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Effect study of the environmental step Euro 5 for L-category vehicles

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Executive Summary

Background and Policy Context

Road-traffic emissions are significant contributors to air quality degradation, in particular in urban areas. Although they only correspond to a rather small fraction of total road transport activity, mopeds and motorcycles may actually be the single most important contributor to HC emissions in specific areas, such as southern European cities, *e.g.* Iodice and Senatore (2013), while two-stroke scooters alone are also prominent contributors of reactive oxygen species and secondary organic aerosol precursors to the atmosphere (Platt et al., 2014). This mostly due to the less demanding emissions control of mopeds and motorcycles compared to passenger cars (Vasic and Weilenmann, 2006), at least so far. An earlier study (Ntziachristos et al., 2013) estimated that L-category vehicles correspond to roughly 25%, 15%, 2% and 2.5% of total HC, CO, NO_x and PM emissions from road traffic in EU for the year 2015. In order to reduce emissions from L-category vehicles, the European Commission introduced several stages of emissions control regulation since 1997, when Directive 97/24/EC first defined emissions limits.

The European Union (EU) classification of L-category vehicles comprises seven vehicle subcategories, including powered cycles and two-wheel mopeds (L1e), three wheel mopeds (L2e), two (L3e) and three wheel motorcycles (L4e), powered tricycles (L5e), and light (L6e) and heavy (L7e) quadricycles. Each subcategory is further distinguished, making up a total number of 25 sub-subcategories. The diversity of types, powertrains, and utility patterns of these vehicles makes this category as one of the most versatile within the road vehicles segments.

Regulation (EU) No 168/2013 provides the details of vehicle classification together with the provisions for approval and market surveillance of L-category vehicles at Euro 4 and Euro 5 levels. This, together with Commission Delegated Regulation (EU) No 134/2014 and Commission Delegated Regulation (EU) No 44/2014 comprise a comprehensive package of measures for the safety, emissions control and placement on the market of such vehicles.

The provisions for the Euro 4 step within Regulation (EU) No 168/2013 were based on an impact assessment study conducted by the European Commission (SEC(2010) 1152), that delivered detailed justification on the need and implementation of the Euro 4 provisions. Regulation (EU) No 168/2013 also set environmental requirements for the Euro 5 stage, thereby creating long-term planning predictability for vehicle manufacturers and the supplier industry. In addition, Article 23 of the same Regulation, mandates that an environmental effect study should be conducted by the European Commission to provide additional underpinning of the Euro 5 step through modelling, technical feasibility, and cost effectiveness analysis.

Towards this aim, Directorate Generals for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) and Joint Research Centre (DG JRC) performed a Preparatory work phase (Zardini et al., 2016a) and Phase 1 (Clairotte et al., 2016) of this environmental effect study with the objectives to take stock of fleet and structure of the L-category vehicle sector, perform relevant data-mining, and to prepare the technical approach for the main environmental study. Phases 2 (verification) and 3 (validation) of the environmental effect study were awarded to a consortium comprising TNO (NL) as the coordinator, and EMISIA SA (GR), HSDAC (DE) and LAT (GR) as partners, through the awarded contract SI2.713570. Under the supervision of DG JRC and DG GROW, the consortium worked to fulfil the objectives of the Terms of Reference of the contract. This is the final report of the verification and validation phases, summarising the findings of the work of the study team.

Test Types Concerned

The environmental performance checking of new L-category model types is based on a type-approval procedure which comprises different Test types:

- Test type I: tailpipe emissions after cold start. This test is conducted on a new (degreened) vehicle in an emissions test laboratory, where the vehicle is tested according to the procedures set out in Annex II, Regulation (EU) No 134/2014, following a predetermined speed and gear shift pattern. The tailpipe emissions are collected and analysed at the end of the test. At a Euro 5 step the measured emission levels must be lower than the emission limits laid down in Annex VI(A2) of Regulation (EU) No 168/2013;
- Test type II: (increased) idle and free acceleration emission test. The new test vehicle is made subject to test type II in order to verify if it can meet the emissions levels of the simplified tailpipe emission test performed in periodical technical inspection (roadworthiness) testing;
- Test type III: crankcase emissions. This test verifies that no gases from the engine crankcase ventilation system directly escape to the atmosphere without being combusted;
- Test type IV: evaporative emissions. Evaporative emissions stem from the fuel storage and supply system, owing to vapour escaping through the fuel tank vent and permeation of fuel hydrocarbons through the fuel tank walls, tubing, and other parts of the fuelling system. This also tests for breathing losses at elevated ambient temperature conditions;
- Test type V: durability of pollution control devices. This test aims at making sure that no excessive deterioration of the emission control system occurs over a useful life equivalent distance, by checking emissions after vehicle mileage accumulation. As an alternative, compliance may be demonstrated by applying deterioration factors on emission levels of a degreened vehicle;
- Test type VII: fuel efficiency test investigating the environmental performance of the vehicle in terms of carbon dioxide (CO_2) emissions, fuel and/or energy consumption and the range in the case of a hybrid electric or fully electric vehicle;
- Test type VIII: environmental On-Board Diagnostics (OBD) verification testing. The test procedure is set out in Regulation (EU) No 134/2014 and consists of a special Type I test in which a malfunction is introduced on the test vehicle before start of the test. The Type I test emission levels are then compared with the OBD emission thresholds (OTLs) set out in Annex VI(B) of Regulation (EU) No 168/2013. The OBD system should be demonstrated of being able to identify the malfunction, if thresholds are exceeded.
- Test type IX: Sound level. This test is outside the scope of this study.

Study Objectives

The main objective of the current study is to provide technical support and a cost-benefit analysis for assessing the individual measures within the Euro 5 L-category package. Based on this, the European Commission will present a Report to the European Parliament and the Council according to paragraph 5 of Article 23 of Regulation (EU) No 168/2013, addressing the following points (all Annexes referencing the same Regulation):

- the enforcement dates of the Euro 5 level referred to in Annex IV;
- the Euro 5 emission limits referred to in Annex VI (A2) and the OBD thresholds in Annex VI (B2);
- that all new types of vehicles in (sub-)categories L3e, L5e, L6e-A and L7e-A shall, in addition to OBD stage I, also be equipped with OBD stage II at the Euro 5 level;
- the durability mileages for the Euro 5 level referred to in Annex VII (A) and the deterioration factors for the Euro 5 level referred to in Annex VII (B).

Recital 12 of Regulation (EU) No 168/2013 requests that the environmental effect study should also assess the feasibility and cost-effectiveness of:

- in-service conformity testing requirements,
- off-cycle emission requirements, and
- a particulate number emission limit for certain (sub-)categories.

The Terms of Reference of the study further detailed the objectives by specifying the requests for each environmental Test Type described in Regulation (EU) No 168/2013. An additional element requested was to explore the international dimension of the OBD component of this study. Finally, during the course of this work, a number of items were raised by members of the European Commission (EC) Motorcycle Working Group (MCWG) and the Working Group on international environmental and propulsion performance requirements for L-category vehicles (UN L-EPPR).

This study aims at addressing the items of the environmental effect study specified in Regulation (EU) No 168/2013, as clarified in the Terms of Reference of the contract to this work and further elaborated by MCWG and L-EPPR. This Executive Summary summarizes the main objectives and findings and makes recommendations for short-term and longer term policy interventions.

Methodology

Experimental Campaign

Basic emissions-related information was collected by means of tests conducted in different environments over a large number of vehicles. In total, 44 vehicles were measured on the chassis dynamometer of DG JRC and one vehicle at LAT, 7 vehicles were measured on the road using Portable Emissions Measurement Systems (PEMS) at TNO and DG JRC, and 6 vehicles were tested in the Sealed Housing Evaporative Determination (SHED) testing chamber of DG JRC. Table ES.1 outlines the main specifications of the individual vehicle types tested.

Additional tests were executed on individual components from a number of vehicles at LAT to provide experimental information to specific environmental performance questions. Experiments were conducted to test catalysts' thermal degradation, ageing effects on evaporation canisters and permeability deterioration of fuel lines.

The tests provided fundamental information on the vehicles and individual components performance. This served a number of purposes, including examining the potential effectiveness of different policy options, providing necessary input information to the modelling approaches adopted in this study, and for validation of the main conclusions reached.

Collection of prior information

Further to dedicated experiments, a large number of other sources were reviewed to collect necessary technical information. A long list of available studies was identified in Phase 1 of the project and an additional number of reports, scientific and technical papers, as well as impact assessment studies for environmental policy measures in the EU and around the world were consulted. Impact assessments for L-category Euro 3 and Euro 4 were particularly useful in this respect. Fleet, activity and emission factor information required to assess the environmental impact of measures were collected from existing emission and projection models and were further refined in the course of the study.

Important information was also collected from field surveys. Type approval technical services personnel were interviewed on current regulatory approaches, industrial and academic experts were consulted on the applicability and limits of existing technology and twelve repair shops around EU were investigated to collect information on the

frequency, impact and extent of malfunctions on current technology L-category vehicles.

Table ES.1: Main specifications of the individual vehicle types tested in this study

Vehicle ID no.	category	category name	engine capacity class [cc]	rated power [kW]	engine combustion type*	# of cylinders	Maximum design speed [km/h]	Transmission	Euro class	Fuel delivery system	SAS	catalyst**	reference mass class [kg]	year	mileage [km]***
J05	L1e-A	powered cycle	30	1	G-2S	1	25	Fixed	Euro 1	carburettor	No	n.a.	100	2009	200
J06	L1e-B	low speed moped	50	3	G-2S	1	25	Fixed	Euro 2	carburettor	Yes	2w	120	2010	500
J07	L1e-B	low speed moped	50	3	G-2S	1	25	CVT	Euro 2	carburettor	No	2w	170	2010	500
J10	L1e-B	low speed moped	50	3	G-4S	1	25	CVT	Euro 2	carburettor	Yes	2w	160	2010	500
J02	L1e-B	high speed moped	50	2	G-2S	1	45	Manual	Euro 2	carburettor	Yes	2w	190	2015	0
J03	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	carburettor	Yes	2w	160	2015	0
J04	L1e-B	high speed moped	50	3	G-2S	1	45	CVT	Euro 2	carburettor	Yes	2w	160	2015	0
J12	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	injection	Yes	2w	170	2013	846
J14	L1e-B	high speed moped	50	3	G-2S	1	45	CVT	Euro 2	carburettor	Yes	2w	180	2015	500
J17	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	carburettor	Yes	2w	170	2013	4926
J29	L1e-B	high speed moped	50	3	G-2S	1	45	CVT	Euro 2	carburettor	Yes	2w	165	2012	400
J26	L2e-U	Three-wheel moped	50	2	G-2S	1	38	Manual	Euro 2	carburettor	Yes	2w	380	2016	100
J27, valid.	L2e-U	three-wheel moped	n.a.	4	E	n.a.	45	Fixed	n.a.	n.a.	n.a.	n.a.	300	2016	4
J19	L3e-A1	low perf. motorcycle	130	7	G-4S	1	90	CVT	Euro 3	carburettor	No	2w	180	2012	1372
J23	L3e-A1	low perf. motorcycle	130	11	G-4S	1	105	CVT	Euro 3	injection	No	3w	240	2010	0
J11	L3e-A2	medium perf. motorcycle	160	10	G-4S	1	95	CVT	Euro 3	injection	No	3w	200	2015	950
J28, valid.	L3e-A2	medium perf. motorcycle	300	16	G-4S	1	125	CVT	Euro 3	injection	No	3w	260	2015	500
J13	L3e-A2	medium perf. motorcycle	280	19	G-4S	1	128	CVT	Euro 4	injection	Yes	3w	240	2015	2871
J15	L3e-A2	medium perf. motorcycle	690	32	G-4S	1	>150	Manual	Euro 4	injection	Yes	3w	230	2016	1000
J18	L3e-A3	high perf. motorcycle	1170	92	G-4S	2	>150	Manual	Euro 4	injection	No	3w	300	2015	1156
T01	L3e-A3	high perf. motorcycle	1170	92	G-4S	2	>150	Manual	Euro 3	injection	No	3w	300	2016	385
J21	L5e-A	tricycle	300	18	G-4S-H	1	125	CVT	Euro 2	injection	Yes	3w	340	2010	773
L01	L5e-A	tricycle	1330	84	G-4S	3	>150	Semi-AUT	Euro 4	injection	No	3w	530	2015	200
J24	L5e-A	tricycle	200	8	G-4S	1	55	Manual	Euro 2	carburettor	No	2w	420	2016	100
J01	L6e-BP	light quadri-mobile	480	4	D-4S	2	45	CVT	Euro 2	injection	No	2w	470	2015	0
J22	L6e-BU	light quadri-mobile	400	4	D-4S	2	45	CVT	Euro 2	injection	No	n.a.	480	2014	988
J16	L7e-B1	all terrain quad	980	15	G-4S	2	65	CVT	Euro 2	injection	No	3w	470	2016	538
J08	L7e-B1	all terrain quad	570	11	G-4S	1	70	CVT	Euro 2	injection	No	2w	450	2015	900
J25, valid.	L7e-B1	all terrain quad	440	17	G-4S	1	67	CVT	Euro 2	injection	No	3w	370	2016	17
J09	L7e-B2	side-by-side buggy	700	15	G-4S	2	78	CVT	Euro 2	injection	No	2w	570	2016	638
J20	L7e-CP	heavy quadri-mobile	n.a.	13	E	n.a.	80	Fixed	n.a.	n.a.	n.a.	n.a.	570	2013	0

* G = gasoline; D = Diesel; E=Electric; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening
n.a. = not applicable
valid. = this vehicle was part of the validation testing programme
SAS = secondary air system

Cost-Benefit Analysis (CBA)

Based on all information collected, a dedicated cost-benefit analysis (CBA) model was specifically developed to assess different policy options within the Euro 5 step and beyond. The main objective of the model was to assess whether a policy option results to positive or negative societal costs. In other words, examine whether the particular policy option results to a net damage or benefit to the society, in monetised terms. In the context of this study, a net benefit is obtained when environmental savings, converted to monetary terms, exceed the investment and implementation costs of introducing the policy option.

Using the CBA model (Figure ES.1), the impact of different policy options was simulated with specific scenarios and the environmental and implementation costs were assessed over a 21 year period (2020-2040), assumed to be a complete life-cycle of Euro 5 Regulation. For each policy option, the CBA model produced:

- Environmental benefit (emission savings) per pollutant, vehicle category, and year of implementation.
- Total (monetised) benefit, total costs, and net benefit per pollutant, vehicle category, and year.
- Average cost per vehicle category (*i.e.*, costs required per vehicle for the implementation of a specific measure).
- Cost-effectiveness results per pollutant and per vehicle category (*i.e.*, costs required per tonne of pollutant emissions saved).

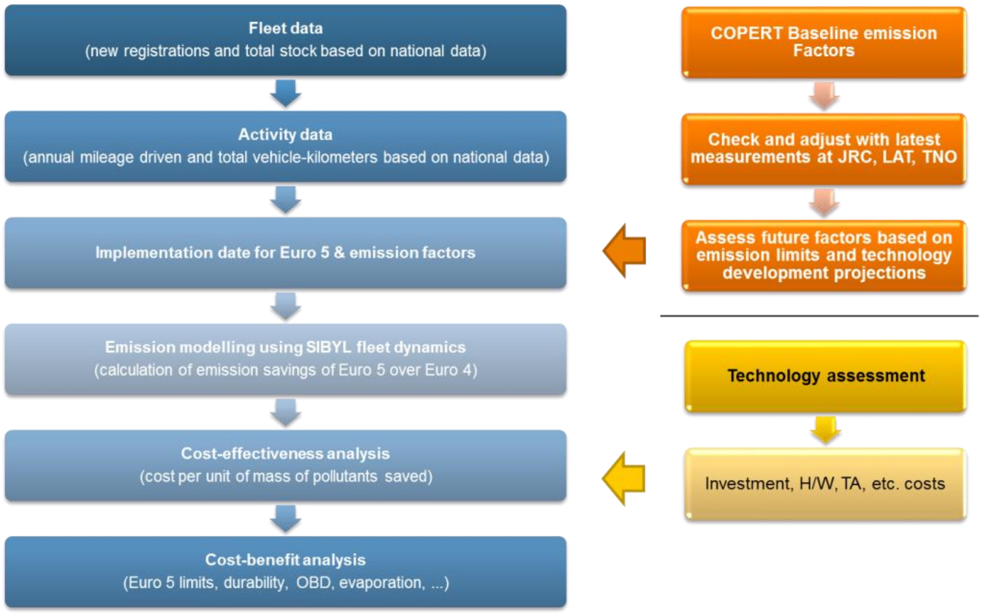

Figure ES.1: Schematic methodological representation of the CBA overview

The following sections summarize the main conclusions reached for each individual test type.

Type I – Tailpipe emissions test after cold start

Objectives

The objectives with Type I testing were four-fold:

i. Examine the feasibility of L-category vehicles other than L3e, L5e-A, and L7e-A to be emission-tested in the revised WMTC, using drivability, engine map coverage and cycle dynamics as criteria for the assessment. The revised WMTC (WMTC Stage 3) is first time introduced in Euro 5 to replace the older ECE cycles (R40 or R47, depending on the sub-category).
ii. Assess the appropriateness of the new limits for CO, THC, NMHC and NO_x for all L-category vehicles introduced with Euro 5.
iii. Assess the feasibility and cost-benefit ratio of the introduction of the separate NMHC limit at Euro 5 step.
iv. Assess the impact of ethanol in the reference fuel on the test type I results.

Conclusions on the suitability of revised WMTC

Based on the tests executed and the analysis of the results, the revised WMTC:

i. was executed with no violations by all L-vehicle types tested, allowing for the flexibility in speed pattern deviations prescribed in Regulation (EU) No 134/2014, Annex II;
ii. offered extended coverage of the engine operation range in all sub-categories, compared to the corresponding ECE cycles it substitutes. This means that the revised WMTC offers more confidence for effective emission control over real-world operation as well;
iii. did not lead to statistically significant differences in emission variance over multiple repetitions of execution, compared to the corresponding ECE cycles.

On the basis of these criteria, the revised WMTC appears suitable to be used as a Type I test for all L-category sub-categories and is expected to provide enhanced environmental protection over real-world operation, than the driving cycles it substitutes.

The study also made specific observations for particular vehicle sub-categories:

i. The speed of vehicles falling into categories L1e-A, L2e and a vehicle falling under L5e-A, but with a powertrain representative of L5e-B vehicles, exhibited deviations from the revised WMTC demanded speed pattern, both in terms of demanded acceleration and maximum speed. Future revision of the driving cycle would allow for improved test execution and enhanced reproducibility both for emissions (Type I) and energy efficiency (Type VII) testing.

ii. Recommendation for future legislation: Measurement campaigns will need to be conducted in order to collect real life operation data for specific vehicle sub-categories (at least for L2e, L5e-B and L7e-B) and assess the representativeness of the revised WMTC.

Conclusions on the appropriateness of the Euro 5 limits

Euro 5 for mopeds (L1e-B, L2e, L6e-A) and motorcycles (L3e, L4e, L5e-A, L7e-A) is technically feasible to be implemented within the 2020/21 (new/all types) time horizon. The emission control technology required to comply with the new limits will have to be significantly improved over Euro 4, especially for mopeds, but such improvements only require incremental technical advancements, rather than new engineering breakthroughs.

Despite technology cost increases, large environmental benefits lead to an overall significant net benefit in monetary terms, which may collectively exceed 330 M€, over the period considered. Moreover, mopeds and motorcycles at Euro 5 step will be amongst the cleanest conventional vehicles on the road, under urban conditions. This eliminates the risk that any demand and access control measures initiatives by the city authorities could affect the accessibility of L-category vehicles to city centres.

ATVs and side-by-side vehicles (L7e-B) are expected to follow technology improvements led by motorcycles, with which they share powertrain technology. Marginally higher costs are expected for L7e-B vehicles compared to L3e because of the different calibration of these vehicles over WMTC.

Different weighting factors for the cold/hot part of WMTC for mopeds (L1e, L2e, L6e) and motorcycles (L3e, L4e, L5e-A, L7e-A) with speed less than 130 km/h are introduced with Euro 5 (50/50) over Euro 4 (30/70). This means that more weighting is given to the cold start part with Euro 5, thus increasing environmental benefits but also corresponding implementation costs for compliance. Overall, net benefits were estimated for both sets of weighting factors, with the relative differences in the two scenarios being within the range of calculation uncertainty.

A detailed analysis for the mini-cars sub-categories (L6e-B, L7e-C) was conducted. In particular L6e-B vehicles are currently powered by small diesel engines or electric powertrains. Positive ignition engines do not provide enough power for this sub-category due to engine capacity limits (50 cc) compared to the relatively high vehicle mass. Euro 5 limits introduce a significant challenge for such diesel engines. It is not certain whether available emission control technology can deliver the necessary NO_x and PM reduction level for small-sized diesel powertrains. Even if this would be proven feasible, this would come at a high cost that the CBA showed to exceed environmental benefits (65M€ total damage). The following scenarios were therefore examined as possible options:

- Retaining the original time frame for Euro 5 introduction (2020/21 – new/all types). This might lead to a strong market distortion, as only battery electric vehicles will be able to reach the stringent limits as such short time frame. This could potentially harm the specific industry, which is largely based on SMEs.

- The second option would be to provide some more lead time, *i.e.* one model year and introduce Euro 5 at the 2024/2025 time frame. This is expected to provide some margin for the possible introduction of alternative powertrains (*e.g.* petrol-electric), continue with the development of charging infrastructure in cities, and benefit from the expected drop in automotive battery costs due to increasing global production. The CBA estimated potential net benefits in the order of 230 M€, due to decreased technology costs and significantly improved environmental performance when introducing electric vehicles. This means that marginal environmental impacts caused by the delay in introducing Euro 5 for these vehicles are totally counterbalanced by the introduction of clean vehicles in the post 2023 period.
- The third option would be to remove the need for a Euro 5 step for these vehicles and remain with Euro 4 even beyond 2024. Our assessment is that this will not be a viable option in the long term as diesel mini-cars will constitute the highest-emitting on road vehicle type in the market with evident consequences in their accessibility to city environmental zones.
- Finally, the fourth option would be to increase the engine capacity of positive ignition engines for L6e-B vehicles to a value that would be enough to guarantee sufficient vehicle drivability. Although this is expected to fulfil the environmental targets of Euro 5, vehicle classification and safety issues, following potential engine tampering, need to be considered. The assessment of those goes beyond the objectives of our study.

Based on this analysis, the following recommendations can be made:

- Euro 5 emission limits of CO, NMHC, THC and NO_x appear technically feasible for introduction in 2020/21 (new/all types) and will lead to overall net monetary benefits.
- A lead time of four years (2024/25) is recommended for introducing Euro 5 in the case of L6e-B vehicles, to allow new powertrain concepts to be developed for compliance with the new limits.

The change of cold/hot weighting factors from 30/70 to 50/50 for some sub-categories (L1e-B, L2e, and L3e-A1) from the Euro 4 to Euro 5 step appears neutral in terms of its cost-benefit.

<u>Conclusions on the feasibility and cost-benefit ratio of the separate NMHC limit</u>

Compliance with a separate non-methane hydrocarbons (NMHC) limit, in parallel to the THC one, is required at a Euro 5 step for all L-category vehicles. Due to the rather small contribution of methane in THC emissions from petrol and diesel powertrains, an equivalent THC could be defined so that vehicles complying with this, would not have to demonstrate compliance with NMHC as well. Our study estimated that the equivalent THC would be at 0.078 g/km. Implementation of this would have neutral environmental impact over the separate NMHC and THC limits and small savings would be gained by reducing investments in emission analyses by manufacturers. Net gains are marginal though (net monetary benefit about 5.4 M€ for mopeds and motorcycles).

The recommendation is made that separate THC and NMHC limits, as foreseen in Regulation (EU) 168/2013, are retained, as these are still required for any natural gas L-category vehicles as well as because they offer the possibility to separately report air pollutants and greenhouse gases emissions levels.

<u>Conclusions on the impact on exhaust emissions of the ethanol content in the fuel</u>

On the basis of specific tests conducted with different ethanol-petrol blends, the following conclusions can be drawn:

i. No consistent impact of E0, E5 and E10 blends on exhaust emissions of any pollutant can be seen in tests on vehicle technologies ranging from Euro 2 to

Euro 4. We do not find technical reasons why this conclusion would be different at Euro 5 level.

ii. Emission impacts are vehicle specific so same emission levels can be reached by properly tuning the vehicle, once the EtOH blend of the reference fuel is known. Fuel flow rate will have to be adjusted to meet the same power demands as fuel energy content drops with increasing ethanol content of the fuel.

Type II – Tailpipe emissions at (increased) idle and free acceleration

Objectives

Regulation (EU) No 134/2014 introduces a revised procedure to check tailpipe emissions at (increased) idle and free acceleration, in order to align type-approval requirements with other vehicle types and be coherent with the requirements set out in the latest legislation on roadworthiness testing. The appropriateness and smooth implementation of the procedure had to be confirmed in this study.

Conclusions

The test was in general easy to perform. However, the description for setting the different engine rotation speeds during the test, as described in the procedure in Annex III, Regulation (EU) No 134/2014 can easily be misinterpreted by test engineers. The study made specific technical recommendations on how the description of the test can be improved.

As a general observation, this study would recommend inclusion of NO_x emissions recording in the Type II test for diesel and gasoline vehicles as well. NO_x is important from an environmental perspective and portable NO_x analysers are today cost-effective. Developing a reference list of NO_x levels during Type II type approval testing could potentially very much increase the roadworthiness test impact, if a decision is later taken to include NO_x for identifying high emitters.

Type III – Emissions of crankcase gases

Objectives

Test type III, according to Regulation (EU) No 168/2013, aims at verifying that 4-stroke L-category vehicles engines are so constructed as to prevent any fuel, lubrication oil or crankcase gases from directly escaping to the atmosphere. Regulation (EU) No 134/2014 requires that the manufacturer provides technical details and drawings as proof to the Type Approval Authority (TAA). In addition to these evidence based requirements, a physical test procedure is required for 'new vehicle types with regard to environmental performance equipped with a new design of the crankcase gas ventilation system'. The procedure consisting of 'the basic method', and two alternative test procedures, designated as 'additional test method No 1' and 'alternative additional test method No 2' have been introduced. If the tested vehicle fails in the basic method, compliance over additional test method No 1 or alternative additional test method No 2 shall be demonstrated. The objective of this study was to verify the Type III test procedure with measurements and to make recommendations to improve the procedure, if necessary.

Conclusions

The study demonstrates that the basic method and the additional test method No 1 are equivalent tests. It is recommended to have these two methods as alternatives to apply at the choice of the manufacturer. And to retain alternative additional test method No 2 as a complementary test. The complementary test shall be mandatory when the vehicle fails in the basic test or additional test method No 1, or can be specifically requested by the TAA, in case of concerns.

The combination of the TAA evidence-based assessment and the prescribed Type III test procedures, guarantees that crankcase gas emissions are thoroughly assessed during the type approval.

The test procedure proposed may be further improved and tailored to L-category vehicles by implementing the following recommendations:

i. include 'considerably deviating engine lay-out and engine displacement' in the definition of when physical testing is required, in addition to evidence-based assessment;
ii. in the basic test method, assess the average pressure in every test condition, or apply a moving average window larger than 10 seconds, instead of the assessment of the instantaneous pressure. The current method is prone to errors of commission (no pass despite no crankcase gas loss). Changing the data assessment method allows pressure pulsations in the crankcase that are typical for L-category engines, and ensures that L-category vehicles with effective crankcase gas control, pass the test;
iii. with respect to the additional test method No 1, more explicitly describe the pass-fail criteria of the test and to make this test method engine-capacity dependent. The study made specific recommendations to implement this:
    - no visible inflation is allowed at the end of each measurement condition (5 minutes);
    - balloon size is maximized to a factor 3 of the engine swept.

Type IV – Evaporative emissions

<u>Objectives</u>
The Euro 4 step introduced a SHED evaporative emission test for the L-category vehicles L3e, L4e, L5e-A, L6e-A and L7e-A. The objectives were:

- To examine the cost effectiveness of a 50% lower Euro 5 emission limit compared to the Euro 4 limit for these vehicles.
- To assess two alternative evaporative emission test procedures, in particular the permeation and SHED test procedures, for vehicles falling in sub-classes L1e-B, L2e, L5e-B, L6e-B, L7e-B and L7e-C.
- Explore the impact of different fuel blends (E0, E5, E10) on the canister performance and fuel permeation of different fuel systems.

<u>Conclusions</u>
Based on the experimental tests and the modelling work conducted in this study the main findings were:

- Introduction of fuel system permeation testing for L1e, L2e, L5e-B, L6e-B, L7e-B and L7e-C is a technically feasible measure. Environmental benefits in this case by far exceed technology costs (net monetary benefit for all vehicles about 61 M€) and this test is highly recommended to be introduced in the regulations.
- Introduction of SHED testing for L1e, L2e, L5e-B, L6e-B, L7e-B and L7e-C vehicles is not environmentally effective (total damage for all vehicles in the order of 8 M€) as this mostly addresses short-term breathing emissions while most evaporation emissions from these vehicles come from longer-term permeation losses.
- Reducing the Euro 5 limit to 1 g/test for L3e, L4e, L5e-A and L7e-A makes little environmental difference as evaporation emissions of these vehicles mostly occur during longer parking events, which an 1-h long test does not address. A longer (12 to 24 hours) diurnal test would be more appropriate if one would decide to introduce more stringent evaporation emissions control.
- Ethanol blends increase permeation losses and faster degrade canister efficiency over neat petrol. Relative effects are similar for both E5 and E10.

Change of the reference fuel to E10 over E5 does not need to be accompanied by adjustment to the permeation or SHED test limits
- Current type approval SHED procedure cannot reveal the long-term negative impacts of ethanol, neither the effectiveness of the purging strategy on evaporation emissions

Hence, the following recommendations can be made for upcoming Euro 5 regulations:
- The permeation test procedure should be mandated for the L1e, L2e, L5e-B, L6e-B, L7e-B and L7e-C sub-categories.
- The Euro 5 limit for the L3e, L4e, L5e-A, L6e-A and L7e-A categories should not be reduced.

The following recommendations can be made for future, more effective control of evaporative emissions:
- A longer diurnal test (e.g. 12-48 h) or different test order (soak then diurnal) could be considered for the SHED test procedure.
- Specific testing to reveal the canister efficiency after several cycles of real-world operation, together with reporting of the purging strategy during type-approval.
- In-service conformity check that would include evaporation testing as well.

Type V – Durability requirements

Objectives

To secure the environmental performance of L-category vehicles over their useful life, durability requirements are introduced to predict expected in-use deterioration rates and emission levels. The designated durability testing of L-category vehicles composes of either running the full equivalent distance of useful life, or running half distance and subsequently extrapolating towards the useful life. As a third option, a mathematical procedure, that calculates emission degradation over the useful life with fixed deterioration factors, may be applied at the choice of the manufacturer.

For physical mileage accumulation over the full or half distance of the useful life, the manufacturer is allowed to choose from two mileage accumulation cycles. The first one is the Standard Road Cycle for L-category Vehicles (SRC-LeCV). The second one is the US EPA Approved Mileage Accumulation (AMA) cycle.

The objectives with the evaluation of the Type V requirements were to:

i. validate the distance accumulation cycle (SRC-LeCV);
ii. determine by when after 2020 the AMA cycle shall be phased out as alternative Type V distance accumulation test procedure;
iii. assess the appropriateness of the deterioration factors which are used in the mathematical durability procedure.
iv. assess the appropriateness of the useful life distance values

Conclusions

The experimental and modelling work conducted in the framework of this task led to the following conclusions:

i. Actual durability testing with mileage accumulation appears more effective in achieving durability of emission control systems, than the use of Deterioration Factors in the mathematical durability procedure.
ii. Complete phasing out the AMA cycle is not necessary. It exposes vehicles with a low or moderate maximum vehicle speed to operation conditions similar to the WMTC.

iii. Phasing out AMA for WMTC class 3 vehicles can be justified with the results of the technical assessment of this study.

iv. The SRC-LeCV will better reflect operation conditions that are observed in the WMTC after revision of the SRC-LeCV sub-classification as specified in table ES.2.

v. When the two preceding conclusions are taken into account, both AMA and SRC-LeCV cycles are technically feasible to be executed and well reflect ageing conditions imposed by the WMTC.

vi. The application of the mathematical method according to Article 23(3c) of Regulation (EU) No 168/2013 does not effectively control emissions over the useful life of the vehicle. Phasing out the mathematical method appears cost-beneficial when AMA is phased out for WMTC class 3 vehicles and when the SRC-LeCV sub-classification is revised (net monetary benefit for all vehicles about 0.5 M€).

vii. Bench ageing is a low cost, well accepted, and reliable physical ageing alternative to distance accumulation cycles. Adoption of the bench ageing procedure could be considered to make the durability requirements for L-category vehicles more cost-effective. The application of the procedure on L-category vehicles shall be validated before this test method is introduced. Bench ageing leads to the highest overall benefit in monetary terms (net monetary benefit for all vehicles about 71 M€).

viii. In-service conformity testing is an alternative method to be considered to check emission control durability under real operation conditions.

ix. With respect to the partial mileage accumulation procedure, introduction of the additive exhaust emission deterioration factor calculation method, as an alternative to the current multiplication approach, leads to a more robust procedure without considerable counter effects.

x. With the exception of mopeds, the prescribed Useful Life values in Annex VII of Regulation (EU) No 168/2013 are considered appropriate for all vehicle categories. The Useful Life value for mopeds quoted in the Regulation are significantly lower than the fleet activity data that are used in the CBA model which stem from a large number of sources. In case these Useful Life values are revised accordingly, physical ageing only remains cost beneficial for mopeds when bench ageing is introduced, otherwise type approval and development costs lead to a net societal damage in monetary terms.

Hence, the following recommendations are made:

i. phase out AMA by 2020 only for WMTC class 3 vehicles

ii. revise the SRC-LeCV sub-classification according to table ES.2

iii. phase-out the mathematical method in 2020

iv. introduce the bench ageing procedure, after validation of the application of the procedure on L-category vehicles

v. revise the Useful Life value for mopeds, following a specific data collection survey

vi. introduce an additive exhaust emission deterioration factor calculation method in the partial mileage accumulation procedure

Table ES.2: Recommended revised SRC-LeCV sub-classification and proposal for harmonisation with the WMTC classification and introduction of a Net Power criterion for the WMTC classification

SRC-LeCV Cycle classification	WTMC classification	Vehicle maximum design speed (km/h)		Vehicle engine capacity (cm3)		Net Power (kW)
		Min.	Max.	Min.	Max.	
1	Class 1		< 100 km/h		< 150 cm3	< 14KW
2	Class 2-1	-≥ 100km/h	< 115km/h	-	< 150 cm3	≥ 14KW
		-	< 115km/h	≥ 150cm3	≤ 1500 cm3	≥ 14KW
2	Class 2-2	≥ 115km/h	< 130km/h	-	≤ 1500 cm3	≥ 14KW
3	Class 3-1	≥ 130km/h	< 140km/h	-	≤ 1500 cm3	≥ 14KW
4	Class 3-2	≥ 140 km/h	-	-	> 1500 cm3	≥ 14KW

Type VII – Energy efficiency tests and electric range

Objectives

The Type VII test procedure determines the CO_2 emissions and fuel consumption of conventional vehicles, and, in case of hybrid and fully electric vehicles, also the electric range. The objective of this task was to assess the Type VII test procedure, to report any issues observed while executing the test procedure, and if necessary, make recommendations to improve the test procedure.

Conclusions

The work under this task has led to the following conclusions:

i. The Type VII test procedure was found to be adequate for determining CO_2 emissions, fuel consumption and electric range for conventional, electric and NOVC hybrid vehicles.
ii. For OVC hybrid vehicles, the value for D_{av}, i.e. the average distance between two battery recharges, has a large effect on the CO_2 emissions and fuel consumption established in the test. The value for D_{av}, should be investigated based on the average trip length, availability of charging facilities and charging behaviour. This can only be done when more hybrid electric L-category vehicles penetrate the market and more real-world data becomes available. Currently, there is not enough real-world data available to assess the D_{av}.
iii. In general, speed limiters on mopeds cause an increased fuel consumption when driving at full throttle position. This is currently not covered in the type I test.
iv. Because there is no engine power criterion, and an electric engine has no displacement volume, electric vehicles with a maximum speed lower than 100 km/h are automatically classified as WMTC class 1, where a vehicle with a conventional powertrain and comparable performance might be classified as WMTC class 2-1.

Hence, the following recommendations are made:

i. retain the D_{av} for the time being. And for future improvement of the procedure investigate what values for D_{av} lead to CO_2 emissions and fuel consumption that reflect real-world conditions well, as soon as more hybrid electric L-category vehicles penetrate the market and more real-world data becomes available.
ii. include an instruction in the test procedure to secure that mopeds with a speed limiter are driven at their maximum speed and at full throttle operation during the maximum speed range of the cycle.
iii. introduce engine power as a WMTC sub-classification criterion, together with the harmonisation of the classification with SRC-LeCV, as proposed in table ES.2

Type VIII – OBD environmental tests

Objectives

Regulation (EU) No 168/2013 introduces OBD Stage II for vehicles falling into subcategories L3e, L5e-A, L6e-A and L7e-A from 2020/2021 (new/all types) on, pending confirmation of the environmental effect study. OBD Stage II introduces additional functionalities over OBD Stage I which, predominantly, focus on monitoring the performance of aftertreatment devices. In addition, OBD Stage II requires misfire and in-use performance monitoring, together with circuit rationality monitoring.

The overarching objectives of assessing the need for introduction of OBD Stage II in the framework of this study, according to the Terms of Reference of this work, were:

i. Identify the technical requirements and their feasibility to introduce OBD Stage II functionalities.
ii. Assess the pros and cons of OBD Stage II over Stage I, in particular with respect to enabling successful repair in case of fault and the additional environmental benefits it offers.
iii. Calculate the cost and benefits of introducing OBD Stage II by means of a modelling exercise.

Conclusions on OBD Stage II technical feasibility

Critical components to enable OBD Stage II implementation include the catalyst ageing and misfire monitoring. Their technical feasibility was assessed in this study.

For some vehicles, predominantly scooters, signal distortion and space limitations issues for placing the downstream sensor that enables catalyst monitoring pose significant technical limitations. Required technical developments are not expected to be ready in the first round of Euro 5 implementation in 2020. As the vehicle models development period is usually 2-4 years, an equal lead time for introducing catalyst monitoring needs to be foreseen after first introduction of the Euro 5 standard.

With regard to misfire monitoring, this is considered as a necessary measure to control excess emissions and protect the catalyst from rapid thermal ageing. Technology to detect misfire is already available from passenger car applications, and at least two readily available techniques have been identified as being suitable for L-category vehicles as well. Due to the low inertia of L-category engines and their high speed, the misfire monitoring engine operation window needs to be properly adjusted to allow efficient monitoring functionality and at the same time eliminate false misfire detections.

The following recommendations are made for a change in the current definition of the misfire window (Regulation (EU) 2014/44 Annex XII, point 3.3.2.2:

> The presence of engine misfire in the engine operating region bounded by the following limits:
>
> a) Low speed limit: A speed of 2500 min^{-1} or nominal idle speed+1000 min^{-1}, whichever is lower;
> b) High speed limit: A maximum speed of 8000 min^{-1} or 1000 min^{-1} greater than the highest engine speed occurring during a Type I Test cycle or maximum design engine speed minus 500 min^{-1}, whichever is lower;
> c) A line joining the following engine operating points:
>   - a point on the low speed limit defined in (a) with the engine intake vacuum at 3.3 kPa lower than the positive torque line, and
>   - a point on the high speed limit defined in (b) with the engine intake vacuum at 13.3 kPa lower than the positive torque.

The following recommendations are also made regarding the regulations, to more clearly specify the requirements for misfire detection:

> - Regulation (EU) 44/2014 defines intake vacuum with the expression “manifold vacuum”. We recommend to change this throughout the Regulation to read “intake vacuum”, as several motorcycles have no manifolds.
> - Intake pressure on a motorcycle engine may considerably vary during operation for a given speed and load operation. To reduce ambiguity in definition and potential exploitation of the exact vacuum level, we propose to define engine intake vacuum as the mean vacuum level at the engine intake at a given engine load and engine speed operating point.
> - As several motorcycles may not use an actual sensor to measure intake pressure, a model value, aka a virtual sensor signal, may be used instead. This possibility can be made explicit in Regulation (EU) 44/2014 by adding the following clarification related to engine intake vacuum: “Engine intake vacuum corresponds to the mean vacuum level measured by an on board intake pressure sensor for a given engine load and engine speed operation point. In the absence of such a sensor, the average intake vacuum calculated by an appropriate model can be used, following demonstration of the equivalence of this model to the actual value and approval by the type approval authority”.
> - For vehicles equipped with Continuous Variable Transmission (CVT), transmission engagement is performed by a centrifugal clutch. Engagement may often take place at speeds higher than the low speed limit determined above. Similar to manual gearboxes, the manufacturer may decide to disable misfire monitoring under such events. This is already foreseen in point Annex XII, paragraph 3.2.2.1 of Regulation (EU) 44/2014. To explicitly include CVT gearboxes, we propose to extend the focus of this to include CVT by explicitly including “centrifugal clutch engagement” in the examples list.

<u>Conclusions on enabling successful repair</u>

OBD Stage II introduces additionally functionalities that may enable enhanced repair capacity also to independent repair workshops. Most importantly, catalyst monitoring capability is important as catalyst malfunction can otherwise be possibly detected only by periodic environmental technical inspections, where these are mandatory. In case a vehicle fails the roadworthiness emission test, the existence or not of a relevant OBD-II trouble code may readily advice whether the reason of failure was the catalyst or not, respectively.

Misfire related trouble codes, together with trouble codes referring to other engine components can provide useful information on the source of a potential technical malfunction. However, reliable misfire diagnosis is necessary; as misfire is the result and not the reason of a malfunction, false misfire detections may lead to unnecessary and costly misguided troubleshooting with no real environmental benefit.

OBD Stage II cost-benefit

Detailed experimental and simulation work was conducted to identify the environmental benefits and investment and repair costs associated with the introduction of OBD Stage II. A number of scenarios were then formed according to available options.

The scenarios executed showed that shifting the full implementation of OBD II with OTL II, including catalyst monitoring, to 2024/25 instead of the original 2020/21 time horizon can be proven both technically feasible and cost-beneficial. In order to make sure that net societal benefits are achieved, OBD II for all other malfunctions, including misfire detection, needs to be introduced from 2020/21 (new/all models). The OTL level in the period 2020-2023 is of moderate importance. This is because malfunctions not related to catalyst performance and misfire lead to emissions increase that in any case exceed OTL I. As a result, implementation of OBD II with OTL I in 2020-2023 (w/o catalyst monitoring) leads to the overall highest net benefit (135 M€). OTL levels become critical when the catalyst monitoring is considered, in the post 2023 period.

The recommendation on OBD-II implementation would therefore be (dates applying to new types, one year later for existing types):

- 2020-2023: OBD II for all malfunctions with OTL I, excluding catalyst monitoring;
- 2024: Full implementation of OBD II with OTL II, including catalyst monitoring.

A further recommendation is that anti-tampering provisions for the downstream oxygen sensor are reviewed and, possibly further enhanced, and that guidance to personnel of periodic inspection test centres is given to reduce the possibility of catalyst monitoring system tampering.

Implementation of In Use Performance Ratios (IUPRs)

IUPRs make sure that OBD diagnosis occurs at frequent intervals in real world driving conditions. For effective IUPR and for reducing the probability of false malfunctions, a gradual implementation of IUPR is considered necessary. The following recommendations can be made to maximize the IUPR effectiveness:

i. Introduce IUPR functionality with OBD-II in 2020/21 (new/all models) for demonstration to technical authorities, without the need to meet a minimum IUPR.
ii. Introduce a minimum IUPR of 0,1, as foreseen in Regulation (EU) 44/2014, in the 2024/25 (new/all types) time frame. This is in consideration of the 30 months required to report results after first implementation of IUPR functionality and time given to manufacturers to develop the next algorithmic version.
iii. Examine with a specific study the cost-benefit of introducing a more stringent minimum IUPR. Foresee in regulations that anonymized IUPR data can be made available in the mean-time for such a study.

OBD Stage II suitability for L-vehicle sub-categories

In the course of the analysis of this study, a number of items not initially foreseen were identified in terms of OBD Stage II applicability to individual sub-categories:

- OBD Stage II is expected to be also applying to L6e-A vehicles which are designed and built around moped specifications in rather small volumes. No OBD requirements are enforced for other moped categories. It is therefore recommended to remove OBD Stage II (and even consider removing OBD Stage I) provisions from L6e-A vehicles.
- L4e vehicles are not included in OBD Stage II provisions, despite they have identical powertrains to the equivalent L3e motorcycles. Inclusion of this sub-category in OBD Stage II is therefore recommended.
- OBD Effectiveness for Enduro (L3e-AxE) and Trial (L3e-AxT) motorcycles in real terms is questionable due to overall low activity and short lifetime of these vehicles. As the relevant industry is dominated by SMEs with limited R&D expenditure, exclusion from OBD Stage II provisions for these vehicles is therefore advised not to significantly distort the market.

OBD Stage II expansion to other UNECE regions

Introduction of OBD-II in other UNECE regions has the potential to further increase the benefit over costs ratio of the calculations made for the EU. This is primarily due to cost compression by economies of scale and the decrease of model varieties for different parts of the world. The actual cost-benefit ratio needs to take into account users responsibility and environmental awareness to repair malfunctions in the different regions. In cases where this is expected low, enabling default modes or no-start of the vehicle after certain distance has been covered following a malfunction may be effective.

Assessment of off-cycle emission (OCE) requirement implementation beyond the Euro 5 step

Objectives

The study assessed the possibility to implement off-cycle emission (OCE) requirements beyond the Euro 5 step. The specific targets of this part of the study were to:

i. Perform an experimental test programme to assess the technical feasibility of off-cycle emission requirements;
ii. Determine cost-benefit ratio ranges for the implementation of in-service conformity requirements.

Conclusions

The experimental results collected and the subsequent analysis led to the following conclusions related to the implementation of off-cycle requirements beyond the Euro 5 step:

i. PEMS is considered to be the most suitable method for controlling OCE
ii. OCE requirements are technically feasible. Further improvements of the accuracy of PEMS for application on L-category vehicles are expected, once OCE requirements become mandatory.
iii. Off-cycle emissions can substantially differ from WMTC emissions.
iv. Due to the large variety in vehicle characteristics, the determination of trip requirements and test conditions cannot be generalised for all vehicles within the L-category.
v. Because of many uncertainties on the effectivity of the Euro 5 measures, pending on how the recommendations from this study are transferred to

adaptation of the Euro 5 measures, the baseline for robust CBA for OCE requirements is unstable. Therefore a robust CBA cannot be performed.

vi. However, it is expected that OCE requirements are a viable measure to safeguard low emissions of L-category vehicles during everyday operation. The expectation is that the benefits of OCE requirements will be significant and will outweigh the additional costs.

Based on these conclusions, the main recommendations are:

i. Retain the introduction of OCE requirements as a possible viable option to safeguard and control low emissions of L-category vehicles during everyday operation;
ii. Anticipate next steps to provide definitive evidence for OCE viability and to prepare for introduction of OCE requirements after 2020

The following accompanying recommendations are made for follow-up:

iii. A robust CBA shall be performed when a robust baseline for the actual performance of Euro 5 vehicles can be determined.
iv. A detailed test protocol for OCE requirements shall be developed, tailored to the Euro 5 baseline. These requirements shall include at minimum:
    a. Trip requirements and test conditions, at minimum per WMTC class. For this purpose, collection of real world operation data of each individual L-category shall be initiated.
    b. Technical requirements for the PEMS.
    c. Data evaluation requirements that are specifically designed for L-category vehicles.
    d. The required level of the accompanying conformity factors shall be researched and determined.

Assessment of in-service conformity (ISC) emissions requirement implementation beyond the Euro 5 step

<u>Objectives</u>

The study assessed the possibility to implement in-service conformity (ISC) requirements, also referred to as in-use compliance (IUC) verification testing, beyond the Euro 5 step. The specific targets of this part of the study were to:

i. assess the technical feasibility of in-service conformity requirements by development of a draft ISC test protocol and performance and running an ISC test programme for a limited number of vehicle models;
ii. perform a cost-benefit analysis for the implementation of in-service conformity requirements beyond 2020.

<u>Conclusions</u>

The experimental results collected and the subsequent analysis led to the following conclusions related to the implementation of in-service conformity requirements beyond the Euro 5 step:

i. There is a need for emission requirements for in-use vehicles, as some of the tested in-use properly maintained vehicles have excessively high emissions compared to their emission limits
ii. It is strongly suspected by the study team that many new mopeds are adjusted by dealerships before delivery to the first owner. Often a larger fuel nozzle is applied, to, according to multiple dealerships, meet the client expectations with regard to drivability and cold start behaviour. As a result,

emissions of the vehicle that is delivered to the end-user may not comply to the emission requirements anymore. This large scale tampering cannot be detected with the current set of type approval procedures, and the questions is if the manufacturer can be held responsible for the adjustments made by the dealerships. It should be remarked that these vehicles are not type approved under the anti-tampering provisions of Regulation (EU) No 168/2013 as these were all Euro 2 and 3 vehicles. Moreover, the size of the issue might be different with introduction of Euro 5 technology.

iii. The introduction of ISC-requirements are proven to be technically feasible. During the study, a demonstration ISC programme was successfully performed with 5 vehicle models that are representative for sales in Europe. In total 15 in-use vehicles were located and tested according to the draft protocol within 8 days of testing.

iv. Implementation of ISC-requirements is an effective and cost-beneficial measure to safeguard proper emissions levels from in-use vehicles during their useful life.

v. Implementation of ISC-requirements delivers the highest net benefit when 28% of the vehicle families are subjected to ISC verification testing. In this scenario, the 20% share of the families with highest sales volume on the market are selected for ISC verification testing, and, of the remaining 80% of the families, 10% is checked on ISC by random selection.

vi. It shall be secured that in-use vehicles are randomly selected from the vehicle fleet that is in-service, in order to prevent the potential risk that ‘prepared’ or ‘carefully selected’ vehicles are tested.

Based on these conclusions, the main recommendation is to:

i. Introduce ISC requirements beyond Euro 5 for 28% of the vehicle families, where 20% of the selection of families is based on representativeness in terms of sales and 8% of the families is randomly selected from the remaining families.

The following accompanying recommendations are made:

i. A part of the ISC-verification testing should be performed under full responsibility of the TAA, including the selection of the vehicles.

ii. When off-cycle emission (OCE) requirements are implemented, it is recommended to perform a cost-benefit analysis on the possibility to perform ISC testing by using the OCE test. This will thoroughly secure real-world emission performance of in-use vehicles during their useful life.

iii. Measures to avoid ‘adjustment’ of emission related components of new vehicles by dealerships before they are delivered to their first owner, affecting the emission performance of the vehicles, are important. The effectivity of the anti-tampering measures according to Regulation (EU) No 168/2013 should be assessed, additional measures might be required in the future.

Assessment of the need to expand the PM limit scope to other vehicle categories than those already subject in the Euro 5 step and introduction of a PN limit

<u>Objectives</u>

The Euro 5 step introduces PM limits for direct injection (DI) positive ignition (PI) and compression ignition (CI), i.e. diesel vehicles at a level of 4.5 mg/km, similar to passenger cars. The specific targets of this investigation were to examine:

- Whether the PM limit needs to be introduced for other sub-categories as well.

- Whether introduction of a PN limit is also needed for some vehicle sub-categories.

Conclusions

The experimental results collected and the subsequent analysis led to the following conclusions related to the regulation of PM and PN emissions from L-category vehicles:

1. PM limits introduced by Regulation (EU) 168/2013 for PI DI and diesel vehicles are de facto cost-beneficial. Such vehicles are not expected in high numbers at Euro 5 step and if new designs appear they will need to respect PM limits.
2. Introducing specific PN limits for any L-category vehicles first requires better understanding of the emissions performance of such vehicles, as new emission control technologies at Euro 5 step become available. In this direction, improvements or confirmation of the PN measuring protocol is first required, especially following current discussions on extending PN size limits, before establishing a number-based limit value.
3. It is not possible to assess the cost-benefit ratio of introducing PN emission limits for PFI vehicles, using equivalencies to passenger cars. PN emissions from L-category vehicles are mostly linked to lube oil consumption and upcoming stringent NMHC limits at Euro 5 may be proven effective to control PN emissions from such vehicles as well, without the need of mandating a separate PN standard.
4. Monitoring and experimental campaigns in assessing whether and to what extent PN emissions from L-category vehicles drop with increasing stringency of NMHC emission standards need to be put in place. In particular, the impact of using low SAPS lube oil on particle emissions (with focus to those below 23 nm) are necessary to better understand the potential of PN reduction by lube oil reformulation.

Based on these, the following recommendations can be made:

1. Provide some lead time (2024/25 – new/all types) for introduction of PM limits for L6e-B (diesel mini-cars) to allow new powertrain concepts development, in line with the lead time recommended to be given for the gaseous pollutants.
2. Introduce PM limits for 2-S vehicles as well, despite these may be infrequent or not at all able to make it to Euro 5 step.
3. Better understand impacts of PN emissions of new emission control concepts at Euro 5 step before introducing specific limits. Understand the impact of lube oil on L-category vehicle PN emissions and consider advanced lube oil specifications to reduce PN emissions.

Contents

Appendices

1 Introduction

1.1 Context

Road-traffic emissions are significant contributors to air quality degradation, in particular in urban areas. Although they only correspond to a rather small fraction of total road transport activity, mopeds and motorcycles may actually be the single most important contributor to HC emissions in specific areas, such as southern European cities, *e.g* Iodice and Senatore (2013), while two-stroke scooters alone are also prominent contributors of reactive oxygen species and secondary organic aerosol mass precursors to the atmosphere (Platt et al., 2014). This mostly due to the less demanding emissions control of mopeds and motorcycles compared to passenger cars (Vasic and Weilenmann, 2006), at least so far. An earlier study (Ntziachristos et al., 2013) estimated that L-category vehicles correspond to roughly 25%, 15%, 2% and 2.5% of total HC, CO, NO_x and PM emissions from road traffic in EU for the year 2015.

In order to reduce emissions from L-category vehicles, the European Commission introduced several stages of emissions control regulation since 1997, when Directive 97/24/EC first defined emissions limits at a Euro 1 step (and Euro 2 for mopeds). This first step only referred to mopeds and motorcycles but since then, additional pieces of regulation introduced more stringent limits, enlarged the vehicle range covered and introduced enhanced control methods. Significant steps in this process have been:

- Directive 2002/24/EC, introducing refinements in the type-approval and conformity of production procedures,
- Directive 2002/51/EC, introducing Euro 2 and Euro 3 steps for motorcycles, tricycles and quadricycles,
- Directive 2006/72/EC, where Global Technical Regulation No 2 (GTR 2) becomes part of the type-approval and emission limits are adjusted to the World Motorcycle Test Cycle (WMTC).

Since 2013, a renewed interest in L-category vehicle emissions has come up, in an effort to further reduce their contribution. Regulation (EU) No 168/2013 linked to a number of follow up delegated Directives and Regulations, introduced the Euro 4 step for all L-category vehicles and a comprehensive package of environmental tests, including durability requirements, fuel evaporation control provisions, and On-Board Diagnostics (OBD). The intention has been not only to make sure that new vehicle models become increasingly clean when placed to the market but also that they remain so throughout their useful life. In summary, the environmental tests for L-category vehicles comprise:

- Test type I: tailpipe emissions after cold start. This test is conducted on a new (degreened) test vehicle in an emission test laboratory and tested according to the test procedures set out in Annex II of Regulation (EU) No 134/2014. Tailpipe emissions are collected and analysed at the end of the test. The test results must be lower than the emission limits laid down in Annex VI(A) of Regulation (EU) No 168/2013 or in Commission Directive 2013/60/EU for mopeds Euro 3;
- Test type II: (increased) idle and free acceleration emission test. The test vehicle is made subject to test type II in order to verify whether it can meet the simple tailpipe emission test requirements performed in roadworthiness testing;
- Test type III: crankcase emissions. This test verifies that no gases from the crankcase ventilation system of the engine directly escape to the atmosphere (without being combusted);

- Test type IV: evaporative emissions. Evaporative emissions stem from the fuel storage and supply system owing to vapour escaping the fuel tank, permeation of hydrocarbons contained in the fuel through the walls of the fuel storage tank, tubing and other parts of the fuelling system. This test also validates the design of the vehicle in terms of preventing fuel evaporation directly into the atmosphere (without being combusted) from root causes other than from permeation, *e.g.* breathing losses at elevated ambient temperature cycles;
- Test type V: durability of pollution control devices. This test aims at verifying that emission limits are not exceeded over the useful life of operation, corresponding to different distances according to vehicle category (*e.g.* 35000 km for a two-wheeled motorcycle). Emission control devices need to be so designed as to little degrade over the useful life. Either physical ageing or default deterioration factors on emission levels of a new vehicle can be applied to demonstrate compliance.
- Test type VII: fuel efficiency test. This reports the environmental performance of the vehicle in terms of carbon dioxide (CO_2) emissions and fuel and/or energy consumption. All electric range is also estimated in case of hybrid vehicles;
- Test type VIII: environmental OBD verification testing. The test procedure is set out in Annex VIII of Regulation (EU) No 134/2014 and intents to identify if emission control malfunction are identified by the OBD system. is a special Type I test in which a malfunction is introduced on the test vehicle before start of the test
- Test type IX: Sound level. This test aims to make sure that sound emission limits are not exceeded. Assessment of this test is outside the scope of the current study.

Further to introducing a comprehensive package of measures for Euro 4 vehicles Regulation (EU) No 168/2013 also introduces the framework for Euro 5, including emission limits and enhanced requirements for a number of environmental tests, including durability, OBD, and evaporation control. The intention to introduce Euro 5 since the beginning has been to deliver long-term planning security for the vehicle manufacturers and the supplier industry.

However, before full implementation of the Euro 5 step, recital 12 and points 4 and 5 of Article 23 of Regulation (EU) No 168/2013 stipulate that the Commission should conduct an ‘environmental effect study’ with respect to the Euro 5 environmental step for L-category vehicles. That study should provide additional underpinning through measurements, modelling, technical feasibility assessment and cost-effectiveness analysis based on the latest available data to support the introduction and, possible refinement, of Euro 5. The current report presents the activities, the results and the conclusions collected in the framework of this study. This work was conducted under contract SI2.713570, awarded by the European Commission Directorate General Growth (DG GROW) to a consortium consisting of TNO, Emisia SA, Heinz Steven and the Laboratory of Applied Thermodynamics (LAT) in Aristotle University of Thessaloniki (AUTh).

In addition to underpinning the Euro 5 step, recital 12 of Regulation (EU) No 168/2013 requests that the study reports on the feasibility and cost-effectiveness of possible measures that can be introduced beyond Euro 5, including in-service conformity (ISC) testing requirements, off-cycle emission (OCE) requirements, the introduction of a particulate number (PN) emission limit for certain (sub-) categories and the application of a particulate matter (PM) requirement for all (sub-) categories. On the basis of the study results, the Commission will be able to consider presenting a proposal introducing these new elements into future type-approval legislation.

1.2 Study preparation

The ‘environmental effect study’ initiated and performed by DG GROW has been structured in 4 individual phases:

- Pre-study phase:
European Commission Directorate General Joint Research Centre (DG JRC) conducted a preliminary study from July 2014 to June 2015, with the main intention to identify the key elements and the technical approach for the main environmental effect study. The technical objectives comprised of (i) developing a commonly applicable engine load variable, allowing to assess the exhaust emission laboratory test cycles in a more objective way, independent of emission approval level and ageing effects of the test vehicles; (ii) execution of an experimental verification and validation test programme to confirm the engine load variable(s); (iii) identification of appropriate miniature emission test equipment (literature + suppliers) for off cycle testing; (iv) providing recommendations and co-authoring of the call for tender specifications. The results of this phase are reported in the pre-study report (Zardini, 2014).
- Phase 1:
DG JRC conducted phase 1 of the study from the end of 2014 to the end September 2015. The objectives were to take stock of the fleet and structure of the L-category vehicle sector and data mine Type I data available in EU to the date; conduct a public consultation on the need for Euro 5; perform a literature study on L-category vehicle emissions and prepare a detailed planning for follow-up phases 2 and 3. The results of this phase are reported by Clairotte et al. (2016) and by Hag et al. (2016).
- Phase 2:
Phase 2 is the main focus of the current report. It was initiated at the end of October 2015 with the intentions to perform a thorough experimental campaign, based on the output of the pre-study and phase 1, to assess Euro 5 package elements. In addition, the objectives were to perform additional modelling, verification testing and analysis of the results and the various components of Euro 5.
- Phase 3:
For further validation of the results in Phases 1 and 2, additional testing was foreseen in a phase 3 of the study, based on a limited vehicle sample not used in the previous phases. Phase 3 results are also reported herein.

The Euro 5 effect study was initiated by DG GROW who are also overall responsible to manage the programme. DG JRC was responsible in whole for the pre-study and phase 1 and significantly contributed to the technical execution of phases 2 and 3 by providing their testing facilities and technical expertise related to L-category vehicle emissions and performance.

1.3 Objectives

The main objective of the current study is to provide technical support and a cost-benefit analysis for assessing the individual measures within the Euro 5 package. The current study aims at providing the technical background for the Report that the European Commission will present to the European Parliament and the Council, according to paragraph 5 of Article 23 of Regulation (EU) No 168/2013. According to this article, the individual items listed in the following textbox need to be covered by this environmental effect study.

Article 23 of Regulation (EU) No 168/2013:

§ 4: By 1 January 2016, the Commission shall carry out a comprehensive environmental effect study. The study shall evaluate the air quality and the share of pollutants contributed by L-category vehicles and shall cover the requirements of test types I, IV, V, VII and VIII…

§ 5: … the Commission shall by 31 December 2016 present… :

(a) the enforcement dates of the Euro 5 level;

(b) the Euro 5 emission limits;

(c) that all new types of vehicles in (sub-)categories L3e, L5e, L6e-A and L7e-A shall, in addition to OBD stage I, also be equipped with OBD stage II;

(d) the durability mileages ... and the deterioration factors….

§ 6: ... determining which of the (sub-) categories L1e-A, L1e-B, L2e, L5e-B, L6e-B, L7e-B and L7e-C for the Euro 5 level are to be subject to SHED testing or to fuel tank and tubing permeation testing;

Moreover, Recital 12 of Regulation (EU) No 168/2013 states that:

Recital 12 of Regulation (EU) No 168/2013:

This Regulation sets environmental requirements for two stages with the second stage (Euro 5) being mandatory for new types of vehicles as of 1 January 2020, thereby creating long-term planning predictability for the vehicle manufacturers and the supplier industry. Based on future available data, an environmental effect study required by this Regulation should provide additional underpinning through modelling, technical feasibility and cost- effectiveness analysis based on the latest available data. In addition, the study should, inter alia, assess the feasibility and cost-effectiveness of in-service conformity testing requirements, off-cycle emission requirements and a particulate number emission limit for certain (sub-)categories. On the basis of the study results, the Commission should consider presenting a proposal introducing these new elements into future type-approval legislation applicable after the stages provided for in this Regulation.

For each measure within the Euro 5 environmental step and for the additional items requested in Recital 12, the current study:

- assessed the technical feasibility of each item, and proposes modifications to the technical descriptions, where necessary, to make each item achievable within the specified period;
- quantified the expected impact of each measure on the environmental performance of L-category vehicles at a fleet level;
- estimated the societal cost for the implementation of each item, considering application to the vehicles, type approval, warranty costs, etc.
- calculated the cost-benefit ratio of each measures, by converting environmental impacts to monetary gains and comparing to implementation costs;

Further to the items outlined above, the Terms of Reference of the contract, on the basis of which this study was executed, requested that additional items are studied

to further clarify the implementation of Euro 5. These items relate to all test Types and the study provides a thorough assessment for each of them. Of particular importance is the international dimension of the results of this study, expressed by the Contracting Parties to the UNECE 1958 and 1998 Agreements. The study is critical for the success of the international harmonization exercise oversighted by Working Group on international environmental and propulsion performance requirements for L-category vehicles (UN L-EPPR), under the United Nations Economic Commission for Europe (UNECE).

Individual issues raised by the stakeholders in L-EPPR, as well as by participants in the Motorcycle Working Group (MCWG) are also addressed in the current study.

1.4 Structure of this report

Chapter 2 contains a description of the general approach, the performed experiments and applied general methods in this study.

The findings on the individual measures within the Euro 5 environmental step are reported in chapters 3 to 9. The study on the possible measures beyond Euro 5 and the international aspects of the study are reported chapter 10 to 13.

The conclusions reached in each case are individually presented in each chapter of this report.

2 General approach, experiments and methods

2.1 Outline of the L-category vehicle structure

L-category comprises a wide range of light vehicles, including powered cycles, two- and three-wheeled mopeds, two-wheeled motorcycles with and without a sidecar, tricycles and quadricycles. A simplified overview of the complete L-category, with typical vehicle examples and key vehicle specifications, is shown In Table 1.

Table 1. overview of the L-category vehicle family

Vehicle categorisation	Typical Photos of Models			Key specifications
L1e- A Powered cycle				≤50 cc (PI), ≤25 km/h, ≤1 kW
L1e -B Two-wheel moped				≤50 cc (PI), ≤45 km/h, ≤4 kW
L2e Three-wheel moped	 L2e-P	 L2e-U		≤50 cc (PI) / ≤500 cc (CI), ≤45 km/h, <4 kW, ≤270 kg
L3e Two-wheel motorcycle	 L3e-A1	 L3e-A2	 L3e-A3	A1: ≤125 cc, ≤11 kW, ≤0.1 kW/kg A2: ≤35 kW, ≤0.2 kW/kg A3: >35 kW, >0.2 kW/kg
L4e Two-wheel motorcycle with side-car				Equivalent to the corresponding L3e
L5e-A Tricycle				3 wheels, ≤1000 kg, max 5 seats
L5e-B Commercial tricycle				3 wheels, ≤1000 kg, max 2 seats, loading volume ≥ 0.6m^3
L6e-A Light on-road quad				≤50 cc (PI) / ≤500 cc (CI), ≤45 km/h, ≤4 kW, ≤425 kg
L6e-B Light quadri-mobile	 L6e-BP	 L6e-BU		≤50 cc (PI) / ≤500 cc (CI), ≤45 km/h, ≤6 kW, ≤425 kg
L7e-A Heavy on-road quad	 L7e-A1	 L7e-A2		≤15kW, ≤450 kg
L7e-B Heavy all terrain quad	 L7e-B1	 L7e-B2		B1: ≤90 km/h, ≤450 kg B2: ≤15kW, ≤450 kg
L7e-C Heavy quadri-mobile	 L7e-CU	 L7e-CP		CU: ≤90 km/h, ≤15kW ≤600 kg CP: ≤90 km/h, ≤15kW ≤450 kg

2.2 Vehicle sample

Table 2 shows the main characteristics of the vehicles tested in the main part of this study. Table 3 shows the specifications of the vehicles tested for in-service conformity test demonstration.

Table 2. Overview of tested vehicles in the main part of this study

Vehicle ID no.	category	category name	engine capacity class [cc]	rated power [kW]	engine combustion type*	# of cylinders	Maximum design speed [km/h]	Transmission	Euro class	Fuel delivery system	SAS	catalyst**	reference mass class [kg]	year	mileage [km]***
J05	L1e-A	powered cycle	30	1	G-2S	1	25	Fixed	Euro 1	carburettor	No	n.a.	100	2009	200
J06	L1e-B	low speed moped	50	3	G-2S	1	25	Fixed	Euro 2	carburettor	Yes	2w	120	2010	500
J07	L1e-B	low speed moped	50	3	G-2S	1	25	CVT	Euro 2	carburettor	No	2w	170	2010	500
J10	L1e-B	low speed moped	50	3	G-4S	1	25	CVT	Euro 2	carburettor	Yes	2w	160	2010	500
J02	L1e-B	high speed moped	50	2	G-2S	1	45	Manual	Euro 2	carburettor	Yes	2w	190	2015	0
J03	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	carburettor	Yes	2w	160	2015	0
J04	L1e-B	high speed moped	50	3	G-2S	1	45	CVT	Euro 2	carburettor	Yes	2w	160	2015	0
J12	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	injection	Yes	2w	170	2013	846
J14	L1e-B	high speed moped	50	3	G-2S	1	45	CVT	Euro 2	carburettor	Yes	2w	180	2015	500
J17	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	carburettor	Yes	2w	170	2013	4926
J29	L1e-B	high speed moped	50	3	G-2S	1	45	CVT	Euro 2	carburettor	Yes	2w	165	2012	400
J26	L2e-U	Three-wheel moped	50	2	G-2S	1	38	Manual	Euro 2	carburettor	Yes	2w	380	2016	100
J27, valid.	L2e-U	three-wheel moped	n.a.	4	E	n.a.	45	Fixed	n.a.	n.a.	n.a.	n.a.	300	2016	4
J19	L3e-A1	low perf. motorcycle	130	7	G-4S	1	90	CVT	Euro 3	carburettor	No	2w	180	2012	1372
J23	L3e-A1	low perf. motorcycle	130	11	G-4S	1	105	CVT	Euro 3	injection	No	3w	240	2010	0
J11	L3e-A2	medium perf. motorcycle	160	10	G-4S	1	95	CVT	Euro 3	injection	No	3w	200	2015	950
J28, valid.	L3e-A2	medium perf. motorcycle	300	16	G-4S	1	125	CVT	Euro 3	injection	No	3w	260	2015	500
J13	L3e-A2	medium perf. motorcycle	280	19	G-4S	1	128	CVT	Euro 4	injection	Yes	3w	240	2015	2871
J15	L3e-A2	medium perf. motorcycle	690	32	G-4S	1	>150	Manual	Euro 4	injection	Yes	3w	230	2016	1000
J18	L3e-A3	high perf. motorcycle	1170	92	G-4S	2	>150	Manual	Euro 4	injection	No	3w	300	2015	1156
T01	L3e-A3	high perf. motorcycle	1170	92	G-4S	2	>150	Manual	Euro 3	injection	No	3w	300	2016	385
J21	L5e-A	tricycle	300	18	G-4S-H	1	125	CVT	Euro 2	injection	Yes	3w	340	2010	773
L01	L5e-A	tricycle	1330	84	G-4S	3	>150	Semi-AUT	Euro 4	injection	No	3w	530	2015	200
J24	L5e-A	tricycle	200	8	G-4S	1	55	Manual	Euro 2	carburettor	No	2w	420	2016	100
J01	L6e-BP	light quadri-mobile	480	4	D-4S	2	45	CVT	Euro 2	injection	No	2w	470	2015	0
J22	L6e-BU	light quadri-mobile	400	4	D-4S	2	45	CVT	Euro 2	injection	No	n.a.	480	2014	988
J16	L7e-B1	all terrain quad	980	15	G-4S	2	65	CVT	Euro 2	injection	No	3w	470	2016	538
J08	L7e-B1	all terrain quad	570	11	G-4S	1	70	CVT	Euro 2	injection	No	2w	450	2015	900
J25, valid.	L7e-B1	all terrain quad	440	17	G-4S	1	67	CVT	Euro 2	injection	No	3w	370	2016	17
J09	L7e-B2	side-by-side buggy	700	15	G-4S	2	78	CVT	Euro 2	injection	No	2w	570	2016	638
J20	L7e-CP	heavy quadri-mobile	n.a.	13	E	n.a.	80	Fixed	n.a.	n.a.	n.a.	n.a.	570	2013	0

* G = gasoline; D = Diesel; E=Electric; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening
n.a. = not applicable
valid. = this vehicle was part of the validation testing programme
SAS = secondary air system

2.3 Test facilities and equipment

2.3.1 Exhaust emissions testing on chassis dynamometer

The majority of chassis dynamometer tests were conducted in the Vehicle Emissions Laboratory VELA 1, which is part of the Sustainable Transport Unit (STU), Directorate for Energy Transport and Climate (previously "Institute for Energy and Transport (IET)), Joint Research Centre (JRC), Ispra, Italy. The laboratory is able to perform emission test in accordance with Regulation (EU) No 168/2013 and Regulation (EU) No 134/2014.

Table 3. Overview of tested vehicles in the In-Service conformity tests

Vehicle ID no.	category	category name	engine capacity class [cc]	rated power [kW]	engine combustion type*	# of cylinders	Maximum design speed [km/h]	Transmission	Euro class	Fuel delivery system	reference mass class [kg]	year	mileage [km]***
J31	L1e-B	low speed moped	50	2	G-4S	1	25	CVT	Euro 2	carburettor	200	2012	6368
J32	L1e-B	low speed moped	50	2	G-4S	1	25	CVT	Euro 2	carburettor	200	2015	5560
J33	L1e-B	low speed moped	50	2	G-4S	1	25	CVT	Euro 2	carburettor	200	2015	5500
J34	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	carburettor	160	2011	3751
J35	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	carburettor	160	2007	8804
J36	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	carburettor	160	2015	1905
J37	L1e-B	high speed moped	50	2	G-4S	1	45	CVT	Euro 2	carburettor	170	2011	7187
J38	L1e-B	high speed moped	50	2	G-4S	1	45	CVT	Euro 2	carburettor	170	2008	8567
J39	L1e-B	high speed moped	50	2	G-4S	1	45	CVT	Euro 2	carburettor	170	2015	614
J40	L3e-A2	medium perf. motorcycle	330	25	G-4S	1	125	CVT	Euro 3	injection	270	2013	7090
J41	L3e-A2	medium perf. motorcycle	330	25	G-4S	1	125	CVT	Euro 3	injection	270	2012	4657
J42	L3e-A2	medium perf. motorcycle	330	25	G-4S	1	125	CVT	Euro 3	injection	270	2012	10516
J43	L3e-A3	high perf. motorcycle	690	55	G-4S	2	>150	Manual	Euro 3	injection	260	2016	13814
J44	L3e-A3	high perf. motorcycle	690	55	G-4S	2	>150	Manual	Euro 3	injection	260	2015	15143
J45	L3e-A3	high perf. motorcycle	690	55	G-4S	2	>150	Manual	Euro 3	injection	260	2014	24940

*   G = gasoline; D = Diesel; E=Electric; 2S = 2-stroke; 4S = 4-stroke
**   2w = 2-way catalyst; 3W = 3-way catalyst
***   mileage at vehicle take-in, before any applied degreening
n.a. = not applicable
valid. = this vehicle was part of the validation testing programme

Table 4 summarizes most important specifications of VELA 1. A schematic overview of the parameters which can be measured and the test facility itself is shown in Figure 1.

Table 4. VELA 1 specifications

Component	Specifications
Chassis dynamometer (Zoellner)	Diameter: 48”
	Inertia range: 150-3500 kg
	Maximum speed: 200 km/h
Fan	Variable speed (following the vehicle speed)
	Maximum speed: 200 km/h
Test cell temperature range	25°C or -7°C
Sampling system (CGM)	Conventional CVS system with a critical flow Venturi
	Flow rate range: from 1.5 m3/min to 11.25 m3/min
	Insulated tunnel
Signal acquisition system	ECU parameters
	Any type of signal from sensors installed on the vehicle
Analysers (AVL)	CO: IR analyser
	NOx: Chemiluminescence analyser
	HC: FID analyser
	CO2: NDIR analyser
	Particulate mass: particulate samples are collected according to the legislative procedure using Teflon coated glass fibre filters and the mass is determined by weighing
	Particle number: PMP system
	On-line measurement of gaseous pollutants on raw exhaust (modal analysis post cat)
Fuel consumption	AVL KMA

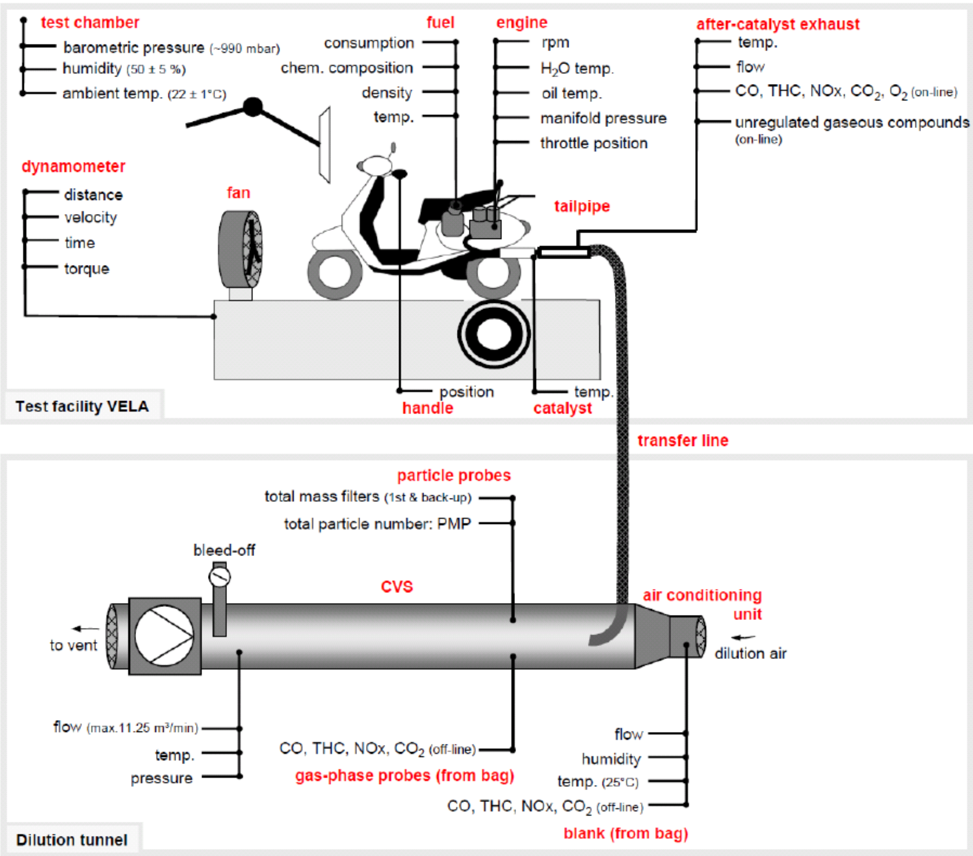

Figure 1. Schematic overview of measured parameters and the test facility (Zardini, 2014)

Some testing was also conducted at the chassis dynamometer of LAT. The key specifications of the Laboratory are summarized in Table 5.

Table 5. Specifications of the chassis dynamometer of LAT

Chassis dynamometer	Type: Ward-Leonard
	Max. vehicle weight: 3.5 t
	Driving cycle programmable: - legislative (NEDC, WLTP, FTP-75, ECE R47, WMTC etc.) - real world (Artemis, ERMES etc.)
Exhaust sampling systems	Full CVS for passenger cars (diesel, gasoline)
	Open CVS for two-wheelers
	Partial dilution sampling system
	PM sampling according to PMP requirements
Emission analysis according to legislation requirements	Bag results
	Gravimetric PM filter results
	Instantaneous results - Gaseous species - PM mass and number according to PMP

2.3.2 *Sealed Housing for Evaporative Determination (SHED) facility*

The complete vehicle testing programme regarding SHED measurements was carried out in the VELA 3 laboratory of JRC. The Variable Temperature (VT SHED) facility used for this programme complies with the Directive 98/69/EC and United States Environmental Protection Agency (EPA) requirements. The measuring chamber is a fixed-volume type one. Volume compensation is achieved by continuous withdrawal of internal atmosphere and refilling with ambient air. Outgoing and incoming flows are controlled by means of mass flow controllers.

In standard evaporative emission tests the vehicle is placed into the airtight measuring chamber (VT SHED) and all the hydrocarbons emitted by the vehicle are released into the SHED. Evaporative emissions are determined by means of a Flame Ionisation Detector (FID) analyzer which continuously monitors the Volatile Organic Compound (VOC) concentration inside the chamber.

Table 6 summarizes most important specifications of the SHED chamber, VELA 3.

Table 6. VELA 3 (SHED) specifications

Component	Specifications
Climatic cell (CGM Electronics)	Temperature range: 20C to 40C
Gas analysers	HC: FID analyser (CGM Electronics)
	VOCs: Bags collection and GC dual FID instrument (Agilent)
Control software (CGM Electronics)	Type: CGM 311 – VT SHED

2.3.3 *Permeation and carbon canister ageing testing*

The tests for the determination of fuel permeation losses through the fuel delivery system and for the ageing of the carbon canister are performed at the facilities of the Laboratory of Applied Thermodynamics (LAT). The test facilities and the equipment used in the tests are in accordance with Annex V, Appendix 2 to Regulation (EU) No 134/2014.

Permeation tests

The test facilities and equipment used for the permeation tests include:

- Temperature-controlled room
  An air-conditioned room has been used in which the temperature is continuously monitored and recorded with a data acquisition device, and is maintained at 31°C ± 2°C during the whole testing period.

- Scale for the determination of fuel losses
  The permeation tests are based on the gravitational method *i.e.* the fuel delivery system is weighted before and after a predefined temperature-controlled period in order to determine the permeation losses through the material of the fuel system components, thus a scale with a range of 0-36 kg and readability of 0.1 g is used for this purpose.

- Test rig for each fuel delivery system
  For each vehicle, a test rig was built consisting of the fuel tank and the fuel lines (a part or all of them) to be used for the weighting process.

Carbon canister ageing tests

The test rig developed for the carbon canister ageing tests is shown in Figure 2.

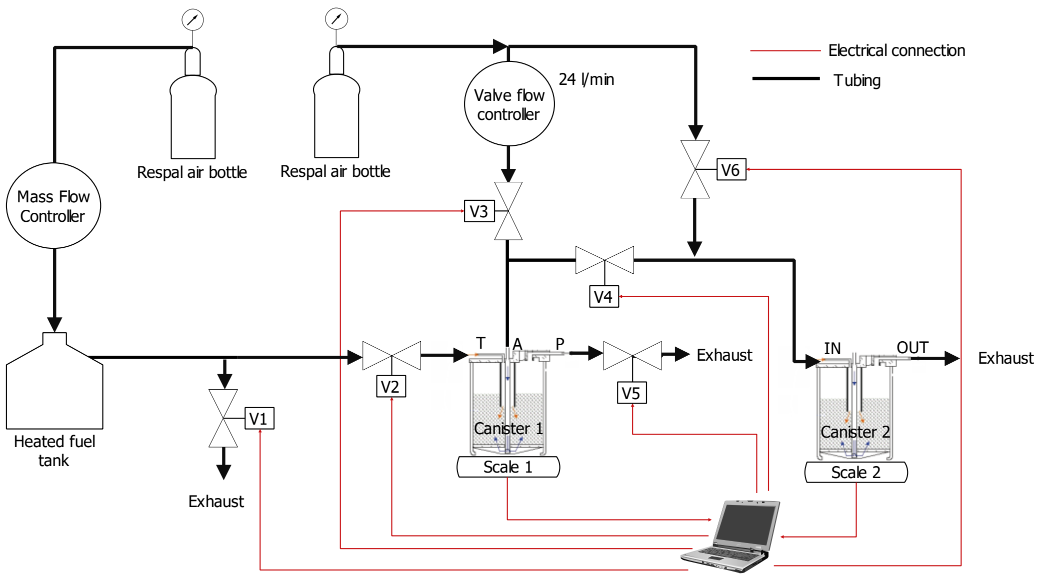

Figure 2. Carbon canister ageing tests equipment

The test equipment used for the tests included:

- Ventilated room with fire extinguishing system

  Gasoline fuel is heated (up to 40ºC) during the tests to create the desired air-fuel mixture for the loading of the canister. As gasoline is highly flammable all tests are carried out in a well-ventilated room equipped with a fire extinguishing system.

- Scales

  Two scales are used for the tests. The first one (range: 0-12 kg, readability: 0.05 g) is used to determine the working capacity of the under-study canister while the second (range: 0-36 kg, readability: 0.1 g) is used to determine the amount of fuel vapors escaping from the canister.

- Heated fuel tank, clean air bottles, mass flow controller, valve flow controller and electrically-actuated valves.

  These components are used to create the desired air-fuel mixture for the canister loading and purge the canister after each loading period.

- PC and Arduino board controller

  The control of the above-mentioned devices and the test procedure is performed by a PC and an Arduino board.

2.3.4 *4-gas analysers*

The Type II tests have been performed mostly using the equipment presented in 2.3.1 above. The validation of the tests though have been performed using two different 4-

gas analysers. The first analyser was used for the validation of the Type II test on mopeds, and the second analyser for the Type II test on motorcycles.

Table 7. 4-gas analysers

#1	Brand: Arex Model: Uitlaatgastester (Exhaust gas tester)
#2	Brand: Motorscan gas analyser Model: MS 805

2.3.5 PEMS systems (including thermocouples)

PEMS (Portable Emissions Measurement System) tests were conducted at TNO on the road and at the JRC on the chassis dynamometer. The most important specifications are summarized in Table 8.

Table 8: Specifications of PEMS

Dimensions and weight	Dimensions: 550 mm x 430 mm x 215 mm Weight: 17.2 kg
Measured parameters	- Time, vehicle speed (GPS), acceleration, engine speed, intake air temperature, manifold absolute pressure, other ECU parameters <u>Measured gases:</u> - HC, CO, CO_2 (NDIR – Non-Dispersive Infrared) / no heated lines - NO, O_2 (Electrochemical cell) - PM_{10} and NH_3 (optional, not used in this study)
Additional parameters	Grams of pollutant per second (g/s), Intake airflow, Computed Exhaust airflow, Fuel consumption
Supplementary equipment	Thermocouples to measure exhaust gas temperatures. These thermocouples are not part of the PEMS but were added by the contractor.

2.4 Driving cycles

The test vehicles were tested on a chassis dynamometer following different driving cycles for the type I type approval, for the type V type approval, for simulating real-world driving and for measuring the vehicle power. Table 9 provides a summary of the specifications of the driving cycles that were executed in the current study. The speed traces of each driven cycle can be found in Appendix O.

Table 9. Summary of the specifications of the cycles driven in this study

Cycle			Time	Expected distance	Average speed	Max speed	Idling	Constant speed	v*a positive	RPA
			[sec]	[km]	[km/h]	[km/h]	[%]	[%]	[m2/s3]	[m/s2]
Type I	WMTC	Class_I_reduced_25	1200	5.9	18	25	20	57	3.40	0.80
		Class_I_reduced_45	1200	7.6	23	45	19	27	3.72	0.60
		Class_I	1200	7.7	23	50	19	22	3.67	0.58
		Class_2_1	1200	12.3	37	83	13	24	5.23	0.54
		Class_2_2	1200	13.2	40	95	13	23	6.22	0.59
		Class_3_1	1800	27.6	55	111	9	30	6.73	0.54
		Class_3_2	1800	28.9	58	125	9	30	6.88	0.53
	ECE	R47_25	895	4.4	18	25	13	72	2.65	0.69
		R47_45	895	6.3	25	45	13	55	8.59	1.25
		R40_UDC	1169	6.0	19	50	32	29	3.66	0.64
Type V	SRC-LeCV	Cycle_1_25kmh	4564	30.0	24	25	1	94	-	-
		Cycle_1_45kmh	3101	30.0	35	45	2	91	-	-
		Cycle_1_50kmh	3051	30.0	35	50	2	91	-	-
		Cycle_2	1856	30.0	58	100	4	85	-	-
		Cycle_3	1548	30.0	70	100	4	80	-	-
		Cycle_4	1209	30.0	89	130	5	68	-	-
	AMA	Class_I_45kmh	6300	66.0	38	45	9	65	-	-
		Class_I	5504	66.0	43	70	11	50	-	-
		Class_II	5366	66.0	44	90	11	49	-	-
		Class_III_option_I	5359	66.0	44	110	11	50	-	-
		Class_III_option_II	5328	66.0	45	110	11	48	-	-
Off-cycle	Real world cycle	Real_World_L1e_B_HS	3453	26.0	27	47	5	25	6.50	0.75
		Real_World_L3e_A1	5836	62.9	39	94	16	21	5.77	0.54
		Real_World_L3e_A3_130	4330	70.5	59	130	11	25	11.77	0.75
		Real_World_L5e	1800	26.4	53	120	5	16	7.14	0.53

* v*a positive and RPA not given for durability cycles as accelerations are instruction based and therefore vehicle specific

Type approval cycles

Type approval cycles for type I – tailpipe emissions after cold start

As prescribed in Regulation (EU) No 168/2013, the 'revised' Worldwide harmonized Motorcycle Test Cycle (WMTC Stage 3) is to be used for type approval according to Test type I at Euro 5 stage. The same cycle is also used for Test types VII (efficiency) and VIII (OBD). At a Euro 4 step, different driving cycles were used for some categories, *i.e.* the ECE R40 and ECE R47 driving cycles (Table 10). These have also been included in the test campaign to put the revised testing procedure, based on WMTC, in context.

The 'revised' WMTC or WMTC Stage 3 is based on the original WMTC laid down in UNECE Global Technical Regulation No 2 (GTR 2) and has been adapted for vehicles with a low maximum design vehicle speed, as prescribed in Regulation (EU) No 134/2014. Different versions of the WMTC are hence executed for different vehicle categories. For L3e vehicles, the driving cycle speed pattern and vehicle specifications correspondence is provided in Table 11 and is identical to GTR 2. According to Regulation (EU) No 134/2014 Annex II, Appendix 6, section (4), paragraph 1, the same driving cycle at Euro 5 step is applicable to L4e, L5e-A, L7e-A, L7e-B and L7e-C vehicles as well. Adapted WMTC has been introduced in the same Regulation for L1e-A, L1e-B, L2e, L5e-B, L6e-A and L6e-B subcategories, based on WMTC Part 1 reduced, where the speed profile of the cycle is further truncated to either 25 km/h or 45 km/h, depending on the corresponding maximum speed of each vehicle sub-category. The corresponding speed profile has been used in this study, based on the sub-category of the vehicle tested in each case.

Table 10: Applicable driving cycle per vehicle category and Euro class.

Euro class	Test cycle	Vehicle category
Euro 4	ECE R47	L1e-A L1e_B L2e L6e-A L6e-B
	ECE R40	L5e-B L7e-B L7e-C
	WMTC, stage 2	L3e L4e L5e-A L7e-A
Euro 5	Revised WMTC	L1e - L7e

Table 11: WMTC vehicle classification per vehicle type.

WMTC class	Vehicle maximum design speed		Vehicle engine capacity		WMTC cycle
	min	max	min	max	
Class 1	-	< 100 km/h	-	< 150 cm3	Part 1_R (2x)
Class 2-1	≥ 100 km/h	< 115 km/h	-	< 150 cm3	Part 1_R + Part 2_R
	-	< 115 km/h	≥ 150 cm3	≤ 1500 cm3	
Class 2-2	≥ 115 km/h	< 130 km/h	-	≤ 1500 cm3	Part 1 + Part 2
Class 3-1	≥ 130 km/h	< 140 km/h	-	≤ 1500 cm3	Part 1 + Part 2 + Part 3_R
Class 3-2	≥ 140 km/h	-	-	> 1500 cm3	Part 1 + Part 2 + Part 3

* 'R' = reduced

Driving cycles considered in Test type V – durability requirements

Two driving cycles are currently prescribed for mileage accumulation according to Test type V; these are either the Standard Road Cycle for L-Category Vehicles (SRC-LeCV) or the USA EPA Approved Mileage Accumulation (AMA) cycle. Both cycles were tested in this study, to identify drivability and relevance for each vehicle sub-category and make recommendations for possible future omission of the AMA cycle.

Based on the vehicle maximum design speed, engine capacity, and net power, different driving patterns for each mileage accumulation cycle are defined according to Appendices 1 and 2 of Annex VI of Regulation (EU) No 134/2014, and the corresponding speed pattern was followed in the testing for this study. In order to obtain record data that are representative for long mileage accumulation, mileage accumulation cycles were repeated at least twice.

Real-world cycles

For the purpose of simulating real-world driving, in some occasions recorded road-cycles were reproduced on the chassis-dynamometer. Cycles for mopeds (L1e-B), low-speed motorcycles (L3e-A1), medium-performance motorcycles (L2e-A2) high-

speed motorcycles (L3e-A3) and tricycles (L5e) were recorded and applied in this study.

Wide Open Throttle (WOT) cycles

Chassis dynamometer emission test cycles are based on vehicle speed (speed profiles) that, when converted to engine load, cover a larger or smaller fraction of the engine map. In order to identify the coverage of the engine map achieved by each driving cycle, a Wide Open Throttle (WOT) test was executed on the chassis dynamometer to reveal the full power curve of the engine map. The test consists of a succession of ascending steady-state velocities up to the maximum vehicle speed achievable on the roller bench (up to 130 km/h), followed by a return to idle, and a full open throttle operation back to the maximum speed. Three versions of the WOT tests were practiced, applicable for the different vehicle sub-categories (Figure 3).

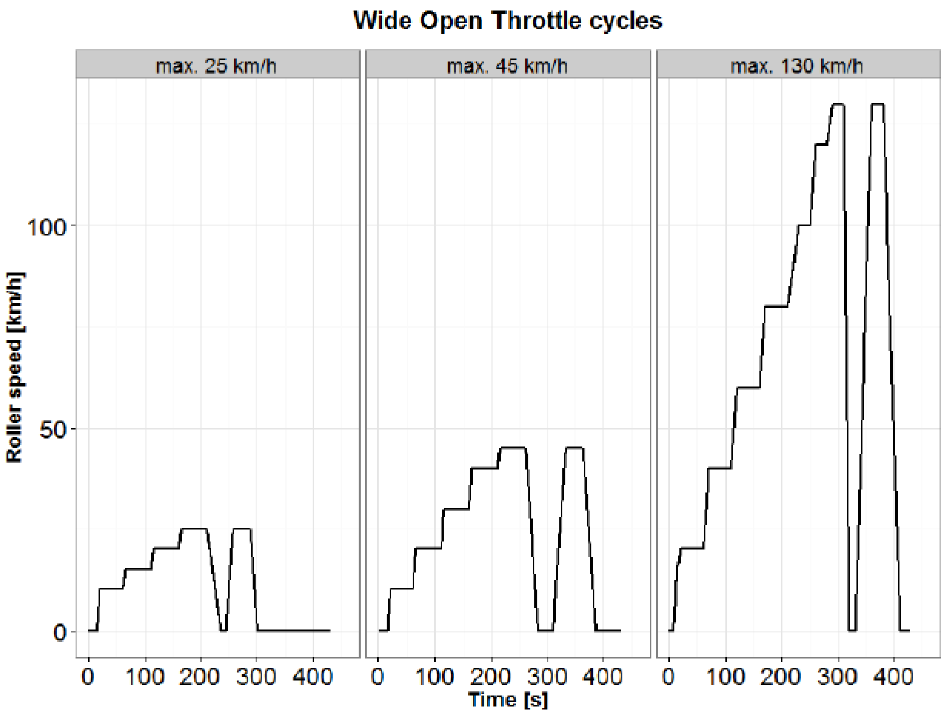

Figure 3. Wide Open Throttle cycles designed for 3 operational ranges of L-category vehicles

2.5 Cost-benefit analysis (CBA) model

The cost-benefit analysis (CBA) model that has been developed in the framework of the project, is the necessary tool for the assessment of measures within the Euro 5 environmental step and possible measures beyond Euro 5. The methodology that has been followed for the creation of the model is analytically described in the subsequent paragraphs. Before this analytical description, a general overview of the model is given first.

2.5.1 Overview of the model

The main objective of the CBA model is to deliver a ***cost-benefit*** analysis, which provides an order of magnitude estimate on whether introducing a new measure

makes sense (*i.e.*, higher benefits than costs) or if the technology costs greatly exceed the (environmental, health, and other) benefits expected.

In general, cost-benefit results show whether the societal investment associated with any environmental measure provides at least similar quantity of benefits, when both are expressed on monetary terms. Intermediate results of the CBA can also be used in assessing the *cost-effectiveness* of alternative realisations of the measure, *i.e.* explore which potential approach provides maximum benefits for a given cost.

