference is calculated as $\frac{F_{i,ISV}-F_{i,TA}}{F_{i,TA}}100$. In this figure only F0 and F2 are compared since F1 of the measured RLs was set equal to the CoC. Deviation of the F2 coefficient is within -12% and 13% and presents a low dispersion, while deviation of F0 has higher values. The correlation graph presented in Figure 25 indicates that the high deviations of the RL coefficients is not reflected at the CED deviation. This means that the direct comparison of the RL coefficients would not provide a solid indication regarding the correspondence of in-service measured and TA RLs.

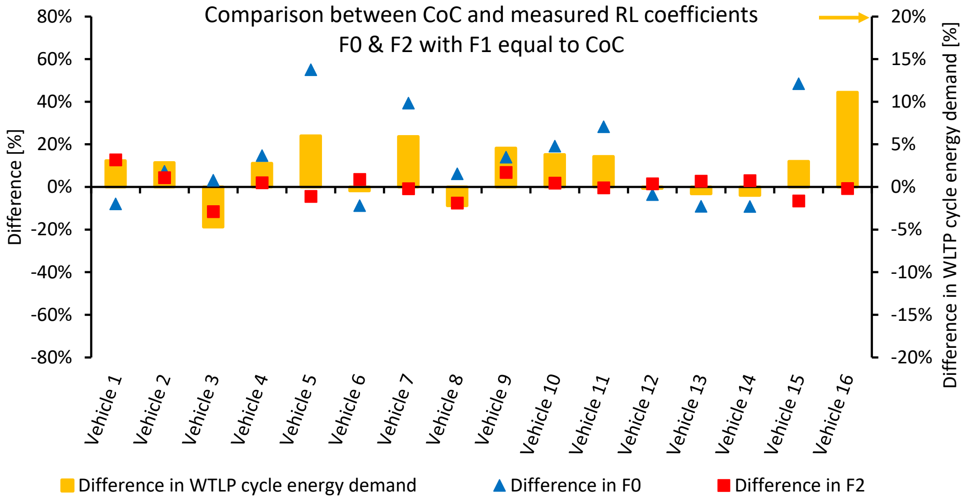



**Figure 24:** Comparison of road load coefficients for the vehicles considered in the analysis when $F_0$ and $F_2$ coefficients are calculated considering a constant $F_1$, equal to the CoC (positive difference indicates that measured is higher than CoC).

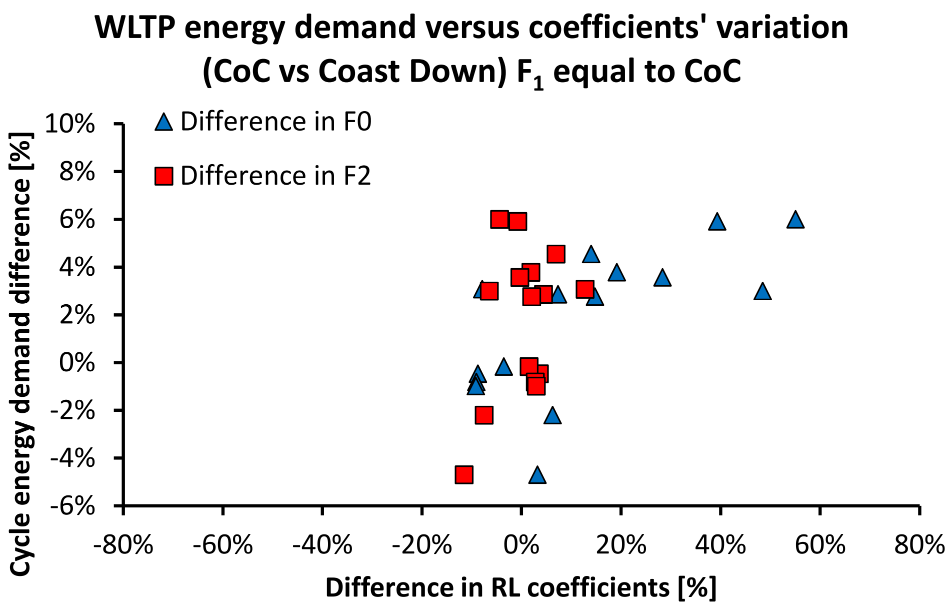



**Figure 25:** Correlation graph for WLTP energy demand and RL coefficients differences

A different option to evaluate and compare the in-service measured and the TA RL is the comparison of the resistance force. This comparison may occur at specific velocity points that are representative of the aerodynamic drag (high velocity points), the rolling resistance (low velocity points) and the total CED. For this purpose, velocity points of 95 km/h, 60 km/h and 25 km/h are selected for the comparison of the total resistance force at these velocities. Figure 26 presents the correlation of the CED and resistance force difference for the 95 km/h, 60 km/h and 25 km/h. For the 95 km/h there is a strong relation between difference in force and CED, while the range of the deviation in force is similar to the CED deviation. For the lower velocities, the dispersion of the difference in force becomes higher and the corelation becomes less evident, still with a match that has an R2 higher than 0.7. Based on this observation a more detailed analysis of the corelation between difference in force and CED was performed. For a velocity range of 10 km/h to 120 km/h and with a 2 km/h step, the corelation of ΔForce and ΔCED is realized. Total results are presented in Figure 27 where it can be observed that the maximum $R^2$ is found for 88 km/h.

Although the comparison of the resistance force also does not provide any robust conclusion for the evaluation of the in-service RL, it proves to be vital at the stage of the RL correction after the fail decision (analysed in paragraph 8.2). For example, the representative velocity points that have a strong relation of ΔForce and ΔCED, can be used to apply the RL corrections. The calculated deviation in resistance force for these specific points can be used to shift the entire curve of the driving resistance force and consequently calculate the corrected RL coefficients.

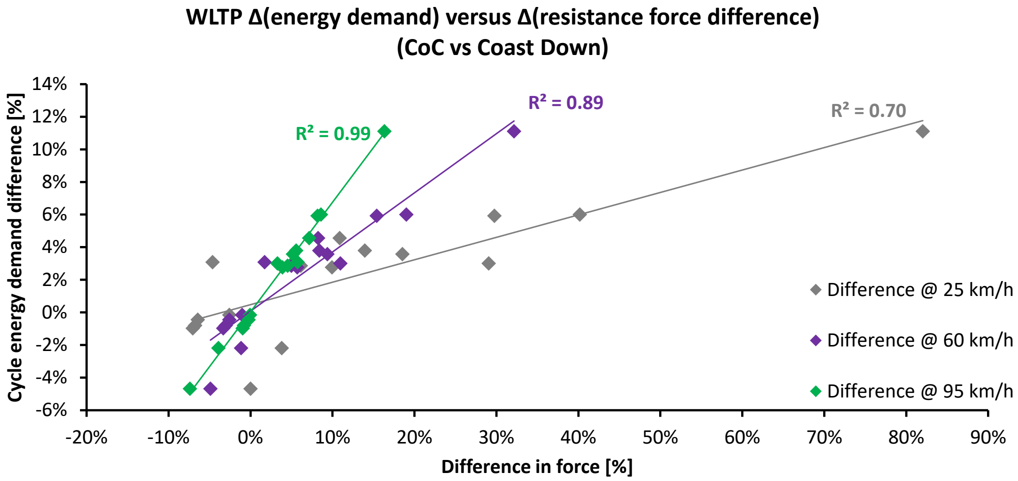



**Figure 26:** Correlation graph for driving resistance force and energy demand difference for velocity 95, 60 and 25 km/h

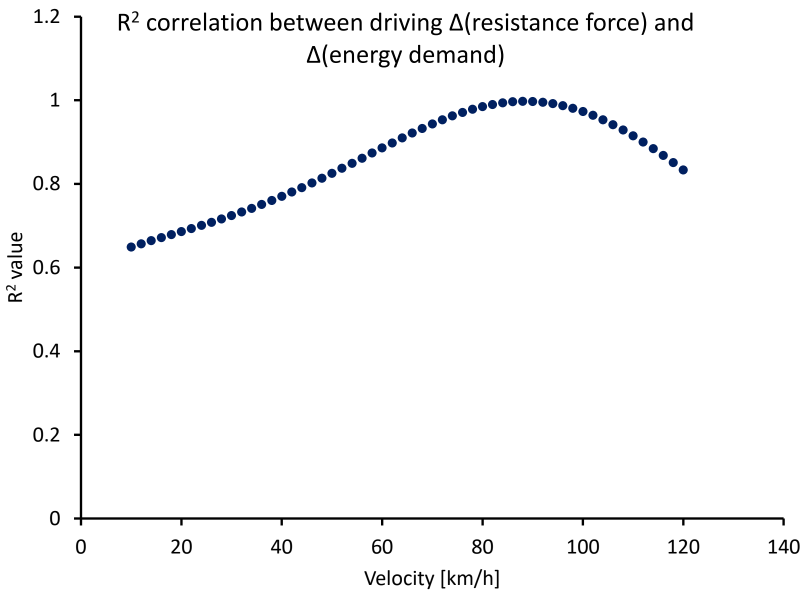



**Figure 27:** $R^2$ correlation between driving resistance force and WLTP energy demand as function of velocity

#### 5.3.5.2 Torque meter method

A methodology for determination of driving resistance curve of light-duty vehicles is proposed by Komnos et al. (2020). The study describes an experimental approach of a simple on-road test and the use of torque meters targeted to the calculation of road load. Torque sensors are installed on the wheels and are calibrated prior to the test. During the on-road testing, the velocity of the vehicle was kept constant whenever possible, and these constant speed segments are extracted from the data. From the obtained data of torque on wheels and speed, power on wheels is determined and the RL is calculated. Although this procedure does not strictly follow the provisions of the regulation for the torque meter method, it is an example of an on-road testing procedure. Applied for a high number of vehicles it can be proved effective for a screening methodology. For this study three vehicles were tested on-road and the road load coefficients were determined. The F1 RL coefficient is set equal to the official value, while the measured F0 and F2 are compared to the respective values for the WLTP High. The mean value for the difference of F0 is approximately 1% while the standard deviation is approximate 18%. For F2 the respective difference is 2% with a standard deviation of 5.3%. One of the interesting findings of this study is the accuracy for the RRC calculation. For all the tests performed, the mean error between calculated RRC from the test results and the RRC from the WLTP high is 4% with a standard deviation of approximately 6%. This indicates that with the torque meter method RRC of the ISV vehicles can be measured accurately. The accurate determination of RRC can support the methodology of F0 correction presented in the previous section.

Vehicle instrumentation could increase the effort of the RL determination, particularly for individual vehicles, since a custom hub for adapting the torque meter is needed. Such a method can be applied from 3rd parties easier because a test with torque meters can be performed to public roads (Komnos et al. (2020)). However, for official testing, a test track may be required.

### 5.3.6 Sources of variability during road load determination tests

The variability during the road load testing can be attributed to the measurement accuracy and the precision of the measurement equipment, the test-to-test variation along with the deviations from the test track and the vehicle conditions. In the following chapter the minimum acceptable deviation is calculated taking into account the aforementioned parameters.

#### 5.3.6.1 Coast down method

***Ambient conditions***

The allowed environmental conditions under which a valid coast down test is described in Paragraph 4.1 of Sub-Annex 4 to Annex XXI of Regulation (EU) 2017/1151. This paragraph includes the permissible wind conditions, the ambient temperature and the test road conditions. The regulation foresees a correction of the measured RL in order to bring the RL coefficients to the reference conditions of zero wind speed, 20°C ambient temperature and 100 kPa ambient pressure. On case of the most favorable from the side of the vehicle (low air density and no extra air resistance), i.e. ambient temperature of 35°C, pressure of 98 kPa and zero wind speed or the least favorable from the side of the vehicle (high air density and maximum extra air resistance), i.e. ambient temperature of 5°C, pressure of 102 kPa and 4 m/s wind speed, the variation between measured and corrected RL of approximately ±10-15%.

For the coast down method the sources of variability due to the measurement accuracy according to Commission Regulation (EU) 2017/1151 are:

- Vehicle speed accuracy: ± 0.2 km/h with a measurement frequency of at least 10 Hz;
- Time: min. accuracy: ± 10 ms; min. precision and resolution:10 ms;
- Wind speed accuracy: ± 0.3 m/s, with a measurement frequency of at least 1 Hz;
- Wind direction accuracy: ± 3°, with a measurement frequency of at least 1 Hz;
- Atmospheric temperature accuracy: ± 1 °C, with a measurement frequency of at least 0.1 Hz;
- Atmospheric pressure accuracy: ± 0.3 kPa, with a measurement frequency of at least 0.1 Hz;
- Vehicle mass measured on the same weighing scale before and after the test: ± 10 kg (± 20 kg for vehicles > 4 000 kg);
- Tyre pressure accuracy: ± 5 kPa;

Considering the RL curve correction formula, equation (6), that is described in paragraph 4.5.5.1 of Sub-Annex 4 to Annex XXI of Regulation (EU) 2017/1151 that refers to the coast down method, it is possible to estimate the minimum acceptable deviation that comes from the measurement precision.

$$F^* = [(f_0 - w_1 + K_1) + f_1 v] \cdot [1 + K_0(T - 20)] + K_2 f_2 v^2 \qquad (6)$$

where:

| | |
|---|---|
| $f_0, f_1, f_2$ | RL coefficients derived from the coast down test |
| $K_0 = 8.6 \cdot 10^{-3}\,[K]$ | Correction factor for rolling resistance |
| $K_1 = f_0\left(1 - \frac{Test\ Mass}{m_{av}}\right)$ | Test mass correction factor |
| $K_2 = \left(\frac{T}{293K} \cdot \frac{100kPa}{P}\right)$ | Air resistance correction factor |
| T [℃] | Arithmetic average ambient atmospheric temperature |
| P [kPa] | Arithmetic average atmospheric pressure |
| $w_1 = 3.6^2 \cdot f_2 \cdot v_w^2$ | Wind resistance correction for the coast down method |
| v [km/h] | Vehicle velocity |
| $v_w$ [m/s] | Arithmetic average of the wind speed |

With the equation (6) and the measurement precision for each parameter used in the correction formula, it is possible to define the minimum acceptable deviation. The total error can be calculated with the following equation and the standard deviations.

$$\sigma_{F^*}^2 = \sigma_P^2\left(\frac{\delta F^*}{\delta P}\right)^2 + \sigma_T^2\left(\frac{\delta F^*}{\delta T}\right)^2 + \sigma_{v_w}^2\left(\frac{\delta F^*}{\delta v_w}\right)^2 + \sigma_m^2\left(\frac{\delta F^*}{\delta m}\right)^2 \qquad (7)$$

where:

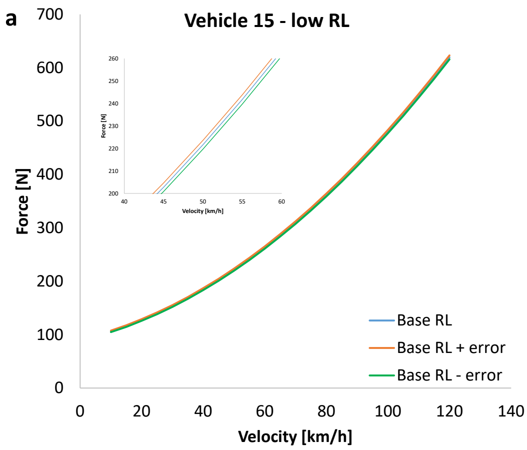
$$\left(\frac{\delta F^*}{\delta P}\right)^2 = \left[-\left(\frac{T}{293K} \cdot \frac{100kPa}{P^2}\right) f_2 v^2\right]^2$$

$$\left(\frac{\delta F^*}{\delta T}\right)^2 = \left[[(f_0 - w_1 - K_1) + f_1 v] \cdot K_0 + \left(\frac{1}{293K} \cdot \frac{100kPa}{P}\right) f_2 v^2\right]^2$$

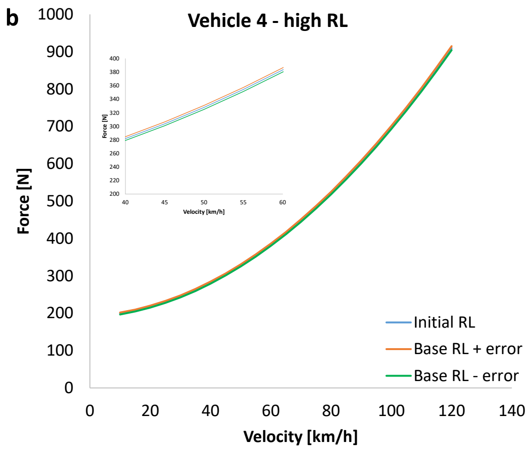
$$\left(\frac{\delta F^*}{\delta v_w}\right)^2 = \left[\,2v_w \cdot (3.6^2 \cdot f_2) \cdot [1 + K_0(T - 20)]\right]^2$$

$$\left(\frac{\delta F^*}{\delta v}\right)^2 = \left[\left[f_0 \cdot \frac{Test\ Mass}{m_{av}{}^2}\right] \cdot [1 + K_0(T - 20)]\right]^2$$

Using the equation (7) the error of the final calculated resistance force is estimated, and RL coefficients are derived for both cases if increased and decreased resistance force. The resistance curves with the maximum possible error are presented in Figure 28a for vehicle 15 (low RL) and in Figure 28b for vehicle 4 (high RL). To calculate the maximum possible deviation with the two case study vehicles, the limits for the ambient conditions were considered. That said, the ambient temperature it was assumed as 35 ℃, the pressure at 98 kPa and the maximum wind speed of 4 m/s. The error calculated at each velocity point was added to the base RL, while the RL coefficients were calculated with least square regression. Finally, the CED for each case was compared to the respective CED from the base RL. For both vehicles considered, the maximum deviation in CED that comes from the measurement precision is 1% (±0.5%). This means that the minimum acceptable deviation between TA and in-service CED is 1%.




| | CED [kJ] | Difference [%] |
|---|---|---|
| Base RL | 10877 | |
| Base RL + error | 10928 | 0.5% |
| Base RL - error | 10825 | -0.5% |




| | CED [kJ] | Difference [%] |
|---|---|---|
| Base RL | 16723 | |
| Base RL + error | 16795 | 0.4% |
| Base RL - error | 16651 | -0.4% |

**Figure 28:** Resistance force calculation for the maximum error, (a) vehicle 15 a & (b) vehicle 4

***Test to test variation***

A second possible source of variation originated from the test-to-test variation, and the deviations that occur between to the repetitions of the test. From the results of the coast down tests of Vehicle 15 and Vehicle 16 it is possible to estimate the deviation in CED between the repetitions of the coast down test. Three repetitions of the tests of Vehicle 15 and Vehicle 16 were evaluated. Each repetition includes measurement for the entire velocity range (0-130 km/h) at both directions of the road. For each repetition the RL curve was determined following the complete procedure, including corrections for the ambient conditions.

Figure 29 presents the comparison between the resistance curves derived from each repetition, the ISV RL (average RL including all the repetitions) and the CoC RL for Vehicle 15. It can be seen that the RLs from the three repetitions are quite close to each other, and the highest absolute difference (difference of the resistance force) is observed at low velocities (i.e. 6%). If the variation is expressed as a standard deviation (expressed as percentage of the averages), then at 100 km/h the variation is 0.6% and at the 25 km/h is 3.1%. Table 6 compares the ISV RL (calculated from all the repetitions following the provisions of the regulation Sub-Annex 4 of Annex XXI to Regulation (EU) 2017/1151 regarding the coast down method) and the RL from the three repetitions. The difference in terms of energy demand between the individual tests and the ISV RL is 0.4% for tests 1 and 2 and -0.7 % for test 3. The deviation in the force is within ±5% (Figure 4) while the deviation in the RL coefficients is ±5% for F0 and ±2% for $F_2$.

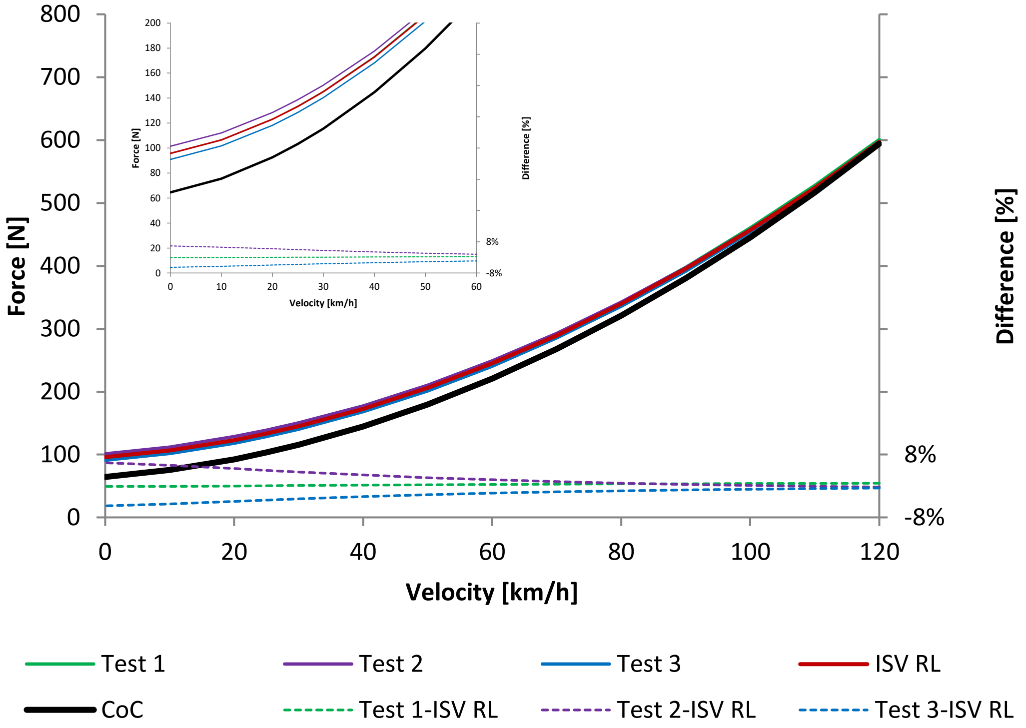



**Figure 29:** Comparison of the tree repetitions of the coast down test from Vehicle 15

**Table 6:** Comparison between RL coefficients and CED from ISV RL (average of the three repetitions) and RL derived from the individual repetitions – Vehicle 15

| RL coefficients | ISV RL | Test 1 | Difference Test 1 - ISV | Test 2 | Difference Test 2 - ISV | Test 3 | Difference Test 3 - ISV |
|---|---|---|---|---|---|---|---|
| **F0 [N]** | 95.75 | 95.67 | -0.1% | 101.4 | 5.9% | 90.91 | -5.1% |
| **F1 [N/km/h]** | 0.8 | 0.8 | 0.0% | 0.8 | 0.0% | 0.8 | 0.0% |
| **F2 [N/(km/h)²]** | 0.0281 | 0.02844 | 1.1% | 0.02765 | -1.7% | 0.02826 | 0.4% |
| **Mass [kg]** | 1224 | 1224 | 0.0% | 1224 | 0.0% | 1224 | 0.0% |
| **WLTP energy [kJ]** | 10522 | 10562 | 0.4% | 10559 | 0.4% | 10449 | -0.7% |

Similar analysis for the Vehicle 16 reveals that again the deviation between ISV RL and the RL determined via each repetition is within ±5%, while the difference in CED does not exceed 1%. Specifically, for Test 1 the difference is -0.2% and for Tests 2 and 3 is 0.6% and 0.7% respectively. If the variation is expressed as a standard deviation (expressed as percentage of the averages), then at 100 km/h the variation is 0.5% and at the 25 km/h is 2.2%. Results are presented Figure 30 in and Table 7.

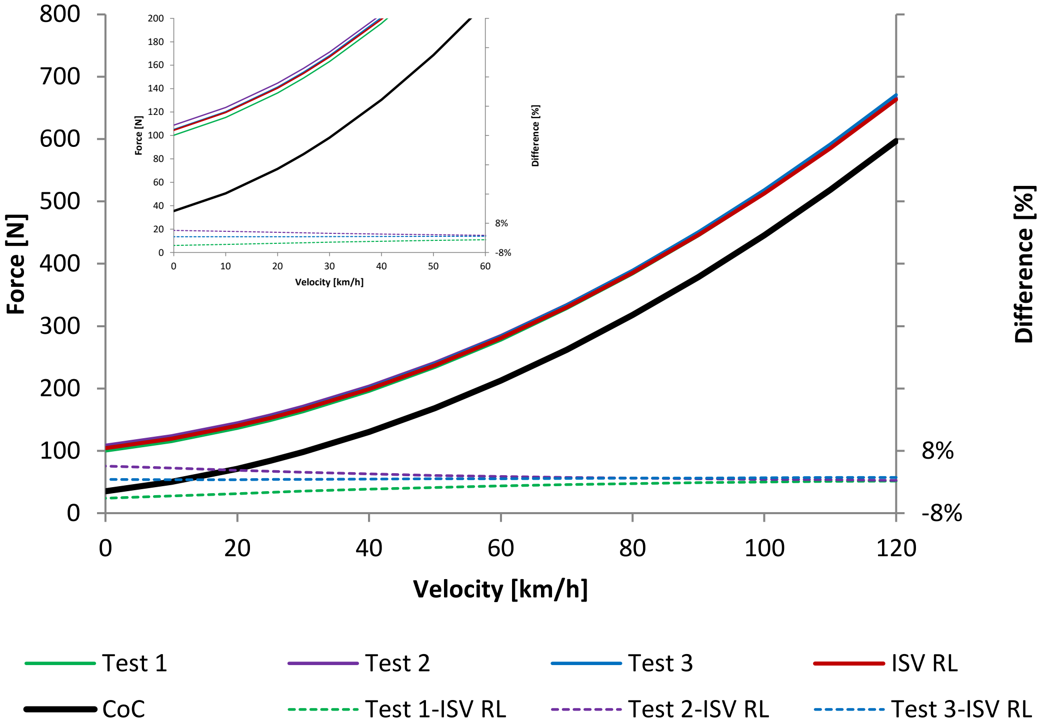



**Figure 30:** Comparison of the tree repetitions of the coast down test from Vehicle 16

**Table 7:** Comparison between RL coefficients and CED from ISV RL (average of the three repetitions) and RL derived from the individual repetitions – Vehicle 16

| RL coefficients | ISV RL | Test 1 | Difference Test 1 - ISV | Test 2 | Difference Test 2 - ISV | Test 3 | Difference Test 3 - ISV |
|---|---|---|---|---|---|---|---|
| F0 [N] | 104.5 | 100.2 | -4.1% | 108.8 | 4.1% | 105.2 | 0.7% |
| F1 [N/km/h] | 1.2286 | 1.2286 | 0.0% | 1.2286 | 0.0% | 1.2286 | 0.0% |
| F2 [N/(km/h)²] | 0.02855 | 0.02898 | 1.5% | 0.02847 | -0.3% | 0.02905 | 1.8% |
| Mass [kg] | 1523 | 1523 | 0.0% | 1523 | 0.0% | 1523 | 0.0% |
| WLTP energy [kJ] | 12272 | 12253 | -0.2% | 12341 | 0.6% | 12355 | 0.7% |

From the dataset presented in TNO study[36] it is possible to also estimate the standard deviation (expressed as percentage of the averages) in the calculated road load from the different runs of each coast down set and evaluate the repeatability of the test. As reported in the test results, the maximum variation is ±4.7% for the low speed (25 km/h) and ±3.2% for the high speed (100 km/h). The largest deviation (due to test repeatability) in CED though is 2%.

***Variation due to vehicle conditions***

Besides the overall measurement accuracy and precision, there are also sources of variability that are related to the vehicle conditions and the test track.

[36] TNO report 2020 R11122 "Final report - CO2 In-Service Verification test campaign and methodology development for light-duty vehicles", J.A. van den Meiracker et al., DG CLIMA, 17 August 2020.

- Vehicle specific elements
  - Brakes dragging (type of brakes, brake wear). During the ISV RL test brakes may be adding additional friction due to the incomplete reset of the brake callipers. This may also be affected by the brake's conditions (brake wear).
  - Drivetrain friction (lubricant temperature, lubricant quality). The lubricant used in the ISV test vehicle may have different properties (type, viscosity, etc.) than the one used during the TA RL determination test
  - Wheel type (alloy, shape, covers). If the type or shape of the ISV test vehicle wheels are different from those used for TA this may have an impact on the RL determination.
- Track specific elements
  - Road surface friction (roughness, texture, material). The regulation mentions that "texture and composition shall be representative of current urban and highway road surfaces". As that is a rather general provision, it leaves some room for variability between different test tracks that might be used for ISV RL testing.

#### 5.3.6.2 Torque meter method

For the torque meter method, the sources of variability due to measurement accuracy are the same as for the coast down method, but in addition the wheel torque and rotational speed accuracy need to be considered, as follows (paragraph 3.1 of Annex XXI, Sub-Annex 4 of Commission Regulation (EU) 2017/1151):

- Wheel torque accuracy: ± 6 Nm or ± 0.5 per cent of the maximum measured total torque, whichever is greater, for the whole vehicle, with a measurement frequency of at least 10 Hz;
- Wheel rotational speed accuracy: ± 0.05 s – 1 or 1 per cent, whichever is greater.

The calculation of the minimum allowed deviation due to the measurement procedure follows the same methodology as for the coast down method. Considering the correction to reference conditions formula for the torque meter method, equation (**8**), and the accuracy mentioned in the previous paragraph the resistance curves for the maximum error are calculated. Due to lack of experimental data the RL coefficients used previously for the error calculation of coast down method were used. To transform the coefficients so that are expressed in Nm, equations (9),(10) and (11) were used. The result leads to a maximum error that is ±0.5% for Vehicle 15 and ±0.4% for Vehicle 4 expressed in terms of CED. The values are similar to those calculated for the coast down method, since the same boundary conditions are applicable.

$$C^* = [(f_0 - w_2 + K_1) + c_1 v] \cdot [1 + K_0(T - 20)] + K_2 c_2 v^2 \quad (8)$$

where:

| | |
|---|---|
| $c_0, c_1, c_2$ | RL coefficients derived from the torque meter method |
| $w_2 = 3.6^2 \cdot c_2 \cdot v_w^2$ | Wind resistance correction for the coast down method |

$$c_0 = f_0 \cdot r \quad (9)$$

$$c_1 = f_1 \cdot r \quad (10)$$

$$c_2 = f_2 \cdot r \quad (11)$$

r: dynamic rolling radius

#### 5.3.6.3 Wind tunnel method

Wind tunnel method is one of the least popular approach to measure the resistance force of the vehicles and is used only by specific OEMS. To identify the deviation that is acceptable for the RL determination a thesis[37] that deals with the RL determination on a wind tunnel was used. Based on the findings from the thesis, the standard deviation in the force measurement fluctuations can be in the order od magnitude of ±6 N, while the deviation in force measurement due to repeatability reach ±0.8 N. The combined uncertainty is found to be dependent on the velocity with a maximum value of ±4.5% and minimum of ±2.1%.

### 5.3.7 Pass/fail decision methodology

The final step of the in-service RL verification is the statistical evaluation of the test results and the decision on the pass or fail for the RL family. This decision will define whether the RL family is verified in terms of road load or not. To that aim a pass/fail statistical approach that is based on the acceptance using a sequential sampling methodology is proposed to be used. The criteria to accept or reject a RL family will be based on the comparison between ISV and CoC WLTP cycle energy demand (ΔCED). The comparison of ΔCED is applied to a pass/fail statistical approach that is similar to the $CO_2$ CoP procedure, where the average (from the different tested vehicles) of the ratio between in-service and TA CED is compared to the limits of the statistical method.

This approach was developed by the JRC and is based on the evaluation of the average value of the ratios $CED_{ISV}/CED_{TA}$ for each individual vehicle tested. This method is also based on a sequential sampling approach. The main design parameters for this method are the A factor that represents the margin allowed to the sample, the maximum sample number (N) and the standard deviation of the family (population). The procedure for this approach is as follows:

- Step 1: For each vehicle (i), $CED_{ISV}$ is divided by the CED derived with the TA RLs

$$X_i = \frac{CED_{ISV}}{CED_{TA}}$$

- Step 2: The mean value of these normalised values ($X_{tests}$) and the sample standard deviation (σ) are calculated

$$X_{tests} = \frac{(x_1 + x_2 + x_3 + \ldots + x_N)}{N}$$

$$\sigma = \sqrt{\frac{(x_1 - X_{tests})^2 + (x_2 - X_{tests})^2 + \ldots + (x_N - X_{tests})^2}{N - 1}}$$

- Step 3: Based on the following equations a pass/fail decision is reached
  - Pass the family if $X_{tests} \leq A - (t_{P1,i} + t_{P2,i}) \cdot \sigma$
  - Fail the family if $X_{tests} > A + (t_{F1,i} - t_{F2}) \cdot \sigma$
  - Take another measurement if: $A - (t_{P1,i} + t_{P2,i}) \cdot s < X_{tests} \leq A + (t_{F1,i} - t_{F2}) \cdot \sigma$

Inputs to the above procedure are:

- Parameter A, which is the allowed margin to the sample.
- Parameters $t_{P1,i}$, $t_{P2,i}$, $t_{F1,i}$, and $t_{F2}$ come from the student's t distribution and in order to be calculated, the confidence intervals need to be decided each time. An example set of these values (for 16 vehicles) is presented in Table 8.

[37] Vogeler, Isabell: Road load determination in a wind tunnel, Darmstadt, Technische Universität Darmstadt, Jahr der Veröffentlichung der Dissertation auf TUprints: 2021, Road Load Determination in a Wind Tunnel (tu-darmstadt.de)

**Table 8:** Example of values for tP1,i, tP2,i, tF1,i, and tF2 parameters (for maximum number of vehicles equal to 16).

| | *PASS* | | *FAIL* | |
|---|---|---|---|---|
| *Tests (i)* | *tP1,i* | *tP2,i* | *tF1,i* | *tF2* |
| 3 | 1.686 | 0.438 | 1.686 | 0.438 |
| 4 | 1.125 | 0.425 | 1.177 | 0.438 |
| 5 | 0.850 | 0.401 | 0.953 | 0.438 |
| 6 | 0.673 | 0.370 | 0.823 | 0.438 |
| 7 | 0.544 | 0.335 | 0.734 | 0.438 |
| 8 | 0.443 | 0.299 | 0.670 | 0.438 |
| 9 | 0.361 | 0.263 | 0.620 | 0.438 |
| 10 | 0.292 | 0.226 | 0.580 | 0.438 |
| 11 | 0.232 | 0.190 | 0.546 | 0.438 |
| 12 | 0.178 | 0.153 | 0.518 | 0.438 |
| 13 | 0.129 | 0.116 | 0.494 | 0.438 |
| 14 | 0.083 | 0.078 | 0.473 | 0.438 |
| 15 | 0.040 | 0.038 | 0.455 | 0.438 |
| 16 | 0.000 | 0.000 | 0.438 | 0.438 |

According to an overall engineering assessment, taking into consideration the previous analysis and the observed deviations in a sample of tested vehicles, the test-to-test variation, as well as the measurement inaccuracies, a pass range for the CED ratio of 0.93 to 1.07 is considered as the final proposal and it is used for the further illustrative calculations. This covers well all the deviations observed in tested vehicles, while it is also broader than the inaccuracies introduced by the road load determination method itself.

Transferring this pass range to the RL family level actually defines the range of the expected values of the CED ratio (ISV CED / TA CED) of the complete population of the family, assuming a normal distribution. Two options are examined, considering the range equal to:

i. 2σ, i.e. the CED ratio is within 0.93 and 1.07 with 95% probability → σ=0.035

ii. 3σ, i.e. the CED ratio is within 0.93 and 1.07 with >99% probability → σ=0.023

These options are illustrated schematically in Figure 31, where the form of the normal distribution is shown for both of the above options (assuming mean value 0.99, as indicative example).

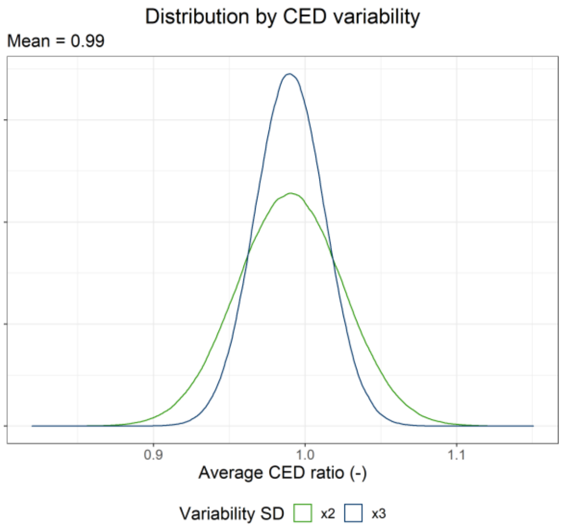



**Figure 31:** Normal distribution of CED ratio for a RL family, mean value 0.99 (indicative example), standard deviation 0.035 and 0.023.

An indicative example of this approach is schematically presented in Figure 32, for two cases of the maximum number of vehicles sampled, i.e. 10 and 16, and for a range of the standard deviation. The fail limit is presented with green line and the pass limit with a blue line. An average value of the sample that lies between the two lines cannot lead to a pass/fail decision and the procedure continues. For this indicative example, the A is selected 1.02 and the mean value 0.99.

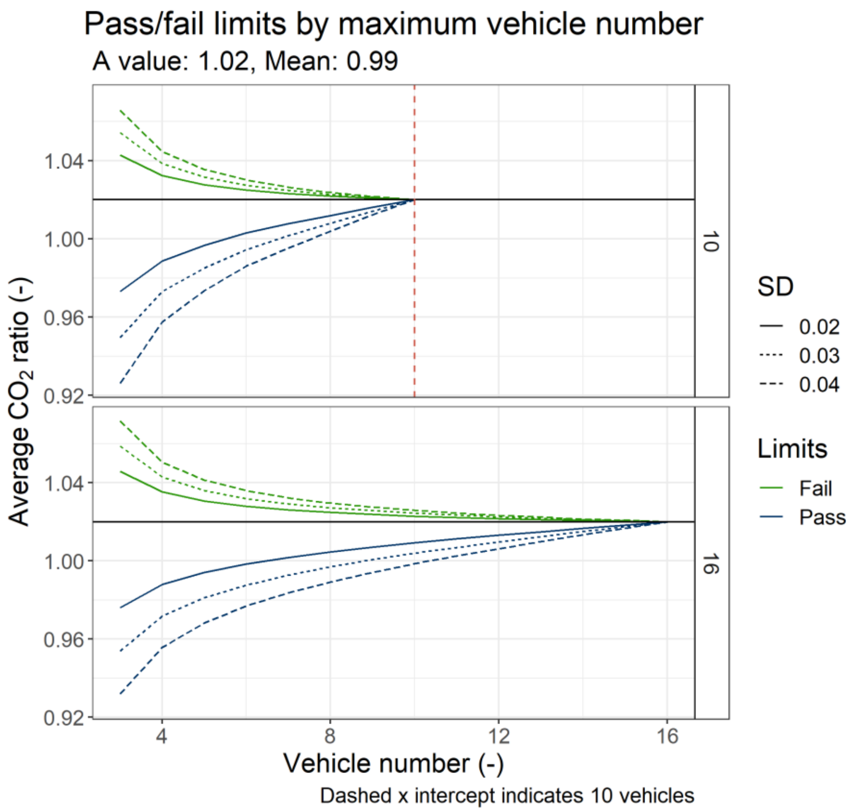



**Figure 32:** Indicative example of the $CO_2$ CoP like pass/fail statistical approach

Combining the RL family distributions of Figure 31 and the pass/fail limits of Figure 32 (for 10 vehicles), results in the overall pass rates for various combinations of the mean value, A and standard deviation as summarised in Table .