Results of the CBA in this report are utilised in the assessment of the various measures and in drawing the final conclusions, and recommendations for policy regulators. The ultimate objective is to underpin the necessity of each Euro 5 step and inform for the optimum implementation policy.

The key outputs delivered by the CBA model for each one of the examined metrics and scenarios are summarised below:

- Environmental benefit (emission savings) per pollutant, vehicle category, and year.
- Total (monetised) benefit, total costs, and net benefit per pollutant, vehicle category, and year.
- Average cost per vehicle category (*i.e.*, costs required per vehicle for the implementation of a specific measure).
- Cost-effectiveness results per pollutant and per vehicle category (*i.e.*, costs required per tonne of pollutant emissions saved).

Figure 4 summarises the main methodological components of the CBA model. These are shortly introduced below, while a more detailed description of each component is provided in the subsequent paragraphs of the report.

- ***Fleet data:*** These include total stock and new registrations data per vehicle category, based on national data and various statistical sources. Fleet data are disaggregated per vehicle age, technology (*i.e.*, emission standard), and fuel, wherever deemed necessary (*e.g.* electric mini-cars, *etc.*).
- ***Activity data:*** These include annual mileage driven and vehicle-kilometres per vehicle category. They are also based on national data and statistical sources, and they are disaggregated per vehicle age, technology (*i.e.*, emission standard), and fuel.
- ***Implementation dates for Euro 5:*** The scenarios for the implementation date of Euro 5 components are derived from the specifications of the project (*i.e.*, Euro 5 introduced in 2020 or 2024).
- ***Emissions modelling:*** This methodological component combines fleet, activity, and emission factors data, in order to derive the various pollutant emissions. Then, depending on the examined metric and specific scenario, the environmental benefit (emissions savings) is calculated as an accumulated difference with time, over a baseline scenario.
- ***Cost-effectiveness analysis:*** It provides the cost per unit of mass of pollutants saved. The costs that have been used in the analysis are based on detailed technology assessment and include for example investment costs, hardware, type-approval costs, *etc.*

- ***Cost-benefit analysis:*** It provides the total (monetised) benefit, total costs, and net benefit for the various examined metrics and scenarios (*e.g.*, Euro 5 limits, durability, OBD, evaporation, *etc.*).

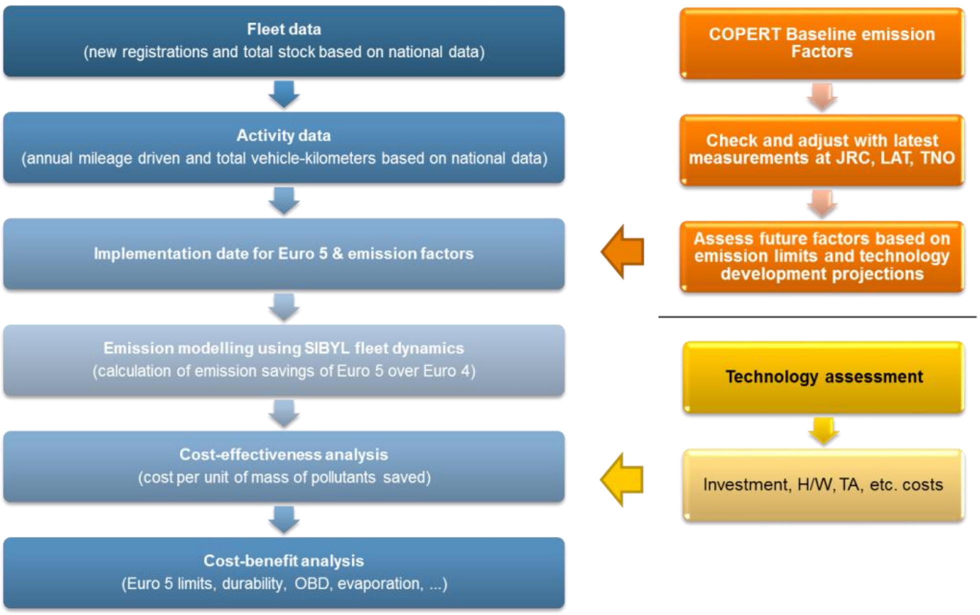

Figure 4: Schematic methodological representation of the CBA overview

The main scenarios and pollutants that have been examined with the CBA model (for measures within the Euro 5 step) are shortly introduced below. A more detailed description is provided in the subsequent paragraphs of the report.

- ***Three possible developments for the fleet/activity data:*** These include a baseline (reference) market growth projection, a high market growth ('optimistic') and a low market growth ('pessimistic') one. The aim of the different fleet developments is to check the sensitivity of results to possible market variations.

- ***Different scenarios for the introduction date of Euro 5 components:*** These include a 'no Euro 5' (reference) scenario, and three scenarios with different introduction dates, *i.e.*, 2020, 2024, or 2020/2024 (which means Euro 5 in 2020 for some vehicle categories of measures, with the remaining vehicles or measures in 2024). Designated years are for new types while always on year of extension is considered for implementation of the particular measures to all types within each category.

- ***Five pollutants:*** The pollutants considered include CO_{2eq} (ultimate CO_2 + CH_4), NO_x, NMHC, $PM_{2.5}$, and CO. From these, CO has zero (monetary) benefit and is examined only regarding its environmental benefit (emission savings), while CO_2 environmental benefits are not considered to originate from the transition from Euro 4 to Euro 5. This is because L-vehicle specific CO_2 targets are not applicable.

Apart from the above, additional specific scenarios have been created, depending on the examined metric, *e.g.* scenarios for durability, separate NMHC limit, evaporation,

and OBD. Before proceeding into the more detailed description of each methodological component of CBA, some additional parameters of the model are summarised below.

- ***Main vehicle categories:*** The CBA has been independently ran for three synthetic vehicle categories, *i.e.*:
    - Mopeds (L1e-B and L2e) and Light on-road quads (L6e-A), cumulatively considered as ‘Mopeds’ for the purposes of the CBA,
    - Motorcycles (L3e, L4e) including tricycles (L5e) and all-terrain vehicles (ATVs – L7e-B), cumulatively considered as ‘Motorcycles’ for the purposes of the CBA,
    - Mini-cars and (diesel) commercial tricycles (L6e-B, L7e-C), cumulatively considered as “mini-cars” for the purposes of the CBA.

  This was the maximum resolution considered to provide reliable results, which basically groups vehicle sub-categories according to powertrain concept. Providing higher resolution would make extremely hard to split investment costs for different vehicle categories. For example, in splitting ATVs from motorcycles, it would be impossible to share the investment cost by manufacturer to each individual vehicle sub-category as they share similar powertrain concepts. Moreover, each synthetic category is dominated by a main-category which also gives its name to the synthetic one. The CBA does not include enduro and trial (L3e-AxE, L3e-AxT) motorcycles

- ***Vehicle technology (emission standard):*** Conventional, Euro 1, Euro 2, Euro 3, Euro 4, Euro 5.
- ***Age of vehicle:*** vehicles of ages of 1-40 years of age are considered. Year 1 refers to vehicles that entered the fleet in the specific year of calculation. Vehicles over 40 years old are considered either removed from the stock (scrapped) or hardly operational.
- ***Year (time period examined):*** 2020-2040[1]. This time horizon was specified in the terms of reference of our contract for work. It is considered to reflect the complete range in which the expected Euro 5 technology will be relevant. Of course, predictions for such a distant future are highly uncertain and a number of external factors may significantly change the L-category market structure and size. However, as we repeat in all our relevant studies, a projection is not a crystal ball on how the future will look like but a scientific tool to justify if a measure will be effective or not, provided that a number of external factors develop in a rather business as usual manner. Obviously, if future developments substantially differ from expectations, fresh policy initiatives will need to be introduced, not necessarily limited to the environmental front.
- ***Main activity parameters:*** Average annual distance driven per sub-category and drop in annual mileage with vehicle age. These lead to an average annual distance driven as a function of vehicle age which, combined with the

[1] This is the period of interest for the cost-benefit analysis, *i.e.*, after Euro 5 is introduced in 2020. In any case, it is noted that all fleet, activity, and emission modelling data cover a wider time period, *i.e.*, 2010-2040. Furthermore, historical statistical data back to 2000 were also utilized in order to create reliable fleet projections for the future.

fleet size of vehicles at the same age, gives the total activity (vkm) for vehicles of the particular age.

- ***Driving mode:*** Emission factors are separately estimated for urban, rural, and highway conditions while mileage is also initially split in these three modes. Moreover, damage costs are separately calculated for urban and non-urban areas. However, results are presented integrated per vehicle category and not split per driving mode

The methodological components of Figure 4 are analytically described in the following paragraphs of the report.

2.5.2 Fleet data modelling

The objective of this subtask is to create reliable fleet data projections for the main L-categories. The creation of such reliable projections is the first step in order to build the stock, activity, and emission models (in the next methodological steps) as input to the CBA. The fleet evolution must:

- Be consistent with statistical data for historical years.
- Be based on justified assumptions for future projections.
- Provide sufficient detail in terms of L-category vehicles type and main characteristics.

The time period that has been considered for the fleet data evolution is 2010-2040, while data back to 2000 were also collected and analysed in order to verify consistency of various sources and assist in more reliable projections for the future. Total stock and new registrations data for EU28 (as a whole) have been produced per vehicle category/age/technology/fuel.

The statistical sources that have been utilised are the following:

- Eurostat[2], EC Statistical Pocket Book 2016[3], EC Working Document 2010[4].
- National authorities' data from the TRACCS[5] project of EMISIA.

[2] http://ec.europa.eu/eurostat/web/transport/data/database
[3] http://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2016_en.htm
[4] http://www.europarl.europa.eu/document/activities/cont/201011/20101130ATT03848/20101130ATT03848EN.pdf
[5] TRACCS (http://traccs.emisia.com/) was a project funded by EC (DG CLIMA) and its aim was the collection of transport data to support the quantitative analysis of measures relating to transport and climate change. The project lasted for two years (Jan. 2012 to Dec. 2013) and its principal objective was to supply DG CLIMA with a general update of the historical transport data for use in the various activity and emission modelling/projection tools (COPERT, TREMOVE, PRIMES, TRANS-TOOLS, SULTAN, EC4MACS/GAINS ...) for policy assessment purposes in Europe.

    - Data from COPERT[6] and SIBYL[7] emission modelling tools of EMISIA.
- Data from industrial associations, *i.e.*, ACEM[8], EQUAL[9], ATVEA[10].
- Previous environmental effect study from LAT-AUTh (Ntziachristos et al., 2013).
- Other literature, *i.e.*, Frost & Sullivan 2011[11], EQUAL presentation at LowCVP[12].

Figure 5 presents the vehicle categorization that has been used in the fleet data model. According to this categorization, the L-vehicles have been organized as described below. In any case, it is noted that, from an emission modelling perspective and for the needs of the cost-benefit analysis, further disaggregation of the main categories is not necessary (*e.g.* vehicles of similar powertrain and technological concept do not exhibit substantial differences in their emissions, technology costs, *etc.*). Furthermore, the categorization that has been used in the current CBA model retains consistency with earlier classes in the previous (2013) environmental effect study from LAT-AUTh.

- ***Mopeds:*** These include all two-, three-wheel and four-wheel mopeds (L1e-B, L2e and L6e-A vehicles). L2e vehicles are technically similar to L1e-B in terms of powertrain and emissions control; therefore, further disaggregation is not necessary. Besides, the market size of the L2e vehicles is very small compared to L1e-B ones (~0.5% of all mopeds sales in 2015). L6e-A vehicles are hardly present in the EU market. For the few available, in case they remain at Euro 5 step, similar powertrain to L1e-B is assumed and these can be fully grouped within the mopeds sector.
- ***Motorcycles:*** These include all two-wheel motorcycles – with or without sidecar – and tricycles (L3e, L4e, and L5e vehicles). All-terrain vehicles are also included, as they are equipped with the same powertrain configuration. For the emission calculation, these are further split into four subcategories:
    - **L3e-A1** (≤125cc) low-performance motorcycles.

[6] COPERT (http://emisia.com/products/copert) is a software tool used world-wide to calculate air pollutant and greenhouse gas emissions from road transport. The development of COPERT is coordinated by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre for Air Pollution and Climate Change Mitigation. The European Commission's Joint Research Centre manages the scientific development of the model. COPERT has been developed for official road transport emission inventory preparation in EEA member countries. However, it is applicable to all relevant research, scientific and academic applications. The COPERT methodology is part of the EMEP/EEA air pollutant emission inventory guidebook for the calculation of air pollutant emissions and is consistent with the 2006 IPCC Guidelines for the calculation of greenhouse gas emissions. The use of a software tool to calculate road transport emissions allows for a transparent and standardized, hence consistent and comparable, data collecting and emissions reporting procedure, in accordance with the requirements of international conventions, protocols, and EU legislation.

[7] SIBYL (http://emisia.com/products/sibyl) is a vehicle stock, air pollutants, and GHG projection and policy evaluation tool with internal energy consumption, emission and cost estimation capabilities. It allows the formation and execution of scenarios, policy assessment and target setting. A detailed vehicle stock baseline database has been hardcoded in the application so that the user can evaluate custom scenarios on real – life data.

[8] http://www.acem.eu/

[9] http://www.equal-mobility.com/

[10] http://atvea.org/

[11] https://www.yumpu.com/en/document/view/4638855/strategic-analysis-of-the-european-microcars-market

[12] www.lowcvp.org.uk/assets/presentations/European%20Quadricycles%20League%20presentation.pdf

- o **L3e-A2** (>125cc, ≤ 35KW) medium-performance motorcycles.
- o **L3e-A3** (>125cc, >35KW) high-performance motorcycles.
- o **L5e tricycles** (L5e-A and L5e-B vehicles).
- o **ATVs** (L7e-B), including all terrain quads and side by side buggies

This split is considered necessary because: i) the mileage (annual distance driven) differs for each class, and ii) due to differences in size, performance, engine capacity, emission control system, *etc.*, different emission factors have to be used in the emission modelling. However, as it was not possible to differentiate costs per vehicle sub-category, the final CBA is provided for the complete motorcycle category.

Note: The number of L4e vehicles (motorcycles with side-car) is very low (~100 units sold per year). Hence, these vehicles are not examined separately, but they are considered technically similar to L3e-A3 vehicles, at least regarding their powertrain and emissions control system.

- ***Mini-cars:*** These include all light quadricycles and heavy quadri-mobiles (L6e and L7e-C vehicles). However, the majority of mini-cars belong mostly to the L6e-B sub-category (light quadri-mobiles designed for young drivers not in hold of a driving license, offering an alternative to two-wheel mopeds). The sales of internal combustion L7e-C (heavy quadri-mobiles) are low, as this category is dominated by electric powertrain vehicles. The main subcategories considered for mini-cars are the following:
  - o Gasoline
  - o Diesel
  - o Electric

  Currently, mini-cars are mostly fitted with diesel engines, while the electric ones represent a fraction of the market which is currently small, but it is expected to increase in the future. Regarding gasoline vehicles, although their number is currently estimated very small (if existing at all due to the limitation of 50 cm^3 of maximum engine capacity), they are examined here as an alternative powertrain concept (*e.g.* gasoline-hybrid) that can offer benefits in meeting both environmental and performance targets.

For the vehicle categories of Figure 5 which are not specifically included in one of the CBA relevant categories, *i.e.*, L1e-A and L7e-A, it has to be clarified that:

- Currently, L1e-A vehicles already mostly comprise electric powertrains. We do not expect any more internal combustion vehicles at a Euro 5 level, both because of environmental regulations but also due to market forces. Electric powertrains do not contribute to exhaust emissions and, hence, they are not relevant for CBA and are not further examined.
- L7e-A vehicles are heavy on-road quads. Currently, we can only hypothesize there are only very few models (if any) available to the market. Due to current type-approval reporting (up to Euro 3), it is not possible to specifically differentiate between individual L7e subcategories. So, our assessment of the few models available is based on our knowledge of the market, at least of large manufacturers, who do not seem to offer such vehicles. Hence, any such vehicles currently may only come from very small manufacturers and therefore marginally contribute to the L7e market size. Regarding future

developments, regardless of the size of this subcategory, the powertrain of such vehicles is expected to be either electric or similar to L3e. Hence, they either can be considered identical to L3e in terms of powertrain – and CBA results may be considered to refer to these as well – or can be considered of electrical powertrain hence do not contribute to exhaust emissions and are irrelevant for the CBA.

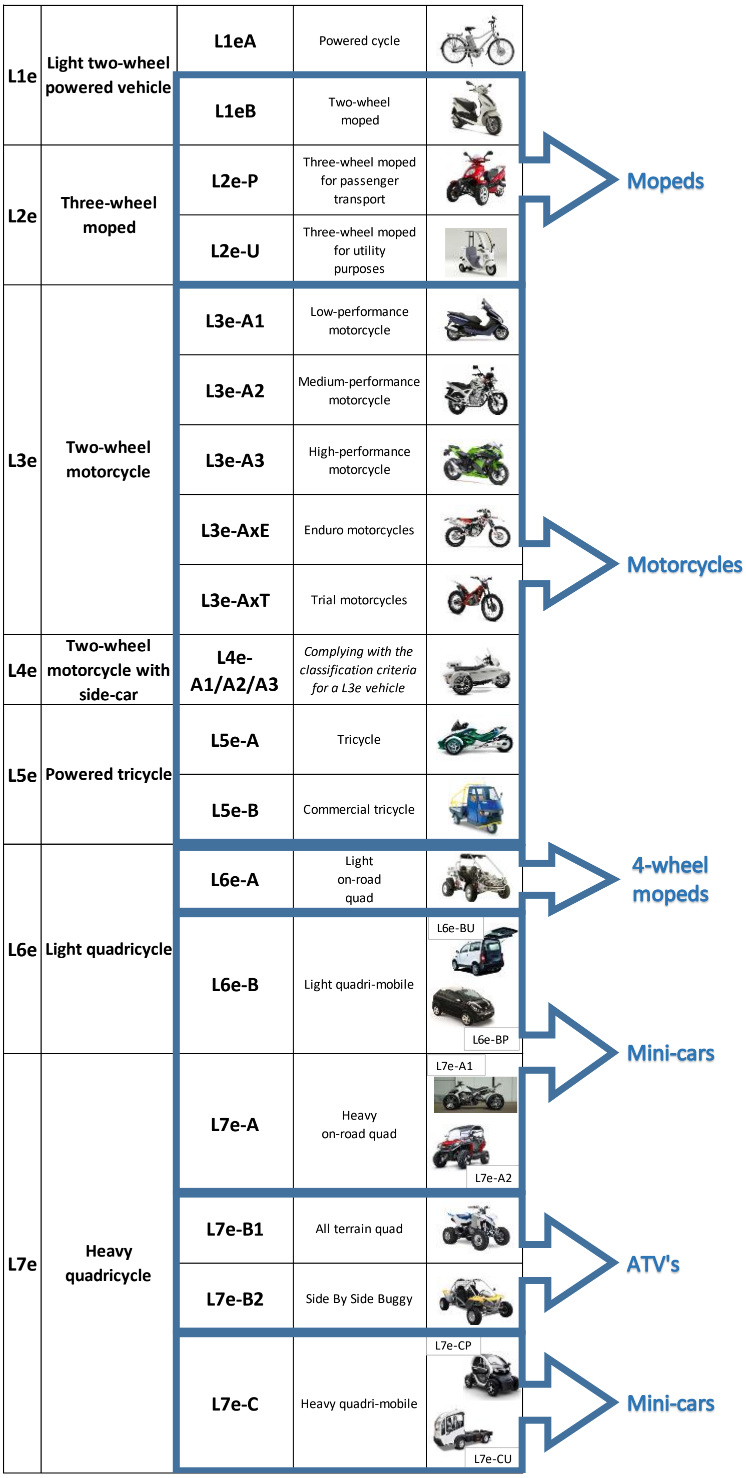

Figure 5: Main L-category vehicles examined

2.5.2.1 Fleet data projections for mopeds and motorcycles

Three possible projections for market growth were examined in the CBA, mostly to reveal the sensitivity of the results to this largely unknown parameter. Vehicle sales (number of new registrations for the future years) differ in each case and this, subsequently, leads to a difference in the overall evolution of the total stock and the age structure. The main assumption for each projection were:

- ***Baseline (reference) projection:*** This assumes that, after an initial sales rebound following the economic (and sales) crisis in the period 2007-2013, sales follow a 'business-as-usual' trend, which is based on typical historic growth data.
- ***High market growth (market 'optimistic') projection:*** This projection assumes increased number of new registrations (compared to baseline), reflecting a possible vibrant future economy in the EU.
- ***Low market growth (market 'pessimistic') projection:*** This assumes decreased number of new registrations (compared to baseline), reflecting possible gross domestic product (GDP) pressures to the EU economy. This should not be seen as an impact of vehicles price to sales – an elasticity of market size due to potential vehicle cost increase has not been included in our CBA modelling.

All three projections respect historical statistical data related to registrations of vehicles in the past years.

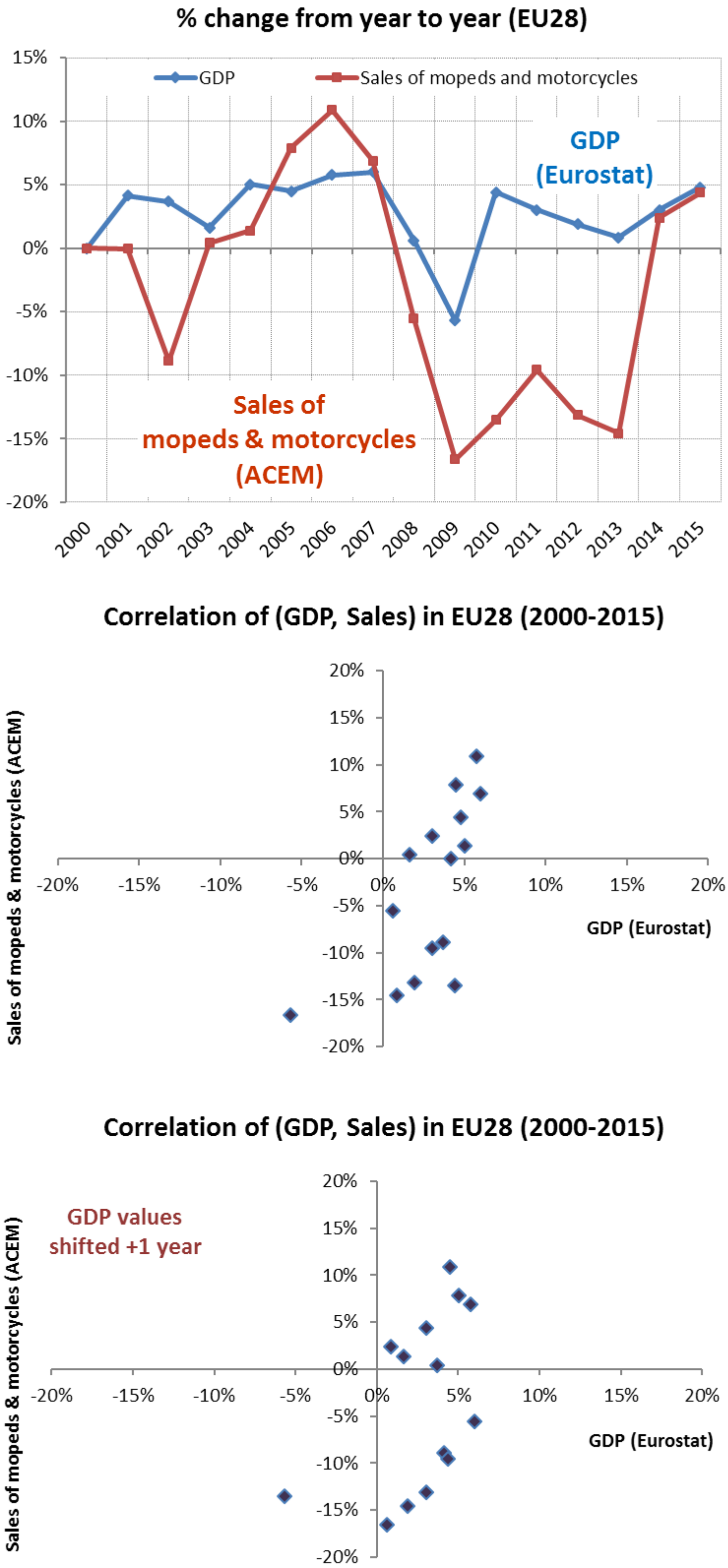

Figure 6: Correlation of sales with GDP (EU28)

A common trend in all projections, to a variable extent in each of them, is that mopeds encounter increased competition from larger scooters (L3e-A1) and such larger vehicles are expected to dominate the market over mopeds.

In order to predict future market growth potential, an analysis of historical data between GDP growth and L-vehicles market growth has been executed. Figure 6 shows the correlation of mopeds and motorcycles sales (ACEM data) with gross domestic product (GDP - Eurostat data) for EU28 in 2000-2015. The top panel presents the percentage (%) change of these two parameters from year to year, while the middle and bottom parts of the figure provide a X-Y scatter diagram of the corresponding values. The bottom part of the figure differs from the middle one in that the GDP values are shifted +1 year in order to check the effect of GDP change in sales of the following year, assuming that the market responds to the previous year.

A general observation based on the results of Figure 6 is that the sales of mopeds and motorcycles in the period 2000-2015 seem to roughly follow the trends in GDP (gross domestic product at current market prices, million euro). Nevertheless, the percentage changes from year to year in sales are more variable than the corresponding GDP ones. For example, from 2007 to 2009 the GPD exhibits a cumulative decrease of -5%, while sales -22%.

Based on these historic data, the three market projections were developed with the following assumptions (Figure 7):

- The **baseline** projection assumes an average annual market growth of 0.9% until 2040, which is a rather timid increase (2.6% per year until 2022, 0.4% from 2023 to 2030, and 0% from 2031 to 2040). This reflects the fact that over the last few years, the market of mopeds is shrinking without a corresponding increase in larger motorcycles. Indeed, despite years of GDP growth in the last five years, the market of mopeds is not reviving. While in the previous report *“Study on possible new measures concerning motorcycle emissions”* (Ntziachristos et al., 2009) the mopeds market was estimated at approximately 1.0 M units per year, based on sales in the 2006-2008 period, the new assumptions are sales to remain at approximately 320 k units per year, *i.e.*, one third of what was earlier foreseen. Hence, even with a slight annual increase of the EU GDP (0.2-0.5%), this is expected not to be reflected in the sales of mopeds, but only in the sales of motorcycles. Based on this projection, the total market size (new registrations) of power 2&3 wheelers (mopeds and motorcycles) is estimated at 22.2 M units for the next 15 years (2016-2030), which is somewhat lower compared to 26.7 M units of past 15 years (2001-2015)[13].

[13] Comparing the current new registrations baseline scenario with that of the previous report *“Input for the preparation of Regulation (EU) No 168/2013 Article 23 Environmental Effect Study”* (Ntziachristos et al., 2013), it is clarified that there are some differences (especially for motorcycles) and this is due to the latest statistical data that became available in the meantime (years 2013-2015). Specifically, for mopeds the difference is very small (~320 k units per year in the current scenario vs. ~360 k units per year in the 2013 one). On the other hand, for motorcycles the current estimation is that the sales will gradually increase to ~1.2 M units per year until 2023 (rebound effect) and then will remain constant; while in the 2013 study the number of sales was projected at ~850 k units per year. In any case, it is believed that the current new registrations baseline scenario is more consistent with the trends observed in sales during recent years (2013-2015).

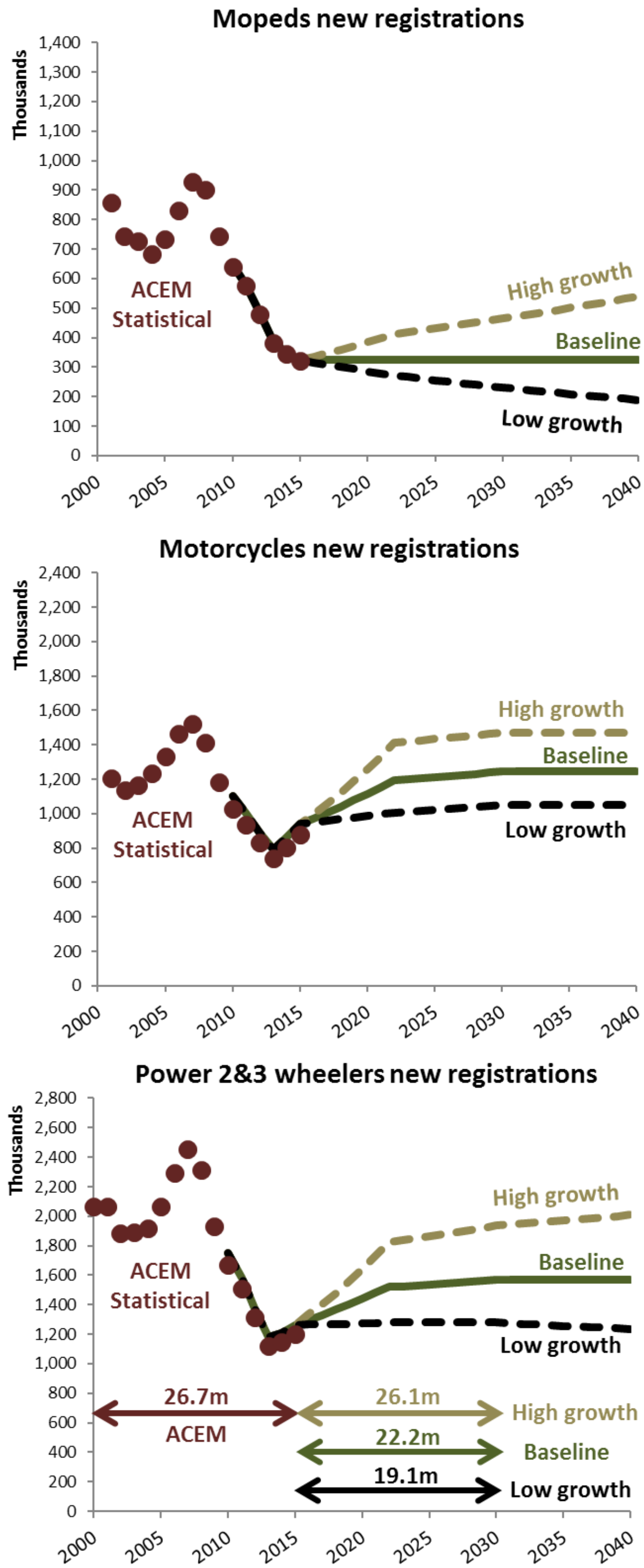

Figure 7: Three projection for the new registrations of mopeds and motorcycles (EU28)

- The **high growth** projection assumes that the number of new registrations of mopeds and motorcycles will grow by approximately 1.9% per year until 2040, reaching average trends of previous years (5.4% per year until 2022, 0.7% from 2023 to 2030, and 0.4% from 2031 to 2040). In this high growth case, emphasis is given on motorcycles sales, while mopeds also exhibit some slight increasing trend to 2040. It should be repeated that our analysis only covers internal combustion engine vehicles, due to the limited tank-to-wheel environmental impact of electric vehicles. An even higher growth in this projection was therefore considered infeasible. We expect that if this market grows stronger in the next several years, this will be mostly through electrical vehicles, which are not included in the current CBA. Hence, the number of internal combustion vehicles in the period 2016-2030 is estimated at 26.1 M units in this projection, which is very close to the 26.7 M units of past 15 years.
- The **low growth** projection assumes that the number of new registrations of mopeds will develop with an annual rate of -2.5% until 2022 and -2% from 2023 to 2040, hence an overall shrinkage of the fleet, and this is considered a pessimistic prediction for the future. In this low growth projection, the motorcycle sales are close to the 2015 value (with a slight increase trend), while mopeds encounter a continuous decrease trend until 2040. The total market size from 2016-2030 in this period is at 19.1 M vehicles.

The effect of the three alternative market projections on the total vehicle stock is shown in Figure 8. For historical years, all three projections respect statistical data (ACEM and/or TRACCS project of EMISIA)[14]. Regarding future projections, all 3 projections are rather consistent with the industry forecast of total stock size up to 2020 (ACEM report, ~36 million units for mopeds and motorcycles)[15]. Assuming same lifetime functions (deregistration of vehicles according to their age) for consistency, the evolution of total stock in the three projections is as follows:

- ***Baseline:*** Total stock of power 2&3 wheelers remains almost unchanged, with a small increase to ~37 million vehicles in 2040.
- ***High growth:*** Significant increase in total stock, ~44 million vehicles in 2040, due to the increased number of new registrations in this projection.
- ***Low growth:*** Decrease of total stock, ~32 million vehicles in 2040, due to decreased number of new registrations in this projection.

[14] There is a difference of ~2 million vehicles in mopeds between ACEM and TRACCS due to some gaps (missing values for 7 countries) in ACEM data and slightly increased values for a few countries in TRACCS (trusted experts' data).

[15] http://www.acem.eu

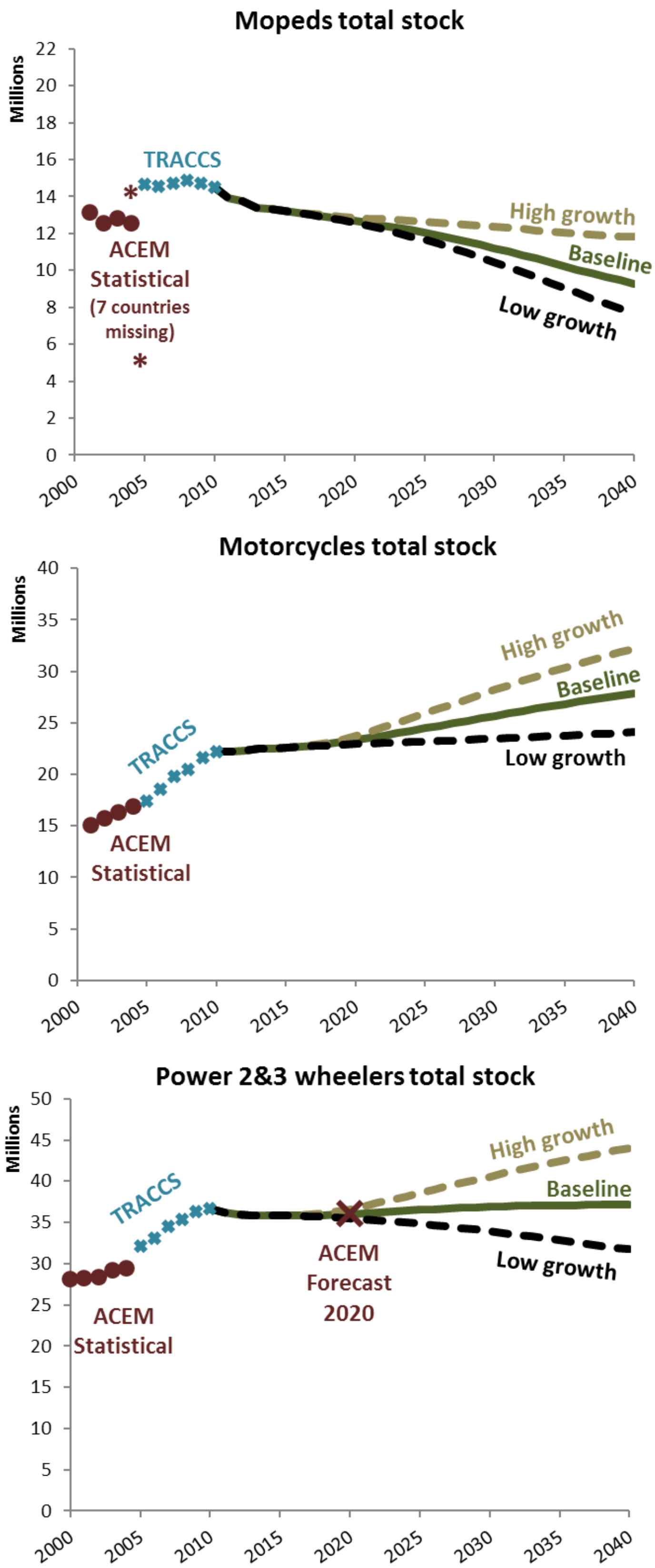

Figure 8: Evolution of total stock of mopeds and motorcycles (power 2&3 wheelers) in the three alternative projections (EU28)

2.5.2.1.1 *Comparison with official statistical sources (Eurostat, EC Statistical Pocket Book)*

The proposed projections are overall consistent with the EC Statistical Pocket Book values for historical years. The only statistical source that deviates from other sources is total fleet data from Eurostat and, hence, had to be further considered before being used in this context. The main reasons for deviations of Eurostat data with other sources are summarised in the following list and are further graphically depicted in Figure 9 (example for mopeds, similar observations for motorcycles):

- Missing values or even complete datasets from specific countries missing.
- Time series often interrupted or incomplete.
- Obvious errors that need correction.
- Artificial increase (or decrease) when summing up EU28 countries, which does not reflect reality, and is due to missing values of previous years.

When comparing data used in this project with year by year and country by country data, our data and Eurostat agree rather well – which provides further validation to the dataset used in this study.

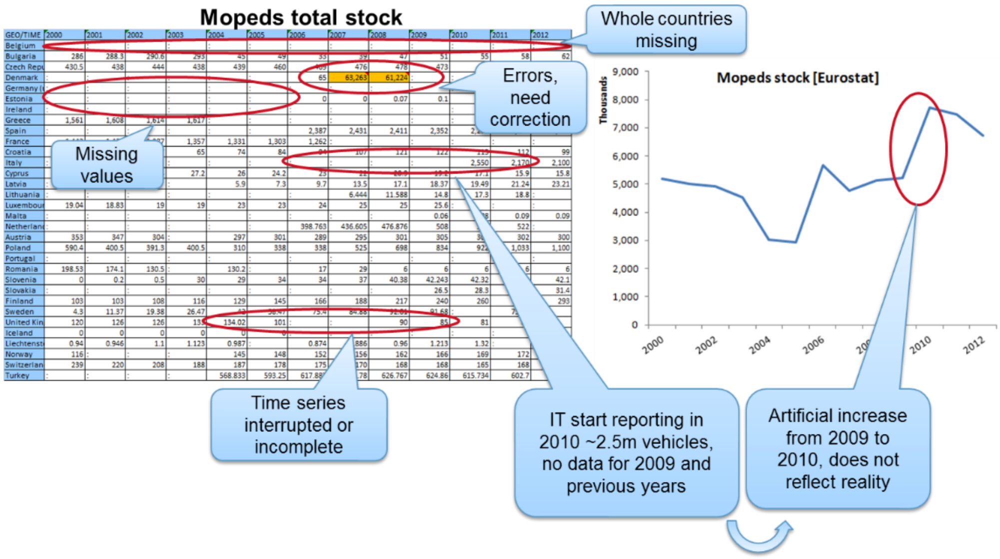

Figure 9: Inconsistencies in Eurostat data (here: mopeds total stock, data extracted on 29/1/2016)

2.5.2.1.2 *Split of motorcycles into L3e-A1, A2, A3, and L5e tricycles*

Figure 10 shows how the fleet of motorcycles (right) and new registrations (left) are split into the subcategories L3e-A1, A2, A3, and L5e tricycles. This figure corresponds to the baseline fleet projection, but similar approach is also followed in the high/low growth ones.

This split of motorcycles is based on ACEM data and reports[16,17], which justify a trend for a market shift towards ‘smaller’ A1 vehicles (started already 10-12 years ago) instead of mopeds. The main reasons for this trend are: i) cost-effectiveness

[16] http://www.pzpm.org.pl/content/download/387/3413/file/ACEM_REPORT.pdf
[17] https://issuu.com/altitudedesign/docs/acem-report-2012

competition to mopeds, and ii) licensing provisions decided at national level by some Member States. As a result, the increase in total new registrations is attributed mainly to A1 vehicles (market share of A1 increase from 36% in 2015 to 44% in 2040, followed by a corresponding decrease in market share of A2 and A3 vehicles).

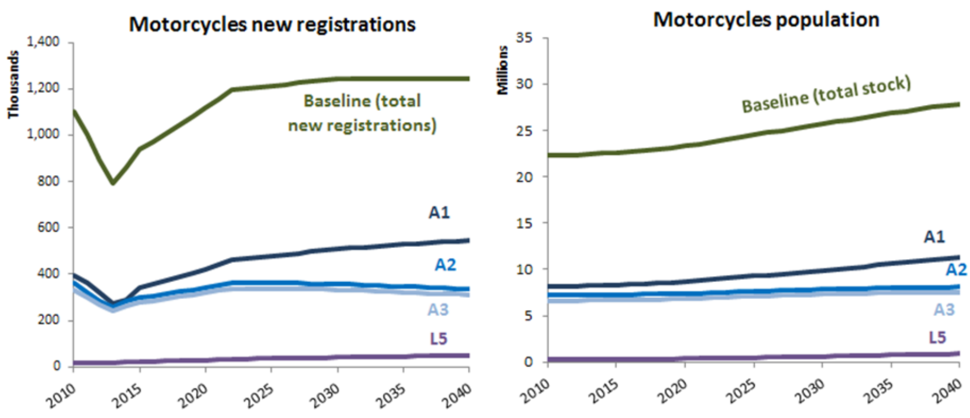

Figure 10: Split of motorcycles new registrations and population into L3e-A1, A2, A3, and L5e tricycles (here: baseline fleet projection)

With regard to L5e vehicles, these constitute a rather small market (~21,000 new registrations in 2015), but with an increasing trend over the last 5-6 years (*i.e.*, the L5e new registrations – as percentage of all motorcycles – increased from 1.6% in 2010 to 2.4% in 2015). This increasing trend is followed in the fleet data model at a lower pace though, reaching 4% in 2040 in all scenarios.

The L5e tricycles are distinguished into L5e-A (passenger use) and L5e-B (commercial use) vehicles. However, according to ACEM, commercial tricycles have a low number of sales (~2,500 vehicles in 2015) and face significant pressures over the last 5-6 years, which is expected to continue in the coming years, at least in the form of internal combustion engine vehicles. Hence, for modelling purposes, commercial tricycles are not treated separately and the majority of L5e vehicles are assumed to perform similarly to L3e-A2 vehicles[18] (*i.e.*, for the emission modelling and emission factors to be used in the next methodological steps, *etc.*).

2.5.2.2 *Fleet data scenarios for mini-cars and ATVs*

<u>*Mini-cars*</u>

Mini-cars also constitute a market of moderate size (~27,000 new registrations in 2015, estimation based on ACEM and EQUAL data). The total vehicle stock is estimated to be ~320-340,000 units, without significant changes in total volume over the last 5 years. The majority of vehicles in this category are fitted with diesel engines, while the electric ones currently represent a rather small fraction of the market (estimated ~7%). However, this percentage is expected to increase in the future as incentives for electric vehicles and the relevant charging infrastructure for them

[18] http://www.motoservices.com/3-4roues/trike.htm

becomes widespread. This is also due to pressures from cities to ban diesel cars, for environmental reasons[19].

Figure 11 shows the 3 alternative projections for the new registrations and total stock of mini-cars. The scenarios retain the same naming as in the mopeds/motorcycles sector and follow, in general terms, the same concept, *i.e.*, baseline for a 'business-as-usual' projection, a high-growth projection to reflect a significant market increase, and a low-growth one with lower sales compared to the baseline. The evolution of total stock assumes same lifetime functions (deregistration of vehicles according to their age) among all projections, for consistency.

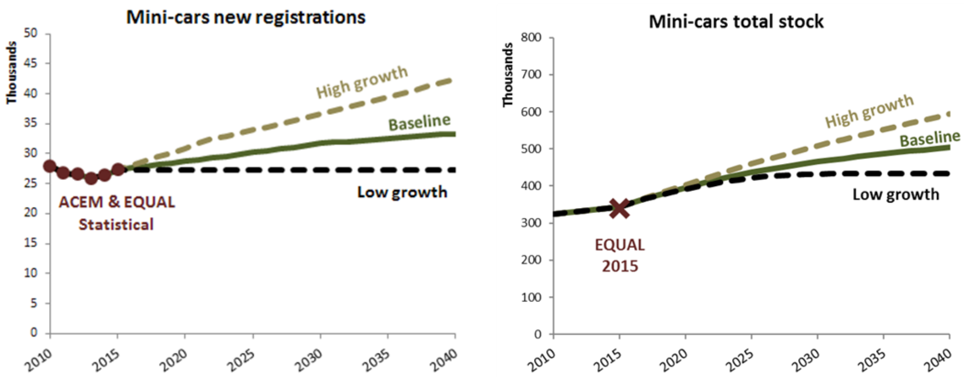

Figure 11: Three alternative projections for the new registrations and total stock of mini-cars (EU28)

Figure 12 presents the split of mini-cars new registrations per powertrain type (gasoline, diesel, electric) in the three projections. As already mentioned, the majority of mini-cars are fitted with diesel engines, while the number of gasoline ones is very small (estimated at 2%); hence, their contribution to the CBA is negligible. With regard to electric vehicles, their percentage (new registrations of electric vehicles compared to total sales) is expected to increase from 7% in 2015 to 14% in 2040 in the baseline projection and to 25% in the high growth projection. The increase in the relative share of electric vehicles in the high-growth projection means that these actually fuel the increase in sales. In the low growth scenario, the percentage of electric vehicles remains unchanged and equal to the 2015 value (7%), reflecting a rather conservative acceptance of this rather new vehicle concept by the consumers. It should be repeated that electric vehicles are not taken into account in the CBA, due to the zero tank-to-wheel exhaust emissions they produce.

[19] *e.g.* https://www.theguardian.com/environment/2016/dec/02/four-of-worlds-biggest-cities-to-ban-diesel-cars-from-their-centres

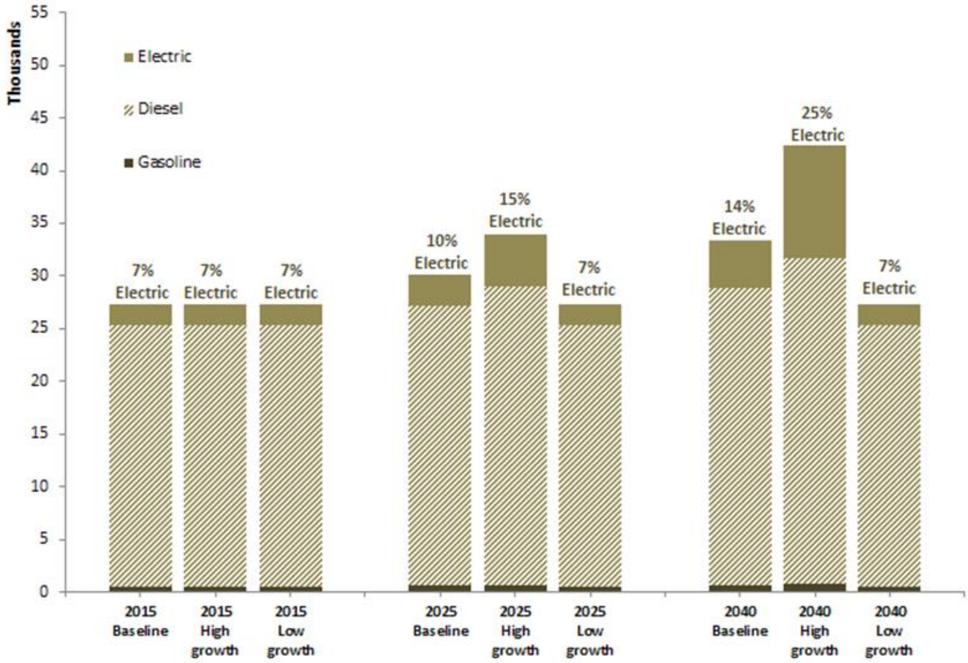

Figure 12: Split of mini-cars new registrations per propulsion concept in the three scenarios

Additional projection examined for advanced mini-cars (gasoline series hybrid)

In all previous projections, the market is always considered to be dominated by diesel mini-cars. In reality, the new emission limits proposed at a Euro 5 step require advanced technology from the diesel engine, which is not at all certain that can be technically provided for these small engines. Moreover, current regulations limit the gasoline engine capacity to this category to 50 cm^3, a size which cannot provide enough torque to satisfactorily accelerate the vehicle. Simplified, series gasoline-electric systems could be used to provide the necessary torque and emissions compliance. Hence, an additional projection has been developed in order for the CBA to model the impact of the new limits to a new powertrain concept that may be devised from market pressure and environmental conditions, *i.e.*, urban initiatives.

The main characteristic of this projection is that the market size (new registrations) of diesel mini-cars starts shrinking, *i.e.*, gradually from 2018 onwards, and the new powertrain concept enters into the projection by replacing diesel sales, so that in 2024/2025 (new/all types) there are no sales of diesel vehicles anymore, and these have been completely replaced by sales of the new mini-cars propulsion concept and pure electric vehicles. The exact split of the market in this scenario is assumed 60% full electric and 40% series-hybrid for the period 2024/2025 until 2040. The total number of new registrations in this additional projection is assumed identical to that of the high growth projection described above.

<u>ATVs</u>

ATVs correspond to a similar size of market to mini-cars with ~27,000 new registrations of on-road vehicles in 2015, an estimation based on ACEM and ATVEA data. The total vehicle stock is estimated at ~330,000 units, with a rather decreasing trend over the recent years. In general, almost similar specifications of ATVs may be

registered as T-category vehicles[20] (agricultural and forestry vehicles) or even as general machinery under the Directive 2006/42/EC, without the need for an on-road licence plate. Therefore, the split of L vs T category vehicles entails some uncertainty and it can be difficult at times to report exact market sales at either of them. The new type approval procedure is expected to shed light on registration of these vehicles per class. As a result, the uncertainty for these L-category vehicles is high and it is difficult to project future trends. In any case, 3 projections have been created for the modelling purposes (baseline, high/low growth), following similar concepts as in mopeds/motorcycles and mini-cars (see Figure 13).

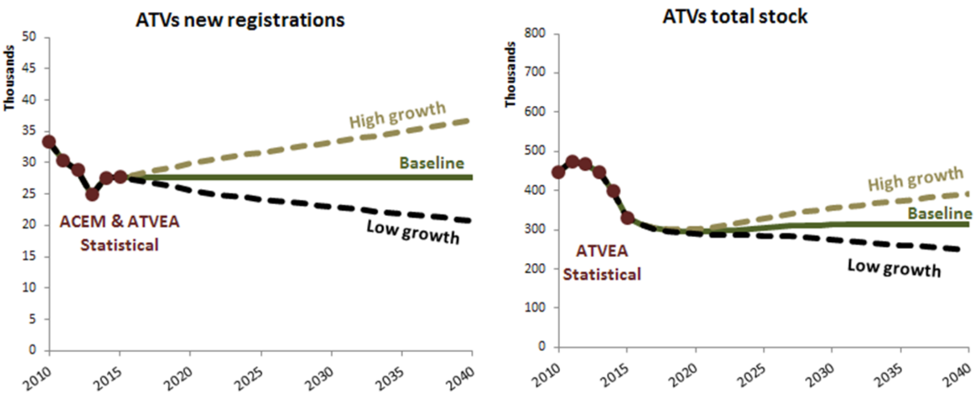

Figure 13: Three projections for the new registrations and total stock of ATVs (EU28)

For the CBA, Euro 5 impacts on ATVs are calculated together with those for motorcycles. This is both because the powertrain and emission control systems required are similar between the two vehicle types but also because the majority of L7e-B manufacturers are also L3e manufacturers, hence the L3e investments would also be used for L7e-B.

2.5.3 *Activity data modelling*

Total emissions calculations require total activity (vkm) as an input. Total activity is estimated by multiplying fleet size with the mean annual distance driven (average mileage, km/year) by a representative vehicle of the particular category. Two important variables in the activity model are the following:

- In general, annual mileage drops as vehicles grow older, *i.e.* older vehicles are driven less than new ones.
- The frequency of operation and the emission performance of vehicles in different sub-categories varies between urban, rural and highway. Hence, total activity needs to be split per mode.

Figure 14 provides the average mileage (km/year) for the main L-vehicle categories of the activity model. Specifically:

[20] http://atvea.org/wp-content/uploads/2014/02/ATVEA-Presentation-Leaflet.pdf

- Mopeds: ~2,900 km/year (based on national authorities' data from the TRACCS project and ACEM data).
- Motorcycles: ~5,100 km/year (based on national authorities' data from the TRACCS project and ACEM data).
    - Note: 'smaller' motorcycles (*i.e.*, A1) have lower mileage compared to larger ones (*i.e.*, A2 and A3)[21].
- Mini-cars: ~5,000 km/year (estimation from EQUAL[22]).
- ATVs: ~600 km/year (estimation from ATVEA[23]) – these vehicles should mostly be counted to hours of operation per year, on-road ones do not exceed 40-50 hours annually. This is much lower than off-road vehicles, which are often used professionally for farming and forestry activities and other purposes.

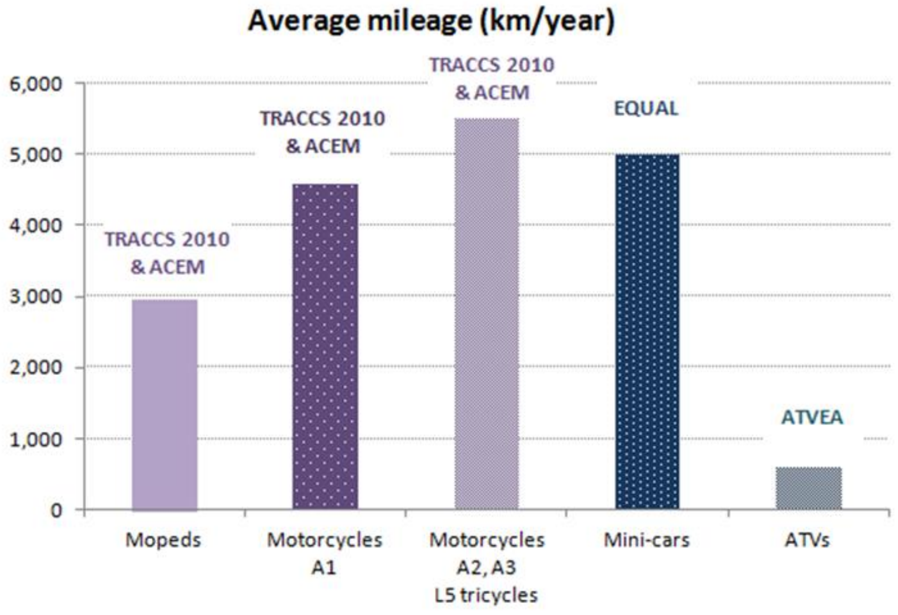

Figure 14: Average mileage (km/year) for the main L-vehicle categories of the activity model

Figure 15 presents the activity data (vkm) per vehicle category: mopeds, motorcycles, mini-cars, and ATVs (3 projections, following the naming of the fleet data model, that is, baseline, high growth, low growth). It is reminded here that total annual activity data are calculated as vkm = fleet size × average annual mileage. The main observations that can be made are the following:

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[21] http://mff-dk.dk/upload_dir/docs/Presse/ACEM-Position.pdf
[22] Estimation based on advertisement websites *e.g.* http://www.leboncoin.fr/voitures/offres/provence_alpes_cote_d_azur/occasions/?o=11&q=aixam
[23] No available data specific to the European context. The latest survey of owners conducted in 2014 in the US shows an average of ~600 km/year, but concerned only ATV users and did not distinguish between recreational and utility use. Additional info (US) can be found in
http://www.newridersatvclub.com/en/articles/m00101.aspx
http://www.nohvcc.org/docs/economic-impacts/Economic_Contributions_of_ATV_Related_Activities_in_Maine.pdf?sfvrsn=0
https://www3.epa.gov/otaq/regs/nonroad/2002/r02023.pdf

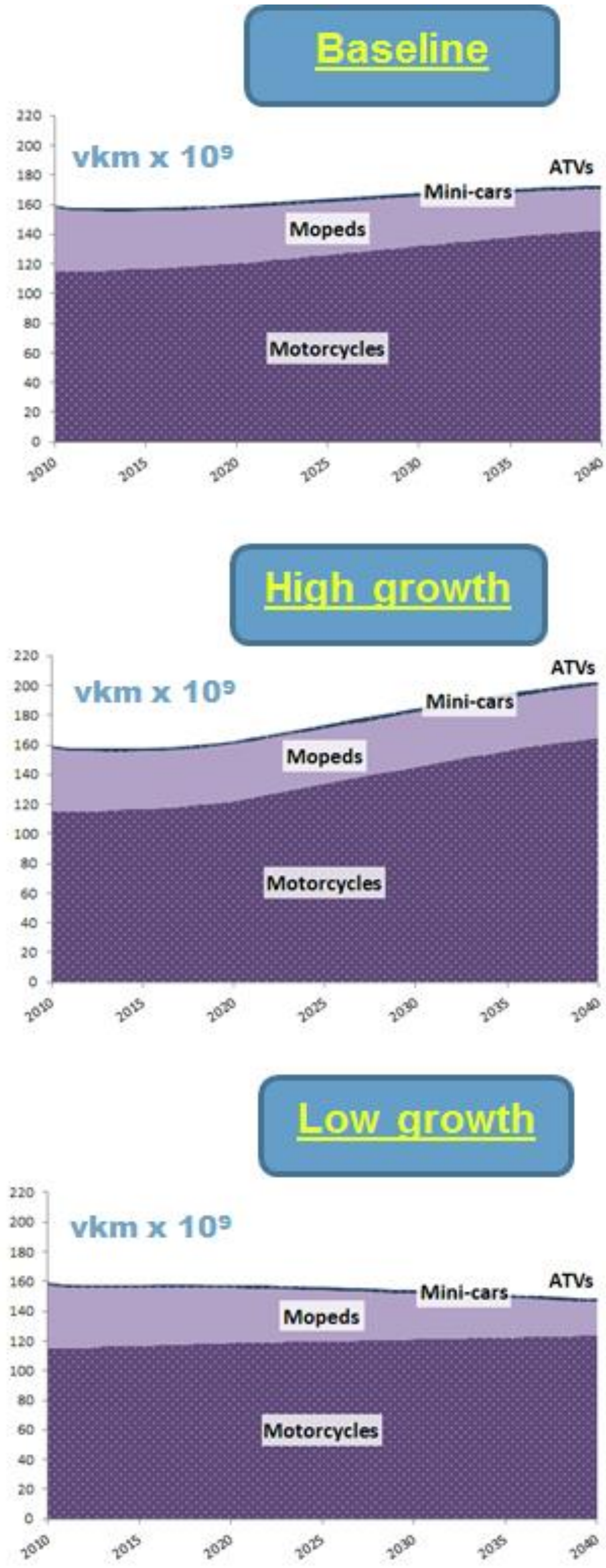


Figure 15: Activity data (vkm) per vehicle category in three alternative projections (EU28)

- Motorcycles: their contribution to activity dominates in all 3 projections, mainly due to pressures to the mopeds sub-category and higher annual mileage per vehicle of motorcycle over mopeds.
- Mopeds: their contribution to activity presents a decrease from 2010 to 2040, practically in all projections.
- Mini-cars and ATVs: small overall contribution to total activity.

Table 12 shows the percentage split (%) of the activity data (vkm) to urban / rural / highway mode. The split is based on COPERT national data. Mopeds and mini-cars operate mostly in urban conditions and have no mileage in highways. ATVs operation is equally split (50%-50%) in urban and rural mode. The vehicles with the highest percentage of operation in highway mode are large motorcycles, L3e-A3 (30%).

Table 12: Split of activity data (vkm) to urban / rural / highway mode

Mode	Urban	Rural	Highway
Mopeds	75%	25%	
Motorcycles A1	50%	40%	10%
Motorcycles A2	40%	40%	20%
Motorcycles A3	30%	40%	30%
L5e tricycles	40%	40%	20%
Mini-cars	80%	20%	
ATVs	50%	50%	

2.5.3.1 *Are all registered vehicles active?*

Figure 16 presents the average age of fleet/activity data over period 2010-2040 (weighted average of all L-vehicles) for the 3 projections (baseline, high/low growth). The rationale behind this figure is that some of the older vehicles (*e.g.*, >20-25 years for mopeds and motorcycles) remain in the fleet and are not deregistered, but their mileage is very small (or even negligible) and, hence, do not contribute to activity (vkm). As a result, the average age based on activity data is lower than the average age of fleet (~8 vs. ~13 years).

The corresponding values in the high growth projection are lower than in the baseline projection, due to increased number of new registrations (fleet renewal which 'lowers' the average age of fleet and, consequently, of activity data). The opposite holds true for the low growth projection.

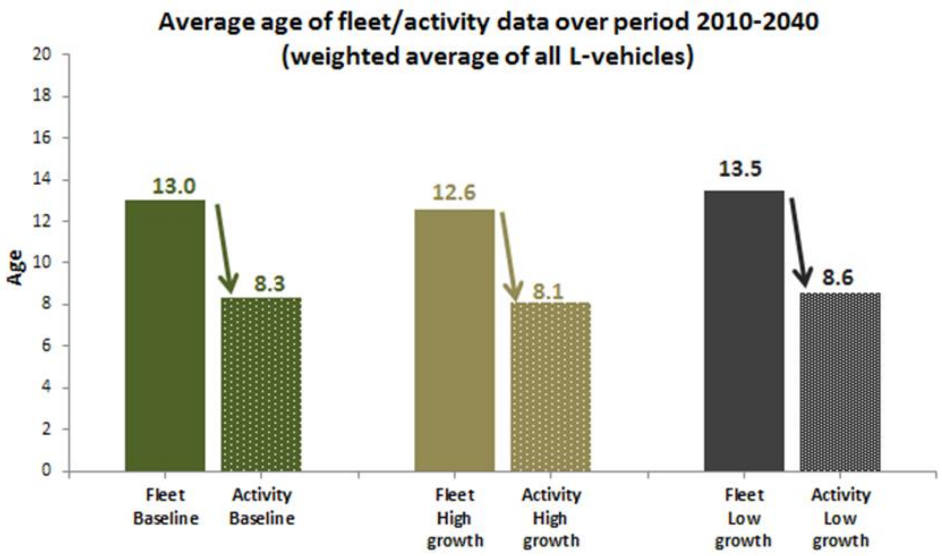


Figure 16: Average age of fleet/activity data over period 2010-2040 (weighted average of all L-vehicles)

2.5.4 Emission factors

A set of base emission factors (EFs) has been used for estimating emissions of CO_2, NO_x, HC, PM, CO from existing vehicle types. The sources that have been utilized for these legacy EFs are the following:

- Previous environmental effect studies, *i.e.*, Ntziachristos et al. (2009) and Ntziachristos et al. (2013)
- The latest COPERT emission factor dataset
- TNO report on moped emission factors (van Zyl et al., 2015)
- New experimental data produced in the current study

In general, reliable EFs up to Euro 3 are already available from COPERT and previous environmental effect studies (cross-checked with new JRC and LAT data). For Euro 4 and Euro 5, emission standard equivalencies, emission limits, or justified estimates, based on the expected technology, have been used. The base exhaust EFs for the CBA model are discussed in more detail in the relevant subsection – discussion for the "Appropriateness and cost-benefit ratio of the Euro 5 limits". For other emission modelling, *i.e.*, evaporative emissions, there is a separate discussion on EFs in the relevant subsection of the report.

2.5.5 Emission modelling, environmental and monetised benefit

This methodological component of the CBA model combines fleet, activity, and emission factors data, in order to produce the various pollutant emissions (emissions = fleet size × mileage × EF). Then, depending on the examined metric and specific scenario, the environmental benefit (emissions savings) is calculated, *e.g.* from the introduction of Euro 5 over Euro 4, from more stringent catalyst degradation method in durability scenarios (*e.g.*, physical degradation instead of using the DF method), *etc.* This environmental benefit aspect of the model is discussed in each chapter separately, depending on the examined metric.

In order to calculate the monetised benefit (in €) derived from the emission savings, the latter are multiplied with the external marginal (damage) costs per tonne of pollutant emissions, taken from the study of (Korzhenevych et al., 2014). These external costs, once saved from the implementation of a new measure, correspond to the monetised environmental benefit in the current study from the introduction of Euro 5 or other related measure. Specifically, the benefit calculation is as follows:

total benefit in € = (€/t of emissions saved) × *(t of emissions saved)*

where the total benefit is the benefit (in €) from emission savings of all pollutants, due to the introduction of Euro 5 or other related measure. The benefit is calculated per year and per vehicle category (mopeds, motorcycles, and mini-cars).

Table 13 shows the external marginal (damage) costs of pollution used in the current study to monetize the emission savings from the introduction of Euro 5 or related measures. The values of this table are mean values used as EU averages.

Table 13: External marginal (damage) costs used as benefit to monetise the emission savings[24]

Pollutant	€/t
CO	0
NMHC	1,566
NO_x	10,640
$PM_{2.5}$ (mopeds)	129,177[25]
$PM_{2.5}$ (motorcycles)	87,393[26]
$PM_{2.5}$ (mini-cars)	130,672[27]
$PM_{2.5}$ (ATVs)	71,654[28]
CO_2	94[29]
CH_4	2,350[30]

[24] The values are based on Table 15 (for NMHC, NO_x, $PM_{2.5}$) and Table 34 (for CO_2, CH_4) of RICARDO-AEA study and they are mean values used as EU averages. CO has zero (monetary) benefit. Although it is acknowledged that there are differences in the external marginal costs between Member States, we have used a single value for EU as a whole. In any case, it is clarified that the EU average values that are used in the present study are very close to the weighted average of the five key markets in Europe (FR, IT, DE, ES, UK).
Specifically for the $PM_{2.5}$ values, it is clarified that:

- The $PM_{2.5}$ urban EU average value of Table 15 of the Korzhenevych et al. (2014) study (270,178) seems wrong, as the EU28 arithmetic mean gives 202,612, while a weighted average based on population of each country gives 207,642. We have used a value of 201,000, in-between IT and FR which have large populations of L-category vehicles.
- Similar observation has been made also for the $PM_{2.5}$ suburban EU average, where a value of 58,000 seems more appropriate as an EU average than the value 70,258 in Table 15 of the Korzhenevych et al. (2014) study.

[25] The 75% of urban activity of mopeds in Table 12 is split into 55% urban and 20% suburban, in order to utilize the $PM_{2.5}$ values of Table 15 of the Korzhenevych et al. (2014) study. The remaining 25% comes from the rural part.
[26] For motorcycles, it was assumed 35% urban, 10% suburban, and 40% rural, in order to utilize the $PM_{2.5}$ values of Table 15 of the Korzhenevych et al. (2014) study. The highway part does not contribute to the monetized benefit calculations.
[27] The 80% of urban activity of mini-cars is split into 55% urban and 25% suburban, in order to utilize the $PM_{2.5}$ values of Table 15 of RICARDO-AEA study. Rural adds another 20%.
[28] The 50% of urban activity of ATVs is split into 20% urban and 30% suburban, in order to utilize the $PM_{2.5}$ values of Table 15 of RICARDO-AEA study. Rural adds the other 50%.
[29] Based on Table 34 of RICARDO-AEA study.
[30] For CH_4, the global warming potential (GWP100) has been used, *i.e.*, CO_2 value multiplied * 25.

It needs to be repeated that no CO_2 benefits or detriments were calculated by the introduction of Euro 5, as this step is not relevant for CO_2 emissions and no greenhouse gas targets exist for L-vehicles.

2.5.6 Cost analysis

The cost-benefit analysis model directly involves the total societal cost incurred for the implementation of each new regulatory component. This societal cost is defined as an incremental cost, without considering taxes and profit margins. In reality, the cost used in this study for the introduction of a new measure can be defined as:

$$\text{Incremental Cost} = \Delta(\text{Final Price} - \text{Taxes} - \text{Markup})$$

The total costs are calculated as a function of multiple cost categories, in an effort to make a reasonable assessment for the many diverse measures that had to be considered in our analysis. All cost items are expressed as incremental cost differences over the state-of-art (Euro 4).

- Implementation costs
  - Basic investment [€/manufacturer], this refers to new facilities, equipment, tools and logistics investments required by each manufacturer to introduce a new technology component or method at a Euro 5 step. The cost is estimated on a per manufacturer basis.
  - Research and development (R&D) costs
    - Development [€/engine family], this takes into account additional man-effort, computer simulation, prototyping and experimental testing work for the development of a new engine family.
    - Calibration [€/model], an engine family can be used in different vehicle models but additional calibration cost will be required per vehicle model. For example, compliance with Euro 5 limits of a particular model will require additional calibration of a Euro 5 engine fitted on the vehicle, to account for transmission, weight, and performance characteristics of the particular mode.
  - Hardware (H/W) [€/vehicle]: Enhanced hardware for emission control is required at Euro 5 level, ranging from improved catalysts, advanced ECUs, improved fuel lines, etc. Although estimating real H/W costs are difficult, a number of studies in the past, have provided a frame of reference on the order of magnitude of costs for emission control related components. These have been considered and adjusted to match the technical requirements of the current study.
  - Type approval costs
    - cost/new facility [€/facility], reflects the cost of new facilities that will have to be built or equipment that will have to be bought by technical services for specific requirements of type-approval, *e.g.* new facilities for physical mileage accumulation testing.
    - cost/new model [€/new model], corresponds to additional man-effort and duration for type approval, *e.g.* if a new procedure or pollutant is added in testing.

- Repair costs
    - labour [€/malfunction], cost of labour to repair vehicle, expressed as average labour cost in the EU[31] and an estimated time required to repair the particular malfunction, once diagnosed by the OBD.
    - parts [€/malfunction], the cost of the part that has to be replaced – this may significantly differ from part price, as it is known that replacement parts entail a significant profit margin.
- Other costs
    - maintenance [% vehicle value cost / lifetime], this this different to repair cost as this expresses increase in preventive maintenance costs in case more sensitive or complex components have been used for compliance.
    - fuel penalty [% of FC], this was used as a placeholder in our model for most Euro 5 measures. The only case this has been directly used is to calculate the fuel saved when an evaporation canister is used for evaporation control.
    - warranty [% vehicle value cost/lifetime], increase in warrant costs reflects the fact that more complex components and enhanced monitoring may increase warranty costs for the manufacturer. The incremental difference in warranty over Euro 4 is estimated at up to 0.1% of total vehicle cost for some of the measures considered.

Not all of these incremental cost items are required to assess the impact of each measure. In each case, one or more of these cost elements need to be introduced to assess the total societal cost.

The estimation of exact values for each cost item depends on a number of variables:

- Introduction date of each new measure (2020, 2020/2024, 2024): In general, regular technology advancement and technology depreciation decreases implementation costs when a new measure is shifted further in time.
- Fleet/activity projection (baseline, high growth, low growth): Depending on the cost source, the fleet evolution may have a positive or a negative overall impact. For example, for initial infrastructural investments costs, a high growth of the market increases net benefits as the infrastructural costs are mostly independent of vehicle sales. However, hardware costs increase proportionally
- Initial cost level: Technology, infrastructural, repair costs, etc. are difficult to accurately assess because these depend on market structure, size, and competition while negotiated prices between suppliers and manufacturers are confidential. In order to take uncertainty into account, our calculations include three potential cost levels (low, moderate, high), to reflect the uncertainty in cost estimation. The percentage range of cost for each cost item differs, reflecting the uncertainty in the estimation.
- Technology depreciation: Technology costs drop with time as the state-of-the art generally increases and manufacturers and supplied become fully familiar with the new technology. This applied both to industrial methods and, in particular, to hardware costs. The technology depreciation may be different per component. For example, the cost of an oxygen sensor I not expected to significantly drop as this is a mainstream commodity for a number of years. A thermally optimized exhaust line though has significant margins for cost

[31] Eurostat: http://ec.europa.eu/eurostat/statistics-explained/index.php/Wages_and_labour_costs

reduction with time, as manufacturers become familiar with the design of such a component. In other cases, the price of a component may depend on external factors, *e.g.* the cost of precious metals for catalysts. The depreciation degree of each technological component is based on the assessment of technology and the state of art. This depreciation is considered to take place within 6 years in our scenarios. The faster this takes place, the lower the costs, although the sensitivity of the final result to exact depreciation period is rather limited.

- Investment amortization period: The higher the amortization period of investment costs, the lower the real costs in terms of net present value. This is usually fixed between 6-8 years for industrial investments. We have used 6 years in our calculations, considering the L-vehicles models round are usually fasters than larger vehicles and other machinery. The exact amortization period considered little changes CBA results.

Figure 17 schematically presents the block diagram of the cost analysis. The green coloured blocks represent the broad cost categories, while with red and orange colour the main cost subcategories and the base cost subcategories of the cost tree structure are illustrated, respectively.

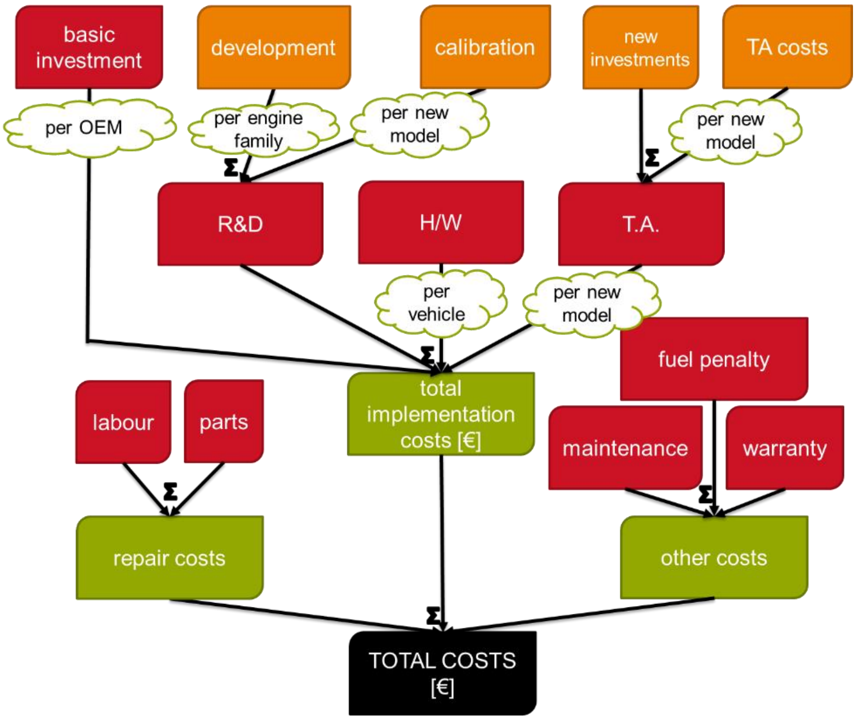


Figure 17. Cost analysis block diagram

Some important parameters for the calculation of total costs are summarized in Table 14. This information has been compiled from analysis of market and industry information. The number of manufacturers reflects the major manufacturers per vehicle type which are active in the EU, *i.e.* those considered to have complete design, prototyping, testing, and manufacturing departments for powertrains. These manufacturers are estimated to comprise more than 90% of the market. Several manufacturers are active in several sub-categories, hence a distinction is made to those that can be mostly considered to be active in the particular sub-category. Those

in the moped sector are all practically active in producing motorcycles. Similarly, only three out of the main 8 ATV manufacturers are primarily in this vehicle segment; the remaining five are primarily motorcycle manufacturers. Finally, the mini-cars segment is the only one where all manufacturers are independently active.

Several other manufacturers are presently active in the EU with smaller volumes of vehicles. In most of these cases, these manufacturers lend power units from larger ones. In this case, societal costs only scale with vehicle production (sales) figures and no independent societal cost has to be estimated. Given the increased technical demands at a Euro 5 step, the practice of using a third party engine from smaller manufacturers is expected to increase. For this reason, it is not necessary to perform separate modelling for smaller manufacturers, once total societal costs are in the end calculated per sold vehicle.

Table 14. Input information for the cost modelling

	Mopeds	Motorcycles	Mini-cars	ATVs
Number of manufacturers[32]	5	16	6, all independent	8 in total, 3 mostly on ATVs
Number of engine families in market	20	80	5	16
Number of total models in market[33]	80	350	15	48
Number of new models/year	15	60	5	12
Mean vehicle price (€/veh.)	1700	5700	10000	7000

With regard to major engine families in Table 14, this may actually be lower of what currently present. The Euro 4 and, most significantly, the Euro 5 steps are expected to gradually lead to a decrease of engine families and available models – at least in terms of the different powertrain and emission control configurations. This is a trend which has taken place for passenger cars and is expected to also take place for motorcycles in order to retain economies of scale and to simplify design and manufacturing burden.

In order to conclude to the costs for each of the cost categories, the following data sources are considered:

- Questionnaire survey of the Phase I of the Study (Hag et al., 2016)
- Earlier studies on L-Vehs by Emisia/LAT
- US EPA study on highway motorcycles (US EPA, 2002)
- Technology costs studies (Euro 4 study (Ntziachristos et al., 2009), Ricardo-AEA/R/ED58334 (Gibson and Hill, 2012), ICCT studies (Sanchez et al., 2012))
- Engineering assessment of the study team, based on the technology requirements foreseen and input received from stakeholders

[32] Major manufacturers considered only

[33] A 'model' may stand for a family of models sharing the same emission control

2.5.7 Cost-benefit and cost-effectiveness analysis

The CBA is performed taking as input the results of the previous tools, *i.e.*, the benefit and the cost analysis tools. The CBA is built for each of the examined broad vehicle categories, *i.e.*, mopeds, motorcycles, and mini-cars.

A number of different implementation scenarios and/or a number of different Euro 5 introduction date scenarios are examined for each of the examined metrics as will be discussed in detail in the following sections.

The CBA is implemented with a tool, specifically developed for the purposes of this study. Figure 18 presents schematically the block diagram of the CBA tool. A number of parameters are taken into account in order to implement the cost-benefit and the cost-effectiveness model of the examined scenarios, as previously presented in detail. The red blocks represent the input form the environmental benefit analysis, the black block represents the input coming from the cost analysis, the green block represents an intermediate calculation step towards the final results shown with the blue blocks.

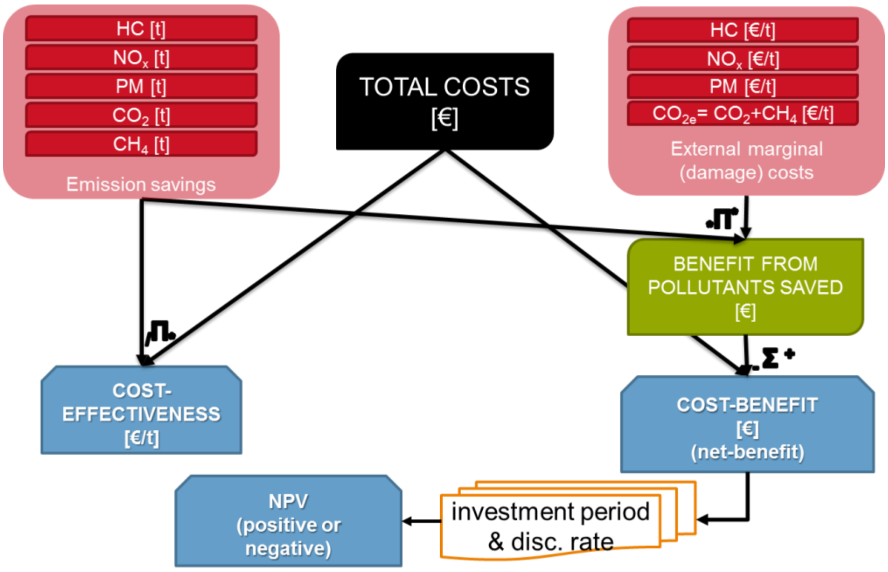


Figure 18. Cost-benefit analysis block diagram

The equivalent monetised total benefit in coming from the pollutants saved is calculated by multiplying the emission savings in tonnes, with the external marginal costs in euros per tonne, for each of the examined pollutant. The net benefit is then calculated by subtracting the total cost from the pollutants benefit. The net-present value (NPV) is derived by allocating the net benefit to the investment period, using a discount rate. The discount rate considered in costs and benefits together from the point of view of society as a whole is equal to 4%, as recommended by the European Commission (2015).

The cost-effectiveness analysis provides the cost per unit of mass of pollutants saved. This is derived by dividing the implementation costs over the emission savings for each pollutant. In order to split the total implementation cost to each of the pollutants, a ratio is obtained from the benefits of each pollutant, for each of the vehicle categories. Although cost-effectiveness values are available, we actually do

not present them in the current study as they are not relevant in justifying the different Euro 5 components. Cost-effectiveness is useful in examining variable options which is not the objective of the current study.

As earlier expressed, a caveat of the CBA is that the time horizon of the model is rather distant, *i.e.*, up to 20 years after initial introduction of Euro 5, a fact that increases the uncertainty either because completely new technologies may dominate the market or if the market size is significantly distorted. Indeed, policy and industry targets for the passenger car sector call for a significant share of the market be based on electric vehicles, with the horizon of this penetration be located around 2025-2030. Hence, assuming that the L-vehicles sector will remain mostly based on internal combustion engines until 2040 (with the exception of mini-cars where electric or electrified is already taken into account in our calculations) corresponds to a larger uncertainty in our calculations.

ASSESSMENT OF THE MEASURES WITHIN THE EURO 5 ENVIRONMENTAL STEP

3 Type I – Tailpipe emissions after cold start

3.1 Applicability of the “revised” WMTC test cycle

3.1.1 Background and objectives

The main objective of the Type I test is to provide a comprehensive, technology neutral, fair and reproducible assessment of the tailpipe emissions of new types and models of L-category vehicles, during their type approval. During this test, the tailpipe emissions are measured following an engine cold start. A “revised” WMTC testing procedure together with more stringent exhaust emission limits were defined in Regulation (EU) No 168/2013 for Euro 5 L-category vehicles, compared to Euro 4.

The objective in this section of the report is to assess the applicability and feasibility of the new requirements introduced with the Euro 5 environmental step for Type I test, as laid down in Regulation (EU) No 168/2013. According to this, and specifically the explanatory notes to Annexes I to VIII (note no. 10): “*The environmental effect study in Article 23(4) and (5) will also report on the feasibility for L-category vehicles other than L3e, L5e-A and L7e-A to be emission-tested in a revised WMTC*”.

Specific target of this task is to evaluate the applicability of the revised WMTC driving cycle and testing procedure on the extended list of L-vehicle categories by assessing the drivability of these vehicles over the specific cycle, the quality, quantity and dynamics of emission sampling over the WMTC as well as to identify any potential issues related to the emission measurement procedure. A fair comparison of the WMTC results with the statutory United Nations Economic Commission for Europe (UNECE) R40 and R47 test cycles is performed. The latter statutory cycles entered into force in 1979 (UNECE, 1979) and in 1981 (UNECE, 1981), respectively, as annexes to the UNECE Agreement of Geneva, 1958.

The applicability of WMTC is examined on the basis of three indicators, which are requested by the terms of reference of this study and are further examined in the following sections:

- Drivability, expressing the ability of tested vehicles to follow the speed profile.
- Engine map coverage, reflecting how many and how frequently possible engine operation modes are covered by the cycle.
- Cycle dynamics effects on emissions variability, by examining emissions variability in multiple executions of the cycle.

3.1.2 Assessment of WMTC drivability

The first indicator in assessing the applicability of WMTC is related to its drivability, *i.e.*, the vehicle’s ability to follow the speed trace demanded by the driving cycle. This was assessed by analysing the results of the tests of the sample of all non L3e vehicles tested in the current study. The metrics examined for this analysis involved:

(i) speed pattern deviations, including both the number of events where measured speed deviated from demanded speed and their total duration. An assessment was then conducted to check if the deviation was due to the vehicle being unable to follow the cycle or due to rider’s error in

performing the test. Cycles where speed differentiations were due to rider related issues were not included in the analysis. These turned to be overall very few cases, already identified during testing. In such cases, the relevant cycle was usually repeated for correct execution;

(ii) the distance (m) covered during the test in comparison to the nominal test distance, with this being an integrated expression of the fidelity in following the speed pattern;

(iii) the mean positive acceleration (MPA – m/s^2) delivered by the vehicle in comparison to the one imposed by the cycle, as an expression of the responsiveness and ability of the vehicle to follow cycle accelerations; and

(iv) the speed × MPA [m^2/s^3, or W/kg] product, which is an approximation of instantaneous, mass-specific power required by the cycle vs. that delivered by the vehicle.

In order to assess speed deviations, the allowable speed tolerances are specified in Regulation (EU) No 134/2014, paragraph 4.5.4.2; the calculated speed pattern deviations follow paragraph 4.5.4.2.1, within which it is mentioned:

> *The vehicle speed tolerance ... is defined by upper and lower limits. ... Vehicle speed variations greater than the tolerances (such as may occur during gear changes) are acceptable provided they occur for less than two seconds on any occasion. Vehicle speeds lower than those prescribed are acceptable provided the vehicle is operated at maximum available power during such occurrences …*

Moreover, regarding deviations from the speed pattern and the correct execution of the cycle, Regulation (EU) No 134/2014, Annex II, prescribes:

> *4.5.4.2.2. If the acceleration capability of the vehicle is not sufficient to carry out the acceleration phases or if the maximum design speed of the vehicle is lower than the prescribed cruising speed within the prescribed limits of tolerances, the vehicle shall be driven with the throttle fully open until the set speed is reached or at the maximum design speed achievable with fully opened throttle during the time that the set speed exceeds the maximum design speed. In both cases, point 4.5.4.2.1. is not applicable. The test cycle shall be carried on normally when the set speed is again lower than the maximum design speed of the vehicle.*

In assessing drivability issues, the analysis of the test results took under consideration the following:

- Speed pattern deviations during decelerations: they are not relevant for driveability and emissions, in most occasions these can be improved with rider/driver practice.
- Speed pattern deviations during stop phases: they are also not relevant; instead, they only occur due to vehicle speed recording noise or as an offset in speed recording.
- Speed pattern deviations during quasi constant or constant speed phases: if they occur for a vehicle with a design speed higher than the maximum speed of the cycle, and also considering the tolerance of ±3.2 km/h, this originates by poor driving or a performance issue of the particular vehicle.
- Speed pattern deviations during acceleration phases: the tolerance transgressions and the underruns occurrences are checked here. If the

acceleration from standstill starts too late, so that this time delay is responsible for the underruns, but the rate of acceleration itself is ok, then this only indicates poor cycle execution performance. Only underruns that the rate of acceleration is overall poor are considered.

- Very low instant accelerations: many low accelerations of small duration occur when the driver tries to keep a constant speed, especially in low speed mopeds. They are not at all relevant for driveability, they only show, that the cycle could be better followed by training of the driver.

Table 15 shows the drivability assessed separately for each test vehicle, for both the WMTC and ECE driving cycles. The input to this table is explained and presented in detail in Appendix **A**, separately for each vehicle. Green color cells indicate no deviation from the speed pattern, while the orange shaded cells indicate deviations either in the demanded acceleration (A) or maximum speed (maxS).

Table 15. Vehicle specific drivability assessment

Vehicle	Transmission	Driveability assessment			
		WMTC		ECE	
J05 – L1e-A	Fixed	A	maxS		
J06 – L1e-B, low speed	Fixed	A			
J07 – L1e-B, low speed	CVT				
J10 – L1e-B, low speed	CVT				
J02 – L1e-B, high speed	Manual				
J03 – L1e-B, high speed	CVT				
J04 – L1e-B, high speed	CVT				
J12 – L1e-B, high speed	CVT				
J14 – L1e-B, high speed	CVT				
J17 – L1e-B, high speed	CVT				
J26 – L2e-U	Manual	A	maxS		
J27, valid. – L2e-U	Fixed				
J24 – L5e-A	Manual	A	maxS		
L01 – L5e-A	Semi-automatic				
J01 – L6e-BP	CVT				
J22 – L6e-BU	CVT				
J08 – L7e-B1	CVT		maxS		
J16 – L7e-B1	CVT				
J25, valid. – L7e-B1	CVT				
J09 – L7e-B2	CVT				
J20 – L7e-CP	Fixed				

A: demanded cycle acceleration was not met but no cycle violation
maxS: demanded cycle speed was higher than the maximum design speed of the vehicle, but no cycle violation

The L1e-A powered cycle experienced difficulties following the speed pattern, with both demanded speed and acceleration exceeding the vehicle's capabilities. However, this was a vehicle with an internal combustion engine and we do not expect any more such vehicles at a Euro 5 step. Already this market is dominated by electric vehicles, and this is expected to further extend in the future. Electric vehicles will have more low speed torque, so the cycle demanded acceleration may be possible.

Moreover, only Type VII (energy consumption test) and no Type I test is specified for electric vehicles (Regulation (EU) No 168/2013).

Further to the L1e-A, the demanded WMTC acceleration was not achieved by the J06 vehicle (L1e-B, low speed), though, it mostly stays within the speed bounds. This vehicle has a simplified transmission configuration, which has a single 'fixed' ratio. This is an over-simplistic system which significantly harms the drivability of the vehicle but is used to suppress transmission, hence vehicle, costs. The two other low-speed mopeds with a more contemporary and mainstream transmission system (continuously variable transmission – CVT) had no issues follow the driving pattern. Therefore, the J06 related issue is considered to be vehicle specific and is not expected to be viable at Euro 5, where engine tuning and transmission will have to be optimized for emissions compliance.

The demanded WMTC speed was higher than the maximum design speed for the J08 (L7e-B1), although this can satisfactorily follow the speed pattern for the rest of the cycle duration. Not reaching mean surrounding travelling velocity for such vehicles is also typical for vehicles with moderate levels of maximum design speed. In such occasions, such vehicles usually trail traffic driven close to their max design speed. Hence, requesting travelling at max design speed for relatively long over the cycle is not seen as a real issue. However, as this study does not explore the representativeness but the drivability of the revised WMTC, missing the high speed part is not expected to create any confusion to the rider/driver during execution of Type I test. In such cases, it is relatively simple to just follow the speed trace again when the travelling speed reaches the speed pattern at its subsequent deceleration part.

The acceleration pattern and the maximum demanded speed of WMTC was not reached for vehicles J26 (L3e-U) and J24 (L5e-A). In principle, according to explanatory note (10) of Regulation (EU) No 168/2013, vehicles under L5e-A do not fall under the scope of the environmental study and the WMTC is already used at a Euro 4 step. It is characteristic that the other L5e-A vehicle tested (L01) could easily follow the WMTC pattern (even including part 3), in terms both of speed and acceleration.

The L5e-A (J24), that had issues following the speed pattern, was based on a vehicle mostly popular on its L5e-B configuration. Therefore, we should rather take this vehicle of being rather more representative of the L5e-B category rather than L5e-A. Hence, it should be considered that the two vehicles for which acceleration and max speed issues appear (J24 and J26) are the ones used for utility rather than passenger transport. These vehicles may be indeed tuned differently than passenger vehicles, as their real-world operation entails many stop-and-go conditions, rather low speed driving and the need of high torque at low RPM to start up when loaded.

The deviation from the driving cycle pattern for these two vehicles does not constitute a violation of the driving cycle, according to Annex II, point 4.5.4.2.2 of Regulation (EU) No 134/2014. In principle therefore, these two vehicles would not have issues executing Type I test based on the revised WMTC and our tests have confirmed this. Long deviations from the speed pattern though and general inability to follow the driving profile may lead to arbitrary interpretations of how the driving cycle has to be executed, during Type I execution, and could potentially be exploited for type-approval emission optimization. Recommendations on improving the situation follow

in section 3.1.5, after the other WMTC applicability indicators have been presented as well.

It should be stated that no drivability remarks were observed for the ECE cycles. This is for two reasons: ECE R47 (L1e-A, L1e-B, L2e, L6e) is a rather customizable driving cycle to the performance of each vehicle, in terms of both max speed and acceleration. This is because, for positive loading, no exact speed profile is determined but the cycle requests the max acceleration and speed that can be delivered by the vehicle. In principle, speed deviations can theoretically be observed only during braking conditions, but this is also not relevant for the emissions performance. In terms of ECE R40 (L5e-B, L7e-B, L7e-C), the driving cycle has untypically low acceleration rate (1 m/s^2) and a maximum speed of only 50 km/h, which are both easy to follow. In both cases, as it will be shown in the next section, these two cycles only cover a small portion of the engine map operation.

3.1.3 Engine map coverage

The applicability of the WMTC is also assessed by investigating the engine map coverage as a second indicator. This indicator expresses the sampling frequency of possible engine operation points, when executing a driving cycle. A value of 100% would mean that the entire engine map is well covered. This complete coverage makes sure that no engine operation condition would lead to excessive emission rates. Such a coverage is not always possible following a driving cycle executed on the chassis dyno, due to safety concerns and drivability limitations. As some engine operation points may be infrequent in road operation (*e.g.* high speed, low load), not including them in the engine map is not detrimental in terms of real world emissions. Therefore, an as much as high, but not necessarily complete, coverage is required in general.

The detailed results of the engine map coverage, separately for each vehicle tested are shown in Appendix **B**. This section explains the process followed and the summary of the results.

In producing the indicator, the power delivered at the wheels, as set and measured by the chassis dyno, is converted to torque using the following equation:

$$Torque = 9548.8 * \frac{Power[kW]}{Engine\ Speed\ [rpm]} \quad [Nm]$$

It is known that the power measured at the chassis dyno is not identical to the one produced by the engine, due to mechanical losses in transmission, wheel/roller interface, and dyno friction. Hence, using the manufacturer provided full load curve (when this was available) to calculate the fraction of the engine load this torque would correspond to, would result to a lower than true partial load estimation and an overall negative bias for the level of the coverage indicator.

A more reliable estimation of the engine map coverage was made possible by performing wide open throttle (WOT) tests, thus identifying the max power available to the wheels at the conditions of the testing for various engine speeds. Although this test is not reliable to assess the actual engine output power, it is appropriate for the objectives of the current study, as we are interested in the ratios of driving cycle over WOT power and hence mechanical losses cancel out. Moreover, our intention has

been to examine the coverage of actual on-road possible conditions, hence executing this test on a chassis dyno and not an engine dyno better corresponds to the power really available on the road. Therefore, the full load curve that we have used is shaped as a typical trapezoid max torque line with its level, vertices location and sides adjusted to the torque levels recorded over WOT testing. It is repeated, this should not be considered as the engine out torque curve. The engine speed was recorded by the vehicles' ECU or an by directly reading the speed sensor signal at the flywheel.

An example of this approach is given in Figure 19. Each point corresponds to a pair of torque and speed, over the corresponding driving cycle. The WOT line corresponds to the full load curve recorded on the chassis dyno. With this approach, the assessment of the distribution of the sampling points along the engine map is mainly based on a scatter plot of the torque versus the engine speed in rpm. This is performed for the examined driving cycles WMTC, and ECE R40 or R47.

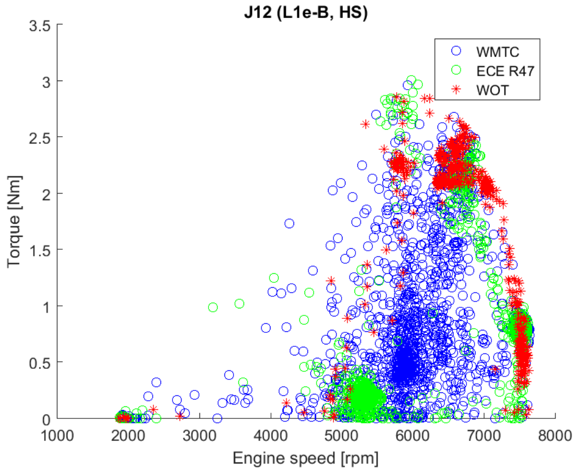


Figure 19: Torque vs speed scatter plot for measured WMTC and ECE R47 data points. The red points determine the max load torque curve, determined by wide open throttle (WOT) operation. Example shown for vehicle J07 – a low speed moped.

The indicator of part load coverage is completed by estimating the frequency distribution (counts) of pairs of torque at the wheel and engine speed, indicating the level and distribution of loads reached during the different driving cycles. Since the scatter plots do not clearly show the density of the points, the engine map coverage density is investigated with gridded graphs better outlining the most dense areas of the engine map. An example of this representation is shown in Figure 20.

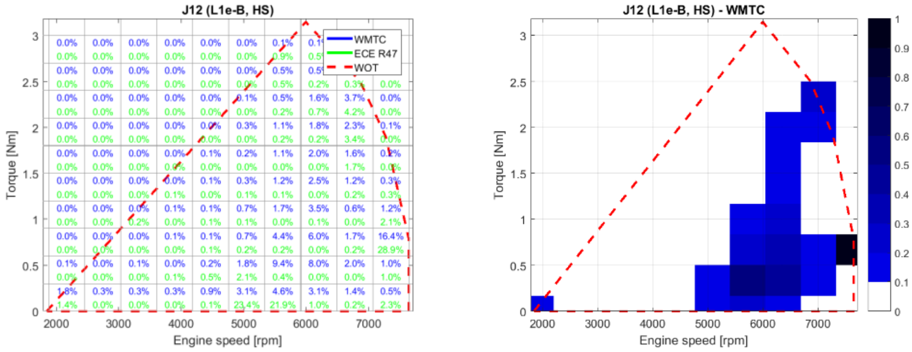


Figure 20: Discretised coverage of engine map. Left: Frequency distribution of datapoints over the engine map, Right: Shade-sensitive representation of frequency distribution.

In this the engine map area is discretized into blocks of sufficient resolution for which the distribution of the sampling points is indicated for the WMTC and the ECE cycles inside the WOT cycle area (left panel in Figure 20). Then, the blocks for which the frequency distribution exceeds 10% of the highest value observed in any of the blocks are colourized. The detailed results individually for every vehicle test are presented in Appendix B. The relative engine map area covered by such blocks - *i.e.* those where sufficient sampling points are found – is presented in Table 16 for each one of the vehicles.

Table 16. Part-load area coverage comparison between WMTC and ECE with reference to the percentage of area covered under the max torque curve (100%).

Vehicle	Transmission	WMTC coverage	ECE coverage	Wider engine map area coverage [WMTC / ECE]
J05 – L1e-A	Fixed	7%	3%	Neutral
J06 – L1e-B, LS	Fixed	6%	11%	Neutral
J07 – L1e-B, LS	CVT	9%	14%	Neutral
J10 – L1e-B, LS	CVT	5%	11%	Neutral
J02 – L1e-B, HS	Manual	47%	17%	WMTC
J03 – L1e-B, HS	CVT	38%	10%	WMTC
J04 – L1e-B, HS	CVT	48%	10%	WMTC
J12 – L1e-B, HS	CVT	34%	9%	WMTC
J14 – L1e-B, HS	CVT	44%	9%	WMTC
J17 – L1e-B, HS	CVT	38%	9%	WMTC
J26 – L2e-U	Manual	48%	31%	WMTC
J24 – L5e-A	Manual	31%	36%	Neutral
L01 – L5e-A	Semi-automatic	66%	20%	WMTC
J01 – L6e-BP	CVT	39%	7%	WMTC
J22 – L6e-BU	CVT	30%	3%	WMTC
J08 – L7e-B1	CVT	25%	25%	Neutral
J16 – L7e-B1	CVT	57%	38%	WMTC
J25, valid. – L7e-B1	CVT	37%	15%	WMTC
J09 – L7e-B2	CVT	38%	19%	WMTC

The table allows to draw some interesting conclusions in terms of engine map coverage:

- For most vehicle types, the ECE cycles cover only a small fraction of engine operation which, in the cases of most CVT vehicles is in the order or below 10%.
- In practically all cases, the WMTC achieves at least the same coverage with the ECE cycles and in most cases, significantly better coverage than the ECE cycles. In the case of L6e vehicles, the increase appears to be up to 10-fold.
- In a few cases of low speed mopeds, both the ECE and the WMTC exhibit a rather small coverage of the engine map operation. This is to be expected, as vehicles need to operate mostly on max load/max speed conditions or idle – partial speeds are hardly achievable on the road, especially on CVT transmission.
- CVT operation could potentially be further tuned to WMTC speed pattern and this could in the future lead to a decrease of the engine map coverage for Euro 5 vehicles. This has to be monitored and make sure that WMTC continues to provide sufficient coverage for Euro 5 vehicles. In any case, WMTC is expected to provide more operation variance than the corresponding ECE cycle.

A specific discussion is required for the J26 (L2e-U) and J24 (L5e-A) vehicles that were shown in the previous section to have specific drivability issues over the WMTC. The engine map coverage for the corresponding cycles in those cases is provided in Figure 21.

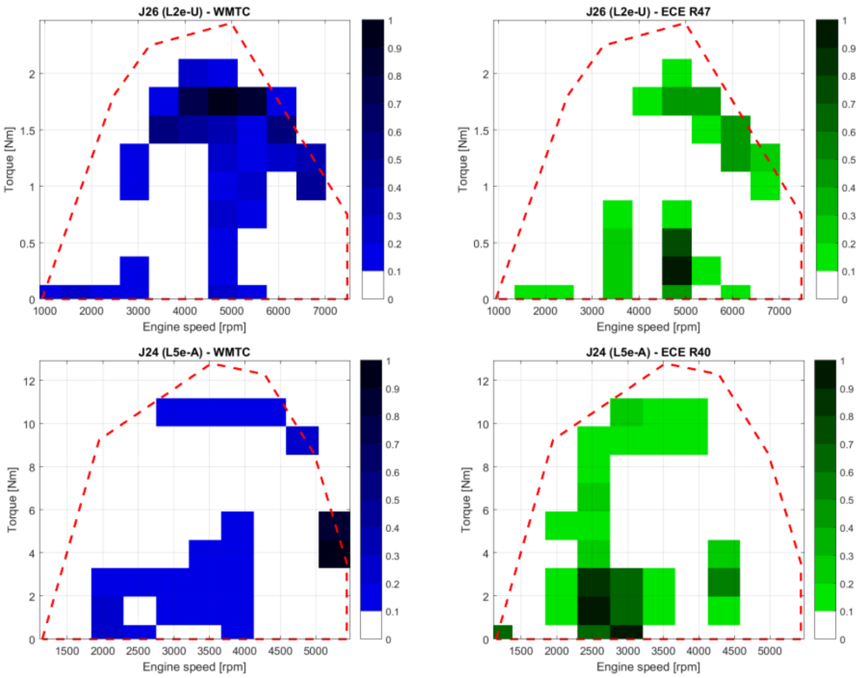


Figure 21: WMTC and ECE engine map coverage in case of an L2e-U and an L5e-A vehicle

In both cases, it is seen that WMTC covers portions of the engine map which include higher loads and overall higher speed conditions. Hence, not only the overall coverage but also the relative contribution of different regions are rather different in this case. The measured values for the ECE are mostly at low loads (despite the ECE R47 is intended to be performed at full throttle), hence these low are the ones contributing to the emission levels of these vehicles.

3.1.4 *Variability of emissions*

The third indicator for the assessment of the applicability of the WMTC is the variability of emissions over different repetitions of the driving cycle. The variability may show, to a certain extent, how much the dynamics of the cycle, *i.e.* speed transitions and acceleration changes can be precisely followed by the driver/rider. High variability may mean that the cycle dynamics cannot be precisely followed and this may induce difficulties with the type-approval procedure. As described in Fig. 1-5 of paragraph (5), Annex II of Regulation (EU) No 134/2014, passing the limits may requires multiple executions of the type-approval driving cycle. Variability between the executions may lead to difficulties complying with the test procedure.

Emission variability might not only originate from cycle execution but also from vehicle specific performance difference. For example, storage-release effects in the catalyst and the exhaust system may result to emissions difference even for identical repetitions of a driving cycle. In general, storage release effects are less prominent in dynamic cycles where the vehicle, exhaust and sampling system reach a quasi-equilibrium condition. In less dynamic cycles, *e.g.* mostly constant speed with scheduled acceleration and decelerations, storage may occur at low temperature and release at higher temperature modes. Therefore, depending on preconditioning and operation history, these may affect the emission repeatability. In any case, emissions variability is overall a good proxy to check the impact of cycle dynamics, when different cycles are compared.

The variability of emissions indicator in this study is examined by calculating the coefficient of variation (CV) metric for each of the examined pollutants. The coefficient of variation is defined as:

$$CV = \sigma/\mu$$

where σ is the standard deviation and μ is the mean of the emission bag results for the multiple runs of each test cycle, individually for each vehicle. The Shapiro-Wilk test was employed in order to test the normality of the data. The paired samples T-test was used to compare two dependent samples, when the relevant data appeared to be normally distributed. Additionally, its non-parametric equivalent, *i.e.* Wilcoxon's signed-rank test was employed to test for any potential differences between the two driving cycles in the case of non-parametric data. In the case of very small sample sizes, like the ones in the L6e and L7e categories, the non-parametric testing was directly employed without first testing the normality of the involved data. The small sample size of the L6e and L7e-categories is a limitation of this particular analysis, leading to less reliable conclusions. The tests were performed at the $\alpha=0.05$ or 5% significance level.

The base emission results (as average of the bag results) as well as the coefficient of variation for each test vehicle are presented in Appendix C. A summary of the results for the coefficient of variation is presented in the following table.

Table 17. Coefficient of variation [%]

	Euro	Cycle	THC	CO	NO_x	CO_2	CH_4	FC	NMHC
L1e	Euro 1 and Euro 2	ECE	6.8	8.9	6.2	2.4.	4.9	2.4	6.9
		WMTC	5.8	7.3	7.3	3.1	12.3	3.1	5.8
L2e	Euro 2	ECE	2.0	5.5	2.9	1.6	4.0	1.6	2.0
		WMTC	0.1	2.4	1.6	0.3	1.5	0.2	0.1
L5e	Euro 2 and Euro 4	ECE	0.8	3.7	6.6	1.7	20.8	1.7	2.8
		WMTC	11.0	9.2	11.0	0.7	4.8	0.5	4.9
L6e	Euro 2	ECE	4.8	9.1	2.4	1.0	33.7	1.0	22.1
		WMTC	31.2	20.7	15.8	15.3	84.0	15.3	16.9
L7e	Euro 2	ECE	17.0	9.1	7.1	0.8	9.1	0.8	14.0
		WMTC	4.7	6.6	3.9	2.1	2.3	1.9	5.7

A set of statistical tests were conducted (level of significance α=5%) in order to detect potential differences in the variation of both emissions and fuel consumption between the two driving cycles. The respective value-ranges for the observed significance levels (p-values) were as follows (per vehicle category): (i) L1-category vehicles, 0.050 to 0.959; (ii) L5-category vehicles, 0.180 to 0.655; (iii) L6-category vehicles, 0.180 to 0.655; and (iv) L7-category vehicles, 0.068 to 0.465. The CV samples in the L2-category vehicles included only one value, thus statistical analysis was not applicable to these data.

Conclusively, the results do not provide sufficient statistical evidence in order to support the existence of any difference in the variation of emissions and fuel consumption between the two driving cycles, *i.e.* ECE and WMTC, for none of the vehicle categories examined. Therefore, the two driving cycles appear to be similar in terms of the dispersion of the respective THC, CO, NO_x, CO_2, CH_4, and NMHC emissions and fuel consumption variables. In general, larger sample sizes would enhance the reliability of the associated inference process.

3.1.5 Final assessment of WMTC applicability and recommendations

A revised WMTC test procedure is foreseen at Euro 5 step for vehicles not falling in categories L3e, L4e, L5e-A and L7e-A, for which WMTC has become mandatory already at Euro 3 or Euro 4 steps. Hence, an experimental campaign to assess its suitability for the other L-vehicle sub-categories was conducted in this study. Since no experience on WMTC applicability for L5e-A had been accumulated, we also took the opportunity to asses suitability for this category as well. The conclusions of this analysis are summarized in this section.

<u>L1e-A</u>

The single vehicle on internal combustion engine that we could locate, in a market already dominated by electric vehicles, had issues following the speed and acceleration rate of the WMTC. However, we believe that such vehicles will not be existent at a Euro 5 step which will only comprise electric ones. For the latter, no Type I test is foreseen but only Type VII test. We therefore consider that the discussion on driving cycle suitability will be initiated again when and if energy efficiency labelling or targets are initiated for this category. A driving cycle better suited to how L1e-A vehicles are driven on the road may then be considered.

L1e-B

Out of the 9 vehicles tested in total the driving cycle speed pattern could be successfully followed by all 6 high speed mopeds and by 2 of the low speed ones. Hence, no drivability issues could be identified in the majority of cases.

For the three low speed mopeds, both WMTC and ECE only covered a small portion of the engine map. This is because these mopeds were equipped with a CVT gearbox and a speed limiter which lead the engine to operate on a reduced range (practically single load point and idle), under real-world conditions. Hence, the limited coverage is not considered to lead to inadequate control in real-world conditions. In general, it should be mentioned that tampering or altering speed limiters may lead to higher emissions of such vehicle types in real-world conditions (van Zyl et al., 2015). This is an area to be addressed by the anti-tampering specific terms and not the driving cycle per se.

For all six of the high speed mopeds, no drivability issues and a much higher WMTC coverage of engine map (42%) compared to ECE R47 (11%) could be achieved, regardless of CVT or manual transmission.

A single low-speed moped, which could not follow the demanded acceleration, was equipped with a fixed ratio transmission. We also expect no such systems being viable at Euro 5 step, as both emissions compliance and drivability issues will require a more modern transmission, like CVT.

Therefore, the overall conclusion for this vehicle sub-category is that WMTC drivability is not an issue and that the revised WMTC offers more thorough engine map coverage and potential for emissions control than ECE R47.

L2e

This sub-category consists of both passenger (L2e-P) and utility (L2e-U) vehicles. We consider L2e-P to be identical to L1e-B in terms of powertrain and emission relevant specifications, so we consider conclusions reached for L1e-B to hold in this case as well.

A single vehicle within the L2e-U subcategory, was measured in this sub-category, which appeared to have difficulties following both the acceleration profile and reaching the maximum speed of the cycle. Despite these issues, WTMC led to a wider coverage of the engine map while higher load/speed areas contributed relatively more to WMTC than in ECE R47.

WMTC is therefore expected to lead to more thorough emissions control than R47 at a Euro 5 step, while Regulation (EU) No 134/2014 provides the necessary flexibility for driving profile speed deviations so that no actual test violations are reported in executing Type I test. It is therefore recommended to use WMTC instead of R47 at a Euro 5 step.

Missing the speed profile for a large portion of the cycle may though potentially create difficulties in the reproducibility of the test or could even be exploited, through arbitrary interpretation, for vehicle tuning and emissions compliance. Moreover, the complete lack of relevant data makes impossible to anchor the WMTC imposed operation profile to any real-world conditions.

The recommendation of this study is that measurement campaigns have to be initiated to collect real-world operation data for such rather specialised utility (L2e-U) vehicles. Such data should be used to develop a revised operation profile that can guarantee adequate emissions control, improved drivability, and referenceability to real world operation.

We actually believe that the L2e-U sub-category, comprising vehicles of specialized use, will dynamically change in the future and electric vehicles will most probably prevail as cost goes down, due to low speed torque benefits, quiet and clean operation and the rather timid requirements for operation range of such vehicles. Hence, developing a new operation cycle to correctly report energy efficiency for labelling or monitoring purposes is highly advised.

L5e

Two L5e-A vehicles were measured in this study. As earlier explained, WMTC is already mandated for L5e-A at a Euro 4 step so no assessment on its suitability for this vehicle sub-category is conducted in this report. We can only confirm that for vehicle L01, which a typical example of an L5e-A vehicle, WMTC presented no drivability issues and led to a much wider engine map coverage than ECE R40.

The second L5e-A vehicle (J24) is more characteristic of the L5e-B one, hence it could be used a proxy to reach conclusions for such vehicles. Based on the experimental results, the demanded accelerations and maximum speed of the cycle were not followed by the particular vehicle. However, the degree of deviation was much smaller than in the case of the L2e-U vehicle. Moreover, WMTC offered similar engine coverage to ECE R40 for the higher load and speed range. ECE R40 sampling points were mostly found in the low load, low speed range, practically leaving all high power conditions unsampled. Therefore, in this case as well, WMTC is better suited for the Euro 5 step, than ECE R40.

Similar to L2e-U and because of the reported drivability issues and the complete lack of real-world operation data, our recommendations for enhanced real-world data collection and the possibility to further revise WMTC in the future also hold in the case of L5e-B vehicles.

L6e

Two L6e vehicles were tested in this study, one falling in the L6e-BP and the other in the L6e-BU sub-categories, both equipped with a diesel engine and CVT. No vehicle in the L6e-A subcategory could be located in the market.

For the two vehicles tested, WMTC led to no drivability concerns and an up to 10-fold map coverage compared to ECE R47. Hence, WMTC seems to be much better suited than R47 for this sub-category.

As later discussed in this document, we consider no viability of diesel powertrains at a Euro 5 step in this subcategory, and we expect the market to be shifting to electrified or fully electric vehicles. In this case, our recommendation to collect real-world data reflecting the operation of the new powertrain concepts holds for this sub-category as well. Depending on the data collected, considering a further revision of the cycle may be necessary in the future.

L7e

With regard to L7e-A, we could locate no such vehicles in the market while WMTC is in any case mandated at Euro 4 step. Hence, no further assessment is conducted for these vehicle sub-category.

With regard to L7e-B, three vehicles were measured in total, two falling in the L7e-B1 sub-category (ATVs) and one in the L7e-B2 (side by side) sub-category. All vehicles were equipped with positive ignition engine and a CVT transmission. Only one of the L7e-B1 vehicles failed to reach the maximum demanded speed but this cannot be considered a significant drivability issue neither this can lead to any arbitrary interpretation on the correct execution of the cycle. In all cases, WMTC offered a wider engine coverage, including a higher share of high load / speed conditions. This is overall expected to lead to more thorough emissions control.

Finally, a single electric L7e-C vehicle was measured but results are not reported here as this vehicle is not relevant for Type I test. To the extent that internal combustion engine L7e-C vehicles remain viable at a Euro 5 step, we expect the WMTC to be more suitable than ECE R40. This argument is based on the conclusions from L6e vehicles and considering that L7e-C are similar in terms of configuration and more powerful in terms of powertrain.

3.2 Assessment of the appropriateness of the Euro 5 limits

3.2.1 Background and objectives

The main objective of this section is to provide the CBA for introducing Euro 5 emission limits and deliver latest air pollution projections that quantify the contribution of L-category vehicles to road transport emissions for today and in the future.

A technical assessment of the required vehicle features to meet the Euro 5 limits is required for the cost/benefit analysis, in order to assess the technical feasibility and the associated costs in reaching these limits.

The values Euro 5 tailpipe emission limits laid down in Annex VI (A2), Regulation (EU) No 168/2013, are considered here. Euro 5 aims at reducing the over-proportionally high HC emissions of L-category vehicles compared to other vehicle types, as well as keeping NO_x, together with CO under control. Moreover, Euro 5 introduces a separate NMHC limit, in addition to THC, as well as limits for PM, for some L-category types. This section addresses CO, THC, NMHC, NO_x and PM emissions, while the next section specifically addresses options for the NMHC/THC ratio.

The environmental effect study covers the timeframe 2020-2040, as this is expected to cover the full life-cycle of the Euro 5 standard.

A number of scenarios were conducted, based on the requirements of the terms of reference of this study. Due to relevant discussions and requests in the MCWG and EPPR, the foreseen scenarios were modified to reflect latest technology developments and open issues. The scenarios that were executed and are later discussed in detail included:

i. Baseline scenario: continue with Euro 4 tailpipe emission limits and no introduction of Euro 5;

ii. Euro 4 and Euro 5 tailpipe emission limits as currently set-out in Regulation (EU) No 168/2013 and Regulation (EU) No 134/2014;

iii. Euro 4 and Euro 5 tailpipe emission limits as currently set-out in Regulation (EU) No 168/2013 with modified weighting factors over Regulation (EU) No 134/2014;

iv. Euro 4 and Euro 5 tailpipe emission limits as currently set-out in Regulation (EU) No 168/2013 and Regulation (EU) No 134/2014 and alternative powertrains for mini-cars (L6e-B and L7e-C);

3.2.2 Emissions modelling

As discussed in the description of the CBA model methodology, a set of base exhaust emission factors has been used for CO_2, NO_x, THC, PM, CO, in order to produce results on emission savings from the introduction of Euro 5. These EFs are summarized in Table 18. The base Euro 5 EFs correspond to the 0.5/0.5 cold/warm weighting factors for relevant categories (L3e-A1, L1e-B, L2e). These base emission factors do not contain the impact of emissions degradation and the impact of malfunctions on mean fleet emissions levels, these are taken later into account in the calculations.

Below, some notes on the EFs are provided for clarification purposes.

- The EFs of L5e vehicles are assumed equal to those of L3e-A2 (see earlier discussion in "Split of motorcycles into L3e-A1, A2, A3, and L5e tricycles" subsection).
- When the base EFs (for NO_x, HC, PM, CO) are used in the model, there is a deterioration of them with the age of vehicle (*e.g.*, due to an aged catalyst). This results in higher emissions after a few years of vehicle use. More details on this issue are provided in the discussion for "Type V – Durability requirements".
- An improvement in the EFs of CO_2 is expected in the years to come. This is mainly due to natural technology development and engine efficiency improvements, and/or market pressure to reduce fuel consumption in the L-category vehicles. As a result, any improvements in CO_2 cannot be attributed to the transition from Euro 4 to Euro 5 step and this is why these are not shown in Table 18. In any case, for modelling purposes, the improvement in CO_2 EFs is estimated at 1.5% per year until 2025 (and 0% afterwards) for most vehicle categories (except large L3e-A3 motorcycles and ATVs, for which it is estimated at 0.6%). These has been taken into account in the modelling, regardless of whether Euro 5 or Euro 5 is introduced, hence the net benefit of introducing Euro 5 is zero in this case.
- The Euro 5 EF of THC consists of a NMHC and a CH_4 part. For NMHC at a Euro 5 level, the emission limit of 0.068 g/km has been used, while for CH_4 an EF of 0.020 g/km has been estimated for most vehicle categories (except diesel mini-cars, for which it is estimated at 0.010 g/km). More details on this issue are provided in the discussion for the "Feasibility and cost-benefit ratio of the separate NMHC limit".

Table 18: Base exhaust emission factors used in the model (0.5/0.5 weighting factors used for relevant categories)

g/km		CO_2	NO_x	THC	$PM_{2.5}$	CO
Mopeds, L1e-A, L2e	Conv.	77.6	0.056	8.40	0.176	14.7
	Euro 1	62.1	0.190	2.74	0.044	5.12
	Euro 2	62.1	0.170	1.87	0.018	3.36
	Euro 3	58.0	0.170	0.918	0.008	2.43
	Euro 4	52.2	0.170	0.596	0.005	1.73
	Euro 5	52.2	0.057	0.088	0.001	1.21
Motorcycles, L3e-A1	Conv.	95.9	0.335	1.42	0.058	17.9
	Euro 1	78.8	0.354	1.16	0.025	13.2
	Euro 2	67.3	0.306	0.503	0.008	4.97
	Euro 3	67.3	0.271	0.314	0.004	2.74
	Euro 4	62.0	0.112	0.280	0.004	1.19
	Euro 5	62.0	0.060	0.088	0.001	1.05
Motorcycles L3e-A2	Conv.	130	0.394	2.19	0.058	23.4
	Euro 1	123	0.377	1.29	0.025	11.3
	Euro 2	113	0.154	0.668	0.008	4.20
	Euro 3	113	0.078	0.418	0.004	2.32
	Euro 4	107	0.080	0.215	0.002	1.80
	Euro 5	107	0.060	0.088	0.001	1.58
Motorcycles L3e-A3	Conv.	149	0.262	2.25	0.058	23.2
	Euro 1	139	0.304	1.02	0.025	11.2
	Euro 2	139	0.303	0.465	0.008	4.57
	Euro 3	139	0.155	0.290	0.004	2.52
	Euro 4	132	0.090	0.149	0.002	2.00
	Euro 5	132	0.060	0.088	0.001	1.75
Mini-cars diesel[34]	Conv.	108	0.589	0.308	0.250	1.15
	Euro 1	93.7	0.814	0.161	0.150	0.94
	Euro 2	93.7	0.814	0.161	0.150	0.94
	Euro 3	93.7	0.814	0.161	0.150	0.94
	Euro 4	84.3	0.689	0.120	0.080	0.94
	Euro 5	84.3	0.060	0.078	0.001	0.94
ATVs	Conv.	150	0.047	16.7	0.200	33.5
	Euro 1	130	0.300	9.00	0.080	13.3
	Euro 2	130	0.300	2.32	0.040	7.77
	Euro 3	130	0.300	2.32	0.040	7.77
	Euro 4	126	0.187	0.603	0.010	1.79
	Euro 5	126	0.060	0.088	0.002	1.00

As already mentioned earlier, in general, reliable EFs up to Euro 3 are available from COPERT and previous environmental effect studies (cross-checked with new JRC and LAT data). For Euro 4 and Euro 5, emission standard equivalencies, emission limits, or justified estimates, based on the expected technology, have been used. Table 19 summarizes in a compact manner the justification of the Euro 4 and Euro 5 base EFs that have been used in the model. Some worth-mentioning points are also discussed below.

- For mopeds, separate EFs are calculated in COPERT for vehicles with 2-stroke and 4-stroke engines, at least up to Euro 4 step, and the EFs finally used are the weighted average. Since there is a trend of shifting to 4-stroke

[34] EFs for gasoline mini-cars are not presented in Table 18 because their number is very small and their contribution to the CBA is negligible (see earlier discussion in "Fleet data scenarios for mini-cars and ATVs" subsection). Regarding the EFs of the new advanced mini-cars powertrain concept (gasoline series hybrid), these vehicles (when they will enter the market) are assumed to have the Euro 5 EFs of mopeds for NO_x, HC, PM, and CO.

engines in recent years, the majority of Euro 4 and Euro 5 mopeds are assumed to be with 4-stroke engines (90% of the vehicles at Euro 4 and 95% at Euro 5).

- In deciding on the emission factors for mopeds, the ratios of ECE R47/WMTC and the Cold/Warm ratios in each case were taken into account, based on the measured results of this study. Hence, the Euro 4 emission factors were based on the Euro 3 ones, and were reduced according to the proportionality of the emission standards. The Euro 5 ones were based on the Euro 5/Euro proportionality, however, increasing in stringency to take into account the WMTC 0.5 vs ECE R47 0.3 ratio. For example, in the case of THC, this leads to an additional reduction of emission levels of approximately 50%.
- For motorcycles, the Euro 5 EFs of NO_x, THC, and $PM_{2.5}$ are (almost) equal for all sub-categories (A1, A2, A3) since they converge to the emission limit values, while for CO there is some differentiation (higher values for A2 and A3, compared to A1). Regarding the Euro 4 EFs, they present small differentiations for all pollutants due to specific technological characteristics of each sub-category (A1, A2, A3).
- For diesel mini-cars, there is a significant improvement in the EFs from Euro 4 to Euro 5 (especially in NO_x and $PM_{2.5}$). This is mainly attributed to the significant reduction in the emission limit values for these vehicles (Euro 5 vs. Euro 4).
- For ATVs, there is also noticeable improvement in the EFs from Euro 4 to Euro 5 (especially in THC and $PM_{2.5}$) and this is also due to the reduction in the emission limit values for these vehicles (Euro 5 vs. Euro 4).

Estimating emission factors for different sub-cycle weighting factors

In order to determine the new EFs when shifting from 0.5/0.5 to 0.3/0.7 cold/warm weighting factors, the cold/warm ratios of the moped vehicles emissions measured in the framework of this project over WMTC have been examined. According to those, the shift to more relaxed weighting factors would give ‘room’ for the following increase in emissions for each of the pollutants affected:

- HC & $PM_{2.5}$: 1.15
- CO: 1.10
- NO_x: 1.01
- This is the picture obtained on Euro 2 vehicles, measured in this study. Those are expected to have different cold vs. warm start performance than Euro 5 ones. In particular, experience from Euro 5 and Euro 6 passenger cars and Euro 4 motorcycles shows that measurable emissions levels basically appear during the cold-start phase and, then, they decrease to very low levels over warm operation. For example, Table 20 shows the cold/warm ratios for moped Euro 2 and motorcycle Euro 4 measured in the framework of this project and LAT Euro 5/6 petrol passenger car measurements. We do not expect Euro 5 motorcycles to have as large catalyst as passenger cars, due to space restrictions, so hot operation levels are expected to be somewhat larger under real-world conditions.

Table 19: Justification of the Euro 4 and Euro 5 EFs that have been used in the model

		NO_x	THC	$PM_{2.5}$	CO
Mopeds	Euro 4	No change over Euro 3	Close to emission limit	(Almost) proportionally to THC improvements	Better catalyst and engineering improvements
	Euro 5	Difference in emission limit and emission cycle	NMHC emission limit + CH_4 estimate		Better catalyst and change in type approval cycle
Motorcycles A1	Euro 4	Significant drop due to better catalyst, better lambda adjustment, not much correction to HC	Marginal correction to already good levels		Proportionally to emission standard ratio (Euro4/Euro3)
	Euro 5	Emission limit	NMHC emission limit + CH_4 estimate		Proportionally to emission standard ratio (Euro5/Euro4)
Motorcycles A2	Euro 4	Mixture will become leaner to fulfil HC, CO, hence not much change in already good NO_x levels	Proportionally to emission standard ratio (Euro4/Euro3)		WMTC covers a small fraction of real-world operation
	Euro 5	Emission limit	NMHC emission limit + CH_4 estimate		Proportionally to emission standard ratio (Euro5/Euro4)
Motorcycles A3	Euro 4	Emission limit	Proportionally to emission standard ratio (Euro4/Euro3)		WMTC covers a small fraction of real-world operation
	Euro 5	Emission limit	NMHC emission limit + CH_4 estimate		Proportionally to emission standard ratio (Euro5/Euro4)
Mini-cars diesel	Euro 4	Proportionally to emission standard ratio (Euro4/Euro3)	Estimate	Emission limit	Estimate
	Euro 5	Emission limit	NMHC emission limit + CH_4 estimate	Estimate	Estimate
ATVs	Euro 4	Proportionally to emission standard ratio (Euro4/Euro3)	Proportionally to emission standard ratio (Euro4/Euro3)	(Almost) proportionally to THC improvements	Proportionally to emission standard ratio (Euro4/Euro3)
	Euro 5	Emission limit	NMHC emission limit + CH_4 estimate		Emission limit

Table 20: Cold/warm ratios obtained from measurements

Pollutant	Moped Euro 2 4-stroke over WMTC	Motorcycle Euro 4	LAT petrol passenger cars Euro 5/6
HC	1.96	5.6	22
CO	1.60	2.3	36
NO_x	1.04	1.3	2.85

Based on the above considerations, the proposed cold/warm ratios for Euro 5 vehicles and the ratios for the worsening of EFs expected when shifting to more relaxed weighting factors for L1e-B, L2e, and L3e-A1 vehicles are shown in Table 21. These proposed ratios are close to the motorcycle Euro 4 ones (for HC and NO_x), as it is considered that this will be closer, technology-wise, to Euro 5. Some further optimization in the warm phase over the Euro 5 steps is considered to lead to marginally higher ratios, which are reflected in the table. The CO ratio is not increased for technical reasons, *i.e.* with this value Euro 5 CO emission levels reach Euro 4 ones. It is reminded that CO is not relevant in the CBA due to zero damage cost to the environment, hence no further tuning is necessary.

Table 21: Proposed cold/warm ratios and ratios for worsening the Euro 5 EFs

Pollutant	Proposed cold/warm ratio for Euro 5 L1e-B, L2e and L3e-A1 vehicles	Derived ratio for worsening (relative increase) in Euro 5 EFs due to relaxed weighting factors
HC	6.0	1.40*
CO	1.6	1.10
NO_x	1.5	1.09

* Same value also for PM

3.2.3 *Technology assessment and associated costs*

The Kraftfahrt-Bundesamt (KBA) Type Approval (TA) database (KBA, 2016) shows that from the existing Euro 4 motorcycles (L3e) about 40% of the L3e type approvals are numerically be below the Euro 5 HC/NOx limits, as shown in the following figure, while CO compliance reaches 96%. This means that, technically, current state of the art L3e motorcycles are not that far off of Euro 5 limits. This should not immediately be read as if 40% of the current motorcycles already comply with Euro 5 emission limits as there are a number of factors which are not taken into account, *i.e.* Euro 5 calls for NMHC limits which are more stringent than THC ones, the difference in weighting factors between Euro 4 and Euro 5 needs to be considered, and a margin for application of deterioration factors or for the impact of physical ageing needs to

be added. Still, the moderate difference of current Euro 4 TA levels over Euro 5 levels is a positive sign.

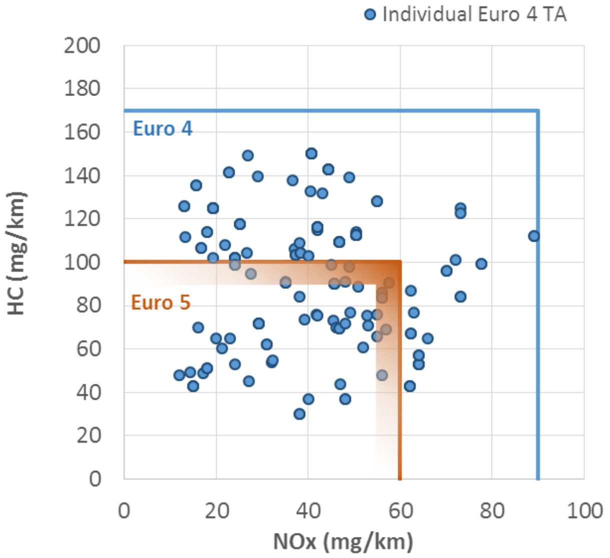


Figure 22. Euro 4 vehicles complying with Euro 5 limits. (*Source: Sept. '16 Kraftfahrt-Bundesamt Type Approval data*). The shading for the Euro 5 step limits comes from uncertainty on the impact of different weighting factors at Euro 5 compared to Euro 4 (for L3e-A1 vehicles).

Mopeds (L1e-B, L2e)

Euro 5 brings significant reductions to Type Approval emission levels for the moped category, as a result of three factors. First, emission limits drop significantly, by almost 7-9 times for NMHC, and almost 3 times for NO_x. Furthermore, the driving cycle shifts from ECE R47 to WMTC which, as shown before, covers a wider area of the engine map. Third, weighting factors are required to change from 0.3/0.7 for the cold/warm parts to 0.5/0.5, respectively. In order to achieve these targets, significant R&D and hardware costs will be required.

Our assessment is that basically only 4S engines equipped with electronic fuel injection and advanced ECUs for strict control of the lambda value can be used to achieve these limits. Two stroke engines could potentially still make it but will require advance direct injection fuel injection, air metering and combustion improvements, advanced aftertreatment, and possibly secondary air injection, that all seem to increase costs beyond 4S engines. In principle, 2S concepts may only remain in niches to signify a different character for specialised vehicles but at higher cost than 4S systems.

Further to improved charge and exhaust handling, Euro 5 moped engines will have to operate on improved combustion and decreased lube oil consumption, to limit HC. This would require higher manufacturing precision, improved friction materials and piston sealants, and better injectors for fuel dispersion. Therefore, design and manufacturing costs will increase.

Third, the exhaust line, including the aftertreatment will have to be improved. First, fast light-off will be required, which will need a thermally optimised catalyst. Second,

a larger catalyst and higher precious metal (Platinum Group Metals – PGM) content will be required.

Despite the fact that those are significant technology advancements, we do not consider that these constitute a bottleneck for the introduction of the technology already in 2020. The technology proposed is already used for larger motorcycles, hence implementation of the Euro 5 requires a scaling down to smaller engines and, of course, resolving technical complications that will arise in the development and calibration phases.

Further to development and manufacturing costs per engine type, calibration costs per model will increase over Euro 4, due to additional time and effort required to match the engine and aftertreatment to the specific powertrain and drivability requirements of each vehicle model.

The costs these enhancements entail are presented in Appendix **E**, separately for each cost category. A cost range also takes into account the uncertainty in the estimation. Development and calibration costs assume a 500 €/man-day average cost for engineers and mechanics, including the cost of testing. Hardware costs are based on relevant estimated from US EPA (US EPA, 2002). For reference, the cost of a moped catalyst at Euro 3 step for the manufacturer is estimated at 15-20 €/piece (w/o canning).

The calculation, in net present values terms, results to a cost increase of 78-111 €/veh in this sub-category. A number of observations need to be made on this number:

- The range reflects the uncertainty in the estimation of cost, the uncertainty in the evolution of the market (low or high growth) and the uncertainty in the rate of drop of technology costs (6-10 years to reach residual cost).
- This is a significant cost increase, in the same range of the cost of powertrain of current Euro 3 mopeds.

Relaxing the cold/warm weighting factors from 0.5/0.5 to 0.3/0.7 for will result to marginal reduction costs as well. We do not expect though that the change in weighting factors will lead to fundamental differences in the Euro 5 emission control concept. We expect the difference in cost to come from reduction in the engine calibration, but not development, costs and a decrease in the catalyst cost, originating both from the change of the catalytic converter as such, as well as its packaging, due to the relaxation in demand of a fast light-off, as the cold start weighting factor decreases. Our estimate is a decrease of 20% in calibration costs and another 10% in emission control material costs.

Finally, we have assumed increase in maintenance and warranty costs over vehicle lifetime, equal to 0.3% and 0.1%, respectively, of the vehicle price. These reflect the increased complexity of the system.

Motorcycles (L3e, L4e, L5e-A, L7e-A), including ATVs (L7e-B)

Motorcycles and ATVs have together been included in the estimations of technology and costs as powertrains are very similar between the two concepts. A differentiation in the two technologies is discussed in the following paragraphs, where necessary.

Significant technology improvement over Euro 4 is required in this case as well. However, compared to mopeds, relative emission limits reduction over Euro 4 is lower. For example, in terms of hydrocarbons, reductions are ~2.5-5 times, *i.e.* approximately half of what this was in the case of mopeds.

In terms of H/W costs, higher PGM loading on the catalyst will be required, and a larger catalyst in some of the models. In some applications, maybe a split catalyst case may be necessary (*i.e.* a small close coupled one for fast light off) and a larger one further downstream the exhaust line. Engine improvements may also be required, in terms of lube oil consumption and air induction handling, but these are rather marginal. For some vehicle models, especially the smaller ones, an Electronic Throttle Valve (ETV) may be necessary, which is currently not mandatory at Euro 4 step. We have taken into account that out of the 40% of L3e vehicles that more or less correspond to the L3e-A1 class, some 20% will need an ETV to reach Euro 5. The cost of ETV is considered at 50 €/piece.

Higher engine development costs and calibration costs are also foreseen, compared to Euro 4. However, incremental calibration costs drop more than in the case of mopeds because of the larger model variation in case of the motorcycles which contributes to experience gaining and the fact that WMTC calibration is already part of the Euro 4 type-approval.

The advanced technology is estimated to lead to an equivalent of 0.1% and 0.05% of vehicle price increase for maintenance and warranty costs, respectively.

With these considerations, the cost increase for the average motorcycle is estimated at 33-44 €/veh., over the 20 years horizon. If the cost increase is considered for the first four years of implementation of the measure (one model year), the mean cost comes to 74 €/veh.

Similar considerations have also been done in the case of ATVs. However, five out of the eight main ATV and SbS manufacturers are also active in the motorcycle sector, hence initial investment and engine development costs are only considered for the three remaining manufacturers. In terms of hardware and calibrations costs, these are considered to be 30% higher than in the case of the average motorcycle. This is because the average ATV catalyst is expected to be larger than for the average motorcycle and because of the wider engine coverage of WMTC for L7e-B than L3e, that will entail higher costs.

Mini-cars (L6e, L7e-C)

The L6e and L7e-C vehicles, *i.e.* mini-cars, would require very advanced technology to meet the Euro 5 limits, if their powertrain continues to be based on the diesel engine cost. As the limits both of PM and NOx reach Euro 6 passenger car levels, it is expected that similar technology will have to be utilized. At minimum, in terms of engine technology this corresponds to high pressure fuel injection, exhaust gas recirculation (EGR), as well as enhanced electronic control of combustion

parameters. In terms of aftertreatment, this would necessitate the introduction of lean NO_x trap (LNT) and diesel particulate filter (DPF), as a minimum. No selective catalytic reduction (SCR) would be required due to the small capacity of the engine.

Before estimating costs, it should be made clear that the feasibility of using such technology in such small engines and vehicles is questionable. We are not aware of any dedicated research study looking at the combination of a small diesel engine with LNT and DPF. A specific study will be required to examine whether thermal management of the system together with packaging and space limitations can make this concept viable for 500cc engines. The cost for the specific vehicle technology implementation is given in Appendix **E**. Hardware costs are based on corresponding technology costs for larger vehicles, scaled down to the specific engine size. Development costs are also high due to vehicle and powertrain developments required to reach the limits.

Two more technology options are currently available, based on the engine capacity limitations in Regulation (EU) No 168/2013. These options are analyzed below and the cost estimates are done for their introduction in 2024/5, allowing sufficient time for the system development

i. A fully electric vehicle powered by an electric motor.
ii. A series hybrid vehicle where a 50 cc petrol engine is used as the power source to charge a battery, delivering power to an electric motor.

Electric vehicles are already available in this category with the Renault Twizy being the most representative example. This comes either as an L6e-A or L7e-C version, with a price in the order of 7000-8000 €/veh., without battery costs being included. The battery lease cost is approx. 50 €/month (for typical ranges). Assuming a 6 years lifetime for the vehicle, the total cost reaches 10600-11600 €/veh. This is already below the cost of the most widespread diesel microcars, which range from 12700-15000€/veh. Moreover, significant cost reductions are expected for Li-Ion batteries as the production of electric vehicles increases. A recent study for the US Department of Energy (Chung et al., 2016), estimated that a sustainable societal costs for Li-Ion batteries is at around 250 $/kWh. Assuming a 6 kWh pack for such microcars, this decreases the total battery pack cost to approximately 1500 €/veh. (assuming an exchange ratio of €/$ approximately equal to 1). This leads to potentially significant cost benefits of electric vehicles/compared to diesel powertrains in this category. The reason that vehicles in this category have almost the immediate potential to be cheaper than their diesel counterparts is the relatively small battery pack size. We estimate here 6 kWh, compared to 100 kWh for the battery pack of a typical full-size M1 vehicle (*e.g.* Tesla Model X).

The second option is a ‘series hybrid’ system where a 50 cc petrol engine charges the battery which in turn powers an electrical motor of 4-6 kW for an L6e or a larger motor for L7e-C. A peak power by a 50 cc engine is in the order of 6 kW but this is achieved at high speed, hence using this as a powertrain would make a 500 kg vehicle extremely noisy, difficult and uncomfortable to drive. On the contrary, an electrical motor of 6 kW may deliver the necessary torque at low RPM. Moreover, in such an application, the battery pack can be significantly smaller than a full electric vehicle, as the petrol engine will be charging this, while the vehicle operates. For example, a 2 kWh battery pack would allow max power from the motor to be delivered for at least 15 mins. A cost and weight split for such a system could be as follows:

- Euro 5 50 cc petrol engine + aftertreatment: 300 €
- 6 kW Electric motor: 500 €
- 2 kWh Battery pack: 1000 €
- Power electronics: 500 €

This is leads to a total cost of 2300 €/veh. which is comparable, or even lower, to the cost of a Euro 4 500 cc diesel engine. Hence, even in this case, our expectation is that Euro 5 can be achieved even with benefit in total technology costs, assuming that sufficient time is given for engine development. The advantage of this vehicle, over a fully electric one, is that there is no need for vehicle recharge – in case the latter is not at disposal for specific users (*e.g.* for rural than urban use).

For estimating total costs, we estimated significant initial investment costs and development costs for each of the manufacturers in this market segment and additional calibration costs over Euro 4 – which should be read as specific vehicle model development costs. However, in either of the cases examined, we estimate that hardware costs will be lower than even retaining Euro 4 diesel powertrains. In order to keep a conservative approach, we assumed that the cost of electric and series-hybrid vehicles can be 900 € and 200 € lower than diesel powertrains and that the market can be split to 60% full electric and 40% series-hybrid. This leads to an overall H/W benefit of 620 €/veh.

3.2.4 Environmental benefit

Table 22 and Figure 23 present the environmental benefit (emission savings) from the introduction of Euro 5 emission limits in 2020 for all L-vehicles in the baseline fleet scenario, as an example. The complete set of environmental benefit results for all scenario combinations are provided in Appendix F.

Table 22: Environmental benefit (emission savings for each pollutant) due to the introduction of Euro 5 emission limits in 2020 for all L-vehicles (here: baseline fleet scenario)

Emission savings for specific pollutant (2020-2040)	HC	NO_x	PM	CO
kt	**509**	**141**	**6.6**	**776**
% benefit over Euro 4	HC emission savings / Euro 4 vehicle emissions = 509kt / 979kt = **52%**	NO_x emission savings / Euro 4 vehicle emissions = 141kt / 408.5kt = **34.5%**	PM emission savings / Euro 4 vehicle emissions = 6.6kt / 12.8kt = **51.5%**	CO emission savings / Euro 4 vehicle emissions = 776kt / 6,541kt = **12%**
% benefit compared to total L-fleet emissions	HC emission savings / total L-fleet emissions = 509kt / 1,950kt = **26%**	NO_x emission savings / total L-fleet emissions = 141kt / 566kt = **25%**	PM emission savings / total L-fleet emissions = 6.6kt / 27.3kt = **24%**	CO emission savings / total L-fleet emissions = 776kt / 9,628kt = **8%**

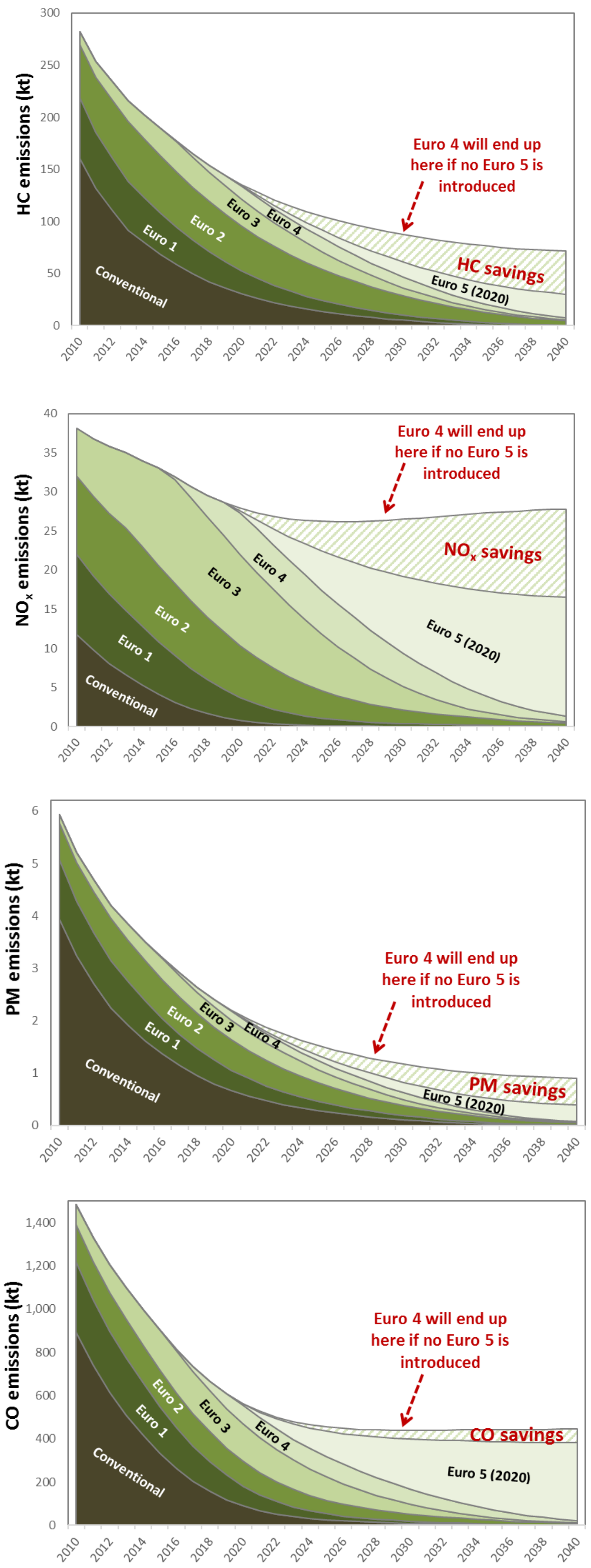


Figure 23: Environmental benefit (emission savings) from the introduction of Euro 5 emission limits in 2020 for all L-category vehicles (here: baseline fleet scenario)

The emission savings (environmental benefit) calculated per scenario are used as input to the cost-benefit model that follows. In general, it can easily be observed that there are significant emission savings in all major pollutants, both in terms of absolute and relative reductions over projected L-vehicles fleet emissions.

Figure 24 shows more clearly the impact of Euro 5 on different pollutants, by providing the emission savings (%) of Euro 5 compared to Euro 4 and total L-fleet for each pollutant (baseline fleet scenario, introduction of Euro 5 limits in 2020 for all L-vehicles). From this figure, it is observed that HC, PM, and NO_x exhibit the highest percentages in emission savings due to the introduction of Euro 5 limits, followed by CO. For example, compared to Euro 4 (no Euro 5 introduction), the emission savings are 52% for HC and PM, 34% for NO_x, and 12% for CO. Even when the emission savings are compared to total L-fleet emissions, significant percentage reductions are achieved (26% for HC, 25% for NO_x, 24% for PM, and 8% for CO).

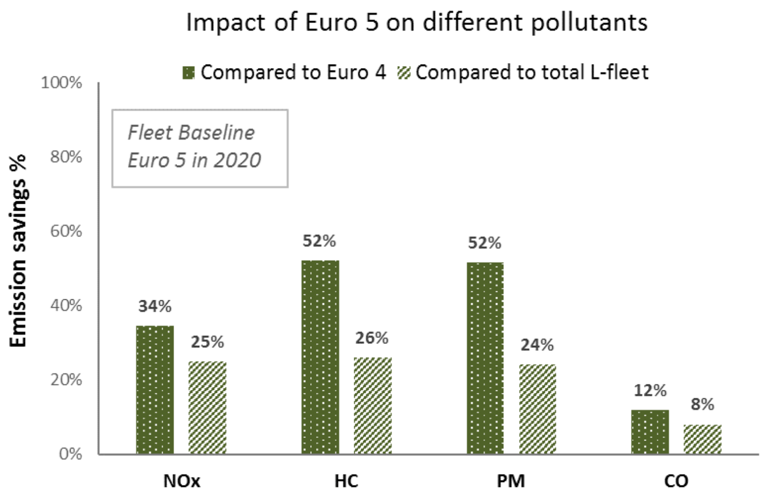


Figure 24: Emission savings (%) of Euro 5 compared to Euro 4 and total L-fleet

Figure 25 presents the contribution of L-categories to the above emission savings (split %). This contribution depends on the activity data (vehicle-kilometres) of each vehicle category and the improvement of the corresponding EF from Euro 4 to Euro 5 step. It can be seen from this figure that most of the reduction observed is owed to motorcycles, followed by mopeds in most of the cases (except PM, where mini-cars have the highest percentage). Apart from PM, mini-cars contribute significantly on NO_x, while their percentage on HC and CO is negligible.

These observations in Figure 25 correspond to the baseline fleet scenario and introduction of Euro 5 limits in 2020 for all L-vehicles. Similar observations (with marginal changes) for the contribution of L-vehicles to emission savings can also be made when examining other fleet (*e.g.* high/low growth) or Euro 5 introduction date scenarios (*e.g.* in 2024).

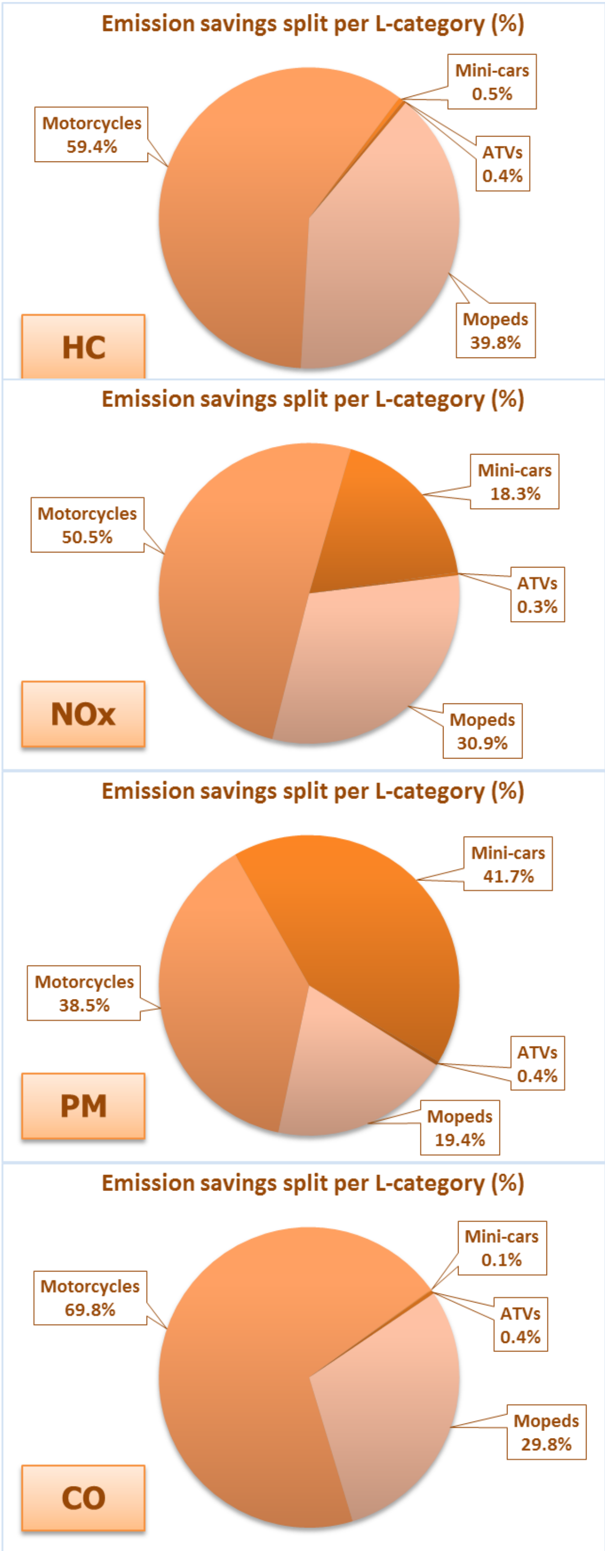


Figure 25: Contribution of L-categories to emission savings (split %)
(here: baseline fleet scenario, Euro 5 limits in 2020 for all L-category vehicles)

3.2.5 Cost-Benefit calculation

Using the environmental benefits presented in the previous section, converted into monetary terms, and the associated costs, the overall benefit can be calculated over the 20 years horizon. A positive value corresponds to an overall net benefit, while a negative one corresponds to a net societal cost to the society. All costs are expressed as a net present value (NPV).

The baseline scenario is the one formulated assuming Euro 5 is not introduced and that Euro 4 is the last step. This scenario corresponds to zero costs. The two scenarios for Euro 5 both assume introduction of the step in 2020/21 (new types/all types). However, in one of the two scenarios, the weighting factors for the cold/hot WMTC parts are 0.5/0.5 according to Regulation (EU) No 134/2014, while the other option is to relax those to 0.3/0.7.

For each scenario formulated, we provide a central value and a range to reflect the uncertainty in the calculation. The central NPV estimation is calculated considering the baseline fleet projection, moderate cost estimates and technology depreciation period 6 years, following the analysis of Section 1.1. The range is estimated by subtracting the difference between two extreme scenarios. The low NPV (benefit) estimate is formulated considering high costs, technology depreciation period of 10 years and the low growth projection. This leads to low NPV because investments are high but the actual vehicles placed on the market to deliver the environmental benefit are relatively low. The high NPV (benefit) estimate is conducted assuming low costs, faster technology depreciation period (6 years) and the high growth projection

Mopeds and Motorcycles

With regard to the mopeds and motorcycles (including ATVs) broad vehicle categories, the introduction of the Euro 5 emission limits in 2020 seems technically feasible as well as cost-beneficial, as shown below.

The overall benefit or cost is presented in NPV terms (2020 values) in Table 23 for each vehicle category. A clear benefit from the transition from Euro 4 to Euro 5 in 2020 is seen both for the mopeds and for the motorcycles (including ATVs). Despite the significant cost that is demanded per vehicle, the environmental benefits appear to be even larger in monetary terms, leading to an overall benefit in any of the scenarios and for both vehicle sub-categories.

Table 23. NPV for the Euro 5 Type I emission limits introduction in 2020 – mopeds and motorcycles (including ATVs).

Cost-benefit over 2020-2040 (Values in M€)	0.5/0.5 cold/warm weighting factors (Regulation (EU) 134/2014)	0.3/0.7 cold/warm weighting factors
Mopeds	137^{+76}_{-63}	135^{+74}_{-59}
Motorcycles (including ATVs)	196^{+111}_{-125}	123^{+100}_{-112}

Shifting from 0.5/0.5 to 0.3/0.7 cold/warm weighting factors for mopeds and for L3e-A1 low-performance motorcycles leads to marginal differences of the NPVs in Table 23. In particular for mopeds, the NPV is practically identical, meaning that any additional development costs are perfectly counterbalanced by environmental benefits. In the words, this says that the overall societal benefit is identical in both cases.

For motorcycles, the 0.3/0.7 ratio seems to lead to marginally lower benefits NPV. This is well within uncertainty, therefore, again the CBA cannot be used to clearly distinguish a scenario from the other. Again, the analysis shows that societal benefits will be achieved by introducing Euro 5 in any of the two approaches.

Mini-cars

Two scenarios were explored for mini-cars:

- The first assumes that the diesel powertrain continues and that the Euro 5 limits are introduced in 2020.
- The second assumes that a margin until 2024/25 (new/all types) is given, where Euro 4 diesel continue to that point and then electric and hybrid-electric vehicles are introduced at Euro 5 step.

Results for the two scenarios are given in Table 24. The net overall cost (negative NPV) observed for the diesel powertrain scenario means that despite significant environmental benefits, high technology and investment costs lead to an overall societal damage.

On the other hand, significant benefits appear when introducing advanced mini-cars, even when allowing sufficient time for their development and delaying the introduction of Euro 5. Benefits in this case appear both from the fact that some of the vehicles introduced are zero emitters (fully electric vehicles) and from the fact that technology hardware cost is expected to be lower than Euro 4 diesel powertrains.

Table 24. NPV for the Euro 5 Type I emission limits – mini-cars

Cost-benefit over 2020-2040 (Values in M€)	Cost-benefit
Diesel mini-cars (introduction in 2020)	-65^{+67}_{-102}
Advanced mini-cars (introduction in 2024)	227^{+43}_{-42}

3.2.6 *Conclusions and recommendations*

Mopeds and Motorcycles

Euro 5 for mopeds (L1e-B, L2e-P) and motorcycles (L3e, L4e, L5e-A, L7e-A) is technically feasible to be implemented in the 2020/21 (new/all types) time horizon. The technology required to achieve the new limits will have to be significantly

improved over Euro 4 but such improvements only require incremental technical advancements rather than new breakthroughs.

The upgraded hardware and related R&D costs entail significant costs for the new vehicles, especially in the case of mopeds, in relation to the rather low purchasing price. The increase in cost is expected to further increase the competition from larger scooters. However, the possibility of mopeds to be driven without a driving license is considered to lead to a sustainable market, despite of cost increase.

Despite technology cost increases, large environmental benefits lead to an overall net benefit in monetary terms. Moreover, mopeds and motorcycles at Euro 5 step will be amongst the cleanest conventional vehicles on the road, under urban conditions. This eliminates the risk of measures that could potentially limit the accessibility of such vehicles to city centres.

ATVs and side-by-side vehicles (L7e-B) will follow technology improvements shared by motorcycles, with which they share powertrain technology. Marginally higher costs are expected for L7e-B vehicles compared to L3 because of the different tuning and engine coverage by the WMTC.

Mini-cars
It would be advantageous for reaching conclusions to consider sub-categories of rather heavy vehicles with power restrictions within the L-category under the same point of view. This refers to L2e-U and L6e vehicles for which power is limited to 4 kW (or 6 kW for L6e-B) and engine capacity for positive ignition engines to 50 cc and compression ignition to 500 cc. So far, these segments were served either from 2-stroke engines of 50 cc or diesel engines of 500 cc. These concepts delivered enough power and torque to adequately provide propulsion to these relatively heavy vehicles. Introduction of Euro 5 makes these two engine concepts either financially not viable or even technically impossible to comply with the new standards. This changes the play-level field for these vehicles. A number of possible options therefore appears:

The first option is to allow some further lead time so that new powertrain concepts that could provide both performance and environmental targets are developed. Two such concepts are proposed in the current study, one consisting of a fully-electric powertrain and the other based on a petrol-electric principle. Fully-electric powertrains are already available but the lack of charging infrastructure and battery costs are obstacles in their wider market penetration. Both charging stations increase with time (especially in the 2025 horizon where a rather significant penetration of electric M1 vehicles is scheduled) and the price of batteries drops. On the other hand, petrol-electric concepts are not yet available and some more lead time will be required, if such a concept is to make it to the market. Petrol-electric offer the advantage that no external charge is required and could be more suitable for rural areas. Hence, in this option, additional lead time will be required for viably introducing the two concepts to the market. We modelled the impact of delaying Euro 5 introduction for mini-cars to the 2024/25 (new/all types) time frame and we found significant benefits in monetary terms for the society, despite the delay. Hence, this could be a viable and cost-beneficial option.

The second option would be to retain the Euro 5 approach following the time frame of Regulation (EU) No 168/2013, *i.e.* requiring that Euro 5 is reached at the 2020/21

(new/all types) time frame. In principle, the only powertrain concept that could be market ready by that time frame would be the fully electric one. Due to customer acceptance limitations and battery costs issues, retaining only this concept already by 2020 is considered to lead to significant market shrinkage in this sub-sector. Electric vehicles of this kind are already available today but correspond to less than one fourth of the total market. As several of the industrial players in this sector are SMEs only operating in this rather niche market, such a significant market drop is expected to significantly harm their viability. This could be caused to the benefit of larger industries offering their products in this sub-categories, as these would not be so much harmed by a drop in an already relatively small market segment. Hence, such an option could create unfair competition leading small but dynamic and viable industries out of the market.

The third option would be to relax Euro 5 limits or overall cancel Euro 5 for these vehicle sub-categories and remain with Euro 4. Although this could provide a short-term solution, its medium/long-term viability is questioned. Cities around the EU introduce more extended and stringent environmental zones as they strive to remove most polluting vehicles from their centres, in order to meet their environmental targets. Retaining a limit of 550 mg/km for diesel NOx and 80 mg/km for PM would mean that small diesel mini-cars would emit even higher than current technology Euro VI urban busses under real-world conditions. For those, a TNO study found Euro VI urban bus emissions as low as 210 mg/km (Spreen et al., 2014). Hence, environmental targets, city bans, but also the perception of these vehicles as being ‘dirty’ would inadvertently harm their sales and cannot be considered a viable solution.

The fourth option would be to provide some more margin for petrol engines in terms of capacity, in order that enough power and torque, for satisfactory drivability of the vehicles can be delivered. Industry sources expect that a capacity of 200 cc and 300 cc, respectively, for L2e-U and L6e-B vehicles would provide the necessary performance. This could indeed be a technical solution to reach drivability and emission control targets and, although we have not attempted a detailed modelling, it would also make sense in terms of its cost-benefit ratio. However, extension of petrol engine capacity would create administrative problems in the classification and type-approval of these vehicles, as this is different to UNECE and EU classification regulations. Even if administrative obstacles could be resolved in good time for the introduction of these vehicles, safety concerns arise. The limit of 50 cc, further to power limits, was introduced to make sure that tampering could not lead to significant power increase of these vehicles. Equipping a such small vehicle with a 300 cc engine introduces a big incentive for tampering and power gains. Having in mind that these vehicles are accessible without a driving license from youngsters of 16 years of age, this safety concern needs to be seriously taken into account. Our study did not touch on this issue but a specific study would be highly advised to explore the technical implementation of this approach, before any recommendations can be made.

3.3 Feasibility and cost-benefit ratio of the separate NMHC limit

3.3.1 Background and objectives

The objective of this task is the assessment of the necessity to regulate non-methane hydrocarbons (NMHC) as one of the emission constituents, during type-approval. It

is also examined in comparison to the feasibility of establishing a correlation between measured total hydrocarbons (THC) and NMHC emissions, and establish a limit through a mathematical calculation. Moreover, the overall intention has been to report on typical ranges of THC and CH_4 / NMHC per vehicle type based on the measurements conducted in this study.

Exhaust THC emissions contribute to air pollution and climate change. Some of species are toxic upon inhalation while most of the species contribute to ozone and smog formation. Therefore, THC emission limits are part of the regulations. Methane is also part of THC. Although methane emissions barely contribute to local air pollution and are harmless at inhalation, they do contribute to global warming, since they are a potent greenhouse gas. Following the Paris Climate agreement (COP21) even more strict control and detailed reporting of GHG is mandated. Further to CO_2 which has for long been in focus, black carbon, methane, and nitrous oxide also come to focus and detailed plans are being sought in correctly accounting for their contribution. In this regard, being able to derive separately determine CH_4 levels appears beneficial. On the other hand, NMHC emissions have a negligible climate change contribution and these are mostly ozone forming species, in reaction with NO_x. Hence, splitting THC to CH_4 and NMHC provides serves the need to report on THC emissions contribute to both climate change and air pollution.

It is necessary to reflect on the history of introducing separate NMHC and THC limits and their levels, a decision taken with the introduction of Euro 5/6 passenger car regulatory package. European Commission, on its proposal for a Euro 5/6 light duty vehicle regulation (COM(2005) 683 Final) proposed a decreased by 25% limit on THC compared to Euro 4, *i.e.* a value of 75 mg/km compared to the Euro 4 value of 100 mg/km. This was based on the views of an expert panel (TNO Report 05.OR.VM.032.1/NG) that a THC limit of 75 mg/km was already technically feasible at that time with limited, if any, additional costs to Euro 4 technology. This was based on evidence that the majority of Euro 4 cars were already demonstrating THC levels under type approval that fell even below 75 mg/km. The EC, in its impact assessment to the European Parliament (EP) argued that a further reduction of the limit would infer further costs and hence was deemed as not necessary.

At the same time, when this proposal was put in place, discussions in UNECE GRPE (WP.29) on natural gas vehicles (NGV) were initiated. In terms of emission limits, NGVs were considered cleaner than their petrol and diesel counterparts and several stakeholders were of the opinion that their introduction in the light duty vehicle segment would be beneficial for the environment. However, NGVs of that time were known to emit higher amounts of methane than petrol cars. Therefore, following similar approach in US and in the heavy duty sector, a proposal was made to allow a relaxed THC limit just for NGVs.

The discussion was then taken up at an EP level. In order to accommodate NGVs, the decision was taken to retain the Euro 4 THC limit to 100 mg/km, even for Euro 5 and 6 cars. On the other hand, to promote cleaner vehicles in terms of the ozone forming potential, a new NMHC limit was introduced. The limit value at 68 mg/km was based on the earlier THC proposal of the EC of 75 mg/km reduced by 10% to account for the share of CH_4 of non-NGVs vehicles to THC. Some proposals were made to regulate a separate NMHC limit for NGVs and stick to the THC limit for non-NG ones, but this suggestion was rejected in order to allow a level playing field for both vehicle types.

Based on this analysis, the following observations need to be made:

- The THC limit of 100 mg/km for petrol and diesel cars was of no importance any more, as long as the 68 mg/km NMHC limit was established, as the typical CH_4 / THC was at or below 10%
- The THC limit was retained basically only for NGVs, to make sure that no excessive CH_4 would be emitted by such vehicles.

This short historical review is important to understand the rationale in having separate NMHC and THC limits and assess the relevance of this in the case of L-category vehicles. This is especially true as NGVs are practically not existent in the L-vehicles sector. In this respect, the objective of this study was to assess the necessity of the different approaches in case of the L-category vehicles. For this reason, a cost-benefit analysis was performed for the following two scenarios:

i. Euro 4 and Euro 5 tailpipe emission limits as currently set-out in Regulation (EU) No 168/2013, used as a reference.
ii. Use a fixed NMHC/THC ratio.

3.3.2 Measured results

The experimental measurements conducted in this study allow to study the NMHC/THC of L-category vehicles in Table 25. The results confirm the general levels known from passenger cars, *i.e.* that the ratio of CH_4/THC is below 10% for typical petrol cars.

Table 25. Mean NMHC/THC ratios measured per L-vehicle subcategory

Category	Euro	Cycle	NMHC/THC ratio (range shows min-max values)	NMHC/THC ratio (validation vehicles)
L1e	Euro 1 and Euro 2	WMTC	$0.97^{+0.024}_{-0.033}$	-
		ECE	$0.97^{+0.022}_{-0.036}$	-
L2e	Euro 2	WMTC	0.97^{+0}_{-0}	-
		ECE	0.98^{+0}_{-0}	-
L3e	Euro 3 and Euro 4	WMTC	$0.91^{+0.048}_{-0.062}$	0.92
		ECE	-	-
L5e	Euro 2 and Euro 4	WMTC	0.92^{+0}_{-0}	-
		ECE	0.93^{+0}_{-0}	-
L6e	Euro 2	WMTC	$0.94^{+0.005}_{-0.005}$	-
		ECE	$0.95^{+0.010}_{-0.010}$	-
L7e	Euro 2	WMTC	$0.82^{+0.061}_{-0.061}$	0.83
		ECE	$0.82^{+0.075}_{-0.056}$	0.91

The results also show that the contribution of methane to THC seems to increase with more recent vehicle technologies. The lowest NMHC/THC ratio was observed for L3e vehicles and this has mostly to do with the fact that these were the only vehicles for which Euro 4 technology was available. CH_4 is difficult to oxidize in catalysts or at least most difficult than heavier gaseous HC, hence an increasing CH_4 contribution as THC limits become more stringent is expected.

3.3.3 Environmental benefit

The concept of having a fixed ratio of NMHC/THC should in principle lead to zero environmental impacts, *i.e.* it should be set at a value that would deliver the same emissions control stringency as having separate limits. Hence, the environmental benefit over implementing the separate Euro 5 limits in Regulation (EU) No 168/2013 is zero.

3.3.4 Cost calculation

Cost benefits in the case of fixed ratio originate from a marginal decrease in R&D costs. In principle, if a fixed ratio for NMHC/THC is introduced, then no separate development and verification costs are required at the manufacturer's side. Therefore, we have assumed that costs are saved by refraining from the need of purchasing new Flame Ionization Detectors (FID) analysers for equipping additional test cells (five analysers per manufacturer) as well as by saving 10 equivalent per engine type development. Similar savings are also expected at the type approval side. The relevant cost savings are presented in detail in Appendix E.

3.3.5 Cost-Benefit calculation

Following the same rationale with the CBA for Type I emission limits of paragraph 3.2.4, among the various combinations of the variable parameters being examined, the most feasible-important ones, giving input for the final recommendations, are presented in this paragraph. The central estimate for the NPV is calculated considering the baseline fleet/activity scenario, while the range corresponds to uncertainty in the estimation of costs.

Table 26 shows the cost saving, distinguished for each vehicle category. There is a marginal benefit because of lower cost but not significant for a 20-y horizon.

Table 26. NPV for the Type I separate NMHC limit

Cost-benefit over 2020-2040 (Values in M€)	Scenario: Fixed ratio for CH_4
Mopeds	$0.59^{+0.06}_{-0.06}$
Motorcycles (including ATVs)	$4.78^{+0.45}_{-0.46}$

3.3.6 Recommendations

The fixed ratio for NMHC/THC could potentially be used and appears to offer small societal benefits due to the decreased costs for the manufacturer and for type-approval.

In order to propose a fixed ratio NMHC/THC that would provide the same environmental stringency as the separate limits, one should accurately know the fraction of CH_4 in THC emissions at Euro 5 stage. This is not possible, as no Euro 5

vehicles are available and values for Euro 4 vehicles can be used as a proxy. In principle, the two boundary conditions are defined the following two options:

- OPTION 1: THC_{TA} = 0.068 g/km * (1 + f_{CH4}). In using this option, one makes the assumption that the ratio of CH_4/THC is the same between Euro 4 and Euro 5 vehicles. This would imply that the Euro 5 emission control system will be equally efficient in converting CH_4 and NMHC. In principle, this corresponds to the most stringent option.
- OPTION 2: THC_{TA}= 0.068 g/km + $FIXED_{CH4}$, assuming that CH_4 will not be further reduced from Euro 4 to Euro 5 because of difficulties in the oxidation of CH_4, outlined above. This corresponds to a more relaxed limit.

Based on the limited current Euro 4 measured data, the following ratios and limits would apply. The ratios are close to each other and our assessment would be that the Euro 5 performance would be in between these values, *i.e.* $FIXED_{CH4}$ will be somewhat less and f_{CH4} somewhat higher at Euro 5 compared to Euro 4. Therefore, a value of $THC_{Euro\ 5}$ of 0.078 g/km seems appropriate.

- OPTION 1: f_{CH4} = 0.105 → THC_{TA} = 0.075 g/km
- OPTION 2: $FIXED_{CH4}$ = 0.012 g/km → THC_{TA} = 0.080 g/km

With this approach, the manufacturer may decide to demonstrate vehicle compliance with the separate NMHC and THC limits of Regulation (EU) No 168/2013, or compliance just with the alternative $THC_{Euro\ 5}$ limit. As earlier explained, the two approaches are environmentally equivalent, with limited cost benefits of the alternative approach.

The alternative approach should not apply to natural gas vehicles, for which separate THC and NMHC limits should be mandatory. Assuming equivalencies between different technologies and emission control systems of natural gas powertrains is not possible and any potential NG L-category vehicles should demonstrate compliance with both limits.

The main disadvantage of the alternative approach is that it cannot be used to provide separate HC emission levels for air quality relevant pollutants (NMHC) and GHG contributions (CH_4). Following requirements of the COP21 Paris Agreement, more detailed reporting of GHG is required. Because of this deficit, the limitations of the method to non-NG vehicles only, and the overall marginal cost benefits achieved, suggest that retaining the original approach of separate limits proposed in Regulation (EU) No 168/2013 would be highly advisable.

3.4 Impact of EtOH on Type I test emission levels

3.4.1 Background and objectives

The objective of this task was to investigate the impact of ethanol content in the reference fuel on the test Type I tailpipe emission results.

The use of biofuels is a measure towards the Greenhouse Gas (GHG) emissions reduction. A pathway to do so is to have substantial admixtures of biofuels added to the base market fuels. The reference fuel for type approval testing is E5 (Regulation

(EU) No 134/2014), i.e. petrol with 5% (4.7%-5.3% - EN 1601 / EN 13132) vol. of ethanol blend. In practice, the ethanol content in the market available fuel may vary per country.

Hence, additionally to the reference fuel, E0 and E10 fuels were used to examine the impact of ethanol blend on Type I emission levels of selected vehicles. The revised WMTC (WMTC Stage 3) was applied in each case.

3.4.2 Test results and discussion

The vehicles tested with alternative ethanol blends were following, following the specifications of the terms of reference of the study contract:

- L1e-B, high speed: 2 vehicles at Euro 2 level
- L3e-A2: 3 vehicles (2 vehicles Euro 4 and one vehicle Euro 3)
- L3e-A3: 1 vehicle, Euro 4

The main objective of the task was to study the relative impact of E0 and E10 blends on emissions levels, relative to E5. In parallel, an assessment was made on engine operation parameters, including:

- Drivability of the “revised” WMTC
- Engine map coverage of the different driving cycles
- Second-by-second emission, fuel consumption and lambda sensor data
- Engine speed and engine load related parameters
- PM / PN emissions levels

The detailed results are presented in Appendix G.

3.4.3 Results and conclusions

Figure 26 and Figure 27 show the impact of EtOH (ethanol) on the average emission level of two high speed mopeds (J03 and J12) and of four medium and high performance motorcycles (J11 (L3e-A2), J13 (L3e-A2), J15 (L3e-A2), J18 (L3e-A3)), respectively. Emissions are shown as percentage differences over the levels measured with E5. In general, average differences per pollutant range within ±18%, with two exceptions, one for E10 CO Mopeds (-24%) and one for CH_4 for motorcycles (47-59%). The following general trends can be observed:

- There is no clear trend on the impact of EtOH content on emissions, neither for Euro 2 mopeds, nor for Euro 3-4 motorcycles. Emission levels of all pollutants may either increase or decrease when ethanol content increases.
- There are no specific trade-offs established between pollutants. Shifting from E5 to E0 increases CO but decreases NO_x and NMHC for mopeds. In the case of motorcycles, shifting from E5 to E0 increases all pollutants but shifting from E5 to E10 also increases NO_x. No specific pattern can be identified.
- The whiskers, corresponding to the minimum and maximum values (range) of relative difference over E5 for individual vehicles, are much larger than the average. This points towards three conclusions. First, the impact of ethanol blend on emissions is vehicle specific and it depends on how each vehicle is specifically calibrated. Both positive and negative differences are observed for each pollutant and the same fuel change. Second, for a substantial size of test vehicles, average emission differences should be marginal or even

non-existent. Third, vehicle calibration may be tuned to comply with a given emission limit, regardless of the reference fuel used.

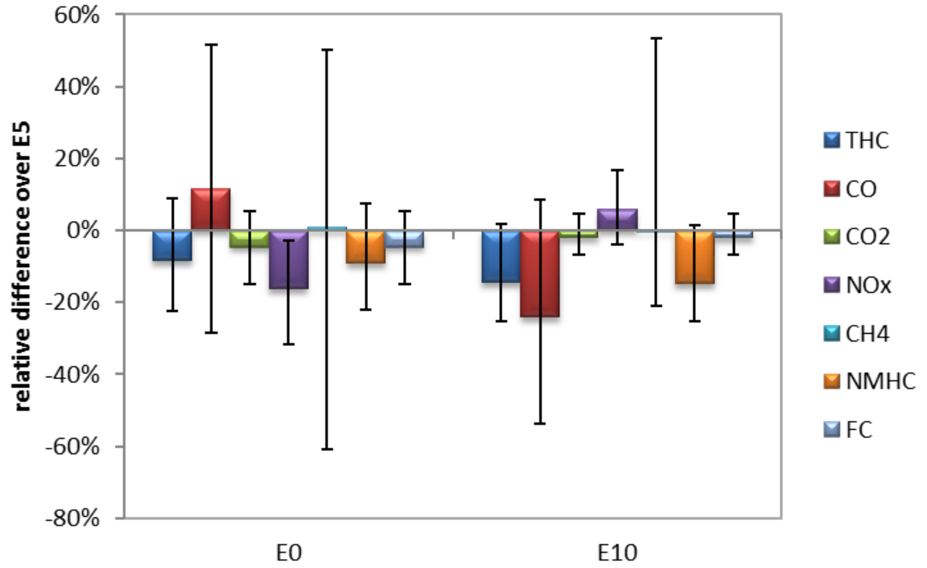


Figure 26: Relative impacts of EtOH blends (E0, E10) on gaseous pollutant emissions of two high-speed mopeds, over E5 reference fuel.

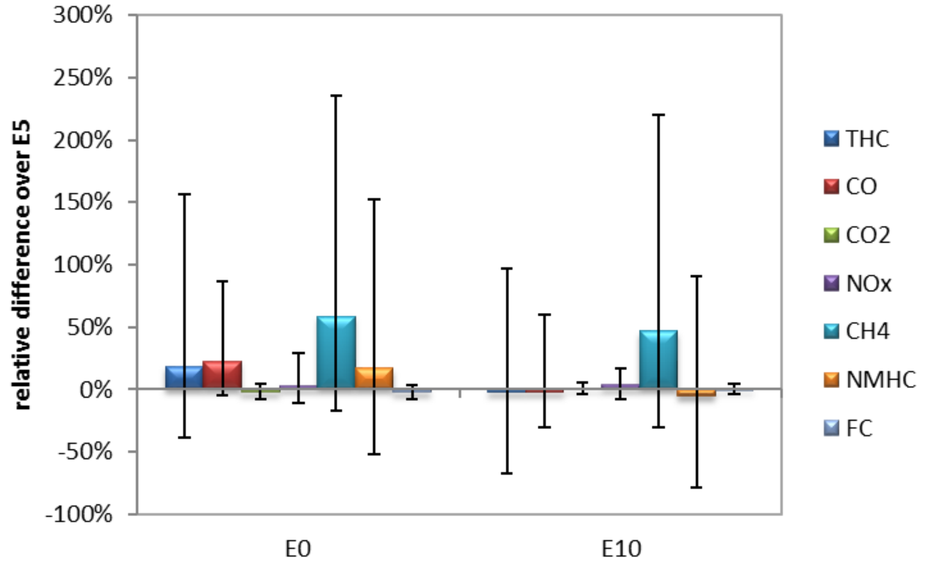


Figure 27: Relative impacts of EtOH blends (E0, E10) on gaseous pollutant emissions of four medium and high performance motorcycles, over E5 reference fuel.

With regard to the other performance criteria, the relative impact of ethanol blending ratio was also minimal:

- For one of the mopeds, E10 resulted in a marginal reduction of the mean positive acceleration and the total distance travelled. E10 has a lower energy content so the total power may indeed drop if the volumetric fuel flow is not properly adjusted.

- No consistent impact to engine map coverage could be seen for different fuels

Based on this analysis, the following conclusions can be drawn:

i. Based on technologies ranging from Euro 2 to Euro 4 and including both motorcycles and mopeds, no consistent impact of EtOH blend ratio on emissions of any pollutant can be seen.

ii. Emission impacts are vehicle specific so same emission levels can be reached by properly tuning the vehicle, once the EtOH blend of the reference fuel is known.

iii. We do not see reasons why relative emissions impacts of different fuel EtOH blends would be different than the ones measured in this study, at a Euro 5 level.

Fuel flow rate will have to be adjusted to meet the same power demands as fuel energy content drops with increasing ethanol content of the fuel.

3.5 Conclusions and recommendations

<u>Suitability of revised WMTC for emissions testing</u>

Based on the tests executed and the analysis of the results, the revised WMTC:

- was executed with no violations by all L-vehicle types tested, allowing for the flexibility in speed pattern deviations prescribed in Regulation (EU) No 134/2014, Annex II;
- it offered extended coverage of the engine operation range in all sub-categories, compared to the corresponding ECE cycles it substitutes. This means that revised WMTC offers more confidence for effective emission control over real-world operation as well.

On the basis of these conclusions, the revised WMTC appears suitable to be used as a Type I test and is expected to provide enhanced environmental protection over real-world operation, than the driving cycles it substitutes.

The study also allowed to make specific observations for particular vehicle types:

- The speed of vehicles falling into categories L1e-A, L2e and a vehicle falling under L5e-A, but with a powertrain representative of L5e-B vehicles, exhibited deviations from the revised WMTC demanded speed pattern, both in terms of demanded acceleration and maximum speed. Future revision of the driving cycle would allow for improved test execution and reproducibility for emissions (Type I) and energy efficiency (Type VII) testing.
- Measurement campaigns will be required to assess the representativity of the revised WMTC for specific vehicle sub-categories, to collect operation patterns of such vehicles.

<u>Appropriateness of the Euro 5 limits</u>

Euro 5 for mopeds (L1e-B, L2e, L6e-A) and motorcycles (L3e, L4e, L5e-A, L7e-A) is technically feasible to be implemented within the 2020/21 (new/all types) time horizon. The emission control technology required by to comply with the new limits will have to be significantly improved over Euro 4, especially for mopeds, but such improvements only require incremental technical advancements rather than new breakthroughs.

Despite technology cost increases, large environmental benefits lead to an overall significant net benefit in monetary terms, which may collectively exceed 330 M€, over the period considered. Moreover, mopeds and motorcycles at Euro 5 step will be amongst the cleanest conventional vehicles on the road, under urban conditions. This eliminates the risk of any city-specific measures that could potentially limit the accessibility of such vehicles to city centres.

ATVs and side-by-side vehicles (L7e-B) will follow technology improvements shared by motorcycles, with which they share powertrain technology. Marginally higher costs are expected for L7e-B vehicles compared to L3e because of the different calibration of these vehicles over WMTC.

Different weighting factors for the cold/hot part of WMTC for mopeds (L1e, L2e, L6e) and motorcycles (L3e, L4e, L5e-A, L7e-A) with speed less than 130 km/h are introduced with Euro 5 (50/50) over Euro 4 (30/70). This means that more weighting is given to the cold start part with Euro 5, thus increasing environmental benefits but also implementation costs for compliance. Overall net benefits were estimated for both sets of weighting factors, with the relative differences in the two scenarios being within the range of calculation uncertainty.

A detailed analysis for the mini-cars sub-categories (L6e-B, L7e-C) was conducted. In particular L6e-B vehicles are currently powered by small diesel engines or electric powertrains. Positive ignition engines do not provide enough power for this sub-category due to engine capacity limits (50 cc) compared to the relatively high vehicle mass. Euro 5 limits introduce a significant challenge for such diesel engines. It is not clear whether available emission control technology can deliver the necessary NOx and PM reductions for such small engines. Even if this would be proven feasible, this would come at a very significant cost that the CBA showed to exceed environmental benefits. The following scenarios were therefore examined as possible options:

- Retaining the original time frame for Euro 5 introduction (2020/21 – new/all types). Our estimate is that this will only be achieved by electric vehicles. Offering a single powertrain option may initially reduce the market of such vehicles, especially as the consumers acceptance of the available electric vehicles in this sub-category is still rather low. A strong market distortion may prove detrimental for the specific industry, which is largely based on SMEs. Furthermore, if diesels would be retained, this option would lead to negative overall costs (damage) to the society.
- The second option would be to provide some more lead time, *i.e.* one model year and introduce Euro 5 at the 2024/2025 time frame. This is expected to provide some margin for the possible introduction of alternative powertrains (*e.g.* petrol-electric), continue with the development of charging infrastructure in cities, and benefit from the expected drop in automotive battery costs due to increasing global production. The CBA estimated net benefits in the order of 450 M€, due to decreased technology costs and significant environmental performance when introducing electric vehicles. This means that marginal environmental impacts caused by the delay in introducing Euro 5 for these vehicles are totally counterbalanced by the introduction of clean vehicles in the post 2024 period.
- The third option would be to remove the need for a Euro 5 step for these vehicles and remain with Euro 4 even beyond 2024. Our assessment is that this will not be a viable option in the long term as diesel mini-cars will constitute the highest-emitting on road vehicle type in the market with evident consequences in their accessibility in city environmental zones.
- Finally, the fourth option would be to increase the engine capacity of positive ignition engines for L6e-B vehicles to a value that would be enough to guarantee sufficient vehicle drivability. Although this is expected to fulfil the environmental targets of Euro 5, vehicle classification and safety issues,

following potential engine tampering, need to be considered. The assessment of those goes beyond the objectives of our study.

Feasibility and cost-benefit ratio of the separate NMHC limit
Compliance with a separate non-methane hydrocarbons (NMHC), in parallel to the THC one, is required at a Euro 5 step for all L-category vehicles. Due to the rather small contribution of methane in THC emissions from petrol and diesel powertrains, an equivalent THC could be defined so that vehicles complying with this, would not have to demonstrate compliance with NMHC as well. Our study estimated that the equivalent THC would be at 0.078 g/km. This would have no environmental impact over the separate NMHC and THC limits and small savings would be gained by reducing emissions analysers investments from manufacturers. However, the recommendation is made that separate THC and NMHC limits are retained, as these are still required for any natural gas L-category vehicles as well as because they offer the possibility to separate report air pollutants and greenhouse gases emissions levels.

Ethanol content in fuel
No consistent effect of the EtOH blending ratio, from 0-10% vol. in the fuel, could be identified in terms of impacts on emissions levels. Vehicles can be tuned to perform the same, both in terms of power and emissions performance, once the blending ratio of the reference fuel is known. Although these results have been obtained in vehicles ranging from Euro 2 to Euro 4 emission standards, we see no technical reason why these should not be applicable on a Euro 5 level as well. Our measurements indicate that Euro 5 limits could be also achieved with the same technical approach in regions where different fuels than E5 are used for type approval.

4 Type II – Tailpipe emissions at (increased) idle and free acceleration

4.1 Background and objectives

Regulation (EU) No 134/2014 introduces a revised procedure to check tailpipe emissions at (increased) idle and free acceleration in order to align type-approval requirements with other vehicle types and be coherent with the requirements set out in the latest legislation on road worthiness testing (Directive 2009/40/EC). The appropriateness and smooth implementation of the procedure have to be confirmed by means of limited tests on representative test vehicles.

The objective of this task was to validate the applicable test procedure as set out in Annex III to Regulation (EU) No 134/2014, in order to examine whether revisions of the test procedure need to be proposed.

4.2 Test procedure followed

The testing procedure of the Type II test is presented in Appendix H. The pollutants examined included CO, HC and NOx. The latter is not included in the specifications of Regulation (EU) No 134/2014, neither is included in any roadworthiness testing that we are aware of in EU. However, it is reported here for completeness.

The test procedure was followed in two rounds. In round one, practically all vehicles that took part in the assessment of Test type I were also assessed in Type II test, using laboratory analysers. In round two, four vehicles which were used for validation of the conclusions of the study were tested using a four gas analyser (detail in section 2.3.4), following the exact specifications of Regulation (EU) No 134/2014.

The validation of the Type II test have been performed on 4 vehicles, from which the test on the L7e-B1 validation vehicle has been performed using the JRC equipment, while the tests on the validation mopeds and motorcycle have been performed using the 4-gas analysers. The list of vehicles tested, the conditions and the results of the tests are shown in Appendix I.

Assessing the results is beyond the scope of the study. However, one should monitor the occasional high emissions of NO_x at low and high idle, even for latest technology petrol vehicles.

4.3 Conclusions and recommendations to improve the test procedure

The evaluation of the Type II test and the test procedure lead to the following conclusions:

- The description for setting the different engine rotation speeds during the test, as described in the procedure in Annex III, Regulation (EU) No 134/2014 can be easily misinterpreted by test engineers who do not have large experience with reading test procedures in the type approval legislation. For the study an unofficial working procedure (Appendix **H**) was developed to guide the

engineers during execution of the tests. It is recommended to simplify and improve the wording of the procedure in the Regulation.

- As a general observation, this study would recommend inclusion of NO_x emissions recording in the Type II test for diesel and gasoline vehicles as well. NO_x is important from an environmental perspective and portable NO_x analysers are today cost-effective. Developing a reference list of NO_x levels during Type II type approval testing could potentially very much increase the roadworthiness test impact, if a decision is later taken to include NO_x for identifying high emitters.

Chapter 4 of Annex III could be improved as follows:

- ‘*Normal idling speed*’ can be put between quotation marks in the text
- In 4.2.2 replace ‘*high idle*’ with ‘*high idling speed*’
- In 4.2.2 add a sentence ‘*The definition of possible positions of the adjustment components to adjust ‘normal idling speed’ is defined under point 4.2.5*’
- In 4.2.2 add a finishing sentence ‘*The ‘high idling speed’ is reached and kept stable by manually operating the throttle pedal or throttle handle*’
- In 4.2.5 change the wording to ‘*The possible positions of the adjustment components to adjust the ‘normal idling speed’ shall be limited by any of the following*’
- Add numbering in 4.2.5.1 like in 4.2.5.2:
- ‘*the larger of the following values:*
  (a) the lowest idling speed which the engine can reach;
  (b) the speed recommended by the manufacturer, minus 100 revolutions per minute‘

5 Type III – Emissions of crankcase gases

5.1 Background and objectives

The Regulation (EU) No 168/2013 supplemented by Regulation (EU) No 134/2014 introduces a test procedure to verify that engines of vehicles with a 4-stroke engine are so constructed as to prevent any fuel, lubrication oil or crankcase gases from directly escaping to the atmosphere from the engine (crankcase gas ventilation system), without being combusted.

Crankcase gases are mainly caused by:

i. Blow-by exhaust gas and non-evaporated fuel from the combustion chamber(s) to the crankcase via piston rings and valve seals; and
ii. Oil vapours at hot engine operation;

The crankcase is pressurized by blow-by gases and oil vapours. If the pressure is not released and vapours inside the crankcase are not ventilated, emissions (and oil) might escape through the engine seals and gaskets. A crankcase ventilation system is applied to ventilate the crankcase gases and vapours to the combustion chamber, so that the gases and vapours are burned during combustion.

In order to do demonstrate that crankcase ventilation system is working properly, the manufacturer shall provide technical details and drawings as proof to the Type Approval Authority (TAA). In addition, Regulation (EU) No 168/2013 introduces physical test procedures to check if fuel, lubrication oil or crankcase gases do escape to the atmosphere, on top of the evidence based requirements described above. In annex IV of Regulation (EU) No 134/2014 the Type III test procedure is described.

This so-called Type III test is only to be executed on request of the TAA or technical service in the following cases:

- for new vehicle types with regard to environmental performance equipped with a new design of the crankcase gas ventilation system; or
- if the TAA or technical service have doubts whether any fuel, lubrication oil or crankcase gases escape to the atmosphere.

In all other cases, the vehicle will go through the approval process without the Type III test being performed, and the manufacturer can suffice by providing the test report of the Type III test that has been executed on the so-called “parent vehicle” with the same type of crankcase ventilation system. With this current design of the test procedure, the manufacturers are offered a cost-efficient procedure.

Should the Type III test be required, the procedure as described below and summarized in Figure 28 shall be followed:

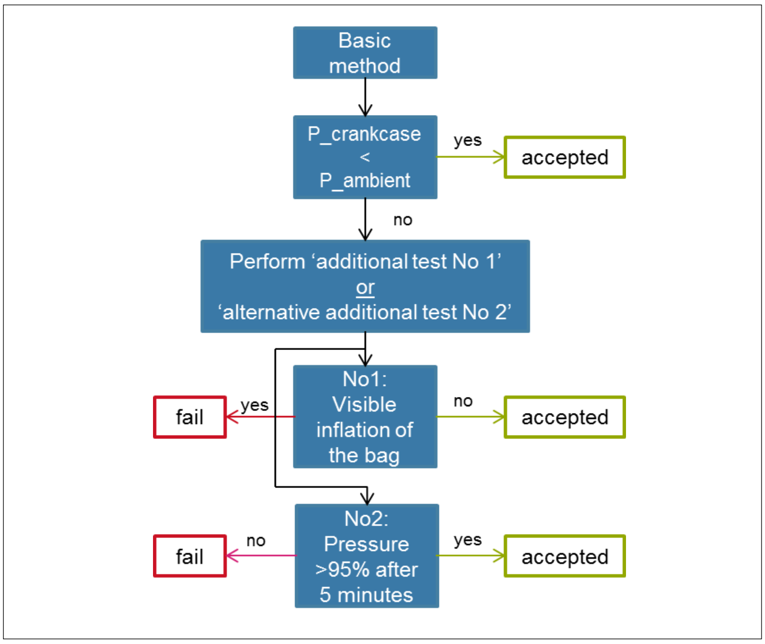


Figure 28. Summary of the Type III test procedure. Fail means the that the vehicles fails the Type III test, accepted means the vehicle passes the Type III test

Basic method: This test method, referred to in this chapter as the *basic test*, is mandatory and shall always be performed in case Type III testing is required. The crankcase ventilation system is tested by measuring the pressure in the crankcase, while driving three load-points during chassis dynamometer testing:

- Condition 1: Idle
- Condition 2: 50 km/h or 50% of max vehicle speed
- Condition 2: Load of condition 2 multiplied with 1.7

The vehicle passes the test when the pressure measured in the crankcase does not exceed the atmospheric pressure in each condition of the test. Important condition during the test is that the apertures of the engine shall be "left as found".

If the basic method is not passed 'additional test method No 1' or 'alternative additional test method No 2' shall be performed, as chosen by the manufacturer.

Additional test method No 1: A 5 litre plastic bag is connected to the crankcase by connecting it – preferably - to the dipstick hole. The vehicle again drives the load-points equal to those of the basic procedure. The vehicle passes the test if no visible inflation of the bag occurs in every condition of measurement. Important condition during the test is that the apertures of the engine shall be "left as found".