**Table 9** Pass rate for various combinations of mean value, A and standard deviation

| **Mean** | | **0.98** | **0.98** | **0.99** | **0.99** | **1.00** | **1.00** | **1.01** | **1.01** | **1.02** | **1.02** | **1.03** | **1.03** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SD** | | 0.023 | 0.035 | 0.023 | 0.035 | 0.023 | 0.035 | 0.023 | 0.035 | 0.023 | 0.035 | 0.023 | 0.035 |
| | | 3 x SD | 2 x SD | 3 x SD | 2 x SD | 3 x SD | 2 x SD | 3 x SD | 2 x SD | 3 x SD | 2 x SD | 3 x SD | 2 x SD |
| **A** | 1.01 | 100% | 99% | 99% | 93% | 86% | 75% | 43% | 43% | 7% | 15% | 0% | 3% |
| | 1.02 | 100% | 100% | 100% | 99% | 99% | 93% | 86% | 75% | 43% | 43% | 7% | 15% |
| | 1.03 | 100% | 100% | 100% | 100% | 100% | 99% | 99% | 93% | 86% | 75% | 43% | 43% |

# 6 Task 3 – Elaborate detailed procedures for in-service verification of $CO_2$ emissions (LDV) – Sub-Task 3.2: Verification of chassis-dynamometer test results

## 6.1 Requirements and objectives

The objective of Task 3.2 is to develop the detailed procedures for the chassis dynamometer testing part of the $CO_2$ emissions ISV procedure, based on the WLTP. The procedure needs to be able to quantify the deviations between the $CO_2$ emissions of a vehicle in-service and the value recorded in its CoC. To that aim, a number of different steps will be developed.

## 6.2 Approach

The $CO_2$ emissions in-service verification procedure would be explicitly based on an experimental approach, while the correspondence between in-service and TA $CO_2$ emissions would be based on a statistical approach. In the schematic illustration of the $CO_2$ verification procedure, presented in Figure , the initial steps would be the screening and the selection of the $CO_2$ family that would undergo the verification.

The initial steps could be based on the evaluation of OBFCM data to identify families that have a high deviation between real-world and TA fuel consumption/$CO_2$ emissions. The following step would be a screening which potentially could be based on a simulation/computational approach. A computational approach, based on a simulation tool/model, could be applied to estimate WLTP $CO_2$ emissions. $CO_2$MPAS model is calibrated with the OBFCM real-world data so that to translate them into the equivalent ones under the type-approval WLTP testing conditions. In order to do so, instantaneous data, derived for example from an ISC test or a targeted RDE test (similar to HDV VTP), from the OBFCM device will be needed, further to the lifetime values. In the case of PEMS test, $CO_2$ from the PEMS analysers can also be used, so that the verification of the OBFCM fuel consumption signal could also be possible. At this stage, it would be necessary to harmonize the collected data due to the different usage of the auxiliary system, driver's behaviour and gear selection. To that aim targeted simulations will be conducted to calculate the sensitivity of $CO_2$ emissions on these factors, providing the respective corrections. This homogenization will help to identify suspicious vehicles, but also to exclude extreme cases (outliers, as defined in paragraph 3.20). At this step vehicle mass and RL as defined during the in-service RL verification will be provided to the model. This is based on the proposal that the same vehicle selected for RL verification will also undergo the $CO_2$ verification procedure. $CO_2$MPAS model calibration can be also based on WLTP official data that are/will be gathered by the EC via the monitoring procedure. As a result, these data may constitute the basis for calibration of the models that will be used to calculate real-world fuel consumption/$CO_2$ emissions performance. Such an option is discussed with the JRC. The in-service $CO_2$ emissions in terms of WLTP are calculated applying the computational approach and the simulation model calibrated from Step 2. Here detailed information concerning vehicle weight and driving resistance (in-service and TA values) along with the model input parameters concerning the in-service vehicle would be necessary. This computational approach can be used as a screening method to calculate the WLTP and/or the real-world $CO_2$ emissions using $CO_2$MPAS. Data sources for this approach would be the DICE database or on-road/RDE tests (ISC tests could be used). Such an approach is presented in detail in Annex IV – Simulation approach for WLTP/Real World $CO_2$ emissions determination.

The main verification procedure, as mentioned above, would be based on the realization of the appropriate number (defined from the statistical approach) of chassis dynamometer tests. For the $CO_2$ emissions family, the goal would be to investigate whether the $CO_2$ interpolation line is verified. However, it is important to state that a simple re-testing of the WLTC. would not identify strategies that artificially improve the vehicles' $CO_2$ performance in the type approval test. Dedicated tests aimed to identify such strategies are analysed under Task 4 (paragraph 8).

This sub-task will also look into criteria to be used to decide whether in-service $CO_2$ emissions correspond with the values reported on the CoC. Pass/fail criteria exist for the ISC procedure according to the sample size of the tested vehicles. The applicability on $CO_2$ emissions or energy consumption of such an approach will be investigated, taking into account the fundamental differences in limit/target setting.

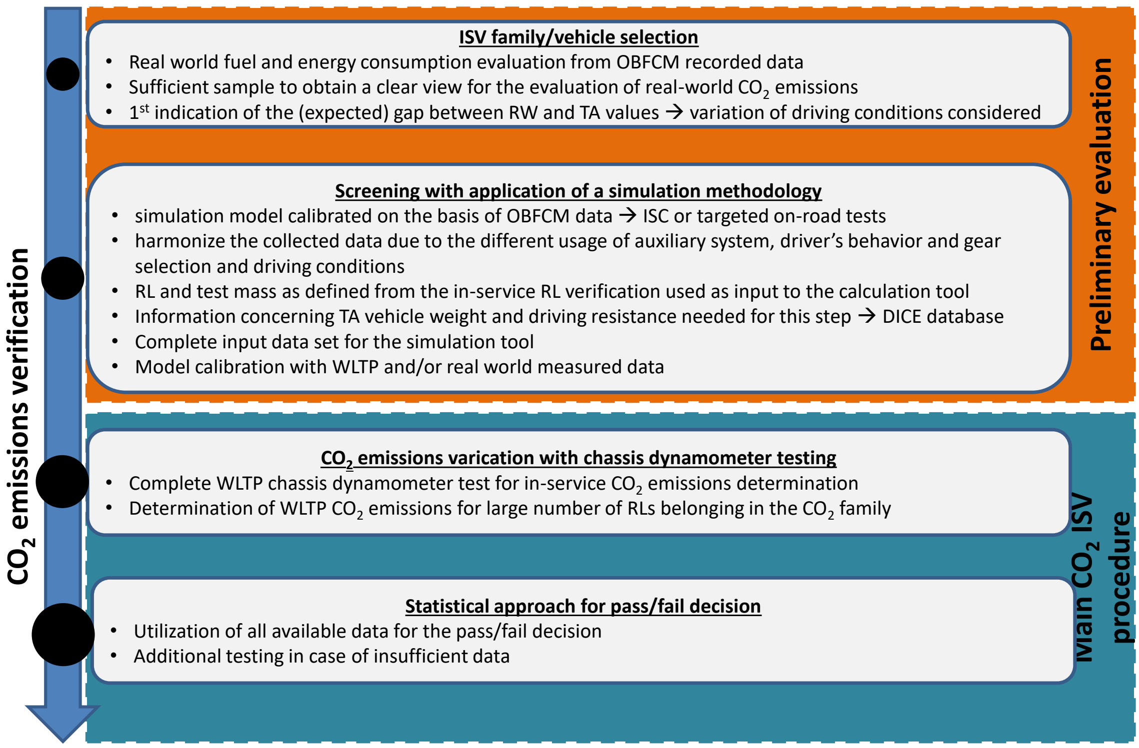



**Figure 33:** Schematic illustration of the proposed approach for the $CO_2$ verification

## 6.3 Experimental determination of in-service $CO_2$ emissions

For the selected in-service vehicles, a WLTP chassis dynamometer test would be performed in order to determine the in-service $CO_2$ emissions. The vehicle testing shall be conducted in accordance with the provisions of Sub-Annex 6, of Annex XXI, Regulation (EU) 2017/1151. For the WLTP testing, it is important that correction factors for the ATCT and Ki are known a priori so that the final results are directly comparable to the $CO_2$ emissions reported in the CoC. Regarding the target speed and the RCB corrections that are related to each individual WLTP measurement, shall be applied to all tests. The most important parameter that has to be defined explicitly prior to the test is the target RL with which the tests would be performed.

### 6.3.1 Selection of the RL for the chassis-dyno testing

The selection of the RL for the $CO_2$ emissions testing is an important decision and it is mainly based on the overall ISV procedure that would be followed, a parallel or sequential approach (see paragraph 8). Consequently, there are three main options for the selection of the RL:

- Option 1: use only the CoC RL regardless of the decision from the RL verification procedure. The chassis dynamometer tests would be performed using the RL coefficients that are mentioned in the CoC of the vehicles belonging to the same $CO_2$ family. Consequently with e.g. one vehicle all RLs can be potentially measured and define the $CO_2$ emissions for each RL. The aim would be to verify the $CO_2$ interpolation line and its correspondence to the TA one. This would require testing also the vehicle's High and Low configurations. The advantage of this option would be that a high number of RLs from the same IP line can be potentially tested with a limited number (e.g., <5) of vehicles. The main disadvantage of this option is that the RL verification is disconnected from the $CO_2$ verification. Furthermore, in case of the RL is not verified, the quantification of the $CO_2$ due to the different RL would require additional testing (or simulation at least). Another disadvantage would be that the possibility to identify a defeat device may be lost if the verification stops at $CO_2$ (meaning that $CO_2$ is verified). This option is applicable to the parallel approach for the in-service verification
- Option 2: Use the CoC RL in case the RL is verified and use the ISV RL in case the RL is not verified. The decision over the selection of the RL would be based on the pass/fail criteria applied to the stage of RL verification. This option provides the benefit of a more linear procedure that covers all the parameters of the verification. In case RL is verified, then the ISV and CoC RLs are considered equivalent ensuring that any deviation found during $CO_2$ verification would derive from efficiency and powertrain operation. In case the RL is not verified, then a mew IP line needs to be created, consequently, the $CO_2$ testing needs to be performed with the ISV RL to immediately provide input for the remedial measured of correcting the $CO_2$ emissions. This will also provide the necessary input for the correction of the IP line and will ensure consistency between corrected $CO_2$ and energy demand (RL). Additionally, testing with ISV RL and getting $CO_2$ results close to TA (within the acceptable margins) may provide a flag of the potential existence of a defeat device. This option would be applicable to the sequential approach and the selection of the RL is explicitly based on the outcome of the RL verification.
- Option 3: use only the ISV RL regardless of the decision from the RL verification. For this option, all vehicles tested under $CO_2$ emissions verification should have been initially tested also for RL determination. Always selecting the ISV RL will cancel the RL verification procedure, as no deviation between CoC and ISV RLs is accepted. Furthermore, $CO_2$ emissions results will not be directly comparable to the CoC value. The only possible comparison would occur only after the calculation of the $CO_2$ emissions for the ISV RL based on the IP line. Hence, the IP line should be known if this option is applied. This option is not recommended, however, using different RLs for chassis dynamometer testing could be proved useful for the defeat devices detection.

Option 1 and Option 2 can potentially be combined with the restriction of a verified RL. That said, if the ISV RL is within the acceptable margins, then the $CO_2$ verification can be realized by testing vehicles' High, Low, and intermediate RLs from an IP family using e.g. 1-3 vehicles. This may reduce the vehicle sourcing burden since with the RL verified the $CO_2$ verification will investigate the correspondence of the TA CED and $CO_2$ emissions (i.e. the IP line).

### 6.3.2 $CO_2$ emissions test result correction – ATCT and Ki

In order to make a direct comparison between the ISV test results and the CoC values possible, the chassis dynamometer in-service test results need to be corrected with the factors applied for the TA $CO_2$ emissions determination. The necessary corrections are divided into two categories, those that are test specific and those that are vehicle specific. The former includes the target speed and RCB corrections that shall be applied to all the WLTP tests during the ISV procedure. The later are the Ki correction and the ATCT correction. The Ki correction factor is the one related to the periodically regenerating systems, the so-called Ki factor. The value of the Ki is determined by the respective OEM or a default value of 1.05 is selected. The FCF (Family Correction Factor) is applied to increase the $CO_2$ emissions so that it reflects the average temperature of 14 ℃. This factor is defined by the Ambient Temperature Correction Test (ATCT) and it is constant for a specific family, the ATCT family. The final result of the WLTP $CO_2$ emissions will be the value that will be compared with the CoC value. Prior to the $CO_2$ emissions tests, a preconditioning cycle shall be performed, following the applicable WLTC. The $CO_2$ emissions test shall be repeated in case a regeneration takes place during the test. Consequently, for the determination of the ISV $CO_2$ emissions, the test results should be corrected using the TA ATCT and Ki factors. This information would be provided from the OEMs or the GTAAs to the other involved TAAs. In the case of third parties, would be possible either to get the correction factors from the OEMs or the GTAAs, or they can report test results to the responsible authorities for the ISV (who would have the information).

At this point, it is important to state that the ATCT and the Ki correction factors would be taken directly from the TA data. An experimental verification of those two factors would be out of the scope of the $CO_2$ emissions verification. Furthermore, this would significantly increase the test burden, particularly in the case of Ki factor determination.

## 6.4 Evaluation of measured $CO_2$ emissions and comparison to TA $CO_2$

For the purpose of the study, two vehicles were tested on the chassis dynamometer after the determination of their RL with a coast-down test. The 1st vehicle was a B-segment 1.5l petrol vehicle with an automatic gearbox (in the dataset presented in 5.3.5 this is Vehicle 15) and the 2nd is a C-segment 1.6l diesel vehicle with a manual gearbox (in the dataset presented in 5.3.5 this is Vehicle 16). To evaluate the in-service $CO_2$ emissions, the vehicle was tested under the WLTC using both the CoC and the in-service RLs. To that aim, the test protocol included both cold and hot start WLTC tests. For those vehicles, an ATCT and Ki correction was applied, using the actual values of the families those cars belong to. Consequently, a direct comparison with TA $CO_2$ emissions is possible. For Vehicle 16, an RCB correction was also applied.

Figure 34 presents the raw (corrected only for target velocity) $CO_2$ emissions (bag analysis) results from the dyno testing of the (Vehicle 15) B-segment 1.5l petrol vehicle. The variability between the test with the same RL is approximately ±1g/km for both the cold start and hot start tests. In order to get a direct comparison between the test results and the TA, the result of the cold WLTC test was adjusted for the target speed and the ATCT corrections. To that aim, the FCF for the vehicle was used to make the test results comparable with the CoC $CO_2$ emissions. Figure 35 presents the comparison between the TA and measured $CO_2$ emissions with the applied FCF of 1.018. The average $CO_2$ emissions from the tests with CoC RL and the FCF are -0.1% lower than the CoC value, whereas for the tests with ISV RL the difference is 2.9%.

Similarly, with the C-segment 1.6l diesel vehicle (Vehicle 16) the $CO_2$ emissions under WLTP using TA and in-service RL were measured. Figure 36, presents the comparison between TA and measured $CO_2$ emissions. The measured values presented in the figure, include all the possible corrections, i.e. the correction for target speed, the RCB correction, the ATCT (1) and the Ki (2.6531 additive) correction. From the comparison, it can be seen that using the TA RL the measured $CO_2$ is lower by 3% for the h cold start cycle, while in the case of the tests performed with the in-service RL, the deviation is 5% for the cold start cycle. For this vehicle only one repetition of each test was realized, consequently, it is not possible to get an indication of the test-to-test variation.

From the analysis of the results for both vehicles, it is observed that using the CoC RL to set-up the chassis dynamometer, the resulting $CO_2$ emissions are lower than the TA. On the other hand, using the measured in-service RL $CO_2$ emissions are measured slightly higher than the TA, with the deviation not exceeding 5%.

As regards the test repeatability, from the experimental campaign presented above, it can be seen that the repeatability between the consecutive tests lays between ±1 g/km. For all the tests the same fuel was used and was also analysed to identify its properties. Values with a similar magnitude are reported in Williams et al. (2019) where the average repeatability within the different tests regarding the $CO_2$ emissions measurement is ±3 g/km. This study presents an extensive experimental campaign with 3 different vehicles, 14 different fuels and 2 cycles (cold/hot start NEDC and WLTP). For all the tests presented the repeatability is consistent with almost no impact from the different combination of set-ups (fuel, cycle or vehicle).

In the TNO report[38] the repeatability from repetitions of the WLTP $CO_2$ emission testing with the CoC RLs is presented. For the vehicles tested the typical variation observed lays between ±3 g/km in maximum. In the same order of magnitude (1-2 g/km) is the repeatability of the $CO_2$ emissions result from the test of the same vehicle at different labs.

[38] TNO report 2020 R11122 "Final report - CO2 In-Service Verification test campaign and methodology development for light-duty vehicles", J.A. van den Meiracker et al., DG CLIMA, 17 August 2020.

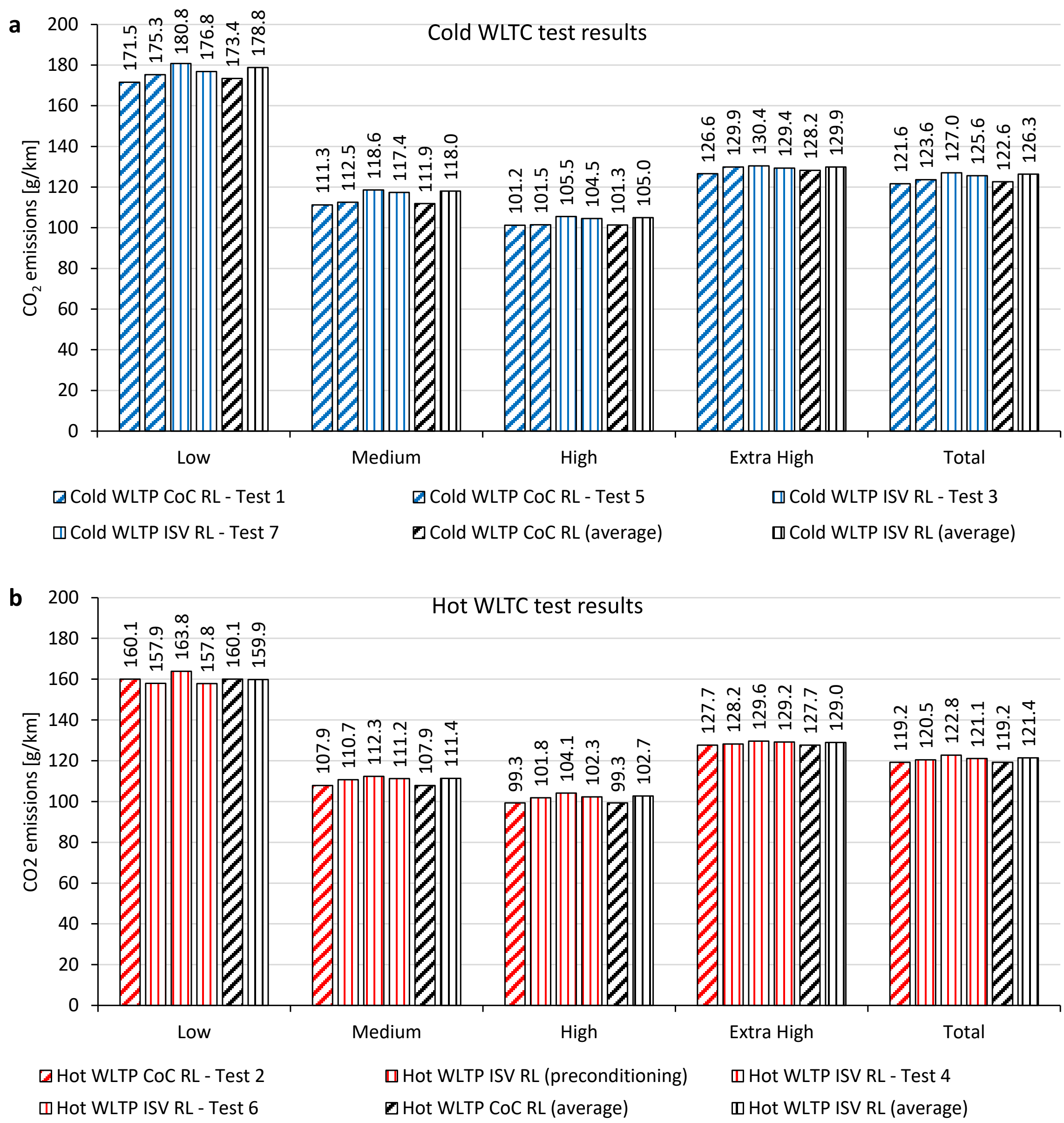



**Figure 34:** Test results for the WLTP tests of the B-segment 1.5l petrol vehicle, (a) cold start cycles and (b) hot start cycles

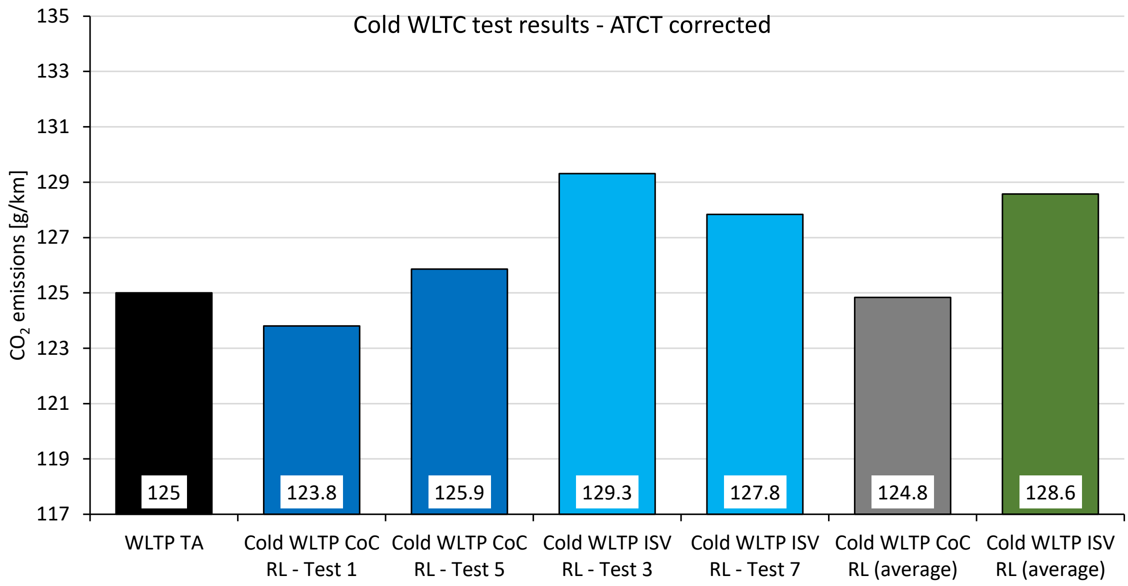



**Figure 35:** Comparison of WLTC $CO_2$ emissions results for the tests performed (vehicle 15), the total $CO_2$ emissions are multiplied by the FCF to address the ATCT correction

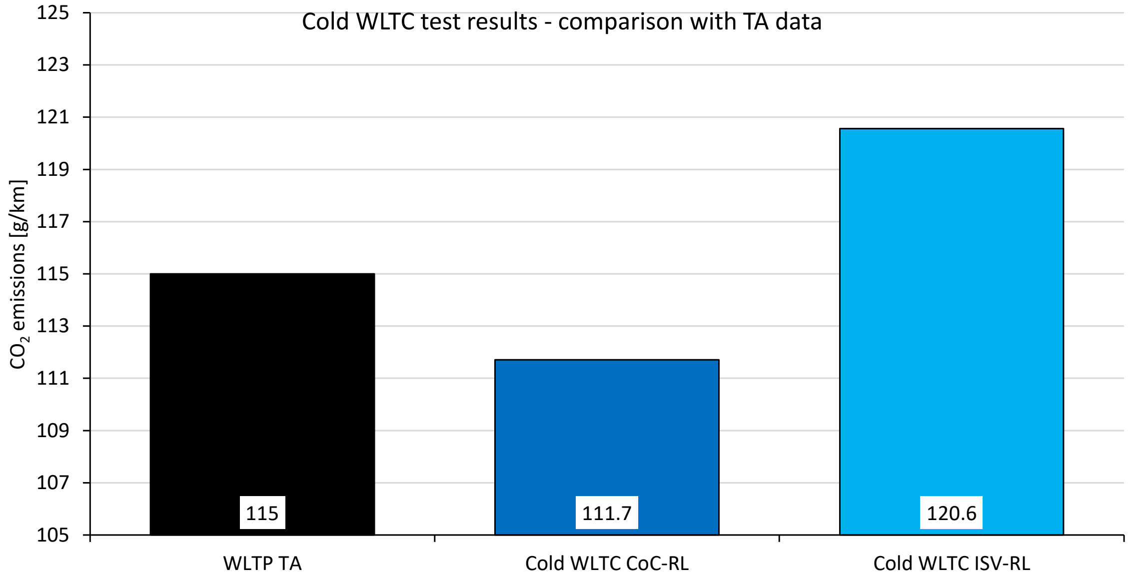



**Figure 36:** Comparison of WLTC $CO_2$ emissions results for the tests performed (vehicle 15), the total $CO_2$ emissions are calculated after the application of all corrections

## 6.5 Acceptable deviations for the $CO_2$ emissions verification

### 6.5.1 Comparison between variation of the CED and the $CO_2$ emissions

The determination of the acceptable margins investigated the correlation between $CO_2$ emissions and energy demand deviations. The main goal is to investigate the correspondence of the ΔCED and $\Delta CO_2$

to provide a guideline for the determination of the acceptable margins. This is done to avoid situations that will allow a ΔCED which corresponds to higher $\Delta CO_2$ than the respective margin. To that aim, a batch calculation using $CO_2$MPAS and 24 validated models from actual vehicles was conducted and the cycle energy demand and WLTC $CO_2$ emissions were calculated for all the possible combinations. The vehicles considered for this batch calculation activities were all used in the context of previous $CO_2$MPAS-related activities and cover a wide range of conventional (diesel and petrol) vehicles, covering all vehicle segments. As shown in Table 10, the range of engine displacement, vehicle mass and driving resistance (expressed in RL coefficients) represent the European LDV fleet.

**Table 10:** Contents of the database and range of the vehicle specifications that were considered for the $CO_2$MPAS parametric analysis simulations

| Parameter | | Number of vehicles / Value |
|---|---|---|
| Fuel type | Petrol | 13 |
| | Diesel | 11 |
| Gearbox | Manual | 11 |
| | Automatic | 13 |
| Engine capacity [l] | Minimum | 0.9 |
| | Maximum | 3.5 |
| Vehicle Test mass | Minimum | 933 |
| | Maximum | 3032 |
| Constant part of RL, $F_0$ coefficient [N] | Minimum | 56.5 |
| | Maximum | 428.8 |
| Square part of RL, $F_2$ coefficient $[N/(km/h)^2]$ | Minimum | 0.025 |
| | Maximum | 0.102 |

For each vehicle, the WLTP RL and a WLTP test for $CO_2$MPAS calibrations were available, along with all the vehicle specifications. The complete dataset was used as the basis to calculate the WLTP $CO_2$ emission and energy demand for a variation of the RL coefficients. For each vehicle, the WLTP RL was considered as a base case, while a variation of coefficient of ±16% for F2 with a step of 2% and a variation of ±50% for F0 with a step of 5%. All combinations were simulated, hence for each vehicle model, a total of 348 cases were calculated. At this point, it is important to state that the F1 coefficient and test mass were not varied and kept constant, equal to the base case, for all the variations. The same simulation was repeated with a variation of coefficient for F2 of ±50% with a step of 5% and a variation of ±16% for F0 with a step of 2%. The range of F0 and F2 that was simulated, is presented in Figure 37, where it can be seen that the performed simulations cover an extended set of the RL parameters.

The main objective of this activity is to investigate the correlation between the deviation of energy demand and $CO_2$ emissions. The difference and divergence between energy demand and $CO_2$ emissions is calculated between the base case and each variation case. The results from all the vehicles indicate that the ratio between $CO_2$ emissions and energy demand divergence is on average at 0.71, meaning that a 7% divergence in cycle energy demand is translated to a 5% divergence in $CO_2$ emissions. The results from all the simulations are presented in Figure 38 as a correlation graph between the divergence of $CO_2$ emissions and cycle energy demand. At this point it is important to state that the calculation results presented in Figure 38 cannot determine the acceptable margins, however, they support the selection of the acceptable margins and ensure the cohesion between RL and $CO_2$ emissions margins.

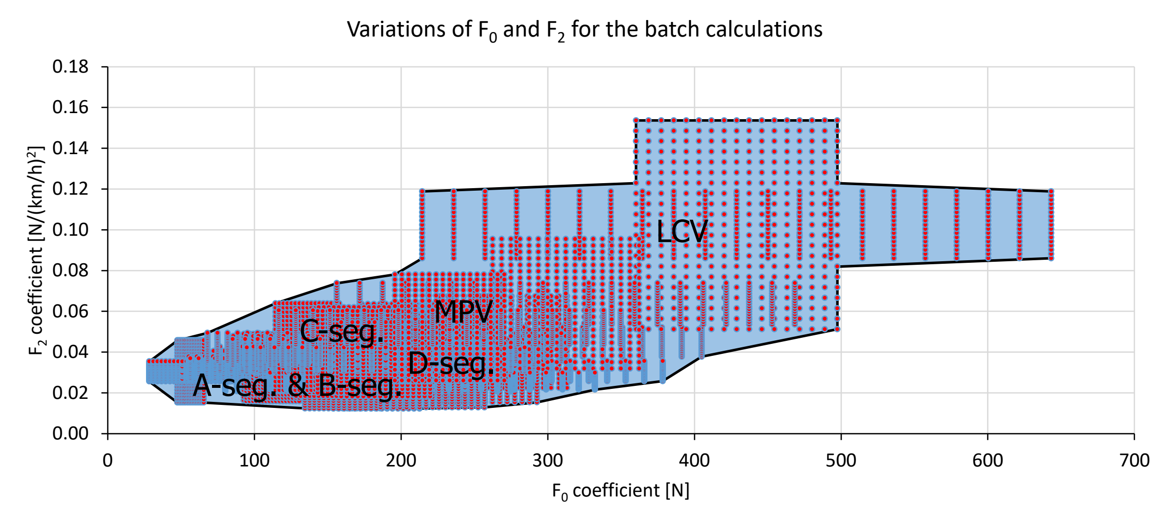



**Figure 37:** Variations of F0 and F2 RL coefficients and range covered with the simulations

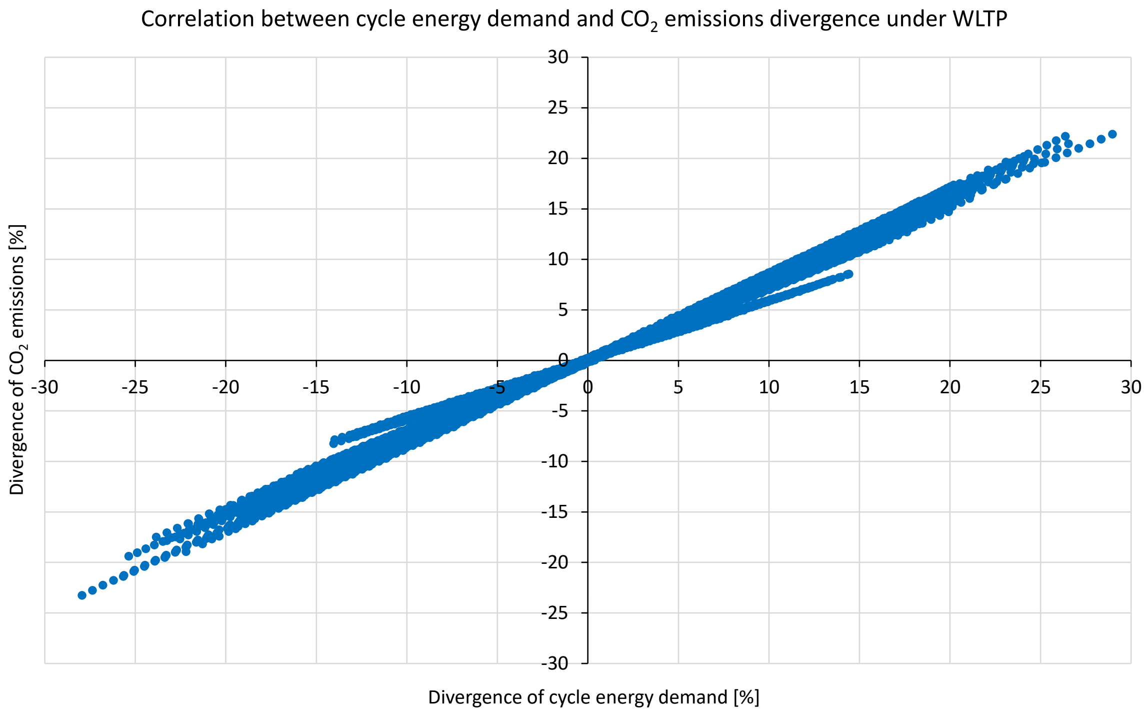



**Figure 38:** Correlation between cycle energy demand and $CO_2$ emissions divergence under WLTP for all the simulated cases

## 6.6 Pass/fail decision methodology

The final step of the in-service $CO_2$ verification is the statistical evaluation of the test results and the decision on the pass or fail for the IP family. This decision will define whether the IP family is verified in terms of $CO_2$ emissions. To that aim, a pass/fail statistical approach that is based on the acceptance using a sequential sampling methodology is proposed to be used. The criteria to accept or reject an IP family will be based on the comparison between ISV and CoC WLTP $CO_2$ emissions $\Delta CO_2$) The comparison of $\Delta CO_2$ is applied to a pass/fail statistical approach that is similar to the $CO_2$ CoP procedure, where the average (from the different tested vehicles) of the ratio between in-service and TA $CO_2$ is compared to the limits of the statistical method.

This approach was developed by the JRC and is based on the evaluation of the average value of the ratios $CO_{2,ISV}/CO_{2,TA}$ for each individual vehicle tested. This method is also based on a sequential sampling approach. The main design parameters for this method are the A factor that represents the margin allowed to the sample, the maximum sample number (N) and the standard deviation of the family (population). The procedure for this approach is as follows

- Step 1: For each vehicle (i), in-service measured $CO_2$ emissions are divided by the declared TA $CO_2$ emissions

$$X_i = \frac{CO_{2,ISV}}{CO_{2,TA}}$$

- Step 2: The mean value of these normalised values ($Xtests$) and the sample standard deviation ($s$) are calculated

$$X_{tests} = \frac{(\mathrm{x}_1 + \mathrm{x}_2 + \mathrm{x}_3 + \ldots + \mathrm{x}_\mathrm{N})}{\mathrm{N}}$$

$$s = \sqrt{\frac{(x_1 - X_{tests})^2 + (x_2 - X_{tests})^2 + \ldots + (x_N - X_{tests})^2}{N-1}}$$

- Step 3: Based on the following equations a pass/fail decision is reached
  - Pass the family if $X_{tests} \leq A - (t_{P1,i} + t_{P2,i}) \cdot \sigma$
  - Fail the family if $X_{tests} > A + (t_{F1,i} - t_{F2}) \cdot \sigma$
  - Take another measurement if: $A - (t_{P1,i} + t_{P2,i}) \cdot s < X_{tests} \leq A + (t_{F1,i} - t_{F2}) \cdot \sigma$

Inputs to the above procedure are:

- Parameter A, which is the allowed margin for the sample.
- Parameters $t_{P1,i}$, $t_{P2,i}$, $t_{F1,i}$, and $t_{F2}$ come from the student distribution and in order to be calculated, the confidence intervals need to be decided each time. An example set of these values (for 16 vehicles) is presented in Table 11.

**Table 11:** Example of values for tP1,i, tP2,i, tF1,i, and tF2 parameters(for maximum number of vehicles equal to 16).

| | *PASS* | | *FAIL* | |
|---|---|---|---|---|
| *Tests (i)* | *tP1,i* | *tP2,i* | *tF1,i* | *tF2* |
| 3 | 1.686 | 0.438 | 1.686 | 0.438 |
| 4 | 1.125 | 0.425 | 1.177 | 0.438 |
| 5 | 0.850 | 0.401 | 0.953 | 0.438 |
| 6 | 0.673 | 0.370 | 0.823 | 0.438 |
| 7 | 0.544 | 0.335 | 0.734 | 0.438 |
| 8 | 0.443 | 0.299 | 0.670 | 0.438 |
| 9 | 0.361 | 0.263 | 0.620 | 0.438 |
| 10 | 0.292 | 0.226 | 0.580 | 0.438 |
| 11 | 0.232 | 0.190 | 0.546 | 0.438 |
| 12 | 0.178 | 0.153 | 0.518 | 0.438 |
| 13 | 0.129 | 0.116 | 0.494 | 0.438 |
| 14 | 0.083 | 0.078 | 0.473 | 0.438 |
| 15 | 0.040 | 0.038 | 0.455 | 0.438 |
| 16 | 0.000 | 0.000 | 0.438 | 0.438 |

Based on the previous analysis and considering the observed deviations in a sample of tested vehicles and the consistency between CED variation and $CO_2$ variation, the proposed pass range for the $CO_2$ emissions ratio is 0.95 to 1.05.

Transferring this pass range to the IP family level actually defines the range of the expected values of the $CO_2$ emissions ratio (ISV $CO_2$ / TA $CO_2$) of the complete population of the family, assuming a normal distribution. Two options are examined, considering the 5% deviation equal to:

i. 2σ, i.e. the $CO_2$ emissions ratio is within 0.95 and 1.05 with 95% probability → σ=0.025
ii. 3σ, i.e. the $CO_2$ emissions ratio is within 0.95 and 1.05 with >99% probability → σ=0.017

These options are illustrated schematically in Figure 39, where the form of the normal distribution is shown for both of the above options (assuming a mean value of 0.99, as an indicative example).