Alternative additional test method No 2: A leak check of the engine is performed with compressed air. The crankcase is pressurised to the maximum recorded peak pressure as observed during the basic test. The pressure should at least be 5 kPa over ambient pressure. For this test, intake and exhaust manifolds may be removed and hermetically sealed, the crankcase ventilation system will remain intact. The vehicle passes the test if the crankcase pressure remains at > 95% of the initial pressure after 5 minutes.

The objective of this study is to verify the Type III test procedure with measurements and to make recommendations to improve the procedure if necessary.

5.2 Test approach and results

In order to verify the different test methods, the contractor selected seven vehicles for Type III measurements. Out of the seven tested vehicles one vehicle has a diesel engine, the other vehicles were gasoline fuelled vehicles. The test results are summarized in Table 27.

Table 27: status Type III testing

Vehicle class	Vehicle ID	Fuel type	Basic test method	Additional test method No 1	Alternative additional test method No 2*
L1e-B	J03	Gasoline	Fail	Pass	Fail
L1e-B	J17	Gasoline	Fail	Pass	Pass
L3e-A1	J19	Gasoline	Fail	Pass	Pass
L3e-A2	J15	Gasoline	Fail	Pass	Fail
L3e-A3	J18	Gasoline	Fail	Fail	Not performed
L6e-B	J22	Diesel	Pass	Pass	Not valid
L7e-B1	J08	Gasoline	Pass	Pass	Fail

* The engine plugging is performed without manufacturer assistance and while the engine is mounted in the vehicle. Hence, there is a risk that not all openings of the engine are detected and properly sealed. During an official type approval, the engine of a vehicle may be placed on a test rig. By doing so, possible leakages can be detected and sealed in a better way.

The crankcase pressure is measured at the oil dipstick connection. During the basic test also the manifold absolute pressure (MAP) was measured as prescribed in the regulation – except for the tests with the diesel vehicle.

The reason to measure MAP is to assess whether an under pressure within the inlet manifold is maintained or not. This indicates – when there is a connection between the crankcase and the inlet manifold – if the crankcase gas emissions should be able to flow back into the combustion chambers of the engine or not. However, there is no requirement set for MAP and many L-category vehicles do not have this connection with the inlet manifold to create an under pressure but have connection to inlet air filter instead. For the latter case it does not make sense to measure MAP. Nevertheless, if possible, MAP was also measured.

Two basic tests were performed; one test with the crankcase and ambient pressure measured and another test where crankcase pressure and MAP was measured.

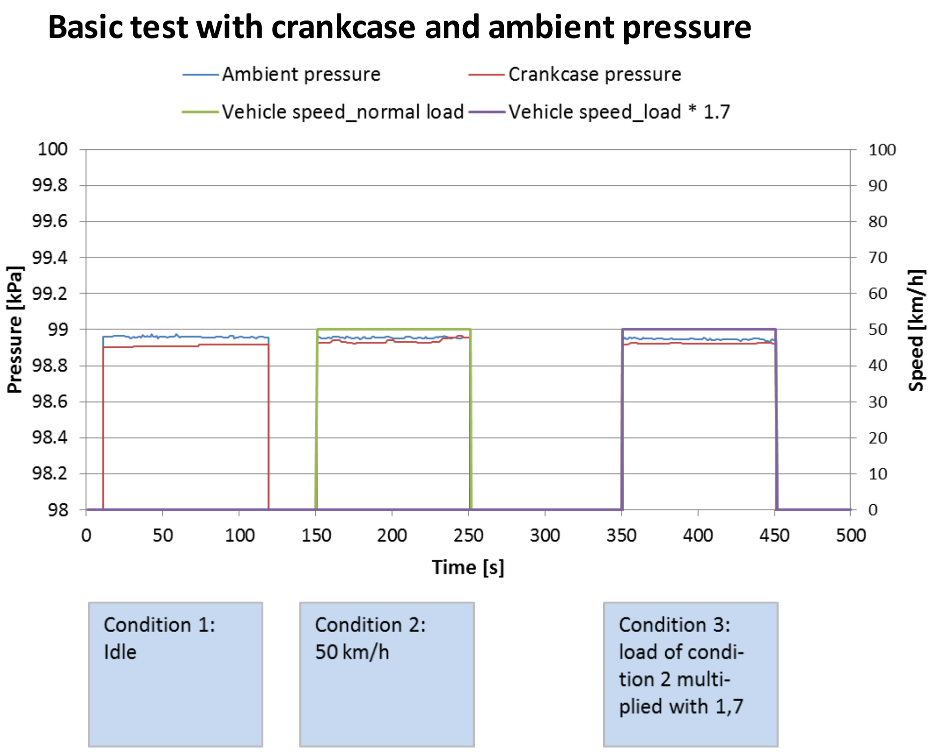
The tests have been performed at the VELA 1 laboratory of DG JRC under guidance of the contractor. The procedure description in Regulation (EU) No 134/2014 is legislative text and can easily be misinterpreted by test engineers that perform the tests and do not have broad experience with reading test procedures in the type approval legislation. Therefore, a working instruction was created to guide the engineers during preparation of the test vehicles and during execution of the test. This document is attached to this report under Appendix J for reference.

Detailed test results, vehicle specifications and pressure sensor specifications are shown by means of a 'factsheet' per individual test vehicle in Appendix K.

5.3 Assessment of test procedure

Issues related to basic test method

As shown in Table 27 only vehicle J22 (with diesel engine) and vehicle J08 passed the basic test. For vehicle J22, the differences between the crankcase and ambient pressure during the test was very small. In general, the same applies to the other tested vehicles which did not passed the test. In most cases the difference was not larger than 0.1 kPa (which is the same as the prescribed measurement accuracy), as illustrated in Figure 29. The crankcase pressure difference between the three required measurement conditions generally also did not exceed 0.1 kPa. Unlike the crankcase pressure, the MAP did vary between the three measurement conditions. Moreover, throughout the complete test the MAP shows an under pressure. This indicates that the tested vehicles do not have a connection between the crankcase and inlet manifold. Hence, it is very difficult to pass this test for these vehicles because there is barely any under pressure available. However, vehicle J08 was an exception amongst the measured vehicles. This vehicle passed the basic test with a substantial difference between the crankcase and ambient pressure throughout the test. During idling the pressure difference was around 3 kPa. During the other two test conditions the pressure difference was approximately 6 kPa.



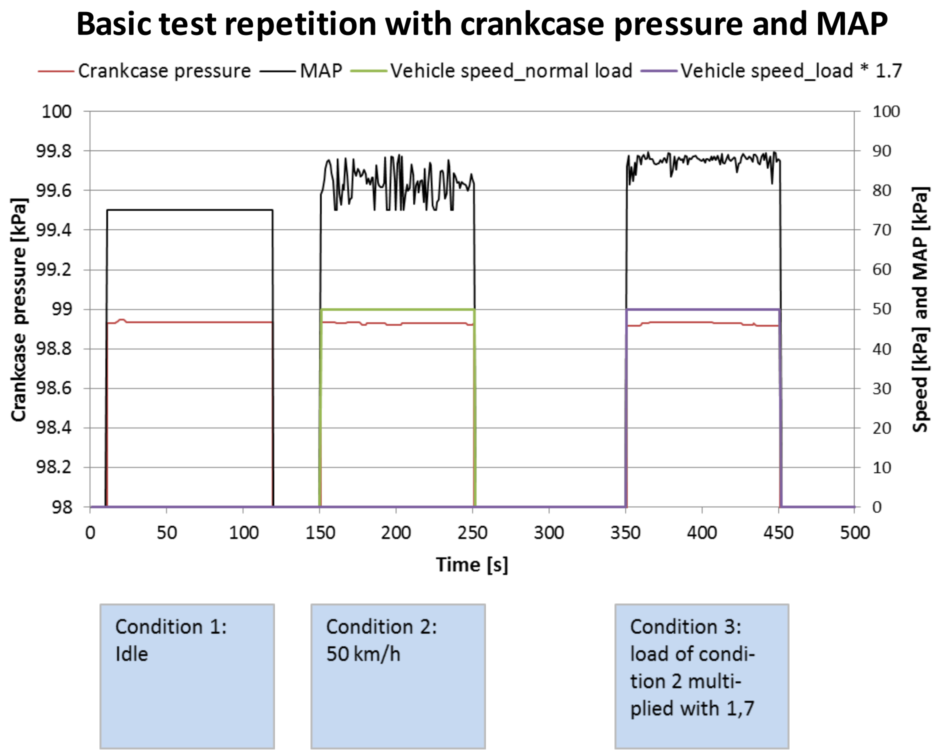


Figure 29. Type III test result of the basic test with vehicle J15. The results of this vehicle illustrate the trend for all test results. All test results are found in Appendix K

In some cases – mostly during idling – the pressure sensors show some noise. Possibly this is the result of pulsations. Pulsations are caused by the up and down movement of the piston. With the downward movement, a small overpressure, including some blow-by, is introduced and vice versa. If the crankcase has a small volume – which is specifically the case for a large part of L-category vehicles – these movements can cause measurable pulsations, certainly for engines that have an odd number of cylinders. Depending on the specifications and settings of the pressure sensors these pulsations are (partly) measured. Especially at low engine speeds – such as idle – the pressure sensors can pick up the relatively low pulsation frequency as noise. This makes it hard to pass the test, since the instantaneous crankcase pressure should always be lower than the ambient pressure.

Issues related to additional test method No 1

The regulation prescribes to perform this test with a sample bag of 5 litres connected to the crankcase. Basically, the crankcase volume is expanded with volume of the sample bag. The crankcase volume enables buffering of the pumping effect of the engine, certainly for engines with an odd number of cylinders. Expanding the crankcase volume with the sample bag expands this buffering capacity. The 5 litre criteria is identical to demand for passenger cars (Regulation (EU) No 692/2008).

However, where passenger cars usually have an engine displacement of approximately 1,6 litres and up to even 8,0 litres, L-category vehicle engine displacements vary roughly between 0,025 and 1,6 litres. The large majority of L-category vehicles have an engine displacement which is lower than 1,0 litre. Certainly for the engines with much smaller engine displacement, a sample bag of 5 litres is too large, because it increases the buffering capacity of the crankcase too much. For

example the pumping capacity of a 0,050 litres engine with 1 cylinder is 0,050 litres. Application of a 5 litres bag would increase the buffering capacity of the crankcase with a factor 100 of the pumping capacity.

In order to account for the sensitivity of the test result for the size of the sample bag, during one measurement a sample bag of 5 litres was used, for the other six measurements a 1 litre sample bag was used.

Six of the seven tested vehicles were compliant with the Additional test method No 1. Only vehicle J18 did not pass the test. This vehicle also clearly failed the basic test. It should be mentioned, that this vehicle has an engine displacement of almost 1.2 litres. Hence, the applied 1 litre sample bag was maybe too small and the vehicle might have passed the test when a larger sample bag would have been applied. However, other vehicles with a large engine displacement, for example vehicle J15, with an engine displacement of 0.69 litres, were tested with a 1 litre bag and were still compliant. This specific test vehicle (J15) almost passed the basic test. Since this test is based on the same principles as the basic test, one would expect this vehicle to pass this test, the same applies for vehicle J22 which passes the basic test.

Based on the basic test one would expect some inflation of the sample bag for the mopeds (category L1e-B). However, no inflation of the bag was noticed, even though the (smaller) 1 litre sample bag was applied – which is still large for an engine with a displacement of 0,05 litres. Most likely pulsations are buffered by the plastic bag, as the plastic bag virtually increases the crankcase volume.

Issues related to alternative additional test method No 2

Six vehicles were tested with alternative additional test method No 2. Only two vehicles passed this test. All tests were conducted without assistance of the manufacturer. It is recommended to perform the engine plugging with assistance of the manufacturer. Otherwise, there is a risk that not all openings of the engine are detected and/or properly sealed. During an official type approval, the engine of a vehicle may be placed on a test rig. By doing so, possible leakage can also be detected and sealed in a better way.

5.4 Discussion

Basic test and additional test method No 1:

The basic test and additional test method No1 are meant to check if the crankcase ventilation system works properly, though it does not check if the crankcase is gas leak-tight.

Basic test

Many L-category vehicles do not pass the basic test despite the fact that the crankcase ventilation system is working properly. Small pressure differences between crankcase and ambient air pressure in combination with the effect of pulsations – due to a small crankcase volume typical for many L-category vehicle engines – are the root cause for this. The pulsations cause the instantaneous pressure to go above ambient pressure for very short moments, while on average the crankcase pressure lies below ambient air pressure.

Short exceedances of the ambient air pressure could be acceptable, if the crankcase pressure on average lies below ambient pressure. These short exceedances could be allowed by changing the data assessment to a method that assesses the test result on average crankcase pressures over each condition. Alternatively, a moving average can be introduced to filter pressure peaks caused by pulsations. These kind of data assessments would make the test more comparable with Additional test method No 1, which is more often passed.

Moreover, the differences in pressure between ambient and crankcase are difficult to measure accurately with such small differences. In some cases, a 0.1 kPa accuracy does not suffice. When pressure differences are smaller than 0.1 kPa, a delta P sensor would be more accurate than a separate measurement of both the ambient and crankcase pressure.

Additional test method No 1
According to interviews with the TAAs for L-category vehicles, additional test method No 1 is not often applied. In case the test vehicle fails the basic test method, manufacturers often choose to apply alternative additional test method No 2.

One issue with additional test method No 1 is found in the allowed sample bag size. The fixed ‘5 litre sample bag’ used in the additional test method No1 is not suitable for most L-category vehicles. This sample bag size is directly copied from the passenger car regulation (Regulation (EU) No 692/2008). In general, the crankcase volume is virtually heavily increased by connecting the sample bag, especially for light motorcycles and mopeds, which makes it easier to be compliant with this test. Instead of fixed sample bag size, one may consider to adjust the sample bag size to the engine displacement.

For the case of passenger cars, the sample bag size is 5 litres, with an average engine displacement of 1,6 litres. This means that on average the bag size is less than a factor 3 larger than the engine displacement. Also larger engines with a displacement of for example 6 litres or 8 litres are tested with the bag size of 5 litres. Then the bag size is smaller than a factor 1 of the engine displacement. Based on these facts and the experimental experiences that were gained during execution of the tests, the proposal is to introduce a bag size requirement that is no larger than factor 3 of the engine displacement. This means that for example a moped with an engine displacement of 49cc (0.049 litres) shall be tested with a sample bag size which is smaller than 147cc (0.147 litres).

Another issue is that from the test procedure it is not clear if there is no inflation allowed at the end of each measurement condition (5 minutes) or that no visible inflation is allowed at all. Free interpretation is possible based on the current description in the test procedure.

Both tests
High loads and dynamic conditions are not part of both the testing methods. However, especially for vehicles with a connection between the crankcase and inlet manifold, these are the most critical conditions.

Assessment alternative additional test method No 2:
The alternative additional test method No 2 checks if crankcase is gas leak-tight but it does not check if the crankcase ventilation system works properly. A possible high

crankcase pressure which occurs at full load or dynamic conditions is not simulated (if higher than 5 kPa).

No other issues with this method are observed.

General

The basic test and additional test method No 1 are equivalent tests meant to check if the crankcase ventilation system works properly, though it does not check if the crankcase is gas leak-tight. The alternative additional test method No 2 checks if crankcase is gas leak-tight but it does not check if the crankcase ventilation system works properly. The vehicle passes the Type III test procedure if only one of the above items is demonstrated during a test.

One could consider to make the basic and additional test method No 1 as the two alternatives to choose from and to keep alternative additional test method No 2 as a complementary test. Test No 2 shall then be mandatory and to be passed in case the vehicle failed during the basic test or the additional test method No 1. In this way, it is checked whether the engine is leak tight and thus secured that no venting of crankcase gases occurs when the crankcase pressure (occasionally or constantly) lies above the ambient pressure. In other cases, additional test method No 2 can be requested by the TAA or technical service. This can be requested when they have doubts whether any fuel, lubrication oil or crankcase gases escape to the atmosphere although the vehicle pass either the basic test or additional test method No 1.

Alternatively, one could consider to make the basic and additional test method No 1 as the two alternatives to choose from and to introduce alternative additional test method No 2 as a mandatory complementary test. In this way, the test procedure always secures that both the working of the crankcase ventilation system and the tightness of the engine are assessed. However, then the procedure would leave no room for vehicles that fail the basic test or additional test method No 1, which is allowed in the current procedure and which vehicles do not necessarily vent crankcase emissions to the atmosphere. For those vehicles, a new crankcase ventilation system, with a Positive Crankcase Ventilation (PCV) valve, might be needed to meet such requirements. This technology makes use of the vacuum in the manifold to create a low pressure in the crankcase. The environmental benefit of making the requirements more strict like this, can be doubted. Because, when the TA is properly performed as described in the previous paragraph, venting of crankcase gases is also prevented by the procedure.

According to Regulation (EU) No 134/2014, Type III testing is currently only performed for '*new vehicle types with regard to environmental performance equipped with a new design of the crankcase gas ventilation system*'. Hence, the application of one crankcase ventilation system on different engine types and models is only tested once. This can lead to scientifically undesirable situations, because – in theory – only one crankcase ventilation system in combination with one engine needs to be compliant to the test. However, a certain crankcase ventilation system installed on a different engine does not have the same effectiveness by definition. For instance, engine size and lay-out can have a large effect on the effectiveness of the crankcase ventilation system.

During the 72nd Working Party on Pollution and Energy (GRPE) of 12-15 January 2016, the Informal Working Group on Environmental and Propulsion Performance

Requirements (EPPR) presented their proposal (Informal Working Group on Environmental and Propulsion Performance Requirements (IWG EPPR), 2016) for Technical Report on the development of global technical regulation for test Type III (crankcase emissions) and test Type IV evaporative emission. The proposal states that *"For Test Type III crankcase emissions: a written declaration from the vehicle manufacturer that the propulsion unit is equipped with a closed crankcase system preventing crankcase gas to be discharged directly into the atmosphere as a first step. The EPPR IWG decided that the physical crankcase emission test(s) which a Contracting Party may require to validate the declaration under certain conditions to be defined will be developed together and when agreed this UN GTR will be amended accordingly."* A combination of the current methods of Regulation (EU) No 134/2014 have the potential to demonstrate that no crankcase emissions are escaping to the environment, when minor revisions in the procedure, like for example adaptation of the bag size volume for alternative test method No 1, are made.

However, the methods, even after revision, do not secure that crankcase emissions are not escaping to the environment in the useful life of the vehicle. Crankcase emissions might increase over the vehicle life time due to wear of the piston rings and possible clogging of the ventilation system. Ideally crankcase requirement is incorporated in the durability requirements and in possible future In-Service-Conformity requirements.

High or full engine load and dynamic conditions are not part of the current testing methods of Regulation (EU) No 134/2014. For the current crankcase ventilation technology for L-category vehicles, which often does not involve a connection between crankcase and manifold, but a connection between crankcase and inlet air filter, there is no direct need for the inclusion of requirements at high load conditions. This is confirmed by the measurement data. In the future, a PCV valve might be applied more often. As described before, this technology makes use of the vacuum in the Manifold, which decreases at increasing load. Hence, the crankcase ventilation system might become less effective at high load conditions. Therefore, from a technical perspective, one could consider the introduction of measurements at high engine load. Though, one should consider that this has implications for the test facilities, because many facilities are not able to drive a high-speed motorcycle for a duration of 5 minutes on the chassis dynamometer. One should also consider that for passenger cars such a requirement does not exist.

5.5 Conclusions and recommendations to improve the test procedure

The evaluation of the test and the test procedure lead to the following conclusions:

i. The TAA or TS should always make an engineering assessment to make sure if a crankcase ventilation system is in place. Hence, the engineering assessment described in 2.1 of Annex IV of Regulation (EU) No 134/2014 is an important part of the procedure.

ii. The basic method and the additional test method No 1 are equivalent tests. Both methods are potentially good methods to assess if the crankcase ventilation system works properly.

iii. Alternative additional test no 2 is a good method to assess if the engine is gas leak-tight.

iv. Basic test and additional test no 1 could be passed even when the engine is not gas leak-tight. The alternative additional test no 2 could be passed while the crankcase ventilation system is not working.

The evaluation of the tests and the test procedures lead to the following recommendations to improve the test procedure:

i. Consider to introduce a provision to allow pulsations in the basic test. This should compensate for the lack of crankcase volume that cannot buffer the pulsations. Such a provision could be the assessment of the average crankcase pressure and ambient pressure over each condition, instead of the assessment of the instantaneous pressures. Alternatively, a moving average window larger than 10 seconds can be introduced to filter pressure peaks caused by pulsations.
ii. Consider to limit the size of the sample bag and relate the size of the sample bag to engine volume in additional test no1. The proposal is to maximize the sample bag to a factor 3 of the engine swept.
iii. Consider to more explicitly describe in the procedure of additional test no1 that no visible inflation is allowed at the end of each measurement condition (5 minutes).
iv. Together with recommendations i, ii and iii we recommend to have the basic and additional test method No1 as alternatives to apply at the choice of the manufacturer. And to retain alternative additional test method No 2 as a complementary test. Test No 2 shall be mandatory and to be passed in case the vehicle failed during the basic test or the additional test method No 1. In this way, it is checked whether the engine in leak tight and thus secured that no venting of crankcase gases occurs, in those cases that crankcase pressure lies above the ambient pressure. In other cases, additional test method No 2 can be requested by the TAA or technical service when they have doubts whether any fuel, lubrication oil or crankcase gases escape to the atmosphere although the vehicle pass either the basic test or additional test method No 1.
v. More explicitly describe in 2.2 of Annex IV of Regulation (EU) No 134/2014 when the Type III test is mandatory for new engine types instead of the current description '*new vehicle types with regard to environmental performance equipped with a new design of the crankcase gas ventilation system*'. It is recommended to make explicit reference to a considerably deviating engine lay-out and/or engine displacement and to require Type III testing in those cases.
vi. One further recommendation is to consider adopting these recommendations made for improvement of the Type III test procedures in the proposal for Technical Report on the development of UNECE global technical regulation for test Type III (crankcase emissions).

The minor revisions in the procedure described in delegated act Regulation (EU) No 134/2014, as recommended above under i to iv, will make the basic test and additional test no 1 better applicable to L-category vehicles and will guarantee prevention of crankcase emissions escaping to the atmosphere in a cost-effective way.

6 Type IV – Evaporative emissions

6.1 Background and objectives

Emissions due to fuel evaporation occur in all petrol-fuelled road vehicles. This occurs due to the natural behaviour of the fuel molecules to reach a state of lower vapour pressure. Evaporation has several impacts: First, it contributes to increased emissions of hydrocarbons that have a negative impact on air quality. Second, it artificially – even marginally – increases fuel quality. Third, it may lead to annoying odour especially when the vehicle is parked in an enclosed space. For all these reasons, fuel evaporation needs to be controlled.

Emissions due to fuel evaporation occur via different mechanisms. Most important, the need to balance pressure in the fuel tank as fuel is consumed means that the tank needs to be vented to the atmosphere. This leads to vapours escaping the tank. To control venting emissions, an active charcoal canister is placed in the venting line that adsorbs fuel vapours generated in the tank due to temperature variation. The canister may become saturated after some time, hence an active purging strategy is employed so that fresh air through the canister carries adsorbed species away. These are then led to the engine intake and are subsequently combusted. As purging is only available while the vehicle is operational, prolonged parking events (typically more than one day) may lead to canister saturation with subsequent vapour breakthrough to the atmosphere that may substantially increase HC emissions. Moreover, fuel may escape through the permeable walls of the fuel system, including the fuel tank, the fuel lines and other secondary systems. Emissions due to fuel permeation may be significant if the materials of the fuel system are not properly designed. Finally, fuel may escape through leakages or through openings in the fuel system, such as in some carburettor systems.

A very basic fuel storage permeability test for L-category vehicles equipped with a plastic fuel tank is already in place since 1997 as part of the type approval procedure. This test examines the quality of the materials used but does not address possible breathing emissions, *i.e.* losses through the tank vent. However, it is much cheaper to execute, does not require expensive equipment and it is easy to comply with using materials of proven quality.

For larger L-category vehicles (L3e, L4e, L5e-A, L6e-A, L7e-A) complying with Euro 4, evaporation emissions are being checked with a SHED procedure, where the vehicle is placed in a sealed compartment and total hydrocarbons produced during a temperature ramp up and during hot soak are combined and need to be below a 2 g/test limit value. A SHED test is considered to be a holistic approach in estimating evaporation emissions because it takes into account all possible sources, including permeation, breakthrough and leakages if any. However, it is a costly option because it requires expensive equipment and facilities – including two driving cycles to be executed on a chassis dynamometer test bench. For these vehicles the cost effectiveness of a reduced emission limit is examined.

For all other vehicles (L1e-B, L2e, L5e-B, L6e-B, L7e-B and L7e-C) two alternative approaches are examined as these vehicle types will be also subject to an evaporative emissions test procedure in the Euro 5 step. Apart from the SHED test,

there is an alternative test procedure that only examines the permeation rate of the fuel system. This must not exceed a certain rate per unit of surface area. Hence, the aim is to identify the most cost-beneficial option (SHED test or fuel permeation test) for controlling evaporation emissions from these types L-category vehicles.

In summary, the main objectives of the assessment of the Type IV – evaporative emissions test are as follows:

- Assessment of evaporative emission test procedure set out in Annex V to Regulation (EU) No 134/2014, in particular the permeation and SHED test procedures;
- Investigation of the cost effectiveness of a 50% lower Euro 5 evaporative emission limit compared to the Euro 4 limit for vehicles subject to the SHED test;
- Investigation of the impact of fuel quality on the evolution of fuel permeation rate over time as well as the ageing effects of the carbon canister.

To this aim, the following scenarios are evaluated in the subsequent sections:

- **Reference scenario**
    - **L1e-B, L2e, L5e-B, L6e-B, L7e-B and L7e-C:** No evaporative emission limits
    - **L3e, L5e-A and L7e-A:** No further reduction of Euro 5 limit
- **Permeation test scenario (L1e-B, L2e, L5e-B, L6e-B, L7e-B and L7e-C)**
  Apply fuel system permeation test for evaporative emission test procedure as currently set-out in Regulation (EU) No 134/2014
- **SHED test scenario (L1e-B, L2e, L5e-B, L6e-B, L7e-B and L7e-C)**
  Apply SHED test for evaporative emission test procedure as currently considered in Regulation (EU) No 134/2014
- **Lower Euro 5 limit (L3e, L5e-A and L7e-A)**
  Further reduction of Euro 5 limits (1.0 g/test) than currently set-out in Regulation (EU) No 168/2013 (1.5 g/test)

6.2 SHED test results

6.2.1 SHED test procedure

The SHED test procedure followed for the determination of evaporative emissions was in accordance with the process described in Annex V, Appendix 3 to Regulation (EU) No 134/2014. All tests were carried out at the JRC facilities in Ispra, Italy, equipped with a chassis dyno (VELA 1) suitable for L-category vehicles and a SHED enclosure (VELA 3). The VELA 1 test cell is able to perform emission test in accordance with Regulation (EU) No 168/2013 and Regulation (EU) No 134/2014 (see also section 2.3). As the SHED facility hadn't been used for a few years, we performed a verification test to ensure proper functioning according to the procedures prescribed in the Regulation (EU) No 134/2014. The exact procedure and test protocol followed for this verification process are presented in Appendix **L**. Results from all relevant tests conducted were found to be within the acceptable limits in line with the relevant EU Legislation. Hence, the SHED test results can be used for the purposes of the present Euro 5 effect study without any adjustment or correction.

Table 28 shows the test protocol followed for the SHED tests. The reference E5 fuel was used in all tests conducted under this task.

Table 28. SHED test protocol

Phase	Test type	Facilities	Duration [h]	Comments
Preparation	-	-	3-4	
Conditioning	Driving cycle	Chassis dyno (VELA 1)	0.3-0.5	ECE R40/R47 or WMTC depending on the vehicle category
	Vehicle soak	Temperature-controlled test cell (VELA 2)	~18	6-36 h depending on the vehicle category
Test	Diurnal 1	SHED	2.5-3	Fuel tank venting hose inside the SHED
	Diurnal 2	SHED	2.5-3	Fuel tank venting hose outside of the SHED
	Driving cycle	Chassis dyno (VELA 1)	0.3-0.5	ECE R40/R47 or WMTC depending on the vehicle category, starts within 60 min from end of diurnal test
	Hot soak	SHED	1	Starts within 7 minutes from end of driving cycle

The typical duration of a complete set of tests for each vehicle is approximately 2 days.

As a first step, the vehicle is prepared for the chassis dyno and SHED tests. In most cases, the vehicle has already been tested on chassis dyno for other tasks, so no additional preparation was needed. Thus, the main part of the preparation phase consists of any modifications needed for the SHED tests. More specifically, in order to monitor and record the liquid fuel and fuel vapor temperature in the tank as prescribed by the regulation, a new fuel tank cap was manufactured for each vehicle, accommodating the necessary thermocouples and fuel tank venting hose, as shown in Figure 30.

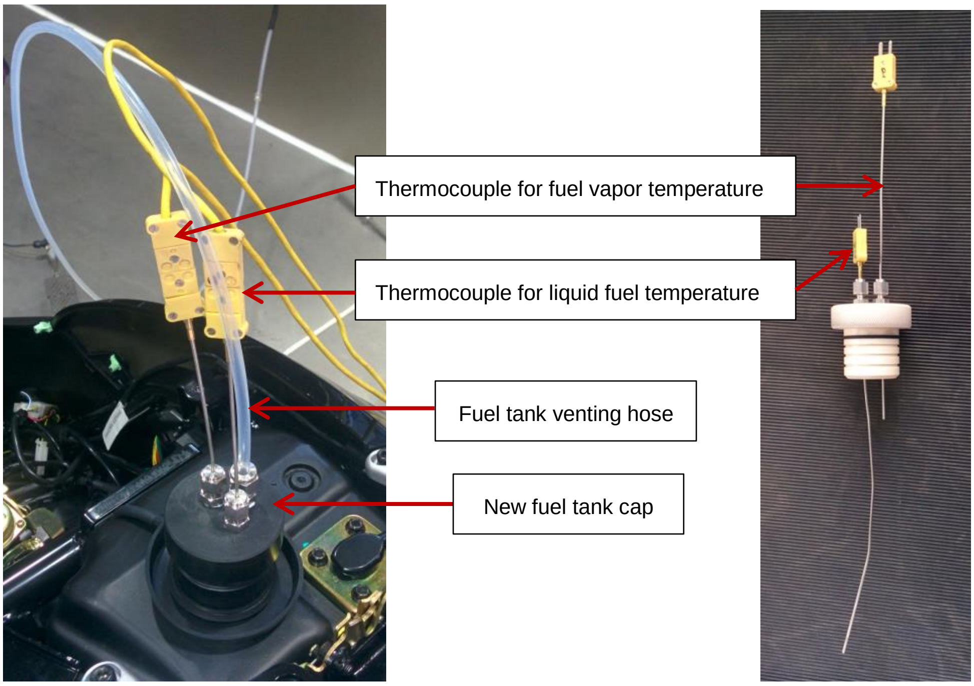


Figure 30: Example of a new fuel tank cap with thermocouples installed

After the vehicle preparation, the conditioning phase follows. The vehicle runs a driving cycle on the VELA 1 chassis dyno (Figure 31) without any exhaust emissions recordings. The type of the driving cycle is either ECE R40/R47 or WMTC depending on the vehicle category as described in Regulation (EU) No 134/2014, Annex V, Appendix 3, paragraph 5.2.2 ("The vehicle is placed on a chassis dynamometer and driven through the test cycle specified in Part A of Annex VI to Regulation (EU) No 168/2013 as appropriate for the class of vehicle being tested"). After that, the vehicle is parked in a temperature-controlled (~20°C) test cell and is left there for the overnight soak period.

Figure 31: Vehicle on the chassis dyno during the preconditioning phase

After the soak period, the main part of the SHED test starts. Initially, the vehicle is refuelled with fresh E5 reference fuel at a temperature of 10-14°C to 50 ± 2 % of its nominal volumetric capacity and is parked in the SHED chamber for the first diurnal test (Figure 32). During the test the fuel is heated from 15.5°C to 29.4°C. In order to build the desired temperature slope, the temperature inside the SHED is kept constant at around 38°C. A typical heating slope for the fuel and fuel vapor is illustrated in Figure 33.

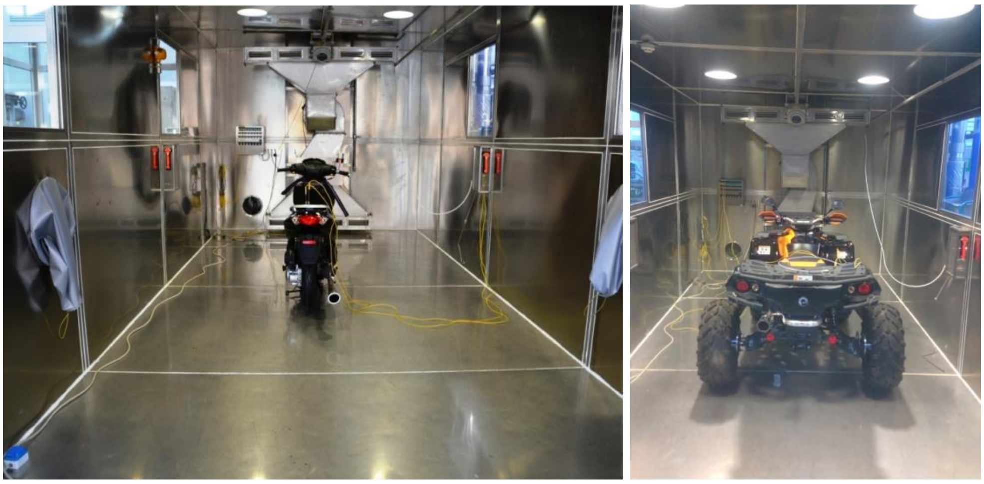


Figure 32: Moped (left) and all-terrain quad (right) in the SHED enclosure

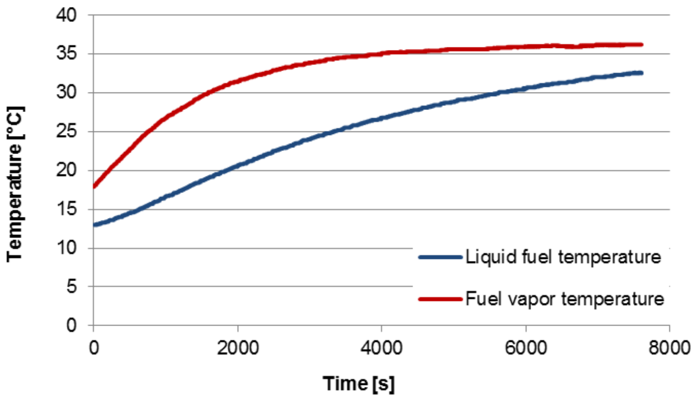


Figure 33: Liquid fuel and fuel vapour temperature heating slope during a diurnal test.

Immediately after the end of the first test the vehicle is refuelled again and the second diurnal test starts. In this test, the fuel tank is vented outside the SHED enclosure in order to determine the HC sources other than breathing losses through the tank vent. These may include permeation losses through the fuel tank and fuel lines materials, emissions from tires and other fluids of the vehicle.

After the end of the two consecutive diurnal tests and within one hour, the vehicle is placed on the chassis dyno to run a driving cycle. Within 7 minutes from the end of the driving cycle the vehicle is pushed again into the SHED and the hot soak test starts, which is the last part of the SHED test procedure. The temperature in the SHED is maintained at 25°C, the same as in the chassis dyno test cell during the driving cycle.

During each SHED test the following signals are continuously recorded:

- Liquid fuel temperature
- Fuel vapour temperature
- Hydrocarbon concentration in SHED enclosure
- Temperature and pressure in SHED enclosure

The mass of hydrocarbon emitted over each test (diurnal, hot soak) and the overall evaporative emissions for the vehicle are determined from the above recordings according to the relevant equations (Ap3-3 and Ap3-4 respectively) specified in Appendix 3 of the Regulation (EU) No 134/2014.

6.2.2 *Test vehicles*

Table 29 summarizes the main technical specifications relevant for evaporative emissions of the vehicles tested. The full testing schedule described above has been followed for all vehicles.

Table 29. Test vehicles for SHED tests

Vehicle Code	Vehicle category	Vehicle description	Fuel tank capacity [l]	Fuel tank material	Carbon canister
J03	L1e-B	High speed moped	6.8	Plastic	No
J08	L7e-B1	Heavy all terrain quad	17	Plastic	No
J11	L3e-A2	Low performance motorcycle	8	Plastic	No
J16	L7e-B1	Heavy all terrain quad	20.5	Plastic	No
J23	L5e-B	Commercial tricycle	10.5	Metal	No
J29	L1e-B	High speed moped	7.5	Plastic	No

6.2.3 *SHED test results*

Results from all SHED tests conducted are summarised in Figure 34 below.

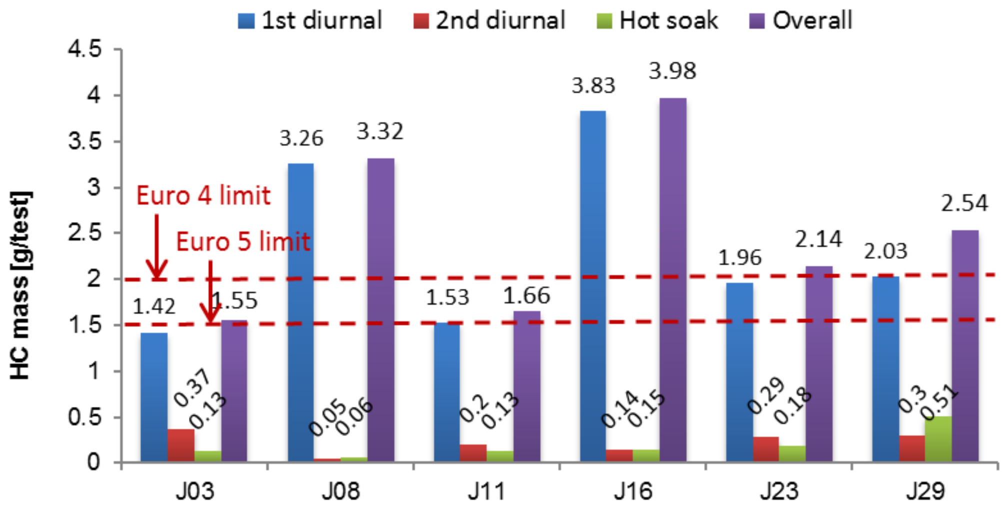


Figure 34: Summary of SHED test results.

Out of the six vehicles tested, only two (the J03 and the J11) are below the Euro 4 limit (2 grams/test) and only slightly above the Euro 5 limit (1.5 grams/test). This is because both vehicles are equipped with small fuel storage tanks (up to 8 litres) and hence there is a physical limit in the amount of vapours that can be generated in the fuel tank during the SHED test.

For the other vehicles (J08, J16, J23 and J29) their measured emissions – and in particular the difference between the first and the second diurnal test – are consistent with their fuel tank size (see also relevant discussion in section 6.3.2).

Results from the second diurnal and the hot soak test (with the tank vented outside the SHED) provide an indication of the permeation emission levels of the tested vehicles. These were found to be much higher than the relative Euro 4 permeation test limits. This is because there is no provision for the permeation emissions of pre-Euro 4 vehicles and hence most vehicles are equipped with mono-layer fuel tanks.

Only one of the tested vehicles, the J08 vehicle which is a heavy all terrain quad, is equipped with a multi-layer low-permeability tank and hence its permeation emissions are within the Euro 4 limit.

6.3 Modelling of evaporation losses

For the modelling of evaporative emissions, the COPERT methodology and algorithms have been used. Proper adjustments were made to take into account the results of the experimental testing described in the previous section.

6.3.1 COPERT background

COPERT[35] (COmputer Program to calculate Emissions from Road Transport) is a tool that is used world-wide to calculate air pollutant and greenhouse gas emissions

[35] COPERT 5 (http://emisia.com/copert) is the latest version

from road transport. The European Environment Agency (EEA) coordinates the development of COPERT, and the European Commission (Joint Research Centre) manages the scientific development.

For the calculation of evaporative VOC emissions a wide range of input parameters are required to run the model. These can be grouped into the following categories:

- Fuel related parameters: (i) vapour pressure; (ii) ethanol content
- Vehicle related parameters: (i) fuel tank size and structure; (ii) mass and quality of activated carbon; (iii) purging strategy
- Vehicle activity related parameters: (i) parking duration; (ii) distance travelled; (iii) ambient temperature.

The model includes algorithms for calculating canister breakthrough or tank breathing emissions and emissions due to fuel permeation. The total evaporative emissions for each evaporation process (diurnal emissions, hot-soak emissions and running losses) are determined by the sum of breakthrough emissions and permeation emissions.

6.3.2 Determination and validation of emission factors

The main emission algorithms and emission factors included in the evaporation module of COPERT were checked to ensure they are up to date and in line with the results of the experimental testing. These are summarized in the following.

Fuel tank vapour generation

In COPERT the vapour generation in the fuel tank is calculated as a function of fuel volatility, temperature variation, fuel tank size and fill level by means of a simple physical model (Reddy equation). Based on this model, the uncontrolled emissions of the tested vehicles were calculated and compared against measured losses. For the latter, the difference in emissions between the two diurnal tests (tank vented in the SHED and outside the SHED) was taken.

The results of this comparison are summarized in Table 30 and confirm that the model can be used without adjustments for estimating uncontrolled emissions from the L-category vehicles.

Table 30. Modelled vs measured fuel vapour generation

Vehicle Code	Vehicle category	Fuel tank capacity [l]	Measured (g/test)	Modelled (g/test)
J03	L1e-B	6.8	1.05	1.49
J08	L7e-B1	17	3.21	3.72
J11	L3e-A2	8	1.61	1.75
J16	L7e-B1	20.5	3.69	4.37
J23	L5e-B	10.5	1.67*	1.38*
J29	L1e-B	7.5	1.73	1.64

* Due to a mistake the diurnal test was conducted with 7.5 litres of fuel, instead of 5.25 (50% of the tank capacity). This has been taken into account for the modelling of diurnal emissions, and hence the calculated value is lower than for the J03 and J11 vehicles which have smaller fuel tanks.

Fuel tank permeation emissions

A permeation emissions rate (in grams/hour) has been estimated based on the results of the second diurnal test and the hot soak test for each vehicle tested. The surfaces of the fuel tank and the fuel tubing were then used to produce emission factors in g/m^2/day. For this it was assumed that the fuel tubing has a permeation rate which is tenfold compared to the fuel tank. This assumption is based on the relevant permeation emission limits for the fuel tank (1.5 g/m^2/day) and fuel tubing (15 g/m^2/day) in Regulation (EU) No 168/2013, Annex VI. The estimated permeation rates are summarised in Table 31.

Table 31. Estimated fuel permeation rates for the tested vehicles

Vehicle Code	Vehicle category	Fuel tank capacity [l]	Tank perm. rate (g/m^2/h)	Tubing perm. rate (g/m^2/h)
J03	L1e-B	6.8	0.85	8.54
			0.37	3.75
J08	L7e-B1	17	0.31	3.08
			0.30	3.00
J11	L3e-A2	8	0.04	0.38
			0.07	0.69
J16	L7e-B1	20.5	0.14	1.40
			0.23	2.26
J23	L5e-B	10.5	0.49	4.86
			0.45	4.52
J29	L1e-B	7.5	0.52	5.23
			1.33	13.33

Activated carbon canister emissions

The semi-empirical model developed for passenger cars in previous studies (*e.g.* JRC/CONCAWE/EUCAR study, passenger cars Euro 6 CBA study, etc.) is used for the L-category vehicles with proper adjustments for the carbon canister size. The model is described in detail in the relevant chapter (1.A.3.b.v – Gasoline evaporation) of the EMEP/EEA air pollutant emission inventory guidebook[36].

Carbon degradation for the L-category vehicles was assumed to be similar to small passenger cars. These are typically equipped with canisters containing high degradation carbons, which lose about 12% to 20% of their capacity over the lifetime of the vehicle, due to repeated cycling with petrol fuel. This assumption is confirmed by canister degradation testing results.

Summary of emission factors

Based on the above, emission factors have been calculated for the vehicle categories relevant for each of the scenarios considered.

Table 32 summarises the emission factors for the vehicle categories for which the permeation test and SHED test scenarios are assessed. In addition to the uncontrolled and controlled emission factors, the following information is also included in the table for each vehicle type and scenario:

[36] http://www.eea.europa.eu/publications/emep-eea-guidebook-2016

- The fuel tank size considered for the calculations. These are average values based on market data for popular vehicle models of each category;
- The permeation emission factor (in g/day);
- The permeation test result according to legislation (TA: type approval) (in $g/m^2/day$);
- The SHED test result according to legislation (in g/day);
- The tank breathing emissions (in g/day) with and without a carbon canister installed;
- The canister size, relevant only for the SHED test scenario.

Table 32. Summary of emission factors used for the permeation test vs SHED test scenarios

	Euro 4				Euro 5 (permeation test)				Euro 5 (SHED test)			
	Mopeds	L5-B tricycles	Mini-cars	ATVs	Mopeds	L5-B tricycles	Mini-cars	ATVs	Mopeds	L5-B tricycles	Mini-cars	ATVs
Fuel tank size (l)	7.5	17.5	16.5	22	7.5	17.5	16.5	22	7.5	17.5	16.5	22
Permeation (g/day)	1.80	4.20	3.96	5.28	0.52	1.22	1.15	1.53	1.80	4.20	3.96	5.28
TA permeation test ($g/m^2/day$)	4.99	4.99	4.99	4.99	1.50	1.50	1.50	1.50				
TA SHED test (g/test)	1.72	4.00	3.77	5.03					1.72	1.50	1.48	1.44
Emissions without canister (g/day)	2.47	5.75	5.43	7.23	1.19	2.77	2.61	3.49	2.47			
Breathing emissions (g/day)	0.67	1.55	1.47	1.95	0.67	1.55	1.47	1.95	0.67			
Canister size (l)										0.21	0.20	0.27
Controlled by canister (g/day)										4.78	4.57	5.75
Breathing through canister (g/day)										0.58	0.61	0.47

From the above data the following observations can be made:

- Mopeds are already very close to the 1.5 g/test SHED test limit without emission control due to their small fuel tank size as there is a physical barrier in the amount of vapours that can be generated in the tank;
- Permeation emissions are very high, being more than 3 times compared to permeation test limit (see also section 6.2.3);
- There is little benefit (in terms of EFs reduction) from the introduction of the SHED test because permeation emissions are much higher than tank breathing losses.

Table 33 summarises the emission factors for the vehicle categories which are already subject to SHED test and for which the lower Euro 5 emission limit scenarios are assessed. In addition to the uncontrolled and controlled emission factors, the following information is also included in the table for each vehicle type and scenario:

- The fuel tank size considered for the calculations. These are average values based on market data for representative vehicle models of each category;
- The permeation emission factor (in g/day). It is assumed that all vehicles are equipped with low permeability fuel tanks;
- The SHED test result according to legislation (TA: type approval) (in g/day);
- The tank breathing emissions (in g/day) with and without a carbon canister installed;

- The canister size. It is assumed that all vehicles are equipped with a carbon canister, except L3-A1 which have very low emissions due to the small fuel tank size.

Table 33. Summary of emission factors used for the lower Euro 5 limit scenarios

	Euro 4 (2.0 g/test)				**Euro 5 (1.5 g/test)**				**Euro 5 (1.0 g/test)**			
	L3-A1	L3-A2	L3-A3	L5-A	L3-A1	L3-A2	L3-A3	L5-A	L3-A1	L3-A2	L3-A3	L5-A
Fuel tank size (l)	5	10	21	17.5	5	10	21	17.5	5	10	21	17.5
Permeation (g/day)	0.35	0.70	1.46	1.22	0.35	0.70	1.46	1.22	0.35	0.70	1.46	1.22
TA SHED test (g/test)	1.11	0.98	1.92	2.00	1.11	0.98	1.46	1.50	1.11	0.98	0.97	0.99
Emissions without canister (g/day)	0.79	1.58	3.33	2.77	0.79	1.58	3.33	2.77	0.79	1.58	3.33	2.77
Breathing emissions (g/day)	0.44	0.89	1.87	1.55	0.44	0.89	1.87	1.55	0.44	0.89	1.87	1.55
Canister size (l)		0.15	0.21	0.18		0.15	0.24	0.20		0.15	0.30	0.25
Controlled by canister (g/day)		1.47	2.08	1.95		1.47	2.00	1.83		1.47	1.88	1.69
Breathing through canister (g/day)		0.77	0.62	0.73		0.77	0.54	0.62		0.77	0.42	0.47

From the above data the following observations can be made:

- Small size motorcycles (L3-A1) are already below the Euro 5 test limit of 1.5 g/test SHED due to their small fuel tank size and very close to the reduced 1.0 g/test limit;
- There is little benefit from lowering the Euro 5 limit down to 1.0 g/test because the actual emission factors are only marginally reduced.

6.4 Calculation of environmental benefits

The scenarios defined in section 6.1 were simulated in COPERT taking into account the emission factors and the adjustments in the model described previously. The modified COPERT model was then used for calculating the evaporative VOC emissions from the relevant vehicle categories and scenarios.

Because of the diverse climatic conditions and fuel specifications (vapour pressure) across the EU Member States (MS) it was not possible to perform the calculations for the EU as a whole. Therefore, the calculations were performed for the five EU-MS with the highest populations of L-vehicles (above 2 million vehicles), *i.e.* Italy (8.5 mio), Germany (6 mio), Spain (5 mio), France 2.6 mio) and Poland (2.3 mio). These five MS make up for more than 70% of the EU L-category population (33.8 mio vehicles in 2013) and hence they can be considered as representative of the entire EU.

Values for the vapour pressure of summer grade petrol were taken from the annual reports on the quality of petrol and diesel used for road transport that EU MS transmit to the European Commission in line with their obligations set in the Fuel Quality Directive (Directive 98/70/EC as amended by Directive 2009/30/EC).

6.5 Cost calculation

The costs used as input for the modelling of the Type IV– evaporative emissions of the CBA tool are presented in this section for the scenarios defined in section 6.1.

The cost data presented here is a moderate estimation of the costs, while a low and a high estimation of them is also calculated, based on a constant fluctuation rate, different for each cost category.

For all vehicle categories, there are no additional costs incurred for the reference scenario, *i.e.* for not introducing evaporative emission limits for L1e-B, L2e, L5e-B, L6e-B, L7e-B and L7e-C vehicles, and for not reducing the current Euro 5 limit for L3e, L5e-A and L7e-A.
Appendix **E** summarizes the cost inputs for the cost analysis model.

Mopeds
For the permeation scenario the only R&D costs involved for mopeds are for low-permeability fuel tanks, whereas for the SHED test there are no such costs as mopeds would pass the test without any additional emissions control. A standard cost for the type approval process is foreseen for both scenarios. The cost for one Type Approval (TA) facility (SHED) is foreseen for the SHED test scenario to accommodate for the increased number of new models to be certified.
In addition to the different costs, a fuel benefit (this is a negative cost) has been calculated for the permeation test scenario, corresponding to the amount of fuel saved by installing low-permeability tanks.

ATVs
For the permeation scenario the R&D costs for the ATVs are similar to those of mopeds, with the cost for low-permeability fuel tanks being somewhat higher for ATVs.
For the SHED test there are additional R&D costs. Further to the hardware costs for the carbon canister, purge valve and tubing, there is a cost for the development of the entire vapour control system.
A standard cost for the type approval process is foreseen for both scenarios as for mopeds. The cost for one TA facility (SHED) is foreseen for the SHED test scenario to accommodate for the increased number of new models to be certified.
The fuel benefit for the permeation test scenario is higher than for the SHED test because of the higher amounts of fuel saved by a low-permeability tank compared to a carbon canister.

Mini-cars
For the mini-cars the same costs as for ATVs have been assumed. However, only about 2% of the mini-cars are gasoline, the rest being diesel. Hence, the costs for the entire mini-cars fleet are estimated to be 2% of the above costs for ATVs.
The fuel benefits are much lower than for the ATVs because the annual mileage of mini-cars is higher and hence any fuel savings are divided by larger distances travelled.

Motorcycles
Two different groups of motorcycles are taken into account for the cost estimations. The first group includes the L5-B tricycles, for which the permeation test and SHED

test scenarios are considered. These however constitute only a very small fraction of the entire motorcycles category, on the order of 0.2%.
Assuming similar costs as for mini-cars, the costs for the entire motorcycles fleet are estimated to be 0.2% of the costs for mini-cars for both the permeation test and SHED test scenarios.
The vast majority of motorcycles (L3e, L5e-A and L7e-A) are subject to the SHED test and hence only the lower Euro 5 limit is examined. Since they are already equipped with a complete vapour control system, there are some R&D costs assumed for further development, as well as for a larger carbon canister. There are no additional costs for type approval.

Appendix **E** summarizes the cost inputs for the cost analysis model.

6.6 Cost-Benefit analysis

Reference scenario

For all vehicle categories, there are no costs and no benefits for the reference scenario, *i.e.* for not introducing evaporative emission limits for L1e-B, L2e, L5e-B, L6e-B, L7e-B and L7e-C vehicles, and for not reducing the current Euro 5 limit for L3e, L5e-A and L7e-A.

Permeation test scenario (L1e-B, L2e, L5e-B, L6e-B, L7e-B and L7e-C)

There are no initial investment costs for this scenario, only hardware and type approval costs. Hence, the total cost decreases over the years due to amortization and technology depreciation, whereas the total benefit increases with the number of new registrations.

The average cost per vehicle category is negative because the fuel benefits from the installation of low-permeability tanks in the vehicles outweigh the associated costs.

The NPV is presented Table 34, for each vehicle category. The best estimation is calculated considering the baseline fleet/activity scenario, the moderate cost scenario and technology depreciation period 6 years, as analysed in Section 1.1. The low and high estimates of NPV are calculated considering for the former the high cost scenario, technology depreciation period 10 years and the low/high growth fleet/activity scenario depending on the vehicle category, and for the latter the low cost scenario, technology depreciation period 6 years and the high/low growth fleet/activity scenario depending on the vehicle category.

Table 34. NPV for the permeation test scenario of the Type IV test evaporative emissions

(Values in M€)	Cost-benefit over 2020-2040
Mopeds	$47.2^{+17.8}_{-17.7}$
L5e-B Tricycles	$3.6^{+0.6}_{-0.6}$
Mini-cars & ATVs	$10.5^{+2.4}_{-2.7}$
Total	$61.3^{+20.8}_{-21.1}$

There is a clear benefit from the introduction of the permeation test for all vehicle categories due to the combined effect of reduced evaporative emissions, high fuel savings and low implementation costs. The benefit of permeation test is highest for mopeds because of the significant NMHC savings offered by low-permeability fuel tanks and their relatively low cost. For motorcycles (L5-B Tricycles), mini-cars and ATVs the benefits are lower because of the much smaller population of these vehicle types.

SHED test scenario (L1e-B, L2e, L5e-B, L6e-B, L7e-B and L7e-C)
There is an initial development cost for this scenario, which however decreases over the years due to amortization and technology depreciation. The total benefit increases with the number of new registrations; they are however low because of the marginal emissions reductions offered by the SHED test.

The average cost for mopeds and motorcycles is negligible because the cost for the additional hardware or development required is very low and is compensated by the cost of the fuel saved. For mini-cars the cost is marginal because of the low share of gasoline vehicles (around 2%) in the total fleet. For ATVs the cost is significantly higher because of the implementation costs.

The NPV is presented in Table 35, for each vehicle category. As previously, the same approach for the best estimation values as well as the low and high estimates of NPV are considered.

Table 35. NPV for the SHED test scenario of the Type IV test evaporative emissions

(Values in M€)	Cost-benefit over 2020-2040
Mopeds	$-1.4^{+0.2}_{-0.2}$
L5e-B Tricycles	$2.4^{+0.4}_{-0.4}$
Mini-cars & ATVs	$-9.1^{+2.4}_{-4.9}$
Total	$-8.1^{+2.3}_{-4.7}$

There is a damage calculated for mopeds, mini-cars and ATVs (benefit only for motorcycles). When comparing the results to the permeation scenario, there is a clear benefit of the latter over the SHED scenario. This is mainly because the NMHC savings of the SHED test are much lower (compared to permeation test) for all categories because there is no need to equip vehicles with low-permeability fuel tanks to pass the SHED test. The costs are also higher mainly because of the R&D costs to develop the vapour control system (carbon canister, purging strategy, etc.).

Lower Euro 5 limit scenario (L3e, L5e-A and L7e-A)
There are no initial investment costs for this scenario, only additional hardware (larger canister) and development costs. Hence, the total cost decreases over the years due to amortization and technology depreciation, whereas the total benefit increases with

the number of new registrations; they are however low because of the marginal emissions reductions offered by the SHED test.

The NPV is presented Table 36. As previously, the same approach for the best estimation values as well as the low and high estimates of NPV are considered.

Table 36. NPV for the lower Euro 5 evaporative emission limit scenario of the Type IV test

(Values in M€)	Cost-benefit over 2020-2040
Motorcycles	-27^{+9}_{-19}

There is a damage calculated for motorcycles, which is explained by the marginal NMHC savings of lowering the SHED test limit by 0.5 g/test. This is because most of the emissions in real-world occur during longer parking events (above 24 hours) which are not captured by the current SHED test procedure.

6.7 Investigation of the impact of fuel quality on the evolution of fuel permeation rate over time as well as the ageing effects of the carbon canister

6.7.1 Context

According to Regulation (EU) No 134/2014, the reference petrol fuel to be used for tailpipe and evaporation emissions testing is a 5% vol. ethanol (EtOH) blend (E5). It has for long been known that EtOH has a multitude of effects with regard to evaporation emissions:

- EtOH is a polar molecule that is more difficult to purge when adsorbed in activated carbon. Hence, prolonged E5 used may artificially reduce canister capacity and hence efficiency.
- Although EtOH is less volatile than petrol, E5-E10 blends actually result to higher volatility than neat petrol alone hence producing more vapour, leading to higher evaporation emissions.
- EtOH molecule is smaller than the average petrol molecule and exhibits higher diffusivity through fuel tank and lines walls.
- Several plastic materials are incompatible with EtOH and degrade with prolonged use thus leading to increased permeation and leakages when EtOH blends are being used.

The main objective of this investigation was to identify what are the short term and long term effects of EtOH blends on evaporation emissions from L-category vehicles, taking into account the following factors:

- The current reference fuel in the EU is E5
- E0 is still used in many parts of the world that follow the EU emissions standards
- The amount of EtOH blended in petrol may increase to 10% vol. (E10) in the future (already used as market fuel in some EU markets).

6.7.2 Carbon canister ageing test procedure

The procedure followed for the ageing of the carbon canisters is described in Annex V, Appendix 3.2 to Regulation (EU) No 134/2014. Based on this, a specific amount

of test cycles of loading and purging the canister is performed in order to rapidly age the activated carbon contained in the canister. The ageing of the carbon results in a reduction of the canister fuel storage capacity and consequently a reduction in efficiency.

In order to determine the possible effect of ethanol on the canister storage capacity, the above ageing process was performed using E0 and E10 as test fuels. The test protocol followed in order to investigate the ethanol effect is summarized in Figure 35. The first step includes loading of the canister with fuel vapours until a 2 g breakthrough is detected. Then, a 5-minute dwell period is applied and in the last step the canister is fully purged to prepare for the next cycle. When all cycles with the first fuel (E0) are completed, an extensive canister purging is performed and the same procedure is followed for the second test fuel (E10).

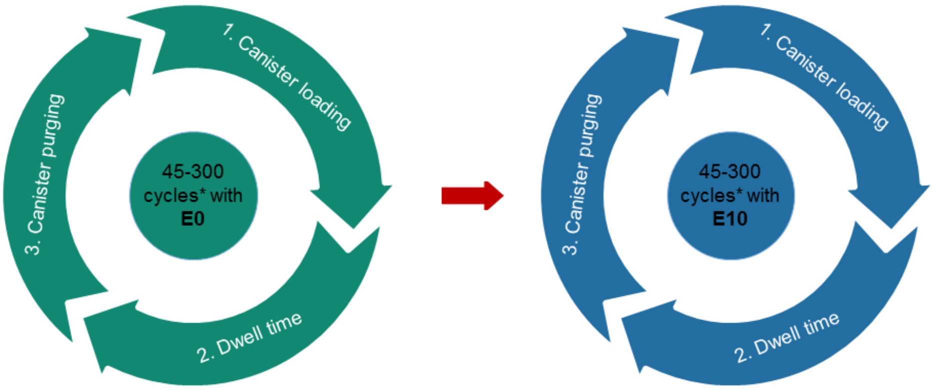


Figure 35: Carbon canister test procedure (*The exact number of test cycles depends on the vehicle category)

The exact number of cycles to be performed varies between 45 and 300 depending on the vehicle category (see Table Ap3.2-1 of Regulation (EU) No 134/2014). A larger number of test cycles is typically required for bigger vehicles. In this study, the ageing process was considered completed when the canister capacity was stabilized as explained in the following.

In order to perform the above mentioned tests a test set-up was built as shown in Figure 36 and Figure 37. With this set-up a fully automated iterative process for loading and purging the test canister (indicated as “Canister 1” in the following figures) is performed. The exact test equipment used in this experimental set-up is described in section 2.3 (Test facilities and equipment) of this report.

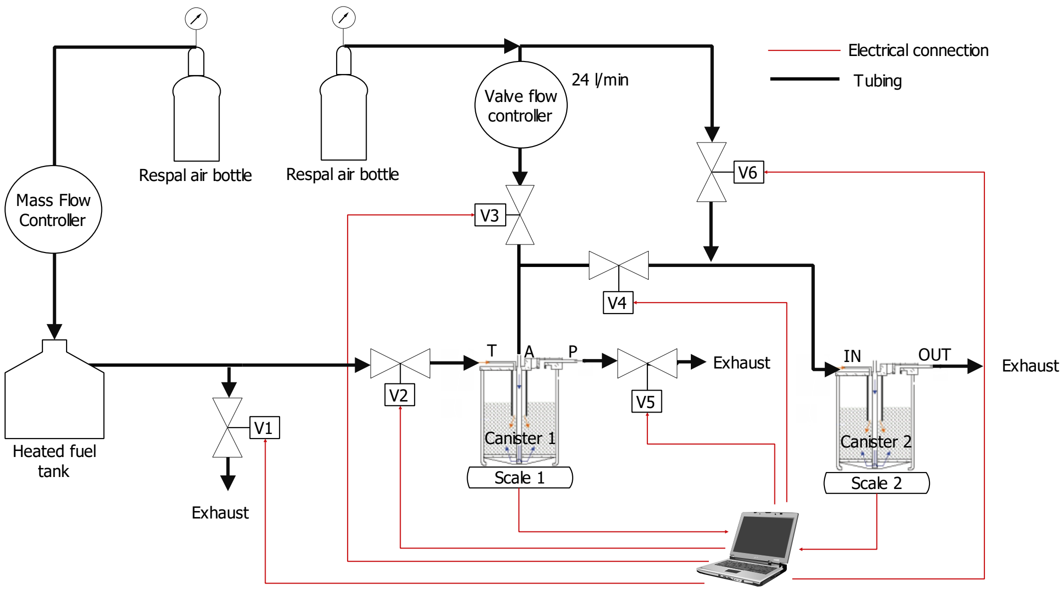


Figure 36: Schematic diagram of the test set-up built for the carbon canister ageing tests.

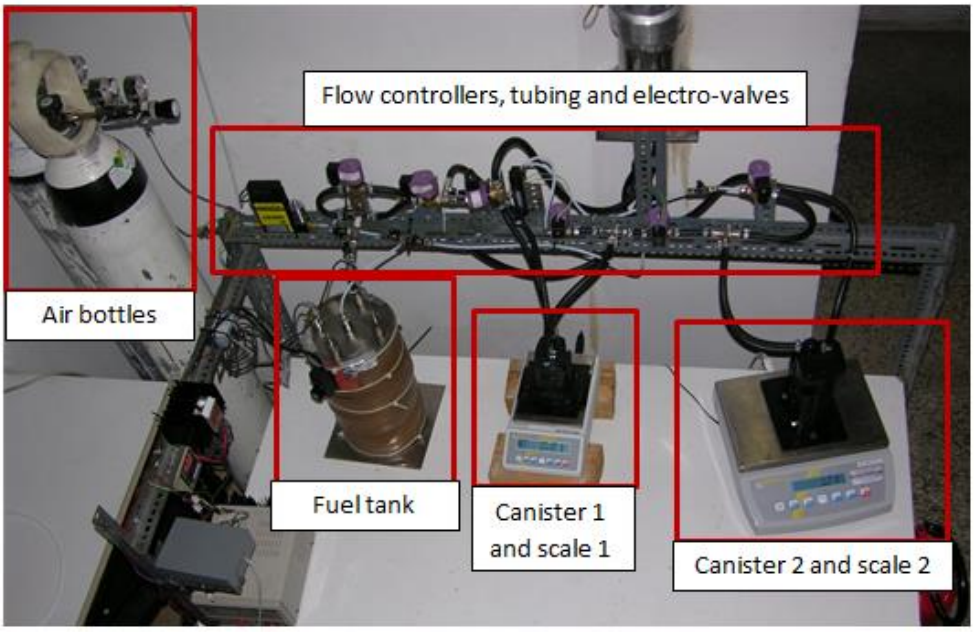


Figure 37: Test set-up built for the carbon canister ageing tests.

Figure 38 shows a detailed view of a typical carbon canister used in automotive applications. The canister has three connection ports. The fuel vapours generated in the fuel tank enter the canister through the fuel tank port whereas the clean air port and the purge port are used to clean the canister during the purging process. More details about the use of each port during the ageing process are provided in the following paragraphs.

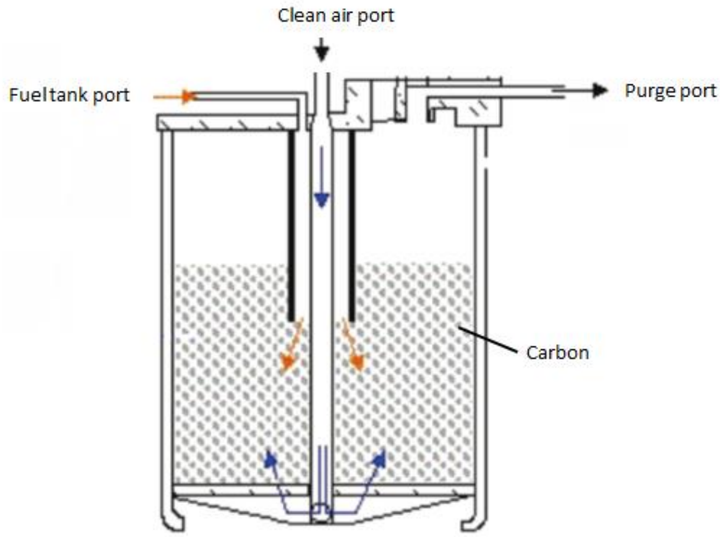


Figure 38: Detailed view of a typical carbon canister

The operation of the test set-up presented in Figure 36 during a typical test cycle (canister loading, dwell time and purging) can be summarized as follows:

1. Canister 1 loading:
   - The purge port is capped.
   - The clean air port is open.
   - Fuel vapours (mix of 50% air and 50% test fuel by volume) enter through the tank port of the test canister at a flow rate of 40 g/h. The petrol vapour is generated in the fuel tank at a petrol temperature of 40 ± 2^{o}C.
   - Loading is finished when a weight increase of 2 g in Canister 2 is detected (breakthrough of 2 ± 0.1 g), i.e. 2 grams of petrol vapour have escaped from Canister 1 through clean air port.

2. Dwell time: During this 5-minute period, all ports of Canister 1 are capped and the air-fuel mix is diverted to the exhaust.

3. Canister 1 purging
   - The tank port is capped.
   - Dry clean air (400 canister bed volumes) at a rate of 24 l/min enters the canister from the clean air port in order to remove the fuel vapours stored in the canister (i.e. adsorbed by the activated carbon during the loading phase).

6.7.3 *Fuel Permeation test procedure*

The procedure followed for the determination of fuel permeation losses through the fuel delivery system (fuel storage tank and fuel hoses) is described in Annex V, Appendix 2 to Regulation (EU) No 134/2014. The permeation tests are based on the gravimetric method i.e. the fuel delivery system is weighted before and after a predefined temperature-controlled period in order to determine the losses through the material of the fuel system components.

A similar method for the determination of permeation emissions is also used in the US, for example in the fuel permeation studies carried out for the California Air Resources Board (CARB) and the Coordinating Research Council (CRC) (Haskew et al., 2006).
In the present study we have followed the test procedure depicted in Figure 39 to investigate the effect of ethanol on the fuel permeation rate of different fuel tanks.

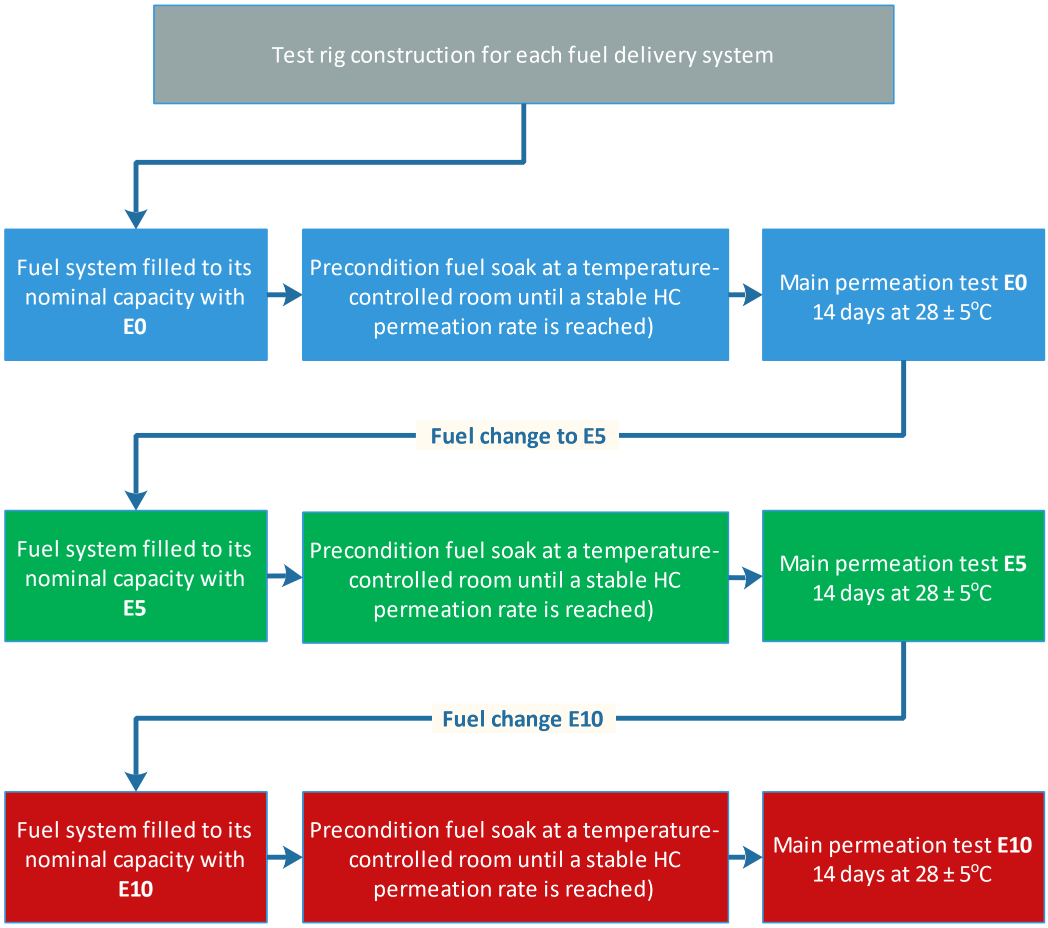


Figure 39: Test protocol followed for the determination of fuel permeation losses

As a first step a test rig was built for each vehicle (shown in Figure 40) consisting of the fuel tank, the fuel hoses (a part or all of them) and the fuel pump (when applicable). In this test rig all the tank and hoses openings were sealed with non-permeable fittings in order to prevent possible fuel leakage during the duration of the test.

Figure 40: Fuel delivery system test rigs containing the fuel tank and fuel hoses of the vehicles.

After the test rig construction, the actual test procedure starts. The first step is to fill the fuel system to its nominal capacity (this refers mainly to the fuel tank capacity) with the appropriate fuel. If the test rig contains also the fuel pump it is turned on for a few seconds in order to allow the fuel to circulate through the fuel lines. After that, the system is placed in the temperature-controlled room and the conditioning period starts. The temperature in the room is kept constant at around 30°C in order to reach the permeation rate stabilization point as quickly as possible. Figure 41 shows the temperature variation in the test room during the 10-week conditioning period.

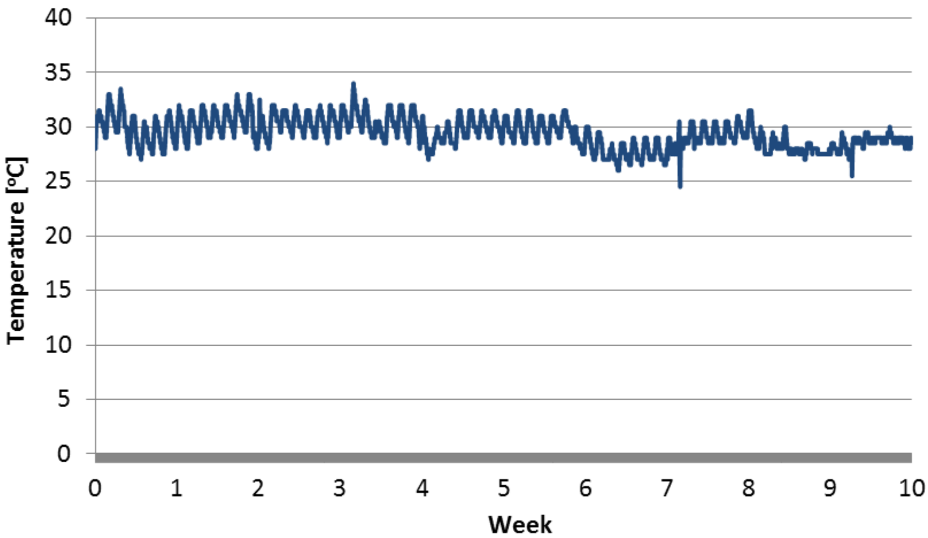


Figure 41: Temperature recording in the conditioning test room during permeation tests.

During the conditioning phase, each test rig is weighted once per week to determine the permeation rate of that week. By dividing the measured weight loss by the internal surface of the fuel tank and fuel lines, and the number of days between the last two weight recordings (typically seven days) a permeation rate in g/m²/day is calculated. The conditioning period ended when the permeation rate stabilized. Stabilization was established when the four-week average of the permeation rate reversed in trend, i.e. when the average rate either increased or decreased over the previous trend’s rate.

An example is shown in Figure 42. The last four-week average value before the trend is reversed is considered the final permeation rate. This method of establishing stabilization of the permeation rate is consistent with the CRC study of Haskew et al. (2006). In the final step the fuel tank and fuel lines are drained and filled with the next test fuel.

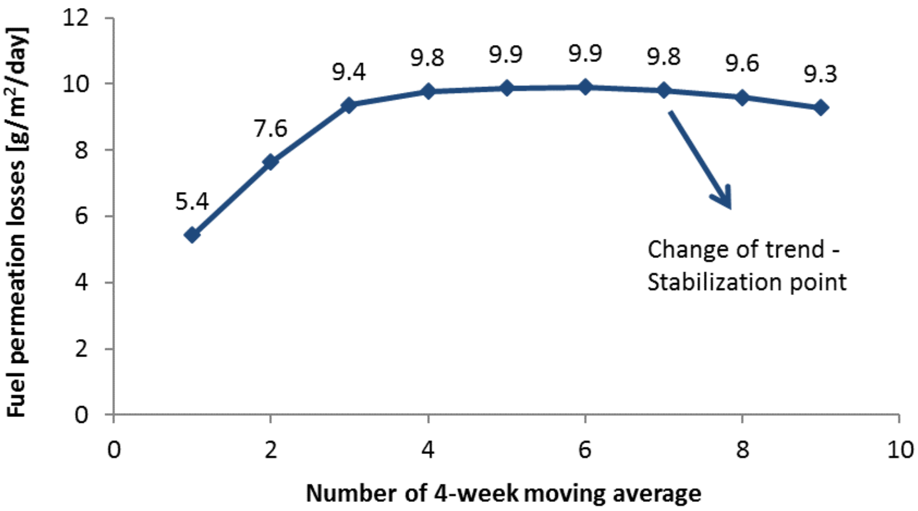


Figure 42: 4-week moving average permeation rate

6.7.4 *Test results and discussion*

<u>Carbon canister ageing</u>

One carbon canister with a volume of 0.55 lt from an L5e-A vehicle with a 26 lt fuel tank capacity has been tested. Typically, there are 300 grams of activated carbon contained in a one-litre canister, hence there are around 165 g of activated carbon in the test canister.

The canister fuel storage capacity with number of cycles is depicted in Figure 43.

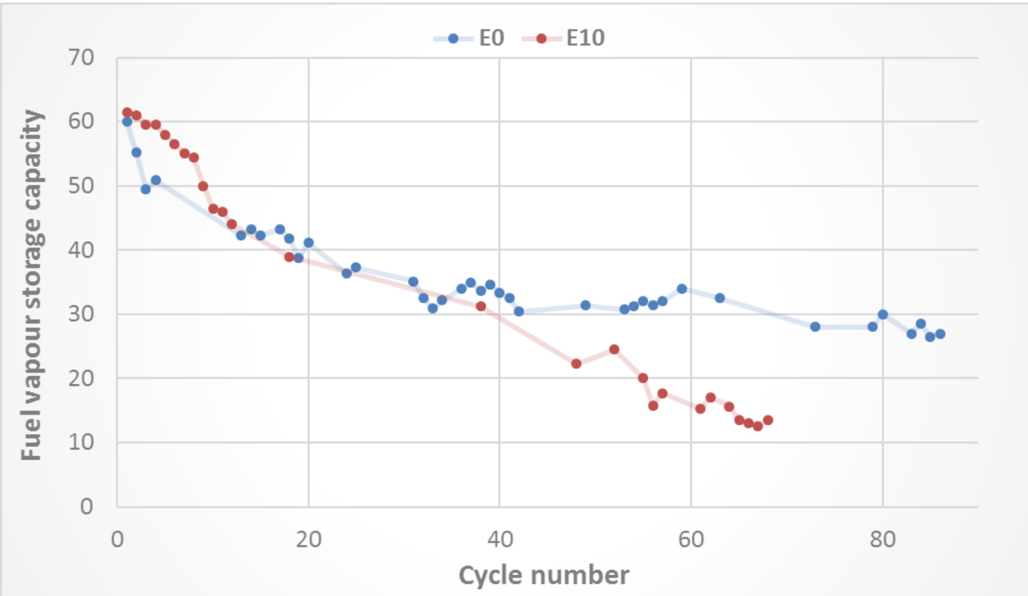


Figure 43: Fuel storage capacity of Canister 1 during the ageing process with E0 and E10.

For the non-ethanol containing fuel (E0) the working capacity of the canister is 27 g, whereas this is reduced to about 15 g after repeated cycles with ethanol-containing fuel (E10). This additional loss in capacity is explained by the fact that ethanol is a polar molecule forming chemical bonds with the activated carbon and hence being more difficult to purge. In comparison, vapours of a pure hydrocarbon fuel form loose bonds of electrostatic nature with the activated carbon and can be thus purged more easily.

It should be noted however that in both cases (loading with E0 and E10) an “extended” purging process can increase the canister storage capacity and restore it to the initial values.

The above are consistent with findings of the German and Swedish in-use compliance programmes which were used, i.a. in the modelling work conducted with COPERT for the revision of the current evaporative emissions test procedure for Euro 6 light-duty vehicles (Haq et al., 2013). In this study there were different carbon degradation factors suggested for ethanol and non-ethanol containing fuels for three different vehicle sizes (small, medium, large). For small size cars (assuming these have more similarities with L-category vehicles) a 13% carbon efficiency loss over vehicle lifetime was found for E0, which increases to about 20% (i.e. 50% higher) for E10.

<u>Fuel tank permeation</u>
Three typical fuel systems were tested for investigating the impact of ethanol content on fuel permeation over time. To this aim three vehicles of the categories L3e, L5e-A and L7e-A were selected and the parts of their fuel delivery system were used in the construction of the above-mentioned test rigs. The main technical characteristics relevant for the permeation tests of the selected vehicles and the fuel systems used are summarized in Table 37.

Table 37: Vehicle characteristics and fuel system parts used for the permeation tests

Fuel tank code	Vehicle category	Fuel tank material	Fuel tank capacity	Parts used in permeation tests
P1	L5e-A	Plastic	26	Fuel tank and part of fuel lines
P2	L3e-A3	Steel	23	Fuel tank and part of fuel lines
P3	L7e-A	Plastic	17.5	Fuel tank, fuel pump and fuel lines

The measured permeation rates for the three fuel systems tested are presented in Table 38. These rates correspond to permeation rates after stabilisation was achieved according to the protocol described previously.

Table 38: Stabilised permeation rates (g/m^2/day) found for the three fuel tank systems measured

Fuel tank code	Vehicle category	E0	E5	E10
P1	L5e-A	0.21	0.39	0.34
P2	L3e-A3	0.22	0.32	0.31
P3	L7e-C	9.8	10.6	9.5

The fuel permeation rates of the P1 and P2 tanks are very low, on the order of 0.2 to 0.4 g/m^2/day when tested with ethanol-free fuel (E0). These rates are considerably lower than the 1.5 g/m^2/day Euro 5 limit of the legislation.

The P2 is a steel fuel tank and only some parts (fuel tank neck and fuel lines) are plastic. Therefore, its permeation rate is by definition low. The P1 fuel tank is taken from a L5e-A vehicle that is already subject to SHED testing and hence equipped with a low permeability multi-layer plastic fuel tank in order to pass the type IV test. This explains the low permeation rate found.

Even though the emission rates found for these two fuel tank systems are very low, the effect of ethanol is visible.

In absolute terms, however, this effect is relatively low (0.1 to 0.2 g/m^2/day) and is consistent with findings of the CRC study reporting a 0.3 g/day average diurnal permeation rate increase for E10 compared to E0. The latter value of 0.3 g/day refers to bigger fuel tanks fitted in passenger cars in which the capacity is typically 2-2.5 times higher than the P1 and P2 tested here.

The permeation emissions level of the P3 fuel tank system is significantly higher compared to the other two fuel systems examined. This is explained by the fact that this fuel system is typically fitted in L6e and L7e-C vehicles which are not subject to any evaporative emissions testing. The effect of different fuel tank material and structure (mono-layer vs multi-layer) is widely recognised, for example in a recent study of the JRC in support of the revision of the current evaporative emissions test procedure for Euro 6 light-duty vehicles (Haq et al., 2013).

The evolution of the measured permeation rates for the P3 fuel system are presented in Figure 44, whereas Figure 45 shows the 4-week average used to determine stabilisation.

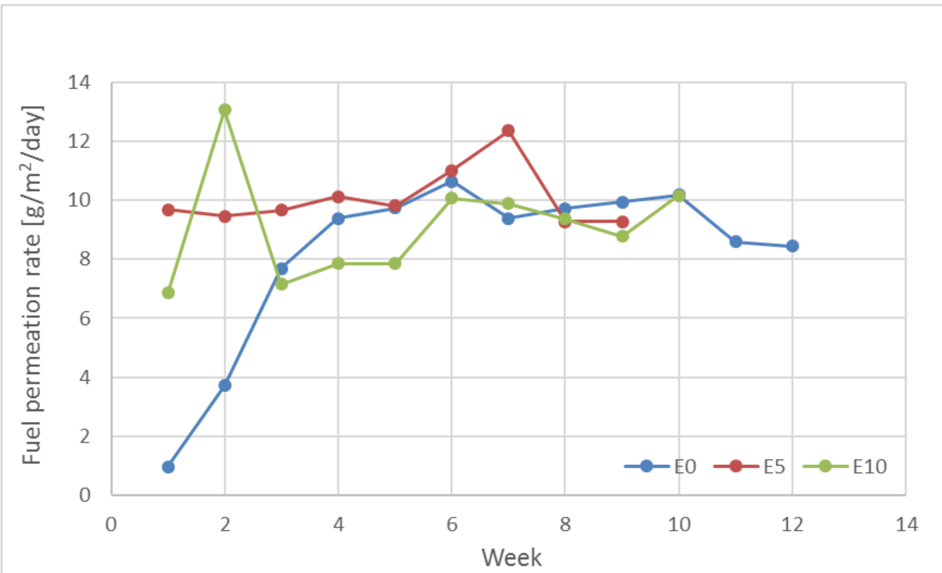


Figure 44: Fuel permeation rate for the P3 fuel delivery system.

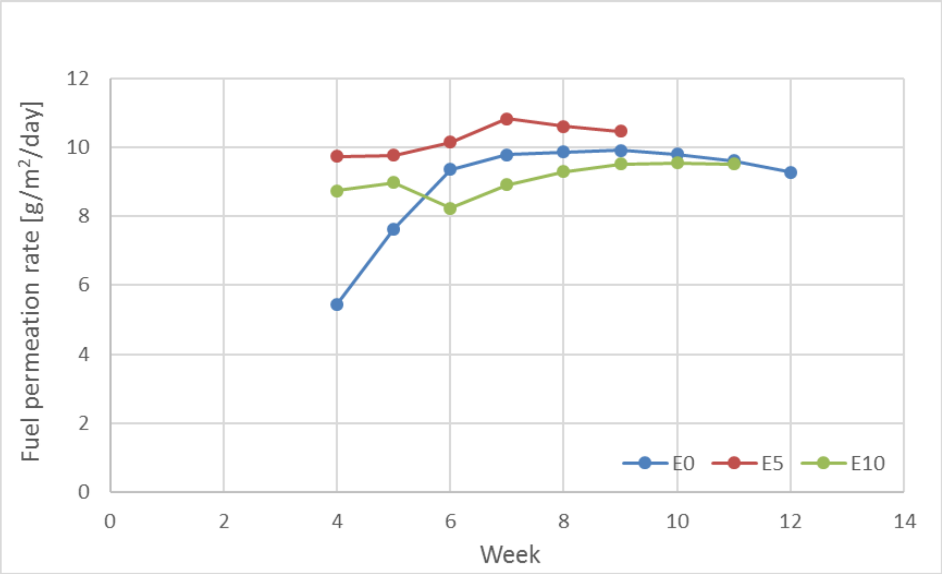


Figure 45: 4-week moving average permeation rate for the P3 fuel delivery system.

The time required for stabilisation ranged from 8 to 10 weeks and is consistent with stabilisation times found in the CRC report (5 to 13 weeks).

Contrary to the other two fuel systems (P1 and P2) the effect of ethanol is not obvious for the P3 fuel system. Whereas a slight increase in permeation emissions is observed for the E5 fuel compared to the E0, the respective rate for E10 is closer to the E0. Hence, there is no clear indication of any ethanol effect for this fuel tank with extremely high permeation emission (more than 6 times the Euro 5 permeation test limit of 1.5 g/m²/day).

6.8 Conclusions and recommendations

With regard to the Type IV test results, the following conclusions may be drawn:

- Introduction of fuel system permeation testing for L1e, L2e, L5e-B, L6e-B, L7e-B and L7e-C is a measure technically feasible. Environmental benefits by far exceed technology costs.
- Introduction of SHED testing for L1e, L2e, L5e-B, L6e-B, L7e-B and L7e-C vehicles is not environmentally interesting as this mostly addresses breathing emissions while most evaporation emissions from these vehicles come from permeation losses.
- Hence, it is recommended to apply the permeation test procedure for the L1e, L2e, L5e-B, L6e-B, L7e-B and L7e-C categories.
- Reducing the Euro 5 limit to 1 g/test for L3e, L4e, L5e-A and L7e-A makes little environmental difference as evaporation emissions of these vehicles mostly occur during longer parking events, which an 1-h long test does not address. A longer (12 to 24 hours) diurnal test would be more appropriate to capture these emissions.
- It is recommended to not reduce the Euro 5 limit for the L3e, L4e, L5e-A and L7e-A categories. A longer (12 to 24 hours) diurnal test should be considered for the SHED test procedure.

With regard to the EtOH content in the fuel and its implications on canister efficiency and permeation losses, the following conclusions may be drawn:

- Ethanol has a clear negative impact on carbon canister efficiency, which becomes more apparent with accumulated mileage and canister loading cycles. Fitting of bigger canisters, with larger quantities of carbon contained, would only slightly improve the performance (in terms of evaporation losses) of vehicles.
- A proper purging of the canister during vehicle operation is essential to ensure evaporative emissions remain at low levels. The importance of the vehicle purging strategy however is not reflected in the current type approval test. Therefore, real-world operation of actual vehicles may significantly vary, despite these have been approved according to the same test. The impact of purging strategy becomes more important for ethanol blends.
- It should always been taken into account that different qualities of carbon are available in the market. Low degradation carbons lose about 4% to 9% of their capacity over the lifetime of the vehicle, due to repeated cycling with fuel, whereas high degradation carbons lose about 12% to 20% of their capacity. Selection of low grade or high grade carbon is at the manufacturer discretion and is not affected by the current type-approval procedure.
- The negative effect of ethanol on permeation emissions is also well demonstrated in different studies. The exact amount of ethanol blended in petrol (for low – up to 10% v/v – blends) does not seem to have any significant effect; it's rather the presence of ethanol in petrol that increases permeation emissions. The increase is in the order of 50%.
- The current SHED test cannot capture high emitting fuel tanks because of the limited duration (about on hour) of the test. Hence, the effect of ethanol is rather insignificant for the SHED test and may discourage vehicle manufacturers to use low-permeability tanks in their vehicles.
- For vehicles type approved according to SHED, because of the limited short term effects of ethanol blends on canister efficiency and the limited contribution of permeation on hydrocarbon loss because of the short duration of the test, the impacts of low ethanol blends are considered marginal, if existent, over neat petrol fuel.
- For vehicles type approved according to permeation testing, ethanol blends will increase permeation losses. The difference from E5 to E10 is however marginal. Increase of the reference fuel ethanol content (E5 to E10) is not considered to require an adjustment of the permeation limits.
- Changes in the SHED testing procedure will be required to control evaporation emissions in the real world. Longer duration of tests or change in the order of testing (diurnal, drive cycle, hot soak) can be examined as possible options. Durability type of regulation for the canister should be in the position to check both carbon quality and purging strategy. Inclusion of evaporation emissions check to potential ISC testing would also potentially be effective in controlling real-world emissions.

7 Type V – Durability of pollution-control devices

7.1 Background

According to article 23 of Regulation (EU) No 168/2013, durability testing of L-category vehicles is based either running the full distance or running half distance and extrapolation of the useful life in Annex VII of Regulation (EU) No 168/2013. As a third option, a mathematical procedure can be applied at the choice of the manufacturer.

According to Article 23(4) and (5) of the same Regulation, these durability requirements need to be confirmed by collecting and evaluating latest scientific data and findings. The intention of the durability distance accumulation cycle is to replicate common part-load conditions and to repeat this over the useful life distance, as set out in Annex VII(A) to Regulation (EU) No 168/2013.

For the physical mileage accumulation over the full or half distance of the useful life, the manufacturer can choose from two mileage accumulation cycles to accumulate the full or half distance. The first mileage accumulation cycle is the Standard Road Cycle for L-category Vehicles (SRC-LeCV) mileage accumulation cycle, developed by TRL (Nathanson et al., 2012) and as described in Appendix 1 of Annex VI of Regulation (EU) No 134/2014. The second mileage accumulation cycle manufacturers can choose to apply is the US EPA Approved Mileage Accumulation (AMA) durability cycle as described in Appendix 2 of Annex VI of Regulation (EU) No 134/2014.

According to 3.4.2 of Annex VI of Regulation (EU) No 134/2014, *the AMA durability mileage accumulation cycle may be conducted as alternative Type V mileage accumulation cycle up to and including the last date of registration set out in point 1.5.2. of Annex IV to Regulation (EU) No 168/2013*. This means that currently the AMA procedure is meant to be phased out after 31.12.2020.

As clearly described in the United Stated Environmental Protection Agency (US EPA) final rule that first introduced the Standard Road Cycle (SRC) for passenger cars, the durability demonstration process should be designed not to reflect realistic ageing conditions but to predict expected in-use deterioration rates and emission levels that represent a significant majority (approximately 90%) of the distribution of emission levels and deterioration in actual use. In the same document it is stated that the AMA cycle was developed before vehicles were equipped with catalytic converters. It is in fact focused mainly on low speed driving responsible for deposit formation that was the main emission deterioration mechanism in engines without after-treatment devices.

Both mileage accumulation cycles consist of successions of accelerations and decelerations to fixed target velocities. The target velocities depend on the vehicle specifications. The distance accumulation may be performed on a test track, but also on a dynamometer. In the latter case robot-operated driving is allowed, due to the length of the procedure.

Although vehicle speed correlates well with engine speed, it does not correlate well with thermal exposure which mainly depends on engine load. The European Commission has proposed the SRC for L-category vehicles (SRC-LeCV) on the basis of a study of TRL (Nathanson et al., 2012) in which the AMA, the SRC and the WMTC were compared. It was found that the SRC shared a greater similarity with the varied real-world use represented in the WMTC emission cycle than the AMA, meaning that the SRC was a better basis for the design of a cycle compatible with L-category vehicles (the SRC-LeCV).

In addition, it was found that while simulating moderate vehicle ageing conditions representative for average driving conditions around the world, the SRC-LeCV (based on engine speed and load of the WMTC) can be executed in average twice as fast than the AMA cycle which leads to significantly lower development cost and greater flexibility in the design process of the vehicle.

It should also be pointed out that the TRL study (Nathanson et al., 2012) found that the SRC-LeCV includes multiple coast-through decelerations, which the AMA cycle lacks as there are no deceleration prescriptions defined for this test cycle. Coast-through deceleration possibly triggers deceleration fuel cut-off which results in cold intake air striking on a hot catalyst for a prolonged time, which has been determined as one of the main thermal ageing contributors of the emission abatement components in the exhaust.

However, the backside is that the AMA distance accumulation cycle is wide-spread over the globe as single motorcycle durability test procedure and it may take time and effort to convince other countries of the need to abandon the AMA cycle too and replace it with the SRC-LeCV.

7.2 Specific objectives

The first specific objective is to **deliver Supplemental validation of the distance accumulation cycle (SRC- LeCV)**. Secondly this study shall **assess the appropriateness of the useful life distances shall as well as the deterioration factors of Annex VII(B)** to be used in the mathematical durability procedure, as defined in the Annex VII of Regulation (EU) No 168/2013. In addition the objective is **to determine by when after 2020 the obsolete AMA cycle shall be phased out** and be deleted from Regulation (EU) No 134/2014 as alternative Type V distance accumulation test procedure. Lastly, this study shall provide **a cost effectiveness analysis based on the measurement programme** and validate the economic analysis provided in the 2013 durability study of TRL (Nathanson et al., 2012).

Mileage accumulation cycles
The main questions on mileage accumulation cycles within the durability requirements, especially in the light of the emission control technology needed for Euro 5 emission limits, is how well the procedures predict expected in-use deterioration rates and emission levels that represent a significant majority (approximately 90%) of the distribution of emission levels and deterioration in actual use. One could argue that the two mileage accumulation cycles are not equivalent due to the different thermal load they will introduce to the catalyst – which, as found in the study of TRL (Nathanson et al., 2012), is the most relevant emission control device for L-category vehicles – imposed by their speed profile.

The intention of a mileage accumulation cycle is to replicate everyday part-load conditions and to repeat this over the useful life distance, set out in Annex VII(A) to Regulation (EU) No 168/20143. The WMTC was developed as a worldwide standardized cycle for on-road L-category vehicle operation, and shall be the benchmark for the analysis of mileage accumulation cycles (Nathanson et al., 2012).

This study among others will be used as well to provide scientific evidence within the EU but also to the international community under the UNECE umbrella to underpin the relevance of the SRC-LeCV and to advocate the possible gradually phasing out of the AMA cycle beyond 2020 within the EU and possibly at the world level.

Deterioration Factors and Useful Life Values

According to Article 23(3c) of Regulation (EU) No 168/2013 one of the three alternative durability procedures is the method referred to as “mathematical method”. In this procedure the Type I emission test results – executed on a vehicle that has been run in according to the manufacturers’ specification and has driven at least 1000 km before the test – shall be multiplied with the fixed deterioration factors set out in Annex VII(B) of Regulation (EU) No 168/2013 in order to account for vehicle and exhaust gas abatement ageing effects.

It is anticipated that the mathematical method hardly provides a true image of an aged vehicle from the fleet and its effectiveness might be marginal to zero as this method might only be an incentive to design a new vehicle to be very clean. The mathematical method as stand-alone method may not safeguard that the actual ageing slope of the tailpipe emissions will stay consistently under the applicable emission limits laid down in Annex VI(A) during its useful life (representative distance collected as set out in Annex VII(A)). Although perhaps not effective, it is on the other hand very cheap in comparison to the alternatives set out in article 23(3a) of Regulation (EU) No 168/2013 actual and full distance accumulation and in article 23(3b) of Regulation (EU) No 168/2013 allowing partial distance accumulation. Confirmation of these assumptions are subject of this study. If the assumptions are confirmed by this study, they are also to be addressed in this study.

7.3 Assessment of the two mileage accumulation cycles SRC-LeCV and AMA

The catalyst of L-category vehicles is the most important emission control device that suffers from ageing. The durability demonstration process (Type V) should be designed to predict expected in-use deterioration rates of emissions that effect from ageing of the emission control devices.

The assessment of the two mileage accumulation cycles starts with a theoretical comparison of the vehicle speed distribution in the different cycles, based on the of the different mileage accumulation cycles and the WMTC. In reality the catalyst does not age by exposure to high vehicle speeds, resulting in high engine load and speeds, but mostly due to exposure to thermal load, for which high engine load and speeds and thus high vehicle speeds can be taken as a proxy.

The outcome of the first assessment that is described in this paragraph is mirrored to an assessment of engine map coverage of the different cycles, so a direct comparison of the measured engine load and speed measured in the different cycles. Lastly the thermal load to which the catalysts of the test vehicles in this programme

are exposed in the different cycles (WMTC, AMA and SRC-LeCV) is assessed. This third assessment is an extensive and advanced validation of the theoretical assessment and the engine map coverage comparison.

Exposure to thermal load is not the only factor which leads to catalyst deterioration. Also factors such as thermal shock, poisoning and physical deteriorating - as a results of plugging or cracking - can have an effect. According to United States legislation for the durability demonstration of exhaust emissions, 90% is caused by thermal deactivation (US EPA, 2016). Also the earlier TRL study concluded that the main contributor to catalyst deterioration is thermal deactivation. Thermal deactivation consists of thermal load and thermal shock. The thermal load on a catalyst is based on the level of the exhaust gas temperatures and the duration of exposure to these temperatures. The thermal shock on a catalyst is based on the temperature change rate (℃/s) of the exhaust gas.

As already mentioned before, the TRL study (Nathanson et al., 2012) concluded that SRC-LeCV includes multiple coast-through decelerations, which the AMA cycle lacks as there are no deceleration prescriptions defined for this test cycle. Coast-through deceleration possibly triggers deceleration fuel cut-off which results in cold intake air striking on a hot catalyst, *e.g.* thermal shock.

The earlier finding of TRL on the coast-through decelerations are argued by this study. It is true that no deceleration prescriptions are defined in the AMA procedure, while the SRC-LeCV includes clear deceleration prescription. However the AMA procedure does include multiple coast-through deceleration. The number of coast-through decelerations per kilometer is even higher than in the SRC-LeCV. The decelerations in the AMA, performed according to best insight of the operator that is driving the test on a track, will be performed by releasing throttle (leading to fuel cut-off) either with or without combined braking.

This means that coast-through decelerations and the resulting effect (thermal shock) on catalyst deterioration are part of both procedures. The prolongation of the time to which the catalyst is exposed to the thermal shock is depending on the way the driver performs the braking. The effect of possible shorter prolongation of thermal shock in individual coast-through deceleration, in the worst case occasion that the operator applies braking, is fully compensated by the fact that the AMA includes a higher number of coast-through decelerations. Therefore the differences between AMA and SRC-LeCV with respect to the effect of thermal shock effecting from coast-through decelerations is estimated to be negligible.

Also, on average the contribution of thermal shock to thermal deactivation is found marginal compared to thermal load (Boll et al., 2013; Bonifer, 2016). In individual cases, the effect of thermal shock, poisoning and physical deterioration can be determining factors in catalyst deterioration, but on average thermal load can be seen as the main contributor to catalyst deterioration.

7.3.1 Theoretical comparison of the share of high speed driving in the cycles as a proxy for engine load

As will be explained in more detail later, high vehicle speeds – close to maximum design speed of a vehicle – introduce high engine load, as the engine has to deliver high power output to reach high speeds. Therefore, the share of high speed driving

– defined as the ratio between 'average cycle speed' and 'vehicle maximum design speed' – is an important parameter that can be used as a proxy for engine load. Engine load can be seen as a proxy for thermal load. This theoretical comparison of the ratio between 'average cycle speed' and 'vehicle maximum design speed' of the different mileage accumulation cycles and the WMTC is explained in this sub-section.

Average cycle speed as a proxy for load introduced to the powertrain

Appendix O shows the speed profile of each driven cycle within this project, including the WMTC, SRC-LeCV and AMA cycles. As a summary, Table 39 shows the specifications of these driving cycles. For some specific vehicles multiple columns will deviate from this table as the target cycle speed of the cycle cannot always be met by all vehicles, which is allowed within the requirement of the test procedure. Moreover, the accelerations and decelerations of SRC-LeCV and AMA are based on instructions, such as 'moderate acceleration', and thus very vehicle specific. RPA (relative positive accelerations) and v*a positive (speed * accelerations) are acceleration based parameters which cannot be calculated for both durability cycles because of the instruction based acceleration and since this is very vehicle specific.

Table 39. cycle parameters of the WMTC, SRC-LeCV and AMA

Cycle			Time	Expected distance	Average speed	Max speed	avg speed / max speed	Idling	Constant speed	v*a positive	RPA
			[sec]	[km]	[km/h]	[km/h]	[-]	[%]	[%]	[m2/s3]	[m/s2]
Type I	WMTC	Class_I_reduced_25	1200	5.9	18	25	0.71	20	57	3.40	0.80
		Class_I_reduced_45	1200	7.6	23	45	0.51	19	27	3.72	0.60
		Class_I	1200	7.7	23	50	0.46	19	22	3.67	0.58
		Class_2_1	1200	12.3	37	83	0.45	13	24	5.23	0.54
		Class_2_2	1200	13.2	40	95	0.42	13	23	6.22	0.59
		Class_3_1	1800	27.6	55	111	0.50	9	30	6.73	0.54
		Class_3_2	1800	28.9	58	125	0.46	9	30	6.88	0.53
Type V	SRC-LeCV	Cycle_1_25kmh	4564	30.0	24	25	0.95	1	94	-	-
		Cycle_1_45kmh	3101	30.0	35	45	0.77	2	91	-	-
		Cycle_1_50kmh	3051	30.0	35	50	0.71	2	91	-	-
		Cycle_2	1856	30.0	58	100	0.58	4	85	-	-
		Cycle_3	1548	30.0	70	100	0.70	4	80	-	-
		Cycle_4	1209	30.0	89	130	0.69	5	68	-	-
	AMA	Class_I_45kmh	6300	66.0	38	45	0.84	9	65	-	-
		Class_I	5504	66.0	43	70	0.62	11	50	-	-
		Class_II	5366	66.0	44	90	0.49	11	49	-	-
		Class_III_option_I	5359	66.0	44	110	0.40	11	50	-	-
		Class_III_option_II	5328	66.0	45	110	0.41	11	48	-	-

In the table especially the columns 'average speed', 'maximum speed' and 'constant speed' are important parameters used for this assessment. The share of constant speed driving in the SRC-LeCV and AMA is significantly higher than the share of constant speed driving in the WMTC. With this high share of constant speeds, the average vehicle speed is an important cycle parameter to indicate the load a durability cycle introduces to a vehicle powertrain.

As shown Table 39 the variety in average speed between the different AMA cycles is – unlike the WMTC - very low. Figure 46, which depicts the speed distribution per cycle, clearly shows the same low variety. The speed bin 0 is dedicated to stop phase, while bin 0-5 is dedicated to start phases after stop or phases just before stop.

The different AMA cycles – meant for vehicles with different specs – are very similar in terms of average speed. All AMA classes are comparable with WMTC class 2 in terms of average cycle speed. In general this would mean that the AMA – when compared to the WMTC – introduces a higher engine load (and thus thermal load) to the powertrain of WMTC class 1 vehicles, but introduces lower engine load to vehicles from WMTC class 3 vehicles. This statement is supported by the fact that for all AMA cycles, the majority of the time the target speed is lower than 75 km/h, as shown in Figure 46 and finding of the pre-study of DG JRC (Zardini, 2014). Compared to WMTC class 3 and SRC-LeCV cycle 4, the maximum speed for AMA class III is rather low with 110 km/h.

The SRC-LeCV does have a wide variety in average speeds. However, the average speeds are significantly higher than the average speeds of corresponding WMTC classes. Which imposes that the SRC-LeCV introduces a load to the powertrain of the vehicle which on average is higher than the load a corresponding WMTC would introduce. This also becomes clear from a comparison of the maximum cycle speed and the average cycle speed. This ratio of average speed / maximum speed (see Table 39) is on average a lot higher for the SRC-LeCV than for the WMTC. Also Figure 46 shows that the SRC-LeCV cycles 3 and 4, when compared to the comparable WMTC and AMA cycles, are more focussed at the higher speed ranges, which again imposes a higher load that is introduced to the powertrain.

Share of high speed driving in the cycles as a proxy for engine load

High vehicle speeds – close to maximum design speed of a vehicle – introduce high engine load, as the engine has to deliver high power output to reach high speeds. Therefore the share of high speed driving – defined as the ratio between ‘average cycle speed’ and ‘vehicle maximum design speed’ – is an important parameter that can be used as a proxy for engine load. This ratio representing the share of high speed driving is calculated for the different sub-classes of the WMTC, AMA and SRC-LeCV. The higher the ratio, the higher the share of high speed driving because the closer the average cycle speed is to the maximum vehicle speed, and thus the higher the engine load. Figure 47 shows these ratios for every cycle as a function of the maximum vehicle design speed, which can be seen as proxy for engine load.

From Figure 47 it shows that all cycles have a higher share of high speed driving for vehicles with a low or moderate maximum vehicle design speed, as one might expect. Especially for vehicles with a maximum design speed up to 75 km/h this is caused by full speed driving during a relatively large part of the cycle. This is also representative for the everyday operation of the majority of these vehicles. For example a moped with a maximum design speed of 45 km/h will often drive in its high speed range. Figure 47 also shows that vehicles with a high maximum design speed have a relatively lower share of high speed driving, thus a lower average engine load.

The SRC-LeCV and WMTC show a clear difference between the different cycle categories, while for the AMA there are no difference between the different cycle categories. This is acceptable, because this delivers no “unfair advantage” for the AMA over the WMTC in terms of engine load, as the ratio is still always high compared to the WMTC. Lastly it can be observed from Figure 47 that share of high speed driving – and thus the engine load – is clearly higher for the SRC-LeCV sub-cycles than for the WMTC throughout the complete speed range.

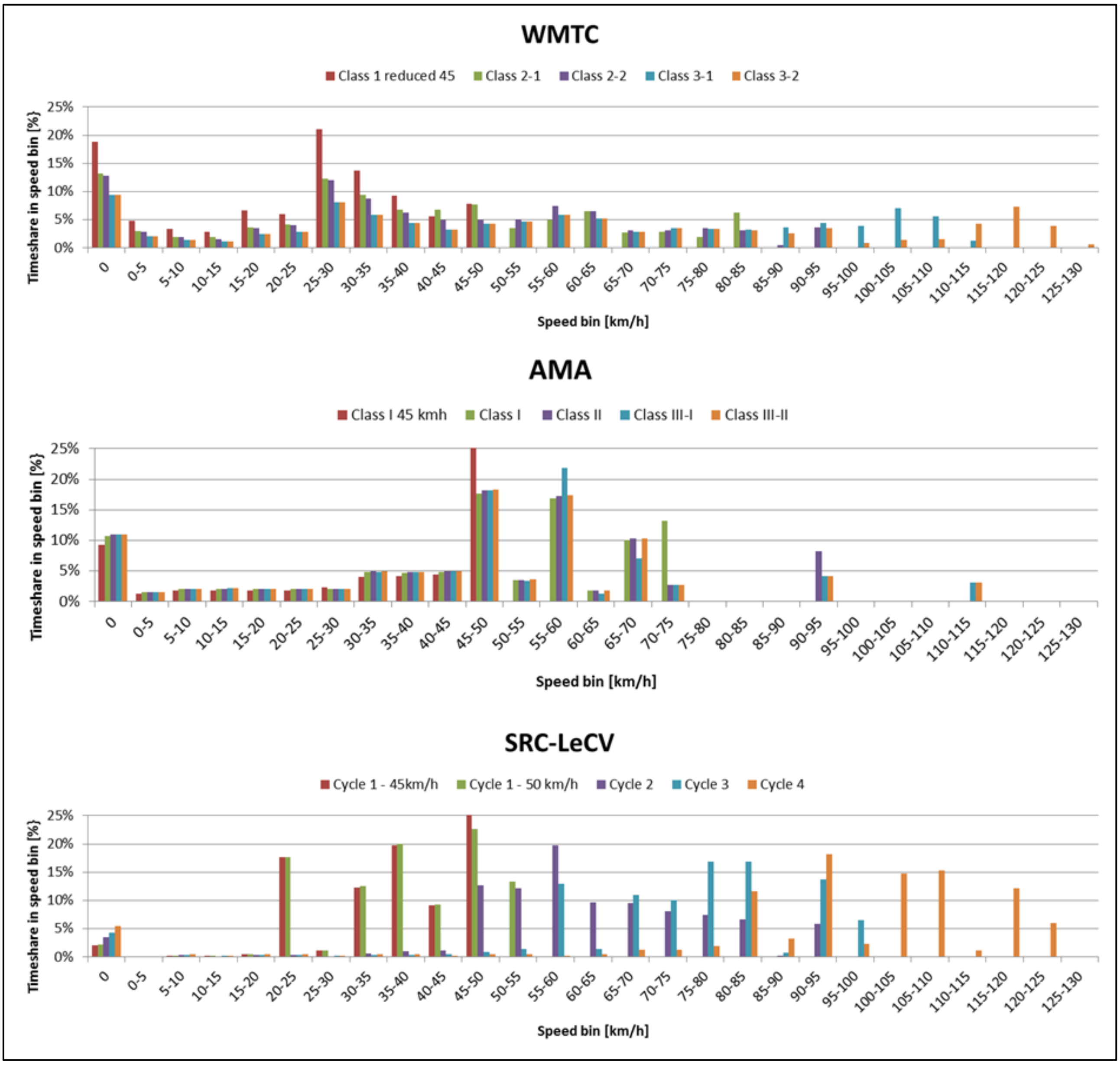


Figure 46: speed distribution per cycle (contains all velocities, including the accelerations and decelerations). For the 45 km/h cycle versions of the AMA and SRC-LeCV (red bars) not the complete timeshare is shown in the bin ‘45-50’, as this does not fit on the scale of the figure and extending the scale would make the other bins unreadable. The timeshare for bin ’45-50’ is 67% for the AMA and 37% for the SRC-LeCV. The speed bin 0 is dedicated to stop phase, while bin 0-5 is dedicated to start phases after stop or phases just before stop.

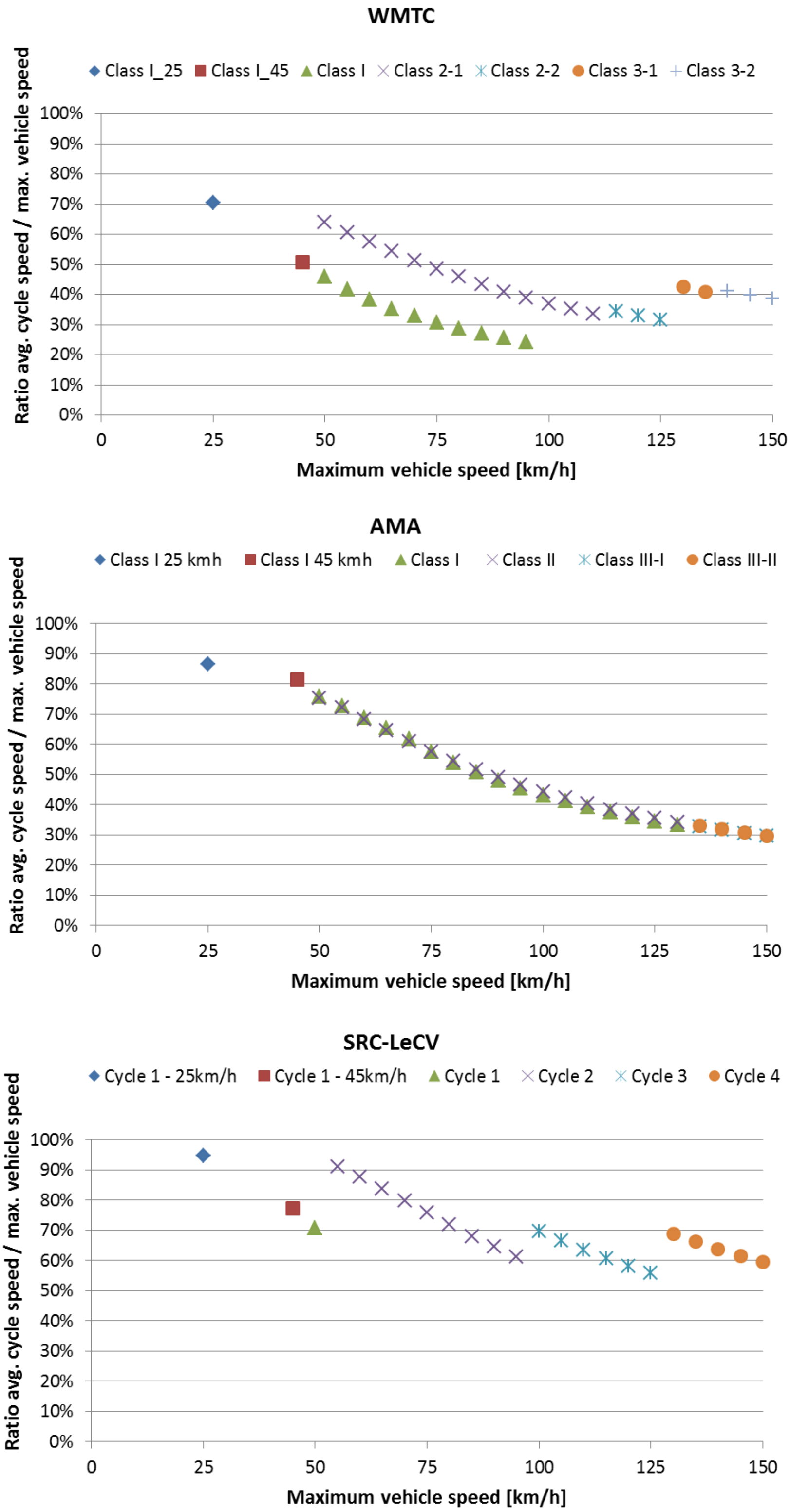


Figure 47 ratio between 'average cycle speed' and 'maximum vehicle speed' – which can be seen as proxy for engine load for the different classes of the WMTC, AMA and SRC-LeCV

To compare the engine load introduced by the AMA and the SRC-LeCV, the share of high speed driving in these cycles can be referenced to the share of high speed

driving in the WMTC. For this purpose the difference between the share of high speed driving in the AMA or SRC-LeCV and the WTMC is calculated. A difference close to zero means that the share of high speed driving – and thus the engine load introduced by the durability cycle – is comparable to the WMTC. When the difference more than zero, the share of high speed driving – and thus the engine load introduced by the durability cycle – is higher than in the WMTC.

Figure 48 shows this comparison of AMA and the SRC-LeCV. For both the SRC-LeCV as well as for the AMA partly two lines for the same max vehicle speeds are observed. This is clarified by the speed overlap in WMTC class 1 and class 2. Clearly, the SRC-LeCV contains more high speed driving than the WMTC. Meaning that the engine load introduced by the SRC-LeCV is higher than the engine load in the AMA. Moreover, with the exception for vehicles with a maximum vehicle speed lower or equal to 50 km/h, the share of high speed driving of the SRC-LeCV is higher than the AMA. Especially for vehicles with a maximum speed between 50 and 100 km/h the SRC-LeCV contains a higher share of high speed driving, thus a higher engine load is introduced for these vehicles.

The AMA contains less high speed driving than WMTC for vehicles with a maximum design speed which is higher than 130 km/h. In general the difference between AMA and WMTC is relatively small for vehicles with a maximum design speed between 50 km/h and 130, with the exception for WMTC class I vehicles (see upper line of purple dots in Figure 48).

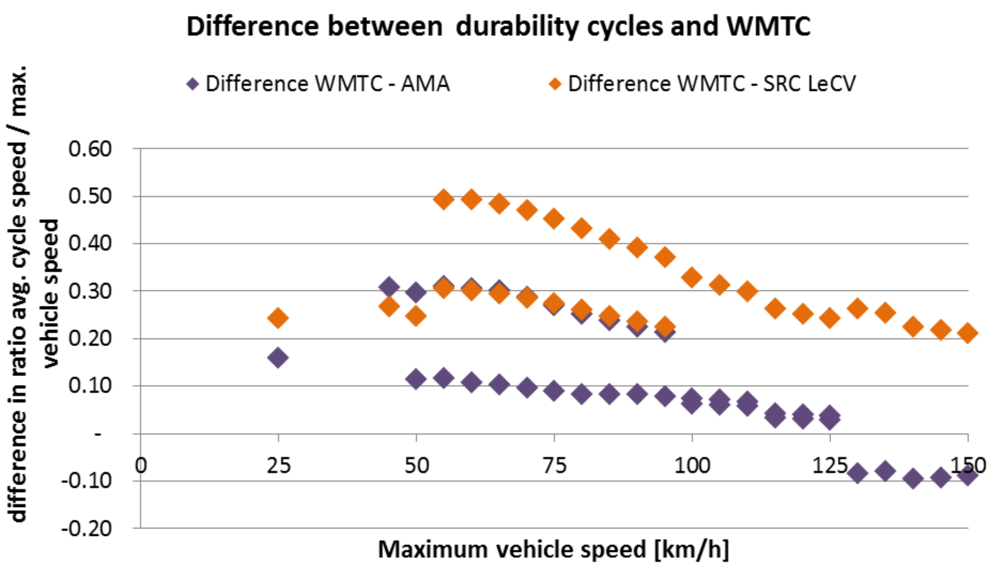


Figure 48: difference between the ratios of the WMTC and both durability cycles

Summary of observation and conclusions from the theoretical comparison of the share of high speed driving in the cycles as a proxy for engine load

Observations and conclusions for AMA

- Except for vehicles with a maximum speed up to 50 km/h, the AMA introduces as much or less engine load than the SRC-LeCV.
- The AMA in general introduces a higher engine load than the WMTC, though no high excursions are observed.
- The AMA introduces especially higher engine load for WMTC class 1 vehicles and mopeds compared to the WMTC.
- In contrast, AMA class III introduces lower engine load than WMTC for WMTC class 3 vehicles.
- Phasing out the AMA is not necessary, as the engine load for AMA in general is not lower than WMTC, so the AMA does not underestimate WMTC engine load condition, except for WMTC class 3 vehicles. This could be expected as US EPA (US EPA, 2016) previously stated that the AMA cycle focused mainly on low speed driving. For vehicles with a lower maximum design speed, the AMA is still well applicable. However phasing out AMA for WMTC class 3 vehicles can be supported by this theoretical comparison.

Observations and conclusions for SRC-LeCV

- The SRC-LeCV introduces significantly higher engine load than the WMTC for all vehicle classes.
- For most vehicle classes, a lower SRC-LeCV classification would lead to a better fit with the WMTC in terms of engine load that is introduced by the cycle.
- It is recommended to align the SRC-LeCV classification table with the WMTC classification. By aligning the SRC-LeCV classification with the WMTC classification, a large part of the vehicles (not all) would be placed one class lower. A proposal for such a revision of the cycle sub-classification is provided in Table 40. This would result in a share of high speed driving that lies closer to those from the WMTC and AMA.

Table 40. summary of the current cycle sub-classification and proposal for a revision of the SRC-LeCV sub-classification "recommended SRC cycle"

WMTC class	Vehicle maximum design speed		Vehicle engine capacity		WMTC cycle	Current SRC cycle classification	Recommended SRC cycle classification
	min	max	min	max			
Class 1	-	≤ 50 km/h	-	≤ 50 cm3	Part 1_R (2x)	Cycle 1	Cycle 1
	> 50 km/h	< 100 km/h	> 50 cm3	< 150 cm3		Cycle 2	
Class 2-1	≥ 100 km/h	< 115 km/h	-	< 150 cm3	Part 1_R + part 2_R	Cycle 2 or 3	Cycle 2
	-	< 115 km/h	≥ 150 cm3	≤ 1500 cm3			
Class 2-2	≥ 115 km/h	< 130 km/h	-	≤ 1500 cm3	Part 1 + part 2		
Class 3-1	≥ 130 km/h	< 140 km/h	-	≤ 1500 cm3	Part 1 + part 2 + part 3_R	Cycle 4	Cycle 3
Class 3-2	≥ 140 km/h	-	-	> 1500 cm3	Part 1 + part 2 + part 3		Cycle 4

When this proposal is introduced into the comparison of the engine load introduced by the AMA and the SRC-LeCV, this leads the scenario as depicted in Figure 49.

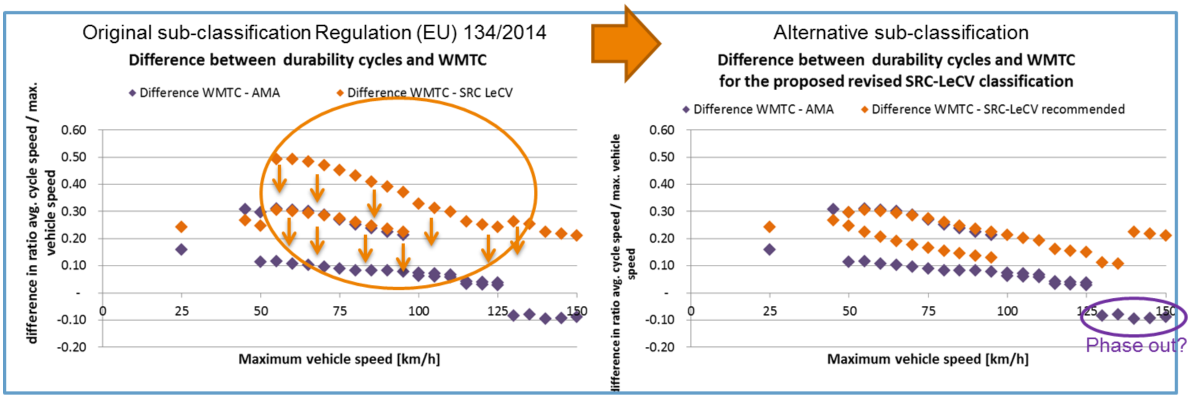


Figure 49. comparison of the engine load of the durability cycles in the sub-classification specified by Regulation (EU) No 134/2014 and the proposed alternative for the sub-classification

A revision of the SRC-LeCV sub-classification leads – according to this theoretical comparison – to engine load conditions that lie closer to those from the WMTC and AMA, without any scientifically unwished counter effects.

7.3.2 Assessment of the engine map coverage

This paragraph provides an assessment of the engine map coverage during the AMA, SRC-LeCV and WMTC. For this evaluation, the engine torque as a function of the engine speed is calculated for each driven cycle and plotted in a graph together with the Wide Open Throttle (WOT) cycle. The results of the analysis of all tested vehicles can be found in Appendix M. It should however be noted, that for some of the measured durability cycles, not all required data was available for the engine torque calculation.

High speed mopeds (L1e-B)

The engine operation area during both the SRC-LeCV and AMA lies within the range of the WMTC and is generally lower than WOT operation. However, on average, the engine operation area of AMA is more close to the WOT operation. Both the AMA and the SRC-LeCV cover a rather concentrated part of the engine map. This is because of the high amount of constant driving during the AMA cycle, and in particular, the SRC-LeCV cycle, certainly when compared to the WMTC. The AMA requires more accelerations and decelerations than the SRC-LeCV and therefore covers a slightly larger engine map area than the SRC-LeCV. From this engine map coverage assessment, the AMA is considered to be more representative for WMTC driving than the SRC-LeCV. On the contrary, if one compares the average engine loads of the WMTC to the AMA and SRC-LeCV, the SRC-LeCV is more representative.

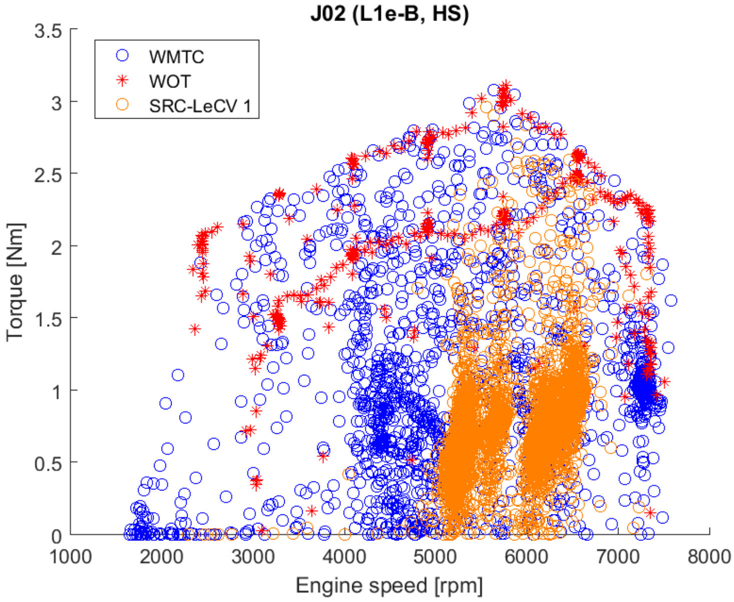


Figure 50. engine map coverage of the WMTC and SRC-LeCV of L1e-B HS (high-speed moped) test vehicle J02. For this vehicle, the engine map coverage data of the AMA is not available

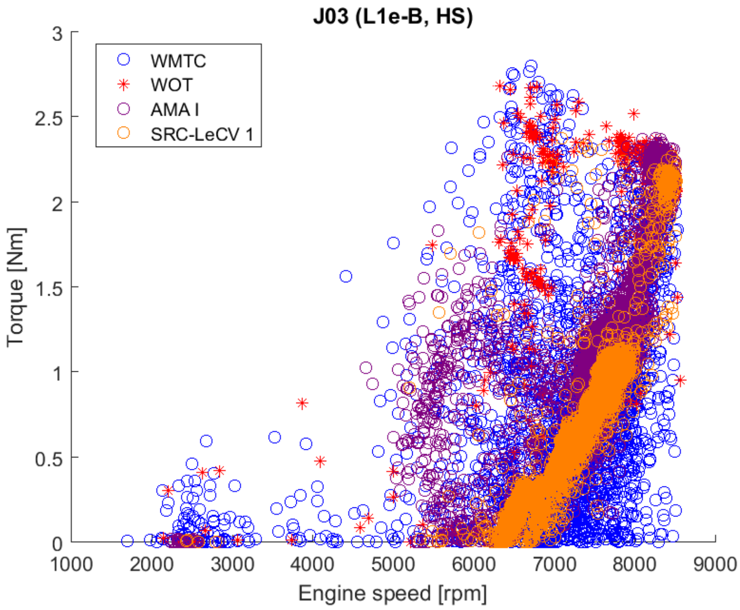


Figure 51. engine map coverage of the WMTC, AMA and SRC-LeCV of L1e-B HS (high-speed moped) test vehicle J03.

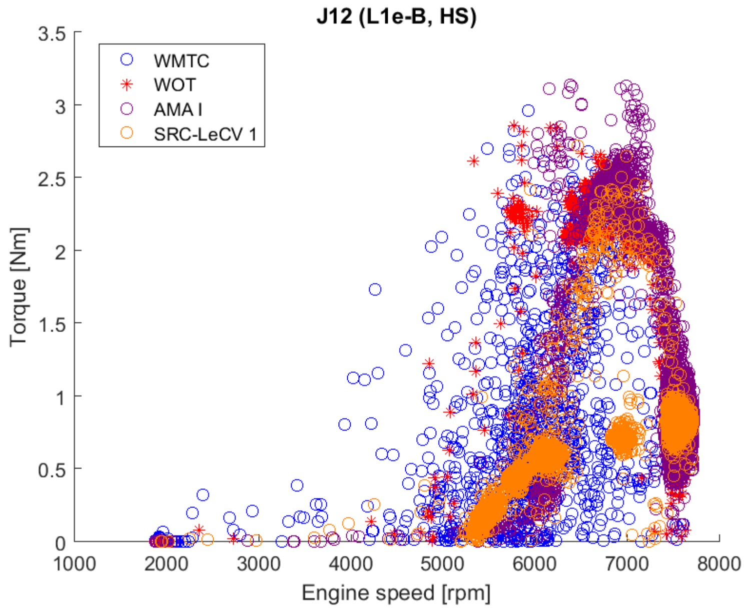


Figure 52. engine map coverage of the WMTC, AMA and SRC-LeCV of L1e-B HS (high-speed moped) test vehicle J12.

WMTC class 1 and class 2 vehicles (except L1e-B)

When mopeds (L1e-B) are excluded, vehicles that fall into WMTC class 1 or 2-1 have a maximum speed between 50 and 115 km/h. According to the sub-classification described in Regulation (EU) No 134/2014, these vehicles shall drive either SRC-LeCV 2 or 3, respectively AMA I or II.

In most of the cases the maximum speed of the durability cycle will be higher or equal to the maximum speed of the applicable WMTC. As a result, the engine operating points of the SRC-LeCV and AMA fall largely within the WMTC operation area. Sometimes the operation area of the SRC-LeCV and AMA is somewhat higher than the WMTC operation area. No results are available for WMTC class 2-2 vehicles. Though, for these vehicles this issue is less relevant, because the designated WMTC has a higher maximum speed.

For the examined WMTC class 2-1 vehicles, the AMA generally covers a larger part of the WMTC operation area than the SRC-LeCV. The AMA better covers the lower engine operation area, *i.e.*, lower engine speeds and lower engine torques. The engine operation area of the SRC-LeCV is generally concentrated at relatively high engine speeds and torques.

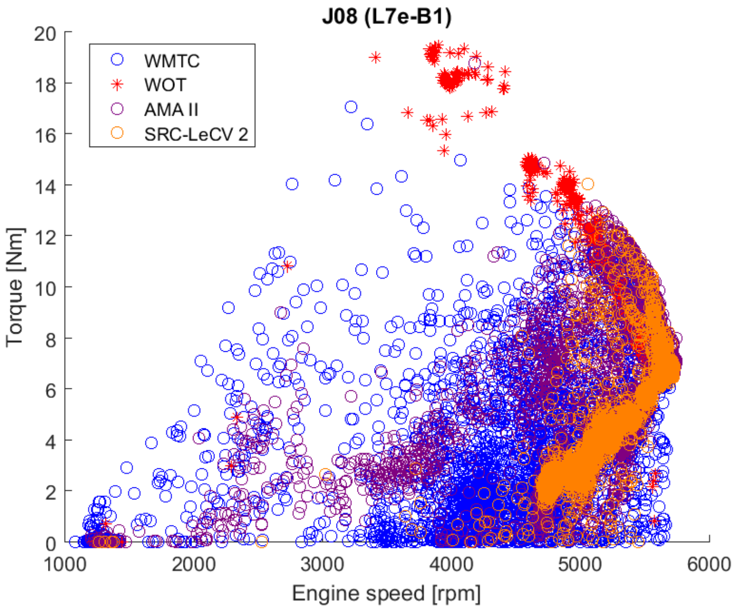


Figure 53. engine map coverage of the WMTC, AMA and SRC-LeCV of L7e-B1 test vehicle J08

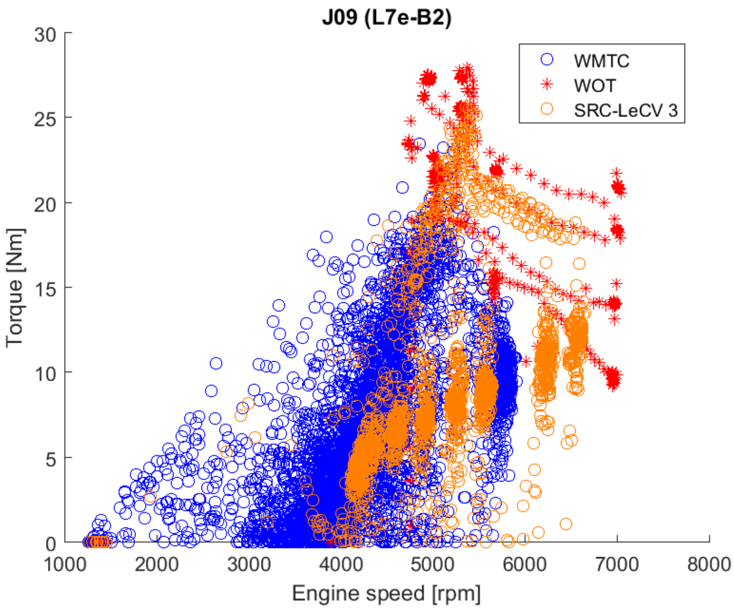


Figure 54. engine map coverage of the WMTC and SRC-LeCV of L7e-B2 test vehicle J09. For this vehicle, the engine map coverage data of the AMA is not available

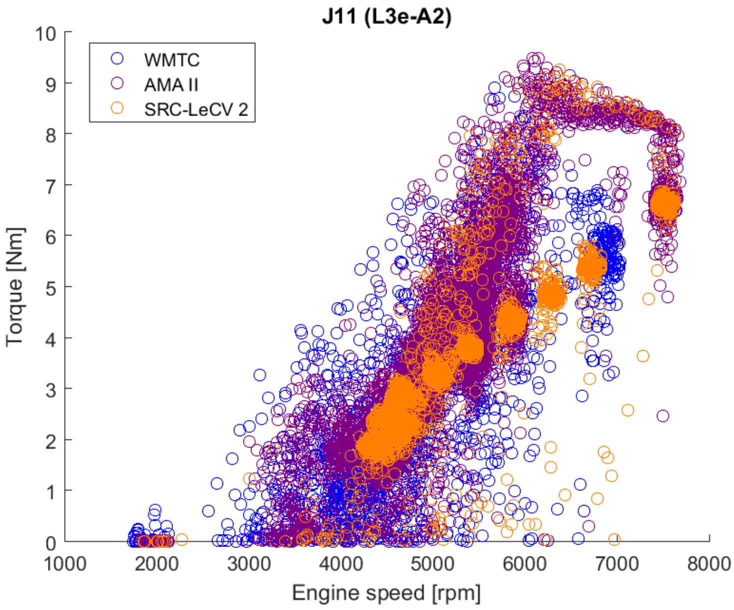


Figure 55. engine map coverage of the WMTC, AMA and SRC-LeCV of L3e-A2 test vehicle J11

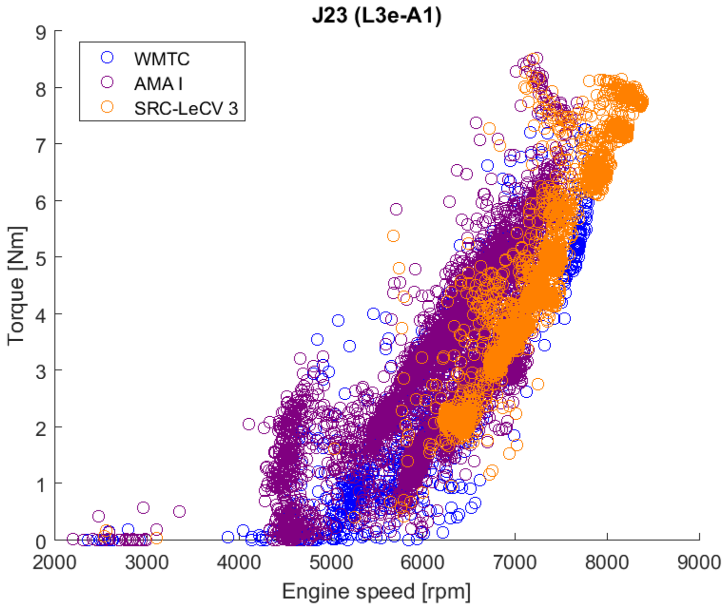


Figure 56. engine map coverage of the WMTC, AMA and SRC-LeCV of L3e-A1 test vehicle J23

WMTC class 3 vehicles.

Two WMTC class 3-2 vehicles are measured. For these vehicles the SRC-LeCV engine operation area lies within the range of the WMTC. It should, however, be noted that vehicle J18 should have driven SRC-LeCV 4 instead of SRC-LeCV 3. Only for one vehicle the engine operation of the AMA is available. The AMA has a rather wide engine map coverage. However, the WMTC shows a wider engine map coverage with some higher operating points.

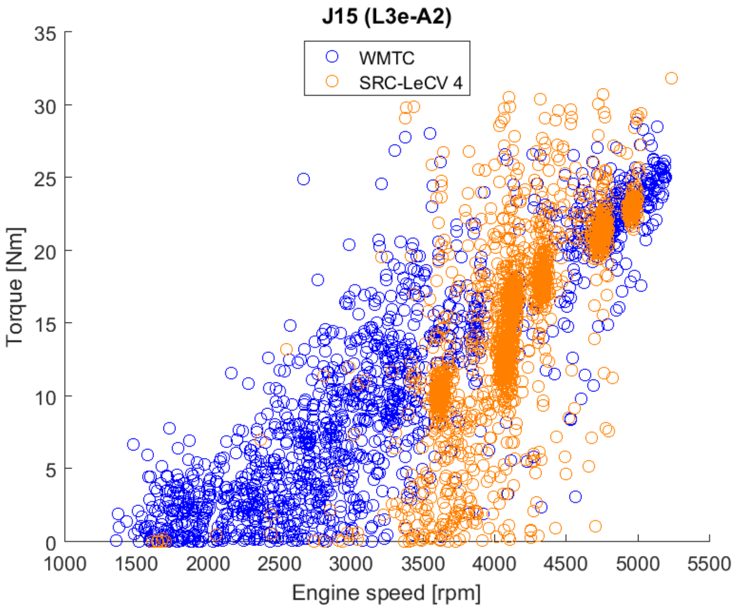


Figure 57. engine map coverage of the WMTC, AMA and SRC-LeCV of L3e-A2 test vehicle J15

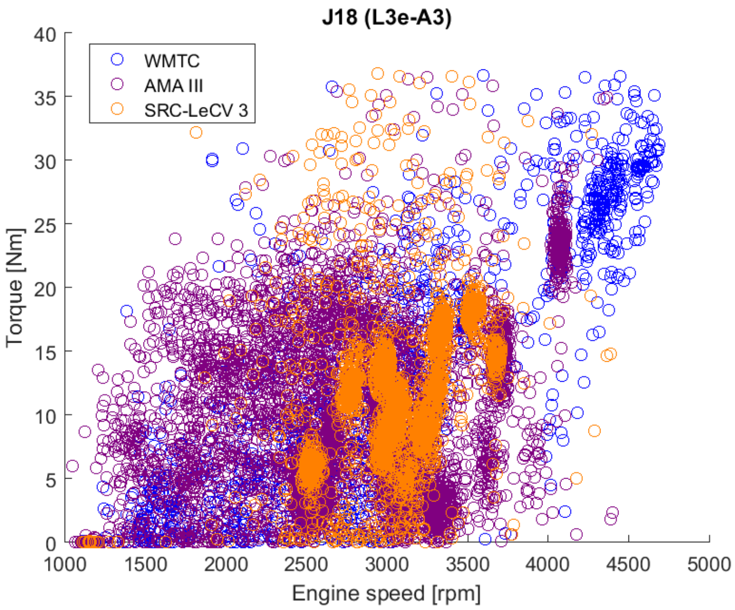


Figure 58. engine map coverage of the WMTC, AMA and SRC-LeCV of L3e-A3 test vehicle J18

The results of the assessment of the engine map coverage of the two mileage accumulation cycles are in line with the findings of the theoretical comparison of the share of high speed driving in the cycles as presented in paragraph 7.3.1.

7.3.3 Assessment of the thermal load

In this paragraph the thermal load assessment is described. This second assessment is an extensive and advanced validation of the theoretical assessment. Within the assessment the following steps are taken:

i. Measurement of temperatures before the catalyst during different driven cycles with each vehicle.
ii. Development of a vehicle specific thermal model (based on WMTC test data and vehicle specifications) which predicts the exhaust gas temperature behavior for durability cycles. In those cases the durability cycles were not driven. In other words, the model is applied to extend the dataset that was used for this assessment, and enables modelling of the effects in case a vehicle would shifted a lower SRC-LeCV.
iii. Calculation of the thermal load per cycle by applying the Arrhenius principle.

Measurements and modelling

Since the thermal load is based on the level of the exhaust gas temperatures and the duration of exposure to these temperatures, the temperature measurements form the basis for the thermal load assessment. Figure 59 shows the used locations for the temperature measurements. Most important measurement is the temperature before the catalyst, as this is the temperature of the exhaust gases that enter the catalyst.

These temperature measurements are performed during each performed test and on each tested vehicle, also when no durability cycle was driven with the specific test vehicle. In Appendix M a more detailed overview of the test and modelling results of all tested vehicles is given, including the relevant sub-classes and sub-cycles.

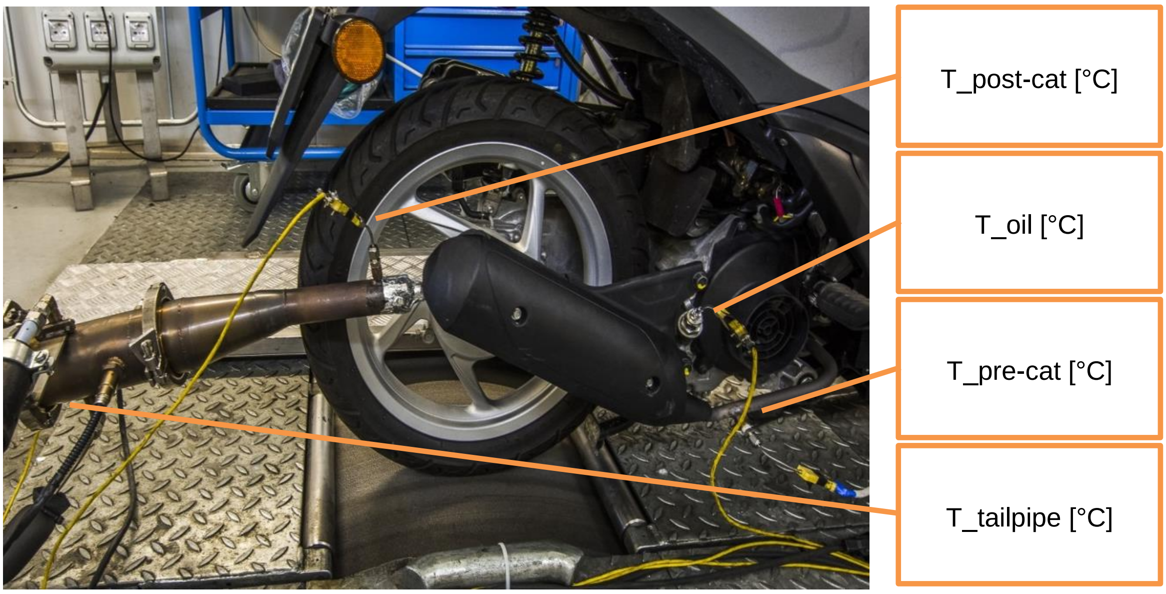


Figure 59: All temperature measurements

Vehicle specific thermal model:

According to the specification of the study and as shown in Appendix M and Table 41 and Table 42 only a limited share of the test vehicle has driven the durability cycles. However, every test vehicle is measured over the WMTC. In order to expand the thermal load data for the assessment of the thermal load, a vehicle specific thermal model is developed based on the specific WMTC temperature measurement. The model predicts the instantaneous exhaust gas temperature behavior for those durability cycles that were not driven. The applicability of the model is two-fold:

i. It predicts exhaust gas temperature profiles of SRC-LeCV and AMA for vehicles that did not drive the durability cycles
ii. It predicts exhaust gas temperatures for the cycles that would be driven when vehicles would fall into a different sub-class for SRC-LeCV or AMA

Table 41: Summary of measured and modelled durability test cycles

Vehicle class	AMA		SCR-LeCV	
	Tested vehicles	Modelled vehicles	Tested vehicles	Modelled vehicles
L1e-A	0	1	0	1
L1e-B LS	0	3	0	3
L1e-B HS	3	6	3	6
L2e-U	1	1	1	1
L3e-A1	1	2	1	2
L3e-A2	3	3	3	3
L3e-A3	1	1	1	1
L5e-A/B	1*	2	1*	2
L6e-BP/BU	1	1	1	1
L7e-B1/B2	2	3	2	3
Total	13	23	13	23

Table 42: Tested and modelled cycles with each test vehicle

Vehicle category	Vehicle ID no.	Type I WMTC Class 1_25	WMTC Class 1_45	WMTC Class 1	WMTC Class 2-1	WMTC Class 2-2	WMTC Class 3-1	WMTC Class 3-2	Type V SRC-LeCV Cycle 1_25	SRC-LeCV Cycle 1_45	SRC-LeCV Cycle 1	SRC-LeCV Cycle 2	SRC-LeCV Cycle 3	SRC-LeCV Cycle 4	AMA Class I_45	AMA Class I	AMA Class II	AMA Class III
L1e-A	J05	T							M						M			
L1e-B	J06	T							M						M			
L1e-B	J07	T							M						M			
L1e-B	J10	T							M						M			
L1e-B	J02		T							M					M			
L1e-B	J03		T							T					T			
L1e-B	J04		T							M					M			
L1e-B	J12		T							T					T			
L1e-B	J14		T							M					M			
L1e-B	J17		T							M					M			
L2e-U	J26		T							T					T			
L3e-A1	J19			T								M				M		
L3e-A1	J23				T							M	T			T		
L3e-A2	J11				T						M	T					T	
L3e-A2	J13					T						M	T				T	
L3e-A2	J15							T					M	T				T
L3e-A3	J18							T					T	M				T
L5e-A	J21					T						M	M				M	
L5e-A	J24				T						M	T					T	
L6e-BU	J22				T					T							T	
L7e-B1	J16				T						M	M					M	
L7e-B1	J08				T						M	T					T	
L7e-B2	J09				T						M	M	T				T	

Legend: T = tested
M = modelled
correct cycle according to the vehicle sub-classification

Based on the predicted exhaust gas temperature the thermal load can be calculated. By the development of this thermal model, the available data for the thermal load assessment is significantly expanded, which makes the results more robust. Secondly it enables validation of recommendations that are related to potential revision of SRC-LeCV sub-classification.

The thermal model is vehicle speed and acceleration based. The model is parametrized for each vehicle based on the exhaust gas temperature data from the WMTC and vehicle characteristics. The WMTC is taken as the basis for the model, because it covers a large variety of velocities and accelerations. The model can predict temperatures very well for those temperature, speed and acceleration conditions that are obtained in the WMTC. The conditions cover the conditions that are obtained in the durability cycles. Figure 60 shows an example of a measured WMTC trace compared to a modelled temperature trace to illustrate the accuracy of the thermal model.

For each vehicle the generated model coefficients are reported in Appendix M. With the A, B and C coefficients the following equation can be used to predict exhaust gas temperatures of any speed profile, where 'power' is equal to 'v*a positive'.

*T[°C]= A + B * velocity [km/h] + C * power [m²/s³]*

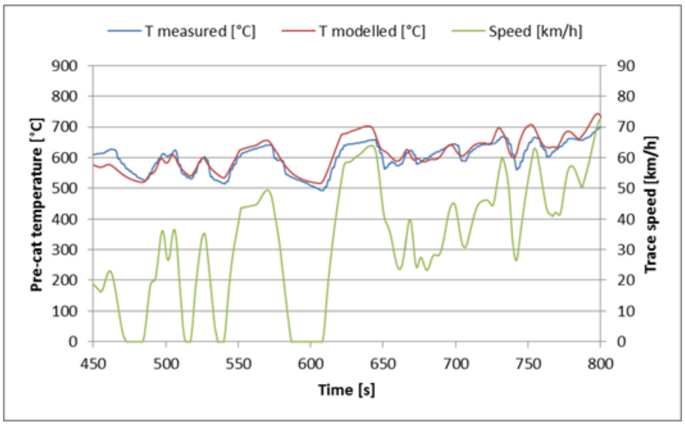


Figure 60: Example of measured versus modelled temperature of vehicle J16. The modelled temperature results of all vehicles are found in Appendix M

Calculation of the thermal load by application of the Arrhenius principle.

In order to determine the thermal load of catalytic converters during the different testing cycles, the Arrhenius principle is applied. The Arrhenius principle is a globally accepted and applied method that accounts for the effect of higher catalyst temperatures to cause exponentially higher deactivation rates. Figure 61 shows an example of deactivation at different temperatures. In this example, at 400°C the catalyst thermal deactivation is close to zero. At 700°C, theoretically the deactivation is more than 4500 times higher.

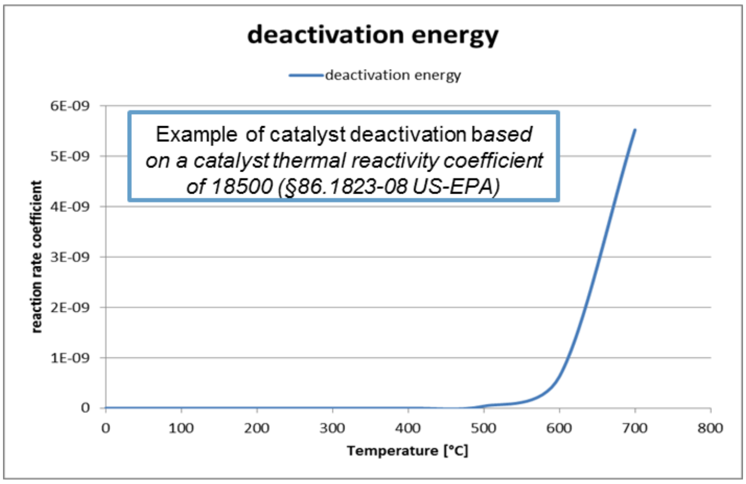


Figure 61: Example of deactivation at different temperatures

As input for the calculation the measured and modelled temperature traces are processed in temperature bins of 1 degree Celsius (see Figure 62 (in this case the bins have a size of 10 degrees Celsius, in order to have a visually attractive depiction of the analysis)). Then, based on the distance per temperature bin and the total distance, the thermal load can be calculated by using the equation below.

$$\frac{\sum sbin * e^{\frac{-R}{Tbin}}}{stot}$$

Where:

s_{bin} = distance in temperature bin [km]

R = catalyst thermal reactivity coefficient of 18500 (US EPA, 2016)

T_{bin} = average bin temperature [K]

s_{tot} = total distance [km]

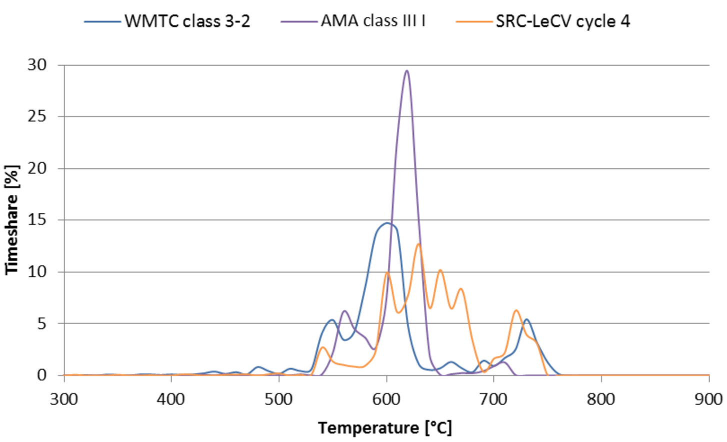
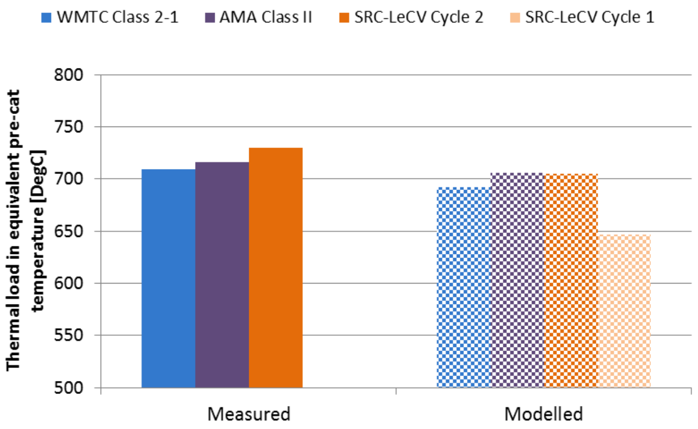


Figure 62: Example of temperature histogram of vehicle J15 based on 10 degrees Celsius temperature bins of vehicle. Temperature histograms of all vehicles are found in Appendix M.

After the calculation of the thermal load a single equivalent temperature is calculated, in order to have a thermal load equivalent that has a dimension and is easy to compare. Theoretically this is the effective exhaust gas temperature to which the catalyst is aged over the full useful life distance. The following equation is used for this calculation:

T = -18500/log(thermal load) - 273

Both for the measured as well as for the modelled thermal load, the equivalent temperature is calculated per relevant cycle. Figure 63 shows an example of the result of the analysis for one vehicle. In this specific case both the WMTC as well as the durability cycles were driven. The model is applied to assess the effect when the vehicle would drive an SRC-LeCV cycle 1 instead of an SRC-LeCV cycle 2 (the lighter orange bar). Figure 64 shows an example where only the WMTC is driven and all other results are modelled. Also in this example of Figure 64, one lower sub-class SRC-LeCV cycle is modelled and presented.



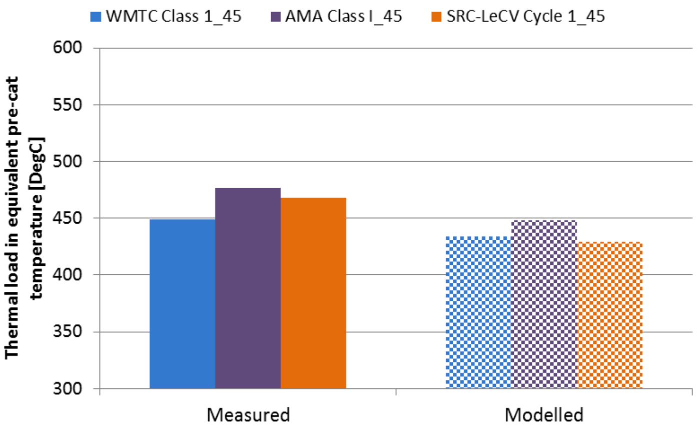


Figure 63: Examples (J11 and J12) of measured and modelled thermal load results. The measured and modelled results of all vehicles are found in Appendix M.

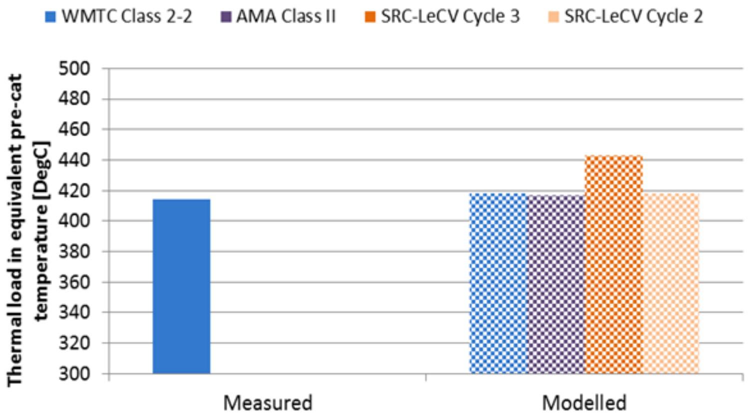


Figure 64: Example (vehicle J21) of a measured and modelled thermal load result with only a WMTC driven. The measured and modelled results of all vehicles are found in Appendix M.

Observations from thermal load assessment

In Appendix **M** all thermal load assessment results are presented by means of a ‘factsheet’ per vehicle. This factsheet shows all relevant information per vehicle:

i. Vehicle specifications;
ii. Measured and modelled test cycles;
iii. A temperature histogram of the measured and/or modelled exhaust gas temperatures;
iv. Measured and modelled thermal load results;
v. Ratio between average cycle speed / maximum vehicle design speed;
vi. Thermal pre-cat model specifications;
vii. Engine operation area per test cycle.

By comparing all thermal load results the following observations are made:

- The differences between AMA and SRC-LeCV thermal load results are mostly vehicle specific and highly depending on the vehicle classification;
- The AMA is in general as severe or less severe than the SRC-LeCV in terms of thermal load;
- The AMA thermal load is mostly lower than the WMTC thermal load for vehicles which have a maximum speed higher than 130 km/h, *i.e.* WMTC class 3 vehicles (that fall in AMA class III);
- The SRC-LeCV thermal load would have a better fit to the WMTC thermal load when most vehicles are placed in a lower SRC-LeCV class. By aligning the SRC-LeCV classification with the WMTC classification, like proposed in section 7.3, a large share of the vehicles would be placed one class lower. The result of the theoretical assessment was that this leads to an engine load that lies closer to the engine load introduces by the WMTC and AMA. This conclusion is validated by the assessment of the engine map coverage and thermal load of the different cycles.

7.4 Discussion on costs and the application of the AMA and SRC-LeCV

Practical applicability and costs are also important items to consider. These items are also discussed in the TRL study (Nathanson et al., 2012). However, application of the cycles in the current study and several interviews with Type Approval Authorities and Technical Services deliver new and sometimes controversial insights.

So far – to the knowledge of the study team – manufacturers only chooses to apply the mathematical method. In those cases rare cases that a manufacturer decides to perform mileage accumulation, he performs partial mileage accumulation according to article 23(3b) of Regulation (EU) No 168/2013. In those cases the manufacturer always chooses to accumulate this distance over the AMA cycle, because this is also applied in the US. Manufacturers only choose for AMA partial mileage accumulation when they are able to perform US and European type approval at the same time. Global acceptance of the SRC-LeCV might increase the application rate of this cycle.

Both the AMA and the SRC-LeCV cycles applied for mileage accumulation on the road or on a chassis dynamometer. In those cases AMA is applied, it is most often applied on the road. This is rather cheap in comparison to accumulating mileage on the chassis dynamometer. The AMA cycle is easy to follow by a driver on a test track, because it is very repetitive. The driver only needs small notes written on the bike to help him remember which speeds he shall follow. Application of the SRC-LeCV on the road is very hard or by some Technical Services even claimed to be impossible, because it is impossible to remember the speed and acceleration instructions of the SRC-LeCV. This means that almost by definition the mileage accumulation with the SRC-LeCV will be performed on the chassis dynamometer.

This will increase type approval costs, as mileage accumulation on the chassis dynamometer is more costly than mileage accumulation on the road. Application of mileage accumulation on a chassis dynamometer will require initial investments in additional chassis dynamometer facilities from the manufacturers. Robotizing the driving can be a cheap solution on the long run, but also requires initial investment. These initial investments put serious pressure on the cost-effectiveness of the mileage accumulation cycles, as will be discussed in sections 7.9 and 7.13. An alternative solution is to outsource the mileage accumulation to testing houses that have these facilities. Though, also for these facilities an increase of testing capacity will require investments that will in the end be paid back by the clients of those facilities.

These findings are controversial to the earlier findings of the TRL study (Nathanson et al., 2012). However it should be noted that for vehicles in a high sub-class, mileage accumulation over the SRC-LeCV is less time consuming than the AMA, because the average speed is higher. Though the costs saved as a result of this time benefit will most likely not compensate for the higher (mostly initial investment) costs of mileage accumulation on a chassis dynamometer.

7.5 Bench ageing as an alternative to distance accumulation cycles

The study shortly investigated the bench ageing as an alternative to the application of a distance accumulation cycle. Although this short exploratory investigation was outside of the original scope of the study, the adoption of bench ageing in the type approval for L-category vehicles Regulation (EU) No 168/2013 was brought to the attention in this study, as it might form a relatively cheap and reliable alternative to the application of physical mileage accumulation.

Bench ageing is a method for time lapsed ageing of the catalyst to determine the deterioration of pollutant emissions over the useful life. For light-duty vehicles this accelerated ageing test is an accepted method to replace the full mileage

accumulation process during type approval. This test method is described in Regulation (EU) No 692/2008 Annex 7 and in US EPA (2016). The procedures for both regulations are identical except for the US EPA (2016) there is no procedure for compressed ignition engine vehicles. For L-category vehicles no bench ageing procedures are currently allowed in European type approval.

US EPA (2016) describes bench ageing as follow: "*Ageing on the bench is conducted by following the Standard Bench Cycle (SBC) for the period of time calculated from the Bench Ageing Time (BAT) equation. The BAT equation requires, as input, catalyst time-at-temperature data measured on the Standard Road Cycle (SRC).*" This process is shown in figure below. First the temperature profile (1) of the two SRC's is obtained. Next the time-at-temperature data (2) is used to determine the BAT (3). The SBC (4) is repeated until the BAT is met. The SBC for light-duty vehicles requires an ageing bench and an engine which provides the feed gas for the catalyst. During this procedure the air/fuel ratio is repeatedly changed.

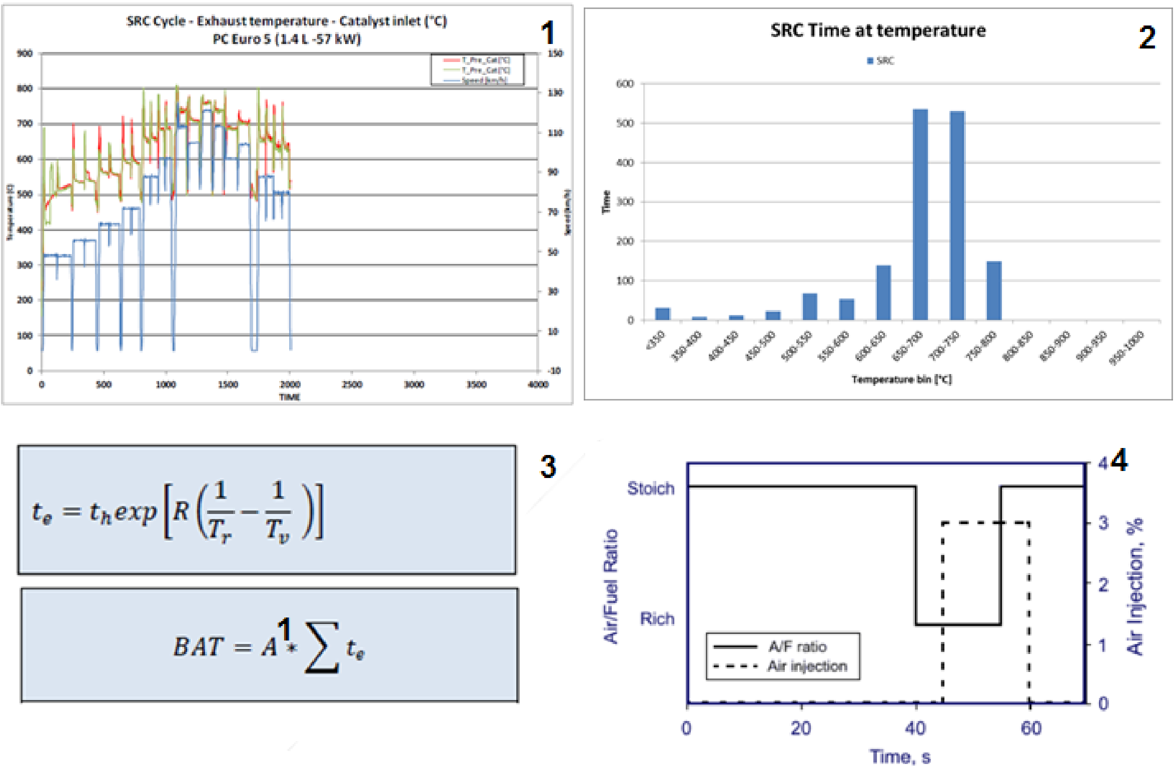


Figure 65. Bench ageing procedure depicted in 4 individual steps (Regulation (EU) No 692/2008; (Galassi and Martini, 2014))

The bench ageing procedure provides a widely accepted method for ageing of the catalyst, as alternative to application of a mileage accumulation cycle during type approval. However further improvements of the current procedure for passenger cars could be considered – also for passenger cars:

- The current bench ageing procedure for passenger cars does not account for the composition of the exhaust gas. To get better correlation between the bench ageing test and a chassis dynamometer test, dynamic exhaust gas compositions could be introduced (Wille et al., 2011).
- Another important factor for proper deterioration on a bench is that the catalyst must be exposed to dynamic temperature profiles. Otherwise the

deterioration will “stuck” at a certain steady condition. The deterioration process only proceeds towards maximum deterioration under dynamic temperature conditions (Bonifer, 2016).

In case adoption of the bench ageing procedure will be considered, the time-at-temperature data measured on the Standard Road Cycle (SRC) that serves as input for the calculation of BAT shall be replaced by time-at-temperature data measures on the SRC-LeCV, taking account of the recommended revision of the sub-classification of the SRC-LeCV of this study.

The advantages and disadvantages of the currently applied bench ageing procedure for passenger cars were assessed in an earlier study, leading to the following results in comparison to the application of distance accumulation cycles (Galassi and Martini, 2014):

Advantages of bench ageing:

- The cost of the bench ageing procedure are lower
- The procedure is less time consuming
- The procedure is conducted with well controlled engine operations
- The procedure has a higher repeatability

Disadvantages of bench ageing:

- Fundamental mechanisms of chemical interactions and physical stress could be altered using the bench ageing method. Therefore the ageing process could also be altered.
- Bench ageing may not adequately account for poisoning, soot decomposition, etc. which are factors influencing the catalyst durability.
- It is unclear whether all components of the pollution control device are evaluated under the same conditions.

7.6 Conclusions on the distance accumulation cycles and alternative methods

Based on the evaluation on engine load and thermal loads – with the measurements up to now – it is recommended to:

- Phase out AMA class III for WMTC class 3 vehicles only, since the AMA class III introduces lower engine load and thermal load than WMTC for WMTC class 3 vehicles. Since the AMA introduces especially higher engine load and thermal load for WMTC class 1 vehicles and mopeds compared to the WMTC, and equal engine load and thermal load for WMTC class 2 vehicles, complete phase out is not necessary.
- At the same time consider to introduce SRC-LeCV as a globally accepted mileage accumulation cycle.
- Align SRC-LeCV classification with WMTC classification. Table 40 shows both the current classification of the WMTC and SRC-LeCV as well as the recommended classification of the SRC-LeCV.
- Consider to adopt the bench ageing procedure of Regulation (EU) No 692/2008 in article 23 of Regulation (EU) No 168/2013 as a low cost physical ageing alternative to distance accumulation cycles.

7.7 Discussion on the representativeness of the “mathematical method”

Actual deterioration of emissions can significantly differ from “mathematical method” of article 23 of Regulation (EU) No 168/2013 according to which the emissions of a new (de-greened) vehicle obtained during a Type I test are multiplied with a fixed Deterioration Factor (DF) to calculate the emission level of a deteriorated vehicle. The “mathematical method” is most often applied by the manufacturers during type-approval, since the method is cheap and the results are very predictable.

However, the representativeness of the “mathematical method” for real-life vehicle ageing can be highly doubted; it only requires new (de-greened) vehicles to meet the emission limits and does not guarantee durable environmental performance of vehicles for a long lifetime. In fact it introduces a potential loop-hole that allows installation of inferior catalysts that “quickly” deteriorate – possibly even in the first year / in the first ~2,000km. The effect of this potential loophole is visualized in Figure 66.

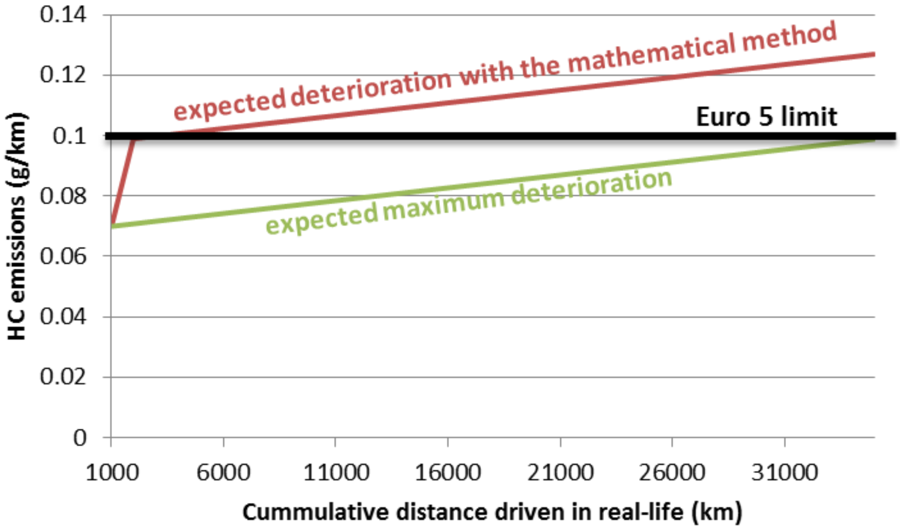


Figure 66. Example of HC emissions of a vehicle over its lifetime as a visualisation of the expected effect of the potential loop-hole that allows quickly deteriorating emissions, compared to the expected maximum deterioration according to the deterioration factor of 1.3.

The total emissions increase at minimum with around 30% as an effect of this potential loophole. The situation might even be worse. The measurement data in this programme and earlier studies (Hensema et al., 2013; van Zyl et al., 2015; Eijk et al., 2016) confirm that some vehicles in-service exceed the emission limits as an effect of quick emission deterioration.

Hence, a solution is required to secure environmental performance of L-category vehicles over the useful life. Such solutions can be found in phase-out of the mathematical method and mandating a more representative methodology with physical degradation/ageing of the emission control devices (*e.g.* catalyst). Or – following the example from passenger cars – solutions can be found in additional measures that close the potential loop-hole like for example in-service conformity (in-use compliance) requirements.

7.8 Environmental Benefit of mandatory physical degradation

The environmental benefit is calculated taking account of the fleet and activity and the emission factors. The environmental performance baseline is set to the expected emissions when the mathematical method is applied. This baseline scenario is referred to as scenario 1.

Scenario 2 calculates the benefit of the application of physical degradation according to a method in which the emission control systems are being aged to an emission deterioration level that does not exceed the deterioration factor during the useful life. This scenario is also referred to as "physical degradation". It reflects the situation in case AMA mileage accumulation or SCR-LeCV mileage accumulation according to the proposed revised sub-classification is performed and the mathematical method is phased out.

Scenario 3 calculated the environmental benefit of the application of "stringent physical degradation". The applied method is similar to scenario 2, only with increased stringency resulting from exposing the catalyst to increased thermal load, effecting from a more severe mileage accumulation cycle. This scenario reflects the situation in case SRC-LeCV is applied with the current sub-classification as specified in Regulation (EU) No 134/2014 and the mathematical method and AMA are phased out. The degradation is expected to be stronger than the equivalent DF as a result of the increased thermal load. This requires that the base emissions of a de-greened vehicle should be of a lower level in order not to exceed the emission limit at Useful Life.

The applied scenarios are presented in the figure below. The calculations takes account of the expected effect that after useful life, the deterioration of the emissions is less steep and intense, following the exponential catalyst ageing conversion curve.

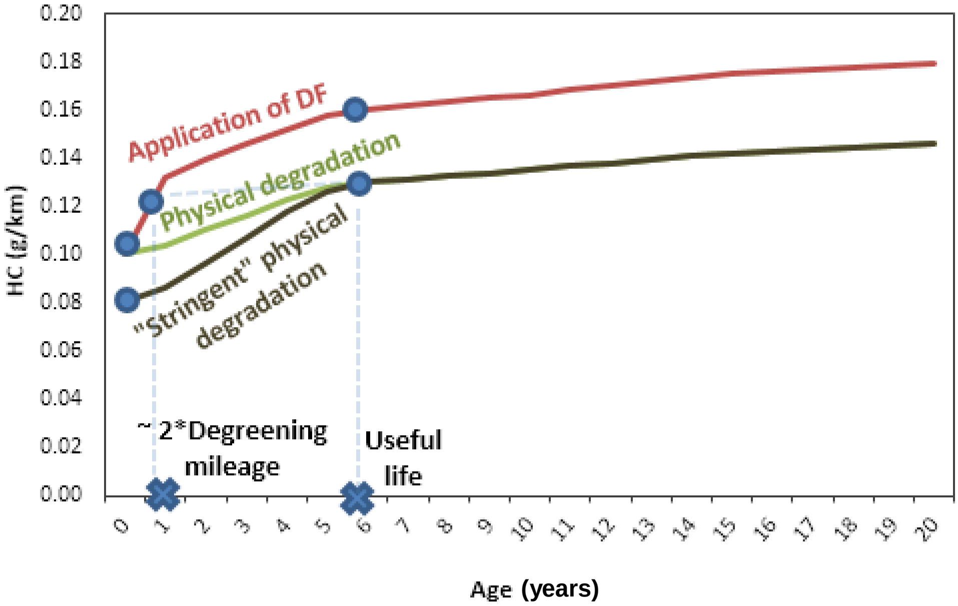


Figure 67. Application scenarios for the calculation of the environmental benefit

The environmental benefit for each regulated component of performing physical degradation from 2020 is presented in Figure 68 and are summarized in Table 43.

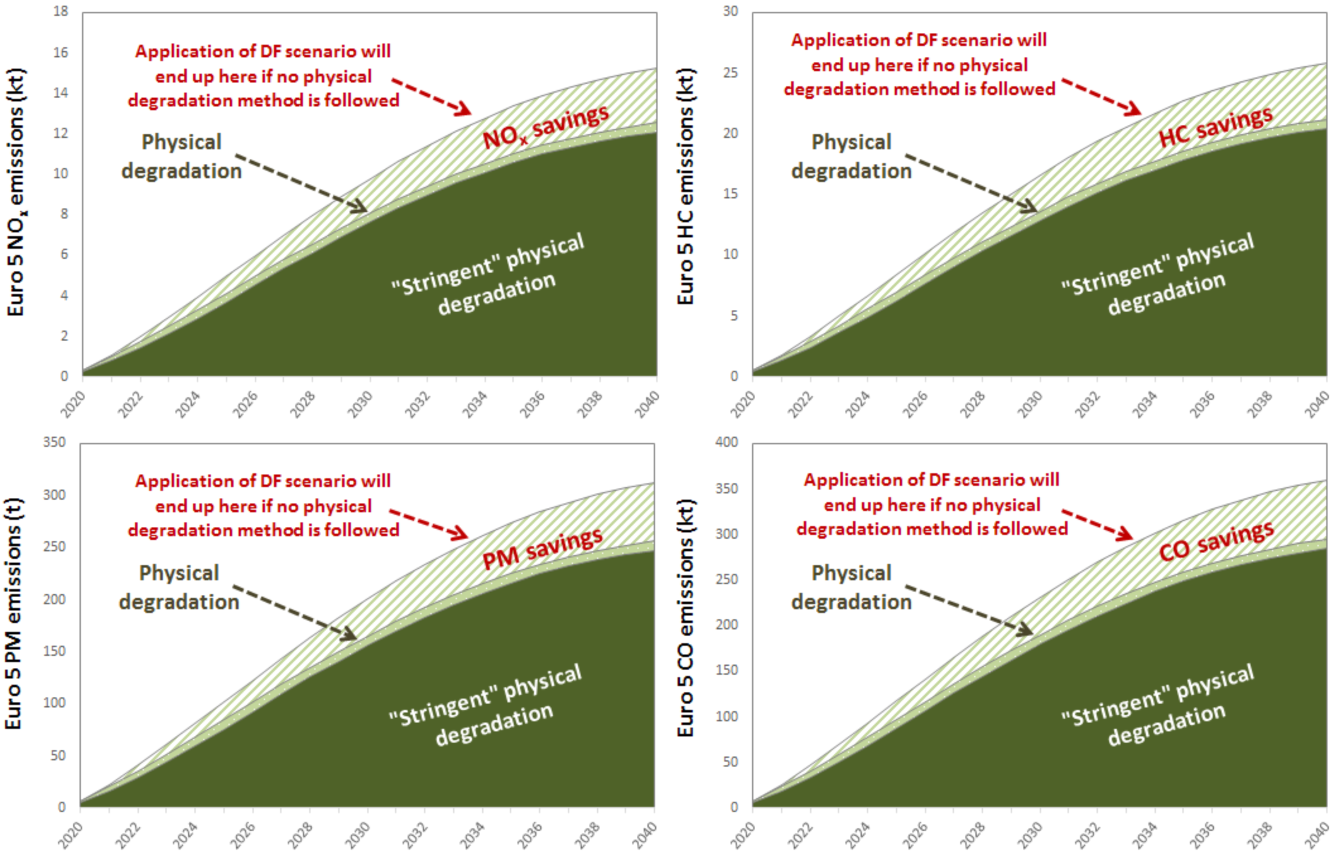


Figure 68. Environmental benefit of performing physical degradation and phasing-out of the mathematical method from 2020

Table 43. Emissions saved from the L-category vehicle fleet in Europe of the period 2020 to 2040 compared to the application of the mathematical method

Component	Physical degradation savings	Stringent physical degradation savings
HC	50 kt	62 kt
NO_x	33 kt	41 kt
PM	0.68 kt	0.85 kt
CO	787 kt	982 kt

In general, the emission savings in scenario 2 – physical degradation – are 18% of the total fleet emissions. In scenario 3 – stringent physical degradation – 22% is saved.

7.9 Cost Benefit Analysis of application of the mileage accumulation cycles

The emission savings that can be obtained from physical degradation and phasing-out the mathematical method are significant. However, physical ageing will require

initial investments from manufacturers to understand the ageing process by performance of tests:

- Most of these costs can be considered per vehicle propulsion family and as initial investment.
- Additional cost is expected to significantly decrease with time as experience is growing.
- Additional technology costs basically include marginal costs for improved catalysts.

Also type-approval costs will significantly increase when mileage accumulation becomes mandatory. It is expected that in the case of physical ageing, the manufacturers will choose to run the partial mileage accumulation method. In order to allay the test burden for manufacturers it is allowed to make use of vehicle propulsion families. A vehicle propulsion family makes use of a representative parent vehicle which covers the type approval of several models. As such, there is no need for an individual type approval of each model. The criteria for vehicle propulsion families are set out in Annex XI of Regulation (EU) No 134/2014. Depending on the vehicle type, the Cost Benefit was analyzed for application of a vehicle propulsion family of four to eight models.

The best estimation is calculated considering the baseline fleet/activity scenario, the moderate cost scenario and technology depreciation period 6 years, as analyzed in section 1.1. The low and high estimates of NPV are calculated as follows:

- for the former the high cost scenario, a technology depreciation period of 10 years and the low/high growth fleet/activity scenario depending on the vehicle category are considered,
- and for the latter the low cost scenario, a technology depreciation period of 6 years and the low/high growth fleet/activity scenario depending on the vehicle category are considered.

Two scenarios have been evaluated in the Cost Benefit Analysis:

- In scenario 1 “Stringent physical degradation”, the mathematical method is phased out. The AMA is also phased out by 2020 and the SRC-LeCV will remain to be the only mandatory mileage accumulation cycle.
- In scenario 2 “Physical degradation”, the mathematical method is also phased out. The AMA remains existing, except for WMTC class 3 vehicles. The sub-classification of the SRC-LeCV is changed according to the proposal in section 7.3.

The results of the CBA are presented in the tables below.

Table 44. Results of the CBA for Scenario 1: "Stringent physical degradation"

(Values in M€)	Cost-benefit over 2020-2040
Mopeds	$-12.84^{+8.16}_{-14.15}$
Motorcycles	$-0.07^{+42.71}_{-41.85}$
Mini-cars	$-1.70^{+0.72}_{-0.47}$
ATVs	$-7.10^{+1.56}_{-1.92}$
Total	$-21.70^{+47.23}_{-58.39}$

Table 45. Results of the CBA for Scenario 2: "Physical degradation"

(Values in M€)	Cost-benefit over 2020-2040
Mopeds	$-4.76^{+4.76}_{-8.14}$
Motorcycles	$13.57^{+36.42}_{-32.29}$
Mini-cars	$-2.19^{+0.62}_{-0.76}$
ATVs	$-6.12^{+1.27}_{-1.51}$
Total	$0.51^{+42.07}_{-37.33}$

It can be concluded that the costs for "stringent degradation" are significantly higher than the "physical degradation", because SRC-LeCV in that scenario is the only mandatory mileage accumulation cycle, which will increase testing costs as explained in section 7.4. As a result, and given the small difference in environmental benefit, the physical degradation scenario is more cost-effective than the stringent degradation scenario. In other words, changing the sub-classification of the SRC-LeCV according to the proposal in section 7.3 and phasing-out of only AMA for WMTC class III vehicles is more cost-beneficial than fully phasing out the AMA and maintaining the current SRC-LeCV sub-classification.

From the cost benefit analysis it can be concluded that – taking account of the increased costs when the mathematical method will be phased out and no other adaptations are made other than letting the AMA persist (except for WMTC class 3 vehicles) – the benefits exceed the costs marginally for the complete L-category vehicle fleet. However, it differs per vehicle class whether physical degradation is cost beneficial or not.

7.10 Assessment of the Useful Life Values

According to article 23 of Regulation (EU) No 168/2013 "*manufacturers shall ensure that vehicles are designed, constructed and assembled so as to minimise the impact on the environment. Manufacturers shall ensure that type- approved vehicles meet the environmental performance requirements as set out in Annexes II, V and VI and within the durability mileage as set out in Annex VII*". The durability mileages of the different vehicle categories – indicated here as Useful Life Values – are summarized in the table below.

Table 46. Durability mileage, also indicated as Useful Life Values, as determined in Annex VII of Regulation (EU) No 168/2013

Vehicle category	Vehicle category name	Durability mileage (km)
L1e-A **L3e-AxT (x = 1, 2 or 3)**	Powered cycle Two-wheel Trial motorcycle	5 500
L1e-B **L2e** **L3e-AxE (x = 1, 2 or 3)** **L6e-A** **L7e-B**	Two-wheel moped Three-wheel moped Two-wheel Enduro motorcycle Light on-road quad Heavy all terrain quad	11 000
L3e **L4e** **L5e** **L6e-B** **L7e-C**	Two-wheel motorcycle with and without sidecar (v_{max} < 130 km/u) Tricycle Light quadri-mobile Heavy quadri-mobile	20 000
L3e **L4e** **L7e-A**	Two-wheel motorcycle with and without sidecar (v_{max} ≥ 130 km/u) Heavy on-road quad	35 000

In order to assess the appropriateness of the Useful Life Values, a comparison with the fleet activity data from paragraph 2.5.3 of this report has been made. The data that was input for the fleet activity modelling originates for various sources and databases, as explained in paragraph 2.5.3. Direct comparison is almost impossible, as the aggregation of the vehicle categories in Annex VII of Regulation (EU) No 168/2013 is inconsistent with the aggregation the multiple source for fleet activity data modelling maintain. Therefore – in the comparison – the vehicle categories in Regulation (EU) No 168/2013 are disaggregated. The result of this comparison is presented in Table 47.

Table 47. Comparison of the fleet activity data with the ULVs from Regulation (EU) No 168/2013

Vehicle category name in fleet data	Vehicle category	Annual average mileage (km)	Effective average age (Y)	Average calculated useful life mileage (km)	ULV from Regulation (EU) No 168/2013
“mopeds”	L1e-B L2e	~2900	11*	~31 900	11 000
“motorcycles A1”	L3e-A1 and L4e-A1	~4600	7 to 8	~34 500	20 000
“motorcycle A2 and A3”	L3e-A2/A3 and L4e-A2/A3	~5500	7 to 8	~41 250	35 000
“L5e tricycles”	L5e	~5500	7 to 8	~41 250	20 000
“ATVs”	L6e-A L7e-B	~600**	5 to 6	3 300**	11 000
“minicars”	L6e-B L7e-C	~5000	6	30 000	20 000

* the moped fleet decreases and only partly renewed, as a result the average age is high
** these vehicles should mostly be counted to hours of operation per year, on-road ones do not exceed 40-50 hours annually. This is much lower than off-road vehicles, which are often used professionally for farming and forestry activities and other purposes

Some categories are excluded from the comparison, for various reasons. A summary of the excluded categories is presented in Table 48.

Table 48. Categories that are excluded from the comparison of the fleet activity data with the ULVs from Regulation (EU) No 168/2013

Vehicle category	Vehicle category name	remark
L1e-A	Powered cycle	market segment is negligible and decreasing
L3e-AxT (x = 1, 2 or 3)	Two-wheel Trial motorcycle	no sources available, the expected yearly mileage is very low
L3e-AxE (x = 1, 2 or 3)	Two-wheel Enduro motorcycle	no sources available, the expected yearly mileage is very low
L7e-A	Heavy on-road quad	market segment is negligible, the category can be attributed to the L3e-A3

This comparison leads to the following conclusions and recommendation:

- The Useful Life Values from Regulation (EU) No 168/2013 for mopeds (L1e-B and L2e) are of another order of magnitude than the average useful life mileage obtained from the fleet activity data. The Useful Life Values for mopeds are too low and inappropriate. Reconsideration of the Useful Life Values for mopeds (L1e-B and L2e) is recommended.
- The order of magnitude of the Useful Life Values from Regulation (EU) No 168/2013 for motorcycles L3e and L4e, and minicars L6e-B and L7e-C is in

the same order of magnitude as the useful life mileage obtained from the fleet activity data and considered to be appropriate.

- The Useful Life Values from Regulation (EU) No 168/2013 for tricycles (L5e) are of another order of magnitude than the average useful life mileage obtained from the fleet activity data. However, this needs to be seen in a nuanced light, as the L5e class consist of tricycles used for the carriage of passengers (L5e-A), and tricycles designed as a utility vehicle (L5e-B). It is expected that the Useful Life values for L5e-A vehicles are too low and inappropriate. On the contrary, it is expected that the Useful Life values for L5e-B vehicles are rather high. There is not sufficient data available to make a justified distinction between these sub-categories. Reconsideration of the Useful Life Values for tricycles (L5e) is therefore not recommended.
- The Useful Life Values from Regulation (EU) No 168/2013 for ATVs (L6e-A and L7e-B) are of another order of magnitude than the average useful life mileage obtained from the fleet activity data. Though because of the high variance in average yearly mileage of ATVs because of their specific application, the current Useful Life Values are considered to be appropriate.

7.11 Assessment of the assigned Deterioration Factors

Despite the discussion on the representativeness of the “mathematical method”, the appropriateness of the assigned Deterioration Factors has been examined.

For L-category vehicles the Deterioration Factors (DFs) are prescribed per emission constituent, as can be observed in the table below that is copied directly from the regulations for L-category vehicles (Regulation (EU) No 168/2013). The DF should be multiplied with the Type I test result of a new de-greened vehicle to estimate the emissions of the vehicle at the end of its useful life.

Table 49. Euro 5 Deterioration Factors for L-category vehicles (Regulation (EU) No 168/2013)

(B) Deterioration Factors (DF)

Vehicle category	Vehicle category name	Euro 5 DF+(4) (-)							
		CO	THC		NMHC		NO_x		PM (17) (4)
			PI	CI (18)	PI	CI	PI	CI	CI
L1e-L7e	All	1,3	1,3	1,1	1,3	1,1	1,3	1,1	1,0

An assessment of the DFs by comparison of the DFs with actual measurement data of in-use vehicles that have accumulated mileages is impossible, because:

- The in-use vehicles carry old technology, which emission deterioration might not represent the emission deterioration of Euro 5 emission abatement technology.
- Very limited emission measurement data of in-use vehicles that have gathered some mileage is publicly available.

Therefore a comparison is made with the DFs for passenger cars (UNECE, 2011), which are presented in Table 50. The DFs for passenger cars are in general more stringent than for L-category vehicles. However, the technology that is expected to be applied to Euro-5 L-category vehicles is expected to be less complex and less sensitive to degradation. For example passenger car technology of positive-ignited

engines is more sensitive to degradation as a result of application of measures like EGR and turbochargers, that possibly introduce contamination and poisoning of the catalyst. Based on this simple theoretical evaluation, the DFs for L-category vehicles are considered appropriate. Re-evaluation of the DFs is recommended when emission measurement data of in-use vehicles with Euro 4 and Euro 5 technology becomes available.

Table 50. Deterioration Factors for passenger cars (UNECE, 2011)

Engine Category	*Assigned deterioration factors*						
	CO	*THC*	*NMHC*	*NO_x*	*$HC + NO_x$*	*Particulate Matter (PM)*	*Particles*
Positive-ignition	1.5	1.3	1.3	1.6	-	1.0	1.0
Compression-ignition	1.5	-	-	1.1	1.1	1.0	1.0

7.12 A multiplicative Deterioration Factor for mileage accumulation

For full mileage accumulation, the manufacturer shall provide evidence that *the emission limits in the applicable Type I emission laboratory test cycle, as set out in Part A of Annex VI to Regulation (EU) No 168/2013, of the tested aged vehicles are not exceeded at the start of mileage accumulation, during the accumulation phase and after the partial accumulation.* (3.2.1 of Annex VI of Regulation (EU) No 134/2014).

For partial mileage accumulation, the manufacturer shall plot all arithmetic mean Type I emissions test results against accumulation distance rounded to the nearest kilometer. A trend line with parameters a, x and b of the best-fit straight lines is determined and the calculated pollutant value at the end mileage according to the vehicle category shall be stated in the test report. An example of such a plot is presented in Figure 69 (3.2.4 of Annex VI of Regulation (EU) No 134/2014). This method can be seen as a multiplicative approach, where the parameters on the trend line are the determining factors.

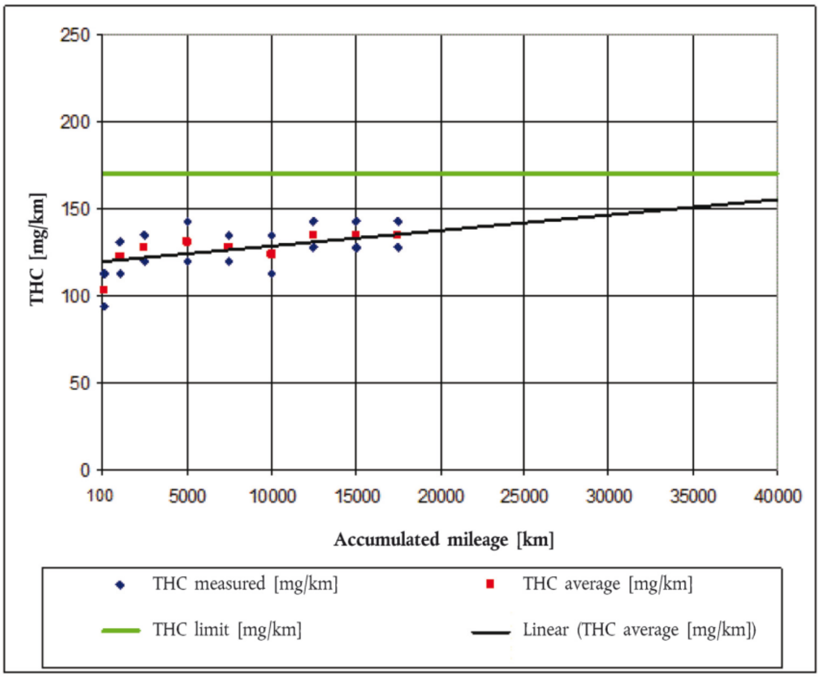


Figure 69. Theoretical example of the plotted Type I total hydrocarbon (THC) emission test results, the plotted Type I THC Euro 4 test limit (170 mg/km) and the best-fit straight trend line of a Euro 4 motorcycle (L3e with v max > 130 km/h), all versus accumulated mileage (source: Regulation (EU) No 134/2014).