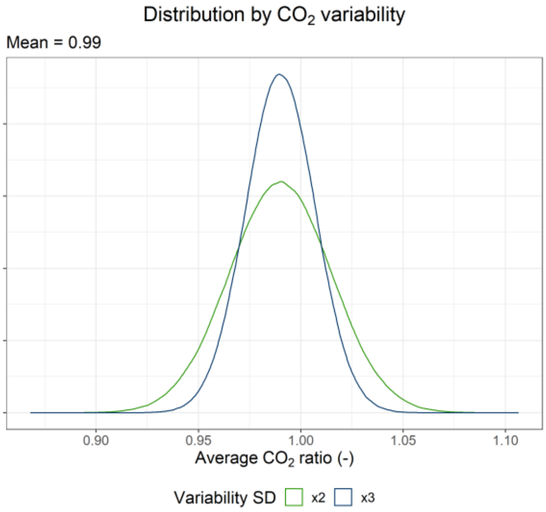



**Figure 39:** Normal distribution of $CO_2$ emissions ratio for an IP family, mean value 0.99 (indicative example), standard deviation 0.025 and 0.017

An indicative example of this approach is schematically presented in Figure 37, for two cases of the maximum number of vehicles sampled, i.e. 10 and 16, and for a range of the standard deviation. The fail limit is presented with a green line and the pass limit with a blue line. An average value of the sample that lies between the two lines cannot lead to a pass/fail decision and the procedure continues. For this indicative example, the A is selected as 1.02 and the mean value 0.99.

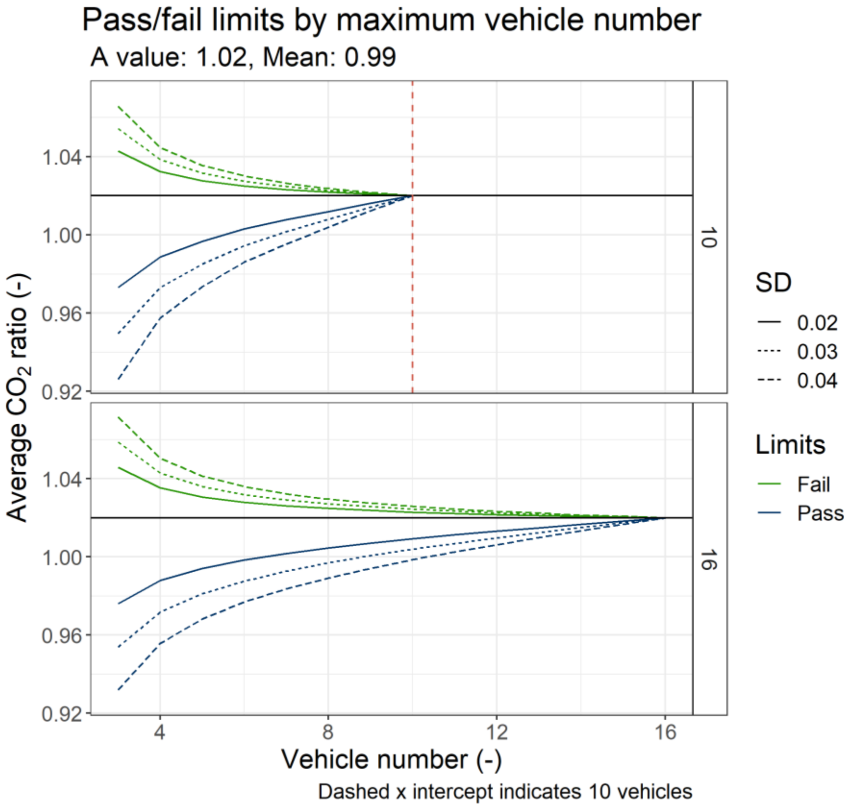



**Figure 40:** Indicative example of the $CO_2$ CoP like pass/fail statistical approach

Combining the IP family distributions of Figure 39 and the pass/fail limits of Figure 37 (for 10 vehicles), then the overall pass rates for various combinations of the mean value, A and standard deviation are summarised in Table 12. This just to illustrate the pass rates for different cases of A and standard deviation and it is not meant to make any recommendations.

**Table 12** Pass rate for various combinations of mean value, A and standard deviation.

| **Mean** | | 0.98 | 0.98 | 0.99 | 0.99 | 1.00 | 1.00 | 1.01 | 1.01 | 1.02 | 1.02 | 1.03 | 1.03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SD | | 0.017 | 0.025 | 0.017 | 0.025 | 0.017 | 0.025 | 0.017 | 0.025 | 0.017 | 0.025 | 0.017 | 0.025 |
| | | 3 x SD | 2 x SD | 3 x SD | 2 x SD | 3 x SD | 2 x SD | 3 x SD | 2 x SD | 3 x SD | 2 x SD | 3 x SD | 2 x SD |
| A | 1.01 | 100% | 100% | 100% | 98% | 94% | 85% | 43% | 43% | 2% | 8% | 0% | 0% |
| | 1.02 | 100% | 100% | 100% | 100% | 100% | 98% | 94% | 85% | 43% | 43% | 2% | 8% |
| | 1.03 | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 98% | 94% | 85% | 43% | 43% |

**In order to further generalize the calculations and the results,**

Table 13 presents the pass rate for a set of generic values of the statistical parameters.

**Table 13** Pass rate for generic values of the statistical parameters

| **Mean** | | **0.98** | **0.98** | **0.98** | **0.99** | **0.99** | **0.99** | **1.00** | **1.00** | **1.00** | **1.01** | **1.01** | **1.01** | **1.02** | **1.02** | **1.02** | **1.03** | **1.03** | **1.03** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SD** | | 0.02 | 0.03 | 0.04 | 0.02 | 0.03 | 0.04 | 0.02 | 0.03 | 0.04 | 0.02 | 0.03 | 0.04 | 0.02 | 0.03 | 0.04 | 0.02 | 0.03 | 0.04 |
| **A** | 1.01 | 100% | 99% | 97% | 99% | 95% | 89% | 89% | 78% | 70% | 42% | 42% | 42% | 5% | 12% | 18% | 0% | 2% | 5% |
| | 1.02 | 100% | 100% | 99% | 100% | 99% | 97% | 99% | 95% | 89% | 89% | 78% | 70% | 42% | 42% | 42% | 5% | 12% | 18% |
| | 1.03 | 100% | 100% | 100% | 100% | 100% | 99% | 100% | 99% | 97% | 99% | 95% | 89% | 89% | 78% | 70% | 42% | 42% | 42% |

# 7 Task 3 – Elaborate detailed procedures for in-service verification of $CO_2$ emissions (LDV) – Sub-Task 3.3: Methodology for detecting strategies to artificially improve the vehicles' $CO_2$ performance in the type approval test

## 7.1 Introduction

### 7.1.1 Background

In recent years the increasing pressure on car and van manufacturers to reduce the $CO_2$ emissions of their vehicles, through the EU fleet-average targets with financial penalties for not achieving them, taxation schemes and increased societal pressure, has led to the development of a range of technologies and strategies to reduce $CO_2$ emissions of new vehicles. The official $CO_2$ emission values to be used in the regulatory context are established by the type approval (TA) test, which has adopted WLTP in place of the NEDC to better reflect the real-world emissions of the vehicles concerned. Inevitably in some cases, the real-world vehicle use or driving scenarios will deviate from the TA test, which means that also the $CO_2$ benefits are different, as seen from the "gap" between the TA test and real-world emissions. However, it is also possible that technologies and strategies could be designed to deliberately improve the $CO_2$ emissions of a vehicle during the TA test only, with little or no benefit in real-world driving. These strategies would be considered an artificial improvement. As foreseen in Article 13 of Regulation (EU) 2019/631, one of the aims of the ISV tests is to identify whether such strategies have been deployed in in-service vehicles.

### 7.1.2 Defining the scope

The subject of this task is to elaborate a "**methodology for detecting <u>strategies to artificially improve</u> the vehicles' $CO_2$ performance in the type approval test**". The understanding of the terminology used is as follows:

- <u>Improving</u> the $CO_2$ performance in the TA test means reducing fuel consumption, which may be through reducing engine power needed, or through improving engine efficiency
- An <u>artificial</u> improvement is not normally seen or sustained in real world driving situations, but is always active in a TA test
    - An improvement which is not available in all driving situations but would be available for a reasonable range of normal operation would <u>not</u> be considered artificial, provided good technical justification of where it is not effective can be made. For example, an improvement that is only effective during a steady cruise is not artificial, but if it is only effective within a narrow speed range it would be.
- A <u>strategy</u> is a broad term that implies a deliberate action or behaviour by a vehicle or engine control system
    - This means providing improved $CO_2$ performance in the TA test that is not directly due to external factors such as the ambient conditions, driving style, or test cycle, although these could be considered by a strategy to detect TA test conditions

- This could mean that the $CO_2$ improving behaviour is only activated during a particular set of conditions that are met in the TA test, but rarely in real-world driving, or the operation of the $CO_2$ improving behaviour is restricted or less effective in most driving conditions except during the TA test conditions

Such a strategy may be considered similar as a "defeat device", a term which is applied to strategies intended to improve pollutant emissions over the TA test, in that it provides a means to deceive the effective measurement for regulatory purposes. However, the term "device" implies a physical hardware element which is generally not the case for $CO_2$ emissions.

There are strategies that are effective only within a limited range of engine speeds and loads, which may be proportionally less used in different driving situations; or that are ineffective or cannot be used outside a particular ambient temperature range, etc. For example, cylinder deactivation can only be used at light load conditions, and stop-start may need to be disabled at low ambient temperatures. While their $CO_2$ benefit might therefore be limited, that does not itself mean such strategies are deliberately intended to artificially improve the TA test result. Indeed, strategies may be declared by the manufacturer as only operating in certain conditions and are intended to save $CO_2$ emissions in real-world driving within those operating constraints. Such strategies should therefore only be a concern if they are deemed "artificial" (not normally seen or sustained in real world driving situations but always seen in a TA test), and so the test methodologies considered later are evaluated for their ability to verify real-world $CO_2$ emissions against the TA test, and so establish how artificial the TA test $CO_2$ result (and the strategies used to achieve it) appears.

Strategies for artificially improving a vehicles $CO_2$ performance in a TA test can only be implemented by the manufacturer of the vehicle (or parties acting for them), since they are responsible for putting the vehicle through type approval. Real-world $CO_2$ performance of a vehicle can also be changed from type approval by tampering – or modification of the vehicle from its intended design – which might be carried out by vehicle owners, operators, or drivers, perhaps to improve performance or even intended to improve fuel consumption. Whatever the motivation such tampering outside of manufacturer approval is not the responsibility of the vehicle manufacturer, excludes the vehicle from in-service verification testing, and is not within the scope of this task.

### 7.1.3 Requirements and Objectives

This task considers the potential for strategies to improve $CO_2$ artificially over a type approval (TA) test, and aims to elaborate test methodologies to identify such strategies as part of ISV testing.

The scope of this sub-task covers the operation of the engine and vehicle systems of the test vehicle during the type approval emissions test. The specific consideration of road-load determination is already covered in sub-task 3.1, and the chassis-dyno test procedure is examined in sub-task 3.2. Nonetheless, the vehicle behaviour should be understood against the background of the test process. In this task only light-duty vehicles and the relevant type-approval process are considered.

### 7.1.4 Approach to this task

This task has been approached as having three inter-related aspects:

- Consider the potential opportunities for strategies that artificially improve a vehicles' $CO_2$ performance during a type approval test (Section 7.2)
- Outline a range of test methods that will verify whether one or more of the identified strategies is present (including the method of verifying against TA $CO_2$) (Sections 7.5 and 7.12)

Rate each of the considered test methods to identify those that are most robust and efficient within the verification process to identify artificial strategies, and the cost, time, and resources burden to the type approval process (Section 7.16)

### 7.1.5 Similarities to detecting defeat devices affecting pollutant emissions

Legislation for the control of pollutant emissions recognises the concept of a "defeat device" which may artificially reduce the effectiveness of pollutant control under normal conditions but not during a TA test[39]. Commission notice of 26/07/17 Part B[40] provides guidance on evaluating for such defeat devices, which includes screening to inform the selection of vehicles to test, the requirements of a testing protocol, and criteria against which to evaluate the test results. Annex III to the notice proposes an example testing protocol.

Both the screening and the testing protocol to detect defeat devices are left open, with only guidance provided rather than a fixed procedure, since a predictable procedure may not detect all types of defeat device (and itself could potentially be "defeated") and the process may have to be adapted to detect specific technology behaviours. The guidance sets out four categories of test to use:

- Category 1 covers laboratory tests with only minor changes from the regulatory TA type 1 test procedure, that should be expected to give the same result
- Category 2 covers laboratory or road tests with some variations to the TA type 1 test (such as changes of ambient or repeating sections of the test), and should be expected to give a similar result
- Category 3 tests are on the road, with a different cycle and conditions to the TA type 1 test, and is expected to give a different result
- Category 4 tests allow for "surprise" testing to detect specific types of defeat device

These categories are used to select suitable thresholds for the evaluation of the increase in emissions (NOx, THC, CO, PN/PM) in those tests, in effect a not-to-exceed limit which varies according to how different the test is compared to the TA test.

The approach to detecting strategies to artificially improve $CO_2$ over a TA test can be expected to be similar in some characteristics. The need to explore conditions outside of the TA test (including on-road), not to fix a rigid test method, and include the freedom to investigate specific types of strategy, are just as applicable to detecting strategies affecting $CO_2$ as for pollutants, as are the benefits of screening vehicles to aid selection, although the nature of the tests may be different. The test methodologies discussed in section 7.5 could be allocated to the listed categories. However, since $CO_2$ is expected to change according to the energy required of the cycle and the engine operating conditions evaluating the results of the test cannot be a simple threshold. Rather, it will need an approach that considers how the $CO_2$ can be related to the TA test, and whether the difference observed can be reasonably explained.

## 7.2 Potential strategies to artificially improve $CO_2$ over a type-approval test

The motive of such strategies is to obtain a better $CO_2$ result in the TA test, with the consequential benefits to fleet $CO_2$ calculations, its commercial advantage to the manufacturer, and vehicle marketing. Therefore, it follows that the strategies will improve $CO_2$ emissions, but their operation will be limited

[39] Articles 3(10) and 5 (2) of Regulation 715/2007 https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32007R0715
[40] https://www.europarl.europa.eu/meetdocs/2014_2019/plmrep/COMMITTEES/EMIS/DV/2017/02-09/C_2017_352_EN.pdf

to the TA test – or a set of conditions very similar to the TA test – and not in real-world operation. This may be because of negative trade-offs of the $CO_2$ improvement for the TA test that are not desired in normal road use.

Before considering the methodologies that could be used to detect such strategies it is necessary to consider first what those strategies might be. This will allow the methodologies to be evaluated for potential effectiveness against the type of strategies that can be used. It has been found helpful to split the consideration of strategies into two aspects:

- **Opportunity: How is the type approval cycle detected?**

  Since an artificial strategy is considered to be one active over the TA test, but not (equally) active in other driving scenarios, it is likely to identify that a TA test is taking place.

- **Means: How is the $CO_2$ emission reduced in the type approval test?**

  The $CO_2$ performance of the vehicle can only be improved during the TA test by some deliberate strategy or change in behaviour that is different to normal operation

These two aspects of potential strategies have been evaluated through a literature review; drawing on expert knowledge of engine development, calibration, and control system specialists; and through structured analysis of the potential of various vehicle systems. For example, for detection strategies both the sensors typically (and potentially) found on a vehicle and the characteristics of the TA test have been considered, while the various vehicle systems that impact fuel consumption were evaluated. Open brainstorming of concepts has thus been refined further into potentially plausible ideas. However, this evaluation cannot and does not claim to identify every potential strategy for all vehicles, the aim is to provide a means by which potential test methodologies can be evaluated.

## 7.3 Strategies for detection of the type approval test

As noted above, strategies to improve the $CO_2$ performance of a vehicle over the TA test are likely to need the running of such a test to be identified in order to be deployed. Detection may be through some intelligent complex analysis, or simply through a very narrow window of criteria for the strategy to operate that are only likely to be met in the TA test. For the purposes of CO2 regulation under WLTP, the TA test consists of coast-down measurements to establish the road-loads to use for the dyno tests, and vehicle dyno testing measuring emissions over WLTC at 23°C and 14°C.

Table 15 lists and rates the potential strategies identified, firstly by identifying the **details of potential strategy**:

- Sensor(s) or parameter: What input devices or situations are used by the strategy
- Status: What conditions detected by the sensor(s) or parameter states could be used to identify TA test conditions
- Limitation: In what situations this may or will not work, or why it may not be effective, including where the scope is so wide it may not be considered an artificial improvement

The potential strategies are then tagged with a **type** grouping, which are used in later evaluation to link the effectiveness of test methodologies to the coverage of strategies. The type groupings used are:

- Dyno related: Strategies that detect the vehicle is on a dyno
- Cycle features: Strategies to recognise characteristic features of the TA test cycle(s)
- Procedural: Strategies that identify TA or typical dyno test procedures are being applied

- Ambient: Strategies monitoring the ambient temperature or pressure (specific elements of the procedural approach)
- Coast-down: Strategies that detect or benefit coast-down testing, providing an improvement in road-loads over normal operation which will have an impact on dyno tests relying on those coast-down measurements[41]

The "**Active in**" columns assess the situations in which the strategy will activate or have an impact are assessed – that is, the test types the strategy may be able to detect (as Y=Yes, N=No, M=Maybe depending on circumstances/test procedures) according to these categories:

- TA Cycle: The type approval test cycle, i.e. a WLTC on a vehicle dyno at 23°C or 14°C
- Any dyno tests: Any test carried out on a vehicle dyno
- On-road tests: Tests carried out on-road (e.g. with PEMS)

Each potential strategy is then given a **rating** numerically from 1-5 for reliability, effectiveness, and security, based on the criteria set out in Table 14. A high score for **Reliability** indicates a strategy that is very likely to successfully detect a TA test taking place. A high score for **Effectiveness** means it is very unlikely to flag a "false positive" (that is, indicate a TA test in normal driving). A high score for **Security** suggests the strategy is very unlikely to be detected by TA authorities or others, at least under normal testing routines. The rating scores are totalled, which is used to evaluate the potential for each strategy as low, medium, or high.

**Table 14:** Rating criteria for potential strategies to detect a type approval test

| Category | Scope | Scoring examples | | |
|---|---|---|---|---|
| | | 1 | 3 | 5 |
| Reliability | Will it always work in TA test? (No false negatives) | Will not work in all circumstances | Effectiveness may be doubtful | Always detects TA test |
| Effectiveness | Limits activation to TA test, no undesired impact? | Likely impact noticeable to user | Occasionally noticeable to user | No user impact in any undesired situation |
| Security | Is it likely to be discovered? | High risk of detection | Detectable with moderate investigation | Low risk of detection |

Although the rating is largely subjective and the list of potential strategies cannot claim to be exhaustive, it is useful to consider the strategies in the light of their potential, so Table 16 lists the same strategies in descending order of the rating score. Interestingly, those with the highest potential – that is, most likely to be reliable and effective with low risk of detection – are all categorised as detecting characteristics of using a dyno. Coast-down strategies, cycle memory (preconditioning), and procedural activities detectable by the vehicle are of moderate potential.

[41] Vehicle influenceable factors might include active aerodynamic or grille devices, transmission mode, etc.

**Table 15:** Potential strategies to detect a type approval test

| Details of potential strategy | | | Type | Active in | | | Rating | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sensor(s) or parameter | Status or situation detected | Limitation on use to artificially improve $CO_2$ in the TA test | Grouping of strategy type (link to test methods) | TA cycle | Any dyno test | On-road tests | Reliability | Effectivenes s | Security | Score (total) | Potential by score |
| Dyno mode[42] | If vehicle is configured to "Dyno mode" | Not all vehicles require a dyno mode setting for TA test, and relies on dyno mode being selected appropriately | Dyno related | Y | Y | N | 4 | 5 | 3 | 12 | High |
| Wheel sensors | Undriven wheels don't rotate (could also use tyre pressure monitoring sensors as these won't "wake" if no movement) | 4WD dynos increasingly common | Dyno related | Y[1] | Y[1] | N | 2 | 5 | 2 | 9 | Low |
| Drive mode selected (eco, sport, etc.) | Default mode is used in TA test. This condition possibly combined with other conditions to detect TA test | Most on-road driving expected to be in the default mode as used for TA tests. $CO_2$ not measured in other modes anyway | Procedural | Y | M | M | 4 | 1 | 3 | 8 | Low |
| Ambient temperature | Not in limited range for dyno tests. Probably low potential on its own, but may be combined with other conditions | Tests at 23°C and 14°C (+/-3°C at test start, so 11-17 and 20-26°C), covers wide range. $CO_2$ increases with colder temperatures anyway | Ambient | Y | M | M | 5 | 1 | 2 | 8 | Low |
| Accelerometer | Acceleration inconsistent with wheel speeds, i.e., on dyno. No cornering forces, gradients, or inclination | Not all vehicles have an accelerometer | Dyno related | Y | Y | N | 5 | 5 | 5 | 15 | High |
| Steering wheel | No movement (no steering on dyno). Maybe even lack of hands on the wheel | | Dyno related | Y | Y | N | 5 | 5 | 3 | 13 | High |

[42] Some vehicles have a "dyno mode" setting that should be activated to enable a dyno test to be carried out, for example disabling city braking, traction control, ABS.

| Details of potential strategy | | | Type | Active in | | | Rating | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sensor(s) or parameter** | **Status or situation detected** | **Limitation on use to artificially improve $CO_2$ in the TA test** | **Grouping of strategy type (link to test methods)** | **TA cycle** | **Any dyno test** | **On-road tests** | **Reliability** | **Effectivenes s** | **Security** | **Score (total)** | **Potential by score** |
| Auto transmission calibration | Strategies dependent on driving style, or boundaries, set such that WLTC driving style within optimum transmission strategy for $CO_2$ | WLTC represents "normal" driving so limited scope to artificially improve $CO_2$ over TA test | Cycle features | Y | M | M | 3 | 2 | 4 | 9 | Low |
| Engine calibration | Strategies dependent on driving style, or boundaries, set such that WLTC driving within optimum engine calibration zone for $CO_2$ | WLTC represents "normal" driving so limited scope to artificially improve $CO_2$ over TA test | Cycle features | Y | M | M | 3 | 2 | 4 | 9 | Low |
| Cycle Timer | Drive time > 30 mins (or maximum likely cycle duration) | Many on-road drives also <30 mins | Cycle features | Y | M | M | 4 | 1 | 1 | 6 | Low |
| After-start Time Based strategies | Calibration parameters that switch with time since trip start such that operation can be geared to be advantageous to fixed cycles. i.e., timed to coincide with idles on WLTC as an example | May not be optimum operation in other driving conditions. | Cycle features | Y | N | N | 5 | 2 | 3 | 10 | Moderate |
| Cycle recognition | Speed, load, pedal, temperatures, and other parameters all consistent with early part of WLTC (e.g., vs time), time to first stop, etc. | Multiple parameters likely to need to be evaluated for reliable cycle recognition | Cycle features | Y | M | N | 4 | 2 | 2 | 8 | Low |
| Cycle memory | Use a memory of the previous drive. Measured cycles are preceded by a pre-conditioning cycle, these also have fixed characteristics and could be recognised as above | Some on-road cycles may look a lot like pre-con cycles, but it wouldn't be hard to detect a WLTP pre-con with basic analysis | Cycle features / Procedural | Y | M | M | 4 | 3 | 3 | 10 | Moderate |
| Parked Timer | Time parked within prescribed limits for TA test procedure soak period | Likely to affect real drives e.g. working day or overnight | Procedural | Y | M | M | 4 | 1 | 2 | 7 | Low |
| GPS (Signal) | Won't get a signal if in a building, or if does, will show no actual movement of the vehicle | Real trips may start in a building (garage, car-park), but not for very long. | Dyno related | Y | Y | N | 5 | 4 | 5 | 14 | High |

| Details of potential strategy | | | Type | Active in | | | Rating | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sensor(s) or parameter | Status or situation detected | Limitation on use to artificially improve $CO_2$ in the TA test | Grouping of strategy type (link to test methods) | TA cycle | Any dyno test | On-road tests | Reliability | Effectiveness | Security | Score (total) | Potential by score |
| GPS (Location) | Location - test locations (vehicle dynos) may be programmed in | Requires knowledge of all test dyno locations! May need signal – see above | Dyno related | Y | Y | N[2] | 3 | 5 | 5 | 13 | High |
| Radar sensors | Front radar for city braking, parking sensors, side radar for lane change - all could be used to detect dyno features (test cell fan and walls fixed distance from vehicle), or that they have been disabled for the test (city braking needs to be switched off for successful dyno test) | Not all vehicles have these sensors, but increasingly common. | Dyno related | Y | Y | N | 5 | 4 | 5 | 14 | High |
| Camera | Cameras for road-sign recognition, parking, or autonomous features offer potential to detect dyno characteristics - e.g., fan, walls, ceiling, indoor lighting – or static surroundings | | Dyno related | Y | Y | N | 4 | 4 | 5 | 13 | High |
| Bonnet catch | Bonnet must be shut during test BUT likely to be opened before test start to check temperatures, fit a current clamp, etc. Time between bonnet open and drive start could be used | | Procedural | Y | M | M | 3 | 4 | 3 | 10 | Moderate |
| Seats occupied | Tests have driver, unlikely to have passengers. Seat in-use detection for seat-belt warnings can be used | Most real-world drives also likely to be driver only | Procedural | Y | M | M | 3 | 2 | 3 | 8 | Low |
| Ancillary use | Use of radio, heating/AC, GPS, indicator lights, opening of windows, changes to vehicle drive or suspension settings, etc. TA tests do not use ancillaries, lights, indicators. | Can be active triggers (e.g., driver's window open before/in test). Not robust, users may not use many of these functions anyway. | Procedural | Y | M | M | 3 | 2 | 3 | 8 | Low |

| Details of potential strategy | | | Type | Active in | | | Rating | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sensor(s) or parameter | Status or situation detected | Limitation on use to artificially improve $CO_2$ in the TA test | Grouping of strategy type (link to test methods) | TA cycle | Any dyno test | On-road tests | Reliability | Effectivenes s | Security | Score (total) | Potential by score |
| Odometer | Vehicle mileage over threshold. Homologation tests at a low mileage, ISC presently covers only emissions | ISV of $CO_2$ addresses this, up to max likely limit of 100k km (as ISC). Little benefit in optimising $CO_2$ only until then | Procedural | Y | Y | Y | 4 | 1 | 2 | 7 | Low |
| Battery SoC | The pre-conditioning and prior charging are likely to lead to the battery being within a state-of-charge (SoC) window (non-hybrid vehicles) | SoC window may be quite large, real world SoC should be similar, so not likely to be reliable or effective | Procedural | Y | M | M | 2 | 2 | 4 | 8 | Low |
| Neutral/ Coasting | When coasting, perhaps related to steering or other sensor, coast-down optimisation for aero or friction (e-machine use) reduction may be deployed. May be combined with other detection strategies for dyno vs road/track | In isolation would affect all driving where coasting is encountered. This could still give unrealistic road loads for other driving conditions. | Coast-down | Y | Y | N | 4 | 3 | 4 | 11 | Moderate |
| Altitude / ambient pressure | Detection of constant altitude values | This would vary very slowly in real driving anyway | Ambient | Y | Y | N | 5 | 2 | 4 | 11 | Moderate |
| Driving resistance forces | Detection of consistent power difference via comparison of engine power and driving resistances calculated with vehicle speed | Assumes dyno road loads are sufficiently different (lower) than real world. Likely to be difficult to implement reliably | Dyno related | Y | M | N | 2 | 2 | 5 | 9 | Low |
| Suspension load detection | Vehicle load different from that used for WLTP, or variable payload distribution on the suspension system (e.g., from cornering or uneven road) | Requires suspension load or position sensors | Dyno related | Y | N | N | 3 | 2 | 4 | 9 | Low |

Notes: [1] If single-axle dyno used, [2] Unless known test track location

Y = Yes, N = No, M= Maybe – depending on strategy and test conditions

**Table 16:** Detection Strategies ordered by rating to detect a type approval test

| Sensor(s) or parameter | Strategy type (link to test methods) | Regulatory (TA) cycle | Other dyno test | On-road tests | Total Rating | Potential by score |
|---|---|---|---|---|---|---|
| Accelerometer | Dyno related | Y | Y | N | 15 | High |
| Steering wheel | Dyno related | Y | Y | N | 14 | High |
| GPS (Signal) | Dyno related | Y | Y | N | 14 | High |
| Radar sensors | Dyno related | Y | Y | N | 14 | High |
| Dyno mode | Dyno related | Y | Y | N | 13 | High |
| Camera | Dyno related | Y | Y | N | 13 | High |
| GPS (Location) | Dyno related | Y | Y | M | 13 | High |
| Neutral/Coasting | Coast-down | Y | Y | N | 11 | Moderate |
| Altitude / ambient pressure | Ambient | Y | Y | N | 11 | Moderate |
| Bonnet catch | Procedural | Y | M | M | 10 | Moderate |
| After-start Time Based strategies | Cycle features | Y | N | N | 10 | Moderate |
| Cycle memory | Cycle features / procedural | Y | M | M | 10 | Moderate |
| Wheel sensors (single axle dyno) | Dyno related | Y | Y | N | 9 | Low |
| Auto transmission calibration | Cycle features | Y | M | M | 9 | Low |
| Engine calibration | Cycle features | Y | M | M | 9 | Low |
| Driving resistance forces | Dyno related | Y | Y | M | 9 | Low |
| Suspension load detection | Dyno related | Y | Y | M | 9 | Low |
| Drive mode | Procedural | Y | M | M | 8 | Low |
| Ambient temperature | Ambient | Y | M | M | 8 | Low |
| Cycle recognition | Cycle features | Y | M | M | 8 | Low |
| Seats occupied | Procedural | Y | M | M | 8 | Low |
| Battery SoC | Procedural | Y | M | M | 8 | Low |
| Ancillary use | Procedural | Y | M | M | 8 | Low |
| Odometer | Procedural | Y | Y | Y | 7 | Low |
| Parked Timer | Procedural | Y | M | M | 7 | Low |
| Cycle Timer | Cycle features | Y | M | M | 6 | Low |

Y = Yes, N = No, M= Maybe – depending on strategy and test conditions

## 7.4 Strategies or behaviours for artificially reducing $CO_2$ emissions during the type approval test

Table 18 lists range of potential strategies or behaviours identified that can reduce $CO_2$ emissions, and may be considered artificial – that is, not effective in most driving conditions or could be activated specifically during a TA test by one or more detection strategies such as those listed above. The objective is to evaluate the potential of each behaviour to effectively and reliably reduce $CO_2$ emissions in the TA test without negative impacts to the vehicle user and without being detected by the testing authority.

Firstly, the $CO_2$ improvement behaviour is detailed by:

- System: What vehicle system behaviour is changed
- $CO_2$ Optimisation Method: What is the changed behaviour and how does it benefit $CO_2$ emissions. The potential magnitude of the $CO_2$ benefit is rated as shown below
- Trade-off, or why the behaviour is not used all the time: What is the expected impact on the end user – that is, whether the driver notices noise, vibration or harshness (NVH[43]), driveability, or reliability impact that is ultimately caused by the behaviour concerned. If there were no negative trade-off the $CO_2$ improvement behaviour would be used in all driving conditions and would not be considered artificial. The expected trade-off of the behaviour is identified, and its significance (in terms of impact to the vehicle user) is also scored in the rating as shown below

Limitation: In what situations this behaviour may or will not work, or why it may not be effective, including where the application is so wide it may not be considered an artificial improvement

As with the detection strategies, the $CO_2$ reducing behaviours are then evaluated numerically from 1-5 based on the criteria in Table 17:

**Table 17:** Rating criteria for behaviours to artificially benefit $CO_2$ over TA test

| Category | Scope | Scoring Examples | | |
|---|---|---|---|---|
| | | 1 | 3 | 5 |
| Artificial? | Is the behaviour suspicious / artificial? | No – known, widely used, considered normal | Questionable purpose or optimisation | Definite defeat strategy, active control |
| Reliability | Will it always work as intended? | Will not work in all circumstances | Effectiveness may be doubtful | Always beneficial to TA test $CO_2$ |
| $CO_2$ Benefit | What is the benefit in cycle $CO_2$? | Marginal: <1% | Worthwhile: >1% | Significant: Several % |
| Trade off | Are driveability, NVH, reliability affected? | Likely impact noticeable to user | Occasionally noticeable to user | No user impact in any situation |
| Security | Is it likely to be discovered? | High risk of detection | Detectable with moderate investigation | Low risk of detection |

The “Artificial” category reflects that there isn’t always a clear distinction between a behaviour that must be deliberate and intended only to be effective in a TA test, and one which is intended to benefit $CO_2$ but has genuine limitations preventing it being effective in many driving situations. The evaluation here is subjective, based on a premise that such a behaviour may be observed during one set of driving conditions (e.g. a TA test) but not in another set of conditions. A clear active intervention would score

[43] Noise, Vibration, and Harshness – an industry term for these qualities which affect customer perception of the vehicle

5, but an unusual optimisation of a calibration might be a 3 or 4, and a behaviour with little negative consequence would score 1 or 2 even if it only occurred in limited situations. Of course, the existence and conditions of emissions strategies that are not able to operate under all driving conditions as declared by the manufacturer should be allowed for, and the conditions and manner in which these operate should achieve their stated aim (in controlling emissions), and not simply improve $CO_2$ emissions during the TA cycle.

The “Reliability” category assesses how robust the behaviour is expected to be in reducing $CO_2$ in the TA test.

The “$CO_2$ Benefit” category evaluates the likely magnitude of $CO_2$ reduction.

As discussed above, the “Trade off” category considers the significance of the negative impacts of the behaviour to the vehicle user.

The “Security” category indicates the risk of the behaviour being detected, such as by type approval authorities (TAA) or third parties, with the reputational and financial damage that would follow high-risk strategies are unlikely to be used. This assumes the behaviour is being used to deliberately improve the $CO_2$ over the TA cycle, even if it has been declared (or partially declared) as an AES for other reasons.