The determination of the emissions at the end of the useful life differs from the method that is applied for passenger cars. The differences are summarized in Table 51.

Table 51. Summary of allowed procedures for L-category vehicles (Regulation (EU) No 134/2014). and passenger cars (UNECE, 2011)

Category	Deterioration factors		Mileage accumulation	
	Multiplicative	Additive	Full	Partial
L-category vehicles	√	x	√	√
Passenger cars	√	√	√	x

For passenger cars (UNECE, 2011) partial mileage accumulation is not allowed. Another difference is found in the calculation method for application of the deterioration factors for the mileage accumulation procedure. For passenger cars, both a multiplicative – though slightly different from the method for L-category vehicles – and an additive calculation method are allowed. Both multiplicative and additive options are existing in EU, ECE, US and Japan for both passenger cars and Non-Road Mobile Machinery

The difference between the multiplicative and additive calculation method have been examined based on a sensitivity analysis in an earlier study of JAMA, which has been extended by the study team (spreadsheet is found in Appendix **N**). It was found that the multiplicative calculation method occasionally leads to scientifically incorrect deteriorated emission values and the introduction of the additive calculation method

– as an alternative method to the multiplicative method – makes the procedure more robust without considerable negative counter effects.

This leads to the recommendation to adopt the additive exhaust emission deterioration factor and multiplicative exhaust emission deterioration factor calculation method from Annex 9 of (UNECE, 2011) for the determination of the deteriorated emission values at useful life for the partial and full mileage accumulation procedures of article 23 of Regulation (EU) No 168/2013.

7.13 Detailed scenario analysis on legislative implementation scenarios

The Deterioration Factors of Annex VII of Regulation (EU) No 168/2013 do not reflect ageing in reality. A solution is required to secure environmental performance of L-category vehicles over the useful life. Different implementation scenarios for durability requirements can be considered. Although it lies outside the scope of this study, several legislative implementation scenarios – including those already discussed in the Cost Benefit Analysis in section 7.9 – are summed up in this paragraph, and qualitative and for half of the scenarios quantitative judgements are made on their implications and cost-benefit.

Leave the durability requirements as-is – the baseline scenario
This will make the durability requirements for L-category vehicles ineffective, because of the possible loop-hole that is introduced by the mathematical method of article 23 of Regulation (EU) No 168/2013. This possible loop-hole introduces vehicles into the market with catalysts that rapidly degrade, leading to rapidly deteriorating emission levels of those vehicles. The costs of the baseline scenario are zero.

Scenario 1 "stringent physical degradation": Phase-out the mathematical method and apply physical ageing procedures as-is – meaning that AMA is phased out and SRC-LeCV classification remains as-is
This will lead to ~22% emission saving for L-category vehicles over the period 2020 to 2040 compared to the baseline scenario. However it also introduces a substantial increase in development and type approval costs. The increase of technology costs is expected to be marginal. Based on the assumption that on average one on four, to one on eight models have to undergo the physical testing procedure, it is expected that in this scenario the costs exceed the obtained benefits. The results of the Cost Benefit Analysis is presented in section 7.9 in Table 44..

Scenario 2 "physical degradation": Phase-out the mathematical method and apply physical ageing procedures according to the recommended revised sub-classification for the SRC-LeCV and phasing out of AMA for WMTC class 3 vehicles
This will lead to ~18% emission saving for L-category vehicle over the period 2020 to 2040 compared to the baseline scenario. Compared to scenario 1, type approval costs are decreased because of the possibility to test over the AMA cycle for most vehicles – which can be driven on the road instead of on the chassis dynamometer. Based on the assumption that on average one on four, to one on eight models have to undergo the physical testing procedure, this scenario is expected to be marginally on the positive side of being cost-beneficial for the complete L-category vehicle fleet. However, it differs per vehicle class whether physical degradation is cost beneficial or not. The results of the Cost Benefit Analysis is presented in section 7.9 in Table 45.

Introduction of bench ageing as a third alternative physical ageing

As discussed in section 7.5, bench ageing is a low cost, well accepted and reliable physical ageing alternative to distance accumulation cycles. Adoption of the bench ageing procedure of the Regulation (EU) No 692/2008 in article 23 of Regulation (EU) No 168/2013 could be considered, after a specific study to assess the procedure in the context of L-category vehicles. Introduction of bench ageing as a third alternative physical ageing procedure leads to scenario 4.

Scenario 3 "Physical degradation with bench ageing": Phase-out the mathematical method and apply physical ageing procedures according to the recommended revised sub-classification for the SRC-LeCV and phasing out of AMA for WMTC class III vehicles AND introduce bench ageing as a third alternative physical ageing method

When the bench ageing procedure is designed to predict expected in-use deterioration rates, it is expected that the benefit of this measure will not differ from scenario 1 and 2. Hence, this scenario will lead to ~18% emission saving for L-category vehicle over the period 2020 to 2040 compared to the baseline scenario. The costs for type approval and development will be strongly reduced compared to scenario 1 and 2. Scenario 3 is expected to be cost-beneficial for the total L-category fleet. The results of the Cost Benefit Analysis is presented in the table below.

Table 52. Cost Benefit Analysis results for Scenario 3: "Physical degradation with bench ageing"

(Values in M€)	Cost-benefit over 2020-2040
Mopeds	$5.70^{+3.38}_{-6.75}$
Motorcycles	$67.97^{+29.6}_{-25.44}$
Mini-cars	$0.91^{+0.15}_{-0.16}$
ATVs	$-3.93^{+0.91}_{-1.15}$
Total	$70.65^{+33.05}_{-28.11}$

Other implementation scenarios

Other implementation scenarios can also be considered. Some options are summarized in the scenarios 4, 5, 6 and 7 below. As this exercise is outside the original scope of the study, and calculation of the CBA for these scenarios demands significant effort, the evaluation of these scenarios is only qualitative.

Scenario 4: Rearrange the Useful Life Values for mopeds + apply scenario 2 (*Phase-out the mathematical method and apply physical ageing procedures and according to the recommended revised sub-classification for the SRC-LeCV and phasing out of AMA for WMTC class III vehicles*)

The benefit of this scenario has not been calculated, but a small increase of benefit is expected compared to scenario 2, mostly due to the increase of useful life of

mopeds. So the savings of are slightly above ~18% emission saving for L-category vehicle over the period 2020 to 2040 compared to the baseline scenario.
The costs for type approval and development will also increase compared to scenario 2, resulting from almost doubling the mileage accumulation distance for mopeds and tricycles. The increase of costs is expected to exceed the small increase of the environmental benefit. Scenario 2 is only marginally cost-beneficial. When the rearranged ULVs are introduced to scenario 2, as in this scenario, then the durability requirements are expected to be non-cost beneficial.

Scenario 5 Rearrange the Useful Life Values for mopeds + apply scenario 3 (*Phase-out the mathematical method and apply physical ageing procedures according to the recommended revised sub-classification for the SRC-LeCV and phasing out of AMA for WMTC class III vehicles AND introduces bench ageing as a third alternative physical ageing method*).
The benefit of this scenario has not been calculated, but a small increase of benefit is expected compared to scenario 3, mostly due to the increase of useful life of mopeds. So the savings of are slightly above ~18% emission saving for L-category vehicle over the period 2020 to 2040 compared to the baseline scenario.
The costs for type approval and development will also increase compared to scenario 3, resulting from almost doubling the mileage accumulation distance for mopeds and tricycles. Though, the cost increase is limited, as bench aging is allowed. Hence, scenario 5 is expected to be cost-beneficial.

Scenario 6 is comparable to the baseline scenario, but includes the introduction of extra measures – securing durable environmental performance of vehicles in-service – like for example in-service conformity requirements
The environmental benefit is expected to increase, as manufacturers are now forced to build vehicles with durable environmental performance. The environmental benefit compared to the baseline scenario over the period 2020 to 2040 has not been calculated. The environmental benefit of such extra measures is expected to be within the same order of magnitude as the durability procedure with physical ageing.
The costs for development will increase in this scenario, technology costs will also slightly increase compared to the baseline scenario. The costs for type approval will also increase compared to the baseline scenario. Though they are expected to be lower than the costs of a durability demonstration procedure, when ISC requirements are designed to be cost-effective. Therefore, this scenario is expected to be cost-beneficial. Only a qualitative assessment – with knowledge of the sensitivity of the CBA – has been made. A full CBA for this scenario has not been performed.

Scenario 7 is comparable to scenario 6, but also includes the rearrangement of Useful Life Values for mopeds
The environmental benefit compared to scenario 6 will be marginal. However the development costs are expected to further increase compared to scenario 6, resulting from almost doubling the mileage accumulation distance for mopeds and tricycles.
It is hard to predict whether this scenario is cost-beneficial. The cost-benefit ratio of this scenario is expected to be lower than for scenario 6. It has to be remarked that also for this scenario only a qualitative assessment – with knowledge of the sensitivity of the CBA – has been made. A full CBA for this scenario has not been performed.

Overview of all implementation scenarios

The expected CBA result of the different implementation scenarios is presented in the table below. The implementation scenarios which are outside the original scope of the study are displayed in a qualitative way, where:

- red indicates that costs exceed the benefits,
- orange indicates that costs are close to equal to the benefit
- green indicates that the benefits exceed the costs

From this qualitative and partially quantitative assessment, scenarios 2, 3, 5, 6 and 7 are most opportune in terms of effectivity and cost-benefit.

Table 53: overview implementation scenarios

Scenario	Cost-benefit over 2020-2040 (M€)
Baseline scenario	0
Scenario 1 “stringent physical degradation”	-22^{+47}_{-58}
Scenario 2 “physical degradation”	0.5^{+42}_{-37}
Scenario 3 “physical degradation with bench ageing”	71^{+33}_{-28}
Scenario 4 : “physical degradation + rearrange ULVs for mopeds”	
Scenario 5: “physical degradation with bench ageing+ rearrange ULVs for mopeds”	
Scenario 6: “baseline scenario with introduction of new measures like ISC requirements”	
Scenario 7: “baseline scenario with introduction of new measures like ISC requirements + rearrange ULVs for mopeds and tricycles”	

7.14 Conclusions and recommendations

- Complete phasing out the AMA cycle is not necessary. It exposes vehicles with a low or moderate maximum vehicle speed to operation conditions similar to the WMTC.
- Phasing out AMA only for WMTC class 3 vehicles can be justified with the results of the technical assessment of this study.
- In order to better reflect ageing conditions that are observed in the WMTC, a revision of the SRC-LeCV sub-classification – as described in 7.3.1 – is recommended.
- When the two preceding recommendations are taken into account, both AMA and SRC-LeCV are technically feasible mileage accumulation procedures that well reflect the ageing conditions that are observed in the WMTC.
- Currently manufacturers seldom choose to perform mileage accumulation. In these rare cases that mileage accumulation is performed, the AMA partial

mileage accumulation is carried out, and only when they can perform US and European type approval at the same time. Global acceptance of the SRC-LeCV might increase the application rate of this cycle.

- When AMA is applied, it is in most cases applied on the road. The AMA is well applicable on the road, the SRC-LeCV is not. Due to the cycle requirements, the SRC-LeCV mileage accumulation is only feasible to be performed on the chassis dynamometer. This will require initial investments in additional chassis dynamometer facilities from the manufacturers. Robotizing the driving can be a cheap solution on the long run, but also requires a substantial initial investment. This makes SRC-LeCV, certainly on the short term, a more costly alternative to AMA.
- Changing the sub-classification of the SRC-LeCV according to the proposal in section 7.3 and phasing-out of only AMA for WMTC class III vehicles is more cost-beneficial than fully phasing out the AMA and maintaining the current SRC-LeCV sub-classification.
- Bench ageing is a low cost, well accepted and reliable physical ageing alternative to distance accumulation cycles. Adoption of the bench ageing procedure of (EC Regulation No 692/2008, n.d.) in article 23 of (Regulation (EU) No 168/2013, 2013) could be considered to make the durability requirements for L-category vehicles more cost-effective. The application of the procedure on L-category vehicles shall be validated before this test method is introduced. Bench ageing leads to the highest overall benefit in monetary terms.
- Actual durability testing with mileage accumulation appears more effective in achieving durability of emission control systems, compared to the use of Deterioration Factors in the mathematical durability procedure.
- The application of the mathematical method according to Article 23(3c) of Regulation (EU) No 168/2013 does not reflect ageing in reality. A solution is required to secure environmental performance of L-category vehicles over the useful life. Such solutions can be found in phase-out of the mathematical method and mandating a more representative methodology with physical degradation/ageing of the emission control devices (*e.g.* catalyst). Or – following the example from passenger cars – solutions can be found in additional measures that are currently not included in the Euro 5 package and that close the potential loop-hole like for example in-service conformity (in-use compliance) requirements.
- Phasing-out the mathematical method is only cost beneficial if physical ageing procedures are applied according to the recommended revised sub-classification for the SRC-LeCV, and phasing out of AMA for WMTC class 3 vehicles. As alternatives, or complementary options, bench ageing and/or requirements such as ISC can be introduced.
- Except for mopeds, the prescribed Useful Life values in Annex VII of Regulation (EU) No 168/2013 are considered appropriate for all vehicle categories. With respect to mopeds, the Useful Life value from the regulation differs substantially from the average useful life value obtained from the fleet activity data. Therefore, it is recommended to revise the Useful Life value for mopeds. However, by doing so, physical ageing only remains cost beneficial in case bench ageing is introduced as an alternative method for physical ageing, due to increasing type approval and development costs.
- With respect to the partial mileage accumulation procedure, introduction of the additive exhaust emission deterioration factor calculation method, as an

alternative to the current multiplication approach, lead to a more robust procedure without considerable counter effects.

8 Type VII – CO_2 emissions, fuel consumption, electric energy consumption or electric range

8.1 Background and objectives

Objective

The main objective of this task is to assess the test procedure laid down in Annex VII of Regulation (EU) No 134/2014. If needed, modifications and/or amendments can be proposed to improve the regulation.

The specific tasks for this assessment are:

i. Carry out measurements according to Annex VII from Regulation (EU) No 134/2014 (from this point Type VII test procedure) with conventional vehicles and one hybrid and one pure electric vehicle;
ii. Report identified issues in the application of the test procedure, if any;
iii. If necessary, make recommendations to improve the test procedure.

The most comprehensive part of the assessment is on hybrid electric and pure electric vehicles. Nonetheless, the scope of the work includes all L-category vehicles and thus vehicles with conventional propulsion technology are also part of the assessment.

Background

For passenger cars the measurement of CO_2 emissions and fuel consumption is required for many years. The procedure to determine the CO_2 emissions and fuel consumption of passenger cars is described in the R101 (UNECE, 2013). This procedure applies to vehicles with a conventional drivetrain and to vehicles with a fully or partly electric drivetrain. The R101 also describes the procedure to determine the electric range for hybrid and fully electric vehicles. The complexity of electric propulsion, which is partially tackled by the test procedure, is the decoupling of CO_2 emissions from the power demand. Hence a single test no longer suffices.

The aforementioned procedures from the R101 has been adopted for the greater part in Annex VII of Regulation (EU) No 134/2014. Corresponding to passenger cars the procedure for L-category applies to vehicles with a conventional drivetrain as well as for vehicles with a pure or partly electric drivetrain. Naturally, passenger cars and L-category vehicles are not identical. Hence some parts of the test procedure cannot remain the same. An important adjustment is related to externally chargeable hybrid vehicles. In order to make the procedure suitable for L-category hybrid vehicles assumptions were made regarding the assumed average distance between two battery recharges (D_{av}). This 'D_{av}' makes certain battery sizes more effective in terms of reducing indicated CO_2 emissions in TA tests than others.

Annex VII of Regulation (EU) No 134/2014 starts with the procedure for vehicles with a conventional powertrain. After that, vehicles with an electric or hybrid powertrain will be addressed. This chapter follows the same order.

8.2 Test and analysis results

8.2.1 Vehicles with a conventional powertrain

The type VII test procedure methodology for L-category vehicles with a conventional powertrain technology is comparable with the procedure of the R101 (UNECE, 2013) for passenger cars. During the Type VII test, CO_2 emissions and fuel consumption are measured according to the Type I test procedure as laid down in Annex II of Regulation (EU) No 134/2014. Fuel consumption is calculated based on the CO_2, CO and HC emission results.

During the type approval test the CO_2 result is compared with the declared value of the manufacturer. This CO_2 result should not exceed the declared value by more than 4%. A lower CO_2 result is always allowed. When the CO_2 result is not exceeded by more than 4%, the declared value is taken as type approval result. A repetition of the test is needed when the declared value is exceeded by more than 4%. Then, the average of the two measurements should not exceed the declared value by more than 4%. When the declared value is still exceeded by more than 4%, a final test shall be driven. The average of the three tests will be taken as taken as type approval result. For fuel consumption such a procedure is not prescribed.

In this project the majority of the tested vehicles were subjected to the Type I test. During these Type I tests, $CO_{2,}$ CO and HC emissions were measured and the fuel consumption was calculated. The majority of these tested vehicles are selected for the evaluation of the Type VII test procedure. This evaluation is focussed on the applicability of the Type VII test procedure. More specific, the test procedure is evaluated at; repeatability, practicality and potential issues. For the evaluation of repeatability, the feasibility to stay within the aforementioned 4% deviation in CO_2 emissions is assessed. For a proper evaluation it is important that the vehicles have driven multiple tests per vehicle and that there are no differences between the performed tests. Hence, the selected vehicles and tests meet the following elements:

i. At least three identical Type I tests;
ii. No problems occurred during the test;
iii. Only tests with cold start;
iv. No preconditioning tests are taken into account;
v. Only tests with reference fuel.

In total 15 vehicles were selected and part of the evaluation. In terms of practicality no issues are found for the Type VII test. Figure 70 and Figure 71 give more insights in the repeatability of the tests. The graphs show the minimum and maximum deviation in CO_2 emissions and fuel consumption compared to the average values. A comparison is made with the average values instead of the declared values because the latter was often not available. In the graphs also the number of tests are shown. The deviations range between ± -9 and +9% for both CO_2 emissions as well as fuel consumption. However, in the general the deviations are relatively low with an average of+2.7% and -3%. Some vehicles have driven eight or more tests and still have a maximum deviation for each individual test that lies lower than 4%.
Within the test procedure the deviation must not be higher than 4% of the declared value. Out of the fifteen vehicles, three vehicles have a maximum deviation which is higher than 4% compared to the average.
Based on this results, a maximum deviation of +4% compared to the declared value is considered as feasible in terms of repeatability. Especially because the test

procedure provides the option to perform extra tests to stay below the 4%, as described above.

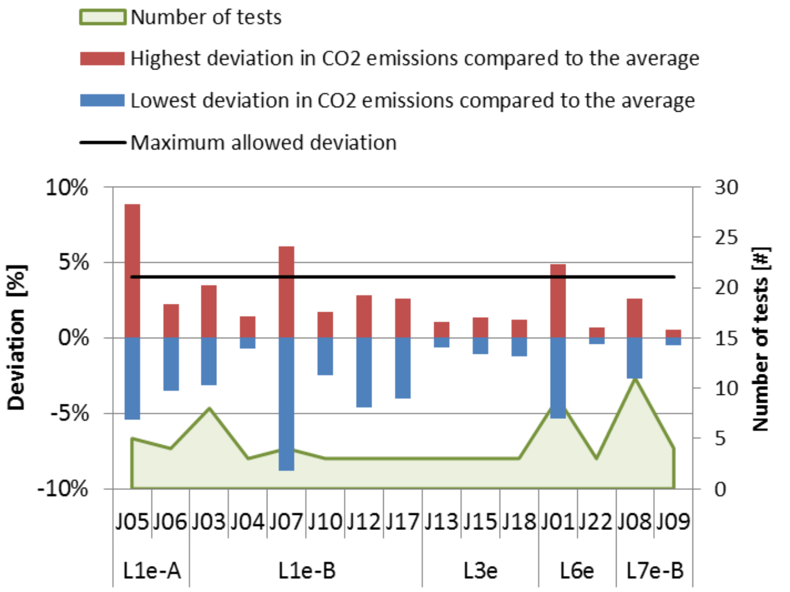


Figure 70: Minimum and maximum deviation in CO_2 emissions compared to the average CO_2 emissions.

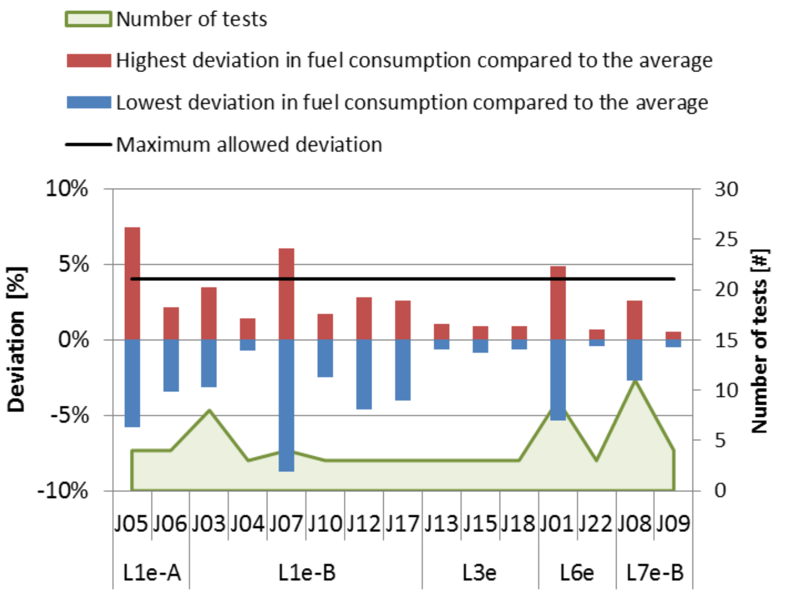


Figure 71: Minimum and maximum deviations fuel consumption compared to the average fuel consumption.

Possible improvements

The real-world fuel consumption of passenger cars can deviate substantially from the type approval test results (Ligterink and Eijk, 2014). This deviation arises due to a

variety of factors. A few examples of elements which may create these differences are; ambient conditions, vehicle condition, driving behavior, road type, type of trip and flexibilities within the testing procedure (Kadijk et al., 2012). For L-category vehicles there are two extra elements compared to passenger cars which possibly create a difference between real-world and Type VII fuel consumption and CO_2 emissions.

The first factor is the effect of the applied road load. Road load is the vehicle resistance on the road which is simulated on the chassis dynamometer. For passenger cars the road load is mostly determined by a so called ‘coast down’ measurement on a test track. As an alternative the manufacturer is allowed to choose from standard road load values. These standard road load values are laid down in Appendix 5 from Annex II of the Regulation (EU) No 134/2014. The standard road load values are organized as a function of reference vehicle mass classes. These standard values are not often applied for passenger cars due to the severity of these factors for passenger cars. A coast down measurement potentially gives a more representative road load, because it takes account of- and represents all vehicle characteristics, where the standard road load values are based on vehicle mass only. Unlike the common practice at passenger cars the common practice for most of the L-category vehicles is the application of the standard road load values (although, a coast down measurement is allowed). Most likely the measurement result will differ from the real-world fuel consumption as a result of this effect. A side effect is that a large variety in vehicle shapes and rider position (mostly for motorcycles and mopeds) are not taken into account, while having a significant influence the air resistance and thus fuel consumption (mostly at higher vehicle speeds).

The second factor is related to vehicles with speed limiters. Speed limiters are often applied to mopeds which are restricted to 25 or 45 km/h. Speed limiters are also applied on other vehicles, such as quads. These vehicles often use a different method for speed limitation than mopeds. This paragraph is focused on speed limiters for 4-stroke mopeds. Commonly applied speed limiters for 4-stroke mopeds are ‘engine speed limiters’ (often applied for vehicles which use a carburetor for the fuel supply) and ‘variomatic limiters’ (transmission ratio limiters). Both types of speed limiters have a negative effect on fuel consumption (Hensema et al., 2013). The ‘engine speed limiter’ can also introduce a difference between real-world fuel consumption and the Type VII fuel consumption as a result of the testing procedure. The engine speed limiter delays the ignition timing for the combustion in order to restrict the engine speed. By doing so, a large part of the fuel is combusted not delivering engine power, resulting in a high fuel consumption. By driving only just below the limited speed, the negative effect of the engine speed limiter reduced, even to zero (Hensema et al., 2013).

During the measurements within this project it was noticed that sometimes the maximum vehicle speed was somewhat higher than 25 or 45 km/h. This is possible because according to annex X in Regulation (EU) No 134/2014, a tolerance of 5% on the maximum determined vehicle speed is permitted. Therefore some vehicles will and did not drive at their maximum (delimited) speed during the Type VII test, and thus the speed delimiter was not activated. It is commonly known that in real-world driving conditions, most drivers will drive those vehicles in full-throttle operation and thus with an activated speed delimiter. The engine speed limiter especially has a negative effect at maximum speed. Hence, driving below maximum speed during the Type VII procedure most likely results in a determined fuel consumption that is lower than the fuel consumption in real-world operation.

8.2.2 *Vehicles with an electric or hybrid powertrain*

Annex VII of Regulation (EU) No 134/2014 prescribes testing procedures for both electric and hybrid vehicles. For hybrid vehicles the regulation distinguish between four different types:

vi. Externally chargeable (OVC) without operation mode switch;
vii. Externally chargeable (OVC) with operation mode switch;
viii. Not externally chargeable (NOVC) without operation mode switch;
ix. Not externally chargeable (NOVC) with operation mode switch.

In Regulation (EU) No 134/2014 tests are prescribed to determine the electric range, energy usage, fuel consumption and CO_2 emissions (if applicable) of L-category vehicles. For NOVC vehicles no range test applies. The type VII test procedure methodology for electric and NOVC hybrid technology is comparable to the procedure for passenger cars (UNECE, 2013). For these vehicle types some minor revisions are needed in the Regulation (EU) No 134/2014. The minor revisions are related to some inconsistencies and some textual improvements. No major issues are found for electric and NOVC hybrid vehicles in Annex VII of Regulation (EU) No 134/2014.

For OVC hybrid vehicles there is an important difference compared to passenger cars. This is the 'D_{av}' which is the assumed average distance between two battery recharges. D_{av} is set to 25 km for passenger cars. For L-category vehicles D_{av} depends on engine capacity and maximum speed of the vehicle:

- D_{av} = 4 km for vehicles below 150 cm³ engine capacity,
- D_{av} = 6 km for vehicles with an engine capacity ≥ 150 cm³ and Vmax < 130 km/h; and
- D_{av} = 10 km for vehicles with an engine capacity ≥ 150 cm³ and Vmax ≥ 130 km/h.

OVC hybrid vehicles are measured in two conditions, respectively condition A and B:

- Condition A: test starts with fully charged energy storage device;
- Condition B: test starts with energy storage device in minimum state of charge (SOC).

The results of the tests with condition A and B (CO_2, fuel consumption and electric consumption) are used in combination with the electric range and D_{av} to weigh the results. The result of condition A is multiplied with the electric range and the result of condition B is multiplied with D_{av}. Then the sum of those two multiplications are divided by the sum of the electric range and D_{av}.

This means that the D_{av} value has a large effect on the weighted result, a lower D_{av} value results in a lower CO_2 and fuel consumption result. For example, when the range is equal to the D_{av} value, and the complete cycle can be driven pure electric, the CO_2 emissions and fuel consumption are halved compared to the conventional drivetrain.

A rough estimation can be made based on the average annual mileage from the activity model (section 2.5.3). When the D_{av} values are compared with an average daily mileage that is calculated with the annual mileage data, taking into account that

most L-category vehicles are not driven on a daily basis, the current D_{av} values seem to be on the low side. This possibly leads to CO_2 and fuel consumption test results that are too low. Not enough statistical and testing data is available to properly assess the D_{av} -value, also because not many OVC L-category vehicles are on the market. For further evaluation, more information on the average trip length, availability of charging facilities and charging behaviour is required.

In general the fuel efficiency testing for electric and hybrid vehicles is typically longer and more complex than that for conventional technology. As a result of the complexity of testing, the practicality of the procedure is reduced. Except for some suggestions for minor text revisions and the recommendation for more research on the D_{av} values, when more L-category OVC vehicles enter the market, no major issues are found in the procedure for OVC hybrid vehicles.

8.3 Discussion

Road load

Insufficient information is known regarding the representativeness of the standard road load values for L-category vehicles. Due to the wide variety in L-category vehicle characteristics one would expect a large variety in road load values. However, this variety is not represented with the standard road load values. Ideally, a comparison between real-world road load and the generic values is made by performing coast down tests with different vehicle types.

Effect of speed limiters

There is no scientifically evidence available that mopeds are used at their maximum speed for a significant period of its operation. Though, to cover for the negative effect of engine speed limiters during the Type VII test, it is recommended to test the vehicles at their maximum speed at full throttle position instead of a maximum of 25 or 45 km/h. With such a provision it is beneficial to develop and apply more efficient speed limiters.

D_{av} value

Multiple OVC hybrids are already available on the passenger cars market. TNO monitored these hybrid vehicles between 2012 and 2015 (Ligterink and Smokers, 2015). The results of this monitoring were:

- During type approval a large part is driven in the electric mode;
- During real-world usage the electric mode is used significantly less, up to 5 times;
- As a result, the average real world fuel consumption is more than 150% higher.

The mentioned aspects can have multiple causes, such as; lower electric range in real world circumstances, infrequent charging of the battery, longer trips than the electric range etc.. Infrequent battery charging can be the result of the unavailability of a charging facility. Also, the incentive for a user to charge, can be low due to the much larger range of the conventional drivetrain configuration. From the aforementioned report it can be concluded that the real-world situation for hybrid passenger cars differs significantly from the type approval situation.

For passenger cars the D_{av} value is 25 km. Many OVC hybrid vehicles have a specified electric range close to 50 km. With a range that's double the D_{av} value and the fact that the complete cycle can be driven in pure electric mode, the CO_2 emissions and fuel consumption are approximately one third compared to the

conventional drivetrain. However, as mentioned above, the real world situation in the Netherlands is clearly different. The D_{av} value of 25 km seems to be too low for OVC hybrids in the Dutch situation. Given the gained experiences with OVC hybrids in the Netherlands, the D_{av} value for L-category seems to be rather low. Therefore, the most appropriate distance as D_{av} value for L-category vehicles is recommended to be investigated in more detail, when more data becomes available when more L-category OVC vehicles enter the market.

In addition, it can also be considered to develop D_{av} values for each WMTC class instead of the three current classes. This would bring more synchronization within the Regulation (EU) No 134/2014.

Classification

The sub-classification can lead to an illogical classification for some electric vehicles. An electric vehicle with a maximum speed lower than 100 km/h is always put into class 1. A comparable vehicle with a conventional powertrain with an engine displacement larger than 150 cm3 would drive the more demanding WMTC 2-1, while the electric vehicle with comparable or even higher performance capabilities drives the relatively mild WMTC class 1 (part 1 followed by part 1). To avoid such illogical classifications it is recommended to consider adding engine power as a classification condition in the WMTC classification.

Range determination

Testing without the use of auxiliaries, especially heating, and at laboratory temperatures, will deliver high electric range result compared to most real-world operation circumstances. Naturally these testing conditions apply for all types of drivetrains and also for the Type I test since this increases the repeatability of the test result. However, the effect of these testing conditions may have a larger effect on vehicles with a fully or partly electric drivetrain.

8.4 Conclusions and recommendations for possible legislative proposals

Conclusions:

- The Type VII test procedure was found to be adequate for determining CO_2 emissions, fuel consumption and electric range for conventional, electric and NOVC hybrid vehicles.
- For OVC hybrid vehicles, the value for D_{av}, i.e. the average distance between two battery recharges, has a large effect on the CO_2 emissions and fuel consumption established in the test. The value for D_{av}, should be investigated based on the average trip length, availability of charging facilities and charging behaviour. This can only be done when more hybrid electric L-category vehicles penetrate the market and more real-world data becomes available. Currently, there is not enough real-world data available to assess the D_{av}.
- In general, speed limiters on mopeds cause an increased fuel consumption when driving at full throttle position. This is currently not covered in the type I test.
- Because there is no engine power criterion, and an electric engine has no displacement volume, electric vehicles with a maximum speed lower than 100 km/h are automatically classified as WMTC class 1, where a vehicle with a conventional powertrain and comparable performance might be classified as WMTC class 2-1.

- In general the fuel efficiency testing for electric and hybrid vehicles is typically longer and more complex than that for conventional technology. As a result of the complexity of testing, the practicality of the procedure is reduced.

Recommendations:

- The most appropriate distance as D_{av} value should be investigated based on the average trip length, availability of charging facilities and charging behaviour. This can only be done when more hybrid electric L-category vehicles penetrate the market and more real-world data becomes available;
- And, based on this evaluation, it is recommended to develop D_{av} values for each WMTC class instead of the application of the three current classes;
- Include an instruction in the test procedure to secure that mopeds with a speed limiter are driven at their maximum speed and at full throttle operation during the maximum speed range of the cycle.
- More research is recommended to compare standard road load values with real-world road load values, as these can have a large effect on fuel / energy consumption and CO_2 emissions;
- It is recommended to introduce engine power as a WMTC sub-classification criterion to prevent possible illogical classification of electric vehicles;
- Minor revisions and some textual improvements in Annex VII of (Regulation (EU) no 134/2014, 2013) are recommended to avoid inconsistencies.

9 Type VIII – OBD environmental tests

9.1 Background and objectives

On-Board Diagnostics (OBD) is one of the key components of an effective emissions control and safety package of any road vehicle. OBD consists of a combination of sensors, circuitry, algorithms and computing power on board the vehicle that constantly monitor the performance of key powertrain and safety components. In terms of environmental performance monitoring, key combustion and aftertreatment devices should be monitored to make sure that they properly perform, so that the vehicle's environmental performance is not significantly hampered by malfunctions or excess ageing of the individual systems.

In order for a proper performance to be verified, the OBD system needs to make sure that vehicle emissions do not exceed a specific 'threshold' per pollutant. This OBD threshold (OTL) is an emissions level expressed in g/km, exceedance of which should enable a malfunction indicator (MI) light (MIL) to be illuminated on the vehicle's dashboard. MI illumination informs the driver of the presence of a malfunction and the need for the vehicle to be properly repaired. In extreme conditions of malfunction, MI illumination may be associated with engine torque reduction (often called 'limp' mode of operation) to protect the vehicle and the rider.

An OBD system does not directly measure pollutants levels but instead it monitors malfunctions that may lead to OTL exceedance. As a result, when an OTL exceedance is determined, the specific malfunction and related parameters are permanently stored on the vehicle's electronic control unit (ECU). Reading the ECU by a special OBD tool allows service centres to fast and efficiently detect the malfunction and, as a result, to replace or fix the affected component. Therefore, OBD should be seen as a tool leading to direct environmental benefits and to cost-effective repair of affected vehicles.

Regulation (EU) No 168/2013 introduces two stages for OBD for L-category vehicles. The first stage – OBD Stage I – is introduced in 2016 for new types of L3e, L4e, L5e-A, L7e-A vehicles and one year later the same requirements become mandatory for all types of vehicles. For L6e-A, OBD Stage I becomes applicable in 2017 and 2018 for new and all types, respectively. As a second step, OBD Stage I also becomes applicable for the remaining L3e-L7e subcategories from 2020/2021 (new/all types) on. OBD Stage I monitors electrical continuity for a variety of sensors and control valves of the engine. The minimum systems monitored (depending on their availability on each vehicle) are shown in Table Ap2-1 in Appendix 2, Annex XII of Regulation (EU) No 44/2014, related to the requirements applying to functional OBD.

Further to OBD Stage I, Regulation (EU) No 168/2013 requests the introduction of OBD Stage II for vehicles falling into subcategories L3e, L5e-A, L6e-A and L7e-A from 2020/2021 (new/all types) on, pending confirmation of the environmental study. OBD Stage II introduces additional functionalities over OBD Stage I which, predominantly, focus on monitoring the performance of aftertreatment devices. Aftertreatment monitoring is not at all included in OBD Stage I. In addition, OBD Stage II requires misfiring and in-use performance monitoring, together with circuit rationality monitoring. OBD Stage II therefore aims at a more thorough monitoring of

the proper operation of an extended list of systems and devices. As a result of the more thorough monitoring, lower OTLs are defined before MI is activated. Hence, the more thorough monitoring together with the lower OTLs indeed allow for more holistic environmental protection.

The overarching objectives of assessing the need for introducing of OBD Stage II in the framework of this study and according to the terms of reference of this work are:

1. Identify the technical requirements and their feasibility to introduce OBD Stage II functionalities.
2. Assess the pros and cons of OBD Stage II over Stage I, in particular with respect to enabling successful repair in case of fault and the additional environmental benefits it offers.
3. Calculate the cost and benefits of introducing OBD Stage II by means of a modelling exercise.

The following sections describe the approach.

9.2 On-board diagnostic requirements - expansion functionality OBD stage I to OBD stage II - relevance for effective and efficient vehicle repair

9.2.1 Background and objectives

Table 12-1 in Annex XII of Regulation (EU) No 44/2014 specifies the OBD stage II additional functionalities, compared to OBD Stage I. For convenience, these are repeated in Table 54.

Table 54. OBD stage II additional functions compared to OBD stage I

Function	Engine type applicability (PI: Positive Ignition) (CI: Compression Ignition)
Catalytic converter monitoring	PI and CI
EGR efficiency / flow monitoring	CI
In-use performance monitoring	PI and CI
Misfire detection	PI
NO_x after-treatment system monitoring	CI
Oxygen sensor deterioration monitoring	PI
Particulate filter monitoring	CI
Particulate matter (PM) emission monitoring	Direct injection PI

All of these elements are satisfactorily applied in the case of passenger cars and the ones related to CI engines are also satisfactorily applied in the case of heavy duty vehicles. However, L-category vehicles are significantly different than larger ones in terms of operation, configuration, and packaging requirements, hence certain of these elements may provide additional challenges in their implementation. The first objective of this task is therefore to assess the technical feasibility of introducing new functionalities.

The second objective is to assess how much the new functionalities will assist in successful maintenance and repair of the vehicle, in particular as a wider list of parameters becomes available with OBD Stage II also to third-party service centres.

Given the technical challenges foreseen, the assessment should take into account different potential periods of implementation of the additional functionalities, including the following options:

- (i) No OBD stage II introduction;
- (ii) OBD stage II introduction in 2020 as laid down in Regulation (EU) No 168/2013;
- (iii) OBD stage II introduction in 2020 with a relaxed period of OTLs and excluding catalyst monitoring, until 2024
- (iv) OBD stage II introduction in 2020 with exclusion of catalyst monitoring until 2024
- (v) OBD stage II introduction in 2024 in the EU;

These options were based on the terms of reference of this study, following limitations of the technical feasibility for some OBD components, as discussed in detail the following sections. In addition, our study makes an attempt to explore the impacts of extending OBD to the UNECE region.

9.2.2 Technical feasibility assessment

As discussed in section 3.2.6, we expect that diesel vehicles will not be viable in the medium term, so we foresee that OBD II is not relevant for diesel powertrains within the L-vehicles category. Hence, the only components of Table 54 for which technical assessment on their feasibility needs to be conducted comprise the ones referring to PI vehicles. Moreover, no direct injection (DI) vehicles are expected to become viable at a Euro 5 step, due to the very low hydrocarbon limits imposed. In L-category vehicles, DI has been only present for two-stroke engines. Such engines will require advance technology and significant investments to meet hydrocarbon limits at Euro 5, thus compromising any packaging specific power and weighting advantages of two-stroke engines over four-stroke ones. DI may become relevant again if CO_2 limits are introduced for L-category vehicles; this time it will be for four-stroke engines. In passenger cars, DI technology has become popular due to the need to increase efficiency and reduce CO_2. Since no discussion on CO_2 targets for L-category vehicles has been initiated yet, we do not see any such engines in the foreseeable future, at least not at large volumes, due to their higher cost over port-fuel injection ones. Hence, OBD for PM emission monitoring requested in Table 54 is not further included in our analysis.

In the same respect, oxygen sensor deterioration monitoring is not a significant challenge. Sensor signals deteriorate with time due to ash accumulation on their surface and general material degradation by thermal ageing. However, algorithms to detect degradation are available from passenger cars applications (*e.g.* Seki et al. (1996)) and can be widely used for L-category vehicles as well, if the sensor is within normal operating conditions. The latter is assessed with regard to the catalytic converter monitoring assessment. Hence, oxygen sensor deterioration monitoring should be considered as a component of monitoring catalyst deterioration which it is further studied in the following paragraphs.

Based on this preliminary assessment, the three elements of OBD Stage II functionality that have to be assessed in terms of technical feasibility include monitoring of:

- The catalytic converter and the oxygen sensor;
- The in-use performance; and,
- Misfiring.

Catalytic converter and oxygen sensor monitoring

The OBD objective with regard to catalyst monitoring is to detect when the catalyst is malfunctioning, causing emissions to exceed OTLs for at least one of the pollutants monitored (CO, NMHC or NO_x).

<u>Catalyst efficiency monitoring</u>
Catalytic converter efficiency drops normally with time mainly as the result of two mechanisms, *i.e.* chemical and thermal ageing (Ruetten et al., 2010). Chemical ageing, or poisoning, refers to the deposition and binding (*e.g.* through chemisorption) of metals and alkali on the catalyst surface that block the actual operation of the actual catalysts in the catalytic converter. Such agents are primarily found in the lubricant oil and secondarily on fuels. The contribution of each of the two mechanisms on total degradation is difficult to quantify and depends on the application. For passenger cars, thermal ageing is considered significantly more important (Ruetten et al., 2010) due to low consumption of lubricant oil.

However, in motorcycles at current emission levels, lubricant oil consumption is relatively higher than passenger cars due to the higher average speed they operate at, also allowed by more relaxed (so far) THC levels compared to passenger cars. Relevant experiments on motorcycle catalysts have found significant deposition of phosphorus (Chen et al., 2011) which denotes a strong poisoning effect on the catalyst. Other species, such as calcium and traces of lead (still remaining in fuel and lube oil) have been also found to block active catalyst centres (Zhao et al., 2006), thus compromising performance.

Because experience on three way catalyst monitoring has been accumulated on passenger cars, thermal ageing has been mostly in focus and is in the focus of durability testing. Thermal degradation is the loss of active surface of the catalyst washcoat via structural modification caused by high temperatures, and can be classified into two types: sintering and solid-solid reaction (Chen et al., 2011). The material change decreases the capacity of the washcoat material to store oxygen (oxygen storage capacity – OSC). Stored oxygen improves the efficiency of the catalyst especially over transient operation where the washcoat acts as a buffer to retain stoichiometry over slightly lean or rich conditions, hence improving reaction rates over transient operation (Shamim, 2008). Monitoring the OSC of a catalyst is therefore a very good indicator of catalyst thermal degradation, especially under transient operation.

The most widespread, practically unique, commercially available method for catalytic converter efficiency monitoring is conducted by combining the signal of an upstream and a downstream oxygen sensor. This field has been extensively studied over the several decades that three way catalyst are popular in light duty vehicles. An adequate OSC means that the downstream oxygen sensor would deliver a much lower variation in its signal compared to the upstream one during rich vs lean variations. On the contrary, a defective catalyst with small OSC and low oxygen buffering capacity would mean that the downstream sensor signal is very similar to the upstream one. Development of proper algorithms on the basis of the two signals provides a reliable method of OSC and hence thermal degradation estimation.

Monitoring challenges

Although the effectiveness of this technique as a diagnostic of thermal ageing is well documented and proven in practice, its capacity to detect chemical poisoning is rather implicit. The probability of poisoning increases with exposure of the catalyst to exhaust gas, similar to thermal ageing. Moreover, extreme poisoning may also reduce the OSC of the catalyst. However, mild poisoning may significantly compromise the efficiency of the catalyst without being detected by OSC monitors. In other words, cases where lubricant consumption is significant may lead to degraded catalysts which are not detected by the twin oxygen sensor technique. The efficiency of the OSC as a detection of low catalyst performance in motorcycles has therefore yet to be proven.

In the course of the study, motorcycle manufacturers have provided three more issues, including experimental evidence, regarding the applicability of twin oxygen sensors for catalyst performance monitoring in L-category vehicles (ACEM (2016), slide #11 in ACEM proposal in MCWG meeting of 22.9.2016). These include:

- Backflow
- Diffusion
- Packaging restrictions

Backflow refers to the entrainment of fresh air in the muffler through the tailpipe during operation. This may occur with two mechanisms, mild pressure variations in the muffler due to exhaust pulsations and, secondarily, through back-diffusion at low exhaust flowrates. Backflow brings oxygen in the tailpipe with the potential to distort the downstream oxygen sensor signal, thus compromising detection possibilities. Back-flow or air re-entrainment may occur in any vehicle exhaust flowing system and it is not motorcycle specific. However, in passenger cars, the location of the catalyst and the oxygen sensors are currently close coupled to the engine outlet (directly after the exhaust manifold) for fast warm-up. Hence, backflow is not an issue as the oxygen sensors are several meters upstream of the tailpipe. In some motorcycles though, especially in scooters, the catalyst is welded in the muffler at the exhaust line end, before this enters the muffler. This only allows a small distance between tailpipe and downstream oxygen sensor. In this case, oxygen backflow may indeed be an issue. Engineering assessment would lead to the suggestion that backflow is more prominent at low load, low RPM conditions where exhaust flow is minimal.

The second issue raised by manufacturers is ‘diffusion’. The study team cannot be certain whether the actual phenomenon observed by manufacturers is indeed diffusion or other types of phenomena. To our understanding, the issue described is a result of flow expansion in the expansion chambers of the silencer. The upstream sensor measures oxygen concentration (or lambda value – depending on the sensor) in a limited cross-section exhaust pipe. The downstream sensor measures the concentration through an expansion chamber. Hence, depending on flowrate and flowrate variations, concentration in the expansion chamber may vary independently from concentration in the tailpipe thus invalidating the detection algorithm based on

the comparison of the responses of the upstream and downstream sensor. The study team has no actual experience with this phenomenon but the physics implied and the experimental evidence presented by the manufacturers seem both plausible to cause an issue in detectability.

The third challenge brought up refers to packaging restrictions. In cars, the catalytic converter is rather well protected either underbody or close-coupled to the engine. Similarly, the cabling of the oxygen sensor can be kept out of sight and kept far from high temperature sources. Despite this, oxygen sensor manufacturers (*e.g.* NGK[37]) report several issues as root causes of oxygen sensor malfunctions, several of which are caused during maintenance. This include melted cables or plugs, frayed or broken cables, loosened cable seal, etc. An on-the-muffler oxygen sensor on a scooter is much more exposed and vulnerable to such issues. One scooters manufacturer informed us that the most frequent problem of lambda sensors is broken cables of oxygen sensor while pulling the exhaust line to removing it from sight in repair workshops that try to fix rear wheel or transmission issues. Packaging for a sensor located in the tailpipe include thermal protection for the sensor and the cabling, and protection against tampering and unintentional damaging during use or vehicle repair and maintenance.

It should be mentioned here that the challenges identified as 'backflow' and 'diffusion' potentially also affect the OBD Stage II rationality check of the downstream oxygen sensor. Hence, solving these two issues is expected to be an enabling factor for oxygen sensor OBD-II monitoring.

<u>Possible solutions</u>
Although it is not possible to bring validated counter-argumentation to all these issues, there are a number of items that the study team would like to raise based on the information collected or submitted by manufacturers (schematically shown on Table 55.

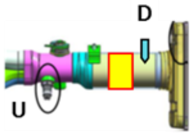
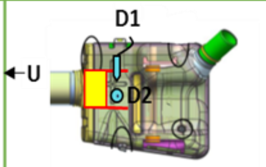
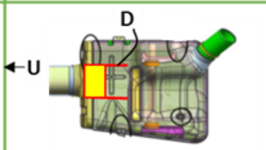
Technical problems are mostly vehicle specific. Scooters in which the catalyst is placed in the muffler are definitely one of the categories for which catalyst monitoring is the most difficult to perform. In other vehicles, like larger motorcycles or tricycles, where the catalyst is placed underbody or further upstream in the exhaust line, this is less of a problem or not a problem at all. Both sensors can be placed on the downpipe and the wiring may be well protected and led to the ECU. Moreover, backflow and 'diffusion' cease to be issues in this case. In those cases with monitoring challenges, a number of technical solutions can be brought.

(i) Option 1: One of them is bringing the catalyst closer to the engine out and out of the muffler. This might also be imposed by the need to meet Euro 5 limits. In such a case, the downstream sensor would also be placed on the downpipe, thus eliminating packaging, backflow and diffusion problems. The counter problem of such a solution is the limited space between engine out and muffler. This will require changing the topology of the engine and possible its fixation angle to make up more space for the catalyst placement. It cannot be excluded that this will require local redesign of the frame to make up space and enable serviceability. Overall, it can be understood that this is

[37] NGK Europe website: https://www.ngk.de/en/technology-in-detail/lambda-sensors/diagnosis/defects/

not an incremental change but a redesign of the powertrain and exhaust system, however it can offer a potential solution.

Table 55: Catalyst monitoring solutions and effort assessment

Option	Oxygen Sensor Location	Schematic	Technical Challenge	Effort Assessment
Current Condition	On muffler (expansion chamber)		▪ Backflow, mixing, location, thermal protection wiring ▪ Requires redesign of muffler	Impossible to reliably monitor
Option 1: Catalyst @ downpipe	On downpipe		▪ Space for both catalyst and lambda (requires increasing distance and even frame changes). Optimum for Euro 5	High
Options 2i, 2ii: In muffler, on primary line (downstream catalyst)	In muffler		▪ 2i: Requires new design of lambda sensor ▪ 2ii: Requires redesign of muffler concept ▪ Electrical connection to muffler	High
Option 3: Alternative monitoring technique	In muffler		▪ Option would be exothermy measurement ▪ Sensitivity needs to be proven ▪ Model specific calibration necessary	High
Legend	Catalyst	Oxygen sensor side view	Oxygen sensor cross-section	

(ii) A second option can be that the oxygen sensor becomes part of the muffler and that the sensor element is not exposed to the flow in an expansion chamber but in the in-muffler pipe transferring the exhaust downstream of the catalyst to the prime expansion chamber (Option 2i in Table 55 – position D1). This will require a custom-made oxygen sensor with the complete body resistant to high temperature and then a special connector to lead the signal outside of the muffler. The muffler will also have to be more carefully redesigned to reduce backflow. Still, backflow in the prime connection line, downstream of the catalyst is considered rather limited. Design, manufacturing, and technology costs will be much higher in this case than with conventional mufflers (*e.g.* up to Euro 4). Still, this is expected not to require engine realignment and design changes. This may also make aftermarket mufflers, that often come without catalytic converters, technically cumbersome to develop and financially uninteresting. Implicitly this may also be a plausible solution to fight tampering and to reduce use of improper mufflers. An alternative to this would be to change the muffler design so that the catalyst line is exposed and the oxygen sensor can be also exposed outside of the muffler as well (Option 2ii in Table 55 – position D2). This will require redesign of the muffler concept so that enough space is found for the sensor to be located at this unique point.

(iii) Alternative techniques to oxygen storage capacity could potentially be utilized (Option 3). Catalyst exotherm monitoring was assessed as a

technique. In this, the difference in temperature between a downstream and an upstream measurement (*e.g.* Theis (1994); Tsinoglou et al. (2002)) serves as an indication of the catalyst condition. Well operating catalysts produce high exotherms compared to aged ones, as a result of the oxidation of pollutants in the catalyst. Such a technique offers the advantage that temperature measurement inside the muffler is technically much easier than oxygen level measurement, hence offering a potential advantage for material and design costs. On the counter-side, this may lack sensitivity (although this has to be proven) and requires more intensive calibration per vehicle model than the oxygen storage method. Heat transfer from the exotherm to the temperature sensor may vary for different muffler designs while OSC is a catalyst property and not at all a muffler property. Third, manufacturers will need to gain experience in effectively utilizing this technique, so enough lead time would be required in this case as well. This is believed though to be an alternative technical solution to OSC monitoring.

Recommendations

In all possible technical solutions we could identify, the technical effort required to properly locate the downstream sensor for reliable catalyst monitoring is high. Expected technical developments required go beyond usual incremental upgrades, which could be implemented in the subsequent model development round. As the model round is usually 2-4 years, an equal lead time for introducing catalyst monitoring needs to be foreseen.

Technical difficulties to introduce a downstream oxygen sensor are limited or not even existent for some motorcycle models, in particular to larger ones. *E.g.* sub-category L3e-A1 comprises both of scooters and normal street motorcycles; the latter being much less critical in introducing catalyst monitoring functionality. As it is not technically possible with the current Regulations to distinguish those model types for which catalyst monitoring would be possible with less technical effort, it seems reasonable to expect that any time margin decided is provided for all vehicle categories relevant to OBD Stage II. It could however be requested that a minimum number of vehicle models per manufacturer already deliver catalyst monitoring functionality from the first round of implementation of Euro 5.

Misfire detection

Misfire definition and monitoring need

Misfire detection is the second critical component of OBD Stage II detection functionality. Misfire is the lack of complete combustion in one or more cylinders. In misfiring, only part of the indicated power is produced and only a fraction of the fuel is consumed. For complete misfire, there is no power produced by the misfiring cylinder at the specific engine cycle. Figure 72 shows the drop in rotational speed of the crankshaft as a result of lack of combustion in the particular cylinder.

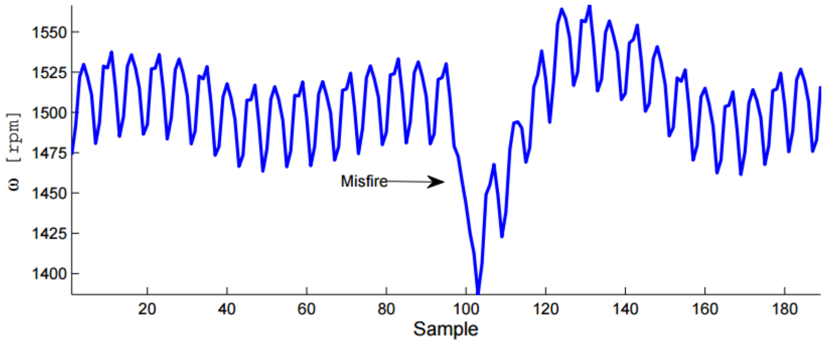


Figure 72. Flywheel angular velocity measurements around speed 1500 rpm of a passenger car. Misfiring appears around sample 100 (Theren, 2014)

In both total and partial misfire cases, fuel hydrocarbons escape the cylinder uncombusted. Misfiring can occur intermittently due to random causes or a cylinder may constantly misfire in more severe malfunctions. Intermittent misfiring can hardly be detected by the rider. Constant misfiring may be detected, especially by experienced riders, by the drop in power and responsiveness and the harsher engine operation. If not detected though, then the rider inadvertently makes up for the lost power by requesting more fuel delivered to the engine that further aggravates the problem of uncombusted HC escape.

Misfiring needs to be detected for a variety of reasons. First, misfiring may be an indication of a more severe problem that may further aggravate itself causing severe damage of the engine or of some of its components. For example, uncombusted fuel gradually mixes with lubrication oil reducing the lubrication activity and causing excess wear, practically destroying the engine.

Misfiring can be caused by a number of reasons. The most common source is a number of failures of the electrical system that lead to weak or no spark generation at the spark plugs. Weak battery, malfunctioning ignition coils, dirty or worn spark plugs, short-circuits or current leakages, etc. are common causes of misfiring. The fuel system is the second frequent suspect, including erroneous fuel metering (*e.g.* failed oxygen sensor), injector fouling, low fuel pressure, etc. Other possible reasons include low engine compression, poor fuel quality, failure in one or more engine timing sensors, or a combination of any of those reasons.

Misfire may have significant environmental endpoints. First, the excess quantity of hydrocarbons emitted corresponds to an environmental concern on its own. With a typical fuel consumption of 25-30 g/km for a typical, 600 cc 4-cylinder motorcycle, missing combustion in one cylinder would mean that HC engine out emissions may reach 6-8 g/km, *i.e.* far above any emission limits. If a catalytic converter is being used, the high HC exhaust content would be oxidized in the catalyst to CO (Connolly and Rizzoni, 1994) thus raising the catalytic converter's temperature to levels that could very fast degrade its washcoat. This would mean a very sharp degradation of the catalyst performance, much earlier than the useful life is reached.

As a result, misfire detection has to be early detected to protect the engine and the aftertreatment devices and to avoid unnecessary hydrocarbon and CO emissions to the environment. However, it has to be understood that in contrast to other OBD monitoring functionalities, misfiring detection points to a consequence of one or more malfunctions rather than a root cause of a problem. Often, misfiring related OBD trouble codes in passenger cars are combined with other codes that report specific failures in one of the individually monitored systems. This provides better guidance in repairing the system.

Misfiring detection techniques and challenges

Several techniques have been proposed over time to detect misfire in internal combustion engines. In identifying the possibilities, the study team collected scientific and technical literature and examined the potential specifically for motorcycle engines. Out of the several literature sources studied, the works of Jung et al. (2015); Kiencke (1999); Cesario et al. (2006); Connolly and Rizzoni (1994); Eriksson et al. (2013); Ho-Wuk and Sang-Kwon (2008); Velmurugan (2011); Millo et al. (2003); Cavina et al. (2006); Mohammadpour et al. (2011); Merkisz et al. (2001); Kuroda et al. (1995) with Chung et al. (1999); Connolly and Rizzoni (1994); Moro et al. (1998) and Wu and Lee (1998) being interesting. The main techniques that have been proposed for misfiring detection are therefore the following:

- *Crankshaft Velocity Fluctuation (CVF)/Crank Angle Roughness* is the method used in the vast majority of applications. It is based on the recording rotational behaviour of the engine. In case of a misfire, the engine produces reduced or no torque from the misfiring cylinder and this causes an abnormal fluctuation in crankshaft angular speed. Based on the predicted behaviour of the engine, this deviation can be extracted and detected. The velocity of the crankshaft is obtained by the signal of the crankshaft position sensor. The algorithms involved for signal processing can be based on time as well as frequency domain analysis. There have been also attempts to use neural networks for misfire detection purposes. During the years, this basic method has been widely developed and refined. Latest approaches use engine torque model-based approaches that have significantly increased the signal-to-noise ratio of the measurement. The downside is the processing time but this gradually ceases to be a problem as computing power on vehicles increases.
- *Combustion Ionization Current (CIC) measurement* can also be used as a method to detect misfiring. So far, this has found limited applications, mainly in larger stoichiometric engines. It is a direct-measurement method, *i.e.* it gives information of the actual combustion process instead of eventual misfire effects on engine behaviour. The combustion of fuel inside the engine cylinder produces ions (electrically charged molecules) and free electrons. A measuring probe, often the spark plug, is used to detect the presence of ions, by applying a low voltage to the electrodes, *i.e.* the spark gap. As the ions of opposite polarity migrate towards one of the electrodes of the sensor, a current is induced in the measuring circuit. The current flowing back to the monitoring system depends on the number of ions formed, and measurement of this current provides information of combustion phenomena, with misfire being one of the easiest to detect (Auzins et al., 1995; Yoshiyama et al., 2000; Delphi, 2016).
- *In-cylinder pressure measurement* becomes a mainstream technology, especially for diesel engines. Piezo-resistive pressure transducers are integrated in the glow-plug in diesel engines and provide crank-angle resolved in-cylinder pressure signals that can be used for same-cycle or next-cycle engine control. For gasoline engines, a special opening to the engine is required for pressure measurement. We are not yet aware of commercial

gasoline engine applications of such a technique. In-cylinder pressure measurement has the potential to offer unique opportunities for engine diagnosis and control and is expected to become mandatory in the future as efficiency and air pollutants emissions targets become increasingly stringent. In-cylinder measurement also offers the potential to remove other engine sensors (*i.e.* knock), hence offering more direct engine control strategies.

- Oxygen sensor signal has also been proposed as a method to detect misfiring (Chung et al., 1999). Distortions in a wide-band lambda signal can be used to understand whether one or more cylinders misfire. Although the technique has shown some potential, we are not aware of commercial applications of the principle in real on-road vehicles.

Further to looking into technical and scientific publications. in assessing the possibilities for misfiring detection, the study team took into account approaches and latest technical possibilities presented by vehicle manufacturers in the MCWG meeting of 22.9.2016 (ACEM (2016), slides #9-10), and work of OBD systems supplied including Delphi (2016); Weyand et al. (2010) and Bosch (2014).

Also, over the course of the project, we made several private discussions with developers of misfiring detection systems from both the industry and the academia to try and get more insights on the issues raised. These discussions were both planned, *e.g.* specific phone calls or more random exchanges of information by talking to experts in meetings, workshops and conferences.

In general, we should again repeat that it is extremely difficult to gain a complete view on a field where industrial competitiveness determines the amount of information that becomes public. Hence, our general assessment may still miss latest developments in the area which, for whatever reasons, have not become public. Based on the information that we were able to collect on the basis of industrial and academic sources though, our technical assessment of possibilities is summarized in the following paragraphs:

- Misfire detection is already used in some L-category vehicles, using the crankshaft velocity fluctuation (CFV). This is because crankshaft sensors are already implemented in motorcycles to measure engine speed and recognize piston position during engine start-up. Since some L-vehicles ECUs contain misfire algorithms, this comes ready for some vehicles. This is mostly for advanced and most expensive models which use passenger-car like ECUs. This basic functionality will have to be better refined for OBD Stage II to avoid erroneous misfire detection signals. Such erroneous signals may come from a variety of reasons, *i.e.* road roughness interference, transmission vibration especially for chain systems, and inherent engine instability due to low inertia. In particular, engine inherent instabilities make misfire detection with this technique difficult for low speed, low load engine operation.
- Combustion ionization current (CIC) technique is also implemented in some L-category vehicles as a general combustion diagnostic but we did not become aware of an application as the single misfire detector on an existing engine. Work in this area continues in improving diagnostics with this technique and, possibly, the full potential is not yet explored.
- Both CVF and CIC techniques have limited capacity to detect misfire at high speed. CVF signal to noise ratio decreases at high speed due to engine inertia that buffers out intermittent misfire events. Available time for current detection after the induction coil is fired up in CIC diagnosis also decreases

at high speed. New developments by intermittent fire-up and current detection have been presented by Delphi (Weyand et al., 2010) that are believed to offer misfire detection capability at high RPM as well.

- In-cylinder pressure measurement has the capacity to detect misfire at any kind of RPM and is a very safe method with limited interference from other factors. It is already used in racing applications like Formula 1 cars with misfire detection capability at least up to 15000 RPM. There are a number of important caveats though. First, the cost of such sensors is not negligible, and significantly increases on a relative scale for small engines. Although industrial prices are difficult to obtain, sensors like those for research purposes cost in excess of 5000 Euros/piece. For mass orders and decreased accuracy specifications, the cost will significantly drop but we do not see this being lower than 50-100 Euros/piece currently, including the enhanced ECU cost required to implement them. In certain applications, like 4-cylinder 125 cc engines this makes the sensors implementation cost reach 50% of the engine cost alone. This will be significantly less for larger engines. Second, the sensors are rather large in physical size so finding place on small cylinder heads to accommodate them as well as engine space to accommodate their main body is indeed a technical challenge. Finally, no evidence on the long-term performance of such sensors on SI engines has been accumulated yet.

A summary of the assessment of the various techniques is shown in Table 56.

Table 56: Assessment of misfiring detection techniques

Technique	Principle / Characteristics	Advantages	Disadvantages	High-speed possibility	Technology readiness level
Crankshaft Velocity Fluctuation	Abnormal engine rotation pattern detected by engine position sensor	▪ No new sensors required ▪ Large experience from M1 ▪ Engine-torque models reduce risk of false detection	▪ Vulnerable to external noise ▪ Detects impact not reason of misfiring ▪ Transmission issues falsely detected as misfiring	No	Ready
Combustion Ion-Current	Combustion produces chemi-ions which are detected by in-sparkplug circuitry	▪ May detect electrical problems ▪ May detect good combustion ▪ Intermittent spark technique could be used at high speeds	▪ Lack of experience ▪ Availability of suppliers (patents) ▪ Additional cost of circuitry	Possibly	Ready
In-cylinder pressure measurement	Pressure waves measured by in-cylinder pressure transducer	▪ High speed, high resolution ▪ Safe detection of misfiring ▪ Can be used for next-cycle combustion optimisation	▪ Cost of sensor/ECU ▪ Space concerns ▪ High temperature durability	Yes	Development needed
Oxygen sensor signal	Oxygen sensor signal distortion may point to misfiring events	▪ No new sensor required ▪ May detect malfunctioning cylinder	▪ Not known commercial applications ▪ Unsafe for sporadic misfiring	No	Development needed

Technical solution for misfiring monitoring

Out of the several techniques examined, the ones with the technology readiness level to be used on commercially available vehicles are CFV and CIC. However, none of them can currently provide reliable misfire detection over the complete engine operation area. One possibility to allow their implementation would be to confine misfiring detection to the engine operation area in which it is possible to reliably diagnose misfires. If such a possibility is to be supported, then the question to be answered regards the environmental impact of leaving part of the engine operation area with no misfire detection. As previously discussed, the environmental impacts can be distinguished into immediate HC emissions exceedances and catalyst degradation impacts.

Starting from the latter, catalyst degradation may occur due to misfires outside of the monitoring window. Catalyst degradation will be detected though, since an independent catalyst degradation monitor is established at OBD Stage II. This means that if misfiring destroys the catalyst, this will be picked up by OBD II. Potential long-term effects would therefore be picked up by this second monitor. Misfiring detection might have helped not destroying the catalyst though and avoiding unnecessary repair and replacement costs.

The second question is related to how much direct environmental benefit would be achieved if misfiring could be detected over the complete engine map. This is a combination of how much time engines spend at high RPM and what are the emission levels compared to normal emission levels.

In case of continuous misfire, HC and CO emissions may increase substantially. However, at high RPM and usually high power conditions, continuous misfire will mean significant drop in engine power and will be easily detectable by the rider. The additional benefit of a direct misfire monitor in this case would only be present if accompanied with a mandatory ‘default’ engine operation. In several cases though, it is expected that the rider will drive in a ‘default’ type of way of power ay high RPM is missing.

In case of intermittent misfire, HC and CO emission levels increase for some operation cycles, hence the increase in average emission levels will depend on the percentage of power strokes that misfire occurs. Given that the engine operates outside the WMTC (emission control) area, some fuel enrichment would in any case take place; fuel enrichment is known to also know to increases HC levels. Therefore, the additional increase is difficult to justify.

As some negative environmental impacts are expected when decreasing the monitoring window, an as wide as possible window is required, to the degree this is technically possible. However, limiting the monitoring window appears as a good compromise to allow introduction of early misfiring monitoring.

Misfiring monitoring window determination

The two currently available techniques (CFV and ion sensing) are limited at high speed. CFV is also limited at low speed due to inherent low engine inertia and transmission vibration. Therefore, in order to allow both techniques to reliably detect malfunctions, limitation of the engine map for both high and low speed as well as low load is required will be required.

In order to determine appropriate misfire detection areas, different approaches were assessed on the actual engine maps of the L3e and L5e-A vehicles tested in the framework of the study. Two of the approaches were :

- The original provisions of Regulation (EU) No 44/2014.
- The proposal of ACEM in MCWG meeting of 22.9.2016 (ACEM (2016), slide #19).

We also formulated our own approach, taking into account the following considerations:

- A low speed limit needs to be introduced, as engine inertia at low speed is limited and the probability for false misfire detection using CFV increases. Inertia increases and idle speed decreases with engine size. This means that the low speed limit can be expressed as a function of idle speed and an additional margin of 1000 rpm, which is considered sufficient. In parallel, we consider that inertia is sufficient even for small engines within the L3e-A1 class once a speed of 2500 rpm is reached. Hence, this is used as an alternative low load limit to avoid losing a large part of the engine operation range for high idle concepts.
- A high speed limit needs also to be introduced for reasons outlined in the previous sections. Kuroda et al. (1995) successfully detected misfire on a motorcycle engine up to 8000 rpm, and we have used this as a maximum limit. We believe this sufficiently covers typical operation range even of high speed motorcycles. As an alternative limit, the WMTC max speed + 1000 rpm was considered, in proportion to the passenger cars regulation. An additional high speed limit can be considered, in case that the previous two limits exceed the maximum design speed, defined as maximum engine speed minus 500 rpm.
- A low load limit was also determined, following several exchanges of information with the manufacturers. The load was considered as a function of intake vacuum and the positive torque line. The high speed load was considered with a margin of 13.3 kPa compared to the positive torque line, similar to passenger cars. No low speed margin is considered for passenger cars however, we consider that a small margin is required for motorcycles due to potential transmission interference at low load, low speed operation. This margin is set at 3.3 kPa. This is a trade-off between covering as much WMTC area as possible and giving a safety margin to avoid false malfunction detection.

Figure 73 shows an example of the three alternative approaches on one of the vehicles tested. The individual points correspond to vacuum manifold pressure over WMTC, monitored by the specific vehicle's ECU. Only steady-speed and acceleration points have been filtered in the graph to avoid fuel cut and high vacuum points during decelerations. The yellow line corresponds to the manifold vacuum at the so-called positive torque line, as provided by the manufacturer of the specific vehicle. The low speed, high speed and low load limits in each case are schematically shown in each graph, which are determined by the shaded polygons.

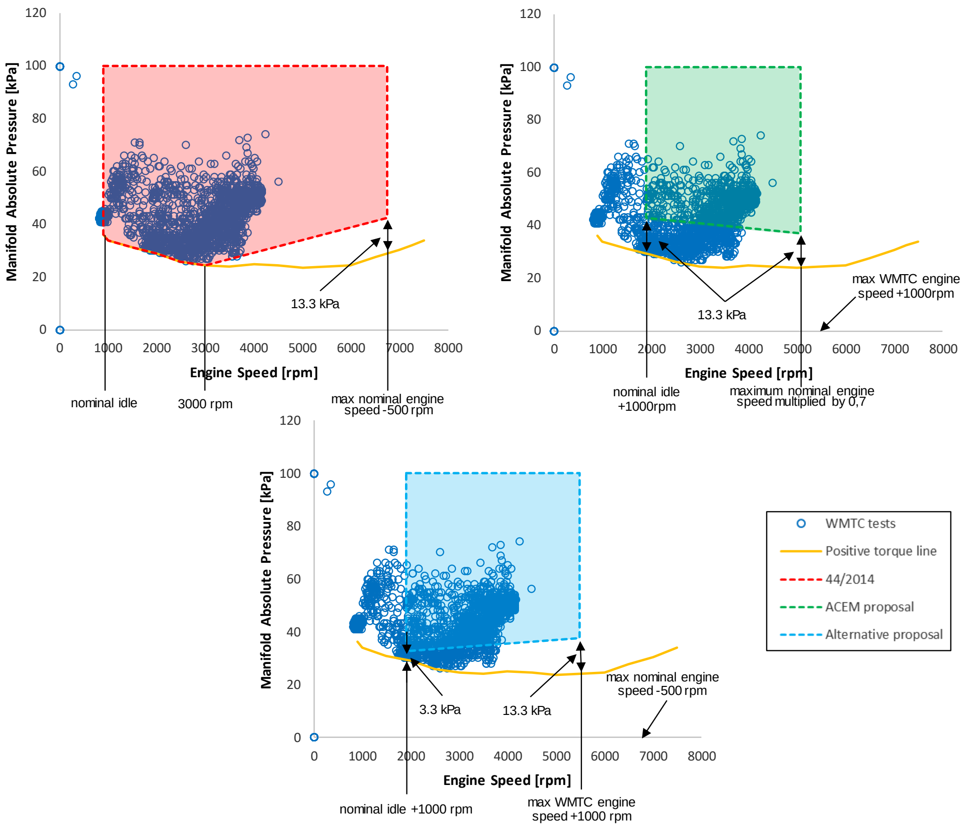


Figure 73. Alternative approaches for the misfire detection window. Top left: Original Regulation (EU) No 44/2014; Top right: ACEM proposal; Bottom: Alternative approach proposed.

Based on the graphs produced for each vehicle, following the method explained with the example of Figure 73, Table 57 shows the percentage coverage of WMTC engine map for the three in total different approaches.

Table 57: Percentage coverage of WMTC points offered by alternative misfire detection windows

Transm.	Categ.	WMTC		
		44/2014	ACEM proposal	Alternative proposal
CVT	L3e-A2 *	98	46	65
Manual	L3e-A2 **	99	51	64
Semi-automatic	L5e-A	100	43	63

* The recorded WMTC manifold pressure coming from measurements presented some artifacts due to purge valve operation, therefore manufacturer's provided data were used after being validated with the correct part of the measurements.
** The positive torque line provided by the manufacturer presented some problems, therefore it has been shifted by 13.3 kPa, as it seems more realistic. The results of the specific L3e-A2 vehicle can only be seen as representative for very similar vehicle/engine configurations, but not for all L3e-A2 vehicle/engine configurations.

Moreover, Figure 74 schematically shows the engine operation range areas covered (or left out) by the different approaches, for the three vehicles included in this study.

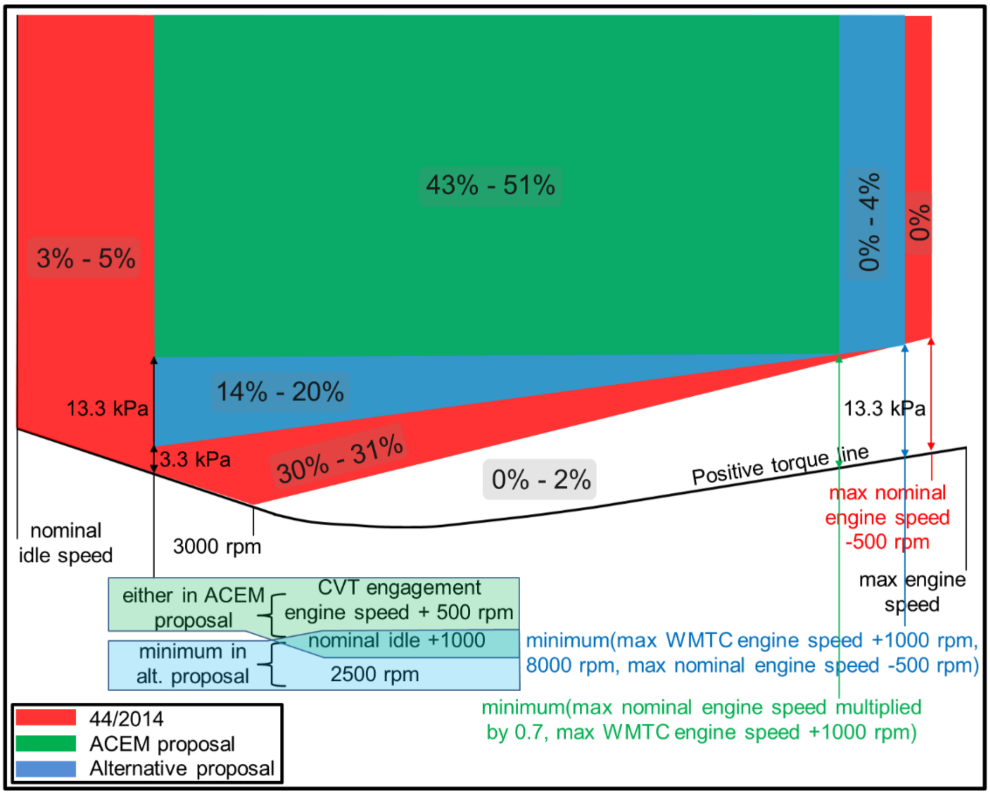


Figure 74.Schematic representation of the three approaches tested in this study and engine operation range fractions included in any of them.

Based on the table, the following observations can be made:

- The ACEM proposal in cases allows a large part of the operation map unsampled, because of a significant low load and low speed area left out of the misfire detection window. The area left out increases for the most powerful motorcycles which operate at relatively low load over the WMTC. The alternative proposal proposed in this study considerably improves coverage without violating high speed and low speed limitations.
- ACEM proposal for maximum speed limit defined in relation to nominal engine speed (0.7×max speed) may in cases leave out a significant part of the engine operation range, without serving any real purpose. Instead, the fixed speed limit established protects against misfire detection need in the technically impossible region.
- ACEM proposal for CVT gearboxes is to enable misfire at 500 rpm higher than engagement. This poses significant risks in leaving a large part of engine operation outside the focus of misfire. For example, CVT vehicles may operate at a limited engine speed range, after engagement, by constantly varying the CVT ratios. Hence, combining the limits of CVT+500 rpm and WMTC+1000 rpm may lead to a condition where most of the engine operation range is left unsampled. In addition, 'CVT engagement' is very ambiguous, as this may take place under a range of engine speeds. Instead, we propose to explicitly include centrifugal clutch engagement as one of the conditions of Regulation (EU) 44/2014 Annex XII paragraph 3.2.2.1, that misfire monitoring may be disabled.

<u>Recommendations for misfiring implementation</u>

Enabling misfire monitoring at OBD stage II for motorcycles is technically feasible, utilizing two methods which are currently available, namely the crankshaft velocity fluctuation (CVF) measurement and combustion ionization current (CIC) measurement. The former is for long successfully implemented in passenger cars and utilizes existing sensors (engine position sensor) to diagnose misfires. Therefore, its implementation in terms of hardware would necessitate an enhanced ECU and incremental improvements in the flywheel-sensor coupling. CIC measurement could be utilized on any engine and would require enhanced induction coils with integrated relevant circuitry. Both systems would require experience to be gained by the manufacturer and engine hardware changes but any of the techniques seems possible for implementation within the next vehicle model development round.

Both techniques require limiting the misfire detection to a suitable engine operation area. High-speed misfire detection is not possible by any of the two techniques while CFV is also limited at low speed and low load by inherent engine rotational instability (low inertia) and external factors (road and transmission).

In order to allow an as early as possible introduction of misfire monitoring for L-category vehicles, it is therefore recommended to limit the area defined in Regulation (EU) No 134/2014 in terms of speed and load to a suitable window for any of the techniques to be applicable. Based on technical assessment and a relative analysis on tested vehicles in this study, the recommendation is that the presence of engine misfire in the engine operating region bounded is by the following limits:

a) Low speed limit: A speed of 2500 min^{-1} or nominal idle speed+1000 min^{-1}, whichever is lower;
b) High speed limit: A maximum speed of 8000 min^{-1} or 1000 min^{-1} greater than the highest engine speed occurring during a Type I Test cycle or maximum design engine speed minus 500 min^{-1}, whichever is lower;
c) A line joining the following engine operating points:
    - a point on the low speed limit defined in (a) with the engine intake vacuum at 3.3 kPa lower than the positive torque line, and
    - a point on the high speed limit defined in (b) with the engine intake vacuum at 13.3 kPa lower than the positive torque.

The following recommendations are also made in the regulations, to more clearly specify the requirements for misfire detection:

- Regulation (EU) 44/2014 defines intake vacuum with the expression “manifold vacuum”. We recommend to change this throughout the Regulation to read “intake vacuum”, as several motorcycles have no manifolds.
- Intake pressure on a motorcycle engine may considerably vary during operation for a given speed and load operation. To reduce ambiguity in definition and potential exploitation of the exact vacuum level, we propose to define engine intake vacuum as the mean vacuum level at the engine intake at a given engine load and engine speed operating point.
- As several motorcycles may not use an actual sensor to measure intake pressure, a model value, aka a virtual sensor signal, may be used instead. This possibility can be made explicit in Regulation (EU) 44/2014 by adding the following clarification related to engine intake vacuum: “Engine intake vacuum corresponds to the mean vacuum level measured by an on board intake pressure sensor for a given engine load and engine speed operation point. In the absence of such a sensor, the average intake vacuum calculated by an appropriate model can be used, following demonstration of the

equivalence of this model to the actual value and approval by the type approval authority".

- For vehicles equipped with Continuous Variable Transmission (CVT), transmission engagement is performed by a centrifugal clutch. Engagement may often take place at speeds higher than the low speed limit determined above. Similar to manual gearboxes, the manufacturer may decide to disable misfire monitoring under such events. This is already foreseen in point Annex XII, paragraph 3.2.2.1 of Regulation (EU) 44/2014. To explicitly include CVT gearboxes, we propose to extend the focus of this to include CVT by explicitly including "centrifugal clutch engagement" in the examples list.

Leaving part of the engine operation area undetected may have some negative environmental impacts in terms of CO, HC and, subsequently, PM. On the other hand, requesting that the complete engine area is monitored would lead to significant delays in introducing misfiring detection overall. It would also lead to a potentially significant increase of false misfire detections, leading to a loss of credibility in the method and disproportional repair and warranty costs by unnecessary part replacement. These potential risks by far outperform environmental consequences of introducing compromises in the engine operation area monitored.

New developments in the area of combustion diagnostics are expected in the future and new techniques offering enhanced combustion control and misfire detection are being developed. Future initiatives to further control misfire need to monitor relevant progress and examine the potential to extend and more reliably diagnose misfire.

Enabling successful repair

This task also aims at identifying what are the potential benefits of introducing OBD Stage II functionalities with regard to the ability to repair of the vehicle, in particular by non-authorized service centres. The potential which is offered needs to be distinguished for catalyst monitoring and misfire related malfunctions.

With regard to catalyst monitoring performance (passenger car OBD II trouble code P0430), the diagnosis method and the trouble code is specific to the catalytic converter. If not combined with any other trouble code (*e.g.* oxygen sensor related), this directly points to a catalytic converter problem. A catalytic converter can easily be replaced by an authorized or a non-authorized dealer.

As the catalyst performance does not otherwise affect the engine and vehicle performance, degraded catalytic converter operation is impossible to be independently detected by the rider or the repair centre. Hence, detecting this malfunction is not really a help to the repair shop; without this code the vehicles most probably would have not had their catalyst replaced as this would have not been detected. This would of course have a large negative environmental impact but in terms of earning repair time, the trouble code itself is of limited use.

The only other possibility that a catalyst may have to be replaced is in case the vehicle fails to pass an environmental periodic inspection test. Periodic environmental inspection tests for motorcycles are currently being conducted in a number of EU countries which examine emissions levels of motorcycles using a Type II test. In case of failure to pass the test, the motorcycle is returned for maintenance before it is tested again. In this case, having catalyst monitoring would of course help in saving time. If a catalyst-related OBD trouble code was reported, this would immediately

point towards the source of the problem. If Type II test was now passed but no catalyst related OBD code was reported, this would again save a potential unnecessary replacement of the catalyst. Therefore, catalyst monitoring can indeed help in this case.

It is not possible to quantify the repair time saved by having catalyst monitoring OBD Stage II in actual real-world conditions. First, we have no data on how many vehicles are sent for maintenance following an environmental test. No such statistics are, at least publicly, available in EU. Second, we have no data on the effectiveness of Type II test. The only, rather old data on motorcycles (Elst et al., 2002), have shown that only 5% of motorcycles sent for maintenance exceeded both Type II and Type I limits. Hence, the efficiency of Type II test to detect actual degraded catalysts is questionable. Hence, in assessing the time saved in deciding to replace the catalyst or not when having no OBD II lacks fundamental data. An experienced technician having a motorcycle in good overall condition not being able to pass the I/M test might decide to directly replace the catalyst even in the absence of an OBD II trouble code. In such a case, no time is saved.

Hence, our assessment is that catalyst monitoring in OBD Stage II is not a major tool in reducing repair times. It is most importantly a safeguard that if a catalyst degrades, this is early detected that would otherwise would not have been possible.

Misfire detection is also one of the generic trouble codes of OBD Stage II. In cars, the trouble code P0300 ("Random/Multiple Cylinder Misfire Detected") is one of the generic codes that do not point to a specific malfunction but to a consequence of a malfunction. In case single cylinder misfire could be detected, the code is further specified to point towards malfunctioning cylinder (*e.g.* P030X – cylinder X misfire) In most of the cases, P0300 appears together with one or more trouble codes, pointing to specific malfunctions. A P0300 code alone would not significantly improve repair times. Web-sites often visited by repair shops to understand trouble codes (*e.g.* www.obd-codes.com, www.random-misfire.com, etc.) point to a large number of possible malfunctions that caused this trouble code and additional checks that need to be performed to isolate the malfunction(s). For example:

- Faulty spark plugs or wires
- Faulty coil (pack)
- Faulty oxygen sensor(s)
- Faulty fuel injector(s)
- Burned exhaust valve
- Faulty catalytic converter(s)
- Stuck/blocked/leaking EGR valve / passages
- Faulty camshaft position sensor
- Defective computer

In other occasions, misfire codes appear due to bend flywheels or unbalanced clutches, thus diverting the mechanic away from the real source of the problem. In particular this can be a more significant issue for motorcycles, due to the more exposed components, the lower rotational inertia and vibrations from the transmission. As already said, the recommendation to reduce the engine operation detection area came from the need to reduce the potential for erroneous misfire detections.

The misfire code is not so much useful in detecting the actual malfunction but rather a verification that the malfunction has been indeed corrected if the trouble code disappears after maintenance. Again, the impact of misfire detection should have mostly to do with the environmental benefits of detecting malfunction, rather than Performed OBD tests and results

9.3 Impact and frequency of malfunctions

For the assessment of the effect of different malfunctions on vehicle emissions, emission tests were performed on four vehicles. The initial screening tests were performed at LAT on the first (L5e-A) of the four vehicles. This allowed the development of test protocols as well as of methods to simulate malfunctions on well operating vehicles. Table 58 summarizes the different malfunctions simulated during OBD testing and Table 59 presents the list of vehicles involved in the testing.

Table 58. Malfunctions introduced for OBD testing

Test	Vehicle configuration
Baseline (original)	Original Euro 4 catalyst
Cat. aged – 0	Extra Euro 4 catalyst - as received
Cat. aged – 1	Extra Euro 4 catalyst - aged to level 1
Cat. aged – 2	Extra Euro 4 catalyst - aged to level 2
Cat. aged - 3	Extra Euro 4 catalyst - aged to level 3
Cat. aged - 4	Extra Euro 4 catalyst - aged to level 4
No Cat.	Inert catalyst brick used
Failed O2 - poisoned	Failed O_2 sensor artificially poisoned
Failed O2 - cut cables	Failed O_2 sensor by disconnection of cables
Misfire	Misfire simulated by ECU
Failed Injector	Failed injector simulated by ECU

Table 59: List of vehicles utilized in OBD malfunction testing

Category	Vehicle type (Vehicle code)	Malfunctions tested
L5e-A	Tricycle (L01)	All
L3e	Small scooter (J07) Medium scooter (J13) Street bike (J15)	Catalyst and O_2 sensor

Accelerated catalyst degradation was performed by means of thermal ageing. Several options were explored including heating of the catalyst in either still atmosphere or ambient air flow at temperatures ranging from 950°C up to 1100°C. The exposure time was 4 h reaching up to 8 h during some sensitivity runs. The ageing method used was proven insufficient to adequately simulate the real world ageing rate. Most probably, the catalyst heating should have been performed under increased humidity or synthetic exhaust atmosphere. Unfortunately, due to time

pressure, it was not proven feasible to repeat these tests. Therefore, the malfunction characteristics were determined on the basis of the measured engine-out emissions, by assuming different catalyst efficiencies. In addition, the pollutants first failing to stay below OTLs were verified against literature and in-house data.

The no catalyst tests were performed in order to determine the engine-out emissions of the vehicles, *e.g.* in the case of complete catalyst removal, but also the high bound expected for a completely deactivated catalyst. In order to avoid any effects due to flow backpressure difference, instead of completely removing the catalyst, an inert catalyst with no catalytic effects was used. All results were valid and in-line to the comparison with normal catalyst emissions and expected catalyst efficiency for all species.

In order to assess the effect of malfunctions in real world conditions, vehicles were tested over both the type-approval and a real-world cycle. This cycle was named IUC (InUse Cycle) was developed specifically for the project using data collected over real world conditions by HSDA. The two tests cycles and the distinct test phases are shown in Figure 75 and Figure 76. Proper and realistic gear shifting strategies were introduced for the vehicles equipped with manual gear transmission that were in line to WMTC prescriptions.

As shown in Figure 77, a specific test sequence and sampling protocol were followed for all malfunctions applied on the test vehicles. Care was taken to ensure proper vehicle preconditioning. Proper preconditioning allowed the engine management system to adjust to any new conditions (*e.g.* adjust fuel trim after the application of a malfunction). In addition it ensured similar thermal conditions at the beginning of hot start cycles.

The O_2 sensor malfunction was performed in two ways. First, poisoning of the O_2 sensor by a spraying a hydrocarbon mix was applied. This was selected as a realistic method that is also expected to occur in real world operation, *e.g.* in case of oil in the combustion chamber escaping combustion. The anticipated effect was twofold: affect poison sensor element and also reduce sensor response time. Since the effect of hydrocarbon poisoning was temporary, this was applied in the beginning of each test and repeated for as many times the cycles were repeated. A second option that was followed was the complete disconnection of the O_2 sensor. All four vehicles were able to operate without visible in loss in power or drivability.

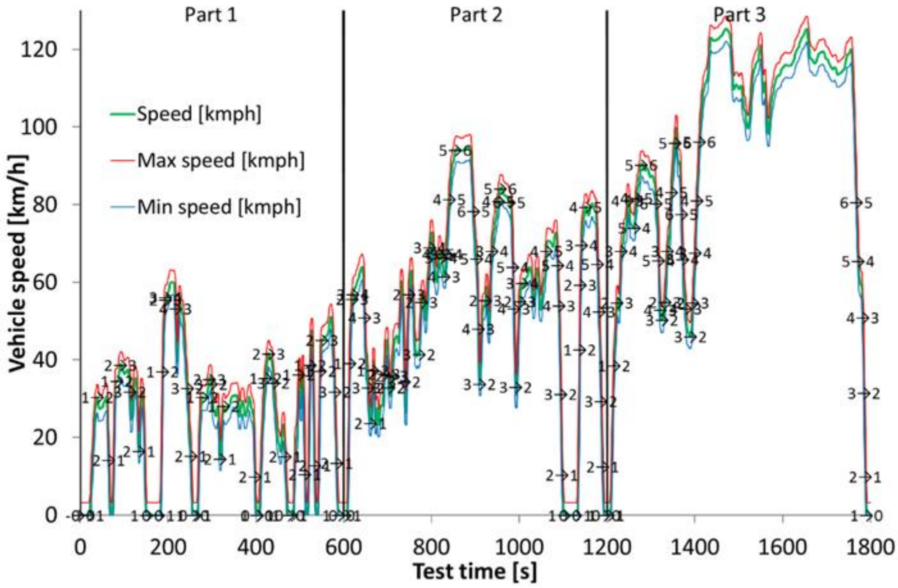


Figure 75. WMTC (type-approval) driving cycle

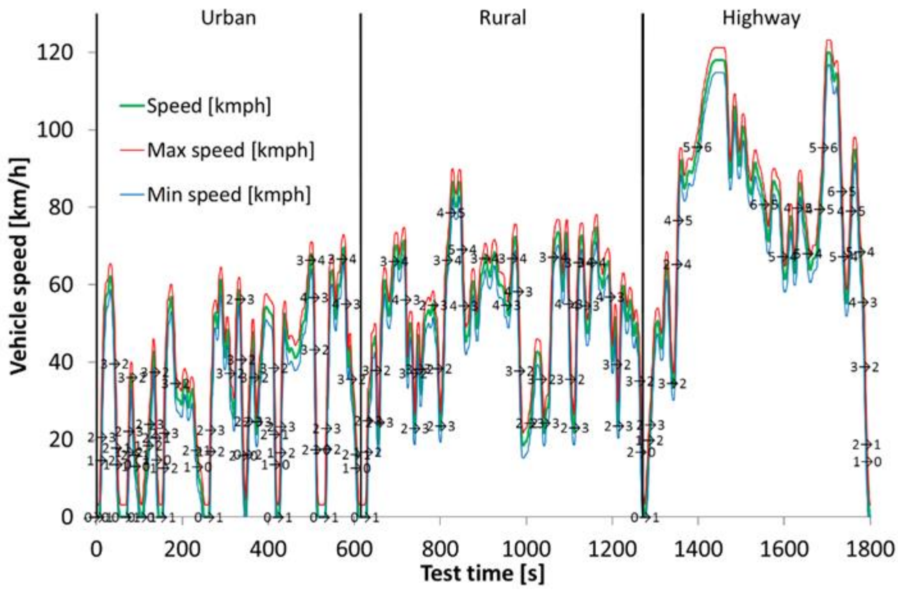


Figure 76. IUC (=In Use Cycle) (real world) driving cycle

Misfire was possible to be simulated on one vehicle by a special software module contained in the ECU. A range of different number of missed sparks was tested to determine the effect of misfire on emissions up to the point when vehicle drivability was severely impaired or vehicle could not operate at all.

Injector failure was also simulated in one vehicle by a special software module contained in the ECU. Reduction in injection flow rate and in injection response time were simulated in different combinations and tested to determine the effect of misfire on emissions up to the point when vehicle drivability was severely impaired or vehicle could not operate at all.

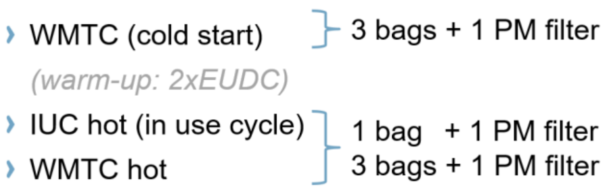


Figure 77. Daily test protocol to monitor the impact on emissions

As already mentioned, for the collection of all malfunction related data, in addition to the one vehicle tested at LAT, three vehicles were tested at JRC. The results collected were properly analysed to produce the impact of malfunctions on emissions. These are summarised in Table 63.

Malfunction frequency in the real world was the second significant element to estimate OBD effectiveness. A real world survey was performed in order to collect data as regards malfunctions usually appearing in the field, detectability of these malfunctions, repair costs associated with these malfunctions as well as frequency of occurrence. The survey was performed using a predefined structured questionnaire that was completed during on-site interviews at repair workshops around Europe including Greece (3 shops), Italy (1 shop) and the Netherlands (8 shops). The shops included both authorised dealerships and free lancers. Coverage of all major manufacturers in EU was attempted. The data were then post processed to harmonize the collected responses, identify most widespread and frequent malfunctions and convert data in the form needed for the OBD modelling work. The final harmonized malfunction frequency data are included in Table 63.

9.4 Modelling of OBD Threshold Limits (OTLs) effectiveness

A methodology has been developed by LAT to evaluate the effects of the application OBD threshold limits on vehicle emissions. The methodology was developed and gradually revised at several steps in order to incorporate more precise data regarding OBD system behaviour as well as advancements in OBD technology. The methodology was applied in previous studies undertaken by LAT for passenger cars up to heavy duty vehicles (Samaras et al., 2004; Tsinoglou D., 2007; Rexeis et al., 2008; and others).

The simulation was performed in three distinct steps:

- Vehicle life emissions modelling, to simulate the emissions from a single vehicle during its lifetime, assuming different OBD policy options.
- Emission calculations and projection, to assess the pollutant emissions from a pilot fleet (*e.g.* 1000 vehicles), assuming different OBD policy options.
- Cost and cost effectiveness calculations.

This methodology was incorporated in a model which is capable of assessing different OBD threshold scenarios in terms of emission benefit and cost of application. The assessment is performed on the basis of a vehicle fleet using specific input data regarding OBD threshold limits, basic vehicle emission behavior, malfunction frequency and evolution and policy options. The basic elements of the methodology as well as the improvements brought to the model within the specific project are described in the following paragraphs.

9.4.1 Introducing the impact of malfunctions

The emission behavior of a vehicle during the occurrence of an OBD related malfunction as simulated by the OBD model is outlined in Figure 78:

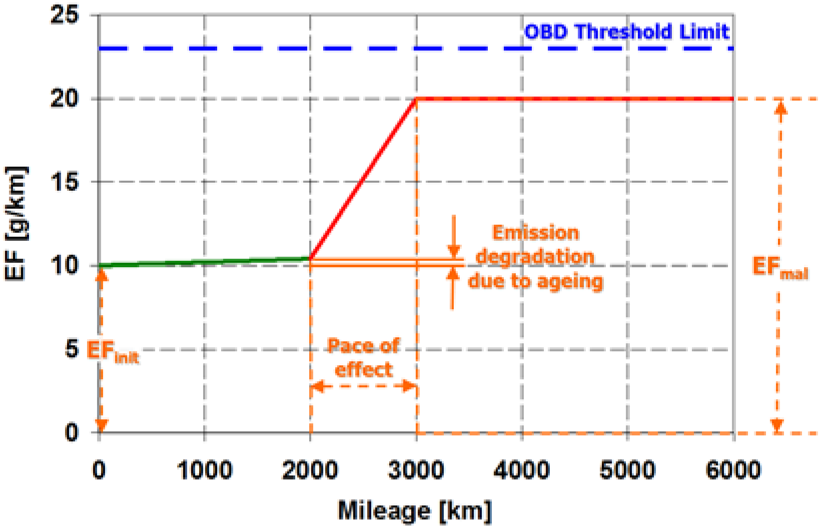


Figure 78. Malfunction simulation scheme and characteristics

For simplicity in the discussion, in all definitions below the emission level that is diagnosed by the OBD system is assumed to be equal to the actual emissions of the vehicle, not taking into account any variability (*e.g.* due to OBD system inaccuracy, driving conditions variation etc.). The initial emissions of the vehicle at mileage 0 are denoted as EF_{init}. As seen in the graph, the emissions of the vehicle with no malfunction occurring (green line) are in any case assumed to gradually increase with mileage as subjected to normal degradation due to vehicle ageing.

The blue dashed line is the OBD threshold limit as defined by the legislation. If a malfunction occurs at a given mileage (*e.g.* 2000 km in the example of Figure 78), vehicle emissions start to increase at a specific rate until a certain level. The maximum emission level that will be reached if the specific malfunction would not be detected by the OBD system is EF_{mal}. This maximum is defined by engine and aftertreatment system restrictions, *e.g.* that would correspond to engine out emissions in case of an aftertreatment component total failure. The emissions increase rate is defined by another characteristic of the specific malfunction, the pace of effect which is the distance driven during the occurrence of an undetected malfunction until the emissions reach maximum level (EF_{mal}).

Figure 79 shows a simplified case of malfunction detection:

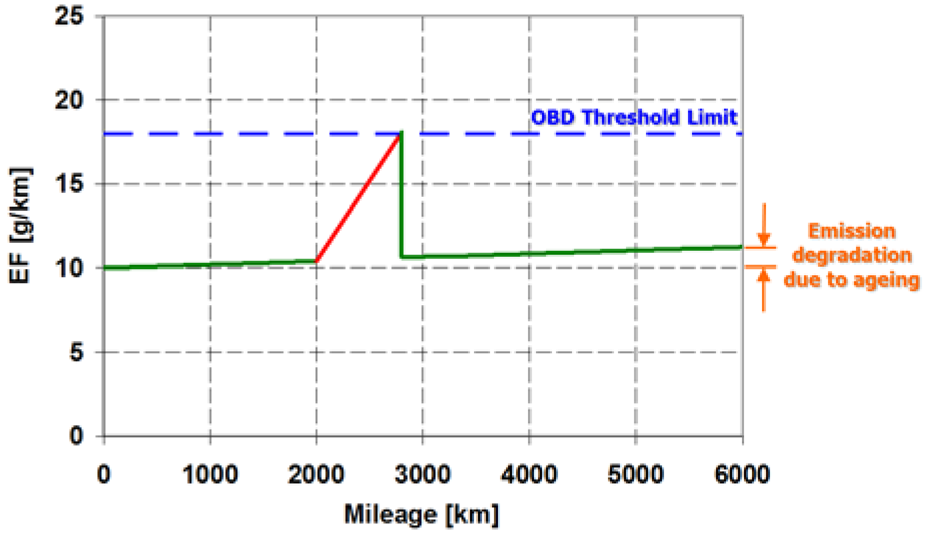


Figure 79. Malfunction simulation scheme and characteristics (detection)

In this case the emissions of the vehicle during the malfunction occurrence reach a critical level at which the OBD system diagnoses the existence of the malfunction. It is then assumed that the vehicle is repaired and the emissions are resumed back to the normal emissions of the non-malfunctioning vehicle, degraded only due to vehicle ageing.

A more complex case of combined malfunction occurrence is presented in Figure 80:

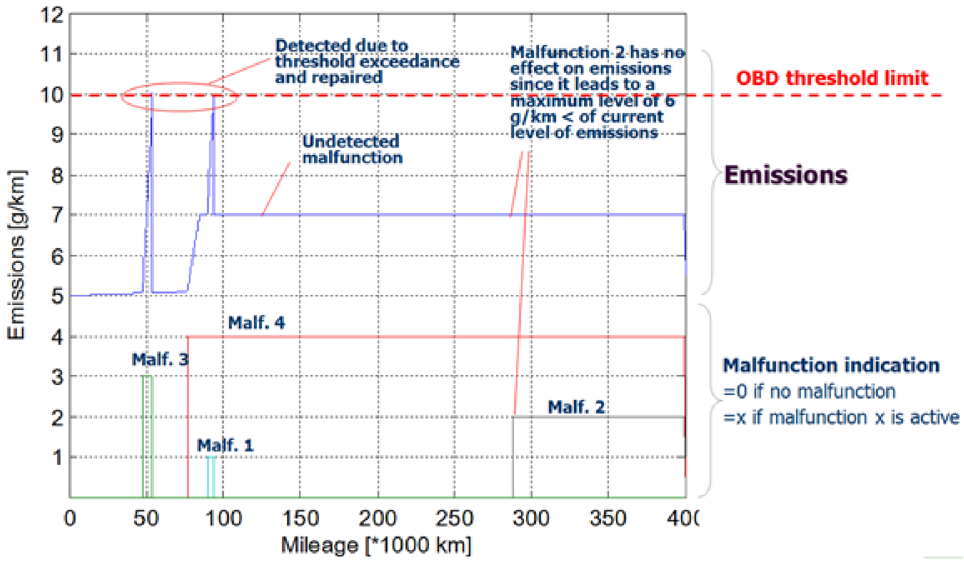


Figure 80. Combined malfunction occurrence

The lower part of the chart is an indication of a malfunction occurring (value = malfunction index, 1 - 4) or not occurring (value = 0).

Malfunction 3 occurs at approximately 50000 km, emissions exceed the OBD detection limit, malfunction is then detected and resolved.

Malfunction 4 occurs after 70 000 km. This EF_{mal} is below the OBD detection limit, thus this malfunction is never repaired and remains on until the end of the simulation time.

Malfunction 1 occurs after the full evolution of malfunction 4. Thus, vehicle emissions are increased further. Since malfunction 1 EF_{mal} is above the OBD threshold, malfunction 1 is detected and repaired. Since though malfunction 4 is still on, vehicle emissions are restored to the maximum emission level reached due to the non-detected malfunction 4.

Finally, malfunction 2 occurs just before 300 000 km (relevant for larger vehicles). Since EF_{mal} of malfunction 2 is lower than the emission increase caused by malfunction 4, it has no effect on vehicle emissions and thus is never detected.

9.4.2 Malfunction detection algorithm

As already discussed, the accuracy of OBD system detecting the actual emissions level is restricted due to several factors, such as:

- Sensors measurement accuracy and scatter.
- Diagnostic model accuracy (variable estimation, monitoring enabling conditions).
- Vehicle to vehicle manufacturing variability
- Driving conditions variability.
- Seasonal and geographical variation of ambient conditions.

These parameters cause a variation of the diagnosed emissions level. This variation is assumed to follow a normal distribution defined by the standard deviation (σ) of the distribution. To overcome problems related to rare extreme values, the error band during all assessments was restricted to ±2.33·σ. This value was defined as such in order to include 98% of the detection values following normal distribution.

This variation must be considered during the calibration of an OBD system. Figure 81 shows the way this is realized during the calibration of an OBD system.

If the OBD system assumes that a malfunction is being detected when emissions reach the OBD threshold, then there is the risk of having a single monitoring event resulting in a diagnosis of -2.33·σ while actual emissions are higher. This would mean that the actual emissions would have already exceeded the OBD threshold without a malfunction detection leading thus to non-detection incompliance. For this reason, the OBD threshold is replaced in the OBD system operation by the OBD monitoring level. The OBD monitoring level is calibrated at -2.33·σ at maximum vehicle mileage and parallel to the slope of vehicle emission due to degradation because of vehicle ageing.

In order to incorporate this behaviour to the model, it was decided to modify the modelled emission behaviour dividing calculations in two cases:

- Actual vehicle emissions following an average linear behaviour (Figure 83, blue line).
- Vehicle emissions as diagnosed by the OBD system following a normal distribution ±2.33·σ the average vehicle emissions (Figure 83, monitoring events denoted with black dots).

The green line in Figure 82 shows the ±2.33·σ limits of the normal distribution.

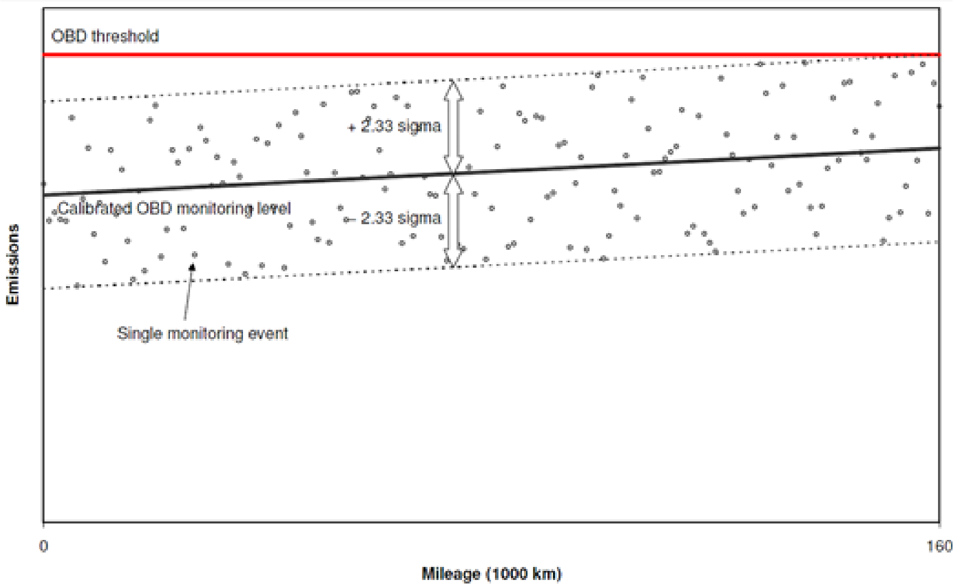


Figure 81. Option for implementing diagnosed emission level distribution

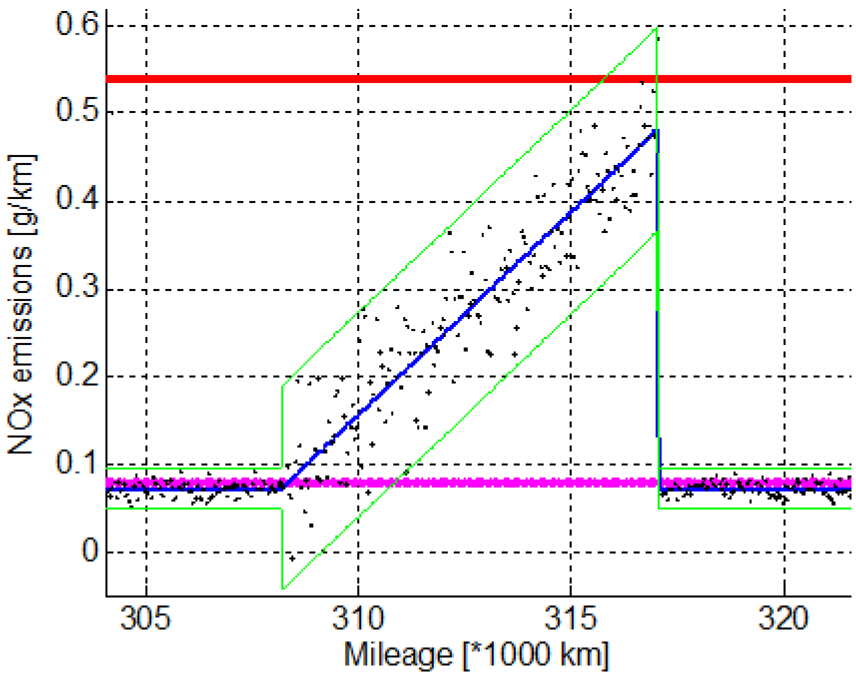


Figure 82. Implementation scheme of diagnosed emission level distribution

Following the above approach, the main areas of concern to this assessment are identified in Figure 83:

Emissions	MIL off	MIL on
	False pass (error of omission)	**OK**
OBD threshold		
	OK	**OK**
Type-approval limit		
	OK	**False failure** (error of commission)
	OBD system reaction	

Figure 83: OBD decision areas

The main OBD system decision areas can be distinguished in:

1. Vehicles identified by the OBD system as **non-malfunctioning** (**MIL off**):
   1a. Vehicle emissions below the OBD threshold: **correct non-detection**
   1b. Vehicle emissions exceed the OBD threshold: **false pass**

2. Vehicles identified by the OBD system as **malfunctioning** (**MIL on**):
   2a. Vehicle emissions exceed the type-approval limit: **correct identification**
   2b. Vehicle emissions below the type-approval limit: **false failure**

Case 1b is being resolved to avoid non-compliance during the calibration of the OBD system as described in Figure 81.

Figure 84 is an example of case 2a, correct failure identification.

In Figure 85 and Figure 86, at the mileage when the detection is achieved, vehicle emissions do not exceed the type-approval limit (case 2b). Regardless of what would be the final emission level if the malfunction was not detected at that early point, the event is considered as false detection.

While a false failure has no environmental effect, it is highly disadvantageous in two ways:

Cost effect: It can have moderate to high cost if the vehicle is respectively either just checked at the workshop, code is erased and released or the workshop is misled to unnecessary replacement and repair of fault-free parts.

Driver effect: False failure detection reduces trust on OBD indications and may lead to disregarding of warnings that have no immediate effect on vehicle performance.

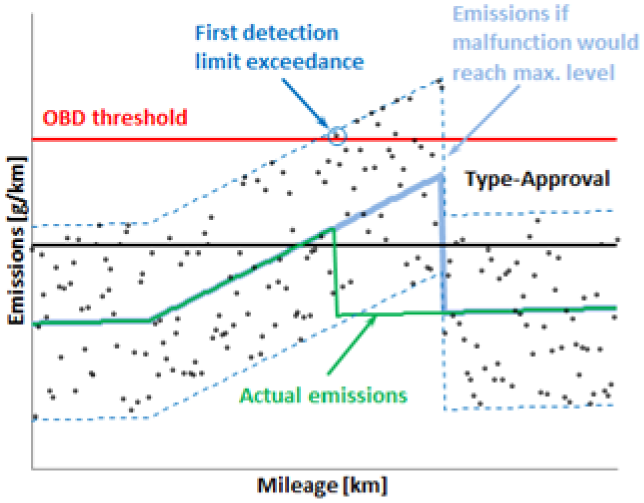


Figure 84. Correct failure identification

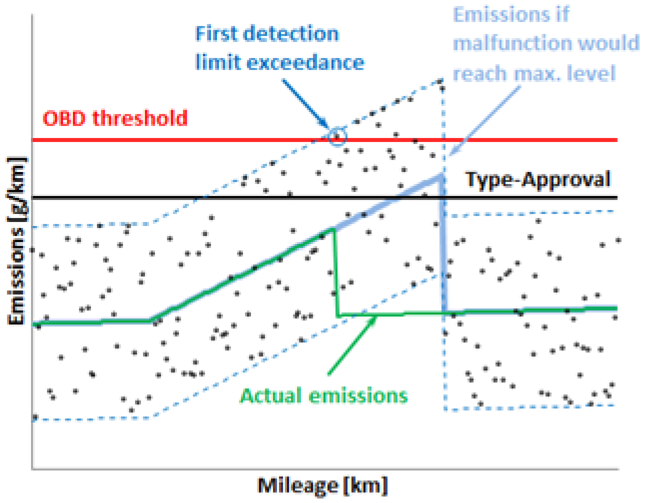


Figure 85. False failure identification (final mal. level not exceeding OTL)

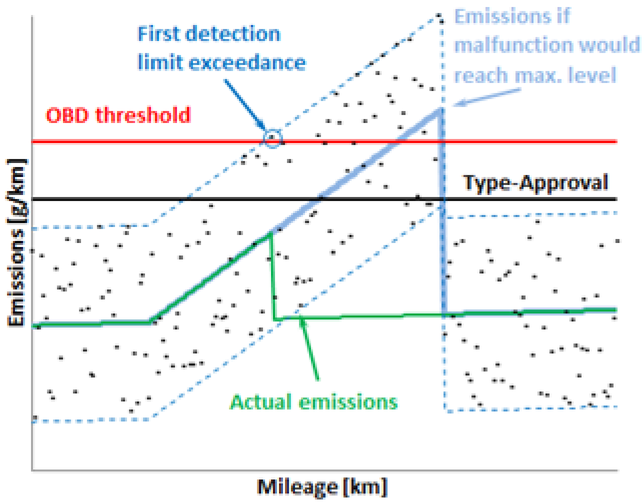


Figure 86. False failure identification

9.4.3 *Simulation on pilot vehicle fleet*

The scheme described above is applied on a pilot vehicle fleet in order to derive the average emission factor and repair cost of an “average” vehicle as function of mileage.

The use of a pilot fleet serves two needs:

- There are malfunctions whose frequency of occurrence per lifetime is less than 1 which means that they may not appear in the lifetime of a certain vehicle. They could though appear once in the lifetime of some vehicles of a pilot fleet. This can define the minimum size of the pilot fleet. For example, if the frequency of occurrence of a malfunction is 0.001, this means that it will appear once every 1000 vehicle which leads to a minimum pilot fleet of 1000 vehicle.
- Furthermore, since the number of malfunctions is low and consequently the appearance mileage distinct, the higher the number of vehicles, the smoother the resulting average curves will be.

The emission and repair cost functions cover vehicles aged up to 200,000 km. It has to be noted that the simulation period is extended up to this high mileage to accommodate some vehicles in the fleet that may reach this high mileage. The contribution of these vehicle though in the total fleet emissions is negligible due to the very low vehicle number and activity that is also taken into account by the model.

Figure 87 shows an example of the average per vehicle emissions curve derived from the application of different OBD scenarios on a pilot vehicle fleet. The emission peak in the beginning of the vehicle life corresponds to malfunctions related to tampering soon after vehicle purchase replacement of muffler with aftermarket racing time with no catalyst.

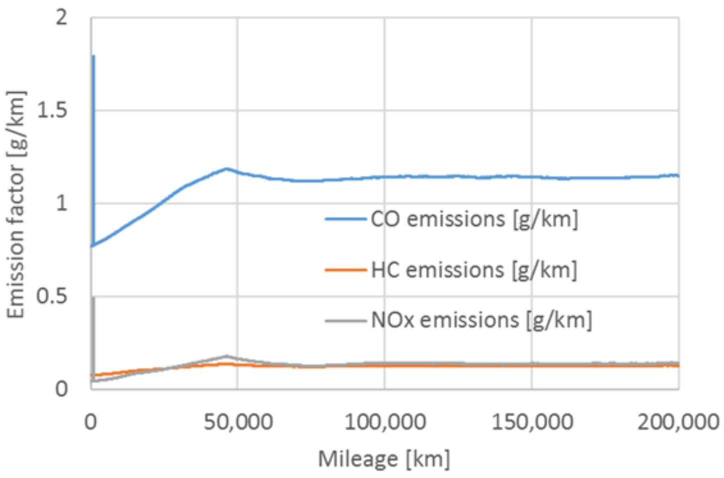


Figure 87. Average vehicle emissions over assessed mileage

Once the modelling of malfunctions has been conducted on the pilot fleet, the results are transferred to the total fleet, which has been in detail presented in section 2.5.2.1.

9.5 OBD Stages and OTL scenarios considered in the study

Based on the OBD Stage II technical feasibility limitations presented in section 9.2, a number of scenarios were formulated to examine the impact of available technical possibilities.

In order to build the required scenarios for OBD implementation, four different components had to be defined with regard to OBD operation and malfunction detectability. These are outlined below and summarized in Table 60:

Table 60: Overview of OBD scenario components

Scenario component	**Threshold**	**Misfire monitored against OTL**	**Catalyst monitored against OTL for…**		**Catalyst degradation rate**
			degradation	**tampering**	
Stage I	Stage I	no	no	no	high
Stage II, no cat	Stage II	yes	no	no	low
Stage II with Stage I OTL	Stage I	yes	no	yes	low
Stage II	Stage II	yes	yes	yes	low

- Stage I: In this case, only the requirements of OBD stage I are to be implemented on the fleet. Stage I does not contain misfiring, catalyst monitoring and circuit rationality control. Stage I is expected therefore to respond to OTL I levels only. Moreover, the lack of misfire monitoring is expected, further to not being able to monitor relevant malfunctions, to lead to increased thermal loads to the catalyst. This leads to higher catalyst degradation rate, as indicated in the last column of Table 60. In this scenario, catalyst tampering (e.g. removal) cannot be detected.
- Stage II, no cat: Technical feasibility analysis showed that catalyst monitoring is not readily feasible for all motorcycles. Hence, a condition has been considered where OBD Stage II requirements are introduced, except for catalyst monitoring. In this case, catalyst tampering cannot be detected but the catalyst degradation rate is assumed low because misfire detection has been included.
- Stage II with Stage I OTL: This is the same condition as in the previous case, but with relaxed thresholds, i.e. at OTL I level.
- Stage II: In this case all malfunctions prescribed by OBD stage II are set to be monitored, including both misfire and catalyst monitoring. Because of misfire monitoring, the catalyst degradation rate is low and tampering can be detected. The low OTLs can also detect normal catalyst degradation.

All scenarios finally selected to be assessed are summarized in Table 61. It should be noted that the assessment period is separated in two sub-periods, 2020-2023 and 2024-2040 to realize possible options in terms of technical feasibility. Baseline scenario 0 and scenarios 1-3 were set as follows:

0. No OBD stage II introduction

This is the baseline scenario against which all other options were assessed. It assumes no OBD II introduction but OBD I with OTL I continuing over the complete period 2020-2040.

1. OBD stage II introduction in 2020 as laid down in Regulation (EU) No 168/2013

Scenario 1 includes what is currently set by the Regulation (EU) No 168/2013, including OBD stage II and OTL II, starting already from 2020. This scenario is technically not feasible, but it has been simulated to examine the benchmark environmental benefit achieved.

2. OBD stage II introduction with OTL I and no catalyst monitoring in 2020 and OBD stage II in 2024/25 for all malfunctions

This scenario allows some lead time to manufacturers to enable catalyst monitoring from 2024/25 (new/all types) on. In the period 2020-2023 OBD II is implemented for all other malfunctions, including misfire detection, assuming OTL I.

3. OBD stage II introduction with OTL II and no catalyst monitoring in 2020 and OBD stage II in 2024/25 for all malfunctions

This scenario is similar to scenario 2, in terms of time periods applying OBD I and OBD II. However, in the period 2020-2023, OBD II is implemented with OTL II.

Table 61: Overview of OBD scenarios modelled

Scenario	2020-2023	2024-2040
0. No OBD stage II introduction in the EU	Stage I	Stage I
1. OBD stage II introduction in 2020 as laid down in Regulation (EU) No 168/2013	Stage II	Stage II
2. OBD stage II introduction with OTL I in 2020 and OBD stage II in 2024/25 for all malfunctions	Stage II with Stage I OTL, no cat	Stage II
3. OBD stage II introduction with OTL II in 2020 and OBD stage II in 2024/25 for all malfunctions	Stage II, no cat	Stage II

9.6 Implementation and repair costs

Effective OBD operation is associated with costs that refer to both implementation and repair costs after a malfunction has been detected. Implementation costs are specific to each scenario and are analyzed in the following sections. The detailed cost data of each scenario are given in Appendix E.

Scenario 0 (Baseline)

This scenario assumes no difference to existing OBD implementation, hence it is not associated with any additional implementation costs.

Scenario 1 (OBD II - 2020):

This scenario is not technically possibly hence no cost has been calculated. The scenario is only executed for benchmarking environmental benefits of other scenarios.

Scenario 2:

In terms of development costs, an additional cost of 100 k€ (50 man-days) is considered per engine family, to allow compliance with OBD Stage II over OBD Stage I in the 2020-203 period. This includes better design and engineering of components to control misfire and software development to enable OBD functionalities. No catalyst monitoring is included in this phase. Moreover, as OTL I is considered in this scenario until 2023, the additional calibration costs of OBD II per vehicle model over OBD I are considered minimal, i.e. at 10 k€ (20 man-days) per model. These are further considered to gradually decrease to 7.5 k€ (15 man-days) with time, as engineers become familiarized with OBD II.

In a second phase of implementation of this scenario, an additional cost of 50 k€/engine family and another 5.0 k€/vehicle model is introduced in 2024 to reflect the cost of catalyst monitoring functionality. This does not correspond to a substantial effort as it basically refers to design improvements, cabling and positioning of the downstream sensor – a large cost of which will have been absorbed by the overall design phase for the new model powertrain. Addition of both cost elements makes total development costs exceeding OBD Stage I by 150 k€/engine family and 20 k€/vehicle model for calibration. The calibration costs decrease with time to 12.5 k€/vehicle model, as engineers become familiar with the new system.

In terms of hardware costs, OBD II with no catalyst monitoring functionalities will require an enhanced ECU and marginally improved sensors and/or cabling. The initial cost difference of the OBD-II ECU and the improved sensors over OBD I (40 €/piece) drops significantly with time as these do not consider material costs but engineering costs at the suppliers' side. The terminal cost difference of hardware over OBD Stage I is estimated at 17 € with another 8 € assumed for the downstream O_2 sensor to implement cat monitoring in the post 2024 period.

Costs also include 500 €/model for the type approval authority to check OBD Stage II functionalities and IUPR. Finally, warranty costs are expected to increase on average by 0.05% of the mean vehicle price due to initial OBD-II errors of commission and unnecessary repair. Costs of this category are kept low as this scenario assumes OTL I in the first phase and ample time is given for introducing OTL II in 2024.

Scenario 3:

The fundamental assumptions are similar to Scenario 2. However, as OTL II are already implemented in 2020, higher initial calibration costs (20 k€/ vehicle model) are assumed as engineers will have to familiarize themselves with OBD II algorithms and functionalities to achieve OTL II compliance. This drops to the same level with time as in Scenario 2.

Moreover, in this case warranty costs are assumed to be initially, increased initial errors of commission derived by the lower OTLs. These high costs are retained for the first four years but then decrease to 0.05%, as in the case of Scenario 2.

With regard to repair costs, these are shown in Table 62 per malfunction. The input data of the repair cost calculation were derived from the initial dataset compiled using information cost elements collected during the real world survey. The total repair cost was then validated against final values also derived from the real world survey. In all cases, total repair cost includes an additional 30 min labour lost time due to commuting to and back from the repair shop.

Table 62: Calculation of repair costs

Malfunction	**Part Cost [€]**	**Time to Replace [min]**	**Cost of Labour in EU[38] [€/h]**	**Total Repair Cost [€]**
Throttle valve*	25	30	25	**50**
Injector fouling	0	20	25	**21**
Injector irreversible failure	40	40	25	**69**
Ignition coils	25	15	25	**44**
Spark plug	5	10	25	**22**
O_2 sensor failure	8	15	25	**27**
Catalyst degradation (long term)	40	15	25	**59**
Catalyst degradation (short term, misfire etc.)	40	15	25	**59**
Catalyst tampering (removal)	0	0	0	**0**
Fuel mixture tampering	0	0	0	**0**

*Throttle valve maintenance involves a mix of repair (cleaning) and replacement. The cost and difficulty to reach throttle valves is vehicle specific. Estimated repair costs assume a 25% replacement need and 75% cleaning need to correct issues with throttle valve malfunctions of the average L3e vehicle.

Figure 88 shows an example of the average per vehicle repair cost curve derived from the application of different OBD scenarios on the ‘average’ vehicle from the pilot fleet.

[38] EU28 mean hourly labor cost value according to Eurostat, http://ec.europa.eu/eurostat/statistics-explained/index.php/Hourly_labour_costs

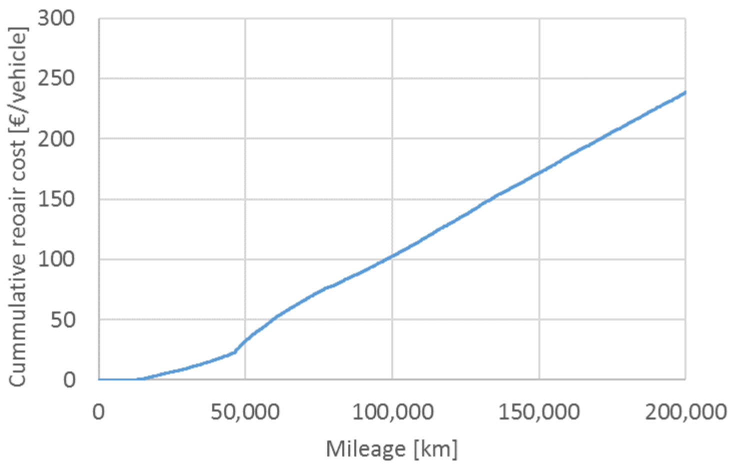


Figure 88. Average repair cost of malfunctions detected by OBD over assessed mileage

9.7 Cost-benefit analysis

Table 63 contains an overview of all OBD modelling data used for the assessment of the different scenarios, including threshold limit options, basic emission factors and emission degradation of vehicles, frequencies of malfunction occurrence (over a 200,000 km lifetime), effect of malfunctions on emissions as well as the mileage within which malfunctions are expected to have fully evolved (column “Mileage [km]”).

Table 63 also includes information on the detectability of malfunctions depending on the OTLs and scenario applied. Light green colour corresponds to OTL stage I and dark green colour corresponds to OTL stage II. Respectively, malfunction emission values that lead to exceedance of stage I OTL are marked in light green while malfunctions that lead to exceedance only of OTL stage II are marked in dark green. If a scenario component includes monitoring of the specific malfunction then in case of exceedance the malfunction will be detected and, assumed to be fixed. The information of whether a specific malfunction is monitored against OTL is given on the right hand side of Table 63. Red cells correspond to pollutant levels at malfunction that do not lead to any OTL exceedance.

Finally, since some OBD threshold limits are set in Regulation (EU) No 168/2013 differently depending on vehicle top speed, the corresponding OTLs were produced as a weighted average of the two values. An 80% contribution of the high speed L-cat vehicles and 20% contribution of the low speed L-cat vehicles to the fleet were assumed to calculate the final OTL levels, as shown in the notes of Table 63.

An important element in the OBD effectiveness is its potential to detect catalyst tampering. According to industrial information (ACEM, 2004), up to 35% of motorcycles operate on illegal exhausts. This is mostly done for altered sound purposes but this practice has as a result that the catalyst is actually removed when the exhaust is replaced. This is done to save weight and tune sound at will. Moreover, third part exhausts may or may not include catalysts as spare part components while the quality of the replacement catalyst is questionable. OBD with catalyst monitoring functionality has the potential to decrease the practice of catalyst removal for exhaust

tuning. This is why OBD effects on catalyst tampering is included in our cost-benefit analysis.

Table 63: Overview of OBD modelling setup (malfunctions, scenario components)

		Frequency of occurrence [#/200 Mm]	CO [g/km]	THC [g/km]	NOx [g/km]	PM [g/km]	Mileage [km]	Repair cost [€]
Limits	**Type-approval limit - Euro 5**		1	0.1	0.06	0.0045		
	OBD threshold - Stage I		2.17	*0.78*	0.43			
	OBD threshold - Stage II		1.9	*0.26*	0.3	0.05		
Emission data	**Emission factor @0 km**		0.769	0.077	0.046	0.001		
	Emission degradation @32,000 km		30%	30%	30%	30%		
Various malfunctions	Throttle valve	1.875	0.77	0.46	0.72	0.006	40,000	50.0
	O2 sensor failure	0.125	2.25	0.11	0.08	0.002	100,000	26.8
	Injector irreversible failure	0.006	1.21	0.29	1.20	0.004	10,000	69.2
	Fuel mixture tampering	0.094	0.77	0.46	0.72	0.006	50	0.0
Misfire related malfunctions	Injector fouling	0.625	0.77	0.08	0.30	0.001	60,000	20.8
	Ignition coils	0.625	2.13	0.12	0.08	0.002	50,000	43.8
	Spark plug	0.625	2.13	0.12	0.08	0.002	35,000	21.7
Catalyst malfunctions	Catalyst degradation (long term)	6.25, 8.125	1.48	0.21	0.40	0.003	64,000	58.8
	Catalyst degradation (short term, misfire etc.)	0.625, 0.813	1.48	0.21	0.40	0.003	16,000	58.8
	Catalyst tampering (removal)	2.5	1.85	0.27	0.50	0.004	50	0.0

		Stage I	Stage II, no cat	Stage II	Stage II with Stage I OTL
Limits	**OBD threshold - Stage I**	✓			✓
	OBD threshold - Stage II		✓	✓	
Various malfunctions	Throttle valve	yes	yes	yes	yes
	O2 sensor failure	yes	yes	yes	yes
	Injector irreversible failure	yes	yes	yes	yes
	Fuel mixture tampering	yes	yes	yes	yes
Misfire related malfunctions	Injector fouling	(not monit.)	yes	yes	no
	Ignition coils	(not monit.)	yes	yes	no
	Spark plug	(not monit.)	yes	yes	no
Catalyst malfunctions	Catalyst degradation (long term)	(not monit.)	(not monit.)	yes	(not monit.)
	Catalyst degradation (short term, misfire etc.)	(not monit.)	(not monit.)	yes	(not monit.)
	Catalyst tampering (removal)	(not monit.)	(not monit.)	yes	(not monit.)

Two more malfunctions have been included for the catalyst monitoring modelling. The first is short term catalyst malfunctioning owed to improper fuel or lube oil use or excessive misfiring, causing fast thermal degradation. The second refers to a longer term degradation that still exceeds the normal one. This can be caused by sporadic and not so important misfires or poor lube oil use for long term but with no immediate effect character.

Further to the catalyst monitoring, frequencies for all other malfunctions over a 200,000 km period are also shown on the table. In order to simulate the uncertainty in malfunction occurrence frequency, the CBA has been executed twice; once with the frequency of occurrence shown in Table 63 and once with that frequency increased by 50%. Moreover, as in all CBA simulations in the previous chapters, the central values of implementation costs outlined above serve to build two scenarios, one for high and for low implementation costs. In the case of OBD modelling, the low cost case is estimated by combining the low implementation and low malfunction frequency scenarios. Respectively, the high cost case is estimated by combining the high cost and high malfunction frequency scenario.

The results of the cost-benefit analysis for the two feasible scenarios and the alternative scenario are shown in Table 64 and Table 65. Table 64 shows the overall environmental benefit achieved by the different OBD scenarios. Scenario 1 is not technically feasible but it is shown here to benchmark emission savings (in monetised terms) of the other scenarios. Obviously, Scenario 1 results to the highest overall environmental benefits, as this is the only one that can detect catalyst tampering and other malfunctions in the 2020-2023 period, which is not possible by any of the other scenarios. However, the environmental benefits of Scenarios 2 and 3 are not much different and these still offer significant overall environmental benefits (in the excess of 1 B€) over the time horizon considered.

Table 65 shows the overall net benefits of the two scenarios. An overall gain is achieved over the period considered, despite relatively large implementation and repair costs. Scenario 2 leads to overall higher benefits as it involves less initial investment and calibration costs that would be required to make the engines compatible with the more stringent OTL II levels. This is because, as outlined before, failures which are not relevant for catalyst monitoring and misfire exceed both OTL II and OTL I when these occur, so that even OTL levels can be used to successfully identify them. OTL II can better be used to diagnose misfire related issues. However, misfire is not associated with high NO_x increases but rather with CO and HC. As the damage cost of CO is minimal and that of HC is moderate, the additional environmental benefit in monetised terms shifting from OTL II to OTL I is marginal and does not counterbalance the additional investment cost required.

The pollutant contributions in achieving the overall benefit are better shown in Figure 89. The figure shows that the lowest cost per ton of pollutant saved is for NO_x. This is for a number of reasons. First, malfunctions (like e.g. in the O_2 sensor) have a big impact on NO_x, which is very sensitive to air/fuel ratio. Therefore, high NO_x levels as reached in these cases. OBD reduces the impact of these failures.

Second, as seen from Table 63, NO_x is the first pollutant to reach the threshold, in particular for OTL II implementation. On the other hand, PM cost-effectiveness ratios are high (high costs for low benefits), as expected from petrol engines, which are low

emitters of PM. No CO values are shown, as this is not the most interesting pollutant environmentally.

It must be stated that a large part of the benefits comes from the monitoring of the catalyst activity and, in particular, from reducing the possibility of catalyst removal. If the catalyst tampering is not sufficiently addressed by OBD Stage II introduction then the overall benefit of shifting to OBD Stage II would actually turn negative. Enhanced anti-tampering provisions are currently foreseen in the regulations. However, specific guidance to periodic roadworthiness test mechanics to check (e.g. visually) for the existence of the downstream oxygen sensor and for any alterations in the ECU to lambda sensor connections (e.g. existence of lambda simulators) should be provided. Motorcycle exhausts are much more exposed than the ones of cars so alterations are often more accessible to perform. At the same time, these are also more accessible to identify, if proper advice has been given to the inspection personnel.

Table 64. NPV of net environmental benefit for the two feasible OBD scenarios modelled.

Environmental benefit over 2020-2040 (Values in M€)	Motorcycles
Scenario 1	1492
Scenario 2	1036
Scenario 3	1037

Table 65. NPV of net societal benefit for the two feasible OBD scenarios modelled.

Cost-benefit over 2020-2040 (Values in M€)	Motorcycles
Scenario 2	135^{+95}_{-106}
Scenario 3	-21^{+72}_{-87}

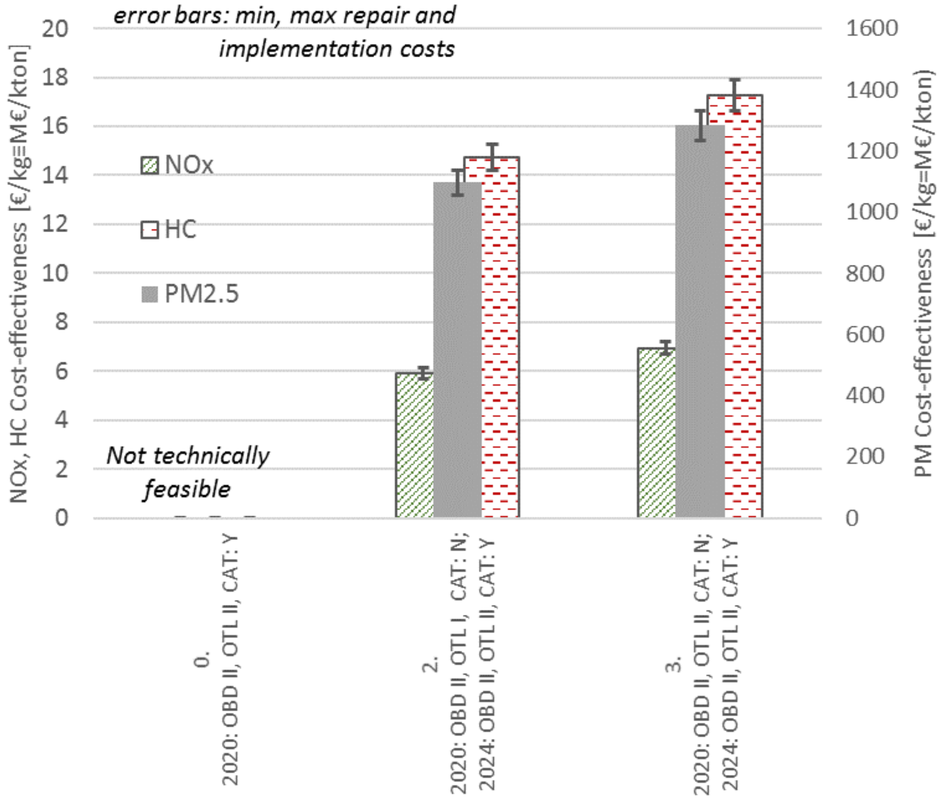


Figure 89. Cost-effectiveness of OBD scenarios per pollutant

Additional benefits introducing OBD-II in the region of UNECE

The results of the CBA performed address the EU and the common market. However, several of the vehicle models produced in EU are sold outside of the EU and vice versa, several L-category vehicles sold in EU are produced in Asia or the Americas. Production within the EU reaches below 50% of annual registrations, which means that imports are a significant part of the market. Further to EU, other large markets for motorcycles include China, India, Indonesia, Japan, USA and Vietnam.

Therefore, several vehicles registered in the EU are designed and produced outside of the EU, while EU regulations have the potential to affect other large markets. Developments in the OBD front may be particularly beneficial for these other reasons for a number of reasons:

- On the manufacturers front, introduction of OBD-II in other regions outside of EU would mean that technical specifications, performance and development are spread over an extended number of vehicle models and sales numbers. This would mean decrease of development and production costs as well as reductions of logistics costs for retaining large numbers of parts and powertrain components for the different markets.
- On the authorities field, OBD-II performs a thorough monitoring of the vehicle operation and identifies malfunctions in a more sophisticated manner than roadworthiness testing does. Therefore, OBD-II is a very good tool to control

emissions, especially in areas where effective periodical technical inspection (road-worthiness) testing is difficult to deploy or there are risks of falsified results.

- On the users front: OBD-II may early diagnose malfunctions that in time could otherwise lead to severe hardware failures with much higher repair cost implications. Early misfire detection is one of them. Moreover, OBD-II compliant vehicles should in principle be of more sophisticated and robust design and construction to enable effective OBD and avoid false malfunction identification, than non-OBD compliant vehicles This results to an overall a superior product of better quality.
- On the repairers front: OBD may assist in vehicle repair by pointing towards specific malfunctions. This is particularly useful for independent repair shops which need to service and repair vehicle models from different brands. In areas where vehicle brand authorised repair shops are not widespread or expensive, OBD can enhance repair cost competition and enable effective repair that would otherwise not be possible.

In assessing the actual effectiveness of OBD-II in other parts of the world, one will have to consider the environmental awareness, the practices as well as the purchasing power of consumers in different countries. Malfunction identification of OBD-II may not necessarily result to malfunction repair, especially if this repair is costly without immediate impact on the vehicle operation. Just to make an example; a malfunctioning catalyst may be expensive to replace while its poor performance does not affect the vehicle operation otherwise. In such a case, the rider may elect not to replace the catalyst, especially when enforcement, environmental awareness and purchase power are low.

In conclusion, introduction of OBD-II in other UNECE regions has the potential to further increase the benefit over costs ratio of the calculations made for the EU. This is primarily due to cost compression by economies of scale and the decrease of model varieties for different parts of the world. The actual cost-benefit ratio needs to take into account users responsibility and environmental awareness to repair malfunctions. In cases where this is expected low, enabling default modes or no-start of the vehicle after certain distance has been covered may be effective. Such concepts have been proven effective for advanced aftertreatment concepts (SCR AdBlue refill) in diesel passenger cars.

9.8 In-Use Performance Ratios (IUPR)

In-Use Performance Ratios (IUPR) are foreseen in Regulation (EU) 44/2014 to make sure that the OBD monitoring takes place frequently enough during real world vehicle operation. In principle, IUPR is defined as the ratio of operation where OBD monitoring takes actually place over conditions that OBD monitoring would be possible. This ratio is kept at 0.1, hence large flexibility is given to the manufacturers to select operation conditions on which to run the monitoring algorithms. For comparison, the corresponding ratio for passenger cars is 0.336 (Regulation (EU) 692/2008).

For demonstrating compliance with IUPR requirements, each manufacturer may group vehicles within an OBD family (so-called ‘vehicle and propulsion family’), according to point 4.1.7 of Appendix 1, Annex XII in Regulation (EU) 44/2014.

However, the technical criteria in defining such a family are not defined in the Regulation.

Regardless of whether an OBD family is defined or not, still the manufacturer will have to demonstrate that the IUPR monitor has been satisfactorily operating for a minimum number of vehicles from the fleet. Criteria for the identification and selection of vehicles does not exist in the current regulations, neither minimum vehicle sample sizes that have to be collected. These are necessary elements to enforce the Regulation and issue Type Approval.

In meeting these requirements, relevant information from the corresponding passenger car regulations may be readily adopted (Regulation (EU) 692/2008 Annex II main and Appendix 2). Possible adjustments to account for the smaller series of L-category vehicles compared to M1 and other technical details in defining and OBD family can be fast made. The lack of specific OBD family and vehicle selection criteria cannot be considered a reason to delay introduction of IUPR.

Monitoring according to IUPR requires determination of suitable real-world conditions and relevant experience from the manufacturer to make sure that monitoring algorithms are well designed to meet the minimum IUPR without increasing the risk of erroneous malfunction identification. In the passenger cars sector, sufficient lead time was given between introduction of OBD-II (2000) and enforcement of IUPR monitoring (2011). This allowed ample time to the manufacturers to understand real world conditions and monitoring possibilities of actual OBD-II compliant vehicles on the road, in order to design their IUPR monitoring strategies. In the case of L-category vehicles, OBD-II and IUPR introduction dates coincide in Regulation (EU) 168/2013. Therefore, this creates the technical complication of making sure that OBD-II algorithms are correctly tuned to identify malfunctions and, also, that they are enabled in the right frequency on the road without causing false malfunction identification. The problem is that current Regulations require enforcement without allowing some lead time to first monitor real-world OBD II data performance and then introduce mandatory minimum IUPR.

Moreover, IUPR is not independent of OTL level. Reducing the thresholds means that less operation conditions are available to identify a malfunction and vice-versa.

To allow a level-playing field and a healthy competition, one has also to consider that some of the L-category manufacturers are active in the M1/N1 vehicle segments, where OBD and IUPR algorithms have matured. Other manufacturers are only active in the L-category sector, hence, accumulating experience on how real-world algorithms operate will be more demanding for them. The risk of false malfunction identification is particularly high in this second case, with a consequence a possible harm of the reputation of such manufacturers and/or market position. This should be avoided.

The following recommendations can be made to reduce the risk of false malfunction identifications while, at the same time, training manufacturers to IUPR monitoring:

i. OBD-II can first be introduced together with IURP functionality that has to be demonstrated by the manufacturer to the technical authority. However, in this first stage, vehicles need not meet a minimum IUPR.
ii. At a second stage, minimum IUPR of 0.1 is enforced and vehicles at this stage need to demonstrate compliance with this. Considering that IUPR

reporting should be made no later than 18 months after the end of the specific calendar year and that OBD-II is introduced in 1.1.2020, the first reporting round of IUPR will be around mid 2022. Allowing then some lead time to the manufacturer to adjust IUPR algorithms, it seems reasonable that the first model year to comply with a minimum IUPR is 2024/25.

iii. As a third step, a specific study would be needed to explore the possibility of increasing the minimum IUPR. A minimum ratio of 0.1 seems too low compared to passenger cars but no experience exists for motorcycles and the real-world conditions allowing monitoring to be performed. Once IUPR is enforced, such conditions will be revealed and a specific study can be made to assess the cost-benefit of increasing this ratio. Current Regulations should foresee that IUPR related data (nominator, denominator, ignition cycle counter, general denominator, operation boundaries allowing monitoring, etc.) can be made available also to third particles, to the request of the authorities, for studying the effectiveness of IUPR. Anonymizing data should be fine for such studies not to reveal manufacturer specific strategies to the competition.

9.9 Conclusions and recommendations

With regard to the implementation of OBD Stage II for motorcycles, the following points have to be summarized. Two feasible scenarios and an alternative (technically not feasible) scenario – on top of the baseline one – were executed to examine a cost-beneficial implementation of OBD Stage II:

i. OBD stage II introduction in 2020 as laid down in Regulation (EU) No 168/2013. This scenario is technically not feasible, but it has been simulated to examine the benchmark environmental benefit that would be achieved.

ii. OBD stage II introduction with OTL I with no catalyst monitoring in 2020 and OBD stage II with OTL II in 2024/25 for all malfunctions. This scenario allows some lead time to manufacturers to start enabling catalyst monitoring from 2024/25 (new/all types) on. In the period 2020-2023, OBD II is implemented for all other malfunctions, including misfire detection, assuming OTL I.

iii. OBD stage II introduction with OTL II with no catalyst monitoring in 2020 and OBD stage II in 2024/25 for all malfunctions. This scenario is similar to scenario ii, in terms of time periods applying OBD I and OBD II. However, in the period 2020-2023, OBD II is implemented with OTL II.

In implementing OBD II, misfire monitoring was considered to have a positive impact to controlling direct CO and HC emissions. Moreover, it was considered to decelerate catalyst ageing due to the protection it offers against thermal degradation owed to excess fuel oxidation events in the catalyst. Moreover, catalyst monitoring was considered as a very effective means of reducing catalyst tampering (removal) which is very frequently today by motorcycle enthusiasts.

The scenarios executed showed that shifting the full implementation of OBD II with OTL II, including catalyst monitoring, to 2024/25 instead of the original 2020/21 time horizon can be proven both technically feasible and cost-beneficial. In order to make sure that net societal benefits are achieved, OBD II for all other malfunctions, including misfire detection, needs to be introduced from 2020/21 (new/all models). The level of OTL in the period 2020-2023 is of moderate importance. This is because malfunctions not related to catalyst performance and misfire lead to emissions

increase that in any case exceeds OTL I. As a result, implementation of OBD II with OTL I in 2020-2023 (w/o catalyst monitoring) leads to the overall highest net benefit. OTL levels become critical when the catalyst monitoring is considered, in the post 2023 period.

The recommendation on first OBD-II implementation would therefore be (dates applying to new types, one year later for existing types):

- 2020-2023: OBD-II for all malfunctions with OTL I, excluding catalyst monitoring
- 2024: Full implementation of OBD II with OTL II, including catalyst monitoring

A further recommendation is that anti-tampering provisions for the downstream oxygen sensor are reviewed and, possibly, further enhanced and that guidance to personnel of periodic inspection test centres is given to reduce the possibility of catalyst monitoring tampering.

With regard to In-Use Performance Ratios (IUPR), the following three stages are considered to enable effective OBD-II monitoring and reducing the risk of false malfunction identification:

i. Introduce IUPR functionality in 2020 w/o need to demonstrate compliance with a minimum IUPR.
ii. Request minimum IUPR of 0.1 in 2024/25 for new/all types.
iii. Initiate a study to consider increasing IUPR to meet passenger car requirements.

A number of additional points on OBD II suitability on different vehicles, needs to be made:

- First, although all L3e subcategories are addressed by OBD Stage II, L4e vehicles are not included. L4e vehicles are technically identical to L3e ones, at least with regard to their powertrain and emission control system. Despite the relative sales of L4e vehicles are marginal compared to L3e, excluding these vehicles from OBD-II may introduce unnecessary regulatory uncertainties whereas a vehicle is registered as L4e, its sidecar is then removed, and operates as an L3e w/o OBD Stage II requirement. Although this may not be a financially attractive option for the potential owner, it is still a possibility that should be remedied at a next step.
- Second, OBD Stage II is proposed for L6e-A vehicles, *i.e.* light on-road quads. This is a category of vehicles dominated by very small series and small powertrains, *i.e.* 50 cc (moped type of engines) up to 4 kW. These are practically mopeds in terms of their powertrain. Hence, although two and three wheel mopeds (L1e-B and L2e) are excluded from any OBD requirements, those four wheel 'mopeds' are even required to introduce OBD Stage II. Due to the simplistic character and the very small series of vehicles, we expect that this category will become extinct or any vehicles will be type-approved only under the 'small-series' provisions, which for this category is limited to 30 units per type (Annex III, Regulation (EU) No 168/2013). Hence, we do not expect any OBD Stage II systems for such vehicles and they are not further assessed in the following sections. Moreover, in order to retain neutrality in regulations and allow level playing field for smaller manufacturers, the recommendation would be to remove OBD Stage II requirements from such vehicles. Since L1e-B and L2e are not included in any OBD regulation and L6e-A use the same powertrain as these categories,

it seems reasonable to remove any OBD requirements from such vehicles. However, OBD Stage I has become applicable for these vehicles since 1.1.2017, although we do not believe that OBD-compliant vehicles have been produced or are going to be produced. Hence, at minimum, OBD Stage II requirements should be lifted and, instead, OBD-I or even no OBD (if possible) requirements are needed for technology neutrality reasons in comparison with L1e-B and L2e vehicles.

- Enduros (L3e-AxE) and Trials (L3e-AxT) are specialised motorcycle concepts produced in rather small series and aiming at a market of approximately 15,000 units per year. These vehicles are not used for regular commuting but mostly for leisure activities in both road and off-road conditions. They are also used, on average, for only a few hours per year (equivalent of 10-15 days) and have short lifetimes (4-5 years). These vehicles need to be compact and light for performance. Moreover, it is customary that tuning is a widespread practice. OBD-II seems to offer minimal advantages in the category due to their low overall activity, and fast replacement cycles. It is also hard to estimate how much users would decide to remove OBD-II components – environmental enforcement practices in such semi-racing vehicles are usually low. Hence, in real terms, the effectiveness of OBD II is questionable. In order to not significantly distort the market, on which a number of SMEs are active, it is recommended to exclude endure and trial vehicles from OBD II provisions.

With regard to OBD effectiveness in parts of the world outside EU, introduction of OBD-II regions has the potential to further increase the benefit over costs ratio of the calculations made for the EU. This is primarily due to cost compression by economies of scale and the decrease of model varieties for different parts of the world. The actual cost-benefit ratio needs to take into account users responsibility and environmental awareness to repair malfunctions. In cases where this is expected low, enabling default modes or no-start of the vehicle after certain distance has been covered may be effective. Such concepts have been proven effective for advanced aftertreatment concepts (SCR AdBlue refill) in diesel passenger cars.

ASSESSMENT OF POSSIBLE MEASURES BEYOND THE EURO 5 ENVIRONMENTAL STEP

10 Off-cycle emission testing

10.1 Background and objective

Background

Recital 12 of Regulation (EU) No 168/2013 requires an environmental effect study that should, inter alia, assess technical feasibility and cost-effectiveness of potential measures to keep off-cycle emissions under control. This can improve the overall environmental performance assessment at type-approval. New vehicle types tend to be optimized towards a defined emission laboratory test cycle.

However, the laboratory test cycle continues to play a pivotal role in type-approval legislation and remains very important as comparison base of one vehicle to another. In the future beyond the Euro 5 step it will be necessary to get a more holistic picture of the tailpipe emissions of the L-category vehicle. For some other vehicle categories this is already the case. For this reason, off-cycle emission requirements may be needed to complement the WMTC test results in due course.

Objective

The objective of this task is to assess the technical feasibility and cost-effectiveness of requirements to keep off-cycle emissions under control.

10.2 Specific tasks

The section below describes the specific tasks in order to reach the aforementioned objective.

1. Carry out an experimental test programme on technical feasibility off-cycle emission requirements

A limited number of vehicles should be selected to be tested with a lightweight portable emission measurement system (PEMS) on-road and under normal condition of use. This means that the engine load conditions are more or less comparable to the conditions in the WMTC. Moreover, multiple road segments shall be included, i.e. urban, rural and, if possible, highway driving. The measurements should be performed in the emission laboratory lab and may in addition be performed on the road as well. The emission measurements on the chassis dynamometer will be used to establish a correlation between PEMS and the emission bench analysis equipment in the test laboratory.

Although it lies outside the original scope of this study, it also identifies characteristics of alternative off-cycle measures next to PEMS. The assessment focusses on PEMS but also three other off-cycle options are briefly touched on.

2. Benefit / cost ratio range and cost effectiveness analysis off-cycle emission requirements

On the basis of the results obtained from the above-mentioned task, the benefit/ cost ratio ranges per vehicle category shall be assessed. In this assessment the additional cost for manufacturers, both in terms of additional testing burden and technologies to

be deployed, as well as the potential environmental benefits resulting from the introduction of off-cycle emission requirements shall be taken into account.

Specifically, the study shall address the cost-benefit ratio of the four alternative scenarios which are specified in the terms of reference:

1. No Euro 5 tailpipe emission limits applied in 2020, continue with Euro 4 limits, off-cycle emission requirements as of 2024;
2. Euro 4 and Euro 5 tailpipe emission limits as currently set-out in Regulation (EU) No 168/2013, off cycle emission requirements as of 2028;
3. Euro 4 limits as currently set-out in Regulation (EU) No 168/2013, Euro 5 limits only for most polluting categories (L1e, L3e-A1, L7e-A and L7e-B) in 2020, other categories Euro 5 limits as of 2024, off cycle emission requirements as of 2028;
4. Euro 5 limits for all L-category vehicle types as of 2024, off-cycle emission requirements as of 2028.

10.3 Technical feasibility

10.3.1 Technical pathways for controlling off-cycle emissions

The focus in this study is on PEMS. However, in order to give a more complete overview of technical pathways for off-cycle emissions, three alternative off-cycle options are shortly discussed. The identified off-cycle options and their characteristics are explained below:

- *Portable Emissions Measurement System (PEMS)*
  - A ‘small’ PEMS suitable for L-category vehicles is installed on the vehicle and measures emissions during a specified test trip on the road. Due to the exhaust flow determination, emissions can be reported in grams per kilometre. The exhaust flow is mostly determined indirectly at a small PEMS. For example, the inlet air flow can be calculated by measuring the engine speed, manifold absolute pressure (MAP) and inlet air temperature (IAT). Then, the exhaust flow can be estimated based on the inlet air flow.
  - A regular PEMS, which is commonly used for light- and heavy-duty vehicles, is often too heavy and too bulky for usage on L-category vehicles, in particular for two-wheeled vehicles. For example, the typical weight of the main unit only, is often already more than 30 kg. A heavy and bulky PEMS makes installation more difficult and may influence the driveability and the test results. Moreover, PEMS is a stand-alone measurement device with a standalone power supply, which makes the packaging of PEMS even more challenging when a large battery or a generator is required. A stand-alone power supply is needed because the use of the vehicle’s electric power output could influence the emission performance. Another complexity is the proper mounting of an exhaust flow meter. In particular for two-wheelers, very little space is available around the vehicle to mount the exhaust flow meter in a proper and safe manner.
  - For the above-mentioned reasons, a PEMS with low energy consumption, low weight and limited dimensions is the focus in this assessment.

- *Concentration measurement, optionally in combination with the registration of ECU parameters.*
  - Such a system is installed on the vehicle and measures emission concentrations during a defined test trip or during ordinary driving on the road.

With the concentration measurement method the exhaust flow is not measured. Either the exhaust flow is calculated based on ECU parameters to obtain values in grams per kilometre, or, emissions are reported relative to CO_2 emissions. An important ECU parameter for the exhaust flow determination is the ‘mass (inlet) air flow’. As an alternative, the ‘manifold absolute pressure’ in combination with the ‘inlet air temperature’ and ‘engine speed’ can be used. Currently, these required ECU parameters, are not available on all L-category vehicles to determine exhaust flow. When emissions are reported relative to CO_2 emissions, the ECU parameters are not needed.

- *Random cycle testing on the chassis dynamometer*
  - Randomly generated cycles are driven on the chassis dynamometer. The random cycle composition is, in contrast to the designated type I test cycle, unknown until right before the test. Hence, there is lower possibility to optimize a vehicle towards a fixed defined emission laboratory test. Nonetheless, the dynamics in random cycles will most probably be comparable to the characteristic of the WMTC. However, it is possible to cover a wider range of driving behaviour with random cycles.

- *Remote Emissions Sensing (RES)*
  - RES equipment is installed along the road or along a test track. When a vehicle passes the RES equipment, the emitted exhaust emissions are measured using infrared, laser and ultraviolet beams. In addition, vehicle speed and acceleration is measured. No exhaust flow is measured. Emissions can be reported as concentrations, e.g., relative to CO_2 emissions.

The different off-cycle options are quantitatively evaluated based on the following criteria:

- Representativeness for real world driving behaviour;
- Statistics: amount of collected data per vehicle;
- Accuracy of measurement equipment;
- Resistance against cycle beating (test cycle recognition);
- Test burden for manufacturer or Type Approval Authority;
- Applicability for L-category vehicles.

In particular, the criteria ‘representativeness’ and ‘cycle-beat resistance’ are considered as very important. These criteria are the main purpose to implement off-cycle emissions.

Table 66 summarizes the characteristics per off-cycle option. Overall, measurements with a PEMS are considered the most suitable method to determine off-cycle emissions. This is the result of positive scores on ‘representativeness’ and ‘cycle-beat resistance’, in combination with acceptable scores on the other criteria as well. In the paragraph that follows, PEMS is discussed in more detail.

Table 66: Characteristics of different off-cycle options

Off-cycle option		Representativeness	Statistics per vehicle	Accuracy	Cycle-beat resistance	Test burden	Applicability
'small' PEMS equipment on the vehicle		**Good**, if there is appropriate variation in trips.	**Very good**, all neces-sary data is available throughout complete test	**Medium**, due to some compromises to make the system small and light.	**High**, especially when PEMS has no interface with the vehicle	**High**, especially due the required time for preparations	**Medium-high**, Directly suitable for most L-cat vehicles
Concentration measurements (HC, CO, NOx, O2) on the vehicle, optionally in combination with the registration of ECU parameters.		**Good**, if there is appropriate variation in trips. More and longer trips are feasible, however, separate limits or conversion is needed	**Good**, many data is available throughout complete test	**Low – medium**, exhaust flow calculation based on ECU parameters, if available	**Medium - high**, high when there is no interface with the vehicle (with CO_2 as a reference)	**Medium**, Time for preparation shorter than with PEMS	**Medium-High**, Required ECU parameters not available on all L-cat vehicles
Random cycle testing on the chassis dynamometer		**Good**, but limited by the cycle length	**Very good**, all neces-sary data is available throughout complete test	**Very high**, similar to regular laboratory tests	**Low**, Many options to recognize testing	**Low**, especially when it is an integral part of the TA test	**High**, similar to regular laboratory tests
Remote Emissions Sensing	On road, without driver instruction	**Low**, due to a single location	**Low**, only a few seconds of limited data	**Limited**, no exhaust flow and measurement is in open air	**High**, almost impossible to detect testing	**Medium**, no installation on vehicle and multiple vehicles at once	**High**, suitable for all vehicles
	On a circuit, with precise driver instruction	**Limited**, due to a single location, but with instruction different driving types can be simulated	**Limited**, but multiple repetitions are possible	**Limited**, no exhaust flow and measurement is in open air	**Medium-high**, due to more precise instruction	**Medium**, no installation on vehicle and multiple vehicles at once	**High**, suitable for all vehicles
	On circuit, with random driver instruction, such as the random selection of velocity prior to acceleration at the sensing location	**Limited**, due to a single location, but with instruction different driving types can be simulated	**Limited**, but multiple repetitions are possible	**Limited**, no exhaust flow and measurement is in open air	**High**, almost impossible to detect testing	**Medium**, no installation on vehicle and multiple vehicles at once	**High**, suitable for all vehicles

10.3.2 *PEMS to determine off-cycle emission*

The table shows that PEMS scores well on most of the criteria. Nonetheless, there are some less positive scores as well, since PEMS has a 'high' test burden and a 'medium accuracy'.

The high test burden for PEMS is caused by the amount of time and effort which is required to complete a valid PEMS test. This also includes the needed preparations, i.e., calibration and the installation and commissioning of the equipment on the test

vehicle. Moreover, a PEMS should be purchased and properly maintained on top of the already required chassis dynamometer.

The availability of commercially viable PEMSs suitable for small vehicles, including mopeds, is rather low in comparison to the light- and heavy-duty vehicles sector. According to the preparatory work for the environmental effect study (Zardini et al., 2016a), there are currently at minimum two systems commercially available which are suitable for L-category vehicles and measure the regulated emission constituents. These systems are developed for light- and/or heavy-duty vehicles but are also suitable for smaller vehicles. In this study one of those two is applied during testing. Next to the commercially available systems, some prototypes are under development as well.

Technical specifications of the PEMS equipment used in this project are described in chapter 2.3.5 in Table 8. It is feasible to install the system on a two-wheeled vehicle. However, for small vehicles, such as mopeds, some modifications to the vehicle are needed to make the PEMS fit. For example, a small platform on the vehicle's frame is often needed for a proper and safe mounting of the PEMS. Due to the afore-mentioned reasons, PEMS scores 'medium-high' on applicability.

As shown in the specifications, the weight of the used PEMS is 17.2 kg, which is rather light for a PEMS. This is without the external power supply, which adds an extra mass of approximately 12 kg. With a regular 12V battery, a trip of approximately two hours is feasible with the used PEMS. It should, however, be noted that the following compromises are made to make this low weight and low energy consumption possible:

- exhaust flow is not directly measured;
- there are no heated lines;
- the set of analysers differ from a 'regular' PEMS. In particular the measurement principle for HC, NDIR instead of FID, may affect the accuracy.

Since an exhaust flow is required to obtain emissions in grams per kilometre, this PEMS estimates the flow based on the inlet air flow. The inlet air flow can be calculated by measuring the engine speed, manifold absolute pressure (MAP) and inlet air temperature (IAT). Then, the exhaust flow can be estimated based on the inlet air flow. The used formula to calculate the exhaust flow is for this specific PEMS not publicly available.

Figure 90 shows how PEMS is installed on one of the used test vehicles.

Figure 90: PEMS installed on a moped

Since the exhaust flow is not measured directly, it may influence the accuracy. Moreover, installation of a proper connection for the required MAP measurement that is applicable to all L-category vehicles is complex. This affects the score on applicability as well as on accuracy. Some L-category vehicles already have an easy accessible port available which allows direct connection to the inlet manifold, this makes the installation more practical. Nevertheless, the actual PEMS is a stand-alone method, which makes it immune for cycle-beating and directly applicable to most of the vehicles. In the case only concentrations are measured in combination with ECU parameters to determine exhaust flow, the accuracy depends on the quality of ECU signals. Moreover, the needed parameters are not always available.

The exhaust flow determination method, together with the difference in analysers and non-heated lines, causes the 'medium' score for accuracy'. A 'regular' PEMS would have scored 'high' at this point. In spite of this, the small PEMS is estimated to be the best option in terms of accuracy compared to the other off-cycle options outside an emission laboratory.

Possibly, PEMS with a direct exhaust flow meter and suitable for L-category vehicles will be developed in future. According to the information at the contractor's disposal, there is currently no suitable PEMS for two-wheelers on the market with a direct exhaust flow meter. The absence of a direct flow meter can also be explained by the fact that there are currently no technical requirements for the applied PEMS on L-category vehicles. As there is no off-cycle legislation for L-category vehicles foreseen until 2020, sufficient time for improvement of the accuracy for indirect exhaust flow measurements is available. Or, time to develop a direct exhaust flow measurement. Also heated lines and an FID for HC measurements are desirable, however, this will have an effect on the driving range and/or the weight of the system. In addition, an FID analyser uses hydrogen, which entails that also safety aspects should be taken into consideration.
Paragraph 10.3.3 describes the accuracy of the used PEMS in more detail.

10.3.3 *Applied programme for off-cycle testing*

In this paragraph the applied experimental test programme on technical feasibility for off-cycle testing is described. During the test programme six vehicles are tested with PEMS on the chassis dynamometer. Some of those vehicles are tested with PEMS on the road as well.

Used equipment and tested vehicles

Technical specifications of the used PEMS equipment and the used chassis dynamometer facility, are described in chapter 2.3. In the previous chapter the configuration and properties of the used PEMS are explained in more detail. Table 67 shows the measured emissions and their corresponding measurement principles.

Table 67: Measured gases with measurement principles

Measured gas	PEMS	Chassis dynamometer
CO	NDIR – Non-Dispersive Infrared	IRD - Infrared Detector
HC	NDIR – Non-Dispersive Infrared	FID – Flame Ionization Detector
$NO_{(x)}$	Electrochemical (NO only)	CLD – Chemiluminescence Detector
CO_2	NDIR – Non-Dispersive Infrared	IRD - Infrared Detector

Table 68 summarizes the main characteristics of the vehicles tested with PEMS. In addition the table provides a list of driven cycles for each specific test vehicles. Vehicle J17, J19 and T01 are tested with PEMS on the road in the Netherlands. These tests were needed to gain experience with the system and to prepare additional test trips with real-world (RW) driving behavior next to the WMTC. In the following section the used test trips are described in more detail. Apart from vehicle T01, the vehicles from Table 68 are tested on the chassis dynamometer with PEMS.

Table 68: Tested vehicles with PEMS

Vehicle ID no.	Category	Engine capacity [cc]	Maximum design speed [km/h]	Transmission	Euro class	Driven cycles
J10	L1e-B	50	25	CVT	Euro 2	WMTC_1 RW_L1e-B
J17	L1e-B	50	45	CVT	Euro 2	WMTC_1 RW_L1e-B
J19	L3e-A1	130	90	CVT	Euro 3	WMTC_1 RW_L3e-A1
J11	L3e-A2	160	95	CVT	Euro 3	WMTC_2-1 RW_L3e-A1
J13	L3e-A2	280	128	CVT	Euro 4	WMTC_2-2 RW_L3e-A1

J18	L3e-A3	1170	>150	Manual	Euro 4	WMTC_3-2 RW_L3e-A3
T01	L3e-A3	1170	>150	Manual	Euro 3	-

Driving cycles
The WMTC is designed to represent average driving behaviour. In order to test the vehicles under normal conditions of use, the vehicles are tested with PEMS on the chassis dynamometer by using the WMTC. Appendix **N** shows the speed profile of each driven cycle within this study required within the Euro 5 step, including the WMTC.
In order to assess emissions in a cycle which covers a larger part of the engine area than the WMTC, additional test cycles are prepared. These additional test cycles are developed in the Netherlands on the road with vehicles J17, J19 and T01, which are, as shown in Table 68, respectively category L1e-B, L3e-A1 and L3e-A3 vehicles. It should, however, be noted that these developed trips are examples of real-world everyday driving for some specific L-categories and are not developed to be used as official test trips.

The trips are developed taking inspiration from the trip guidelines developed for light-duty vehicles (LDV) real driving emission (RDE) legislation, see: Regulation (EU) No 2016/427 and Regulation (EU) No 2016/646. In the LDV RDE legislation trip requirements and test conditions are prescribed. These requirements and test conditions relate among other things to: trip composition, trip dynamics, trip duration, allowed ambient temperatures, etcetera. In order to distinguish between urban, rural and highway driving, the data is divided into the following speed bins:

- Urban: 0 - 60 km/h
- Rural: 60 – 90 km/h
- Highway: 90 – 145 km/h

Table 69 shows the trip composition of the developed real-world (RW) cycles in this study. As mentioned before, the real-world cycles in this study are developed for three vehicle classes. The tested L3e-A3 vehicle has a maximum vehicle speed which allows for urban, rural and highway driving. The tested L3e-A1 vehicle has a maximum speed of 90 km/h, which is not unusual for L3e-A1 vehicles. Hence, the developed test trip consist only of urban and rural driving. Clearly, L1e-B vehicles do not exceed the 60 km/h speed bin. Therefore, the trip composition is labelled as 100% urban driving. However, the L1e-B trip certainly distinguishes driving in urban and rural areas. The trip composition is developed with 50% driving in an urban area and 50% driving in a rural area. Driving in an urban area contains many accelerations and decelerations where driving in a rural area contains significantly more constant driving.

Table 69: Trip composition real-world cycles

		Urban	Rural	Highway
Velocity bin [km/h]		0-60	60-90	90-145
Distance share	**L1e-B**	100%	-	-
	L3e-A1	± 50%	± 50%	-
	L3e-A3	± 25%	± 25%	± 50%

Table 70 shows the cycle specifications of the developed Real-World trips. As a reference, the cycle specifications of the different WMTC cycles are shown as well. The vehicles used for the Real-World cycle development fall in the following WMTC classes:

- L1e-B: WMTC class 1_reduced 45 km/h
- L3e-A1: WMTC class 1
  - It is noted that this specific vehicle falls into class one, but not all L3e-A1 vehicles fall into WMTC class 1. A classification of a L3e-A1 in WMTC class 2-1 is also possible
- L3e-A3: WMTC class 3-2

The most important differences between the Real-World cycles as recorded on the road, and WMTC are:

- Longer trip duration and trip distance
- Higher maximum speed
- Higher accelerations

Table 70: Cycle specifications of WMTC and real world cycles

Cycle			Time	Expected distance	Average speed	Max speed	Idling	Constant speed	v*a positive	RPA
			[sec]	[km]	[km/h]	[km/h]	[%]	[%]	[m2/s3]	[m/s2]
Type I	WMTC	Class_I_reduced_25	1200	5.9	18	25	20	57	3.40	0.80
		Class_I_reduced_45	1200	7.6	23	45	19	27	3.72	0.60
		Class_I	1200	7.7	23	50	19	22	3.67	0.58
		Class_2_1	1200	12.3	37	83	13	24	5.23	0.54
		Class_2_2	1200	13.2	40	95	13	23	6.22	0.59
		Class_3_1	1800	27.6	55	111	9	30	6.73	0.54
		Class_3_2	1800	28.9	58	125	9	30	6.88	0.53
Off-cycle	Real world cycle	Real_World_L1e_B_HS	3453	26.0	27	47	5	25	6.50	0.75
		Real_World_L3e_A1	5836	62.9	39	94	16	21	5.77	0.54
		Real_World_L3e_A3_130	4330	70.5	59	130	11	25	11.77	0.75

10.3.4 Results off-cycle testing programme

<u>Correlation between PEMS and chassis dynamometer</u>

As described in paragraph 10.3.1, PEMS is considered as most suitable method to determine off-cycle emissions. Real-World cycles are then driven on the road with PEMS installed, instead of testing on the chassis dynamometer. In this paragraph the accuracy of one small PEMS is evaluated. The evaluated PEMS is commercially available and suitable for L-category vehicles. The most critical aspects for the accuracy of this PEMS are; the absence of a physical exhaust flow meter, the absence of heated lines and the set of analysers which differ from PEMS equipment used of RDE testing of light- and heavy-duty vehicles in the EU. It should, however, be noted that there are currently no technical requirements for the applied PEMS on L-category vehicles, as there is no off-cycle legislation for L-category vehicles. The assessed PEMS is current state-of-art. However, state-of-art of the PEMS for application on L-category vehicles might develop in future, in case technical requirements for PEMS on L-category vehicles become part of the legislation. The PEMS equipment is described in more detail in paragraphs 2.3 and 10.3.1.

Emission values are usually expressed in g/km. To obtain results in g/km, the first step is to measure emission volume concentrations. Volume emission concentrations are expressed in parts per million [ppm] or percent [%]. Then, with the exhaust flow, these concentrations are calculated into mass emissions, i.e. g/km.

In this paragraph a comparison is made between the volume emission concentrations of PEMS and the concentrations as measured by the laboratory emission analysers. Then, the same comparison is made of the mass emissions. In order to make this comparison, the PEMS is installed on the vehicle and was driven on the chassis dynamometer. As the PEMS measures undiluted exhaust emissions, the comparison between PEMS and the laboratory equipment is made by using the undiluted emissions as measured by the laboratory equipment and PEMS.

Comparison of volume emission concentrations between PEMS and laboratory equipment

Figure 91 and Figure 92 depict the comparison between undiluted volume emission concentrations as measured with PEMS and the laboratory equipment. Figure 91 shows the instantaneous CO emissions in a WMTC with vehicle J17. Figure 92 shows the average emissions of multiple WMTC's. As clearly shown in Figure 91, there can be a very good correlation between the emission concentrations as measured with PEMS and the laboratory equipment. In Appendix Q figures are reported where the comparison of CO, HC, NO and CO_2 instantaneous emissions are made as well for vehicle J17. Figure 92 displays that, except for HC, the PEMS results are in general comparable with the laboratory results. The CO and NO results show some outliers up to a 25% difference, the CO_2 results are almost identical. On the contrary, HC emissions of PEMS are more or less 20 to 50% lower compared to the laboratory emissions. This deviation in HC emissions is possibly caused by:

- No heated lines
- Different type of analyser
- Different expression for the hydrocarbon content (C6 H14 for PEMS and ppm C1 for the laboratory equipment)

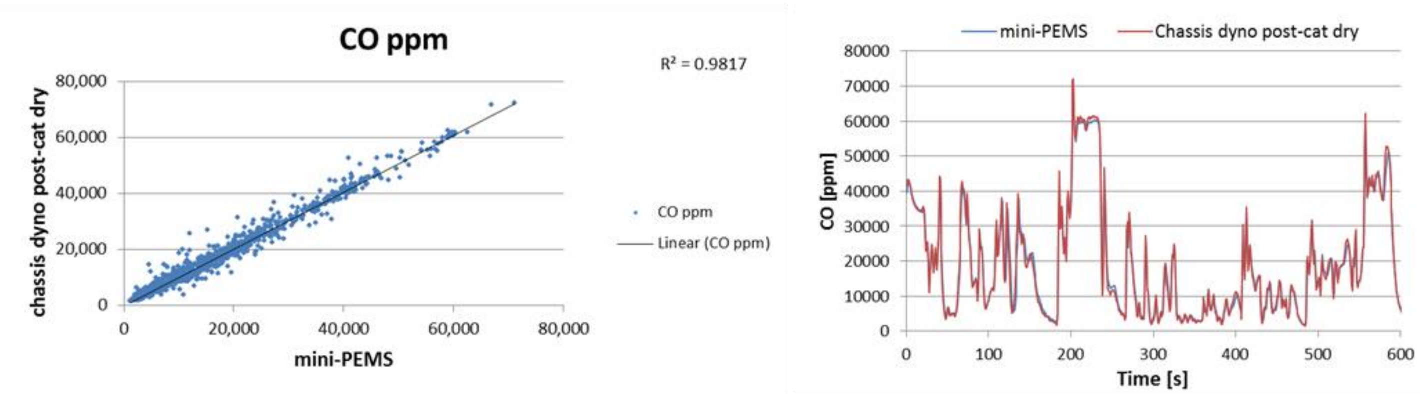


Figure 91: A comparison between instantaneous undiluted volume emission concentrations as measured with PEMS and the laboratory equipment. These figures are based on a WMTC test with cold start driven with vehicle J17.

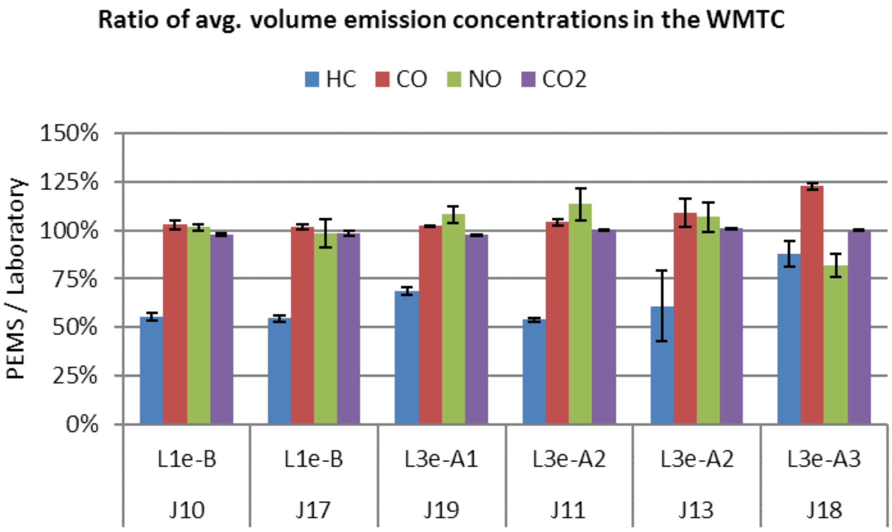


Figure 92: A comparison between average undiluted volume emission concentrations in multiple WMTC's as measured with PEMS and the laboratory equipment. The laboratory values are considered as 100%. The error bars represent the standard deviation between the multiple WMTC's.

Comparison of mass emission between PEMS and laboratory equipment

Figure 93 shows the comparison between the average mass emissions in the WMTC as measured with PEMS and the laboratory equipment.

The figure show the results of three vehicles while six vehicles were measured with PEMS. The PEMS results of the missing three vehicles are assessed as unreliable. In comparison with the laboratory emission results of these vehicles, the PEMS results showed deviations up to a factor two. Possibly, this is the result of an incorrect measurement of the manifold absolute pressure (MAP), which is required for the exhaust flow determination of the PEMS results. This incorrect measurement was caused by the absence of a proper connection.

The difference between the PEMS and laboratory results of the remaining three vehicles is still larger in comparison with the volume emission concentrations. Where the CO2 volume emission concentrations as measured with the PEMS were almost identical to the laboratory equipment, the mass CO2 emissions show deviations up to 25%. The deviations for CO and NO are in general somewhat larger than the deviations for CO2. The HC emission results show the largest deviations. However, this was already the case for the volume emission concentrations. In Appendix Q figures are reported where the comparison of CO, HC, NO and CO2 instantaneous mass emissions are made as well for vehicle J17. In these figures, the deviation is clearly shown as well.

As mentioned before, the exhaust flow is needed to translate the volume emission concentrations into mass emissions, i.e. g/km. Hence, the cause for the deviation in mass emission values are most likely the result of the exhaust flow determination.

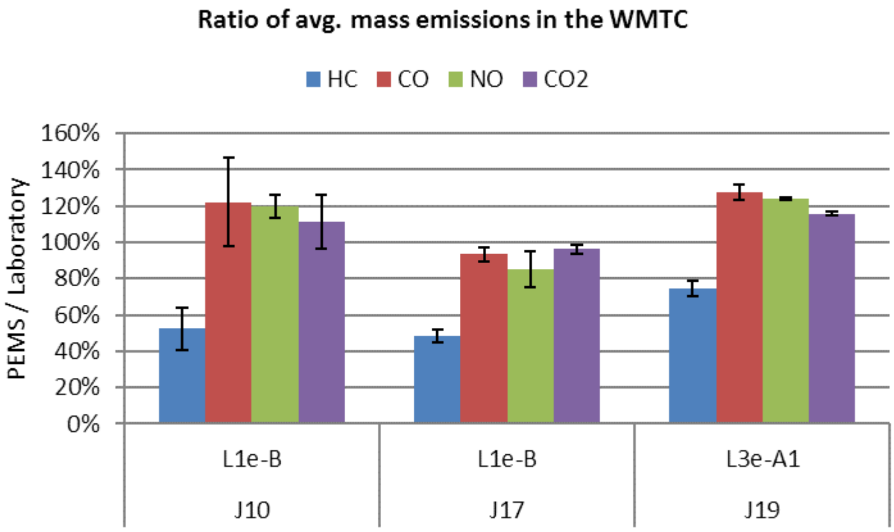


Figure 93: A comparison between average undiluted mass emissions in the WMTC as measured with PEMS and the laboratory equipment. The laboratory values are considered as 100%. The error bars represent the standard deviation between the multiple WMTC's.

Exhaust flow determination

With this PEMS the exhaust flow is calculated based on a set engine displacement, the measured engine speed, manifold absolute pressure (MAP) and inlet air temperature (IAT).

Figure 94 shows the exhaust flow of vehicle J17. The mass emission results as measured with PEMS with this vehicle are the closest to the laboratory results of all vehicles. Nevertheless, the instantaneous exhaust flow values as measured with PEMS still deviate from the exhaust flow as determined by the laboratory equipment.

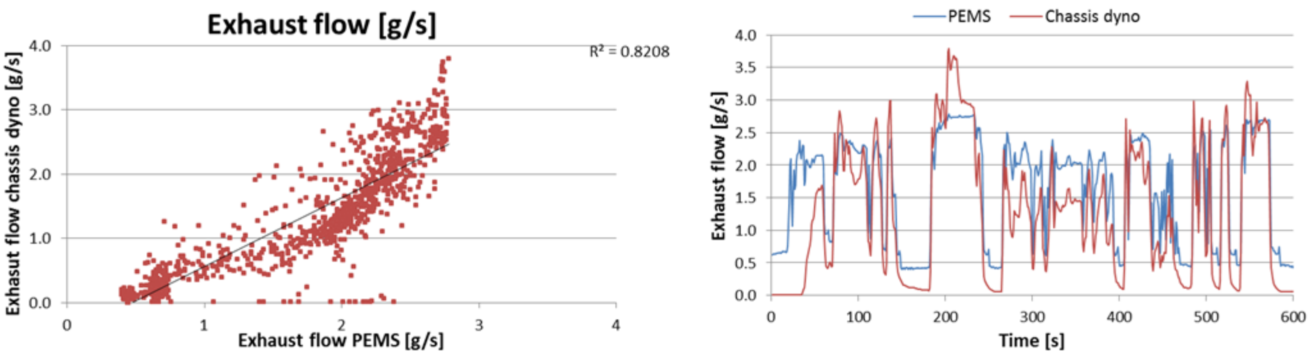


Figure 94: A comparison between the instantaneous exhaust flow as determined with PEMS and the laboratory equipment. These figures are based on a WMTC test with cold start driven with vehicle J17.

These deviations may be the result of the used generic algorithm which is applied to calculate the exhaust flow. Often these algorithms use general assumptions on, among other things, the volumetric efficiency and compression ratio of the engine. Such parameters are different for each engine model and influence the exhaust flow. Another potential cause for such deviations is the MAP measurement. The measured vehicles have an engine with one or two cylinders. Such engines have continuous

manifold pressure variations, even when the engine speed is constant. For passenger cars, which typically have four or more cylinders, the MAP values or more constant due to the continuous flow towards the cylinders. The lack of constant pressures makes the measurement and processing more complex. Moreover, not for all vehicles it is possible to correctly connect the MAP sensor of the PEMS. The absence of a possibility to correctly connect the MAP sensor makes the installation more complex.

In order to know the exact cause of the deviations as shown in this study, more research is needed.

Conclusions of the correlation between PEMS and laboratory results
The correlation between PEMS and laboratory equipment measured volume emission concentrations is rather good, with r^2 values that are often higher than 0.9, except for HC. For HC, average deviations over the entire WMTC were found up to 50%. These deviations are most likely the result of different analyser types and the absence of heated lines.

The mass emission values show significantly more deviations for all emissions in comparison to the volume emission concentrations. The r^2 values of the correlation for individual gases are in the range of 0.75 to 0.95. The cause for these deviations in mass emission values is the result of the inaccuracy of the exhaust flow determination method based on engine speed, MAP and IAT. Moreover, not all L-category vehicles have a proper connection available for the MAP sensor of the PEMS which makes the installation more complex.

Currently there is no off-cycle legislation for L-category vehicles. It is to be expected that the accuracy for indirect exhaust flow measurement will further improve, or direct exhaust flow measurement for L-category vehicles will be developed, when off-cycle PEMS requirements are anticipated. Further improvement might come from (short) heated lines with low energy consumption and possibly an FID for HC measurements are desirable. However, the power consumption involved, will have an effect on the driving range and/or the weight of the PEMS system.

<u>Real-world trip versus WMTC</u>
In this paragraph the emission results of the developed Real-World cycles are compared with the WMTC emission results. The Real-World cycles were developed on the road. However, in order to exclude the accuracy of the PEMS from the comparison, the WMTC and the Real-World cycles were driven on the chassis dynamometer for this comparison. For the assessment of the emissions results, the emission analysers of the laboratory were used.

Figure 95 shows the comparison between emission results of the Real-World cycles and WMTC. This figure shows that a cycle which includes more comprehensive driving conditions than the WMTC, can influence the emission results firmly.
The CO_2 results of the Real-World cycles are somewhat higher than the WMTC, in particular for mopeds. As CO_2 emissions are a fairly good indicator for engine power, the higher CO_2 emissions indicate that these Real-World cycles require somewhat more engine power than the WMTC. In general, the CO emissions in the Real-World cycles are significantly higher than in the corresponding WMTC. In contrast to the CO emissions, the NOx and HC emissions do not show a coherent trend, as these emission values seems to be vehicle dependent.

Vehicle J10 shows excessive high CO emissions during the Real-World cycle. Most likely, these high emissions are mainly caused by the negative effects of the engine speed limiter. Because vehicle J10 is a low speed moped, and the Real-World cycle was developed with a high-speed moped, there is a significant share of wide open throttle driving during the Real-World cycle with vehicle J10. In the WMTC the target speed is followed, which is more or less 2 km/h lower than the wide open throttle speed of vehicle J10. The engine speed limiter can have a significant negative effect in this 2 km/h speed difference (Hensema et al., 2013). The negative effects of the applied speed limiters on mopeds are explained in more detail in section 8.2.
Vehicle J13 shows rather low emissions during the Real-World cycle. Vehicle J13 drove the Real-World cycle which was developed with vehicle J19. However, vehicle J13 falls into WMTC class 2-2 where J19 falls into WMTC class 1. Therefore, the applied Real-World cycle is rather mild for vehicle J13, which explains the rather low emissions.
As mentioned in the previous section, these developed trips are examples of Real-World driving for some specific categories and are not developed to be used as official test trips. Ideally, Real-World trip requirements for each WMTC-class or even per vehicle category are preferable. Extensive research is required for the development of such Real-World trip requirements.

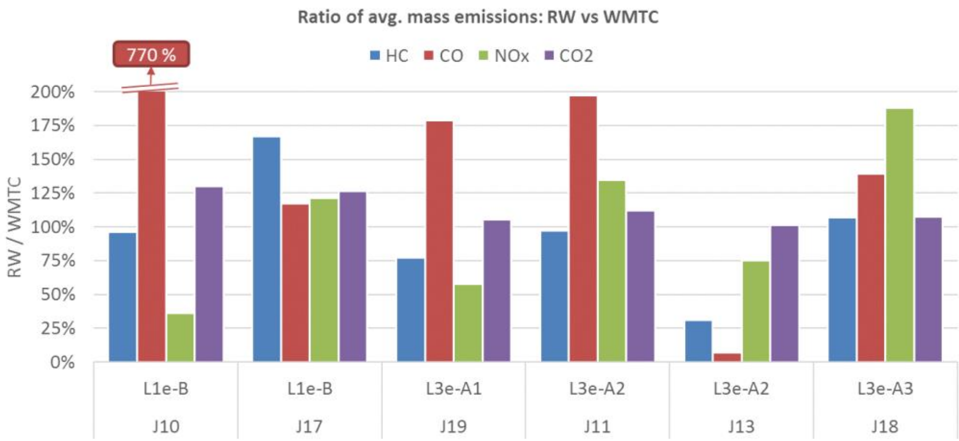


Figure 95: A comparison between average mass emission values of the Real-World cycles and WMTC's. The WMTC values are considered as 100%.

10.4 Discussion on the technical feasibility of OCE requirements

As described in the terms of reference of this study, Off-Cycle Emission (OCE) testing is meant to possibly complement the type I emission laboratory test cycle in the future. Measurements with a PEMS are considered to be the most suitable method for the determination of off-cycle emissions. The chance that vehicles are optimized for a defined emission laboratory test cycle and the risk of cycle beating significantly decrease when OCE requirements are introduced into the type approval process. In addition, by introducing such requirements, exhaust emissions of more comprehensive driving conditions than the WMTC can be assessed. This means a

test trip which covers a larger part of the engine load area, but also different ambient conditions, different road types etc.

In the previous paragraphs it was demonstrated that it is technically feasible to adopt a test procedure for OCE by using PEMS measurements. However, the accuracy of the determined mass emissions is not as high as for passenger cars measured with PEMS. The accuracy of more PEMS systems should be assessed and possible OCE requirements should take this into account. Possibly, the reliability is different for another PEMS, as in this study only one system was assessed. However, there are currently no technical requirements for the applied PEMS on L-category vehicles. In addition, no OCE requirements for L-category vehicles exist at all. When requirements are introduced, it is expected that PEMS manufacturers can develop systems that are tailored for L-category vehicles, which are compliant to accuracy requirements that are more stringent than the currently demonstrated state-of-the-art. Nevertheless, due to the small size and low weight of some L-category vehicles, it can still be challenging to develop a very accurate PEMS with a proper autonomy. For the larger, three- and four-wheeled L-category vehicles, accurate PEMS measurements can already be performed with the currently available PEMS systems for passenger cars.

An important part of the OCE requirements is the test protocol. In paragraph 10.3.3 the applied testing programme for this study is described. However, more research and discussions with stakeholders are needed to develop a suitable test protocol. For light-duty vehicles (LDV) such a test protocol already exists. Table 71 displays some of the important trip requirements per road-type for LDV's.

Table 71: Light-duty vehicle trip requirements for RDE legislation

	Urban	**Rural**	**Highway**
Velocity bin [km/h]	0-60	60-90	90-145
Distance [km]	>16	>16	>16
Distance share[%] (10% tolerance)	34	33	33

Next to Table 71, other trip requirements and test conditions apply for LDV's, such as:

- Maximum values for v*a positive per road type
- Minimum values for RPA (Relative Positive Acceleration) per road type
- Minimum amount of stop time in the urban part
- Maximum value for altitude gain
- Trip duration between 90 and 120 minutes
- Trip time frame: Mo – Fr 07.00 – 19.00 hrs
- Cold start not included
- Temperature between 0 and 30 °C

These above-mentioned test conditions and requirements influence the stringency of a real driving emissions test. For L-category vehicles similar requirements and conditions can be developed. However, due to the large variety in vehicle characteristics, some of these requirements are more complex to determine. In particular, the wide variety in maximum vehicle speed and power-to-mass ratio are important factors for the determination of test requirements. For example, the

maximum vehicle speed influences the road-types considered and the power-to-mass ratio should be taken into account for suitable RPA and v*a positive values.
The majority of requirements can be developed for the different WMTC classes. However, some specific requirements, e.g. requirements related to the power-to-mass ratio, will need to be determined per vehicle category, i.e., for L1e-B, L2e-, L3e-A1 etc.

In order to establish trip requirements, real-world operation data of L-category vehicles is required. Currently, the operation database for L-category vehicles is very limited and scattered around the world. By using GPS, the real-world operation of L-category vehicles can be monitored on a large scale.

Next to these test conditions and requirements, a data-evaluation method needs to be developed. Both for heavy-duty vehicles and light duty vehicles different data-evaluation methods are prescribed. These methods are able to exclude some test data. Hence, the data-evaluation methods also affects the stringency of the test procedure.

Finally, OCE requirements are accompanied with a certain conformity factor. A conformity factor means that the applicable emission limit may be exceeded by that factor. These conformity factors are very welcomed by the manufacturers in order to cope with the more severe and wide variation of possible testing conditions. Moreover, the conformity factor covers for the fact that mobile measurement devices are usually not as accurate as laboratory test equipment. A high conformity factor, on the other hand, negatively affects the stringency of OCE requirements.

10.5 Cost-benefit analysis

The four scenarios for the cost-benefit analysis (CBA) as outlined in the terms of reference of this study, refer to the need to introduce OCE requirements for some or all L-category vehicles, at different time frames.
A robust CBA requires sufficient information on both the costs as well as the benefits of an OCE procedure. As there are no detailed OCE requirements for L-category vehicles in the current situation, and Euro 5 is not yet implemented, there are quite some uncertainties regarding the involved variable in costs and benefits.

Based on the findings in this study, it was concluded that measurements with a PEMS are considered to be the most suitable method for the determination of off-cycle emissions. Hence, in the CBA, measurements with PEMS form the basis.

PEMS requirements are already implemented into emission legislation of light- and heavy-duty vehicles. However, for L-category vehicles the situation is different. In the following section important aspects of PEMS requirements which can affect the CBA for L-category vehicles are addressed.