**Table 18:** Strategies or behaviours to artificially benefit $CO_2$ over TA test

| System | $CO_2$ Optimisation method | What is trade-off? | Limitation | Artificial? | Reliability | $CO_2$ Benefit | Trade off | Security | Score | Potential by score |
|---|---|---|---|---|---|---|---|---|---|---|
| Auto Transmission | Adapt shift strategy for severely optimised gear and change for most efficient drive cycles. | Performance, NVH, driveability | At extreme could make cycle difficult to follow. Eco mode should not be selected for test unless standard. | 3 | 4 | 4 | 4 | 4 | 19 | High |
| Smart alternator | Report SoC inaccurately over cycle to minimise need to charge, without impact of correction (RCB correction) | Battery life | Should be detected by current clamp, though voltage may be misreported | 5 | 3 | 3 | 5 | 2 | 18 | High |
| Hybrid system | Change strategy of battery vs engine use to minimise fuel use, possibly at expense of driveability or performance | Performance, driveability | For hybrid vehicles only, particularly OVC-HEV (plug-in hybrids) | 4 | 5 | 5 | 4 | 3 | 21 | High |
| Hybrid system | Report HV battery SoC or voltage inaccurately over cycle to minimise engine use, without impact of correction. That is: Extend useful SoC, use more battery energy than is reported or measured. Correct SoC on another drive off-cycle. May mean over-discharge of battery with impact on lifetime. | Performance, driveability, HV battery life if deployed frequently | For hybrid vehicles only, particularly OVC-HEV (plug-in) Should be detected by current clamp, unless voltage is misreported | 5 | 5 | 5 | 3 | 2 | 20 | High |
| Hybrid system | Using electrical machine (permanently coupled to wheels) to influence dyno settings: Loading electrical machine to charge battery (regenerating) during coast-down matching on dyno suggests higher rolling resistance, reducing dyno road loads for test. | Driver feel (to pedal) and braking requirement depending if electrical machine is regenerating | For hybrid vehicles only, particularly OVC-HEV (plug-in) Would have to apply during coasting on-dyno but NOT when measuring CD on track, and so needs dyno detection. | 5 | 3 | 5 | 4 | 3 | 20 | High |

| System | $CO_2$ Optimisation method | What is trade-off? | Limitation | Artificial? | Reliability | $CO_2$ Benefit | Trade off | Security | Score | Potential by score |
|---|---|---|---|---|---|---|---|---|---|---|
| Hybrid system | Using electrical machine (permanently coupled to wheels) to influence coast-down results: slight motoring of electrical machine during coast-down test increases coast-down duration and artificially reduces resulting road-loads | Driver feel (to pedal) and braking requirement due to increased coasting effect | For hybrid vehicles only, particularly OVC-HEV (plug-in) Applies to coast-down test scenario (not on dyno). Deploying strategy in straight coasting would always work, ensuring it did NOT do so on a dyno so needs dyno detection | 5 | 3 | 5 | 1 | 3 | 17 | Moderate |
| Electrical system | Reduce electrical system voltage a small amount, all resistive loads (lights, fans, heaters) use a bit less power | Comfort, light brightness, possible max cooling capability | Will be a minimum. Some loads will draw more current | 4 | 3 | 2 | 3 | 3 | 15 | Moderate |
| HVAC | Reduce fan speeds, A/C use, etc. Could still appear to work but in reduced energy mode | Comfort | Benefit likely to be low | 4 | 3 | 2 | 3 | 3 | 15 | Moderate |
| Engine calibration | Adjust use of boost, EGR, valve timing, fuelling, etc. through modified calibration maps or parameters to optimise $CO_2$ | Performance, response, driveability, NVH, or durability. Emissions cannot be compromised | Usually $CO_2$ trade-off is emissions, but in TA test emissions must be protected, so benefits may be limited unless there is a performance, durability, or NVH trade-off to be made | 4 | 4 | 3 | 2 | 4 | 17 | Moderate |
| Engine temperature | Increased engine temperature allowed to reduce friction | Increased risk of knock/PI (gasoline). Increased wear. Damage to components | Thermal management dependent on speed/load are permitted and common anyway, little benefit from taking it further? | 3 | 3 | 1 | 3 | 5 | 15 | Moderate |
| Oil pressure | Reduced oil pressure reduces friction load of pump | Increased wear, risk of component failure or damage | VDOP are permitted and common reducing pump load at low speeds, little benefit (and high risk) in more extreme reductions of pressure | 2 | 3 | 1 | 2 | 5 | 13 | Low |

| System | $CO_2$ Optimisation method | What is trade-off? | Limitation | Artificial? | Reliability | $CO_2$ Benefit | Trade off | Security | Score | Potential by score |
|---|---|---|---|---|---|---|---|---|---|---|
| Oil heating | Heat engine or transmission oil to reduce friction, using secondary battery that is not monitored (i.e. hidden), and is recharged when "off-cycle" | Increased fuel use off-cycle to charge battery. Need to be sure when off-cycle to charge it | Difficult to "hide", maintenance etc. means will become public | 5 | 3 | 1 | 5 | 1 | 15 | Moderate |
| Regeneration Ki factor | Provide misleading information to determine Ki factor during homologation, resulting in lower $CO_2$ penalty to declared value | | | 5 | 5 | 2 | 5 | 4 | 21 | High |
| Long-term adaptions | Long term calibration adaptions e.g. for fuelling could change bias of $CO_2$ optimisation over time | Possibly emissions (offset cat degradation?), increase power? | Benefit likely to be marginal | 4 | 1 | 1 | 3 | 5 | 14 | Low |
| Cylinder deactivation | Cylinder deactivation deployed more aggressively during TA test than in normal driving. Typically, cylinder deactivation is deployed only at light loads (up to 4-6 bar BMEP) up to moderate engine speeds and disabled during transient events. May even be used in cold engine. | Power, responsiveness, NHV, durability | In reality the conditions for cylinder deactivation are more likely to be met in dyno test than real world anyway, and limited benefit in operating over more of the map or in more dynamic conditions. Maybe could be deployed from colder engine conditions | 3 | 2 | 1 | 3 | 4 | 13 | Low |
| Grille shutters, spoiler. Active aero devices | Applies to coast-down tests at track: Adjust active aero devices (grille shutters, spoiler) to give minimum drag during coast down measurement for lower loads during test | Reduced cooling (but engine idling), reduced grip (but straight line no braking). | Needs to detect coast-down test scenario (not on dyno). However, deploying strategy in straight line coasting situation would always work, not need "cheat" strategy, but still not representative of vehicle drag in most driving situations | 4 | 4 | 2 | 4 | 5 | 19 | High |

| System | $CO_2$ Optimisation method | What is trade-off? | Limitation | Artificial? | Reliability | $CO_2$ Benefit | Trade off | Security | Score | Potential by score |
|---|---|---|---|---|---|---|---|---|---|---|
| Lambda control | Increased fuelling or operating slightly rich when NOT on test cycle could improve power and responsiveness of engine at the cost of $CO_2$ and emissions. Also applies to extending rich operation or increasing power in the enrichment zone. | Performance, responsiveness, vs fuel and emissions | Likely to increase emissions over RDE unless detection strategy can be sure of identifying RDE too | 4 | 3 | 2 | 2 | 2 | 13 | Low |
| Active exhaust flap | Reduce backpressure e.g. by bypassing silencer(s) and so engine pumping losses improving fuel efficiency. May be slight | Increased noise if silencers bypassed | Limited actual benefit. Hardware may be questioned. Increased noise may be noticed unless disguised by CVS | 4 | 4 | 1 | 2 | 2 | 13 | Low |
| Coolant temp target | Active thermostats allow speed load and driving style targeting of coolant temperature i.e. 105°C in cycle residency area and 85°C at full load. However, when driven relatively normally on road one will transition regularly into the lower coolant temp window. Due to the inherently slow thermal response the actual coolant temp typically averages 95°C in the nominally hot region due to an inability to quickly meet either temp target | Map-based strategies that are consistent are not defeat devices.<br><br>Increased risk of knock/PI (gasoline). Increased wear. Damage to components | Small percentage difference in BSFC between 105°C and 95°C WLTC reflects relatively normal driving (compared to WLTC), so behaviour for most drivers unlikely to be significantly different to WLTC | 2 | 4 | 2 | 5 | 4 | 17 | Moderate |
| Split cooling | Split cooling is used to warm engine faster | Benefit less if cab heating used | Main aim is usually emissions reduction, $CO_2$ benefit is marginal | 1 | 3 | 1 | 5 | 4 | 14 | Low |
| Positive Knock Adaptions | Some knock systems allow positive correct (advance) if on high RON fuels | None | Most of cycle expected to be in MBT region but beneficial for BSFC in high load DBL region if on a 'good' reference fuel | 2 | 3 | 3 | 5 | 5 | 18 | High |

## 7.5 Testing methodologies

A range of testing methodologies has been compiled through literature review, input from experienced specialists, and systematic review. The test methodologies outlined below are considered against the strategies and behaviours above – will they be useful in isolating strategies such as the examples listed Section 7.2– but also for potential to use the results to verify the $CO_2$ against the TA test. Since the aim of the testing methodologies is to establish the presence of artificial strategies that improve $CO_2$ in the TA test, the challenge for the test methodologies is to establish whether any deviation in $CO_2$ compared to the TA test is due to the use of an artificial strategy, or are attributable to external factors such as driving style, vehicle loading, ambient conditions, etc. Since $CO_2$ emissions are related to fuel consumption, and that is dependent on the drive cycle energy and the way the vehicle is driven as well as other factors such as ambient conditions, any test that is not a TA test can be expected to have different $CO_2$ emissions. Therefore, each test method is considered along with a verification method to establish a deviation from type approval that could be artificial. Some of the verification methods are detailed further in Section 7.12.

The test methodologies have been grouped into broad categories:

- **Analysis of EU-wide On-board fuel consumption monitoring (OBFCM) Data** – the availability of EU-wide OBFCM data will provide a means of evaluating the "in-use" fuel consumption and $CO_2$ emissions of vehicles en-masse across Europe. By comparing $CO_2$ differences to the TA test for similar vehicle types, unusual trends may be spotted that could be used to identify suspect vehicle models for further investigation, although specific strategies will not be detectable. For this reason, OBFCM data analysis can be seen as a methodology for screening rather than identifying the use of strategies.
- **Fleet logging surveys** – actively surveying specific vehicles in real-world use through OBFCM download or installed on-board OBD logging devices. This allows more detail of the real-world use to be measured compared to EU-wide OBFCM analysis, albeit over a limited sample size. As with OBFCM data analysis, such surveys can be seen as a methodology for screening rather than identifying the use of strategies. However, increasing the data parameters evaluated and the resolution of that data provides an approach to monitor larger fleets of vehicles for unusual strategy behaviour, where a strategy is already suspected, and so this approach can also be used to assist detection of specific strategies.
- **Changes to the TA test** – changing procedural or cycle characteristics of the dyno test to identify strategies of high potential, or to isolate a suspected specific strategy. These are expected to be effective in identifying the use of detection strategies that use the cycle features, procedural, or ambient conditions of TA tests.
- **Alternative dyno tests** – to operate outside of the usual TA test boundaries. These are expected to be effective in identifying the use of detection strategies that use the cycle features, procedural, or ambient conditions of TA tests.
- **Engine mapping and simulation** – using simulation to model vehicle cycle emissions. While complex to implement, such an approach has the potential to identify a wide range of types of detection strategy.

**Vehicle tests outside the laboratory** – using PEMS to establish if TA tests are consistent with tests outside the laboratory dyno, including in real-world driving. PEMS allows accurate second-by-second measurement of $CO_2$ (and other) emissions outside the dyno without reliance on ECU parameters. These may be effective in identifying the use of dyno related detection strategy types which were rated as having high potential in Section 7.3, as well as those that use the cycle features, procedural, or ambient conditions of TA tests.

As with the guidance on a testing protocol for pollutant defeat devices[44], these test methods intentionally cover a range of test conditions from minor controlled changes to the TA type 1 test and procedure through to significantly different test cycles and conditions.

## 7.6 Analysis of EU-wide OBFCM data

The introduction of OBFCM under regulation 2018/1832 will provide a means of monitoring the fuel consumption of all equipped vehicles in real-world operation, across the whole of the EU and covering the life of the vehicles. The aim of OBFCM is to investigate the real-world fuel consumption of vehicles and any divergence to TA figures at an aggregate level. The reality is that real-world data will be influenced by a range of noise factors around the way each vehicle is used and the environment in which it operates, which will lead to large variations in the fuel consumption. The question here is if and how that large dataset could be used to identify whether artificial strategies are used that improve the TA test $CO_2$ results compared to the real-world data for specific vehicle models.

Real-world fuel consumption as recorded by OBFCM will be affected by a broad range of factors, to summarise the most significant factors that are widely recognised:

- Driving style – dynamic, aggressive, eco, and impacts of traffic
- Trip characteristics – hot or cold start operation, short runs, heavy traffic, high speeds, or steady cruising
- Vehicle loading – passengers and luggage, towing, roof racks, etc.
- The use of ancillaries: heating, air conditioning, etc.
- Ambient temperature and altitude
- Tyres – pressure, rolling resistance
- Maintenance – frequency and quality of servicing
- Road conditions – surface, bends, gradients, standing water or snow

Further factors apply to different vehicle types, for example plug-in hybrids which may show significantly different $CO_2$ emissions depending on the level of charging, while some commercial vehicles regularly used at high loads or for towing will have a very different use profile.

However, large datasets offer the potential for analysis of trends. The OBFCM dataset provides not just the range of real-world driving, but a meaningful average for the European fleet. Drilling down offers the opportunity to compare average datasets by manufacturer, vehicle, and powertrain type[45], and a comparison to the TA test $CO_2$ of the relevant Certificate of Conformity. Advanced “big data” analysis techniques could be used to evaluate the data, for example:

- A small percentage of worst-case outliers with unusually high fuel consumption could be excluded for each vehicle type analysed, to reduce the potential influence of extreme use cases or vehicles with faults
- The country of registration or reporting for each vehicle will allow broad geographical factors to be understood, such as the impact of the average climate
- Vehicle mileage is reported with the fuel consumption, which provides an indication of average trip characteristics. High mileage vehicles tend to spend more time at higher speeds, whereas low mileage vehicles are likely to encounter more urban traffic. Thus, correlations between fuel

[44] Commission Notice of 26/01/17 part B.
[45] It is assumed that for analysis the OBFCM data can be identified to a vehicle make, model/type, and powertrain/fuel, i.e. each vehicle can by matched to a TA test result / Certificate of Conformity, even though the specific vehicle VIN may be subject to data protection restrictions.

consumption and the WLTC test phase data at different speeds may be found relating increased annual mileage to higher average speeds

A more detailed discussion of some potential techniques for analysing the OBFCM data is included in the technical annex, although it is not possible here to establish the methods of how the data can be analysed. Rather, the objective is to understand whether it is useful for identifying whether real-world fuel consumption indicates an unusual discrepancy to the TA test result, and the potential use of an artificial strategy. This type of analysis of fleet-average behaviour will never be able to identify strategies for specific vehicle models, but it could be used to show trends of fuel consumption for different vehicle types, which will highlight vehicle models that do not follow the usual trends.

While the data analysis is not without cost, particularly given the size of the dataset and the number of vehicle model variations, when compared to active testing (whether in a laboratory or on-road) it can be considered low-cost, although significant effort would need to be invested in establishing effective data mining and analysis techniques. On the other hand, the confidence in any findings will be low due to the many factors that affect in-use fuel consumption, and since conclusions about specific vehicle models are based only on trends and comparisons to other models. The effectiveness of OBFCM analysis for this purpose is dependent on a large enough dataset being available for meaningful statistical analysis, and sufficient information in the data to be able to link individual vehicle results to the relevant TA test without compromising personal data security concerns.

Therefore, analysis of OBFCM data has potential for screening purposes, to target further investigations at models that show unusual fuel consumption characteristics, but it will not provide conclusions about specific vehicles or strategies.

## 7.7 Fleet Logging Survey

Real-world driving data focused on particular vehicle models can be gathered through fleet logging surveys, applied to the vehicles of volunteers or company/lease fleets. This enables a larger number of vehicles to be evaluated than is possible for laboratory testing for example, although any data gathering equipment must not be intrusive. The vehicles remain in regular use, and the recorded driving data can be combined with a wider understanding of the vehicle use, condition, and local environment. Two types of survey are described here, the second having more comprehensive measurements.

**Collecting OBFCM or OBD data from a vehicle fleet**

Two scenarios of data collection are considered here:

1. Downloading OBFCM data from the vehicles periodically over the survey period.
2. Equipping vehicles with an on-board OBD logging device which can record selected operational parameters that are available by OBD providing engine operating conditions. The data is downloaded periodically (or transmitted over the air), and the logging equipment removed at the end of the survey

In either case the recording device would be passive to the vehicle user, with data recorded at low resolution retrieved at the end of the survey or even over the air by some means.

A survey approach can be carried out on single vehicles of particular types, but is of greater value carried out across a fleet of vehicles of the same or different types where drivers or fleets can be found to participate. The selection of volunteers or fleets, equipping vehicles, and recovering data means an increased burden compared to the analysis of EU wide OBFCM data, which will in any case be reported back to the EU. The vehicles monitored will cover a much smaller fleet than EU wide OBFCM, probably focussed on a vehicle type, category, or manufacturer; and covering a more limited range of geographical regions and drivers. On the other hand, a far larger number and range of vehicles can be monitored in this kind of survey than is possible through laboratory testing; many vehicles could be surveyed in this way for the cost of one laboratory tests being carried out on a single vehicle.

The key limitation with this approach is the usefulness of the data in linking real-world observed $CO_2$ emissions to the TA test. While the second option allows the collection of a wider range of parameters through OBD than OBFCM alone, real-world driving (even with an understanding of vehicle use) will show limited correlation to the TA test, and the smaller dataset and period covered doesn't permit the large-data analysis techniques that could be applied to EU-wide OBFCM analysis. It may be possible to associate $CO_2$ emissions to the energy output of each drive (grammes per kilowatt hour, rather than per kilometre) which offers a quantifiable means of comparing a vehicle efficiency over different drive cycles, although that depends on sufficient data being available (from OBD parameters) to allow a meaningful calculation of the energy output in each drive.

This approach alone may have an application for screening, perhaps as a second stage following EU-wide OBFCM analysis to consider specific vehicle types in more detail, but is not expected to have significant value in identifying artificial $CO_2$ enhancing strategies.

**Enhanced Vehicle Data Logging Survey**

While logging a limited range of parameters from vehicles may have limited benefit, expanding the range of parameters recorded and comparing their behaviour with that over the TA test provides a more useful evaluation tool. Vehicles may be equipped with an on-board logging device which can record a range of operational parameters, both via the OBD port and if necessary through additional instrumentation, to provide a rich dataset of vehicle behaviour, allowing the recording full trips in real-time and subsequent analysis to understand the deployment of technologies and strategies, for example:

- Periodic regeneration event frequency – the "Ki factor"
- Hybrid operation including charge sustain or deplete mode, battery charge state
- Engine temperature and (12V) battery voltage regulation
- Use of cylinder deactivation, stop-start, or other efficiency strategies or behaviours
- Separating cold start from hot operation, or urban from motorway driving

The actual data that may be available and the strategies and behaviours that could be monitored will depend on the range of ECU parameters and other measurements available to the data logging device. The standard list of OBD parameters may not give information that directly informs the status of some engine behaviours or hybrid system performance for example. However, use of a dealer-level or 3rd party specialist diagnostic tool can open the possibility of reading a wider range of parameters, while minimally intrusive instrumentation[46] could be used for additional measurements. For each vehicle monitored, consideration of its technologies and likely strategies and behaviours should be used to determine appropriate parameters to evaluate.

The data that can be obtained from detailed on-road data logging can therefore be used to evaluate vehicle and engine behaviours for unusual or unexpected strategies and behaviours in real-world driving compared to the TA test. This is described further in Section 7.13. While this is unlikely to provide conclusive findings about a strategy, it is a means to study unusual findings from the OBFCM data analysis, and to inform the direction of further investigative tests.

Furthermore, methods exist that allow logged second-by-second data from real-world drives to be processed for comparison to dyno cycles:

[46] Such as current clamps on cables or connector pin (low) voltage measurements

- Where engine power can be calculated (from the engine speed and torque provided by OBD), the fuel consumption or $CO_2$ emissions can be calculated in grams per kilowatt hour over the trip, or for parts of the trip. This provides a measure of efficiency of the engine which can be compared to other trips (including dyno test cycles), especially where the average power is similar. This potential method for understanding the relationship between on-road and dyno tests is described further in Section 7.14.
- Cycle-based simulation tools such as $CO_2$MPAS can be used to predict WLTC $CO_2$ emissions based on the recording real-world driving, or a prediction of the real-world $CO_2$ emissions made from dyno test data, and the two compared. This approach is described further in Section 7.15, and would be dependent on sufficient data being recorded for the real-world tests.

The depth of analysis would be limited by the practical limits on the resolution of the data that can be stored, and/or what can be calculated in real-time by the recording device.

This type of enhanced survey approach can be carried out on single vehicles of particular types, or across a fleet of vehicles of the same or different types where drivers or fleets can be found to participate. Carrying out this kind of survey requires significant effort in selecting volunteers or fleets, equipping vehicles (and decommissioning) the additional logging equipment, retrieving, and analysing the data, although it can be expected to become more efficient once a programme of surveying is in place. A laboratory test (according to TA procedures) is likely to be required for each vehicle type evaluated, to provide a comparison to real-world behaviour. Even so, a large number and range of vehicles can be monitored in this kind of survey for a relatively low cost.

This methodology could be used to include a larger number of vehicles in a study without a significant increase in the number of dyno tests required. For example, it could be used where an artificial $CO_2$ performance improvement behaviour is suspected, such as following a TA test and some of the tests discussed below, either to evaluate for possible strategies, or to establish the likely range of vehicles affected if a suspected strategy operation can be monitored.

## 7.8 Changes to the type approval test

Several of the identified potential strategies to artificially improve the WLTP emission results rely on the TA procedure being followed precisely. Such strategies may be detected through repeat WLTC tests with certain key aspects changed. This approach has the advantage that since the test being used is still the WLTC, the $CO_2$ emissions for these tests could be expected to be consistent with, or at least very close to, the WLTC of the TA test, which gives such comparative test results strong evidential value for a potential strategy.

As the test cycle remains the same and a dyno is used, these tests could identify detection strategies that use **procedural** or **ambient** features of the test as identified in Section 7.3, but not those based on cycle features, coast-downs, or the use of a dyno.

There are a number of variations that can be applied to the WLTP, each may identify a particular strategy, but each test takes time and budget to carry out. Some are only likely to be of use where an artificial strategy is suspected, in order to isolate and verify the conditions in which it is active.

**Hot Start WLTC**

The simplest change is to carry out the WLTC from a hot start (with the engine warm from a previous test), rather than soaked at 23° or 14°(+/-3°C). Since this can be carried out immediately following the "normal" WLTC (or any other test) it is simple and relatively cost effective where a vehicle is already being tested. Clearly it will detect any strategies based on engine temperature, and possibly those related to other procedural or cycle identifying characteristics, although only a small selection of possible strategies is likely to be covered.

A hot-start test has other benefits too, enabling the isolation of the CO2 impact expected from cold-start warm-up, and providing a reference for other investigative tests.

**Change preconditioning cycle**

One possible strategy is to use a memory of previous drives, which could be detected by carrying out a WLTC test after a different precondition rather than the prescribed WLTC. This might be a high-speed cruise, or a short low-speed urban drive, but with different characteristics and duration to a WLTC. The preconditioning cycle used would not be expected to have any significant effect on the CO2 in the test cycle, although pollutant emissions can be affected through the condition of aftertreatment and exhaust systems. This test is simple enough to do but is only likely to identify a strategy of moderate potential use.

**Changes to procedures**

Carrying out the WLTC with changes to procedural aspects such as the gear selection, battery charging procedure, under-bonnet pre-test activities, use of ancillaries including air conditioning, and ambient temperature, could identify specific strategies that target those procedures. Note that the TA procedure already covers a test at 14°C, and at much lower temperatures the warm-up penalty on CO2 is likely to be more significant. The changed procedures would have to be carefully considered if the results are not simply going to be inconsistent. For example, starting the engine for just a few seconds during the soak period (but at least 2 hours before the test) would ensure no conditioning or cycle memory timing strategies are being used with no significant impact to the start conditions[47]. Therefore, this approach may be used as part of an investigative process to isolate and verify the presence of a strategy once other tests have indicated one is likely (e.g. through comparison of on-road and dyno tests), but not confirmed. Methods such as the comparison of TA tests to on-road behaviour through PEMS or enhanced vehicle data logging can be used to evaluate the vehicle systems thought to be used by the suspected strategy, and a diagnostic test plan designed accordingly.

**Changed altitude WLTC**

A specific variation of changed procedure aimed at strategies that may detect ambient pressure for altitude. Although the WLTP does not specify ambient pressure ranges, a TA test is likely to be carried out at moderate altitude and pressure will remain relatively constant. Since this is also true for most real-world driving, and RDE compliance (for pollutant emissions) applies up to 700m and up to 1300m with additional margin, the potential for strategies around altitude are limited.

A WLTC test at a changed ambient pressure (for altitude) is possible using a test facility at altitude or equipped with altitude simulation – where the pressure of the chamber or just the engine intake and exhaust is varied. This test is therefore limited to certain facilities, which impacts cost, and may require modification of the engine intake and exhaust systems. Significant increases in altitude are likely to affect engine efficiency and CO2 emissions, making comparisons of altitude test results to the TA test difficult. Since the potential for altitude-based strategies are limited, this test is only likely to be useful where they are suspected, such as from the analysis of fleet data or on-road testing.

**Changed drive mode, use of dyno mode, disabled safety features**

Some vehicles have driver-selectable modes, such as "Sport" or "Eco", which may alter engine calibration characteristics or automatic transmission behaviour. It would be possible for $CO_2$ influencing strategies to deliberately change behaviours when a different drive mode is selected. TA tests are carried out in the default drive mode[48], and probably few users regularly change the drive mode from

[47] The vehicle technology would need to be considered – a PFI gasoline engine start may be affected by fuel vapour remaining in the inlet manifold, while the negative effect on battery SoC could be argued to alter strategies
[48] That is, the mode the vehicle defaults to when started

the default in regular driving anyway. If it is suspected that a vehicle type is likely to be regularly used in a non-default drive mode, a test carried out in that mode would show whether a change in $CO_2$ emissions is apparent. However, alternative drive modes are not included in TA, and the $CO_2$ emissions may be considered to change legitimately.

Some vehicles have a dyno mode to enable safe testing on a vehicle dyno, for example by disabling traction control, city braking (radar braking), and errors from undriven wheels not turning (on a two-wheel dyno). Dyno mode may be engaged through a complex procedure meaning it cannot be enabled by a user accidentally. If a vehicle is tested (such as for TA) using a selected dyno mode, or with certain safety features switched off, there is a risk that an artificial strategy could use that to change vehicle behaviour affecting $CO_2$. It may be possible to test without use of dyno mode or switching off safety features, such as through using an all-wheel dyno, although additional safety features on the vehicle may still prevent it and some safety features (such as city braking) may make a dyno test impossible if not disabled.

**Change phase order of WLTC**

If the WLTC were run with the phases in a different order, or even reversed, the engine will have performed a similar cycle and CO2 would be expected to be close to the standard WLTC. The impact of cold start would be different but running as a hot-start test (and compared to the hot start WLTC suggested above) would eliminate that variable, as well as making it more economical to run. This method has a good chance of identifying some cycle recognition strategies.

**Combined random changes to WLTC test**

Randomly applying any of the approaches listed above, possibly in combination. It is assumed that at least two tests are carried out with different combinations of procedure changes, which allows a range of potential strategies to be identified while reducing the number of tests carried out. Of course, if a change in $CO_2$ is observed it may not be clear which change is the trigger without further testing, but also it is more difficult to understand whether any $CO_2$ variation is the result of a strategy or the combination of procedure changes. However, such an approach could be a deterrent to any possible use of strategies while saving tests (and time, resources) over a more detailed test program if it is not required.

**Deceiving detection strategies**

Where a specific detection strategy is suspected it may be possible to deceive or bypass the strategy. Use of a 4-wheel drive dyno has already been mentioned, other actions might include moving the steering wheel (while stationary), using ancillaries[49], putting weighted dummies on seats[50], or simulating a sensor input such as wheel speed or radar. This is by nature a very targeted approach, suitable only for certain possible strategies, and may be difficult to achieve. It is an approach suitable only to prove the presence of a suspected strategy, rather than as a general tool to detect strategies.

## 7.9 Alternative dyno tests

Rather than changes to the WLTC cycle, an alternative cycle can be used. It is suggested these could be run from a hot start and compared to the hot start WLTC (above), which eliminates warm-up strategies as a variable to CO2 emissions. Another approach is to use a test with the same initial cold-start phase, or with a similar profile and energy demand for similar heating behaviour which might identify cycle recognition strategies. A pathway to associate the $CO_2$ emissions from the test to those

[49] Some ancillaries might impact engine load and so $CO_2$, although the expected change due to the ancillary could be estimated and compared to the actual change to detect if a strategy is changing other behaviours
[50] Since the vehicle's inertia is simulated by the dyno from the measured coast down, the additional mass in the vehicle during the dyno test will have virtually no impact on the engine load or measured $CO_2$

of the WLTC is required for each approach. As with the variations on the type approval test above, repeat tests may be required to show clear results accounting for cycle-to-cycle reproducibility.

**Alternate test cycle with similar characteristics**

If an alternate cycle has similar characteristics to the WLTC (e.g. RTS50) the $CO_2$ emissions would be expected to be similar, allowing easier detection of unexpected $CO_2$ results. This approach is similar to changing the phase order or reversing the WLTC as described in Section 7.8. However, since the test is not the same as the WLTC the $CO_2$ emissions may be expected to be different, and so the deviation to the TA test could be due to the test procedure rather than a strategy. Comparing $CO_2$ emissions by work done (i.e. grammes per kilowatt hour of cycle energy) may be a useful normalisation tool. Nonetheless, since the test has similar characteristics the range of potential strategies that could be detected is likely to be low in any case.

**Alternate, more severe test cycle**

A cycle with more aggressive accelerations and higher engine loads and speeds, and perhaps higher inertia too, would use a wider zone of engine and transmission operation and covers more potential strategies (e.g. RTS95, ADAC BAB130), but since the $CO_2$ would be expected to be very different to the WLTC anyway the identification of a strategy would be difficult.

One approach would be to relate the $CO_2$ emissions to cycle (or engine) energy to compare to the WLTC test result (i.e. on a grammes per kilowatt hour basis). Another approach to comparing the $CO_2$ result from an alternative test to the WLTC test $CO_2$ is through using a cycle-based simulation tool, such as $CO_2$MPAS. These approaches are detailed in Section 7.12. A study to identify a suitable cycle to use, robust method to associate the $CO_2$ to the WLTC, and establish credibility for the approach, would be recommended before deploying this test method.

## 7.10 Engine mapping and simulation

It is common practice within engine development to use vehicle simulation to estimate drive cycle emissions (including $CO_2$) from engine map data. Examples include Ricardo "VSIM" and AVL "Cruise", although other similar tools are used across the industry. The engine map data used is typically derived from steady-state mapping of an engine. It is possible, although relatively novel, to obtain engine mapping data from a vehicle on a dyno by measuring $CO_2$ against engine conditions (speed and load).

A relatively limited map could be obtained at moderate speed and load breakpoints, through steady-state or slow ramped operation and focused on the area of WLTC operation, to be used in a simulation model with appropriate vehicle and transmission characteristics. This reconstructs the vehicle $CO_2$ emissions behaviour in a simulation environment, and so applying the simulation to a WLTC would be expected to give a $CO_2$ prediction close to that measured in the WLTC test. Simulation models can allow for warm-up but for increased confidence the comparison can be made to a hot-start WLTC. The simulation approach could be validated against other non-WLTC test cycles, including on-road RDE, giving extra value in identifying possible strategies.

While a range of strategies could be detected this way including those that detect some procedural and cycle features, those that detect dyno operation or test characteristics that are similar in the mapping test are unlikely to be identified since the data is obtained on a dyno anyway. The dyno-based mapping is relatively novel and would take significant time on the dyno, with the associated cost burden, while interpreting the data (with its variation and uncertainties) and carrying out the simulation requires appropriate resources. The result could give strong indication of artificial $CO_2$ strategies if the simulation result is different to the TA test, or if an unusual strategy behaviour is identified in the testing, but the complexity and uncertainty of the approach means it is unlikely to be considered strong evidence of an artificial strategy without further investigation.

## 7.11 Vehicle tests outside the laboratory

When looking to identify strategies that are different in real-world driving to TA testing it is clear that real-world testing can play a part. Indeed, most of the highest rated potential strategies identified utilise the dyno environment or procedures, so on-road testing addresses a wide range of potentially significant strategies. The methods described in Sections 7.6 and 7.7 consider real world operation, but those in Sections 7.8, 7.9, and 7.10 rely on laboratory tests. The methods in this section apply testing outside the laboratory conditions of a vehicle dyno to exclude dyno and procedural strategies, while aiming to provide a clear path to connect $CO_2$ emissions back to the TA test. As with the laboratory tests several repeat tests would be required to show consistent results given the test-to-test variation, which may be higher for these less tightly controlled test conditions. Generally, these tests would be carried out in conjunction with dyno tests – at least a WLTC to TA conditions – to provide a reference for comparison.

**On-road PEMS or fuel-consumption tests**

On-road RDE testing of $CO_2$ with PEMS is already part of the ISC testing procedures for pollutant emissions, and being able to analyse the same test (or carrying out further tests with the PEMS installed) would be cost-effective. Compared to the analysis of fleet surveys these tests give much more detail but for a small number of individual vehicles over a shorter distance, as with laboratory tests.

The challenge in using on-road testing to validate $CO_2$ is that every drive has different characteristics, and there are many uncontrolled factors that can affect fuel consumption and $CO_2$ emissions including temperature/weather, road surface, and traffic. Some of the factors affecting fleet surveys can be controlled or understood for individual tests, such as vehicle condition, loading, and fuel, and the effects of ambient temperature may be understood within a moderate range, while excluding the cold start phase and comparing to the hot-start WLTC removes another uncertainty.

This leaves the driving characteristics (route, traffic, and driving style) as the main sources of $CO_2$ variation to the TA test. Verification could take similar approaches to those proposed for alternative dyno tests – either through association of $CO_2$ to work (grammes per kilowatt hour), or through use of a cycle-based simulation tool such as $CO_2$MPAS. These methods are discussed in section 7.12. There is also the ability to monitor $CO_2$ emissions or strategy behaviours where conditions are similar to those seen in the WLTC test and identify any unexpected differences. These might include the use of stop-start, cylinder deactivation, or pollutant emissions control strategies, that behave differently during the PEMS test to the WLTC test on a dyno.

Once the PEMS is installed to a vehicle carrying out additional tests is relatively low cost, providing the potential for multiple tests to be carried out, ideally over a range of routes and with different driving styles. Multiple tests in this way reduce uncertainty around the validity of $CO_2$ association, and allow influences on the $CO_2$ emissions to be understood – including trip characteristics, and given sufficient tests, regeneration frequency. Note that each test does not need to fulfil RDE boundary conditions; shorter tests and a range of route types representative of a range of real-world driving are valid and useful, indeed if at least one test has similar characteristics to a WLTC test it would help comparison effectiveness.

**On-track test**

The use of a test track enables on-board emissions measurement testing of a vehicle without the variability and constraints of public road tests, such as traffic, road layouts and junctions, and speed limits. While a test track permits many types of test including high-speed, rural, or city driving, these pose the same challenges to validating $CO_2$ emissions of other non-TA tests through having very different characteristics. Conceptually more relevant is the potential for replicating the WLTC speed profile on the track.

This has significant advantages when the potential strategies for detecting a TA test are considered. There is no need for engaging dyno mode and all wheels are in use, steering is used albeit sparingly, all sensors function normally including GPS, cameras, and radar. The dyno environment is a key characteristic which has been identified as a potential target of detection strategies and being able to replicate the test outside the dyno environment would eliminate them as potential sources of $CO_2$ deviation. Furthermore, there is no reliance on the measurement of road loads or the correct adjustment of dyno settings.

The reality is that this is not without significant practical challenges. Even on a test track the driver will have to follow a road layout, there may be other vehicles present, and attention cannot be solely on following a speed trace. It is unlikely that the speed trace and gear shifts can follow the prescribed demand as closely as is required in the TA test. There will also be safety considerations, though measures such as use of a head-up display, a second person aboard the vehicle, warning signs and beacons, or even a closed track may be applied. However, in principle given a sufficiently level track of large oval or "bowl" design it would be possible to drive the WLTC trace in a vehicle outside of the dyno environment.

There are further obstacles to using this type of test effectively, such as the impact of weather – temperature and wind particularly, assuming precipitation and surface water, snow or ice can be avoided. At low wind speeds and using a circular or oval track the effects are likely to be small over the whole test. The influence of temperature can be inferred from the ATCT over a moderate range with a reasonable expectation of temperature impact on fuel consumption applicable except at extreme temperatures, indeed a variation in temperature relative to the TA conditions may be seen as an advantage as it addresses another potential strategy.

In addition, cornering forces may add to the overall load, as might the additional downforce of a banked curve, though it may be possible to calculate the effect of these over the test. The measurement process using PEMS is significantly different to a dyno test, although the use of PEMS for measurement of pollutants is well established with correlation to dyno facilities as part of their process of use, and accuracy for $CO_2$ measurement would be expected to be high. The installation of PEMS may affect the vehicle aerodynamics or put the total mass beyond the vehicle's WLTP test inertia, more likely on smaller vehicles.

It is likely that a cold-start to the drive cycle is not possible on a track, in which case a warm-up with similar characteristics to the WLTC before starting the test would allow a result comparable to a hot-start laboratory WLTC test. If a cold-start is possible, following it with a hot-start test would allow comparisons to both cold and hot start laboratory tests, and cover more potential strategies, for very little extra cost and effort.

Although there are real challenges to overcome and several variabilities will be present, the potential for an on-track WLTC for validating $CO_2$ and the presence of strategies that improve $CO_2$ in the TA test means it is an approach that is worthy of further investigation.

**Outside Dyno**

Another way to avoid many of the potential strategies associated with an indoor dyno is to use an open-air dyno to drive the WLTC cycle. While such facilities do exist, they are not intended for emissions testing, so measurements for CO2 could use PEMS equipment as for on-road and track methods. Although relatively novel, this test is unlikely to pose significant technical challenges and is expected to be relatively low-cost provided an existing facility can be used.

The range of strategies likely to be covered would be less than the on-track or on-road tests, for example steering and force sensors would still be relevant, a cooling fan would still be present, and it is still dependent on measured and configured road-loads. Using a 2-wheel drive dyno leaves another potential strategy. The variables of uncontrolled ambient temperature, and the different approach and equipment used will reduce confidence in the $CO_2$ result comparison to the TA test. Nonetheless, this test method would be effective in identifying certain strategies and could be applied if they were suspected.

**On-road test replicated on Dyno**

Whereas driving a WLTC speed profile on a track is challenging, replicating a real-world drive on a dyno in a laboratory is relatively easy to do and is an established process for research and development activities. It has the same potential for identifying a wide range of dyno-based and procedural strategies through comparison of the dyno test to the original on-road drive.

The method for replicating the road cycle load on the dyno should take account of gradients, and ideally cornering forces; wind and other weather effects cannot be accounted for but would not be expected to have a large effect. To match road-loads accurately coast-down tests should be carried out on the vehicle in road-test condition (i.e. with PEMS installed or accounted for), though conducting the test using the WLTC inertia and road loads would also be worthwhile, understanding the difference that may make. Alternatively, replicating the road drive by reproducing the vehicle pedal and gear inputs exactly as well as its speed eliminates the need to measure gradient, cornering, wind, or match coast-downs in order to match the wheel torque, this removes sensitivity to road load and increases potential accuracy. However, this is a more novel approach, and is dependent on being able to measure the pedal position at a high enough rate and replicate it fast enough – such as through a “robot” actuator. Note that pedal position and vehicle speed can be measured through OBD or separately of any vehicle system using instrumentation.

A climatic laboratory could replicate the ambient temperature of the road test, or the test could be run at 23°C or 14°C, depending on the investigation requirements. Replicating altitude is also possible but requires more complex equipment and will not be significant if road test and laboratory are at similar altitude. A range of tests could be replicated, and each test need not meet the boundary conditions of an RDE test, although a test that provides similar characteristics to the WLTC test may help the effectiveness of a comparison to WLTC.

Of course, this test method requires that an on-road PEMS test is carried out first, and the rating of this method assumes that. It does not provide a $CO_2$ result that is directly comparable to the TA test (although work-based or cycle simulation methods could be used), rather it compares dyno and road operation, and any operation that is different in a laboratory to on a road would be highlighted. However, it is relatively easy to carry out, covers a wide range of potential strategies, and if done well has strong investigative and evidential potential. Although replicating road drives in a laboratory is already common for development purposes, methodologies vary, and the value of the approach would be strengthened by a study into the most suitable approach and the expected accuracy of replication.

## 7.12 Evaluation of the $CO_2$ emissions abnormalities

Some of the proposed testing methodologies described above make only small changes to the TA test procedure, or use a very similar test procedure, and would be expected to result in very similar $CO_2$ emissions to the TA procedure – so that any significant variation in $CO_2$ to the TA test would require investigation. For example, the methodologies described in Section 7.8 all use the same test cycle (WLTC) as the TA procedure. However, to investigate the possibility of the range of $CO_2$ improvement behaviours identified in section 7.2 it is necessary to operate the engine outside of the controlled boundaries of the TA test and/or over a very different drive cycle to the WLTC. As soon as the test cycle and/or boundary conditions are changed the $CO_2$ results are no longer directly comparable to the TA cycle. And yet, in order to establish if an artificial $CO_2$-enhancing strategy may be present, it is necessary to establish if the relationship of the $CO_2$ emissions in the test to those of the TA test is abnormal – that is, cannot be explained by the changed test cycle or test conditions.

This challenge is discussed for each of the test methods outlined in section 7.5 above, and the methods of relating the $CO_2$ from those tests to the TA declaration to evaluate if there is any abnormality is outlined in more detail here. These evaluation methods can be applied to multiple test methods, so they are discussed separately. The following section (7.16) rates each of the test methods combined with a $CO_2$ abnormality evaluation.

The $CO_2$ abnormality evaluation method chosen for any test method should be proven to be effective on a variety of vehicles to ensure credibility.

## 7.13 Analysis of expected and abnormal differences

Some of the influences on $CO_2$ emissions variation are understood, and expected deviations quantified based on studies across a range of engines. These might include for example the change in $CO_2$ with ambient temperature, the penalty from a cold-start, and the relationship of $CO_2$ to average vehicle speed.

In Section 7.6 covering the use of OBFCM data some of these influences and methods to adjust for them were discussed in the context of large data sets, similar adjustments are possible for smaller data sets and individual tests. When considering large datasets such as OBFCM and fleet analysis, the analysis of and correction for these deviations is based on assumptions and typical behaviour, and the differences due to driving style and route remain. So, while the approach is useful for identifying abnormal patterns in larger data sets, it is unlikely to provide clear evidence of artificial strategies when applied to a particular test or vehicle.

When considering more controlled or well understood differences between driving conditions the analysis of abnormal vehicle behaviour has more value. For example, when comparing similar tests as described in Section 7.9 the difference in $CO_2$ may be expected to be small, or quantifiable based on the differences between tests. While on-road tests as part of fleet logging or PEMS testing might be quite different to the TA WLTC, $CO_2$ emissions and strategy behaviour at similar conditions (for example, cruises or comparable accelerations) should be comparable once engine loads and ambient conditions are allowed for. So, in such cases it is possible to evaluate particular tests against the TA WLTC to find unusual or abnormal differences in $CO_2$ behaviour, and if sufficient data about engine behaviour is available, it would may possible to identify the nature of the $CO_2$-improving strategy.

## 7.14 $CO_2$ association to energy output

While the WLTC is used as a reference to compare the $CO_2$ for different vehicles, other tests and real-world drives have different characteristics. A drive cycle with increased dynamics, vehicle loading, and speeds will require more energy and so more fuel will be used per km travelled, and $CO_2$ emissions will be higher. Since $CO_2$ emissions are proportional to fuel consumption, and the fuel is used to provide the energy required to drive the cycle, relating the $CO_2$ emissions to the cycle energy is a means to quantify the $CO_2$ emissions independently of the cycle.

Calculating the drive cycle energy using the vehicle speed, inertia, and road load forces, is straightforward enough for laboratory-based tests. For an on-road test however, the impact of road gradient, cornering forces, weather effects, and the differences in road load are difficult to capture. An alternative would be to use engine power or work over the cycle, calculated from engine speed and torque which can be recorded via the vehicle OBD port. With the engine power calculated, the $CO_2$ emissions per kilowatt hour can be calculated for a cycle or trip, or part thereof, along with average power. This allows real-world driving to be compared to dyno cycles for similar average speeds and power, and has the additional advantage of allowing better comparison of hybrid vehicle operation tests, where the actual engine use can vary even between similar tests. However, it is dependent on the accuracy of the OBD reported measurements, and the update rate of OBD parameters may not be fast enough for the calculation to be sufficiently accurate.

Relating $CO_2$ to the drive cycle energy or engine power in this way effectively indicates the efficiency of the vehicle powertrain in converting fuel into useful work. The efficiency of an internal combustion engine is not a fixed value, it varies with speed and load (generally being less efficient at lower loads) and therefore is dependent on gear selection and driving style, it is also affected by engine and ambient air temperatures (especially at cold start), altitude, and fuel specification. There are also strategies deployed to control emissions or enable robust and safe operation of the engine which will impact the fuel efficiency – these might include for example the use of EGR, catalyst heating, DPF regeneration, component protection, anti-stall. Furthermore, as mentioned the engine use varies significantly in a hybrid vehicle, even potentially in charge-depleting mode, although measurement of the change in stored battery energy could be incorporated. Even so, it offers a quantifiable measure to compare vehicle performance over drive cycles with dissimilar characteristics and would allow unexpected differences in $CO_2$ emissions to be identified.

## 7.15 Cycle-based simulation

Cycle-based simulation is an approach that uses data recorded from vehicle tests over one type of test cycle to build a model of vehicle performance (e.g. $CO_2$ emissions) under different conditions, and then can use that model to simulate the vehicle performance over a different cycle. An example of such a tool is the $CO_2$MPAS tool, which is designed to predict the $CO_2$ emissions of an NEDC test based on the performance of a vehicle over a WLTC.

This approach can be applied to other test types, as explored by Zacharof et al. (2020), and to real-world driving as described by Mogno et al. (2020). Given different styles of drive, it is likely that using the drive with the largest range of engine map coverage as the calibration input to the tool would give better results, rather than extrapolating simulation from a more limited range of operation, although of course the simulation process could be checked in both directions. Thus, data from a more dynamic dyno cycle or even a road drive using PEMS is input to the simulation tool, which is used to predict WLTC test $CO_2$ for comparison to TA test results. As with other approaches mentioned, test data excluding cold-start could be compared to a hot WLTC as well to eliminate cold-start impacts.

It may also be possible to apply the same approach to data recorded purely from OBD such as through on-board logging device fleet surveys (Section 7.16 OBD logging survey), relying on the recorded fuel consumption, as well as to tests with emissions measurements on dyno and using PEMS. This is dependent on sufficient data being available at adequate accuracy but may be an approach worthy of investigation for the analysis of fleet survey data.

Being easy to apply this method can be used in conjunction with other approaches to compare data from different drives to the TA test and understand whether differences in $CO_2$ are within expectations. Since this approach using $CO_2$MPAS is proven for calculating NEDC $CO_2$ from WLTC tests in a certification context it can be taken to have a good evidential case, although this application could be considered significantly different, and any simulation approach taken in isolation will be open to question and is unlikely to provide conclusive. A way to build trust and confidence in this approach would be to apply it to a range of tested vehicles and establish the expected variance for this purpose, and so demonstrating that any vehicle with a $CO_2$MPAS predicted $CO_2$ from real-world driving significantly different (outside expected variance) from the TA test is likely to be at fault in some way.

## 7.16 Rating of test methodologies

The test methods in Section 7.5 are evaluated and compared against various criteria, such as their practicality and feasibility to undertake, how efficient and robust they are in detecting artificial $CO_2$ improving strategies, and what are the cost, time and resources impact in carrying out each test. The potential sample size has also been evaluated, some methods can be used to evaluate large samples of vehicles efficiently, but some tests are only practical on a small number of vehicles. However, conclusions drawn from large sample approaches are only valuable for screening, and the methods used are quite different from those used for investigating individual vehicles. Therefore, for the purposes of rating the test methods they have been split into those used for screening of large numbers of vehicles for potentially suspicious $CO_2$ behaviour, and those used to detect the presence of artificial strategies in individual vehicles. The categories applied and the scoring used are detailed in Table 19, with the same categories and scoring used for both screening and strategy detection test methods, scoring is from 1 (poor) to 5 (best).

**Table 19:** Rating criteria for evaluation of test methodologies

| Category | Scope | Scoring examples | | |
|---|---|---|---|---|
| | | 1 | 3 | 5 |
| **Practicality, Feasibility** | Practicality of method, how well proven or established | Difficult, complex | New or moderately difficult | Established or straightforward |
| **Efficiency** | Range/scope of potential strategies detectable | Few/specific strategies only | Range of possible or significant strategies | Potentially all identified strategy types, consistent |
| **Robustness** | How reliably is the method likely to be at detecting those strategies | Good chance strategies will not be effectively detected | Likely to detect strategies within scope of method | Strategies in scope unlikely not to be identified |
| **Effective** | How strong/effective is the evidence of artificial $CO_2$ benefit in TA cycle | No established link to TA $CO_2$ | Path to TA $CO_2$ can be established | Strong clear link to TA $CO_2$ |
| **Potential sample size** | Number of vehicles possible to cover in practical sample | Detail study suitable only for small number of vehicles | Practical to apply to similar sample size to ISC tests | All or significant portion of the vehicle parc |
| **Cost and resource Impact (per test)** | Relative cost and resource impact of carrying out each test (test cost, resources) | Significant cost burden and/or resources required | Moderate resources / Similar cost to an additional TA test | Minimal additional cost and resource over pollutant ISC |

Note that while efficiency considers the range of potential strategies that could be detected by that test, robustness considers how likely the test is to detect a potential strategy if it were present. How effective the test considers whether the presence of a strategy could be proven by that test. For potential sample size a score of three indicates a similar sample size to ISC testing – that is, a small number of vehicles. For cost and resource impact, a score of 3 indicates a similar cost to carrying out an additional test under ISC testing, and only moderate extra effort to arrange the test and review the data – so excludes the procurement and preparation of vehicles for testing. Therefore, if a vehicle is being tested for pollutant ISC a TA WLTC test plus an on-road RDE is assumed, the rating for cost and resource impact reflects the on-cost for the further investigation for ISV of $CO_2$.

The test methods described in Section 7.5, are rated in this way in the tables below. Table 20 lists the test methods that are suitable for screening for the possible use of artificial $CO_2$ strategies, by evaluating large numbers of vehicles in real-world operation. Table 20 lists the methods that are suitable for investigating specific vehicles to establish and identify the presence of artificial $CO_2$ strategies.

The test methods are first evaluated by the strategy types they have the potential to detect (Yes, No, Some strategies of this type, Maybe) – the strategy types were identified in Table 15 in Section 7.2. This provides a link to the potential strategies to detect TA tests considered in Section 7.3. They are then evaluated against the criteria above according to the method of verifying $CO_2$ to the TA test, note that some tests are listed with more than one evaluation method as described in Section 7.12. The rating scores provide a total score, which is scaled to percent for convenience. The ratings are to an extent subjective based on the experience of the CLOVE consortium but serve to compare the test methodologies as objectively as possible.

**Table 20:** Rating of test methodologies to screen for artificial $CO_2$ strategies

| Test method | Detection strategy type covered by test method | | | | | Evaluation method | Rating by category | | | | | | Total Rating (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dyno related | Procedural | Ambient | Cycle features | Coast-down | Method to evaluate $CO_2$ emission abnormalities against TA test (See Section 7.12) | Practicality / Feasibility | Efficiency: Range of strategies | Robustness of detecting them | Effective (evidential) | Potential sample size | Cost/Resource Impact | |
| **OBFCM data analysis** | Y | Y | Y | Y | Y | Data mining for abnormal differences over fleet | 3 | 5 | 3 | 1 | 5 | 2 [1] | 63 |
| **OBFCM or OBD logging survey** | Y | Y | Y | Y | Y | Analysis for abnormal differences | 3 | 4 | 2 | 1 | 4 | 4 | 60 |
| | | | | | | $CO_2$ association to energy output | 2 [2] | 4 | 2 | 2 | 4 | 4 | 60 |
| **Enhanced vehicle data logging survey [3]** | Y | Y | M | Y | Y | Analysis for abnormal differences | 4 | 4 | 2 | 2 | 4 | 3 | 63 |
| | | | | | | $CO_2$ association to energy output | 4 | 4 | 2 | 3 | 4 | 3 | 67 |

**Key: Y = Yes, N = No, S = Some strategies of this type, M = Maybe depending on test conditions and procedure**

Notes: [1] Cost of analysis and interpretation assumed to be significant, although works out low per vehicle type screened. [2] Requires data to evaluate vehicle drive cycle energy, which may not be available from OBD [3] Enhanced vehicle data logging survey used for screening purposes

**Table 21** Rating of test methodologies to establish and identify the presence of artificial $CO_2$ strategies

| Test method | Detection strategy type covered by test method | | | | | Evaluation Method | Rating by category | | | | | | Total Rating (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dyno related | Procedural | Ambient | Cycle features | Coast-down | Method to evaluate $CO_2$ emission abnormalities against TA test) | Practicality / Feasibility | Efficiency: Range of strategies | Robustness of detecting them | Effective (evidential) | Potential sample size | Cost/Resource Impact | |
| Enhanced vehicle data logging survey [1] | Y | Y | M | Y | Y | Analysis for abnormal differences | 4 | 4 | 2 | 2 | 4 | 3 | 63 |
| | | | | | | $CO_2$ association to energy output | 4 | 4 | 2 | 3 | 4 | 3 | 67 |
| Hot-start WLTC | N | S | S | S | N | Expect similar $CO_2$ performance | 5 | 2 | 3 | 4 | 3 | 4 | 70 |
| Change precondition cycle | N | S | N | S | N | Expect similar $CO_2$ performance | 5 | 1 | 3 | 5 | 2 | 3 | 63 |
| Changes to test procedures | N | S | Y | N | N | Expect similar $CO_2$ performance | 5 | 1 | 3 | 4 | 2 | 2 [2] | 57 |
| Test in different drive mode | N | S | N | N | N | Expect similar $CO_2$ performance | 5 | 1 | 3 | 2 | 2 | 3 | 53 |
| Change TA test phase order or reverse test | N | N | N | Y | N | Expect similar $CO_2$ performance | 5 | 1 | 3 | 4 | 2 | 3 | 60 |
| Random changes to test conditions (over at least 2 tests) | N | M | M | M | N | Expect similar $CO_2$ performance | 5 | 3 | 3 | 4 | 2 | 2 | 63 |
| Deceive the detection strategy sensor | S | S | N | S | N | Expect similar $CO_2$ performance | 3 | 1 | 2 | 5 | 1 | 2 [2] | 47 |
| Alternate but similar test cycle | N | N | N | Y | N | Expect similar CO2 performance, or establish expected differential | 5 | 1 | 3 | 3 | 2 | 3 | 57 |
| | | | | | | Apply cycle simulation tool | 4 | 1 | 3 | 4 | 2 | 3 | 57 |

| Test method | Detection strategy type covered by test method | | | | | Evaluation Method | Rating by category | | | | | | Total Rating (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dyno related | Procedural | Ambient | Cycle features | Coast-down | Method to evaluate $CO_2$ emission abnormalities against TA test) | Practicality / Feasibility | Efficiency: Range of strategies | Robustness of detecting them | Effective (evidential) | Potential sample size | Cost/Resource Impact | |
| **More severe test cycle** | N | N | N | Y | N | $CO_2$ association to energy output | 4 | 1 | 3 | 3 | 2 | 3 | 53 |
| | | | | | | Apply cycle simulation tool | 4 | 1 | 3 | 4 | 2 | 3 | 57 |
| **Use on-road tests** | Y | M | M | Y | Y | $CO_2$ association to energy output | 3 | 4 | 3 | 3 | 3 | 4 [3] | 70 |
| | | | | | | Apply cycle simulation tool | 3 | 4 | 3 | 4 | 3 | 4 [3] | 73 |
| **WLTC on-track** | Y | M | M | N | Y | Expect similar $CO_2$ performance | 1 [4] | 4 | 4 | 4 | 2 | 3 | 60 |
| **Engine mapping and simulation** | N | Y | N | Y | M | Engine map-based simulation | 2 | 3 | 4 | 3 | 1 | 1 | 47 |
| **WLTC on outside dyno** | S | N | M | N | N | Expect similar $CO_2$ performance | 3 | 2 | 3 | 4 | 2 | 2 | 53 |
| **On-road test then replicated on dyno** | Y | M | M | Y | M | Will show difference of dyno to road. See also on-road tests. | 3 | 4 | 5 | 5 | 3 | 3 | 77 [5] |
| **WLTC with altitude simulation** | N | N | Y | N | N | Expect similar CO2 performance, estimate expected altitude impact | 3 | 1 | 3 | 4 | 2 | 2 | 50 |

**Key: Y = Yes, N = No, S = Some strategies of this type, M = Maybe depending on test conditions and procedure**

Notes: [1] Enhance vehicle data logging survey used for strategy detection purposes [2] Need to work out which procedures to change/sensor to deceive and likely to need multiple tests [3] Assumes PEMS fitment for multiple tests, possibly also for pollutant ISC tests. [4] Could score higher if proven viable [5] Scores for back-to-back against on-road test assuming on-road test is carried out too

In Table 16 of Section 7.2 it was observed that the strategies with the highest potential to be used to detect a type approval test were those that detected the characteristics of a dyno test environment (dyno related), followed those that exploited coast-down tests and TA test procedural characteristics. All the screening test methods have the potential to be able to detect these strategy types, although they are only likely to provide indication of a possible strategy rather than identify its nature. Of the strategy detection test methods, only the enhanced vehicle data logging surveys, on-road tests (with replication on dyno), and testing on track, are capable of identifying both dyno related and coast-down related strategies, unless a particular strategy is suspected and can be actively "deceived" in a dyno test. Put another way, to be sure of identifying strategies that themselves exploit dyno test conditions, it is necessary to test vehicles outside of the dyno.

The screening test methods are ranked by the rating scores in Table 22, and the strategy detection test methods are ranked in Table 23, each with its associated method to evaluate $CO_2$ emission abnormalities against TA test. Test methods which can be evaluated with different methods are scored for each possible method. While as noted above there is some subjectivity in the ratings and so the exact relative position of the test methods should not be given too much value, the general trend is not sensitive to individual scores.

**Table 22:** Rating of test methodologies for artificial $CO_2$ strategy screening - Summary ordered by score

| Test method | Evaluation Method | Total Rating (%) |
|---|---|---|
| **Enhanced vehicle data logging survey** | $CO_2$ association to energy output | 70 |
| **Enhanced vehicle data logging survey** | Analysis to detect abnormal differences | 67 |
| **OBFCM fleet data analysis** | Data mining for abnormal differences over fleet | 63 |
| **OBFCM/OBD logging survey** | Analysis for abnormal differences | 60 |
| **OBFCM/OBD logging survey** | $CO_2$ association to energy output | 60 |

The aim of screening tests is to identify models of vehicles that have an unusual deviation in real-world fuel consumption from TA compared to typical or similar types of vehicle model and are worthy of more detailed (and costly) investigation. As such, they are not expected to identify the nature of an artificial strategy or even prove that one is present, but should be sensitive (given appropriate analysis) to enable $CO_2$ deviations caused a wide range of potential strategies to be picked up.

The use of enhanced vehicle data logging surveys scores highly as they are practical to implement over a fleet of vehicles and cover a broad range of potential strategies. The challenge is using the data obtained to robustly and clearly identify the presence of artificial $CO_2$ strategies, and using $CO_2$ association to energy output (grammes per kilowatt hour) is expected to provide clearer results. However, the fleet size evaluated is limited by the practicalities of installing the necessary logging equipment, and the real-world data obtained will be subject to the usual variations of ambient conditions, usage profiles, and driving styles.

The analysis of EU-wide OBFCM data is potentially capable of capturing a wide range of potential strategies over a very large sample for relatively low cost. However, this assumes the data is available at sufficient resolution for valuable analysis, and the robustness of detection of $CO_2$ deviation depends on that analysis being effective despite the many real-world factors, as discussed in Section 7.6. Such analysis can be expected to take development effort to be effective. Nonetheless, the potential to be able to detect suspicious $CO_2$ performance due to a wide range of potential strategies across such a large number of vehicles means it is a potentially valuable tool.

The use of OBFCM or OBD logging surveys will cover smaller samples and at a higher cost than EU-wide OBFCM data analysis, and with a smaller dataset meaningful analysis is more difficult. Less detailed data is available at lower resolution than enhanced vehicle data logging surveys. Such surveys may prove useful in supplementing data from than EU-wide OBFCM data analysis, perhaps checking on vehicle types or behaviours in certain conditions but are unlikely to be a useful tool in their own right.

**Table 23:** Rating of test methodologies for artificial CO2 strategy detection - Summary ordered by score

| Test method | Evaluation Method | Total Rating (%) |
|---|---|---|
| **On-road test then replicated on dyno** | Will show difference of dyno to road | 77 |
| **Hot-start WLTC** | Expect similar $CO_2$ performance | 70 |
| **Use on-road tests** | Apply cycle simulation tool | 70 |
| **Enhanced vehicle data logging survey** | Work-based relationship | 67 |
| **Use on-road tests** | $CO_2$ association to energy output | 67 |
| **Change precondition cycle** | Expect similar $CO_2$ performance | 63 |
| **Random changes to test conditions (over at least 2 tests)** | Expect similar $CO_2$ performance | 63 |
| **Enhanced vehicle data logging survey** | Analysis to detect abnormal differences | 63 |
| **Change TA test phase order or reverse test** | Expect similar $CO_2$ performance | 60 |
| **WLTC on-track** | Expect similar $CO_2$ performance | 60 |
| **Changes to test procedures** | Expect similar $CO_2$ performance | 57 |
| **Alternate but similar test cycle** | Expect similar $CO_2$ performance, or establish expected differential | 57 |
| **Alternate but similar test cycle** | Apply cycle simulation tool | 57 |
| **More severe test cycle** | Apply cycle simulation tool | 57 |
| **Test in different drive mode** | Expect similar $CO_2$ performance | 53 |
| **More severe test cycle** | $CO_2$ association to energy output | 53 |
| **WLTC on outside dyno** | Expect similar $CO_2$ performance | 53 |
| **WLTC with altitude simulation** | Expect similar $CO_2$ performance | 50 |
| **Deceive the detection strategy sensor** | Expect similar $CO_2$ performance | 47 |
| **Engine mapping and simulation** | Engine map-based simulation | 47 |

Replicating a recorded on-road PEMS test using a vehicle dyno is ranked as the strongest test method to detect artificial $CO_2$ strategies. This combines the use of on-road testing to evade a broad range of strategy types (including those that detect dyno and coast-down conditions) with an effective link to dyno test performance. Such an approach is relatively novel in this context, and well-defined procedures for an effective approach would need to be developed, although replaying on-road tests in a vehicle dyno is not unknown for development purposes and so it is considered feasible.

The running of the WLTC from a hot start also scores highly. Alone it simply quantifies the impact of a cold start on the TA cycle emissions (which can be evaluated against expectations), but by providing a hot test $CO_2$ result it allows comparison of other tests to be carried out using hot starts. This saves time, money, and removes a variable (the cold-start impact) from such comparisons. The hot-start WLTC itself is relatively cost effective as it can be carried out directly after a cold-start WLTC, e.g., when verifying the TA test on the test vehicle.

On-road testing with PEMS is shown to be a valuable test methodology, as could be expected when comparing TA tests to real-world conditions since it has the potential to evade a wide range of TA detection strategies. The challenge of effective identification of $CO_2$-impacting strategies can be helped by using a cycle simulation tool such as $CO_2$MPAS to link the on-road emissions back to an equivalent TA test given the same behaviour, alternatively work-based $CO_2$ (grammes per kilowatt hour) can be compared for dissimilar cycles. These are practical although relatively novel approaches in this context. As already noted, replaying the on-road test on the vehicle dyno provides the strongest link between road and dyno performance. On-road testing is relatively cost-effective once a vehicle has been equipped with a PEMS (especially if that is combined with ISC tests) and a range of driving scenarios can be evaluated.

Enhanced vehicle data logging surveys can be used to detect and identify artificial CO2 strategies, as well as for screening purposes. For example, they can help identify operating conditions or driving behaviours that lead to unusual deviations in fuel consumption and allow real-world understanding of factors such as regeneration frequency and hybrid use. They can also serve to verify that detailed test results on a single vehicle are representative of the vehicle type in general real-world use. With appropriate instrumentation fitted to the test vehicles, it may be possible to identify the use of specific strategies and make comparisons to their use in a TA test. In effect, these surveys can apply many of the benefits of PEMS testing to a larger fleet of vehicles and driving scenarios.

Most dyno test methodologies do not score as highly as the use of on-road tests since they are inherently more limited in the range of TA detection strategies they can evade – in particular the high-scoring strategies that detect dyno and coast-down conditions. However, it can be easier to evaluate $CO_2$ emission abnormalities compared to the TA test since the test procedures are controlled, and any differences between the test carried out and a TA test are understood. So, the tests that involve controlled changes from a TA WLTC test are valuable since although they are each limited in the scope of potential strategies they may detect, which limits their score, they would be effective in providing evidence of those strategies. For example, a change in WLTC $CO_2$ due to use of a different preconditioning cycle would demonstrate a strategy based on drive history, while if running the WLTC phases in a different order changed the $CO_2$ a cycle recognition strategy would be suspected. Similarly, alternative or more severe tests can be used, extending the range of potential strategies that could be detected, but with less effective evidential value in $CO_2$ comparisons. These varied dyno tests are therefore useful in investigating particular strategies but may prove an expensive and time-consuming means to establishing if any strategy is present, especially since a number of repeat tests would be required to show clear results accounting for cycle-to-cycle reproducibility

A novel test approach is to replicate a WLTC on a test track using PEMS. This has potential to provide effective evidence of an artificial strategy if a difference in $CO_2$ was observed, and such a test would evade a range of potential strategies. However, there are practical challenges to overcome if the test is to run correctly. Running a WLTC using an outside dyno is a more practical alternative where such facilities exist. Both of these test methods would require development of robust approaches and an understanding of reproducibility established through study.

It is perhaps worth noting that if a procedure of test methodologies to identify artificial improvements in $CO_2$ emissions for a TA test were established, it is possible that strategies to detect those tests could be implemented to protect any artificial strategies from being detected! Perhaps it is not possible to always be able to detect all possible strategies. However, the highest scoring test methodologies identified above would be difficult to overcome, especially if used in combination, such that any artificial strategy would need to be deployed under so many conditions that it would no longer be artificial, and simply become a benefit to $CO_2$ reduction.

## 7.17 Setting out a test procedure

### 7.17.1 Establishing a testing process for identifying artificial strategies

The rating score and the consequential ranking of the test methods is helpful in selecting the methods to use in identifying the presence of possible artificial strategies to benefit $CO_2$ emissions in a TA test, but in addition overall approach to evaluating a vehicle and the objectives to be achieved by the tests must also be considered. The evaluation process (Figure 41) might need to include screening to identify patterns that might indicate vehicles at higher risk of using artificial strategies and inform selection of vehicles to test, tests of selected vehicles to validate whether there is an unexplainable $CO_2$ discrepancy between the TA test and real-world use, and if there is, investigative testing to establish the nature of the discrepancy.

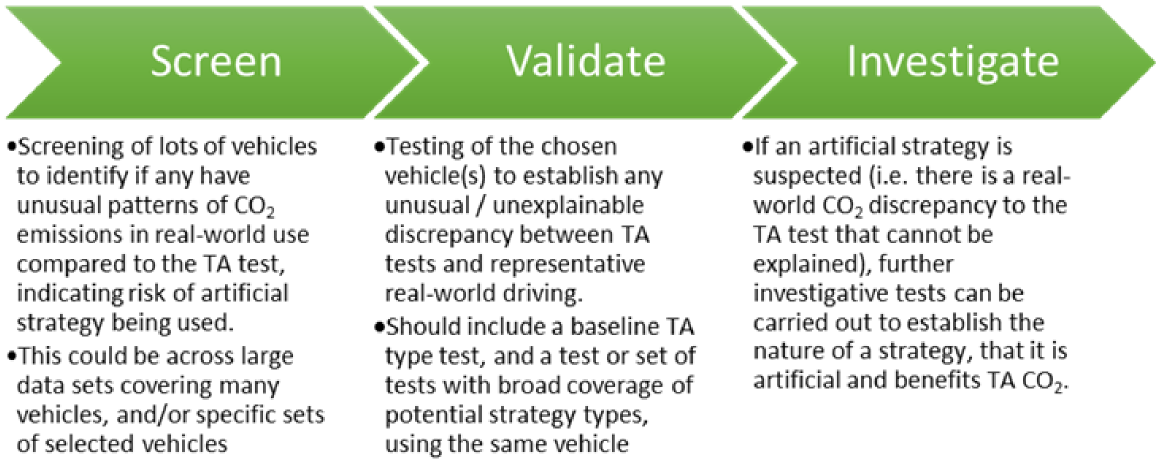



**Figure 41:** Testing process for identifying artificial strategies

The validation tests are the core of the process and would be applied to any vehicle undergoing in-service verification of $CO_2$ emissions, and the methodology would need broad coverage of the potential strategy types identified above as well as a baseline TA test to compare to. A robust method of comparing the non-TA test $CO_2$ results to the TA test will be required to validate that an artificial strategy is not present. However, if the validation tests are not to become overly burdensome, the number and complexity of the tests to be carried out should be minimised.

The screening stage allows validation testing to be applied more effectively by selecting vehicles seen as more likely to have an artificial strategy. The aim would be to evaluate many vehicles at a low cost. The best screening coverage in terms of vehicles included would be achieved by evaluation of OBFCM data, which can be done without any physical tests at all, although this is a novel and unproven approach at this stage and may need to be strengthened by more focused investigations.

The investigation stage would only be applied where the validation demonstrates a difference between real world use and the TA test. The objective would be to at least isolate the conditions under which a difference in $CO_2$ is observed (the type of detection strategy) to establish that it behaves in an artificial manner. The nature of the tests in this stage will depend on the evidence that is needed to verify that $CO_2$ results outside the TA test indicate an artificial strategy, and so it is expected that a specific test plan would need to be developed for each case depending on the suspected nature of the device and evolved based on the results of each test.

### 7.17.2 Proposed methodology to identify artificial strategies

From the analysis of the potential strategies, test methods, and considering the test process that can be applied, an approach to identifying discrepancies in $CO_2$ between TA test and real-world driving might follow a methodology such as this:

1. **Screening** of vehicles in real world use to identify those with unusual deviations in fuel consumption compared to similar vehicles, and at higher risk of having artificial strategies. The approach is likely to develop as experience determines the most effective processes, but this could include:
    a. Screening large samples of/all vehicles through analysis of OBFCM
    b. More detailed screening of select fleets using OBD logging devices, or enhanced vehicle data logging surveys for more detailed data*.
    Although covering smaller data sets and involving more cost than screening OBFCM, these provide more data of the vehicle driving situation and its behaviour, which can be used to strengthen findings from OBFCM screening or identify specific real-world circumstances affecting the $CO_2$ deviation.
2. **Validate** discrepancy between TA test and real-world behaviour. For vehicle types selected as for in-service verification testing (from screening or otherwise), a vehicle is tested over the following series of tests[51]:
    a. A baseline Type 1 (WLTC) test to verify $CO_2$ under TA procedures and isolate any differences not due to strategies (such as tyres, fuel). *This test could be shared with ISC.*
    b. Hot-start Type 1 (WLTC) (following above) – to quantify cold-start impact and allow for comparison of a variety of investigative tests
    c. On-road RDE test(s) using PEMS[52] – Comparing $CO_2$ to the baseline WLTC by calculating expected WLTC $CO_2$ through cycle-based simulation, or by cycle energy specific evaluation. Ideally several tests cover a range of driving styles and hot and cold start tests. *This test could be shared with ISC.*
    d. On-dyno replication of on-road test – ensure laboratory and road tests do not show unexpected difference in $CO_2$ indicating a difference in behaviour in lab. (If ambient temperature differences between dyno type 1 test and on-road tests are considered significant, the on-dyno replication of on-road test can be carried out simulating the on-road test temperature, as well as at the temperature used in TA test procedures*)
3. **Investigate*:** if stage 2 shows a real-world $CO_2$ discrepancy to the TA test that cannot be explained, further targeted investigations to establish the likelihood and nature of a strategy can be carried out. Test procedures selected will depend on the findings of the tests in stage 2 and where/how a potential strategy is suspected to operate.

*Optional, or where considered appropriate

The validation tests (stage 2) in the above process could be applied to vehicles undergoing ISC testing for pollutants, adding relatively little additional work, or where vehicles have been identified for further investigation by the screening (stages 1a and/or 1b). The investigative tests in stage 3 are only

[51] Regarding test order: 2b must immediately follow 2a, and 2d (and 2e if required) must take place after 2c since it is derived from it, so the order 2c, 2d, (2e), 2a, 2b; or 2c, 2a, 2b, 2d, (2e) are also valid and may be convenient in practice (e.g., consolidating dyno tests).

[52] PEMS provides an established comparison to dyno-based $CO_2$ measurement. However, since $CO_2$ is related to fuel use, some tests could use an OBD (OBFCM) logger for simplicity and cost, this would also allow the performance of additional vehicles on-road to be compared at this stage. However, it is suggested PEMS is used for the tests that is/are to be replicated on the dyno in (d).

necessary if the tests in stage 2 identify a high risk of an artificial strategy, and aim to isolate the scenario or conditions in which the suspicious $CO_2$ behaviour is observed.

An overview of this proposed approach is shown in Figure 42~~Figure 6-2~~.

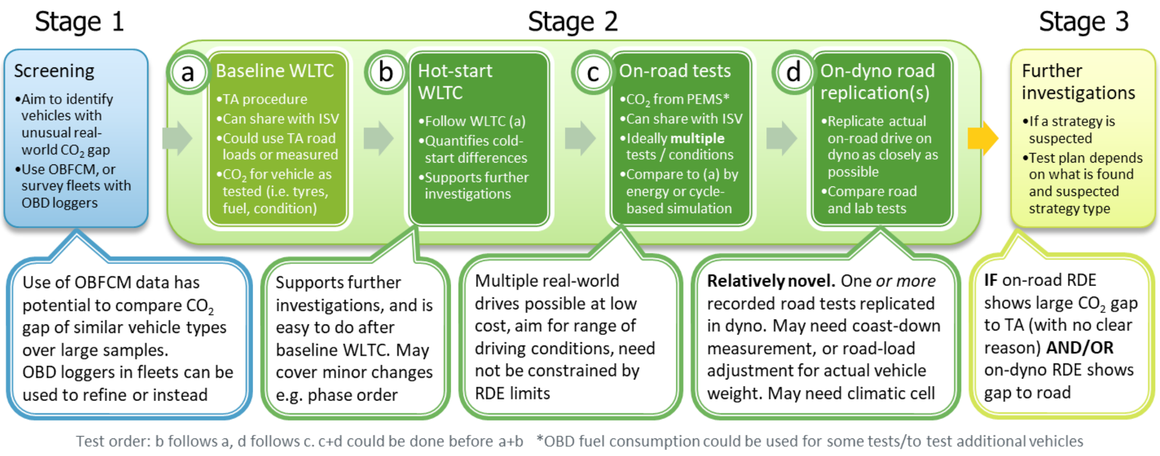



**Figure 42:** Overview of proposed approach to detecting artificial strategies

### 7.17.3 Verifying the absence of artificial strategies for $CO_2$ improvement

It would be expected that the validation tests (stage 2 above) would demonstrate a correlation of real-world tests to dyno tests (using cycle simulation or energy-specific comparisons) and so verify that laboratory (dyno) testing does not introduce unexpected differences to on-road tests. It may be possible to set thresholds for comparisons of test $CO_2$ to verify a low risk of artificial strategies, but these thresholds must be considered for each test comparison, as illustrated in Table 24, since it must allow for the range of possible differences between different test types (despite the comparison technique or normalisation method) as well as test-to-test variation, and yet the influence of artificial strategy behaviours on the $CO_2$ emissions could be relatively small (of the order of a few percent). In fact, it is unlikely that the comparison of test results against a threshold would prove the presence of an artificial strategy, but it can assist in determining if there is a risk of an artificial strategy being present.

**Table 24:** Threshold evaluation for verifying the absence of artificial strategies

| $CO_2$ comparison (tests) | Threshold | Non-artificial factors causing variation (other than test-to-test variability) |
|---|---|---|
| Hot WLTP to cold start? (a-b) | Moderate | Engine size and warm-up strategy, hybrid behaviour |
| Road test(s) to WLTP? (a-c) | Large<br>*[moderate?]* | Climate, vehicle load, vehicle power, road and tyres, as well as route type and driving style.<br>Hot start WLTP allows comparison to hot start road tests, and lessens climatic impact |
| Range of road tests? (c-c) | Large<br>*[moderate?]* | Climate, route type, hybrid behaviour and driving style – assuming vehicle and load the same |
| Dyno replication to road? (c-d) | Small | Accuracy of reproduction, matching of road load, climate, cornering, road surface, hybrid |
| *[if compared by cycle energy or cycle-based simulation]* | | |

Evaluation of the risk of an artificial strategy could use thresholds to determine whether the comparison between the tests confirms there is a low risk of an artificial strategy being present or indicates a high risk that should be investigated further. A key comparison is between the dyno replication and the road test it replicates, which should be possible to achieve a narrow threshold if road load and potentially climate are matched. However, a simple comparison of $CO_2$ differences to thresholds is not by itself sufficient, and the vehicle performance should be considered too:

- Consider unusual characteristics of the tests – are the observed behaviours as expected/seen in other vehicles? Consider the $CO_2$-influencing behaviours identified in Table 18.
- The hot WLTP to cold gives impact of warm-up. Do hot- and cold-start road tests show similar differences?
- A range of on-road tests can show $CO_2$ variability with driving style, cycle energy, and possibly ambient conditions, for that vehicle.

Appropriate thresholds to assess whether the difference in $CO_2$ emissions indicates a risk of use of an artificial strategy could be developed through a study considering typical differences for the test comparisons. Thresholds may need to allow for vehicle types, e.g.: hybrid, high or low power-to-weight, since the variance in $CO_2$ with driving scenario may differ between vehicle powertrains. A well-evidenced study informing thresholds would provide guidance to the TAA assessing the tests.

### 7.17.4 Validating a high-risk of artificial strategies

Where a discrepancy in $CO_2$ between real world operation and the TA test outside normally acceptable tolerance is highlighted by the validation tests (stage 2 of the procedure set out in 7.17.2 ) without clear reason, the vehicle is considered at high risk of using an artificial strategy. At this stage, the TAA would need to apply analysis and judgement to the test results to see if the differences in $CO_2$ can be explained by reasonable behaviour, including the possible use of alternative emissions strategies that may be declared by the manufacturer for the vehicle, since it is possible such strategies also affect $CO_2$.

Further investigative tests can then be carried out with the objective of isolating the conditions or scenarios under which the difference in $CO_2$ performance is observed, and so indicating the presence of an artificial strategy that is not explained. The investigative tests (stage 3 of the procedure set out in 7.17.2 ) should apply a range of tests depending on the nature of the suspected tests, and could include:

- **Changes to TA test or procedures**, including change of preconditioning cycle, test conditions, changed phase order, etc. relative to baseline cold or hot WLTC to establish if a procedural, cycle features, or ambient condition strategy is used
- Use of an **outside dyno**, or replicating **WLTC drive on a test track**, if shown to be viable, to establish if dyno related or procedural strategies are present
- Use of **alternate dyno test cycles** evaluating $CO_2$ through cycle-based simulation, or by cycle energy specific evaluation, to establish the likely conditions for a suspected cycle-feature or procedural strategy
- **Enhanced vehicle data logging surveys** with appropriate vehicle parameters or instrumentation to monitor suspected strategies, to provide understanding of how they are used in real-world driving (compared to the WLTC) and the range of vehicle types affected
- **Specific investigative tests** to confirm the presence of a type of strategy or behaviour, through comparable tests with changed elements, or the elimination or deception of sensors suspected to be linked to the strategy

The selection of tests for further investigation in stage 3 would be based on the findings of the tests so far and consideration of the test types necessary to isolate the suspected strategy behaviour. A fixed procedure would be inefficient, and a flexible approach is more effective since it cannot be predicted. The types of tests listed here indicate the situations in which they may be used, but it may be helpful to set out a decision-tree to determine the likely strategy type(s) based on the test results and so the tests that may be used. An example of such a decision-tree is shown in Figure 43. Other information used to inform the selection of test methods to apply would be the patterns observed from the screening data, variations in $CO_2$ and ambient conditions during the road tests, and the source of the road loads used in the tests.

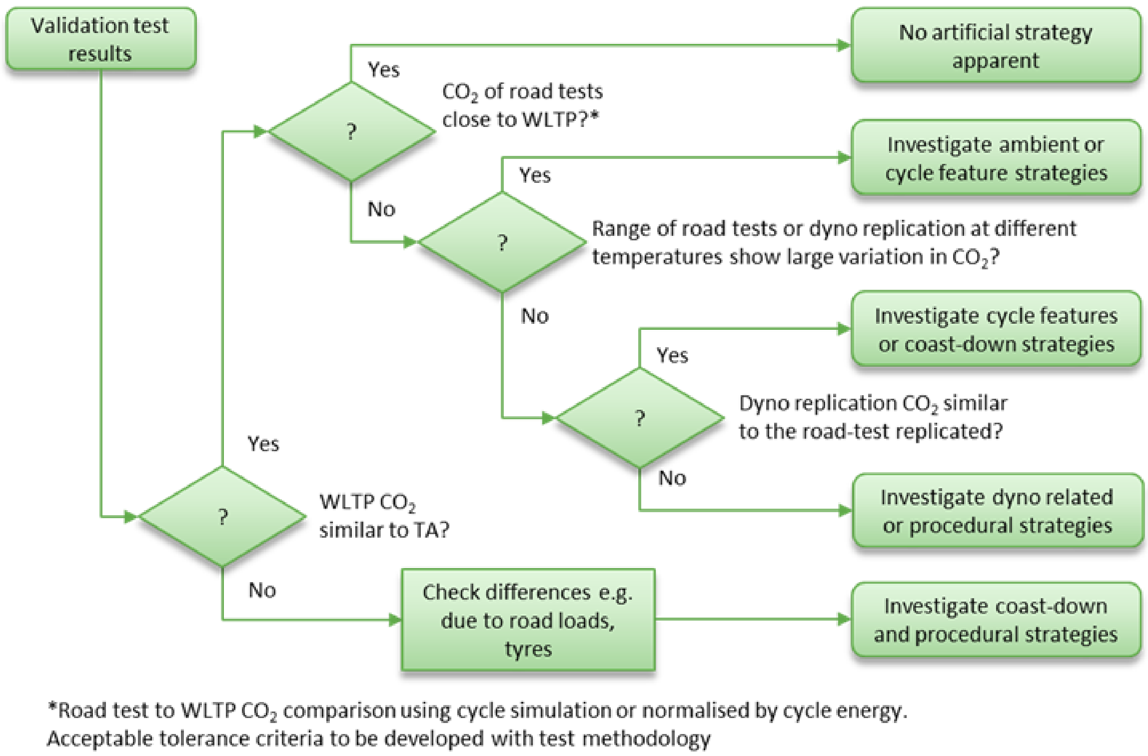



**Figure 43:** Example decision tree for focusing investigative tests

When the TAA is satisfied that the $CO_2$ performance of the vehicle exhibits a difference between TA test conditions and normal on-road use that is not explained by expected differences and strategies, and there is a high risk of an artificial strategy being present, the vehicle manufacturer is requested to explain the cause of the difference to the satisfaction of the TAA. The TAA may wish to involve the manufacturer in the investigation before carrying out additional tests, for example to rule out the possibility that a vehicle fault on the test vehicle is to blame, but the investigative procedure must of course remain independent of the manufacturer.

### 7.17.5 Parallels with the guidance for defeat device testing

The guidance for testing for pollutant defeat devices was discussed briefly in section 7.1.5, and the similarities in test methodologies discussed for $CO_2$ have been noted in section 7.5. It is perhaps no surprise that the proposed approach to identifying strategies artificially affecting $CO_2$ has significant similarity to those given as examples in the pollutant defeat device testing protocol in Annex III of Commission Notice of 26/01/2017[53]. Table 25 compares that example to the proposed tests in stage 2 of the proposed procedure above. Three of the proposed tests are the same for both, and the other two have comparable albeit different tests. It is likely therefore that a shared approach could be used for verifying the absence of artificial strategies for $CO_2$ and defeat devices for pollutants for a vehicle, through the application of a core set of tests, while allowing the freedom to vary the tests and use additional tests as needed.

**Table 25:** Comparison of proposed tests for $CO_2$ strategies to those for defeat devices

| Test | Proposed for $CO_2$ artificial strategy | Example protocol for defeat device test | Notes |
|---|---|---|---|
| **Type 1 standard** | Yes | Yes | Baseline |
| **Type 1 hot start following above** | Yes | Yes | Easy isolation of hot vs cold start behaviour |
| **Type 1 with state of non-engine systems changed** | No, except to investigate suspected strategies | Yes | On-road tests cover different non-engine system states and test procedures |
| **Type 1 on test track** | No | Yes | Strong detection of strategies. On-dyno replication of road test achieves similar dyno to road comparison. |
| **On-road tests (multiple)** | Yes | Yes | Should cover range of driving and ambient conditions |

[53] https://www.europarl.europa.eu/meetdocs/2014_2019/plmrep/COMMITTEES/EMIS/DV/2017/02-09/C_2017_352_EN.pdf

| | | | |
|---|---|---|---|
| **On-dyno replication of on-road test** | Yes | No | Strong detection of strategies and may be easier to implement than type 1 on test track |
| **Type 1 with low ambient temperature** | No, except where suspected ambient strategy | Yes | $CO_2$ TA includes test at 14°C, and on-road tests cover different ambient conditions |

## 7.18 Conclusions and further work for a test method to detect artificial $CO_2$ strategies

### 7.18.1 Potential artificial strategies and test methods to detect them

A range of potential strategies and behaviours that could be used to improve $CO_2$ in a TA test have been identified. These have been split into those that detect that the TA test is being carried out (and could be used for any purpose, including pollutant control) listed in Table 15, and those that provide a method of reducing the $CO_2$ emissions listed in Table 18 which may rely on a means of detection to be implemented. This review does not claim to be comprehensive, and new vehicle technologies may provide new opportunities for strategies, yet the approach identifies the types of strategy that can be used to enable behaviour during a TA test that is not apparent in real world conditions.

The detection strategies identified have been grouped into 5 key types, which are helpful when considering how test methodologies may be used to identify them. These strategy types are:

- **Dyno related**: Strategies that detect that the vehicle is on a dyno. The strategies with the greatest potential were found to be dyno related
- **Procedural**: Strategies that identify TA or typical dyno test procedures are being applied, which may include a memory of previous driving
- **Cycle features**: Strategies to recognise or utilise characteristic features of the TA test cycle(s) (that is, the WLTC test)
- **Coast-down**: Strategies that detect or utilise coast-down road-load testing procedures, which will have an impact on dyno tests that use the coast-down measurements to determine the dyno load coefficients
- **Ambient**: Strategies monitoring the ambient temperature or pressure/altitude (specific types of procedural detection)

The 21 identified strategy behaviours which could be used to artificially benefit $CO_2$ over the TA test considered a range of vehicle systems, including the engine conditions, engine calibration and control strategies, long-term control strategies for aftertreatment regeneration and fuelling adaption, engine electrical system and alternator, engine thermal management, hybrid system (including battery and electrical machines and their control), transmission, cabin heating and air conditioning, and vehicle aero devices.

Test methodologies that have potential to identify artificial improvements in $CO_2$ emissions for a TA test have been presented and discussed. The 18 test methodologies are categorised as:

- **Analysis of EU-wide OBFCM Data** – to identify unusual trends

- **Fleet logging surveys** – using installed logging devices in selected vehicles
- **Changes to the TA test** – changing the procedures or cycle characteristics of the TA dyno test in a controlled manner, but otherwise testing as per the TA test
- **Alternative dyno tests** – to deliberately operate outside of the usual TA test boundaries
- **Engine mapping and simulation** – using simulation to model vehicle cycle emissions based on measurements taken from the engine across a range of operating conditions
- **Vehicle tests outside the laboratory** – using PEMS to carry out emissions tests outside of a dyno (on road or track)

The capability and robustness of the test methodologies to detect the strategy types listed above has been evaluated along with their effectiveness in providing clear evidence, which may depend on an effective method to link the test $CO_2$ to the TA $CO_2$ as discussed in Section 7.12. The practicality, potential sample size, cost and resource impact of each method has also been considered. A rating score for each of these criteria allows each of the test methods to be assessed and compared in Section 7.16, separately considering those useful for screening purposes and those intended to establish and identify the presence of artificial $CO_2$ strategies.

The use of on-road measurement and being able to compare on-road measured $CO_2$ emissions to those of a dyno test, was considered an essential element of the test procedure since the highest ranked strategy types apply to dyno testing and test procedures. The means of linking the $CO_2$ from tests back to the dyno type 1 test is key to understanding the presence of artificial strategies, since $CO_2$ varies with driving conditions and behaviour and yet the impact of an artificial strategy may be small compared to the difference between two drives in different conditions.

### 7.18.2 A proposed approach to identifying the presence of artificial strategies

A proposed approach to identifying the presence of artificial strategies affecting $CO_2$ in the TA test is set out in section 7.16. This has the

**Stage 1: Screening** of vehicles in real world use to identify those with unusual deviations in fuel consumption compared to similar vehicles, and at higher risk of having artificial strategies. The approach is likely to develop as experience determines the most effective processes, but this could include:

a. Screening large samples of/all vehicles through analysis of OBFCM
b. Optionally: more detailed screening of select fleets using OBD logging devices, or enhanced vehicle data logging surveys for more detailed data.

**Stage 2: Validation tests** confirm if the discrepancy between TA test and real-world behaviour is within reasonable/expected thresholds or is at high risk of using an artificial strategy by testing a vehicle over the following:

a. A baseline Type 1 (WLTC) test to verify $CO_2$ under TA procedures and isolate any differences not due to strategies (such as tyres, fuel).
b. Hot-start Type 1 (WLTC) (following above) – to quantify cold-start impact and allow for comparison of a variety of investigative tests
c. On-road RDE test(s) using PEMS or OBD logging – Comparing $CO_2$ to the baseline WLTC by calculating expected WLTC $CO_2$ through cycle-based simulation, or by cycle energy specific evaluation. Ideally several tests cover a range of driving styles and hot and cold start tests.
d. On-dyno replication of on-road test – ensure laboratory and road tests do not show unexpected difference in $CO_2$ indicating a difference in behaviour in lab.

**Stage 3: Investigate further where necessary:** if a real-world $CO_2$ discrepancy to the TA test is observed that cannot be explained and the vehicle is considered at a high risk of using an artificial strategy, further targeted investigations to establish the likelihood and nature of a strategy can be carried out. Test procedures selected will depend on the findings of the tests in stage 2 and where/how a potential strategy is suspected to operate.

The tests described for stage 2 are within the capability of technical services to carry out as part of market surveillance activities, most being well established procedures although the on-dyno replication of an on-road test (2d) is relatively novel and would benefit from the development of a well-defined methodology. Similarly, many of the tests described for stage 3 are easily implemented variations to the TA test, although 3b proposes a novel approach, and 3e would require a flexible investigative approach that develops according to the findings of each test.

This procedure is considered to cover the widest range of artificial detection strategy types and $CO_2$-improving behaviours identified while being efficient to carry out with a minimum number of tests. Indeed, tests 2a and 2c could be shared with in-service conformity of emissions, and test 2b is in the guidance for the detection of pollution defeat devices. The similarity of the suggested procedure to that given in the guidance for the detection of pollution defeat devices is perhaps no surprise, given both procedures aim to identify engine strategies that behave differently in the real world to a TA test, although the method of validating whether $CO_2$ emissions are artificially increased is complicated compared to evaluating emissions since $CO_2$ varies so significantly with the cycle characteristics. Therefore, the proposed procedure details how the $CO_2$ differences between the tests are evaluated and compared to typical and expected behaviours to identify high-risk behaviour.

The procedure is designed to provide confidence to the TAA that the vehicle tested does not have an artificial strategy affecting CO2. Where a vehicle is considered at risk of having such a strategy, further investigation as set out in Stage 3 is applied to isolate the conditions and scenarios in which the difference in $CO_2$ is observed. Where this further investigation concludes that an artificial strategy is present (or highly likely) the manufacturer is requested to explain the $CO_2$ behaviour of the vehicle to the satisfaction of the TAA.

### 7.18.3 Further work could refine the approach

This report sets out an approach to verifying the presence of artificial $CO_2$-affecting strategies that is considered sufficient for guidance to TAA to carry out investigations. However, there are areas where further work could refine the approach.

Detailed procedures for testing could inform a most effective approach to the dyno replication tests, which are relatively novel in this context, including:

- The most suitable approach to setting road load and climate
- How to translate road test recording to dyno

A study to establish reasonable $CO_2$ differences between test types and conditions would allow guidance for high/low risk thresholds (as described in 7.17.3) to be set outside of likely test variance but tight enough to flag possible artificial strategies for further investigation. Literature analysis and/or physical testing could be used to provide an evidence base for the guidance, considering the behaviour of different vehicle types and powertrains. Such a study could also consider how the $CO_2$ of different tests can be compared through normalisation by cycle energy or through using cycle simulation, allowing tighter thresholds to be applied.

Another area that would benefit from further work is the use of OBFCM data to screen for vehicles considered at risk of having strategies affecting $CO_2$. In section 7.6 a range of analysis is proposed using the statistical nature of the OBFCM data set, comparing trends of vehicle types against similar vehicles. However, a study into the evaluation of potential screening approaches using OBFCM data trend analysis could use real data to set out detailed methods.

# 8 Task 4 – Correcting the average specific emissions of $CO_2$ in case of deviations found (LDV and HDV)

## 8.1 Introduction

The ISV procedure is aimed to identify (families of) vehicles, which show deviations in $CO_2$ emission values from the ones declared in the CoC. Task 3 describes the procedure to perform the In-Service Verification by determining the road loads (sub-task 3.1), evaluating the chassis-dynamometer results (sub-task 3.2) and detecting possible defeat strategies (sub-task 3.3). In case these procedures lead to the identification of a deviation (ISV results significantly higher than CoC values) - including due to the presence of an artificial (defeat) strategy to improve $CO_2$ emissions - those deviations will need to be reported to the Commission. Subsequently, the Commission will correct the average $CO_2$ emissions of the manufacturer concerned.

Task 4 is aimed to develop an approach to perform such correction, to support the preparation of implementing legislation as foreseen in Article 7(9) of Regulation (EU) 2019/631.

## 8.2 Correction procedures in case of deviations

The following sections describe possible correction methodologies, distinguishing: a) $CO_2$ emissions (chassis-dyno) fail, b) road load test results fail and c) both chassis-dyno $CO_2$ results and road load test results fail..

### 8.2.1 $CO_2$ emissions fail (IP line non-verified)

In this case, for the given CED, the $CO_2$ emissions should have been higher. Consequently, the interpolation line or the vehicle High value used for calculating the $CO_2$ emissions needs to be adjusted. This practically means that the $CO_2$ emissions of the vehicle High (H) and vehicle Low (L) should be increased by using one of the following options (Figure 44):

- Option 1: new IP line would be shifted along the y-axis ($CO_2$ value) by the average percentage difference observed between the CoC and the measured $CO_2$ emissions. **Recommended.** For the case of the average deviation, three additional cases can be identified. The cases contain the shift of the interpolation line be the absolute average $\Delta CO_2$ emissions, the percentage $\Delta CO_2$ emissions and the best-fitted line for the measured $CO_2$ emissions. (Figure 44a, black line)
- Option 2: new IP line would be shifted along the y-axis ($CO_2$ value) by the maximum percentage difference observed between the CoC and the measured $CO_2$ emissions. **Not recommended – extremely high values could penalize all the vehicles.** (Figure 44a, red line)
- Option 3: new IP line would be shifted along the y-axis ($CO_2$ value) by the minimum percentage difference observed between the CoC and the measured $CO_2$ emissions. **Not recommended – extremely low values, although non-compliant, could benefit all vehicles.** (Figure 44a, green line)
- Option 4: new IP line would be shifted along the y-axis ($CO_2$ value) by the maximum acceptable margin (percentage value) so that the new IP line would result in $CO_2$ emissions that are on

the acceptable limit. **Not recommended – unfair in case of large deviations.** (Figure 44b, green line)

According to Regulation (EU) 2017/1151 in Sub-Annex 7, paragraph 3.2.3.2.4, the calculation of the $CO_2$ emissions for an individual vehicle are calculated as in Eq. (12) for each WLTP phase and as in Eq. (13) for the overall emissions.

$$M_{CO_2-ind,p} = M_{CO_2-L,p} + \left(\frac{E_{3,p} - E_{1,p}}{E_{2,p} - E_{1,p}}\right) \times \left(M_{CO_2-H,p} - M_{CO_2-L,p}\right) \quad (12)$$

$$M_{CO_2-ind} = M_{CO_2-L} + \left(\frac{E_3 - E_1}{E_2 - E_1}\right) \times \left(M_{CO_2-H} - M_{CO_2-L}\right) \quad (13)$$

$M_{CO2-ind,p}$: Mass of $CO_2$ for individual vehicle, p denotes phase, lack of p denotes overall cycle
$M_{CO2-L,p}$: Mass of $CO_2$ for WLTP-L vehicle, p denotes phase, lack of p denotes overall cycle
$M_{CO2-H,p}$: Mass of $CO_2$ for WLTP-H vehicle, p denotes phase, lack of p denotes overall cycle
$E_{x,p}$: Cycle energy demand per phase, lack of p denotes overall cycle. x indicates: 1 = WLTP-L, 2 = WLTP-H, 3 = WLTP individual vehicle

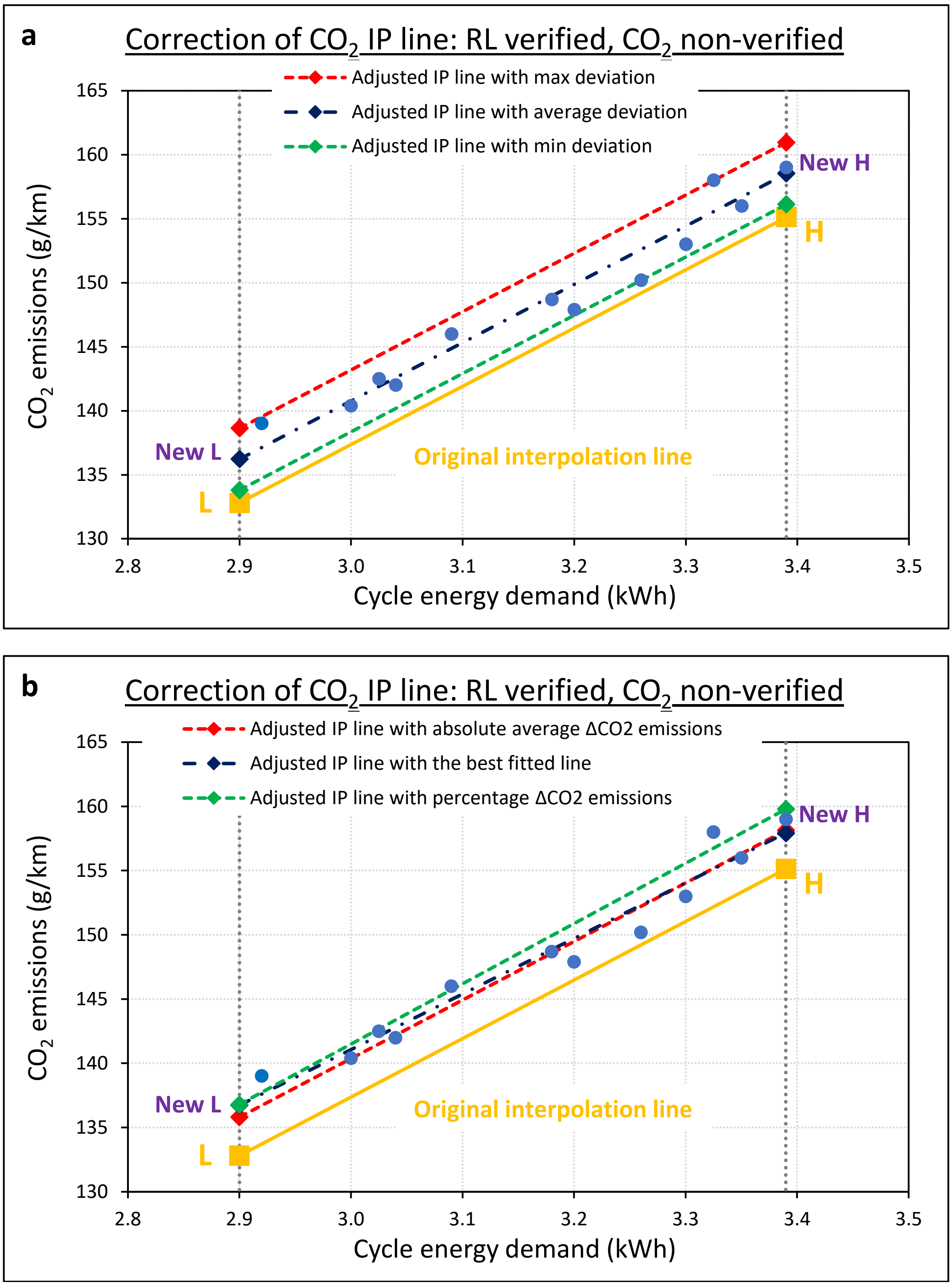



**Figure 44:** Correction of $CO_2$ IP line, in case RL is verified and deviations are found in $CO_2$ emissions (dummy data just for illustration).

### 8.2.2 Road load fail

For this case, the RL of the selected family is not verified and the IP line to which the RL family belongs is verified. Consequently, for all the vehicles of the RL family, the RL coefficients would be corrected based on updated RL interpolation lines. This correction is presented in detail in the following paragraphs utilizing examples in Figure 45 and Figure 46.

The calculation of the RL for an individual vehicle within a RL family is realized by applying the following equations, using the specifications of the individual vehicle and the RL coefficients and specifications of the vehicles High and Low. Coefficient $F_0$ is a function of the product $\boldsymbol{TM} \times \boldsymbol{RR}$. Similarly, the $F_2$ coefficient of the individual vehicle within the RL family is a function of the product $\Delta[\boldsymbol{C_d} \times \boldsymbol{A}]$.

The calculation of the rolling resistance (RR) coefficient is made with the following equation

$$\boldsymbol{RR_x} = (\boldsymbol{RR_{x,FA}} \times \boldsymbol{mp_{x,FA}}) + \left(\boldsymbol{RR_{x,RA}} + (\boldsymbol{1} - \boldsymbol{mp_{x,FA}})\right) \quad (14)$$

x: represents vehicle L, H or an individual vehicle.
$RR_{L,FA}$ and $RR_{H,FA}$: the actual RRCs of the front axle tyres on vehicles L and H respectively, kg/tonne
$RR_{ind,FA}$: the RRC value of the applicable tyre energy efficiency class in accordance with Table A4/2 of Sub-Annex 4 of Annex XXI of Reg. 2017/1151 of the front axle tyres on the individual vehicle, kg/tonne
$RR_{L,RA}$, and $RR_{H,RA}$ are the actual RRCs of the rear axle tyres on vehicles L and H respectively, kg/tonne
$RR_{ind,RA}$: the RRC value of the applicable tyre energy efficiency class in accordance with Table A4/2 of Sub-Annex 4 of Annex XXI of Reg. 2017/1151 of the rear axle tyres on the individual vehicle, kg/tonne
$mp_{x,FA}$: the proportion of the vehicle mass in running order on the front axle
Subsequently, the calculation of the f0 is made as follows:

$$\boldsymbol{f_{0,ind}} = \boldsymbol{f_{0,H}} - \Delta \boldsymbol{f_0} \times \frac{(\boldsymbol{TM_H} \times \boldsymbol{RR_H} - \boldsymbol{TM_{ind}} \times \boldsymbol{RR_{ind}})}{(\boldsymbol{TM_H} \times \boldsymbol{RR_H} - \boldsymbol{TM_L} \times \boldsymbol{RR_L})} \quad (15)$$

The calculation of the Δ(CDA) is performed as follows:

$$\Delta(\boldsymbol{C_D} \times \boldsymbol{A_f})_{\boldsymbol{ind}} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} \Delta\left(\boldsymbol{C_D} \times \boldsymbol{A_f}\right)_{\boldsymbol{i}} \quad (16)$$

$C_D$ is the aerodynamic drag coefficient
$A_f$ is the frontal area of the vehicle, $m^2$
n is the number of items of optional equipment on the vehicle that are different between an individual vehicle and test vehicle L;
$\Delta(C_D \times A_f)i$ is the difference in the product of the aerodynamic drag coefficient multiplied by frontal area due to an individual feature, i, on the vehicle and is positive for an item of optional equipment that adds aerodynamic drag with respect to test vehicle L and vice versa, $m^2$

In the following step, the f2 is calculated as follows:

$$\boldsymbol{f_{2,ind}} = \boldsymbol{f_{2,H}} - \Delta \boldsymbol{f_2} \times \frac{\left(\Delta\left|\boldsymbol{C_d} \times \boldsymbol{A_f}\right|_{\boldsymbol{LH}} - \Delta\left|\boldsymbol{C_d} \times \boldsymbol{A_f}\right|_{\boldsymbol{ind}}\right)}{\left(\Delta\left|\boldsymbol{C_d} \times \boldsymbol{A_f}\right|_{\boldsymbol{LH}}\right)} \quad (17)$$

After the completion of the RL determination of the in-service vehicles, the measured coefficients $F_0$ shall be plotted against the $\boldsymbol{TM} \times \boldsymbol{RR}$ and the measured $F_2$ against the $\Delta[\boldsymbol{C_d} \times \boldsymbol{A}]$. The new $F_0$ and $F_2$ RL coefficients of the Vehicles High (H) and Low (L) shall be defined as the intersect of the best fitting line of the measured values with the $\boldsymbol{TM} \times \boldsymbol{RR}$ and $\Delta[\boldsymbol{C_d} \times \boldsymbol{A}]$ of vehicle H and L, respectively. Figure 45 presents qualitative examples of the correction for F0 and $F_2$ coefficients. With this approach, F0 and $F_2$ are re-calculated, while $F_1$ remains constant and equal to the value reported in the CoC.

As it can be concluded from the above equations, it would be sufficient if the RL coefficients of the vehicles high and low would be corrected. Coefficients of all the intermediate vehicles would then be recalculated from the new/updated RL interpolation lines. The coefficients that are modified are $F_2$ and $F_0$ while $F_1$ is kept constant and equal to the CoC value. The correction of the RL coefficients for the vehicles high and low would be based on the results from the ISV RL determination procedure, and the RL coefficients of the measured RL for the tested vehicles. The possible options for the correction are:

- Option 1: the deviation between the CoC and the ISV resistance curve is calculated for all the tested vehicles and the average deviation is extracted for a 2 km/h step or for representative velocity points (as presented in section "Evaluation of the measured RL and comparison with the TA data" there is a good correlation between ΔCED and ΔForce for 88 km/h). This average deviation is used to increase the CoC resistance curve, and the new RL coefficients are derived by fitting the updated resistance curves of vehicles high and low. An example of this method is presented in Figure 45. Figure 45a presents the difference between CoC and ISV driving resistance for the vehicles tested, and the average deviation. Figure 45b presents the increase (based on the average deviation) of the resistance curves for vehicle high and low of the RL family and the updated coefficients. Finally, Figure 45c and Figure 45d illustrate the updated $F_0$ and $F_2$ interpolation lines respectively.
- Option 2: ISV RL coefficients from a representative vehicle are used to recalculate the new RLs. The vehicle with the maximum deviation in the CoC and ISV CED, and closest to the vehicle's high configuration could be selected as the reference vehicle. An example of these calculation procedures is presented in Figure 48. For this case, the RL coefficients of the vehicle high are calculated using equations (15) and (17), with the unknown parameters being the $\boldsymbol{f_{0,H}}$ and $\boldsymbol{f_{2,H}}$, while the coefficients refereeing to the individual vehicle ($\boldsymbol{f_{0,ind}}$.and $\boldsymbol{f_{2,ind}}$) would be selected from the ISV road load of the reference vehicle. For the example presented in Figure 46, Vehicle 4.2 was selected as the reference vehicle, since it had the maximum ΔCED. For this case, the slope of the two interpolation lines is kept the same as for the TA lines.
- Option 3: considering that the $F_0$ coefficient is strongly dependent on the tyres fitted on the vehicle, it could be assumed that this coefficient would not change during the RL correction. This means that the regression for the corrected RL would allow only the change of the $F_2$ coefficient. Schematically the correction would be similar to the one presented in Figure 45d. for this case since the ΔCED should be covered only by the $F_2$ coefficient, a correlation function $\Delta F_2$=f(ΔCED) can be used. A qualitative example with the application of the RL correction with the modification of $F_2$ only is presented in Figure 47.

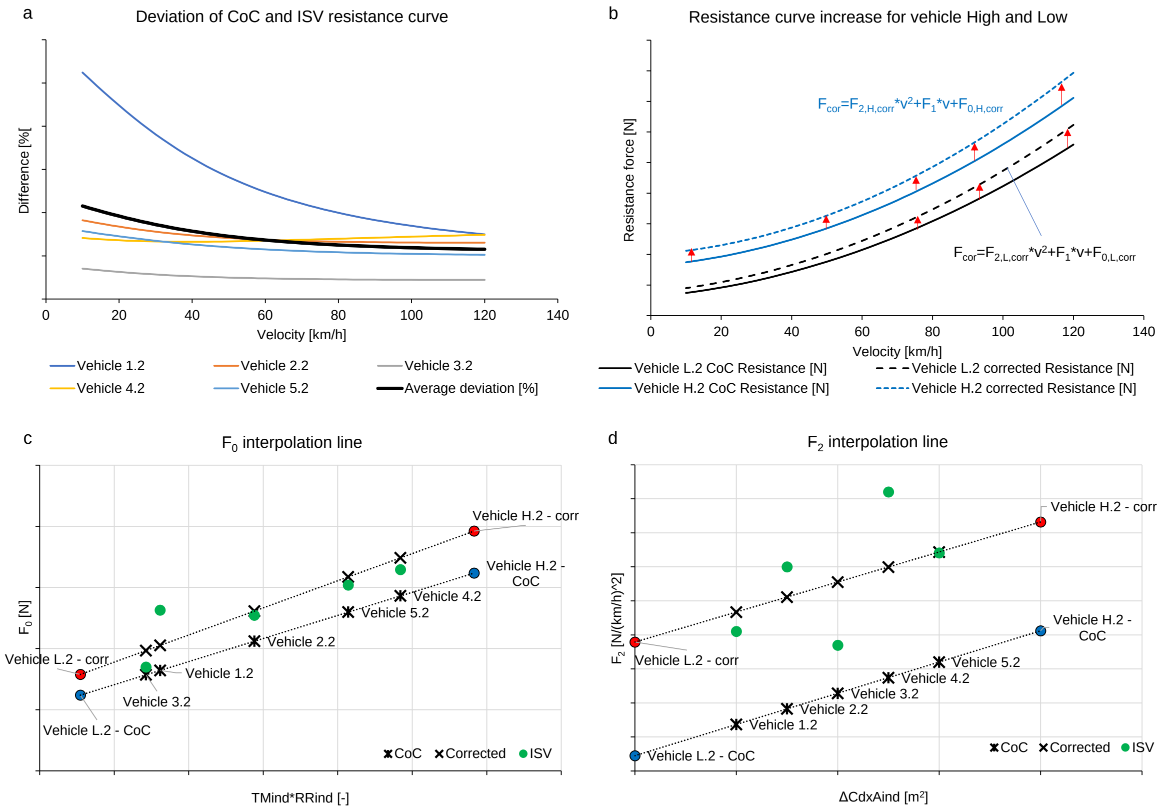



**Figure 45:** Qualitative example of the RL coefficients corrections using the average deviation – Option 1

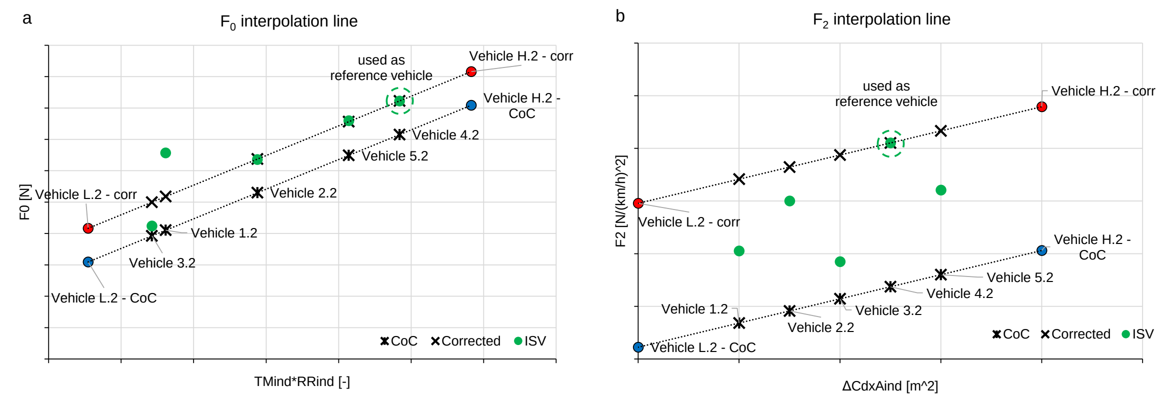



**Figure 46:** Qualitative example of the RL coefficients corrections using the vehicle with the maximum ΔCED as a reference – Option 2

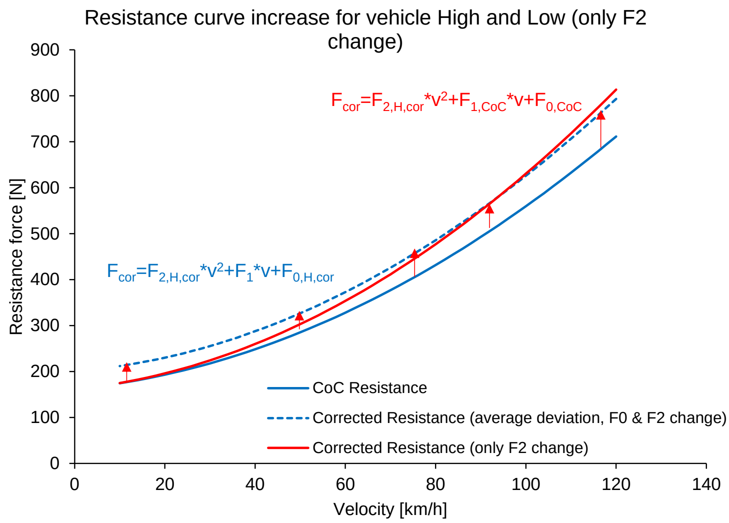



**Figure 47:** Qualitative example for the correction of the RL by modifying only the F2 coefficient – Option 3

With the corrected RL coefficients it is possible to re-calculate the $CO_2$ emissions of the vehicles that belong to the non-verified RL family. Using the verified $CO_2$ interpolation line and the re-calculated CED from the corrected RLs, the new official $CO_2$ emissions are calculated. The correction is schematically presented in Figure 48.

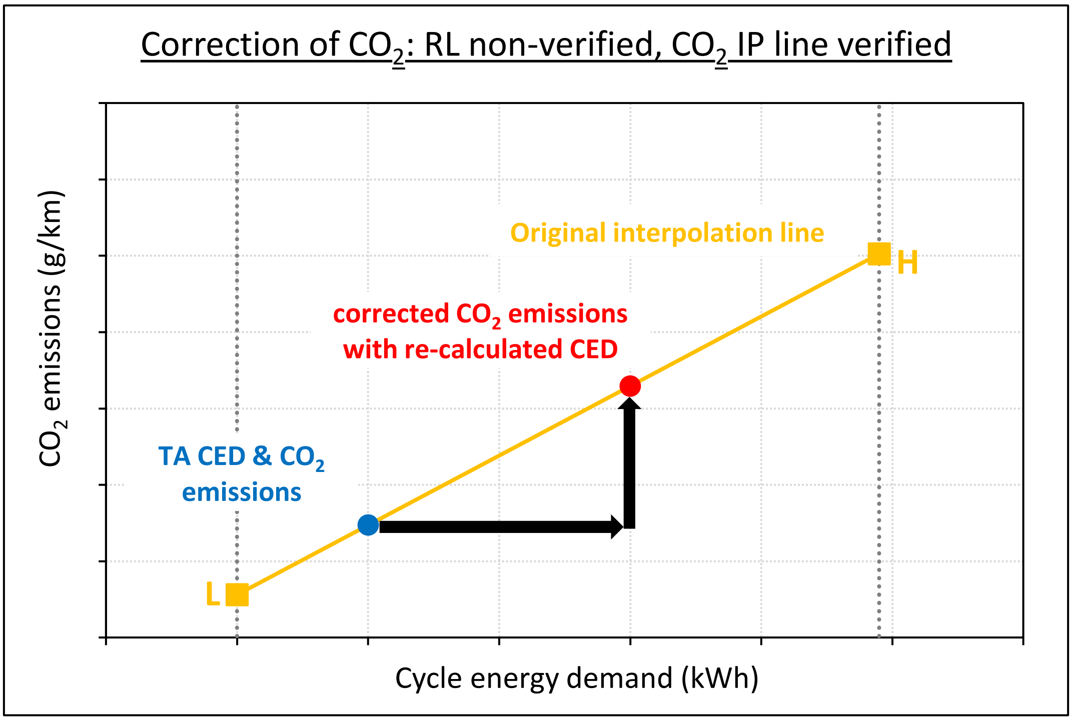



**Figure 48:** Correction of $CO_2$ emissions, in case RL is not verified and the $CO_2$ interpolation line is verified.

### 8.2.3 Road load fail; $CO_2$ emissions fail

The previous paragraphs described the corrections when either the road load or the $CO_2$ emissions were not verified. These two procedures are independent of each other, and they can be applied separately. This addresses the last case when both road loads and $CO_2$ emissions are not verified. This case is expected to be mainly applicable at the sequential approach, where both RL and $CO_2$ verification procedures would take place at the same time for a specific family. In this case, the correction is applied stepwise by initially applying the road load correction according to the agreed provisions for load correction as they were derived from paragraph 8.2.2, where the road load is non-verified. Subsequently, the second correction takes place as described in paragraph 8.2.1. schematically the correction is illustrated in Figure 49. The figure presents the shift of the IP line that is due to the modification of both the CED and the $CO_2$ emissions. In the case where Road load and $CO_2$ emissions fail, then a completely new IP line needs to be created, that is shifted right and upwards, compared to the non-corrected.

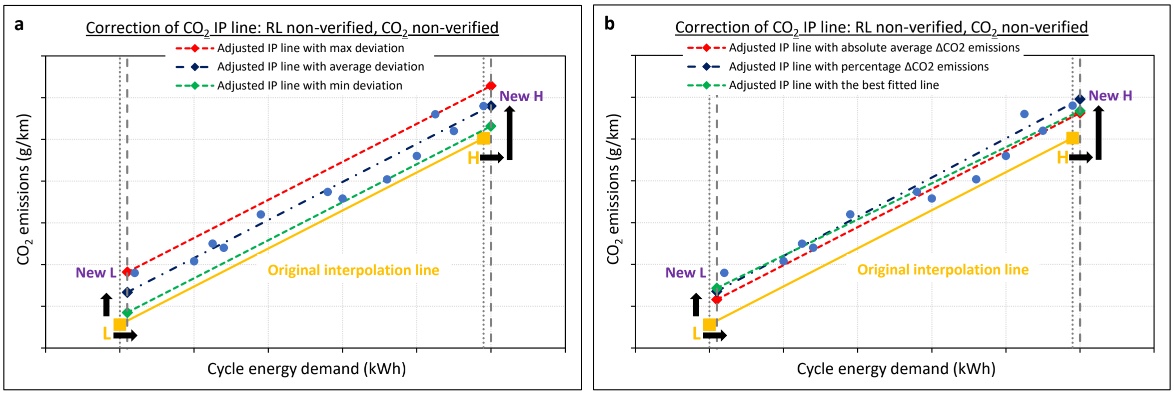



**Figure 49:** Correction of $CO_2$ IP line, in case RL is not verified and deviations are found in $CO_2$ emissions (dummy data just for illustration).

# 9 Summary and overall conclusions

The current study analysed and developed various elements and procedures for the in-service verification (ISV) of $CO_2$ emissions of new LDV and HDV as foreseen in Regulations (EU) 2019/631 (Article 13 and Article 7(9)) and 2019/1242 (Article 13 and Article 9). The aim of such procedures shall be to verify the correspondence of the certified $CO_2$ emissions with the performance of vehicles in-service on the same type-approval procedure, as well as to detect strategies aiming at artificially improving $CO_2$ emissions during type approval (TA).

Initially in this context, a screening of the relevant existing regulations was conducted, covering legislations from both the EU and other areas of the world. The target was to identify elements and procedures of those legislations that could be useful for the ISV of $CO_2$ emissions. To that aim, and after analysing the various regulations, some useful elements were isolated and were further used as input to the development of the actual ISV procedures.

In the next step, the main guiding principles of the ISV procedure were developed, considering different verification options (testing and simulation), and covering all the main elements of the procedure, such as vehicle categories, responsible parties and funding of the procedure, family criteria, sample share and frequency, risk assessment, vehicle selection, sample size, quality assurance, deviations, statistical procedures, corrections, reporting.

After making the general outline of the ISV procedure, the actual methodologies were developed, covering three main elements:

i. Verification procedure for the road load (equivalently, cycle energy demand)
ii. Verification procedure for $CO_2$ emissions
iii. Procedures for detecting strategies aiming at an artificial improvement of the vehicle $CO_2$ performance in the type approval

Two approaches were examined, as follows:

1. "parallel" approach, where each one of the above elements (i-iii) practically runs independently
2. "sequential" approach, where the above elements (i-iii) run in order –element [ii] depends on element [i], while the procedure may integrate some indicative flags for element [iii]

The advantages and disadvantages of each approach were evaluated. However, independently of the followed approach, the actual methodologies for the verification are the same and practically replicate the type-approval procedure. The evaluation is made on the family level and the decision is made according to a statistical procedure, applying the necessary pass/fail criteria, similar to the CoP procedure. For the evaluation of the statistical procedure, indicative results have been produced, showing the pass rate for various combinations of the statistical parameters. Particular values for cycle energy demand and $CO_2$ emissions have been also calculated.

After the testing activities of the ISV procedure and according to the outcome of the decision based on the statistical procedure, the necessary corrections shall be applied. Different cases have been identified here, depending on the pass or fail of the RL (CED) and $CO_2$ emissions. In all cases, an updated value of $CO_2$ emissions is determined, while in case of fail of the RL, then RL coefficients are also corrected to ensure consistency of the values reported on the CoC.

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# Annex I – Guiding principles for HDVs

The Commission requested the CLOVE consortium to indicate if the elements identified for the Task 2 ISV procedure on LDVs could act as a template for the ISV procedure on HDVs. The table below includes an overview of all the elements identified for the LDV procedure, indicating to what extent these elements could be applicable for HDVs as well as what the main differences are.

| |
|---|
| 1. **Objectives of ISV testing; *Which tests are performed, and the measurands to be recorded***<br>The type approval tests for the determination of the CoC $CO_2$ values are fundamentally different between LDVs and HDVs. Where the LDV type approval procedure is based on a chassis dynamometer test, the HDV certification is based on the simulation tool VECTO with input data from component certification tests. The most promising option for an ISV test on HDVs is to use an on-road VTP test which has already been put in place for CoP purposes. The on-board measured fuel consumption is compared against the simulated fuel consumption for this on-road test, as calculated by the VECTO tool on the basis of certified input data. The ratio of measured to simulated fuel consumption can be used as indicator for correction of the declared CoC $CO_2$ value of single vehicle models and consequently of the manufacturers vehicle fleet. Advantage of this verification test is that it is also able to detect any strategies to artificially improve $CO_2$ emission performance during type approval. |
| 2. **Scope of vehicle categories;** *To what vehicle categories will the procedure be applied*<br>The scope of vehicle categories to be included in the $CO_2$ ISV procedure is defined in Article 2 of the main $CO_2$ Regulation (EU)2019/1242[54]. |
| 3. **Responsible parties;** *Define the responsibility for each party involved*<br>Same concept as for LDVs. |
| 4. **Funding of ISV test activities**<br>Same concept as for LDVs. |
| 5. **Family criteria for ISV test;** *Define an ISV family to reduce testing burden*<br>Each vehicle has its own CoC $CO_2$ values, there are no options foreseen to define a vehicle family. |
| 6. **Minimum sample share and frequency;**<br>Same concept as for VTP, sample share and frequency could be based on the total vehicle production volume of the manufacturer. |
| *7.* **Risk assessment methodology**; *Methods to improve the selection process and increase cost-effectiveness of the implementation of the regulation*<br>Same approach as for LDVs, but based on the available data information sources for HDVs. |
| 8. **Test vehicle selection, acquisition and preparation**<br>Mostly based on the procedure for test vehicle selection and preparation as described for PEMS ISC testing and/or VTP |
| 9. **Minimum and maximum sample size for the ISV test;**<br>Same concept as for VTP, sample size is restricted to only one vehicle |
| 10. **Scope of necessary type approval data and their secure exchange**<br>The same concept as for LDVs can be applied. For HDVs the input data are highly confidential, possibly the accreditation procedure needs to be more strict than for LDVs. Note that data availability for ITPs is not fully clear from Regulation (EU) 2018/858. Access is needed to the input information file, the manufacturer record file, the customer information file and to the certificates of components (in the case that deviations are observed) |
| 11. **Quality assurance method;** *Accreditation of testing laboratories*<br>Same concept as for LDVs, quality criteria may need to be extended to the proper use of wheel torque sensors. |
| 12. **Test fuel**<br>Considering that the HDV ISV procedure will largely be based on the VTP it makes sense to have the same requirement, i.e. using reference fuel. |
| 13. **Road load setting**<br>Not applicable for HDVs if the ISV is based on the VTP, which is an on-road test. |
| *14.* **Corrections**; *Additional correction factors such as $K_i$ , ATCT, and RCB*<br>Not applicable for (current) HDVs. If OVC-HEVs become available in the future, RCB correction might be added to the VTP. |
| 15. **Other requirements to ensure un-biased testing**<br>Less relevant for on-road tests such as the VTP, but there are general provisions specified regarding e.g. the shares of urban, rural and motorway driving, ambient temperature window, idling at standstill and maximum altitude. |

[54] Refer to https://eur-lex.europa.eu/eli/reg/2019/1242

| |
|---|
| 16. **Type of tests for ISV**<br>The CoP VTP is already in place, and is seen as the most preferred candidate for ISV. The options to extend this CoP VTP to an in-service verification (ISV) test procedure are currently elaborated within SR 1 of this framework contract. The VTP is based on an on-road test during which the actual fuel consumption, wheel torque vehicle speed and other relevant parameters are measured. Verification is determined from the ratio between measured and simulated fuel consumption, which is then applied to the declared $CO_2$ emissions. To complete the ISV, a verification of the tyre RRC and airdrag should be added. Note that the VTP is tailored to allow verification testing by ITPs. |
| 17. **Tolerance**; *Reference value and allowed deviation from type approval results*<br>The same approach as for LDVs can be applied to determine a suitable tolerance for the HDV ISV. The accuracy requirements for the VTP provide more stringency as those of the ISC PEMS testing. |
| 18. **Pass/fail evaluation criteria statistics**<br>The same pass/fail evaluation as for the VTP can be applied as a basis, possibly reviewed to serve the purpose of ISV testing. |
| 19. **Outliers**; *How to treat large deviations*<br>Not applicable, the VTP result is evaluated over a longer route. If necessary, a second VTP check could take place. |
| 20. **Adjustment of CoC value for ISV family**; *consequences in the case that a fail decision is reached*<br>Same approach as for LDVs, based on the ratio between measured and simulated fuel consumption which is applied to the declared $CO_2$ emission |
| 21. **Reporting**<br>Same concept as for LDVs |

# Annex II – Methodologies for RRC determination of the in-service test vehicle

The correction of the RL due to different tyre RRC class described in paragraph 5.3.4, requires that the RRC class of the tyres fitted on the test car is known. In case that the RRC is not known, then it may be defined during the road load determination procedure. For the determination of the RRC of the ISV tested vehicle three methods can be applied:

- Calculation of the RRC from the measured $F_0$ coefficient and the vehicle test mass
- Acceleration test at a road with constant slope

Considering that the vehicle resistance curve is described from equation (18), the $F_0$ coefficient is mainly connected to the rolling resistance force, equation (5) (Komnos et al., 2020). The correlation between driving resistance and road load formula (F0, F1 & F2) is included in Annex V. Based on the equation (19) it is possible to estimate the RRC using the test mass and the measured F0.

$$\boldsymbol{F_{resistance} = F_0 + F_1 \cdot v + F_2 \cdot v^2} \quad (18)$$

$$\boldsymbol{F_0 = RRC \cdot TM \cdot 9.81} \quad (19)$$

Where:

| | |
|---|---|
| $\boldsymbol{RRC}$ | Rolling Resistance Coefficient [-] |
| $\boldsymbol{TM}$ | Test mass [kg] |

From the CoC data found in the TNO report (vehicles 9-14) and additional tested vehicles (vehicles 1-8) by the CLOVE consortium, the official $F_0$ RL coefficient and the reported test masses were taken and used to calculate the RRC for each vehicle. The estimated value of RRC was compared to the reported in the CoC tire efficiency label. This comparison was performed to check if it is possible to evaluate the correspondence between the RRC reported in the CoCs of the vehicles, and the RRC calculated (using equation (19)) from the $F_0$ and test mass reported in the CoC. In Figure 50 the comparison between the tire label (blue) and the calculated RRC (red) (from TA F0 and test mass) is presented along with the calculated RRC from the test mass and the $F_0$ derived by the coast down test. Considering though the range of each tire efficiency class for the C1 tires (error bars) the calculation accuracy may be considered acceptable. For tire labels only the efficiency class (average value) is reported thus the actual RRC of the tire lays within the range of each class. As a result, the F0 RL coefficient can be described with equation (19) and can be applied to calculate the RRC of the tested vehicle. The calculation of RRC using the equation (19) can be applied in case of a coast down test and used to estimate the RRC of the tyres fitted on the ISV vehicle. For comparison, the RRC calculated (with equation (19)) using the F0 as defined during the coast down test of these vehicles is presented with green bars.

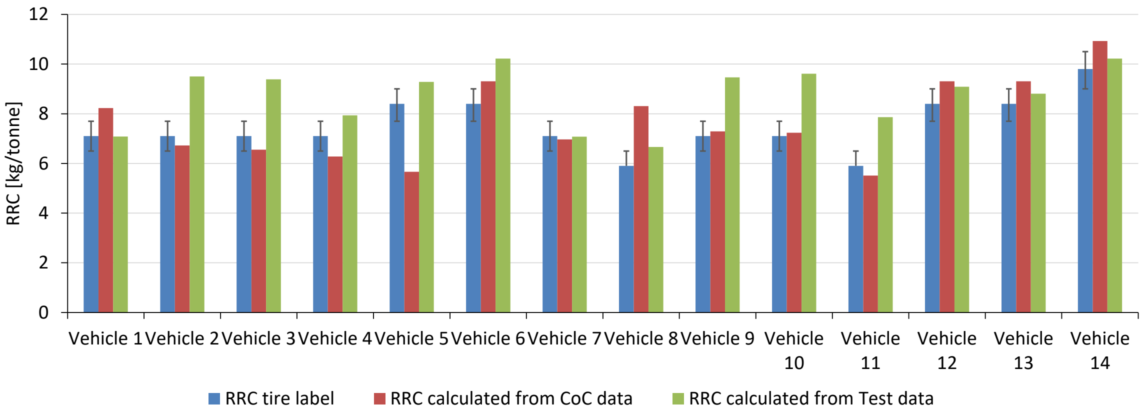



**Figure 50:** Comparison of calculated RRC and tire label

Another method to determine the RRC is to perform an acceleration test (up to 30 km/h) at a road with known gradient. Starting from zero speed, the vehicle is left to accelerate freely at a velocity <30 km/h where contribution of the quadratic term of the driving resistance formula can be neglected (Roussillon, 1981). The vehicles were weighted at a weighbridge, and the acceleration test was performed in a road with constant slope. The experimental campaign was performed by CLOVE consortium in Thessaloniki, Greece with two light commercial vehicles (LCV1 and LCV2). During the test vehicle velocity was recorded while the maximum speed that the vehicles reached before braking was lower than 30 km/h. For the two LCVs the RRC was calculated from the slope acceleration test using the equation (21). Each test (different testing day) included more than one repetitions, meaning that the velocity at the same downhill road was recorded for 3-8 consecutive times. For each repetition the RRC was calculated (Rep i) while for the different tests an average RRC (Test i Average RRC) was also calculated from the resulted RRC of each repetition. Results for RRC calculation of LCV 1 and LCV 2 are presented respectively in Figure 51 and Figure 52. The results indicate that the calculation based on this method has a high variability between the different repetitions. Furthermore, this methodology is mainly affected by the slope of the road where the test is performed, thus road grade needs to be accurately determined. However, average RRC from all the tests is within the lower and higher limit of the efficiency class of the tires which were for both vehicle C2 tyres.

This pethood for the determination of the RRC may increase the test burden and the total cost of the ISV RL determination during.

$$\boldsymbol{RR_m} = \frac{\sum_{i=1}^{N} \boldsymbol{RRC_i}}{\boldsymbol{N}} \quad (20)$$

Where:

$$\boldsymbol{RRC_i} = \boldsymbol{tan(\varphi)} - \frac{\boldsymbol{1}}{\boldsymbol{9.81 co\, s(\varphi)}} \cdot \boldsymbol{\alpha_i}$$

| | |
|---|---|
| $N$ | Total test duration [sec] |
| $RRC_i$ | Instantaneous rolling resistance coefficient at second i, with step equal to 1sec [kg/tonne] |
| $\varphi$ | Road gradient [rad] |
| $a_i$ | Instantaneous vehicle acceleration at second i, with step equal to 1sec [m/s$^2$] |

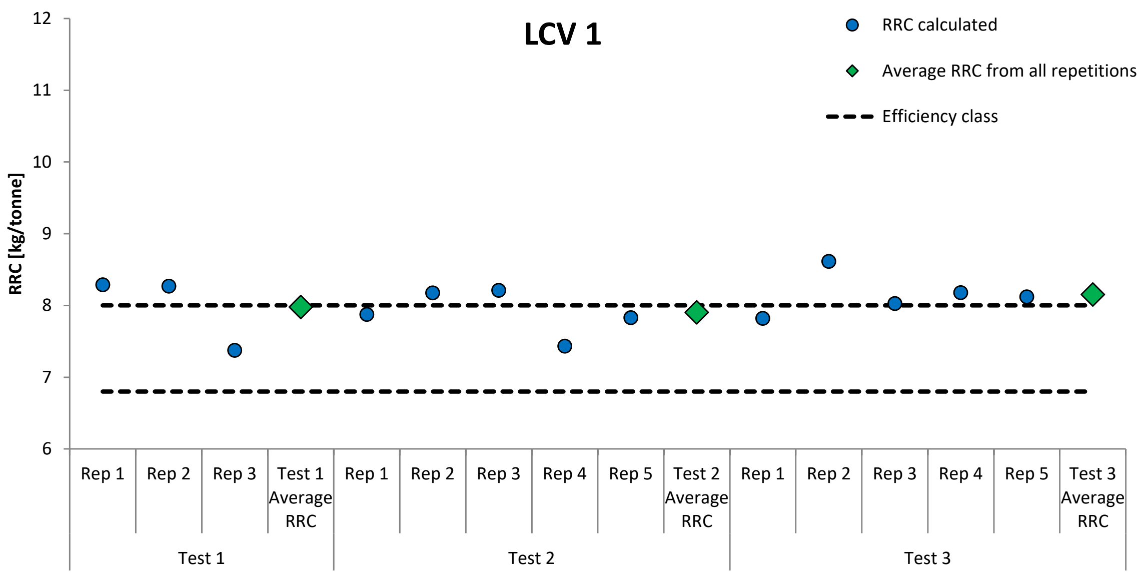



**Figure 51:** Calculation of tyre RRC and comparison with the tyre efficiency class – LCV 1

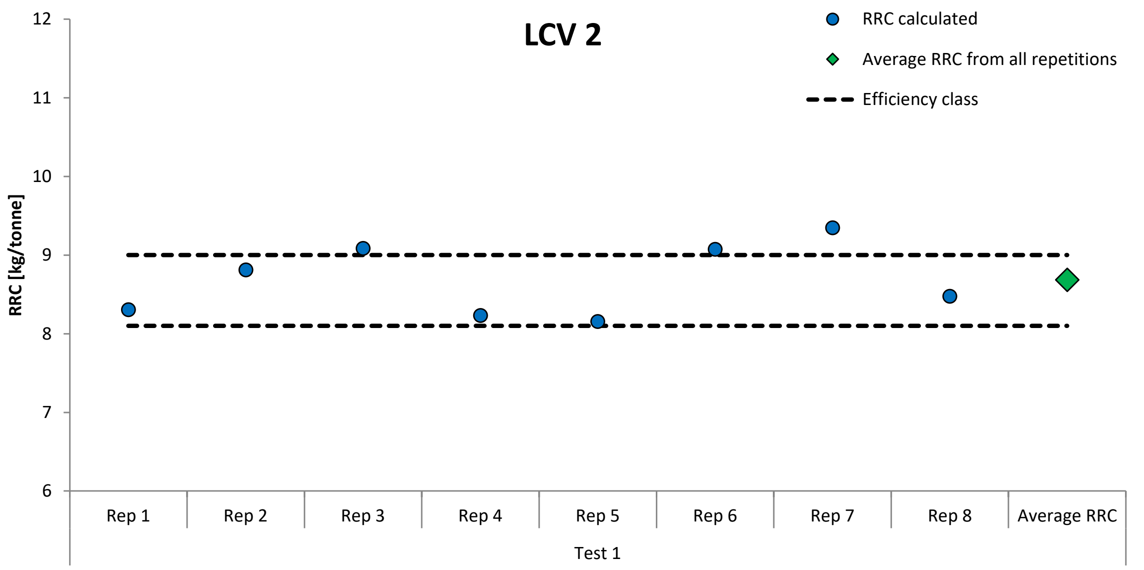



**Figure 52:** Calculation of tyre RRC and comparison with the tyre efficiency class – LCV 2

# Annex III – Check list for vehicle inspection prior to ISV testing

The table below is taken from the discussion paper of the ISV-Group meeting of 15 December 2021

**Selection of Vehicles for In Service Verification Testing**

*Source: Appendix 1 of Annex II of Regulation (EU) 2017/1151. Proposed changes for a potential application for a vehicle selection protocol for ISV purposes are highlighted yellow.*

| | | X = Checked and reported | Confidential |
|---|---|---|---|
| **Date:** | | | X |
| **Name of investigator:** | | | X |
| **Location of test:** | | | X |
| **Country of registration (in EU only):** | | X | |

| Vehicle Characteristics | X = Exclusion Criteria | X = Checked and reported | Confidential |
|---|---|---|---|
| **Registration plate number:** | | X | X |
| **Mileage:** *The vehicle must have a mileage higher than 3 000 km* | X | | |
| **Date of first registration:** *The vehicle must not be older than 2 years* | X | | |
| **VIN:** | | X | |
| **Emission class and character:** | | X | |
| **Country of registration:** *The vehicle must be registered in the EU* | X | X | |
| **Model:** | | X | |
| **Engine code:** | X | | |
| **Engine volume (l):** | | X | |
| **Engine power (kW):** | | X | |
| **Gearbox type (auto/manual):** | | X | |
| **Drive axle (FWD/AWD/RWD):** | | X | |
| **Tyre size (front and rear if different):** | | X | |
| **Is the vehicle involved in a recall or service campaign? If yes: Which one? Has the campaign repairs already been done?** *The repairs must have been done* | X | X | |

## Vehicle Owner Interview

*(The owner will only be asked the main questions and shall have no knowledge of the implications of the replies)*

| | **Confidential** |
|---|---|
| **Name of the owner (only available to the accredited inspection body or laboratory/technical service)** | **X** |
| **Contact (address / telephone) (only available to the accredited inspection body or laboratory/technical service)** | **X** |

| | **X = Exclusion Criteria** | **X = Checked and reported** | **Confidential** |
|---|---|---|---|
| **How many owners did the vehicle have?** | | **X** | |
| **Did the odometer not work?**<br>*If yes, the vehicle cannot be selected.* | **X** | | |
| **Was the vehicle used for one of the following?** | | | |
| As car used in show-rooms? | | **X** | |
| As a taxi? | | **X** | |
| As delivery vehicle? | | **X** | |
| For racing / motor sports? | **X** | | |
| As a rental car? | | **X** | |
| **Has the vehicle carried heavy loads over the specifications of the manufacturer?**<br>*If yes, the vehicle cannot be selected.* | **X** | | |
| **Have there been major engine or vehicle repairs?** | | **X** | |
| **Have there been unauthorised major engine or vehicle repairs?**<br>*If yes, the vehicle cannot be selected.* | **X** | | |
| **Has there been a power increase/tuning?**<br>*If yes, the vehicle cannot be selected.* | **X** | | |
| **Was any part of the emissions after-treatment and/or the fuel system replaced? Were original parts used?**<br>*If original parts were not used, the vehicle cannot be selected.* | **X** | **X** | |
| **Was any part of the emissions after-treatment system permanently removed?** *If yes, the vehicle cannot be selected* | **X** | | |
| **Were there any unauthorised devices installed (Urea killer, emulator, etc.)?**<br>*If yes, the vehicle cannot be selected* | **X** | | |
| **Was the vehicle involved in a serious accident? Provide a list of damage and repairs done afterwards** | | **X** | |
| **Has the car been used with a wrong fuel type (i.e. gasoline instead of diesel) in the past? Has the car been used with non-commercially available EU-quality fuel (black market, or blended fuel?)**<br>*If yes, the vehicle cannot be selected.* | **X** | | |
| ~~**Did you use air-fresher, cockpit-spray, brake cleaner or other high hydrocarbon emission source around the vehicle during the last month?**~~<br>~~*If yes, the vehicle cannot be selected for evaporative testing.*~~ | ~~**X**~~ | | |
| ~~**Was there a gasoline spill in the inside or outside of the vehicle during the last 3 months?**~~<br>~~*If yes, the vehicle cannot be selected for evaporative testing.*~~ | ~~**X**~~ | | |

| | X = Exclusion Criteria | X = Checked and reported | Confidential |
|---|---|---|---|
| ~~**Did anyone smoke in the car during the last 12 months?**~~<br>~~*If yes, the vehicle cannot be selected for evaporative testing*~~ | ~~X~~ | | |
| ~~**Did you apply corrosion protection, stickers, under seal protection, on any other potential sources of volatile compounds to the car?**~~<br>~~*If yes, the vehicle cannot be selected for evaporative testing*~~ | ~~X~~ | | |
| ~~**Was the car repainted?** *If yes, the vehicle cannot be selected for evaporative testing*~~ | ~~X~~ | | |
| **Where do you use your vehicle more often?**<br>% motorway | | X | |
| % rural | | X | |
| % urban | | X | |
| **Did you drive the vehicle in a non EU Member State for more than 10 % of driving time?**<br>*If yes, the vehicle cannot be selected* | X | — | |
| **In which country was the vehicle refuelled during the last two times?**<br>*If the vehicle was refuelled the last two times outside a state applying the EU Fuel Standards, the vehicle cannot be selected.* | X | | |
| **Has a fuel additive, not approved by the manufacturer been used?**<br>*If yes then the vehicle cannot be selected.* | X | | |
| **Has the vehicle been maintained and used in accordance with the manufacturer's instructions?**<br>*If not, the vehicle cannot be selected.* | X | | |
| **Full service and repair history including any re-works**<br>*If the full documentation cannot be provided, the vehicle cannot be selected.* | X | | |

## Vehicle Examination and Maintenance

| | | X = Exclusion Criteria/ F = Faulty Vehicle | X = checked and reported |
|---|---|---|---|
| 1 | **Fuel tank level (full / empty)** Is the fuel reserve light ON? *If yes, refuel before test.* | | X |
| 2 | **Are there any warning lights on the instrument panel activated indicating a vehicle or exhaust after-treatment system malfunctioning that cannot be resolve by normal maintenance? (Malfunction Indication Light, Engine Service Light, etc?)**<br>*If yes, the vehicle cannot be selected* | X | |
| 3 | **Is the SCR light on after engine-on?**<br>*If yes, the AdBlue should be filled in, or the repair executed before the vehicle is used for testing.* | X | |
| 4 | **Visual inspection exhaust system** Check leaks between exhaust manifold and end of tailpipe. Check and document (with photos)<br>*If there is damage or leaks, the vehicle is declared **faulty**.* | F | |
| 5 | **Exhaust gas relevant components** Check and document (with photos) all emissions relevant components for damage.<br>*If there is damage, the vehicle is declared **faulty**.* | F | |

| | | X = Exclusion Criteria/ F = Faulty Vehicle | X = checked and reported |
|---|---|---|---|
| ~~6~~ | ~~**Evap system** Pressurize fuel-system (from canister side), testing for leaks in a constant ambient temperature environment, FID sniff test around and in the vehicle.~~<br>~~*If the FID sniff test is not passed, the vehicle is declared **faulty**.*~~ | ~~F~~ | |
| 7 | **Fuel sample** Collect fuel sample from the fuel tank. | | X |
| 8 | **Air filter and oil filter** Check for contamination and damage and change if damaged or heavily contaminated or less than 800 km before the next recommended change. | | X |
| ~~9~~ | ~~**Window washer fluid (only for evaporative testing)** Remove window washer fluid and fill tank with hot water.~~ | | ~~X~~ |
| 10 | **Wheels (front & rear)** Check whether the wheels are freely moveable or blocked by the brake.<br>*If not, the vehicle cannot be selected.* | X | |
| ~~11~~ | ~~**Tyres (only for evaporative testing)** Remove spare tyre, change to stabilised tyres if the tyres were changes less than 15 000 km ago. Use summer and all season tyres only.~~ | | ~~X~~ |
| ~~12~~ | ~~**Drive belts & cooler cover** *In case of damage, the vehicle is declared faulty. Document with photos*~~ | ~~F~~ | |
| 13 | **Check fluid levels** Check the max. and min. levels (engine oil, cooling liquid) / top up if below minimum | | X |
| ~~14~~ | ~~**Filler flap (only for evaporative testing)** Check overfill line within filler flap is completely free of residues or flush the hose with hot water.~~ | | ~~X~~ |
| 15 | **Vacuum hoses and electrical wiring** Check all for integrity. *In case of damage, the vehicle is declared faulty. Document with photos* | F | |
| 16 | **Injection valves / cabling** Check all cables and fuel lines. *In case of damage, the vehicle is declared faulty. Document with photos* | F | |
| 17 | **Ignition cable (gasoline)** Check spark plugs, cables, etc. In case of damage, replace them. | | X |
| 18 | **EGR & Catalyst, Particle Filter** Check all cables, wires and sensors. *In case of tampering, the vehicle cannot be selected. In case of damage the vehicle is declared Faulty, Document with photos* | X/F | |
| 19 | **Safety condition** Check tyres, vehicle's body, electrical and braking system status are in safe conditions for the test and respect road traffic rules.<br>*If not, the vehicle cannot be selected.* | X | |
| 20 | **Semi-trailer** Are there electric cables for semi-trailer connection, where required? | | X |
| 21 | **Aerodynamic modifications** Verify no aftermarket aerodynamics modification that cannot be removed before testing was made (roof boxes, load racking, spoilers, etc.) and no standard aerodynamics components are missing (front deflectors, diffusers, splitters, etc.). *If yes, the vehicle cannot be selected. Document with photos.* | X | |
| 22 | **Check if less than 800 km away from next scheduled service, if yes, then perform the service.** | | X |
| 23 | **All checks requiring OBD connections to be performed before and/or after the end of testing** | | |
| 24 | **Powertrain Control Module calibration part number and checksum** | | X |
| 25 | **OBD diagnosis (before or after the emissions test)** Read Diagnostic Trouble Codes & Print error log | | X |
| 26 | **OBD Service Mode 09 Query (before or after the emissions test)** Read Service Mode 09. Record the information. | | X |

| | | X = Exclusion Criteria/ F = Faulty Vehicle | X = checked and reported |
|---|---|---|---|
| 27 | **OBD mode 7 (before or after the emissions test)** Read Service Mode 07. Record the information | | |

**Remarks for: Repair / replacement of components / part numbers**

# Annex IV – Simulation approach for WLTP/Real World $CO_2$ emissions determination

The simulation approach was tested with the two simulation tools $CO_2$MPAS and PHEM (Passenger Car and Heavy-duty Emission Model). The aim is to use simulation models to predict the WLTC $CO_2$ emissions using calibration data from real world/RDE test or predict real world $CO_2$ from official WLTC data. The approach shall give an indication of possible irregular $CO_2$ emission behaviour between WLTC and PEMS tests. Therefore, measurement data from WLTC and PEMS tests are needed for this approach. In a first step, the method was investigated for two conventional diesel vehicles and one conventional gasoline vehicle. Table 26 shows the vehicle data and available tests used to investigate the simulation approach.

**Table 26:** Vehicles used to investigate the simulation approach

| Vehicle | Emission standard | $P_{rated}$ @ $n_{rated}$ | Gearbox | Available tests |
|---|---|---|---|---|
| **Vehicle A** | Euro 6b diesel | 82 kW @ 3500 rpm | 6-speed MT | 1x WLTC cold, 4x RDE tests |
| **Vehicle B** | Euro 6c diesel | 66 kW @ 4000 rpm | 5-speed MT | 1x WLTC cold, 1x WLTC hot, 2x RDE tests |
| **Vehicle C** | Euro 6d-Temp gasoline | 85 kW @ 5000 rpm | 7-speed DCT | 1x WLTC cold, 1x WLTC hot, 2x RDE tests |

The test mass and RL for WLTC from the vehicles A, B, and C were known and used for the simulation of the WLTC. Test mass and RL for the simulation of the RDE tests were derived from the WLTC test data, taking into account an increased mass and a 10%[55] increased $C_d$ (aerodynamic drag coefficient) value due to the mounted PEMS.

The simulation and comparison with measured data was performed as follows:

1. Setting up the simulation model with WLTC data and WLTC simulation for each vehicle in case there is a WLTP test available or use the WLTC calibration timeseries of vehicle High or Low DICE database
2. Adjusting the test mass, RL and auxiliary power demand (e.g. to include activated HVAC) in the simulation model to simulate the RDE tests for each vehicle
3. Compare of the simulation results with the measured RDE data[56]

**Simulation with $CO_2$MPAS**

For the simulation using $CO_2$MPAS, des two different approaches were tested:

- Calibration of $CO_2$MPAS using measured data from PEMS testing and calculate WLTP fuel consumption/$CO_2$ emissions

Calibration of $CO_2$MPAS using measured WTLP data and calculate real world fuel consumption/$CO_2$ emissions for a given RDE mission profile.

[55] Determined by coast-down tests with and without PEMS using a C-segment vehicle.
[56] One could also use the RDE test to set up the model and then simulate the WLTC. Due to uncertain wind and road gradient data, the engine load is also uncertain in RDE. As a consequence, the engine fuel map cannot be calibrated with RDE tests as well as with a WLTC.

For the vehicles mentioned in Table 26 the $CO_2$MPAS input files were prepared. The necessary input data were retrieved from the vehicles CoC, the specifications sheet or official brochure and from online databases. For the calibration cycle the following input data were inserted as input to the model:

- OBD velocity [km/h]
- OBD engine speed [rpm]
- OBD engine coolant temperature [oC]
- OBD Calculated engine load [%]
- Altitude [m] in case a PEMS test was used for calibration

For the calibration cycle the time series for 12V battery and alternator current are needed as input, the main source of the official data would be the DICE database (for vehicles High and Low) and monitoring data. For the cases examined by the time of this report such information was not available for the vehicles tested and an option to replace these time series with generic data is investigated.

In the case of $CO_2$MPAS calibration with PEMS data, two different cycles in terms of driver's aggressiveness were used. One cycle was with normal driving while the other included dynamic driving with frequent and abrupt accelerations and decelerations. The aggressiveness[57] of the driver is quantified with the $v{*}a_{pos}$ 95% compared to RDE limits, Figure 53. The selection of the two different cycles was made to investigate the sensitivity of the calculation of WLTP with the different driving styles.

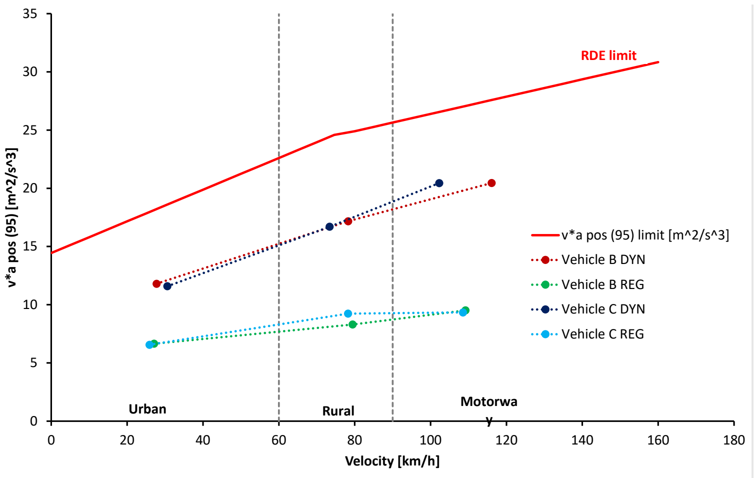



**Figure 53:** Driving dynamics for the RDE tests used in the simulation

In the case of $CO_2$MPAS calibration with WLTP data, the WLTP experimental recordings were used as input to the calibration cycle. To simulate the CO2 emissions under the RDE mission profiles, the velocity and altitude profiles were provided as input. At this point it is important to state that for the vehicles simulated the road load was calculated from a coast down test and the actual mass was defined by weighting the car. These data were retrieved from the experimental campaign realized by CLOVE. Regarding the RDE mission profile, for both vehicles all the trips used were compliant with the RDE regulation. For the simulation of both WLTP and RDE cycles the same (measured) road load was used since the chassis dyno tests were also realized with the measured road load.

The accuracy of this simulation approach was evaluated by comparing the $CO_2$MPAS prediction with the measured data. Figure 54, Figure 55 and Figure 56 present the comparison between $CO_2$MPAS prediction and experimental data for Vehicle A (only simulation of RDE cycles with WLTP calibration),

[57] RDE MOD REG: RDE compliant trip with moderate environmental conditions and normal driving
RDE MOD DYN: RDE compliant trip with moderate environmental conditions and aggressive driving (v*a pos 95 on RDE limits)

Vehicle B and Vehicle C, respectively. For vehicle A there were 4 different RDE (2 cold and 2 hot) measurements available and a WLTP that used for model calibration. For the vehicles B and C there were 2 RDE tests available with different driving style, one with regular (RDE MOD REG) and one with dynamic (RDE MOD DYN) driving, and a WLTP test. The comparison indicates that for all the examined cases the deviation between measurement and simulation is within ±5%, except of one case for Vehicle C where the difference is at 10%. This case is under investigation to identify the root of such deviation, in collaboration with the JRC. From these initial results it can be concluded that regardless the calibration cycle, the achieved accuracy is similar for all the cases. Further investigation on the sensitivity of $CO_2$ prediction from the selected calibration cycle is planned for the next steps. The main goal is to ensure that even if WLTP does not cover the same operating area (as regards the engine operating points, i.e. fuel consumption and torque map) as the RDE one, it is still suitable to be used for model calibration and real-world $CO_2$ emissions prediction with $CO_2$MPAS.

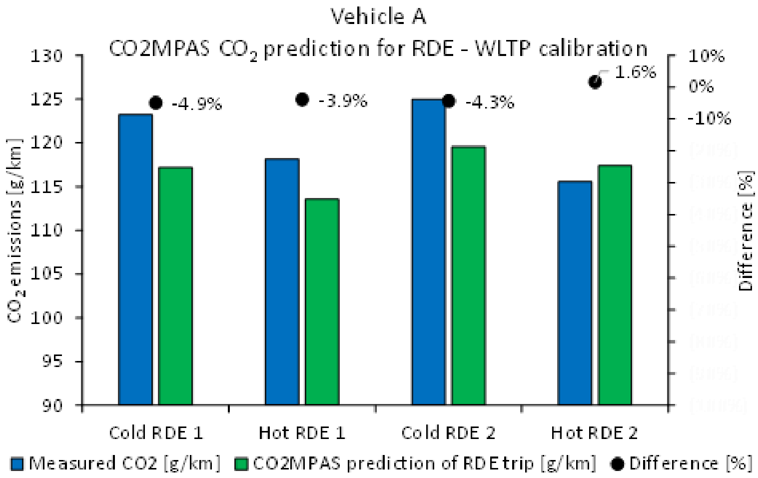



**Figure 54:** Comparison of $CO_2$MPAS prediction and measured CO2 emissions for Vehicle A

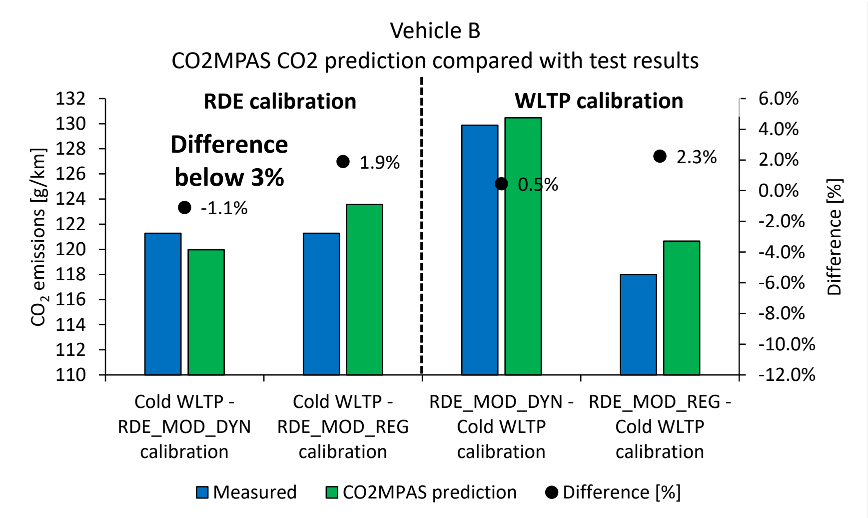



**Figure 55:** Comparison of $CO_2$MPAS prediction and measured CO2 emissions for Vehicle B

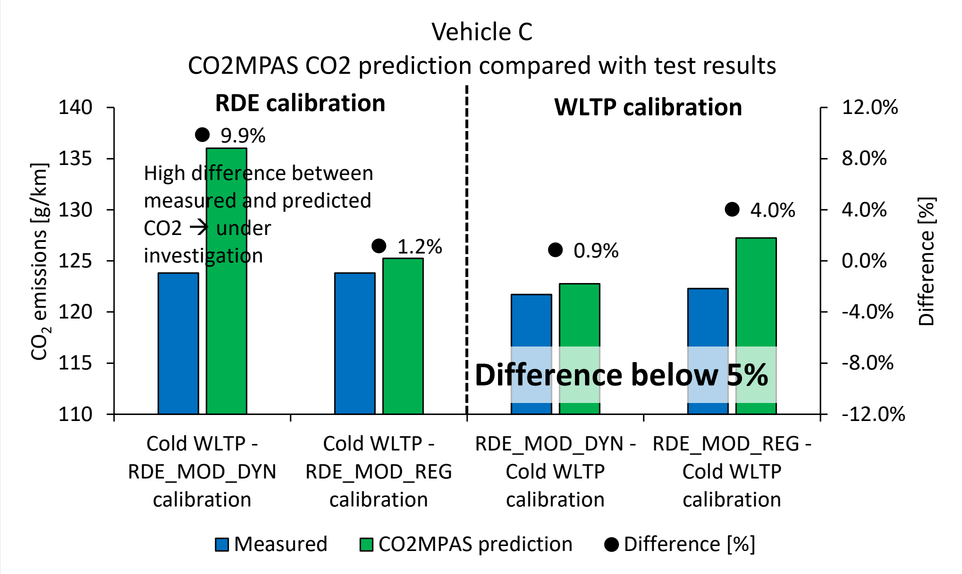



**Figure 56:** Comparison of $CO_2$MPAS prediction and measured CO2 emissions for Vehicle C

In addition to the conventional vehicles, an attempt to apply the simulation methodology to vehicles with electrified powertrains was realized. To that aim a hybrid and a plug-in hybrid vehicle were simulated with $CO_2$MPAS. Due to technical issues and limited accuracy of $CO_2$MPAS prediction the activity was communicated with the JRC and a troubleshooting is currently on progress in collaboration with the JRC.

Furthermore, simulation results for the conventional vehicles were also discussed with the JRC and based on the feedback and advice we got, a further improvement of the methodology and prediction accuracy is expected. For example, JRC team suggested improvements to the preparation of the input files and the introduction of the altitude in the $CO_2$MPAS input.

**Simulation with PHEM**

PHEM was developed at the IVT at TU Graz in the late 1990ies. Development has since then continued to go on including new technologies and improving simulation methods. A short description is given below. For example, more details can be found in (Hausberger, 2003), (Rexeis, 2009), (Zallinger, 2010), (Luz, Hausberger, 2013), (Hausberger, Sams, 2016), (Matzer, 2020).

PHEM calculates fuel consumption and emissions of road vehicles in 1 Hz for a given driving cycle based on the vehicle longitudinal dynamics and emission maps (Figure 57). Engine power demand for the cycles is calculated from driving resistances, losses in the transmission line and auxiliary power demand. The engine speed is simulated by the tire diameter, final drive and transmission ratio as well as a driver gear shift model. Base exhaust emissions and fuel flow are then interpolated from engine maps. To increase the accuracy of the simulated emissions, transient correction functions are applied to consider different emission behaviour under transient engine loads. For the project, no transient corrections were applied to the fuel consumption results. Furthermore, models for the efficiency of exhaust gas after-treatment systems are implemented. The temperatures of catalytic converters are simulated by a 0-dimensional heat balance and from the heat transfer between exhaust gas and the catalysts material and from the exhaust line to the ambient. This routine is especially important in simulating SCR systems (cool down at low engine loads) and in simulating cold start effects, (Rexeis, 2009), (Weller, 2020). The exhaust model includes also heating strategies, which may be relevant also in the CO2 verification tests, since additional fuel is needed during longer low load phases to maintain the SCR catalysts on operation temperature. Due to the thermal inertia of the exhaust system the duration of low load phases is important for the extra energy demand. This effect is not visible in engine CO2 maps gained from the WLTC but may be relevant for RDE tests.

A driver model is implemented in PHEM to provide representative gear shift manoeuvres for test cycles as well as for real world driving behaviour. This model can be applied to compare WLTC and RDE gear shift behaviour of automatic transmission systems.

Since the vehicle longitudinal dynamics model calculates the engine power output and speed from physical interrelationships, any driving condition can be illustrated by this approach. The simulation of different payloads of vehicles in combination with road longitudinal gradients and variable speeds and accelerations can thus be illustrated by the model just like the effects of different gear shifting behaviour of drivers.

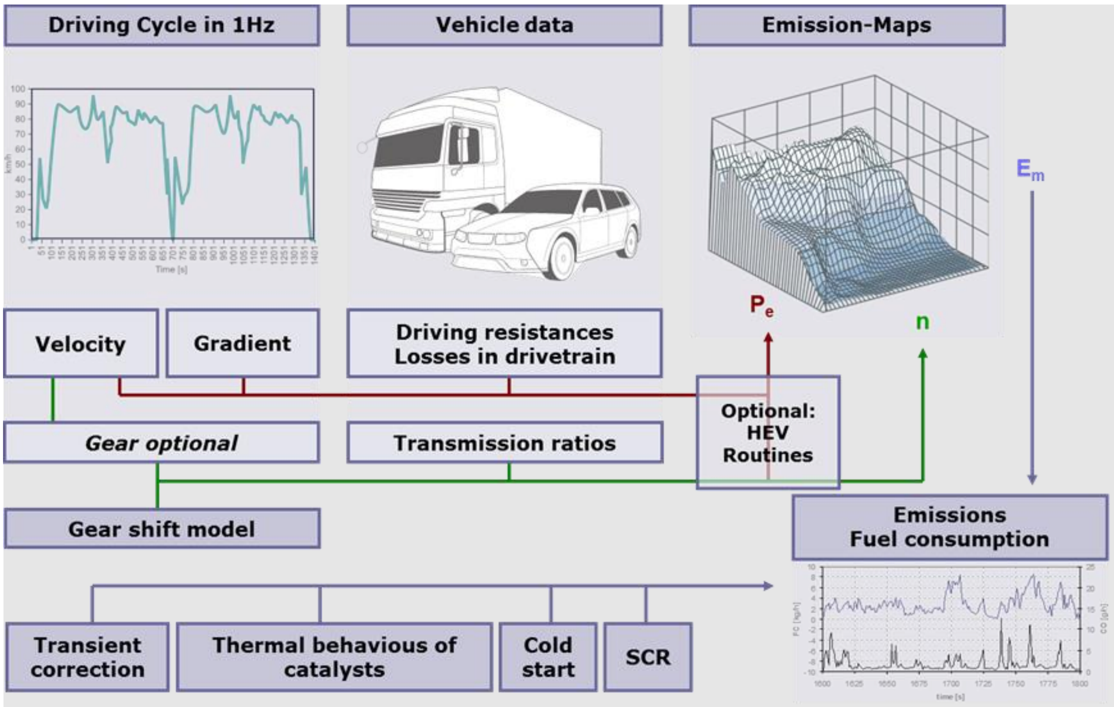



**Figure 57:** Scheme of the PHEM model

The following input data are required for a simulation run with PHEM:

- Vehicle data including test mass, RL, $P_{rated}$, $n_{rated}$, gear ratios etc.
- Engine emission map
- Full load and drag curve
- Driving cycle including vehicle speed, gradient and, if available, engine speed over time

Not all input data were available for vehicles A, B and C. Therefore, generic data for auxiliary power demand, drag curve and $CO_2$ map from HBEFA 4.1[58] were used. The generic data represent the average data of the vehicle fleet in Europe and are available for all LDV emission standards and engine types (diesel, gasoline) from HBEFA 4.1 work. The generic HBEFA data are publicly available.

Since the CO2 map can have a large impact on the simulation result, a $CO_2$ map calibration method was developed to perform a vehicle specific calibration of the generic $CO_2$ map. The adjustment can be performed for each vehicle measured on the chassis dynamometer. The calibration of the generic CO2 map is described below:

[58] HBEFA is the Handbook Emission Factors for Road Transport and provides emission factors for all current vehicle categories (PC, LDV, HGV, urban buses, coaches and motor cycles for a wide variety of traffic situations.

1. Using the chassis dynamometer settings of the measured cycle, PHEM can be used to simulate the measured cycle with the generic $CO_2$ map representing an average map for the engine technology. To adjust the average $CO_2$ map, the simulated $CO_2$ is compared with the measured one. To exclude the influence of the cold start, only the $CO_2$ emissions of the engine at operating temperature are used for calibration. Figure 58 shows the measured (red data points) and simulated $CO_2$ values (yellow data points) versus positive engine power for vehicle B in WLTC (in the figure, $CO_2$ and engine power are normalized by Prated). The red data points represent the bag values of the medium, high, extra high and the average of these three phases. Phase 1 is not included because of the cold start effects. It was assumed that most of the cold start related extra fuel consumption was in the low phase. Each yellow data point represents the average of CO2 and engine power over 20 s to avoid uncertainties regarding the temporal allocation between CO2 and measured engine power.

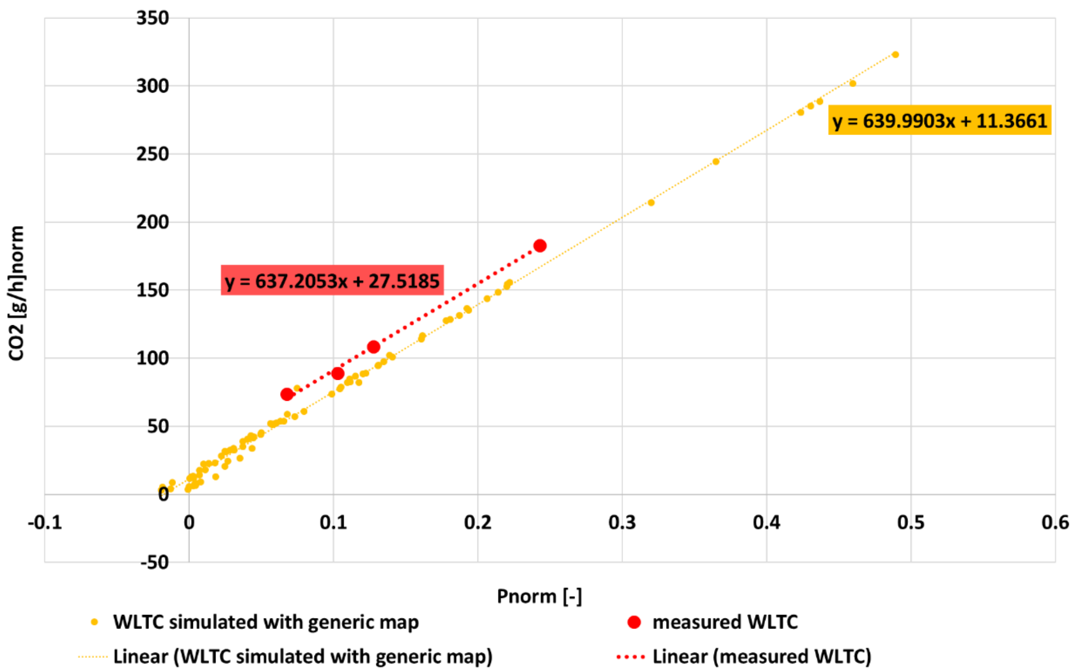



**Figure 58:** Example of measured and simulated $CO_2$ emissions in WLTC of vehicle B with generic $CO_2$ map before calibration, $P_{norm}$: engine power normalized by $P_{rated}$

2. The measured and simulated data points can be well described by linear functions. Such a linear correlation is referred to here as a "veline", derived from "vehicle-line". Velines have been used in the past at IVT, e.g. for WLTP corrections (Hausberger, et al., 2015) or for air conditioning corrections (Hausberger, et al., 2013). The velines are similar to the well-known Willans lines, but are not limited to a constant engine speed. Based on the velines, a correction function is determined to adjust the average CO2 map.
3. If the measured cycle is simulated with the adjusted CO2 map and compared with the measurement, the velines are almost identical (red and green points). The result in Figure 59 shows a successful adjustment.

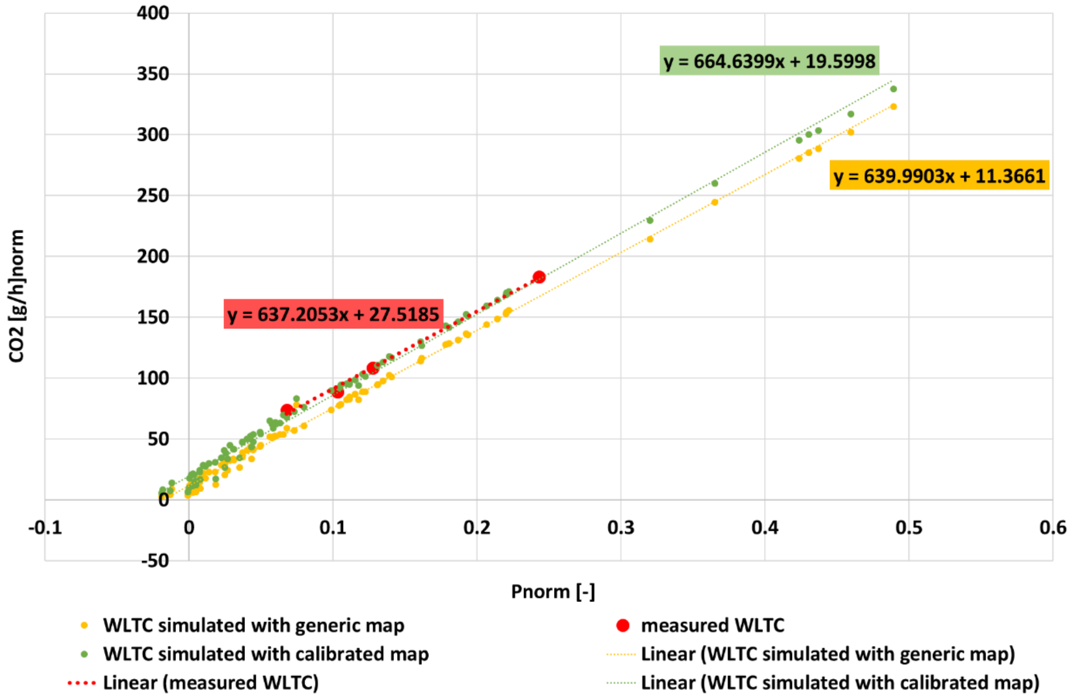



**Figure 59:** Example of measured and simulated $CO_2$ emissions in WLTC of vehicle B with calibrated $CO_2$ map, $P_{norm}$: engine power normalized by $P_{rated}$

The calibration of the $CO_2$ map was applied to vehicle B and C. No calibration was required for vehicle A, as the average $CO_2$ map describes the vehicle specific $CO_2$ emissions well.

Figure 60 shows the deviations between simulated and measured cycles for vehicle A, B and C for WLTC and RDE tests. For the RDE tests, the average of all tests is given, as well as the largest deviation of the individual RDE test. A negative deviation means that the simulation underestimates the measured cycle, a positive deviation means that the measured cycle is overestimated. For vehicle A and B, the deviations for WLTC and all RDE tests are below 5%. For vehicle C, the deviation of the simulated WLTC phases 2+3+4 is small, but including the cold start model in the simulation leads to higher deviations. Therefore, the cold start model in PHEM could be adjusted to minimize the deviation. Due to the low cold start impact in the RDE tests, this adjustment was not performed here.

An interesting effect is the high deviation between measured and simulated RDE tests for vehicle C. Since the cold start share in RDE tests is low, most of the deviation cannot be explained by uncertainties of the cold start model. So far, the reason for the large deviation could not be found. Therefore, vehicle C could be a candidate for extended investigations in case that the method is used to identify suspicious vehicles (e.g. re-testing WLTC on the chassis dyno). In order to derive a deviation threshold above which a vehicle could/should be considered for extended investigations, more vehicles should be investigated. The deviation between measurement and simulation needs to be above the model uncertainty. Without extra measurements, we cannot identify if the deviations for vehicle C are related to vehicle behaviour or simulation uncertainties. However, the low $C_dxA$ value obtained from the WLTC road load indicates, that the road load values used in the chassis tests are too optimistic for real world RDE tests.

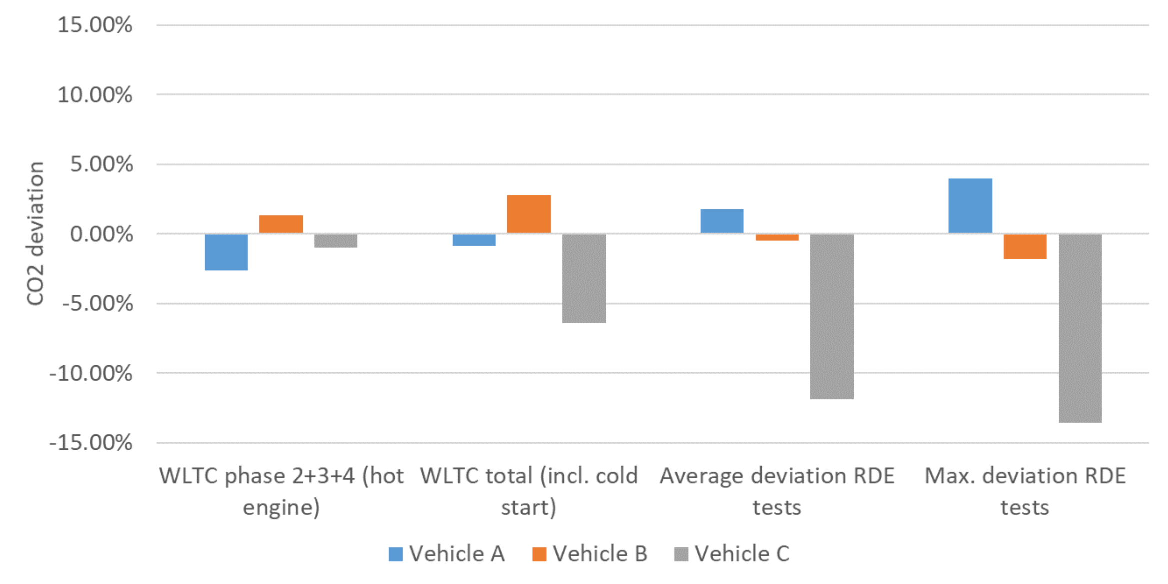



**Figure 60:** Deviations between simulated and measured cycles for vehicle A, B and C

All three vehicles were simulated with PHEM using the measured engine speed (therefore no gearshift model was required). However, this does not allow the detection of different gearshift strategies between WLTC and RDE tests, which could be a topic for cycle optimisations for WLTC especially for automatic transmissions. Therefore, an additional investigation was performed with vehicle C, which had a 7-speed DCT transmission.

In PHEM, the gearshift model uses six coefficients for up-shifting actions and for down-shifting respectively. These gearshift coefficients define the gear shift points as function of velocity and power demand. In PHEM additional checks are included, which e.g. shift back to a lower gear if the actual gear does not provide sufficient torque to follow the driving cycle.

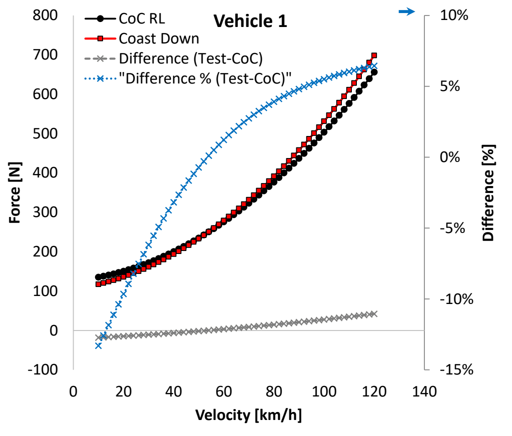
For vehicle C, the gearshift parameter sets were derived from the WLTC and RDE tests. With both gearshift parameter sets, for WLTC and RDE, the WLTC and the RDE tests were simulated respectively. The result was that the deviation between the simulated WLTC with different gearshift parameters was less than 1%. The same result was found for the RDE tests.

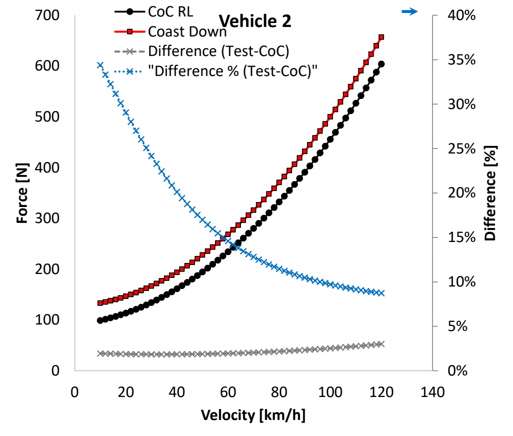
Overall, the simulation approach described above has been demonstrated with two different tools. The target was to explore the capabilities of such tools. Both tools showed similar results for the investigated vehicles with similar computing times. $CO_2$MPAS currently captures more hybrid architectures than PHEM.

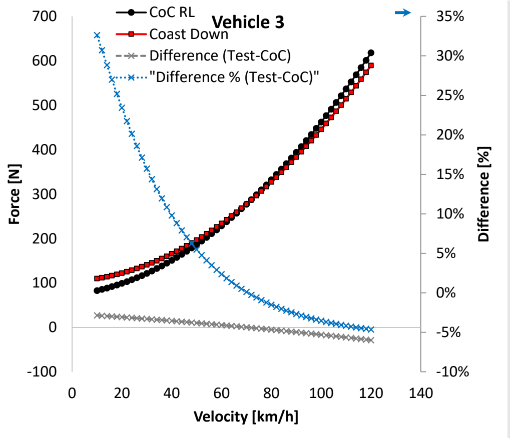
The feasibility study for HEV and PHEV, started with $CO_2$MPAS already, as mentioned before, will be continued. If parallel hybrids are used as test cases, the method developed with PHEM as described above could be applied also for HEVs and PHEVs where all needed WLTC and RDE test data is available. We assume, that the method to parametrise the hybrid strategy in the controller tools of the models will be the most challenging task since the calibration by WLTC test data should then be applicable for RDE driving. Comparing the HEV strategies and calibration options from $CO_2$MPAS and PHEM and the related issues and model uncertainties would allow a broader view on the options for a verification testing procedure of HEVs and PHEVs.

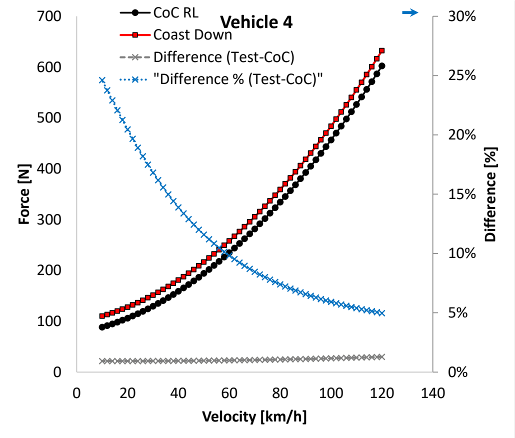
# Annex V – Comparison of driving resistance between CoC and measured ISV road loads.

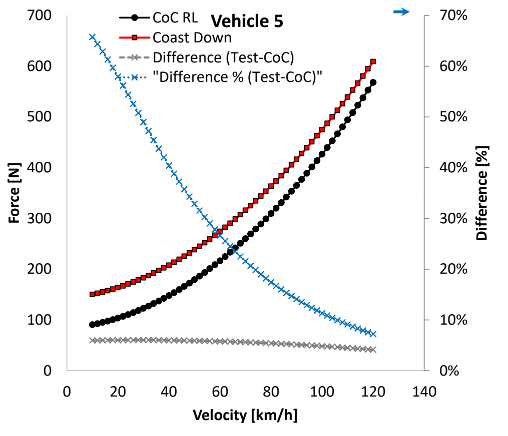
Comparison of driving resistance between CoC and measured ISV road loads.

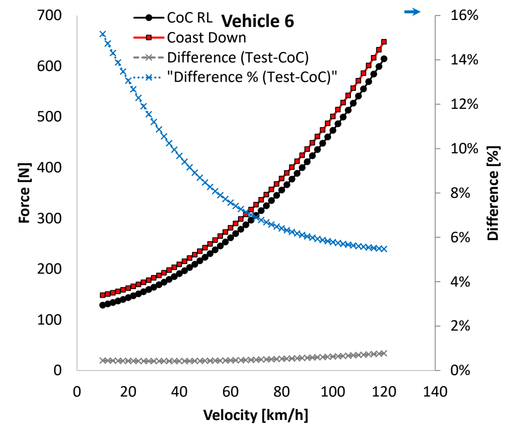


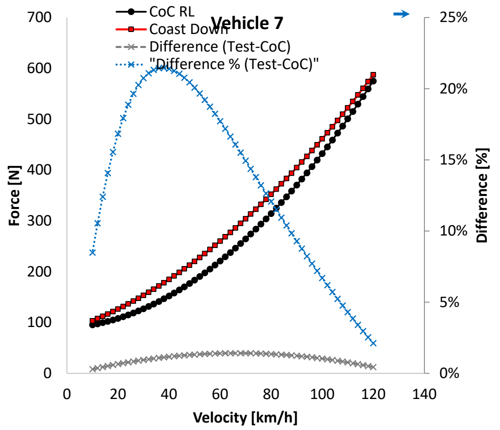



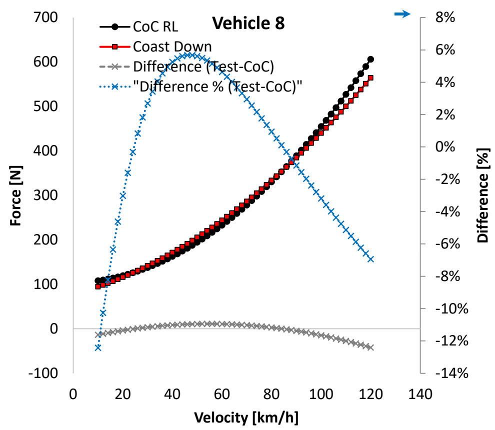



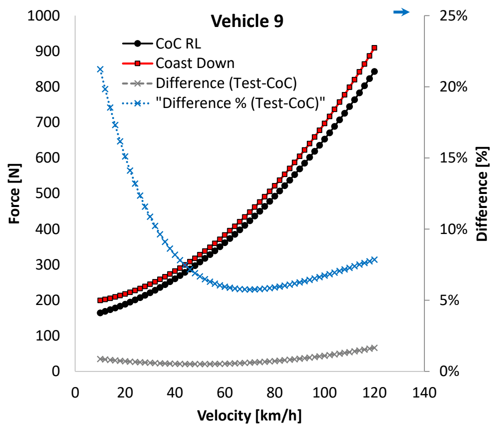



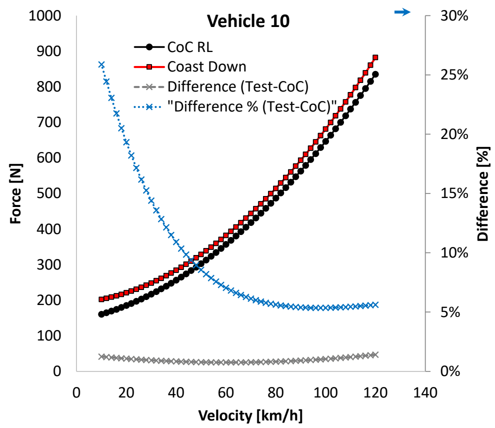



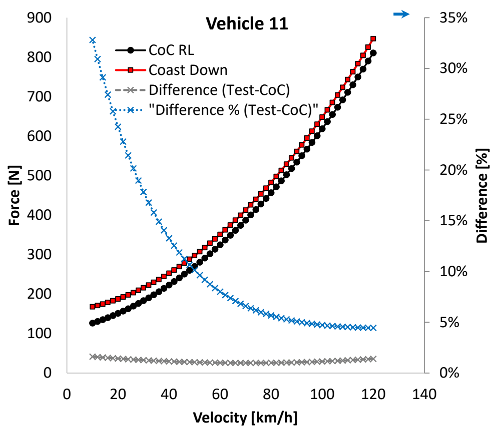



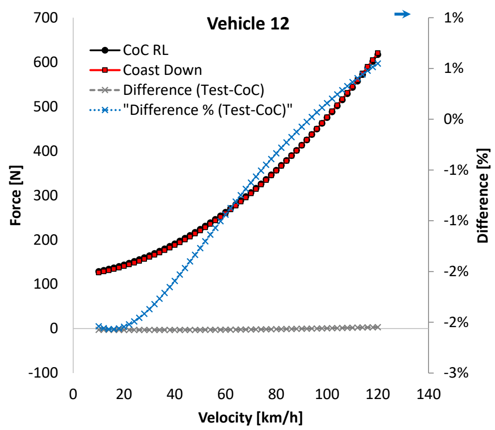

Vehicle 7
CoC RL
Coast Down
Difference (Test-CoC)
"Difference % (Test-CoC)"
Force [N]
Difference [%]
Velocity [km/h]

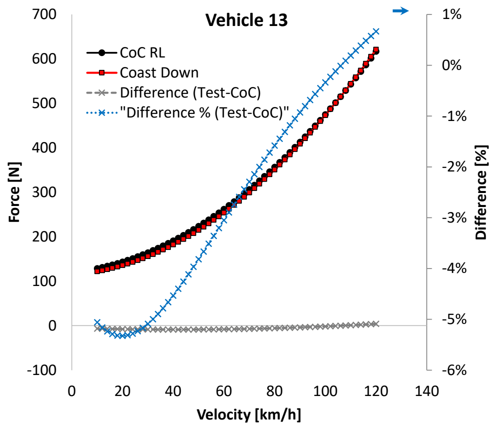

Vehicle 8
CoC RL
Coast Down
Difference (Test-CoC)
"Difference % (Test-CoC)"
Force [N]
Difference [%]
Velocity [km/h]

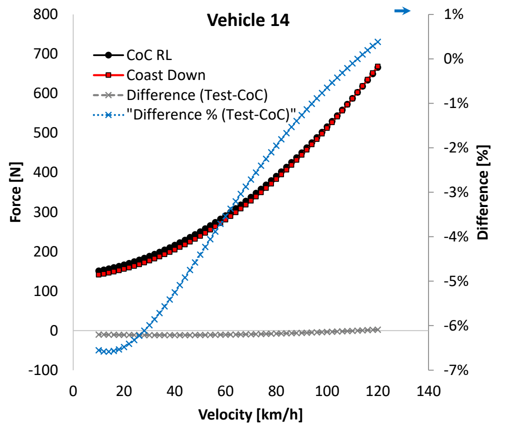

Vehicle 9
CoC RL
Coast Down
Difference (Test-CoC)
"Difference % (Test-CoC)"
Force [N]
Difference [%]
Velocity [km/h]


Vehicle 10
CoC RL
Coast Down
Difference (Test-CoC)
"Difference % (Test-CoC)"
Force [N]
Difference [%]
Velocity [km/h]


Vehicle 11
CoC RL
Coast Down
Difference (Test-CoC)
"Difference % (Test-CoC)"
Force [N]
Difference [%]
Velocity [km/h]


Vehicle 12
CoC RL
Coast Down
Difference (Test-CoC)
"Difference % (Test-CoC)"
Force [N]
Difference [%]
Velocity [km/h]


Vehicle 13
CoC RL
Coast Down
Difference (Test-CoC)
"Difference % (Test-CoC)"
Force [N]
Difference [%]
Velocity [km/h]


Vehicle 14
CoC RL
Coast Down
Difference (Test-CoC)
"Difference % (Test-CoC)"
Force [N]
Difference [%]
Velocity [km/h]

# Annex VI – Correlation between RL coefficients and vehicle parameters

**Correlation between RL coefficients and vehicle parameters**

The driving resistance of the vehicles is described by a second order polynomial that describes the force as a function of vehicle velocity. Equation (21) describes the driving resistance of a car that moves under constant velocity:

$$F_{resistance} = \frac{1}{2} \cdot \rho \cdot c_d \cdot A \cdot v^2 + \mu \cdot m \cdot 9.81 \quad \textbf{(21)}$$

Where:

| | |
|---|---|
| $\mu$ | **Rolling Resistance Coefficient [-]** |
| $m$ | vehicle mass [kg] |
| $\rho$ | Air density [kg/m$^3$] |
| $c_d$ | Aerodynamic drag coefficient [-] |
| $A$ | Vehicle frontal area [m$^2$] |
| $v$ | Velocity [m/s] |
| $F_{resistance}$ | Driving resistance [N] |

The previous equation reveals that the driving resistance is the sum of aerodynamic drag and rolling resistance forces. From equation (21) it also be observed that the driving resistance is a function of the vehicle parameters like the aerodynamic drag coefficient, the frontal area, the mass and the rolling resistance.

The aerodynamic drag is developed during the movement of the car and is proportional to the frontal area and drag coefficient. Frontal area is mainly affected by the dimensions of the vehicle (width and height of the main vehicle body) and secondly by the tires' size. The second parameter related to aerodynamic drag is the $c_d$, that is related to the development of the pressure field and difference of the front and the rear of the car. In general, the aerodynamic drag coefficient is affected by the shape of the vehicle body along with the design of the body surface. Furthermore, $c_d$ is related also with the air flow around the wheels and the engine while is also highly affected by the design and operation of the front grill shutter. The friction force is related to the vehicle mass and the efficiency class of the tires and changes with the decrease of the tire tread depth. In addition, the rolling resistance is strongly affected by the tire pressure.

The main and most cost-effective method to determine the driving resistance of a vehicle is the coast down test, where the vehicle is accelerated to a high speed (e.g. 130 km/h) and left to freely decelerate without braking, at a straight road without slope. During coast down deceleration time and instantaneous velocity are recorded, and for the vehicle test mass using recorded velocity and time the resistance force is calculated. The result of the coast down test is a second order polynomial with $F_0$, $F_1$ and $F_2$ coefficients, equation (22).

$$F_{resistance} = F_2 \cdot v^2 + F_1 \cdot v + F_0 \quad \textbf{(22)}$$

Where:

| | |
|---|---|
| $F_2$ | Second order coefficient $\left[ N / \left(\frac{km}{h}\right)^2 \right]$ |

| | |
|---|---|
| $F_1$ | First order coefficient $\left[N/\left(\frac{km}{h}\right)\right]$ |
| $F_0$ | Constant part [N] |
| $F_{resistance}$ | Driving resistance [N] |

Combining equations (21) and (22) it becomes evident that the $F_2$ road load coefficient is equal to the $\frac{1}{2} \cdot \rho \cdot c_d \cdot A$ and it is proportional to vehicle's frontal area and aerodynamic shape, represented by the cd coefficient. Consequently, $F_2$ the coefficient can be considered as function of vehicle's body dimensions and shape/aerodynamic drag coefficient. Similarly, the constant part, $F_0$ coefficient, of the road load is proportional to the vehicle mass and the tire rolling resistance, hence $F_0$ coefficient can be considered as function of the mass and RRC. For the $F_1$ coefficient there is not a direct connection with a physical parameter. This coefficient includes gearbox losses and a part of rolling resistance. Besides that, for vehicles equipped with torque converter value of $F_1$ coefficient usually appears to be negative, also indicating a connection with torque converter losses.

The investigation on the connection between vehicle specifications and the road load coefficients is based on the collection of road load data and technical specifications of 148 vehicles. The dataset includes 148 vehicles (European models), for which technical specifications, such as length, width, height, mass, frontal area and aerodynamic drag coefficient and tires' specifications, are gathered in addition to RL coefficients. For data sourcing official OEM websites, the internal database, and the EPA $CO_2$ test data. These data were used in the context in a previous study with an aim to develop a simple tool that is able to estimate road load of a vehicle. The 148 cars were grouped in segments with similar characteristics and used as reference to estimate RL coefficients for a vehicle that driving resistance is unknown. For a given input vehicle, the car from the 148 found in the database that has similar dimensions and powertrain is selected as reference vehicle. Road Load coefficients for the input are calculated according to the differences in frontal area, aerodynamic drag coefficient, weight and RRC between input and reference vehicle. An example is given in Table 27 and Figure 61.

**Table 27:** Vehicle specifications for the road load calculation example

| Input vehicle | Reference vehicle (best match) |
|---|---|
| **B segment gasoline 1.4L** | B segment gasoline 1.5L |
| **Max. Power 57kW & Torque 115Nm** | Max. Power 79kW & Torque 140Nm |
| **MT, FWD** | MT, FWD |
| **Mass: 1025kg** | Mass: 1050kg |
| **Length: 4065 mm** | Length: 3950 mm |
| **Width: 1687 mm** | Width: 1694 mm |
| **Height: 1490 mm** | Height: 1509 mm |
| **$C_d$: 0.32** | $C_d$: 0.3 |

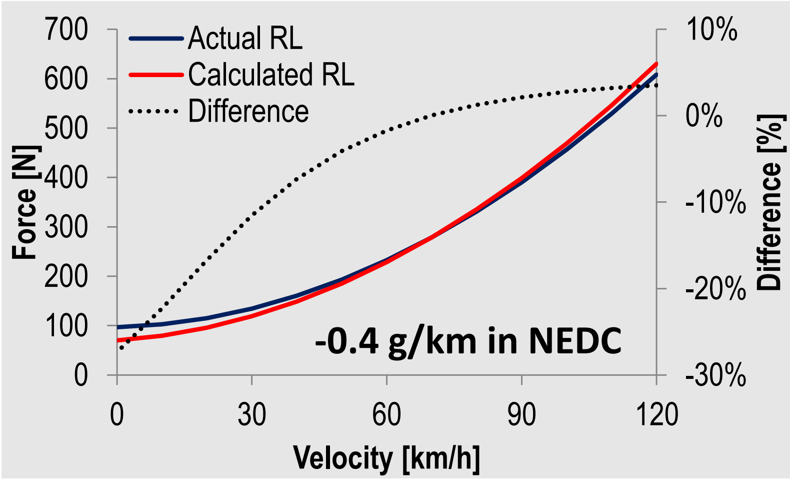



**Figure 61:** Comparison of actual and calculated RL

From the previous study, the main conclusion was that it is possible to estimate the road load coefficients of a vehicle when all its specifications are known, using a reference vehicle for which road load coefficients are also available. This calculation is manly based on the application of the percentage differences between the parameters of the two cars that are related to each of the road load coefficients.

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