<u>Most important aspects and uncertainties affecting the CBA of L-category vehicles</u>

Performance of Euro 4 and Euro 5 vehicles
As OCE is a measure which might be introduced after Euro 5, the performance of Euro 5 vehicles have an effect on the potential benefits. Thus, an estimate of the emission performance of Euro 5 vehicles is required to estimate the potential benefit.

However, the tested vehicles in this study range between Euro 2 and Euro 4 vehicles. Euro 4 vehicles just recently are reaching the market, Euro 5 vehicles are not yet available. The effectivity of measures that will become effective within Euro 5 and that are researched in this study, have an enormous effect of the overall emission performance of Euro 5 and the potential benefit that can be achieved with introduction of OCE requirements. Examples are the way Durability Requirements are revised according to the recommendations from this study and the implications of this study on OBD requirements. These uncertainties make robust determination of the benefits for the CBA, with Euro 5 as a baseline, impossible.

Trip requirements and test conditions
With OCE requirements, exhaust emissions of more comprehensive driving conditions than the WMTC can be assessed. Naturally, these more comprehensive driving conditions will have an effect on the vehicle's exhaust emissions, and thus on the benefits. More detailed operation data is needed to establish detailed requirements per vehicle class. The absence of these requirements make the CBA more complex, as trip requirements and test conditions influence both the costs as well as the benefits. The effect of more or less comprehensive driving conditions on the achievable benefits also interfere with the level of the baseline, as discussed in the previous section. So when Euro 5 measures are optimally implemented, most likely the powertrain is more robust for more comprehensive driving conditions as well, affecting the achievable benefits.

Conformity factor
OCE requirements are often accompanied with a certain conformity factor, as described in the previous paragraph. As the conformity factor affects the stringency of the OCE requirements, this also has an influence on the costs and benefits. This parameter could be incorporated in a CBA with a few scenarios, but that would require at least the baseline to be robustly determined.

Test equipment (availability and costs)
Due to absence of OCE requirements there are only a few PEMS systems available which are suitable for L-category vehicles. However, the accuracy of the determined emissions is not as high as for passenger cars measured with PEMS. When OCE requirements are introduced, it is expected that PEMS manufacturers can develop systems that are tailored for L-category vehicles, this might have an influence on the costs and the dimensions of the PEMS. Also for this parameter, scenarios could be incorporated in the CBA.

Qualitative CBA of OCE requirements
Based on the experiences with passenger cars and the findings in this study, a qualitative CBA is shortly described. However, performance of a robust quantitative CBA is not feasible on the four scenarios from the terms of reference of this study, as explained above.

Costs
Costs for OCE are the result of the additional test burden as well as the required additional technology development costs.

The development costs consist of research and testing effort to identify the technologies to be deployed, the calibration and validation of these technologies and the actual hardware costs, to ensure robust emission performance within the OCE

window. In order to comply with Euro 5, vehicles already are equipped with advanced anti-pollution systems. However, it is expected that a larger catalyst and recalibration are required when OCE requirements are introduced, to safeguard sufficient emission reduction at higher flowrates. It is expected that such additional technologies can be applied for a variety of models, or even for a variety of vehicle families. It is expected that the required technology is available.

The additional test burden mainly originates from the time needed to execute the PEMS tests. Based on the experience of the study team, at least two days per vehicle are needed to execute the actual PEMS programme during the type approval process. This includes the time for installation, calibration and commissioning of the equipment, performing actual test trip(s), data-evaluation and to demount the equipment. However, before the type approval is executed, the PEMS programme is performed a couple of times in order to check whether the vehicle is compliant, and if needed, to modify the calibration.

An addition, test equipment needs to be purchased and needs to be properly maintained. Based on the systems which are currently available on the market for L-category vehicles, the costs for purchasing a PEMS are estimated at approximately 100.000 euros.

Benefits
The emission test results presented in this chapter show that a cycle which includes more comprehensive driving conditions than the WMTC, can influence the emission results firmly. In this study, the effect of different ambient conditions, different road types etc. are not even considered. This might influence the emissions even more. Furthermore, the risk of optimisation of emission reduction technology on the WMTC speed/load map is firmly reduced when OCE requirements are introduced. Lastly, with the more stringent Euro 5 limits, the emission reduction achieved with anti-pollution technology becomes of greater importance. Anti-pollution devices that are less effective in real-world circumstances can easily cause relatively high emission excursion, which could be tackled with the introduction of OCE requirements. As explained before, the achievable benefits highly depend on the effectiveness of the measures within the Euro 5 package.

Next to wide variation in test conditions, an important share of the potential benefit of OCE requirements, is to prevent the risk of cycle beating. The need to avoid cycle beating with OCE alike requirements was recently confirmed for passenger cars.

Cautious qualitative conclusions
With the knowledge of today, it is expected that the benefits of OCE will be significant and will outweigh the additional costs. However, a robust CBA is recommended to be performed when a robust baseline can be determined, e.g. when Euro 5 vehicles enter the market.

10.6 Conclusions and recommendations

Conclusions:

- PEMS is considered to be the most suitable method for the determination of off-cycle emissions.

- The chance that vehicles are optimized towards a defined emission laboratory test cycle and the risk of cycle beating significantly decreases when OCE requirements are introduced into the type approval process.
- Measurements with PEMS are considered as technically feasible for future legislation. However, the assessed PEMS in this study does not reach the level of accuracy and applicability as the PEMS which is currently applied for light- and heavy-duty vehicles. This shall be taken into account when conformity factors of possible off-cycle requirements are defined.
- Further improvements of accuracy, related to the exhaust flow determination method and to the applied analyzers, are expected to be technically feasible and to be realized once off-cycle legislation for L-category vehicles would be introduced. The effect of these expected improvements on accuracy shall be investigated and reflected in the conformity factors of possible future off-cycle requirements.
- Nevertheless, due to the small size and low weight of some L-category vehicles, it can be challenging to develop a very accurate PEMS with acceptable autonomy. For the larger, three- and four-wheeled L-category vehicles, accurate PEMS measurements are already technically feasible.
- Representative Real-World driving, which in some occasions includes more comprehensive driving conditions than the WMTC, can influence the emission results firmly.
- Due to the large variety in vehicle characteristics, the determination of trip requirements and test conditions is complex. The majority of requirements can be developed for the different WMTC classes. However, some specific requirements need to be determined per vehicle category, i.e., for L1e-B, L2e-, L3e-A1 etc.
- It is expected that the benefits of OCE will be significant and will outweigh the additional costs.

Recommendations:

- A CBA is recommended to be performed when a robust baseline can be determined, e.g. when Euro 5 vehicles enter the market. This shall provide definitive evidence that OCE requirements are a viable measure to safeguard low emissions of L-category vehicles during everyday operation.
- Develop a detailed test protocol for OCE requirements that are tailored to the Euro 5 baseline, as soon as emission data of Euro 5 vehicles becomes available. These requirements shall include at minimum:
    - Trip requirements and test conditions per WMTC class, possibly even per vehicle category.
    - Technical requirements for the PEMS. This will enable PEMS manufacturers to develop a system which is compliant to these requirements.
    - Data evaluation requirements and a conformity factor
- Real-world operation data of L-category vehicles is required to establish justified trip requirements. Currently, the operation database for L-category vehicles is very limited and scattered. It is recommended to start the collection of real world operation data of L-category vehicles, for example with GPS.

11 In-service conformity and verification testing

11.1 Background and objective

Background

Regulation 168/2013 requires an environmental study that should, inter alia, assess technical feasibility and cost-effectiveness of in-service conformity (ISC) verification testing. The purpose of ISC verification is to test in-use vehicles on the chassis dynamometer to check whether the vehicles are compliant to their corresponding emission standards. ISC is the responsibility of the vehicle manufacturer.

ISC requirements have a certain overlap with the conformity of production (COP) and the durability requirements. With the COP procedure it is periodically checked whether new vehicles coming directly from the production line and of the same specification as described in the type approval certificate are compliant to the corresponding emission standards. The durability procedure is meant to ensure that the vehicle complies to the emission standards over the useful life.

The Commission's impact assessment - EC (COM(2010) 542 final) - in the preparation of the adoption of Regulation (EU) No 168/2013, took stock on options related to ISC testing. In 2009 it was concluded that "owing to the many disadvantages, including impracticability and only moderate cost-effectiveness, ISC had to be discarded". At the same time it was indicated that this topic would be re-examined in the light of this Euro 5 effects study.

Objective

Assessment of the technical feasibility, cost-benefit ratio ranges and cost-effectiveness of in-service conformity – also referred to as in-use compliance verification testing.

11.2 Specific tasks

The first specific task was to develop a test protocol to simulate an in-service conformity verification process. The simulation of the ISC verification process enabled the identification of potential issues and the assessment differences with the requirement for passenger cars.

After having selected a limited number of vehicles on the basis of market share and usage pattern, in-use and properly maintained vehicles of the selected models were located and made available for testing. For statistical significance, the protocol is applied to three vehicles of the same model. Table 72 shows the composition of the test fleet that was subject of this study.

Table 72: Desired test fleet

Category/sub-category	***Number and type of vehicles to be tested***
L1e-B	1 low speed mopeds / scooters (≤ 25 kph (3 individual vehicles) 2 high speed mopeds / scooters (≤ 45 kph) (3 individual vehicles)
L3e-A1/L3e-A2/L3e-A3	1 L3e-A1 type motorcycle (3 individual vehicles) 1 L3e-A2 type motorcycle (3 individual vehicles) 1 L3e-A3 type motorcycle (3 individual vehicles)

The second specific task was to assess the cost-benefit ratio ranges and cost-effectiveness of in-service conformity .Based on the results obtained and theoretical considerations, the contractor assessed the additional cost for manufacturers. Both the additional testing burden and the technologies to be deployed were assessed. Furthermore, the potential benefit resulting from the in-service conformity checking was investigated. Based on the aforementioned information, a cost-benefit analysis was performed.

11.3 Technical feasibility of an ISC requirement for L-category vehicles

11.3.1 development of a test protocol

Passenger cars already have ISC requirements. These requirements are described in the UN-ECE R83 (UNECE, 2011). ISC needs to be performed per vehicle family. The basic elements of the protocol for passenger cars are directly transferable to L-category vehicles with some adaptations. Table 73 summarizes the most important elements of the test protocol for ISC checking. The column in the middle summarizes the existing criteria for passenger cars. The column on the right gives draft proposals for L-category vehicles.

Table 73: Most important elements for the ISC check

Criteria		**Passenger cars (R83)**	**Proposal for L-category vehicles**
Vehicle selection criteria	*Minimum period in service*	For at least 15,000 km or 6 months, whichever is the later	*For at least 10% of the useful life mileage or 6 months, whichever is the later*
	Maximum period in service	No more than 100,000 km or 5 years, whichever is the sooner.	*No more than 65% of the useful life mileage or 5 years, whichever is the sooner.*
	Maintenance and condition	Proper maintenance record available and no indications of abuse	Proper maintenance record available and no indications of abuse or tampering
	Anti-pollution system	Anti-pollution system is in conformity with the applicable type approval	Anti-pollution system is in conformity with the applicable type approval
Diagnosis and maintenance	*General engine checks + checks for mal-adjustments and/or tampering*	Multiple components and various checks	Multiple components and various checks
	OBD system	Check for proper functioning	Check for proper functioning, *when OBD is present*
In-service testing	*Physical test*	Preconditioning + Type I test on the chassis dynamometer	Preconditioning + Type I test on the chassis dynamometer
	OBD	Check of malfunction indications related to levels of emissions	Check of malfunction indications related to levels of emissions, *when OBD is present*
	Sample	Minimum sample size of three vehicles	Minimum sample size of three vehicles
Evaluation of results	*Evaluation procedure*	Statistical procedure	Statistical procedure
	Deterioration factors	No deterioration factors applied	No deterioration factors applied
Remedial measures	*Outlying emitters*	TAA request the manufacturer to submit a plan of remedial measures to remedy the non-compliance.	TAA request the manufacturer to submit a plan of remedial measures to remedy the non-compliance.

11.3.2 Simulation of an ISC verification process

Based on the test protocol a testing programme for 18 vehicles was designed. Based on the European sales numbers, three models with high sale volumes for both mopeds and motorcycles were selected. Three vehicles per selected model have been located at various official dealerships. Unfortunately, it was not possible to locate three identical and properly maintained L3e-A1 vehicles and to make them available for testing, as these kind of vehicles are scarce in a large part of Europe. Some vehicles were located in Italy, however, it was impossible to make 3 vehicles of the same make and model available for testing. Therefore, the testing programme

consisted of 15 vehicles instead of 18 vehicles. The selected vehicles are presented in Table 3, and are also shown in table below for reference.

Table 74: Test fleet for ISC check

Vehicle model	Vehicle ID no.	category	category name	engine capacity class [cc]	rated power [kW]	engine combustion type*	# of cylinders	Maximum design speed [km/h]	Transmission	Euro class	Fuel delivery system	SAS	catalyst**	reference mass class [kg]	year	mileage [km]***
#1	J31	L1e-B	low speed moped	50	2	G-4S	1	25	CVT	Euro 2	carburettor	0	0	200	2012	6368
	J32	L1e-B	low speed moped	50	2	G-4S	1	25	CVT	Euro 2	carburettor	0	0	200	2015	5560
	J33	L1e-B	low speed moped	50	2	G-4S	1	25	CVT	Euro 2	carburettor	0	0	200	2015	5500
#2	J34	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	carburettor	0	0	160	2011	3751
	J35	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	carburettor	0	0	160	2007	8804
	J36	L1e-B	high speed moped	50	3	G-4S	1	45	CVT	Euro 2	carburettor	0	0	160	2015	1905
#3	J37	L1e-B	high speed moped	50	2	G-4S	1	45	CVT	Euro 2	carburettor	0	0	170	2011	7187
	J38	L1e-B	high speed moped	50	2	G-4S	1	45	CVT	Euro 2	carburettor	0	0	170	2008	8567
	J39	L1e-B	high speed moped	50	2	G-4S	1	45	CVT	Euro 2	carburettor	0	0	170	2015	614
#4	J40	L3e-A2	medium perf. motorcycle	330	25	G-4S	1	>150	CVT	Euro 3	injection	0	0	270	2013	7090
	J41	L3e-A2	medium perf. motorcycle	330	25	G-4S	1	>150	CVT	Euro 3	injection	0	0	270	2012	4657
	J42	L3e-A2	medium perf. motorcycle	330	25	G-4S	1	>150	CVT	Euro 3	injection	0	0	270	2012	10516
#5	J43	L3e-A3	high perf. motorcycle	690	55	G-4S	2	>150	Manual	Euro 3	injection	0	0	260	2016	13814
	J44	L3e-A3	high perf. motorcycle	690	55	G-4S	2	>150	Manual	Euro 3	injection	0	0	260	2015	15143
	J45	L3e-A3	high perf. motorcycle	690	55	G-4S	2	>150	Manual	Euro 3	injection	0	0	260	2014	24940

The gained experiences for each part of the draft test protocol are described below.

Vehicle selection criteria:

- The vehicles were located at dealerships of the corresponding vehicle brand. Most of the contacted dealerships were willing to participate for a reasonable rent per vehicle. Most of the vehicles were meant for sale, only two motorcycles were actual rental vehicles. Some larger dealerships were required in order to find three identical models which comply to the selection criteria. It may be a challenge to find enough representative vehicles for a vehicle family with a low sale volume. It is expected that, in the view of in-service conformity, manufacturer will have easier access to in-use vehicles via their dealer network, so that locating and selecting vehicles is possible.
- The useful life of the selected mopeds according to Regulation (EU) No 168/2013 is 11,000 km. Hence, the minimum mileage is 1,100 km and the maximum mileage is 7150 km, according to the draft test protocol. Many of the located vehicle had much higher mileages and were not selected for testing. This confirms that a reconsideration of the useful life values for mopeds, as recommended in 7.10, is justified. Still four mopeds within the programme are not compliant with the mileage criterion of the draft protocol, but mileages are always in range of +20% of the maximum allowed mileage, which for the purpose of demonstration within this study was considered to be acceptable. The maximum in-service time of 5 years is also exceeded by a number of the selected mopeds.
- The useful life of the selected motorcycles according to Regulation (EU) No 168/2013 is 35,000 km. Hence, according to the draft test protocol, the minimum mileage is 3500 km and the maximum mileage is 22,750 km. One motorcycle had a mileage of 24,940 km and is not compliant with this criterion.
- By using some vehicles that are not compliant with the 'in-service' criteria from the draft protocol, the effect of these criteria can be assessed.

Maintenance and condition

- The maintenance and condition of these vehicles are representative for real-world circumstances as the most of these vehicles are for sale at the dealerships. Moreover, the condition of these vehicles was checked at the dealerships before the vehicle was delivered to the test centre. However, some vehicles do not have a complete maintenance record since not all vehicles went for maintenance to the same workshop during their lifetime. For a formal ISC procedure, the complete maintenance record of the test vehicles shall always be available. A printout of the maintenance record of the dealership should suffice for this purpose.
- The original anti-pollution components, i.e. the exhaust system, of these vehicles were still present. Clearly, this is an important aspect, as tampering with the aim to increase the vehicle speed or power can have significant negative effects on the exhaust emissions (Hensema et al., 2013; Zardini et al., 2016b).
- Based on the discussions with multiple dealerships of mopeds, the study team strongly suspects that many new mopeds are adjusted by dealerships before the new moped is handed over to its first owner. The dealerships claim that they make this adjustment in order to deliver a vehicle to the client that meets the client expectations: a moped with a smooth running engine that starts and drives well under all conditions. This adjustment often involves replacement of the fuel nozzle by a larger one, this applies to vehicles with an engine with a carburettor. According to the dealers, the client expectations for drivability often cannot be met without the adjustments. However, this means that those vehicles are not compliant to the type approval specifications anymore, though they are representative for many vehicles in-use. Still, as a result, emissions of the vehicle that is delivered to the end-user may not comply to the emission requirements anymore. The COP requirements ensure that vehicles are compliant when they leave the factory. These adjustments are made after production and cannot be detected with the current set of type approval procedures. However, this phenomenon may result in a large number of in-use vehicles that are not compliant to the emission requirements during their full lifetime.
  It should be remarked that the used vehicles for this part of the study are not type approved under the anti-tampering provisions of Regulation (EU) No 168/2013 as these were all Euro 2 and 3 vehicles. Moreover, the size of the issue might be different with introduction of Euro 5 technology.
- This part of the experimental study was performed without assistance of the manufacturers, so the size of the fuel nozzle was not verified for the tested mopeds. Hence, it is not clear whether the selected vehicles are compliant to the type approved vehicle on this matter. However, as mentioned before, these vehicles are obtained at various official dealerships and therefore give a good overview of the real-world situation.
- The selected vehicles don't have OBD. Hence, no checks were applied on this matter.

In-service testing:

- The selected vehicles were tested on the chassis dynamometer. The selected vehicles are Euro 2 mopeds and Euro 3 motorcycles. The applicable Type I test cycle for those vehicles is not the same as the WMTC. However, in this study, the WMTC is used as a test cycle because the WMTC is the applicable Type I test cycle for Euro 5.
- The procedure for Type I testing as described in Annex II of Regulation (EU) No 134/2014 is used for these tests. Every vehicle drove a precondition cycle before the actual test. The preconditioned vehicles drove two WMTC's with a cold start.

According to the draft test protocol, one test is sufficient. However, by repeating the test, the repeatability of test cycle and the vehicle was checked.

- In total, 30 tests with 15 vehicles were performed within 8 days.
- The vehicles were able to follow the speed trace of the used WMTC.
- The minimum sample size of three vehicles per model was applied.

Evaluation of results

- The emission results are presented in the next section.
- Formally, if one or more vehicles are not compliant, extra vehicles need to be tested according to the draft ISC protocol. The purpose testing programme within this study was to demonstrate the technical feasibility and acquire information and insights with three vehicles of each selected model, and not to run a full formal ISC testing programme. Therefore, in this programme, the number of vehicles was kept limited to a set of three vehicles per selected vehicle model,

11.3.3 Emission results

In this paragraph the measurement results of the tested vehicles are discussed. As mentioned in the previous paragraph, the WMTC with a cold start was used as a test cycle. Per vehicle two emission tests were driven. The emission results are compared to the emissions limits of applicable emission classes of these vehicles, i.e. Euro 2 and Euro 3 emission limits. Because the WMTC is used as Type I test cycle rather than the applicable Type I test for these vehicles, the assessment of the emission levels is not representative for the formal compliance of the vehicles. However, the purpose of this study is to assess if an ISC procedure is feasible, not to check whether vehicles are compliant to their emission standards. On the other hand, these measurement results provide more insight into emissions of in-use vehicles, and can demonstrate the need for emission legislation for in-use vehicles.
Figure 96 and Figure 97 display the results of the ISC measurement results. The results are presented as conformity factors (CF) per emission constituent, as a function of the vehicle's mileage.

Moped results

Figure 96 show CF's between 1.5 to 25 for the CO emissions of mopeds. This means that the Euro 2 emission limit is exceeded up to 25 times. Again, it should be noted that the formal Type I test with which these vehicles should comply, was not driven. Instead the WMTC was driven. The HC + NOx emissions show conformity factors between approximately 0.4 and 1.2.

The CO emission performance varies significantly per vehicle model. Moreover, the CO emission performance can vary greatly as well between the three tested vehicles of one model. On the contrary, the HC + NOx emission performance per vehicle model does not show significant variations. Furthermore, the emission performance does not vary greatly between the three tested vehicles of one model.

In general, the repeatability of the performed tests per vehicle is relatively good. The vehicles with the highest emissions show the highest deviations between the two test results. The period these tested mopeds are in service, in general does not have a clear relation with the emission performance.

Moped results in more detail

Vehicles J31, J32 and J33 are of the same model and constantly show very high CO emissions. Vehicles J37, 38 and 39 are of the same vehicle model, however, the CO emission vary significantly per vehicle. Vehicle J39 has been in service for approximately 600 km. This vehicle clearly shows lower emissions than vehicle J37 and J38. On the other hand, with approximately 8500 km since 2008, vehicle J38 is in service for the longest period of these three vehicles, while vehicle J37 shows the highest CO emissions.

The vehicle model with the red markers in Figure 96 show relatively low CO emissions in comparison to the other two vehicle models. The total mileage and age of the vehicles do not have a large effect on the emission performance for this vehicle model.

The HC + NOx emission performance are in the same order of magnitude for most of the vehicles. Only vehicle J39, which has the lowest mileage, shows rather low emissions in comparison to the other vehicles.

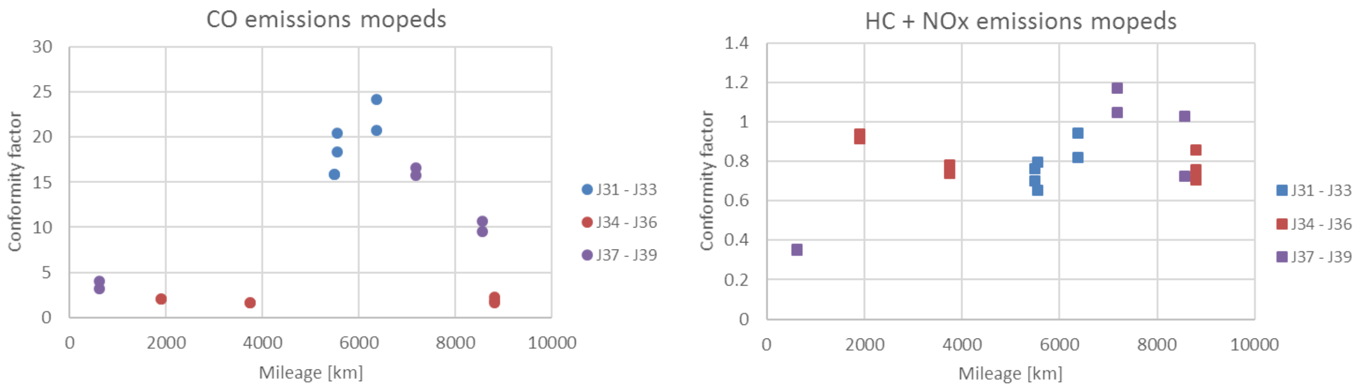


Figure 96: A comparison between emission results of the ISC testing programme and the Euro 2 emission limits as a function on the vehicle's mileage. The conformity factor is determined by dividing the emission results of the WMTC by the applicable Euro 2 emission limit. Each colour represents a vehicle model. Three vehicles are tested per model. Each vehicle drove two WMTC's. It should be noted that the formal Type I test with which these vehicles should comply, was not driven. This means that these figures do not represent formal ISC of the tested vehicles.

Motorcycles results

Figure 97 show CF's between approximately 0.2 and 1.4 for all emissions. In comparison to the CO emission results of mopeds this is rather low.

The emission performance per vehicle model shows quite some variations, in particular for CO and NO_x emissions. For one vehicle model, the emission performance shows some variations as well between the three tested vehicles, in particular for the CO and NO_x emissions. On the contrary, the emission performance of the three tested vehicles of the other vehicle model are rather constant. The repeatability of the performed tests per vehicle is relatively good.

In general, there is no clear relation between the period these tested motorcycles are in service and their emission performance.

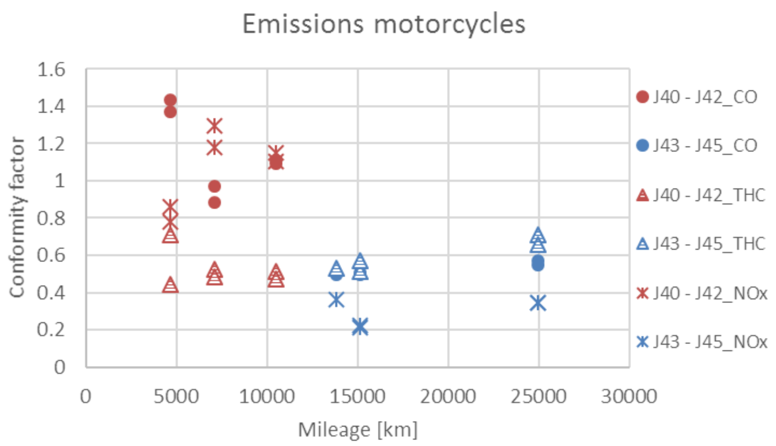


Figure 97: A comparison between emission results of the ISC testing programme and the Euro 3 emission limits as a function on the vehicle's mileage. The conformity factor is determined by dividing the emission results of the WMTC by the applicable Euro 3 emission limit. Each colour represents a vehicle model. Three vehicles are tested per model. Each vehicle drove two WMTC's. The different marker types represent the different emission constituent, i.e. CO, THC or NOx.

11.3.4 Conclusions on technical feasibility and test results

<u>General conclusions</u>

- The measurement results clearly show the need for emission legislation for in-use vehicles, certainly for mopeds, as some of the emission results are excessively high compared to their emission limits.
- It is strongly suspected by the study team that many new mopeds are adjusted by dealerships before delivery to the first owner. Often a larger fuel nozzle is applied, to, according to multiple dealerships, meet the client expectations with regard to drivability and cold start behaviour. As a result, emissions of the vehicle that is delivered to the end-user may not comply to the emission requirements anymore.
  It should be remarked that the used vehicles for this part of the study are not type approved under the anti-tampering provisions of Regulation (EU) No 168/2013 as these were all Euro 2 and 3 vehicles. Moreover, the size of the issue might be different with introduction of Euro 5 technology.
- The introduction of ISC requirements are proven to be technically feasible. However, the vehicle selection may pose some difficulties, as it is a challenge to find enough representative test vehicles for vehicle families with low sales volumes. It can be considered to limit this burden and to introduce ISC-verification testing in a different manner, where less vehicle families need testing. Such an alternative procedure is assessed in paragraph 11.4 where the cost-benefit analyses is discussed.

<u>Test protocol conclusions</u>

- The basic elements of the protocol for passenger cars are directly transferable to L-category vehicles with some adaptations. An important difference is the criterion which determines the minimum and maximum period that the vehicle

may be in service. For L-category vehicles this in service period should depend on the useful life value.

- It may be difficult to find mopeds which are compliant to the type approval specifications, as it is suspected by the study team that the dealerships often make changes to the fuel nozzle at mopeds with carburetted engines. These adjustments might also affect the catalyst health, so bringing the mopeds back to the original state for ISC verification purposes might bring misleading results. These adjustments are made after production and cannot be detected with the current set of type approval procedures. This phenomenon may result in a large number of in-use vehicles that are not compliant to the emission requirements during their full lifetime. However, it is expected that with the introduction of Euro 5 for mopeds, a large part of the mopeds will carry more complex technology (fuel injection systems). This may disable such adjustments and will reduce the need for such adjustments from the perspective of client expectations on drivability and cold start behaviour. Moreover, the anti-tampering provisions of Regulation (EU) No 168/2013 might prevent the possibilities for this kind of tampering.
- For some vehicle classes, it might be a challenge to find vehicles with a complete maintenance record.
- The aforementioned two points are most likely not relevant if the ISC-programme is performed under the guidance of the manufacturer.

<u>Measurement conclusions</u>

- In general, the repeatability of the performed tests per vehicle is relatively good. Depending on the emission constituent, the emission performance can vary significantly per vehicle model. Moreover, the emission performance can vary as well between the multiple tested vehicles per model. Hence, it is useful to test multiple vehicles per vehicle model but it is not per se necessary to perform multiple tests per vehicle.
- In general, there is no clear relationship between the emission performance and the period that vehicles are in service. The emissions are either high or low, once the vehicle has driven more than 10% of its defined useful life mileage. This confirms the issue that was also discussed in the evaluation of the mathematical method for evaluation of the durability requirements (section 7.7).
- The CO emissions of mopeds exceed the applicable Euro 2 limit up to 25 times. The vehicles are tested by using the WMTC, which is not the applicable Type I driving cycle for the tested vehicles. However, such excessive exceedances are cannot solely be the result of changing the driving cycle to the WMTC. It is not clear whether a part of the selected vehicles have modified fuel nozzles, which then might cause higher emissions. Hence, it not clear if these high emissions can be the related to the potentially made adjustments. The high emissions can also be the result of fast degraded anti-pollution devices, as there are no durability requirements for the tested vehicles yet, or a combination of these two issues. Alternatively, ineffective COP can also be a possible cause, which is less probable. It is important to introduce measures for in use vehicles in order to prevent such high emissions.
- The HC + NOx emissions of mopeds are in most cases compliant to the Euro 2 limits. However, other Euro 2 vehicles with a two-stroke engine which were tested in another task of this study showed significantly higher HC emissions. Most of these other mopeds were not provided by dealerships.
- The emissions of the tested motorcycles show emissions that are in general compliant or close to compliant to the Euro 3 limit.

11.4 Cost-benefit analysis

Six scenarios were formulated in total, to reflect the potential of ISC. The scenarios stem from three scenarios to calculate the environmental benefit and two scenarios to calculate the costs. These scenarios are elaborated in the following paragraphs.

11.4.1 Scenarios to calculate the environmental benefit

With regard to potential environmental benefits, the three scenarios examined were the following:

- No Euro 5 limits exceedances: In this case it is assumed that no vehicle model that is in service deviates from Euro 5 emission requirements. Evidently, ISC in this case would have zero environmental benefit.
- Some of the L-category vehicle models severely exceed Euro 5 limits. In this case it is assumed that type-approval and COP checks are not entirely effective to control emissions over the useful life, and that 10% of the in-service fleet exceeds limits. For Euro 5 vehicles in this scenario, the HC and PM emission factors are assumed to be 2 times higher than the limit, CO emissions are assumed to be 3 times higher, while NOx remains at the same level. ISC implementation in this case is considered to effectively eliminate this effect, ensuring that all in-use vehicles comply with the Euro 5 limits, resulting in a modest environmental benefit.
- Total failure of the Euro 5 limits: In this case it is assumed that the Euro 5 fails to control emissions over the useful life. In particular, this scenario considers that despite durability requirements, the real-world performance of vehicle degrades fast over time. Basically, the assumption in this scenario is that the emission impact is similar to the case where degradation based on the mathematical method with the application of fixed deterioration factors is considered. In reality this would mean that the durability provisions are not effective. Again, ISC is considered to effectively identify and remedy the problem, resulting in a high environmental benefit.

The relevant environmental benefits are presented in detail in Appendix **F**.

11.4.2 Scenarios to calculate the costs

In terms of implementation costs, the following two scenarios were examined:

- ISC-verification testing is applied to all vehicle models reaching the market. This scenario may pose technical difficulties, in the sense that a significant number of available and properly maintained in-use vehicles to conduct the ISC might not be readily available for every vehicle model. As discussed in the previous paragraph, this may indeed be a problem for specific vehicles which are produced in relatively small series. However, this technical difficulty is not taken into account in the cost estimate, as it is assumed that this will issue can be solved when ISC-testing is ran under responsibility of the manufacturer.
- ISC-verification testing applied to all high production volume models, representing 20% of the models on the market. And, of the remaining 80% of the models, 10% is checked on ISC by random sampling. Hence, in total 28% percent of the models is subject to ISC-verification testing. This appears as a more feasible approach, in the sense that less ‘small series vehicle models’ are tested. The manufacturer does not know in advance which

vehicle models will be checked on ISC. Hence, all necessary precautions will be made by the manufacturer to ensure that each vehicle model complies to the ISC-requirements. In other words, the environmental benefit of this scenario is assumed to be equal to the scenario where ISC-verification testing is applied to all vehicle models.

The ISC implementation costs originate from a marginal increase in testing and bureau costs. With regard to all vehicle categories, 15 vehicles per model are considered to be tested, with estimated cost per test equal to €650. Besides, the ISC setup, cost includes the cost of replacing the motorist's vehicle with another one, for 3 days, for each of the 15 vehicles, assuming a cost of €50 per day per vehicle. Further to testing, the transfer cost of the motorcycle to the testing facilities and reporting costs demand work of 25 man-hours, while the certification cost demand a work of 8 man-hours, with the mean European cost per man-hour estimated to be €25. The sum of the aforementioned costs is multiplied by the number of the corresponding models for each vehicle category.

The relevant costs are presented in detail in Appendix **E**.

No additional recall and repair costs are considered for ISC. Recent experiences with passenger cars have demonstrated that recall costs for emission control systems can be overly expensive. Hence the manufacturer should take measures to avoid such a possibility. But even in the case of a recall, the associated costs should be borne by the manufacturer and in principle should not constitute a societal cost.

11.4.3 CBA Results

The central estimate for the NPV is calculated considering the baseline fleet/activity scenario, while the range corresponds to uncertainty in the estimation of costs. Table 75 shows the cost benefit analysis for each scenario for each vehicle category segment.

Table 75. Results of the cost-benefit analysis over 2020-2040
for the different application scenarios for ISC-verification testing

Cost-benefit over 2020-2040 (Values in M€)	no Euro 5 exceedances in real world, ISC in all models	no Euro 5 exceedances in real world, ISC for 28% of the models	some Euro 5 models incompliant with Euro 5, ISC in all models	some Euro 5 models incompliant with Euro 5, ISC for 28% of the models	failure of Euro 5 limits, ISC in all models	failure of Euro 5 limits, ISC for 28% of the models
Mopeds	$-3.4^{+0.3}_{-0.4}$	$-1.0^{+0.1}_{-0.2}$	$3.4^{+2.3}_{-1.6}$	$5.9^{+2.0}_{-1.4}$	$36.0^{+10.9}_{-7.5}$	$38.4^{+10.7}_{-7.3}$
Motorcycles (including ATVs)	$-16.6^{+1.7}_{-1.7}$	$-4.6^{+0.5}_{-0.8}$	$27.0^{+7.7}_{-7.1}$	$38.9^{+6.6}_{-5.8}$	$242.0^{+37.8}_{-33.5}$	$254.0^{+36.6}_{-32.3}$
Mini-cars	$-1.0^{+0.1}_{-0.1}$	$-0.3^{+0.0}_{-0.0}$	$-0.5^{+0.2}_{-0.1}$	$0.2^{+0.1}_{-0.1}$	$0.3^{+0.2}_{-0.2}$	$1.0^{+0.1}_{-0.1}$

From the cost-benefit analysis it can be concluded that:

- Testing a limited share of vehicle models, rather than all models is most cost beneficial.

- When the Euro 5 measures are 100% effective in terms of securing the environmental performance of vehicles over their useful life, ISC requirements are not cost-beneficial due to zero environmental benefits.
- If the Euro 5 measures are not effective for 10% of the vehicles, ISC requirements are cost beneficial, up to a large benefit in monetary terms when Euro 5 measures completely fail in terms of securing the environmental performance of vehicles over their useful life.

11.5 Discussion

The measurement results clearly show the need to control emissions of in-use vehicles, as some of the emission results are excessively high. Mainly mopeds demonstrated excessively high emissions. These measurements are performed with Euro 2 mopeds where no durability requirements apply. However, in case durability and/or COP requirements are not fully effective at the Euro 5 stage, ISC implementation can be an effective measure to remedy this problem. This does not just apply to mopeds, but also for the other L-category vehicles that were outside the scope of the ISC measurements in this study, as the emission limits will be much more stringent for Euro 5 than in the current situation. With these more stringent limits, the condition of the anti-pollutant devices will become increasingly important. Ineffective anti-pollution devices can easily cause relatively high exceedances of the emission limits.

Within the ISC requirements for passenger cars, the manufacturer is responsible for the ISC of the type approved vehicle models. The manufacturer needs to submit ISC reports to the Type Approval Authority (TAA) for auditing. Only when the TAA disapproves the submitted report, the TAA shall start a formal in-service compliance surveillance programme on the suspected vehicle type. The TAA which granted the type approval of the concerning vehicle is then in charge of the audit.
However, when the ISC-programme is performed under full guidance of the manufacturer, there still is a potential risk that ‘prepared’ vehicles are used. Instead, representative in-use vehicles deployed in various real-world circumstances, should be randomly selected. Otherwise, the risk of having of non-compliant in-use vehicles is still present. Ideally, the ISC-verification testing is performed by the TAA independent from the vehicle manufacturer. As a compromise, TAAs could randomly perform a part of the ISC-verification testing to prevent the risk of having non-compliant vehicles on a precautionary basis.
Without cooperation of the manufacturer, it may be difficult to find a sufficient amount of vehicles with a proper maintenance record for the ISC-testing. Thus, the scenario where only a limited amount of vehicle models per manufacturer are taken into consideration, seems the most feasible.

By using representative in-use vehicles, any commonly applied adjustments at dealerships which can influence the exhaust emissions, are revealed as well. When vehicles are selected by the manufacturers this issue might not be tackled with the ISC requirements.
However, when tampering adjustments on mopeds to improve drivability and cold start behaviour still occur on a large scale after the introduction of Euro 5, the question will arise who takes responsibility for these adjustments. After all, it may be expected that a new vehicle has a proper drivability and cold start behaviour under all common circumstances. Still the questions is if the manufacturer can be held responsible for the cause of the adjustments made by the dealerships. On the other hand, it is the

dealership who performs the actual adjustments. Measures to avoid these situations should be considered and included in ISC-requirements when they are considered to be introduced beyond 2020.

When off-cycle emission (OCE) requirements are implemented as well, it can be considered to perform ISC testing by application of OCE test, rather than the applicable type I test. By combining these two test procedures, the real-world emission performance of in-use vehicles are thoroughly secured in the most representative way. However, a cost-benefit analysis on this combined scenario is required, but is outside the scope of this study.

11.6 Conclusions and recommendations

Conclusions

- The measurement results clearly show the need for emission legislation for in-use vehicles as some of the emission results are excessively high.
- The introduction of ISC requirements are proven to be technically feasible. However, the vehicle selection may pose some difficulties, as it is a challenge to find enough representative test vehicles for vehicle families with low sale volumes.
- In case durability and/or COP requirements are not fully effective at the Euro 5 stage, implementation of ISC-requirements can be an effective and cost-beneficial measure to secure proper emissions levels from in-use vehicles during their useful life. When the Euro 5 measures are fully effective, the implementation of ISC requirements are not cost beneficial.
- Implementation of ISC-requirements delivers the highest net benefit when 28% of the vehicle families are subjected to ISC verification testing. In this scenario, the 20% share of the families with highest sales volume on the market are selected for ISC verification testing, and, of the remaining 80% of the families, 10% is checked on ISC by random selection.

Recommendations

- Introduce ISC requirements beyond Euro 5 for 28% of the vehicle families, where 20% of the selection of families is based on representativeness in terms of sales and 8% of the families is randomly selected from the remaining families.
- In this manner, ISC-requirements form a proper safety-net for the case Euro 5 measures are not completely effective.
- A part of the ISC-verification testing should be performed under full responsibility of the TAA, including the selection of the vehicles. It should be secured that in-use vehicles are randomly selected from the vehicle fleet that is in-service, in order to prevent the potential risk that ‘prepared’ or ‘carefully selected’ vehicles are tested.
- When off-cycle emission (OCE) requirements are implemented as well, it can be considered to perform a cost-benefit analysis on the possibility to perform ISC testing by using the OCE test, rather than the applicable type I test. This will thoroughly secure real-world emission performance of in-use vehicles during their useful life.
- Measures to avoid ‘adjustment’ of emission related components of new vehicles by dealerships before they are delivered to their first owner, affecting the emission performance of the vehicles, are important. The effectivity of the anti-tampering measures according to Regulation (EU) No 168/2013 should be assessed, additional measures might be required in the future.

12 Expanding the PM limit scope and introduction of a PN limit

12.1 Background and objectives

Regulation (EU) No 168/2013 introduced a particulate matter (PM) limit of 4.5 mg/km for L-category vehicles in the Euro 5 step. This limit is only applicable for vehicles equipped with a direct injection (DI) positive ignition (PI) engine or a compression ignition (CI) engine. This legislation initiative follows upon relevant regulations in the case of passenger cars.

Passenger car regulations also request a particle number (PN) limit for the same combustion concepts. Regulation (EU) No 168/2013 has not included provisions for a PN limit. However, Recital (12) of this Regulation requests exploring whether a PN limit for certain (sub-)categories would be necessary.

In this study, PM and PN emissions data were collected from the sample of L-category vehicles tested in order to assess current PN and PM emission levels and consider whether it is necessary to expand the PM limit to all L-sub-categories and/or introduce a separate PN limit for some or all vehicle sub-categories.

Specifically, the study tries to address the cost-benefit ratio of the four alternative scenarios which are specified in the terms of reference of the current work:

1. No change, only PM limit for L-category vehicles equipped with a DI PI engine and CI engines laid down in Regulation (EU) No 168/2013 in the Euro 5 step (2020);
2. Postpone PM limits in the Euro 5 step (2020) laid down in Regulation (EU) No 168/2013. PM limits for all L-category vehicle types as of 2024;
3. Postpone PM limits in the Euro 5 step (2020) laid down in Regulation (EU) No 168/2013. PM and PN limits for all L-category vehicles as of 2028;
4. PM limits for all L-category vehicles as of 2024, PN limits only for most polluting sub categories (L1e, L3e-A1, L7e-A and L7e-B) as of 2028;

12.2 Experimental campaign

Figure 98 shows the experimental set-up employed to test the vehicles and the specific PN/PM sampling points. The vehicle exhaust gas enters the Constant Volume Sampling (CVS) dilution tunnel where a first dilution takes place and then a constant fraction of the diluted gas is sampled for determination of PM and PN levels at the other end of the tunnel. For the PM measurement, the procedure described in Regulation (EU) No 134/2014 was followed, *i.e.* the particulate sample was collected on a PTFE-coated glass-fiber filter and the PM was calculated by gravimetric determination of the filter loading.

There is no specific experimental procedure prescribed for PN determination from L-category vehicles. Thus the respective procedure from passenger cars was followed, which is based on the UN Regulation No 83. We are discussing the relevance of this in the following sections. Passenger cars Regulations request the determination of

emission rates of particles larger than 23 nm in size, following the so-called Particulate Measurement Programme (PMP) protocol. JRC VELA are amongst the most experienced laboratories in EU on PN measurement and the PMP requirements were precisely followed.

In this study, the target was also to determine the solid PN emissions including the size fraction from 10-23 nm. In addition, the total (both solid and volatile) PN levels were determined for particle sizes above 10 nm. The decision to include these PN fractions was largely based on evidence that suggests that a significant fraction of PN from two wheelers resides below 23 nm (Giechaskiel et al., 2015; 2017). Moreover, there are currently initiatives to extend the particle size coverage in the relevant EU regulations to below 23 nm.

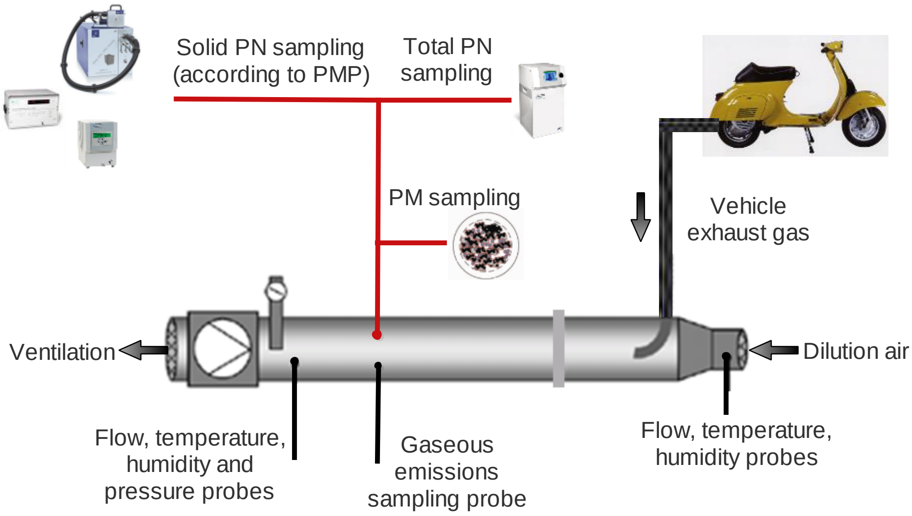


Figure 98: PM / PN sampling from CVS tunnel

The following list contains the instrumentation used for determining PN levels:

- AVL Particle Counter (APC 489). This device operates in accordance to the passenger cars legislation for the measurement of solid particles above 23 nm. After the sampling from the CVS, the exhaust gas is diluted again, then it is heated in an evaporation tube to eliminate the volatile particles and it is diluted again in a second dilutor. The particle number concentration is then measured with a Condensation Particle Counter (CPC).
- TSI CPC 3792 and 3010. These instruments have a cut-off size of 10 nm and were located downstream of the appropriate conditioning (Catalytic Stripper or sampling from APC) for the measurement of the solid PN emissions above 10 nm. The catalytic stripper (CS) used in this study is the one presented by Amanatidis et al. (2012).
- TSI EEPS 3090. This device was used in order to monitor both solid and volatile particles above 10 nm, together with their size distribution in real time. The (diluted) exhaust gas is sampled from the CVS, passes a second dilution stage and it is then measured by the EEPS. EEPS and CPC may differ in the absolute concentrations measured hence the particle number reported by EEPS is indicative and exact comparison with the CPC is to be avoided.

In this analysis, PM and PN measurement data from 24 in total L-category vehicles were collected. These vehicles were classified into 5 classes based on their sub-category and engine type as shown in Table 76, which also contains other basic characteristics of these vehicles.

All measurements are reported as measured, *i.e*. with no corrections introduced for losses. Such an approach will be the objective of a scientific publication on the matter. Giechaskiel et al. (2017) present how losses can be quantified for the different sampling and measurement systems used in this study.

Table 76: Specifications of vehicles tested for PM / PN analysis

Vehicle Class	Number	Sub-Category	Engine Type	Fuel delivery System	Euro Standard
Mopeds 2S	J02	L1e-B	G-2S	carburettor	Euro 2
	J04	L1e-B	G-2S	carburettor	Euro 2
	J05	L1e-A	G-2S	carburettor	Euro 1
	J06	L1e-B	G-2S	carburettor	Euro 2
	J07	L1e-B	G-2S	carburettor	Euro 2
	J14	L1e-B	G-2S	carburettor	Euro 2
	J27	L2e-U	G-2S	carburettor	Euro 2
Mopeds 4S	J03	L1e-B	G-4S	carburettor	Euro 2
	J10	L1e-B	G-4S	carburettor	Euro 2
	J12	L1e-B	G-4S	injection	Euro 2
	J17	L1e-B	G-4S	carburettor	Euro 2
Motorcycles	J11	L3e-A2	G-4S	injection	Euro 3
	J13	L3e-A2	G-4S	injection	Euro 4
	J15	L3e-A2	G-4S	injection	Euro 4
	J18	L3e-A3	G-4S	injection	Euro 4
	J19	L3e-A1	G-4S	carburettor	Euro 3
	J23	L3e-A1	G-4S	injection	Euro 3
	J24	L5e-A	G-4S	carburettor	Euro 2
Gasoline Mini cars and ATVs	J08	L7e-B1	G-4S	injection	Euro 2
	J09	L7e-B2	G-4S	injection	Euro 2
	J16	L7e-B1	G-4S	injection	Euro 2
	J25	L7e-B1	G-4S	injection	Euro 2
Diesel Mini cars and ATVs	J01	L6e-BP	D-4S	injection	Euro 2
	J22	L6e-BU	D-4S	injection	Euro 2

It should be noted that no vehicle of those tested fall into the direct injection (DI) positive ignition (PI) category. Hence, the only class of that list for which PM type approval would be relevant at a Euro 4 step are the “Diesel mini-cars” *i.e.* L6e vehicles.

12.3 Results of experimental campaign

All the graphs used in this analysis present the average emissions of all the cycles and vehicles for each class. The PM/PN emissions for each cycle is calculated as the weighted average of the emissions of each sub-cycle as follows:

Table 77: Weighted average factors for the calculation of PM / PN cycle-average emission levels - WMTC

WMTC			
	Weighting factors		
Vehicle sub-category	Phase 1	Phase 2	Phase 3
L1e, L2e, L3e-A1, L5e-A, L6e	0.5	0.5	-
L3e-A2/A3	0.25	0.5	0.25
L5e-B, L7e-B	0.3	0.7	-

Table 78: Weighted average factors for the calculation of PM / PN cycle-average emission levels – ECE R47 or ECE R40

ECE		
	Weighting factors	
Vehicle sub-category	Phase 1	Phase 2
All	0.3	0.7

The error bars in the graphs following show the standard deviation of the different vehicles. The values of the y-axis of the diagrams is presented in logarithmic scale due to the large differences on emission levels between vehicles falling in the different categories.

<u>PM results</u>

As mentioned before, Regulation (EU) No 168/2013 specified a PM limit of 4.5 mg/km for the DI PI and CI engines at a Euro 5 step. In the following analysis, this limit is taken as a reference for all engines types. Thus, the PM emissions (cycle average) of all vehicles in each class are compared with this (theoretical) limit in order to assess whether there is a need to introduce a respective limit to all vehicles sub-categories.

Based on these summary graphs, the following observations can be made:

- The PM emissions of the 4-S mopeds, the motorcycles and the gasoline mini-cars and ATVs are within the respective limit in both WMTC and ECE cycles. None of these vehicles is equipped with a DI engine and the majority of them are Euro 2 and Euro 3 vehicles and only 3 motorcycles belong to the Euro 4 emission standard. Hence, in principle, these are not covered by the PM limit proposed in Regulation (EU) 168/2013. This shows that even older technology 4-S gasoline vehicles already comply with Euro 5 PM limits. This was largely expected, given the fact that positive ignition port fuel injection combustion is known not to produce high PM emission levels.

- PM emissions of the 2-S mopeds are much higher than the proposed Euro 5 limit, despite these vehicles are not DI but equipped with a carburetor. This is consistent to earlier results, e.g. (Adam et al., 2010; Zardini et al., 2014)
- Diesel vehicles by far exceed emission limits with levels that are close to those of Euro 3 passenger cars, *i.e.* similar to their engine technology.
- No specific trend is observed with regard to ECE and WMTC results. In general, a vehicle complying with the limit over the ECE will also comply over the WMTC and vice-versa.

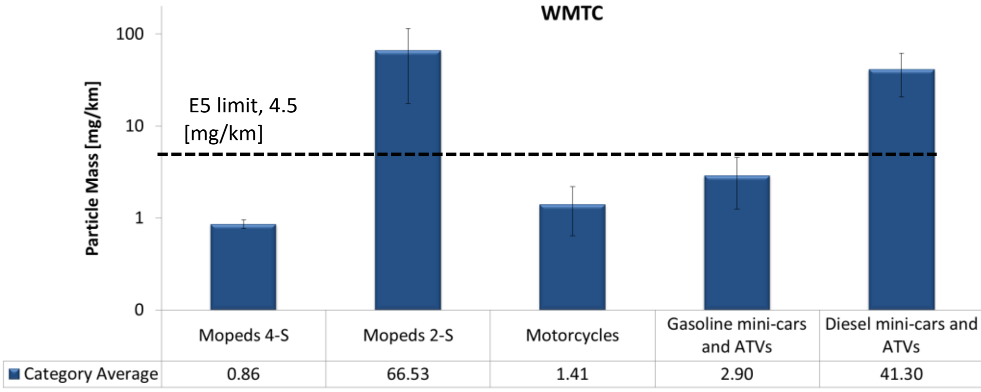


Figure 99: Average PM emissions for each vehicle sub-category - WMTC.

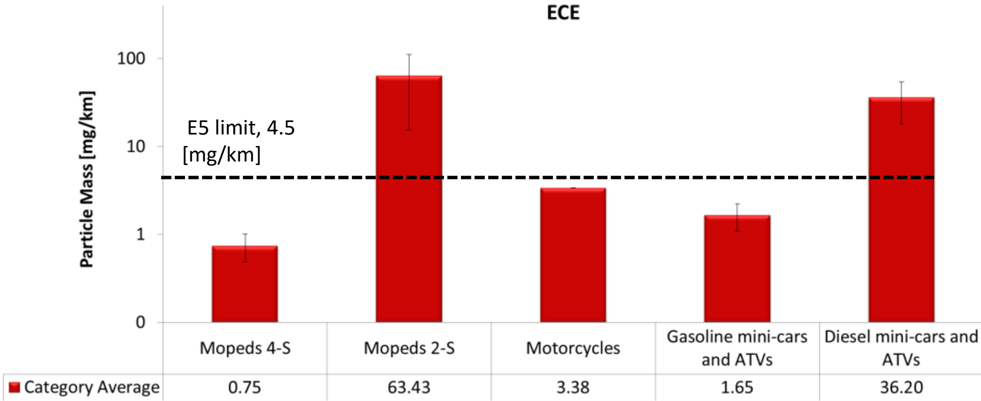


Figure 100: Average PM emissions for each vehicle sub-category – ECE cycles.

Solid particles

In the case of PN emissions, as already mentioned, there is no legislation limit for L-category vehicles, so the respective limit applied on Euro 6 passenger cars is used as a reference (in the diagrams this is referred to as PC E6 limit). Figure 101 and Figure 102 show the average PN emission levels per vehicle class, distinguished over the WMTC and ECE cycles, respectively.

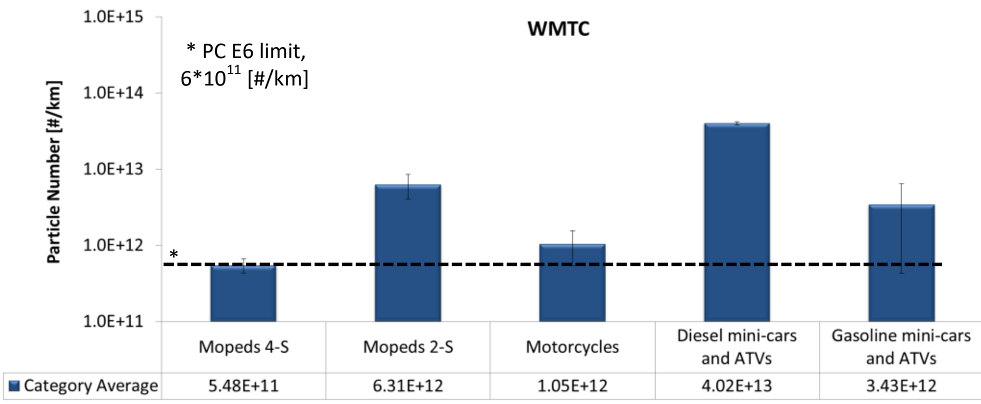


Figure 101: Average solid PN emissions with a cut-off size of 23 nm for each vehicle sub-category – WMTC

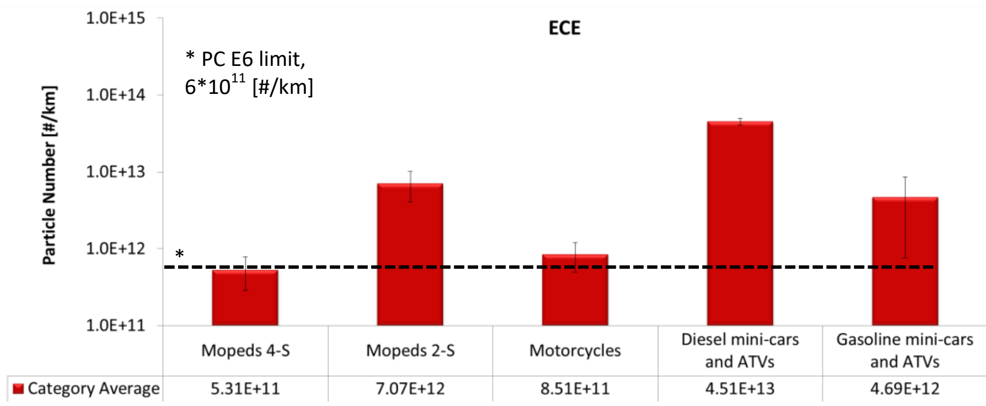


Figure 102: Average solid PN emissions with a cut-off size of 23 nm for each vehicle sub-category – ECE cycles

Mopeds 4-S and motorcycles are at or slightly below the passenger car emission limit while all other categories exceed the limit by far. The latter refers to both diesel and gasoline ones. Figure 103 and Figure 104 show PN but of solid particles larger than 10 nm. In this case, emissions are even higher than when using the 23 nm size cut, as one would expect, but the trends are similar between different vehicle classes, regardless of the cut-point.

Without taking losses into account, the ratio of $PN_{>10\ nm}/PN_{>23\ nm}$ ranges from practically one in the case of motorcycles and diesel vehicles to almost two in the case of Gasoline mini-cars. Assuming approximately 50% additional losses for sub-23 nm particles according to Giechaskiel et al. (2017) for sampling downstream of the APC/CS, these ratios become 1.04 for diesel vehicles, 1.12 for motorcycles, 1.9-2.1 for mopeds and 2.9 for gasoline four-wheelers. These ratios show that a substantial fraction of solid particles resides below 23 m. This is further assessed in the following sections.

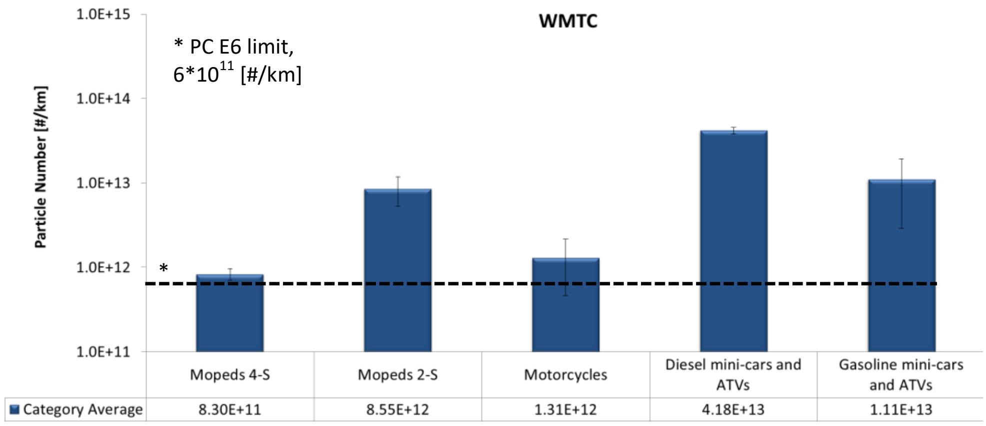


Figure 103: Average solid PN emissions with a cut-off size of 10 nm for each vehicle sub-category – WMTC

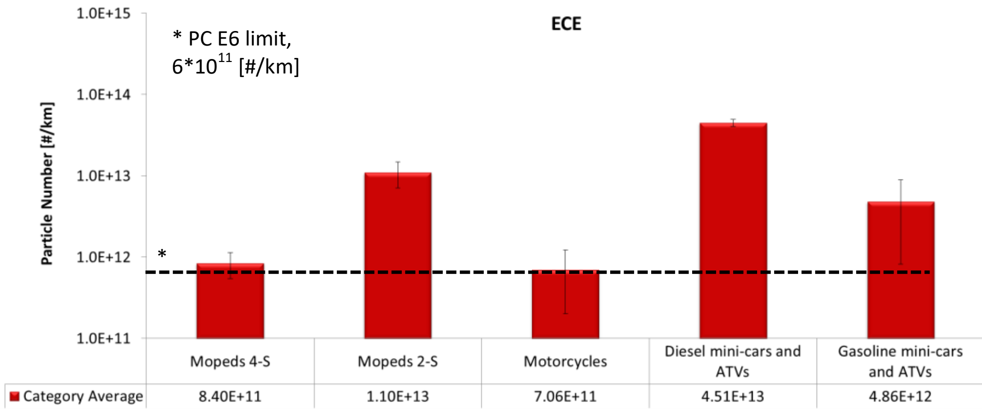


Figure 104: Average solid PN emissions with a cut-off size of 10 nm for each vehicle sub-category – ECE cycles

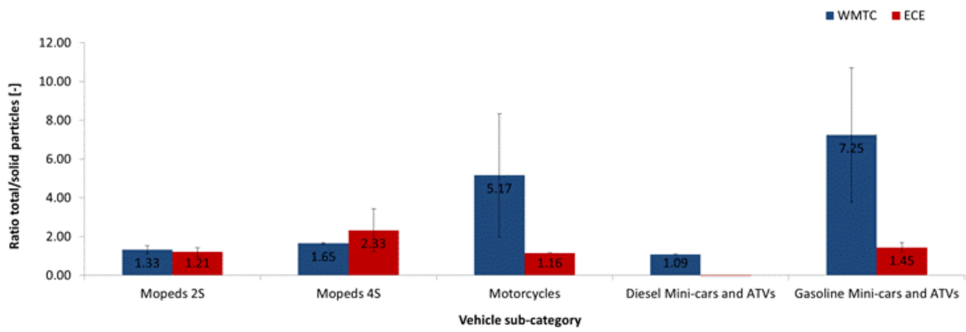


Figure 105: Ratio of total (solid and volatile) over solid particles

Finally, Figure 105 shows the ratio of total particles over solid ones (cut-off 10 nm) for the two cycles. Total particle concentration may be significantly higher than solid ones for all vehicle classes, which means that a significant number of particles is volatile or semi-volatile in nature.

Based on these findings, the following observations can be made:

- The PN emissions with a cut-off size of 23 nm of the 4-S mopeds are slightly below the respective limit from passenger cars. All relevant vehicles tested were compliant with Euro 2 emission standards. In the study of Giechaskiel et al. (2015), PN emissions of such vehicle types were found at levels above 10^{12} km^{-1}. It is reasonable to assume that solid PN emission levels may depend on engine tuning and overall vehicle condition, hence differences in the order of 40-50% in emission levels between individual vehicles seem reasonable.
- In the case of 2-S mopeds, the PN emission levels (both in 23 nm and 10 nm cut-off) are much higher than the passenger car limit, confirming earlier findings (Ntziachristos et al., 2003; Giechaskiel et al., 2015).
- With regard to the motorcycles, their average PN emissions are higher than the limit for passenger cars, in contrast with the PM levels which are below the respective limit. This sub-class consisted of Euro 3 and Euro 4 vehicles. Interestingly, two out of the three Euro 4 vehicles measured exceeded the PN passenger car emission limits. The levels measured for motorcycles are similar to the ones reported by (Giechaskiel et al., 2015), for both cut-points used.
- As expected, the PN emissions of the diesel vehicles are much higher than the limit for passenger cars, which is consistent to the observation made for PM emissions of these vehicles as well.
- The PN emissions (in contrast with the PM emissions) of the gasoline mini-cars and ATVs are roughly one order of magnitude higher than the passenger car emission limit and a significant number resides in the size range below 23 nm.
- The difference in emission levels between WMTC and ECE cycles is not straightforward. Depending on the vehicle class, either the one or the other driving cycle results to a higher emission level.

12.4 Cost-benefit of different options

PM Related Scenarios

The four scenarios outlined in the terms of reference of this study refer to the need to introduce PM and PN limits for some or all L-category vehicles, at different time frames. Moreover, Recital (12) of Regulation (EU) 168/2013 requests to assess whether a PN limit is necessary for some L-sub-categories. We first need to provide some technical details before detailing the specific scenarios.

The first conclusion relates to the relevance of the PM limit at 4.5 mg/km. Our results showed that all vehicles except 2-S mopeds and diesel ones already emitted below the passenger car limit. This was observed despite those vehicles complied with earlier standards than Euro 5, ranging from Euro 2 to Euro 4. This was largely expected, as port fuel injection (PFI) positive ignition combustion does not, in general, lead to high PM emissions.

Homogenous combustion, as PFI engines aim at implementing, in general leads to zero particle formation. Hence, particles in PFI combustion L-category vehicles may only originate from two different mechanisms. The first is incomplete combustion of lubricant oil and ash particles from lubricant oil. In general, lube oil consumption in L-category vehicles is higher than in passenger cars, due to the much higher operation speed and hence the increased lubrication needs to fight friction in these engines. The second mechanism is incomplete combustion of fuel, either due to lack of time at the very high speeds some motorcycle engines operate or because of enrichment in transient operation. Therefore, particles in the exhaust of L-category vehicles originate from incomplete combustion of lube oil and fuel. These two mechanisms are also responsible for the generally much higher HC emissions of motorcycles than passenger cars. As a result, PM, PN and HC seem largely linked in the case of L-category vehicles. This is a conclusion that has been reached already from previous steps of L-category regulations (Rijkeboer et al., 2005), and continues to be confirmed with the most recent findings.

The question that arises is therefore, is a PM limit necessary for all L-subcategory vehicles, or is this a haphazard regulation as Rijkeboer et al. (2005) concluded? Euro 5 vehicles will have to comply with more stringent THC and NMHC limits which means optimized combustion and lower overall lubricant oil consumption. This is the main reason that 2-stroke engines will not make it to Euro 5, unless at very high cost. Hence, when Euro 2 already comply with PM limits, there is no reason to expect that PFI Euro 5 ones would be incompliant.

The PM emission limit is therefore only relevant for the following vehicle types:

- 2-stroke vehicles of port fuel or direct injection concepts: 2-stroke vehicles exhibit high PM (and HC) emissions because of the lube oil which is directly injected in the combustion chamber and because of high scavenging losses. Both carburetor and direct injection vehicles have appeared with 2-stroke engines. As earlier explained, we do not find this combustion concept as being viable to make it to Euro 5 step. This is mostly due to the NMHC limit and the increased cost and complexity of developing an efficient aftertreatment system for this concept. Despite this, upcoming Regulations may extend the PM limit to specifically cover 2-stroke engine concepts, regardless of whether this will be viable or not at Euro 5.
- Diesel vehicles: Section 3.4 also presented that diesel L-category vehicles will not be viable in the long run and recommends to delay the introduction to Euro 5 for new propulsion concepts to be developed. Hence, the recommendation in this case would be to also delay introduction of the PM limit for these vehicles.
- Direct Injection vehicles: No 4-S direct injection vehicles are currently known to exist in the market. DI for gasoline vehicles has become popular for passenger cars due to the better fuel efficiency it offers, compared to port-fuel injection. This also drives CO_2 emissions lower. In the case of motorcycles, no efficiency or GHG targets have been set yet, hence no driving force to introduce DI currently exists. Still, a PM limit in that case is already proposed to be introduced in 2020 and seems relevant and technically feasible.

Based on these considerations, Scenario #1, which is introduction of PM limit in 2020 as foreseen by Regulation (EU) 168/2013 is a *de facto* cost-beneficial. Scenario #1

should only consider the extra lead time given for L6e vehicles and extension of PM limit to specifically cover 2-stroke vehicles, as well.

Based on this suggestion, further examination of scenario #2 seems not necessary, as there is no reason to delay PM limit or to extend it to additional vehicle sub-categories. It is repeated that PM regulation is a cross-category issue which is satisfactorily covered if CI, PI-DI and 2-S combustion concepts are included in this.

PN Related Scenarios

Scenarios #3 and #4, further to PM, also involve the introduction of PN in the emissions regulations. We need to make two separate points of discussions here, one for concepts covered by PM regulations (CI, PI-DI and also include 2-S as earlier proposed) and one discussion point for combustion concepts not covered by PM regulations.

With regard to PM-limited concepts, our assessment is that all of them could potentially meet the PM limit without PM specific aftertreatment (diesel particle filter – DPF or gasoline particle filter – GPF). However, the development costs to make this happen would be very high, especially for the relatively small series considered in the L-vehicles sector. In principle, the only relevant technology that could potentially appear in high volumes in the future is the PI DI concept, if CO_2 limits for these vehicles become mandatory. However, no PI DI 4-S engines exist today. Therefore, for the foreseeable future we see no environmental or cost impact of introducing PN limits for these vehicle types, as no such vehicles exist. PN limits could be introduced as a precautionary principle to make sure that, if such vehicles ever appear in the future, they would be equipped with the latest emission control technology. However, in the absence of any such vehicles on the market and no motivation to introduce them, we believe that a full cost-benefit analysis is not possible.

Therefore, most of the discussion on the introduction of PN limits should be focused to the other concepts, not covered and not proposed to be covered by PM limits. Our results showed that in several cases, tested vehicles equipped with gasoline PFI engines exceeded currently enforced PN limits for passenger cars, even if they were below PM levels of 4.5 mg/km. This means that a PN limit may be relevant for such vehicles. It should be reminded that PN limits for such vehicle technologies do not exist in the case of passenger cars.

The only PN limits introduced for PI cars are the ones related to DI vehicles. This was because there were specific PN formation mechanisms in such a concept that differed from formation mechanisms of other pollutants. In DI combustion, particles are mostly due to incomplete fuel combustion even at normal operation speed and stoichiometric mixtures. In earlier PI DI concepts, fuel would impinge the cylinder walls or the piston head thus leading to coking and heavy soot formation. The same could occur at the injector sac, exposed in high cylinder combustion (CARB, 2017). In most recent systems, PM is formed due to incomplete evaporation in fuel-rich pockets or by injector tip phenomena. These mechanisms have the potential to form high numbers of particles of small size without significant impact to other pollutants and without significant contribution to PM mass. Hence, in this case, a separate PN limit was deemed necessary as no other limit could be used as a proxy to decrease these particles.

In the current case, several of the tested vehicles exceeded the passenger car limit of 6×10^{11} km^{-1} with a particle size cut-off point of 23 nm. This was particularly the case for gasoline ATVs, which fall into the Euro 2 category. Moped 4-S Euro 2, with smaller engines, did not exceed the limit while motorcycles were found 70% above the limit. Those appear as reasons to regulate a separate PN limit.

However, these vehicles were of rather old technology (Euro 2 and Euro 3), complying with high HC emission limits. The average $NMHC_{WMTC}$ level of the L7e vehicles tested in this study was 243 mg/km, that provided a big margin for lube oil consumption. At a Euro 5 step, this will have to drop to 68 mg/km, i.e. some 4 times lower. Applying this ratio to the $PN_{>23nm}$ emission levels of L7e vehicles brings them $9 \times 10^{11} km^{-1}$, i.e. close to the passenger car limit. This is the same with Euro 4 L3e vehicles tested, with $NMHC_{WMTC}$ emissions of approximately 120 mg/km that need to go down to 68 mg/km. This would again bring their emission level down to within the passenger car limit.

The fact that a large fraction of the solid particles of these vehicles originates from lube oil is confirmed by looking at the significant number of solid particles below 23 nm. It has been shown in several studies (Karjalainen et al., 2014; Pirjola et al., 2015; Karjalainen et al., 2016) that such small particles originate from ash in the lube oil and form a so-called ‘core mode’ on which semi-volatile material condenses and particles gradually grow in size. The large number of these particles in L-category vehicles is evidently associated with the high lube consumption of these vehicles.

These particles substantially differ from carbon soot particles produced by PI DI vehicles. Mamakos et al. (2013) assessed the cost-effectiveness of introducing GPFs in PI DI cars by assuming that the particle numbers removed consisted of black carbon. In the case of L-category vehicles, it is not known how much this is the case.

We therefore would expect that controlling PN emissions from PFI vehicles can be to a large extent achieved by addressing lube oil consumption and, partially, lube-oil quality. Lube-oil consumption will have to be reduced to achieve the reduced NMHC limits at Euro 5. Therefore, it is not clear whether a separate PN limit for such vehicles will be any more effective, after the implicit more rigorous control of lube oil consumption introduced with Euro 5.

The discussion in assessing the effectiveness of a PN limit becomes more complicated if one assumes that the PN limit for passenger cars will be extended in the future to cover particle sizes below 23 nm, as is currently being discussed at the UN WP 29 PMP informal group (UNECE, 2017). If particles below 23 nm are included in the regulations, then both the quantity and the quality of lube oil will have to be addressed. Such small particles are derived from Ca, P, Zn, Mg, etc. ash material, which is part of lube oil additives. The concentration of these additives will have to be reduced to meet the regulations, such as in so-called low SAPS (sulphated ash, phosphorus and Sulphur) lube oils. Implicitly, this will also have a positive impact on the durability of emission control devices and avoiding OTL exceedances, as these components are known for long to be poisonous to three way catalysts (e.g. Wilkins and Hannington, 1990).

One might argue that introducing a limit is a good precautionary principle to eliminate the risk of high PN emissions from L-category vehicles. This is not straightforward for three main reasons:

1. It is not entirely sure whether the measurement protocol for sampling non-volatile PN from passenger cars is fully applicable to L-category vehicles. Giechaskiel et al. (2017) identified artifacts still existing after the sampling system for 2-S vehicle sampling. Unless the occurrence of artifacts is clearly identified and relevant changes to the protocol are introduced, introduction of a particle number limit is not possible. Although such technologies are not expected in Euro 5, still a specific discussion on the suitability of the sampling protocol needs to be initiated.
2. PN limits are under discussion in the EU and PMP informal group is now mandated to examine the possibility to sample particles below 23 nm in the medium future. Assessing today the cost-benefit of new PN limits to be introduced in 2028 under such versatile conditions is not possible, in particular given the relatively high particle number of L-category vehicles below 23 nm.
3. Our assessment is that improvement of lube oil and reduction of its consumption may bring PN levels within current emission limits for passenger cars. If this is not the case and if gasoline particle filters (GPFs) are required for L-category vehicles, one will have to assess the technical feasibility of such an approach, especially considering space limitations, high temperature operation and backpressure at high flowrates for GPFs. There is no evidence today on the feasibility of such a configuration.

Therefore, in order to assess the need and the cost-benefit of PN limits for PFI Euro 5 L-category vehicles, one will have to:

1. Monitor emissions of Euro 4 and Euro 5 vehicles, as they become available and see whether particle numbers in both the >23 nm and <23 nm ranges drop with the decrease in NMHC levels.
2. Study whether better quality (low SAPS) lube oil results to lower PN from L-category vehicles and, is positive results are obtained, mandate the use of such oil. It is repeated this will also assist in higher lifetime of three way catalysts and decrease the probability of OTL exceedances due to malfunctioning catalysts.
3. Better understand sampling artifacts, if any, with latest technology L-category vehicles, especially for PN<23 nm.

12.5 Conclusions

The experimental results collected and the subsequent analysis led to the following conclusions related to the regulation of PM and PN emissions from L-category vehicles:

1. PM limits introduced by Regulation (EU) 168/2013 for PI DI and diesel vehicles are de facto cost-beneficial. Such vehicles are not expected in high numbers at Euro 5 step and if new designs appear they will need to respect PM limits.
2. It is recommended to provide some lead time for introduction of PM limits for L6e-B (diesel mini-cars), together with gaseous pollutants proposed in Type I test, to allow for the development of new powertrain concepts.

3. It is recommended to introduce PM limits for 2-S vehicles as well, despite these may be infrequent or not at all able to make it to Euro 5 step.
4. Introducing specific PN limits for any L-category vehicles first requires better understanding of the emissions performance of such vehicles, as new emission control technologies at Euro 5 step become available. In this direction, improvements or confirmation of the PN measuring protocol is first required, especially following current discussions on extending PN size limits, before establishing a number-based limit value.
5. It is not possible to assess the cost-benefit ratio of introducing PN emission limits for PFI vehicles, using equivalencies to passenger cars. PN emissions from L-category vehicles are mostly linked to lube oil consumption and upcoming stringent NMHC limits at Euro 5 may be proven effective to control PN emissions from such vehicles as well, without the need of mandating a separate PN standard.
6. Monitoring and experimental campaigns in assessing whether and to what extent PN emissions from L-category vehicles drop with increasing stringency of NMHC emission standards need to be put in place. In particular, the impact of using low SAPS lube oil on particle emissions (with focus to those below 23 nm) are necessary to better understand the potential of PN reduction by lube oil reformulation.

13 Conclusions and Recommendations

Based on the experimental work and the subsequent analysis conducted in the framework of this study, a number of conclusions and recommendations can be drawn regarding L-category vehicle regulation at Euro 5 step and beyond

Type I – Tailpipe emissions test after cold start

The suitability of revised WMTC for Type I test

Based on the tests executed and the analysis of the results, the revised WMTC:

- was executed with no violations by all L-vehicle types tested, allowing for the flexibility in speed pattern deviations prescribed in Regulation (EU) No 134/2014, Annex II;
- offered extended coverage of the engine operation range in all sub-categories, compared to the corresponding ECE cycles it substitutes. This means that revised WMTC offers more confidence for effective emission control over real-world operation as well;
- did not lead to statistically significant differences in emission variance over multiple repetitions of execution, compared to the corresponding ECE cycles.

On the basis of these conclusions, the revised WMTC appears suitable to be used as a Type I test for all L-category sub-categories and is expected to provide enhanced environmental protection over real-world operation, than the driving cycles it substitutes.

The study also made specific observations for particular vehicle sub-categories:

- The speed of vehicles falling into categories L1e-A, L2e and a vehicle falling under L5e-A, but with a powertrain representative of L5e-B vehicles, exhibited deviations from the revised WMTC demanded speed pattern, both in terms of demanded acceleration and maximum speed. Future revision of the driving cycle would allow for improved test execution and enhanced reproducibility both for emissions (Type I) and energy efficiency (Type VII) testing.
- Measurement campaigns will need to be initiated in order to collect real life operation data for specific vehicle sub-categories (in particular L2e, L5e-B and L7e-B) and assess the representativity of the revised WMTC.

Appropriateness of the Euro 5 limits

Euro 5 for mopeds (L1e-B, L2e, L6e-A) and motorcycles (L3e, L4e, L5e-A, L7e-A) is technically feasible to be implemented within the 2020/21 (new/all types) time horizon. The emission control technology required to comply with the new limits will have to be significantly improved over Euro 4, especially for mopeds, but such improvements only require incremental technical advancements, rather than new engineering breakthroughs.

Despite technology cost increases, large environmental benefits lead to an overall significant net benefit in monetary terms, which may collectively exceed 330 M€, over the period considered. Moreover, mopeds and motorcycles at Euro 5 step will be amongst the cleanest conventional vehicles on the road, under urban conditions. This eliminates the risk of any city-specific measures that could potentially limit the accessibility of such vehicles to city centres.

ATVs and side-by-side vehicles (L7e-B) are expected to follow technology improvements led by motorcycles, with which they share powertrain technology.

Marginally higher costs are expected for L7e-B vehicles compared to L3e because of the different calibration of these vehicles over WMTC.

Different weighting factors for the cold/hot part of WMTC for mopeds (L1e, L2e, L6e) and motorcycles (L3e, L4e, L5e-A, L7e-A) with speed less than 130 km/h are introduced with Euro 5 (50/50) over Euro 4 (30/70). This means that more weighting is given to the cold start part with Euro 5, thus increasing environmental benefits but also corresponding implementation costs for compliance. Overall, net benefits were estimated for both sets of weighting factors, with the relative differences in the two scenarios being within the range of calculation uncertainty.

A detailed analysis for the mini-cars sub-categories (L6e-B, L7e-C) was conducted. In particular L6e-B vehicles are currently powered by small diesel engines or electric powertrains. Positive ignition engines do not provide enough power for this sub-category due to engine capacity limits (50 cc) compared to the relatively high vehicle mass. Euro 5 limits introduce a significant challenge for such diesel engines. It is not clear whether available emission control technology can deliver the necessary NO_x and PM reductions for such small engines. Even if this would be proven feasible, this would come at a high cost that the CBA showed to exceed environmental benefits. The following scenarios were therefore examined as possible options:

- Retaining the original time frame for Euro 5 introduction (2020/21 – new/all types). Our estimate is that this will only be achieved by electric vehicles. Offering a single powertrain option may initially reduce the market of such vehicles, especially as the consumers acceptance of the available electric vehicles in this sub-category is still rather conservative. A strong market distortion may prove detrimental for the specific industry, which is largely based on SMEs. Furthermore, if diesels could be still technically feasible, this option would lead to negative overall costs (damage) to the society.
- The second option would be to provide some more lead time, *i.e.* one model year and introduce Euro 5 at the 2024/2025 time frame. This is expected to provide some margin for the possible introduction of alternative powertrains (*e.g.* petrol-electric), continue with the development of charging infrastructure in cities, and benefit from the expected drop in automotive battery costs due to increasing global production. The CBA estimated potential net benefits in the order of 230 M€, due to decreased technology costs and significant environmental performance when introducing electric vehicles. This means that marginal environmental impacts caused by the delay in introducing Euro 5 for these vehicles are totally counterbalanced by the introduction of clean vehicles in the post 2023 period.
- The third option would be to remove the need for a Euro 5 step for these vehicles and remain with Euro 4 even beyond 2024. Our assessment is that this will not be a viable option in the long term as diesel mini-cars will constitute the highest-emitting on road vehicle type in the market with evident consequences in their accessibility in city environmental zones.
- Finally, the fourth option would be to increase the engine capacity of positive ignition engines for L6e-B vehicles to a value that would be enough to guarantee sufficient vehicle drivability. Although this is expected to fulfil the environmental targets of Euro 5, vehicle classification and safety issues, following potential engine tampering, need to be considered. The assessment of those goes beyond the objectives of our study.

Based on this analysis, the following recommendations can be made:

- Euro 5 emission limits of CO, NMHC, THC and NOx appear technically feasible for introduction in 2020/21 (new/all types) and will lead to overall net monetary benefits.

- A lead time of four years (2024/25) is recommended for introducing Euro 5 limits in the case of L6e vehicles, to allow new powertrain concepts to be developed for compliance with the new limits.

The change of cold/hot weighting factors from 30/70 to 50/50 for some sub-categories (L1e-B, L2e, and L3e-A1) from the Euro 4 to Euro 5 step is neutral in terms of its cost-benefit impacts.

Conclusions on the feasibility and cost-benefit ratio of the separate NMHC limit

Compliance with a separate non-methane hydrocarbons (NMHC), in parallel to the THC one, is required at a Euro 5 step for all L-category vehicles. Due to the rather small contribution of methane in THC emissions from petrol and diesel powertrains, an equivalent THC could be defined so that vehicles complying with this, would not have to demonstrate compliance with NMHC as well. Our study estimated that the equivalent THC would be at 0.078 g/km. This would have no environmental impact over the separate NMHC and THC limits and small savings would be gained by reducing emissions analysers investments from manufacturers.

The recommendation is made that separate THC and NMHC limits, as foreseen in Regulation (EU) 168/2013 are retained, as these are still required for any natural gas L-category vehicles as well as because they offer the possibility to separate report air pollutants and greenhouse gases emissions levels.

Conclusions on the impact on exhaust emissions of the ethanol content in the fuel

Based on this analysis, the following conclusions can be drawn:

i. No consistent impact of E0, E5 and E10 blends on exhaust emissions of any pollutant can be seen in tests on vehicle technologies ranging from Euro 2 to Euro 4. We do not see technical reasons for consistent differences at Euro 5 level.

ii. Emission impacts are vehicle specific so same emission levels can be reached by properly tuning the vehicle, once the EtOH blend of the reference fuel is known. Fuel flow rate will have to be adjusted to meet the same power demands as fuel energy content drops with increasing ethanol content of the fuel.

Type II – Tailpipe emissions at (increased) idle and free acceleration

The test was in general easy to perform. The description for setting the different engine rotation speeds during the test, as described in the procedure in Annex III, Regulation (EU) No 134/2014 can easily be misinterpreted by test engineers. The study made specific technical recommendations on how the description of the test can be improved.

As a general observation, this study would recommend inclusion of NO_x emissions recording in the Type II test for diesel and gasoline vehicles as well. NO_x is important from an environmental perspective and portable NO_x analysers are today cost-effective. Developing a reference list of NO_x levels during Type II type approval testing could potentially very much increase the roadworthiness test impact, if a decision is later taken to include NO_x for identifying high emitters.

Type III – Emissions of crankcase gases

The study demonstrates that the basic method and the additional test method No 1 are equivalent tests. It is recommended to have these two methods as alternatives to apply at the choice of the manufacturer. And to retain alternative additional test method No 2 as a complementary test. The complementary test shall be mandatory when the vehicle fails in the basic test or additional test method No 1, or can be specifically requested by the TAA, in case of concerns.

The combination of the TAA evidence-based assessment and the prescribed Type III test procedures, guarantees that crankcase gas emissions are thoroughly assessed during the type approval.

The test procedure proposed may be further improved and tailored to L-category vehicles by implementing the following recommendations:

i. include ‘considerably deviating engine lay-out and engine displacement’ in the definition of when physical testing is required, in addition to evidence-based assessment;
ii. in the basic test method, assess the average pressure in every test condition, or apply a moving average window larger than 10 seconds, instead of the assessment of the instantaneous pressure. The current method is prone to errors of commission (no pass despite no crankcase gas loss). Changing the data assessment method allows pressure pulsations in the crankcase that are typical for L-category engines, and ensures that L-category vehicles with effective crankcase gas control, pass the test;
iii. with respect to the additional test method No 1, more explicitly describe the pass-fail criteria of the test and to make this test method engine-capacity dependent. The study made specific recommendations to implement this:
    - no visible inflation is allowed at the end of each measurement condition (5 minutes);
    - balloon size is maximized to a factor 3 of the engine swept.

Type IV – Evaporative emissions

Based on the experimental tests and the modelling work conducted in this study the main findings were:

- Introduction of fuel system permeation testing for L1e, L2e, L5e-B, L6e-B, L7e-B and L7e-C is a technically feasible measure. Environmental benefits in this case by far exceed technology costs and this test is highly recommended to be introduced in the regulations.
- Introduction of SHED testing for L1e, L2e, L5e-B, L6e-B, L7e-B and L7e-C vehicles is not environmentally effective as this mostly addresses short-term breathing emissions while most evaporation emissions from these vehicles come from longer-term permeation losses.
- Reducing the Euro 5 limit to 1 g/test for L3e, L4e, L5e-A and L7e-A makes little environmental difference as evaporation emissions of these vehicles mostly occur during longer parking events, which an 1-h long test does not address. A longer (12 to 24 hours) diurnal test would be more appropriate if one would decide to introduce more stringent evaporation emissions control.
- Ethanol blends increase permeation losses and faster degrade canister efficiency over neat petrol. Relative effects are similar for both E5 and E10. Change of the reference fuel to E10 over E5 does not need to be accompanied by adjustment to the permeation or SHE test limits
- Current type approval SHED procedure cannot reveal the long-term negative impacts of ethanol, neither the effectiveness of the purging strategy on evaporation emissions

Hence, the following recommendations can be made for upcoming Euro 5 regulations:

- The permeation test procedure should be mandated for the L1e, L2e, L5e-B, L6e-B, L7e-B and L7e-C sub-categories.
- The Euro 5 limit for the L3e, L4e, L5e-A, L6e-A and L7e-A categories should not be reduced.

The following recommendations can be made for future, more effective control of evaporative emissions:

- A longer diurnal test (e.g. 12-48 h) or different test order (soak then diurnal) could be considered for the SHED test procedure.
- Specific testing to reveal the canister efficiency after several cycles of real-world operation, together with reporting of the purging strategy during type-approval.
- In-service conformity check that would include evaporation testing as well.

Type V – Durability requirements

The experimental and modelling work conducted in the framework of this task led to the following conclusions:

i. Actual durability testing with mileage accumulation appears more effective in achieving durability of emission control systems, than the use of Deterioration Factors in the mathematical durability procedure.
ii. Complete phasing out the AMA cycle is not necessary. It exposes vehicles with a low or moderate maximum vehicle speed to operation conditions similar to the WMTC.
iii. Phasing out AMA for WMTC class 3 vehicles can be justified with the results of the technical assessment of this study.
iv. The SRC-LeCV will better reflect operation conditions that are observed in the WMTC after revision of the SRC-LeCV sub-classification as specified in *Table 79*.
v. When the two preceding conclusions are taken into account, both AMA and SRC-LeCV cycles are technically feasible to be executed and well reflect ageing conditions imposed by the WMTC.
vi. The application of the mathematical method according to Article 23(3c) of Regulation (EU) No 168/2013 does not effectively control emissions over the useful life of the vehicle. Phasing out the mathematical method appears cost-beneficial when AMA is phased out for WMTC class 3 vehicles and when the SRC-LeCV sub-classification is revised.
vii. Bench ageing is a low cost, well accepted, and reliable physical ageing alternative to distance accumulation cycles. Adoption of the bench ageing procedure could be considered to make the durability requirements for L-category vehicles more cost-effective. The application of the procedure on L-category vehicles shall be validated before this test method is introduced. Bench ageing leads to the highest overall benefit in monetary terms.
viii. In-service conformity testing is an alternative method to be considered to check emission control durability under real operation conditions.
ix. With respect to the partial mileage accumulation procedure, introduction of the additive exhaust emission deterioration factor calculation method, as an alternative to the current multiplication approach, leads to a more robust procedure without considerable counter effects.
x. With the exception of mopeds, the prescribed Useful Life values in Annex VII of Regulation (EU) No 168/2013 are considered appropriate for all

vehicle categories. The Useful Life value for mopeds quoted in the Regulation are significantly lower than the fleet activity data that are used in the CBA model which stem from a large number of sources. In case these Useful Life values are revised accordingly, physical ageing only remains cost beneficial for mopeds when bench ageing is introduced, otherwise type approval and development costs lead to a net societal damage in monetary terms.

Hence, the following recommendations are made:

i. phase out AMA by 2020 only for WMTC class 3 vehicles
ii. revise the SRC-LeCV sub-classification according to *Table 79*
iii. phase-out the mathematical method in 2020
iv. introduce the bench ageing procedure, after validation of the application of the procedure on L-category vehicles
v. revise the Useful Life value for mopeds, following a specific data collection survey
vi. introduce an additive exhaust emission deterioration factor calculation method in the partial mileage accumulation procedure

Table 79: Recommended revised SRC-LeCV sub-classification and proposal for harmonisation with the WMTC classification and introduction of a Net Power criterion for the WMTC classification

SRC-LeCV Cycle classification	WTMC classification	Vehicle maximum design speed (km/h)		Vehicle engine capacity (cm3)		Net Power (kW)
		Min.	Max.	Min.	Max.	
1	Class 1		< 100 km/h		< 150 cm3	< 14KW
2	Class 2-1	-≥ 100km/h	< 115km/h	-	< 150 cm3	≥ 14KW
		-	< 115km/h	≥ 150cm3	≤ 1500 cm3	≥ 14KW
2	Class 2-2	≥ 115km/h	< 130km/h	-	≤ 1500 cm3	≥ 14KW
3	Class 3-1	≥ 130km/h	< 140km/h	-	≤ 1500 cm3	≥ 14KW
4	Class 3-2	≥ 140 km/h	-	-	> 1500 cm3	≥ 14KW

Type VII – Energy efficiency tests and electric range

The work under this task has led to the following conclusions:

i. The Type VII test procedure was found to be adequate for determining CO_2 emissions, fuel consumption and electric range for conventional, electric and NOVC hybrid vehicles.
ii. For OVC hybrid vehicles, the value for D_{av}, i.e. the average distance between two battery recharges, has a large effect on the CO_2 emissions and fuel consumption established in the test. The value for D_{av}, should be investigated based on the average trip length, availability of charging facilities and charging behaviour. This can only be done when more hybrid electric L-category vehicles penetrate the market and more real-world data

becomes available. Currently, there is not enough real-world data available to assess the D_{av}.

iii. In general, speed limiters on mopeds cause an increased fuel consumption when driving at full throttle position. This is currently not covered in the type I test.

iv. Because there is no engine power criterion, and an electric engine has no displacement volume, electric vehicles with a maximum speed lower than 100 km/h are automatically classified as WMTC class 1, where a vehicle with a conventional powertrain and comparable performance might be classified as WMTC class 2-1.

Hence, the following recommendations are made:

i. retain the D_{av} for the time being. And for future improvement of the procedure investigate what values for D_{av} lead to CO_2 emissions and fuel consumption that reflect real-world conditions well, as soon as more hybrid electric L-category vehicles penetrate the market and more real-world data becomes available.

ii. include an instruction in the test procedure to secure that mopeds with a speed limiter are driven at their maximum speed and at full throttle operation during the maximum speed range of the cycle.

iii. introduce engine power as a WMTC sub-classification criterion, together with the harmonisation of the classification with SRC-LeCV, as proposed in *Table 79*.

Type VIII – OBD environmental tests

<u>OBD Stage II technical feasibility</u>
Critical components to enable OBD Stage II implementation include the catalyst ageing and misfire monitoring. Their technical feasibility was assessed in this study.

For some vehicles, predominantly scooters, signal distortion and space limitations issues for placing the downstream sensor that enables catalyst monitoring pose significant technical limitations. Required technical developments are not expected to be ready in the first round of Euro 5 implementation in 2020. As the vehicle models development period is usually 2-4 years, an equal lead time for introducing catalyst monitoring needs to be foreseen after first introduction of the Euro 5 standard.

With regard to misfire monitoring, this is considered as a necessary measure to control excess emissions and protect the catalyst from rapid thermal ageing. Technology to detect misfire is already available from passenger car applications, and at least two readily available techniques have been identified as being suitable for L-category vehicles as well. Due to the low inertia of L-category engines and their high speed, the misfire monitoring engine operation window needs to be properly adjusted to allow efficient monitoring functionality and at the same time eliminate false misfire detections.

The following recommendations are made to determine the misfire monitoring window:

a) Low speed limit: A speed of 2500 min^{-1} or nominal idle speed+1000 min^{-1}, whichever is lower;
b) High speed limit: A maximum speed of 8000 min^{-1} or 1000 min^{-1} greater than the highest engine speed occurring during a Type I Test cycle or maximum design engine speed minus 500 min^{-1}, whichever is lower;
c) A line joining the following engine operating points:
    - a point on the low speed limit defined in (a) with the engine intake vacuum at 3.3 kPa lower than the positive torque line, and

- a point on the high speed limit defined in (b) with the engine intake vacuum at 13.3 kPa lower than the positive torque.

The following recommendations are also made regarding the regulations, to more clearly specify the requirements for misfire detection:

- Regulation (EU) 44/2014 defines intake vacuum with the expression "manifold vacuum". We recommend to change this throughout the Regulation to read "intake vacuum", as several motorcycles have no manifolds.
- Intake pressure on a motorcycle engine may considerably vary during operation for a given speed and load operation. To reduce ambiguity in definition and potential exploitation of the exact vacuum level, we propose to define engine intake vacuum as the mean vacuum level at the engine intake at a given engine load and engine speed operating point.
- As several motorcycles may not use an actual sensor to measure intake pressure, a model value, aka a virtual sensor signal, may be used instead. This possibility can be made explicit in Regulation (EU) 44/2014 by adding the following clarification related to engine intake vacuum: "Engine intake vacuum corresponds to the mean vacuum level measured by an on board intake pressure sensor for a given engine load and engine speed operation point. In the absence of such a sensor, the average intake vacuum calculated by an appropriate model can be used, following demonstration of the equivalence of this model to the actual value and approval by the type approval authority".
- For vehicles equipped with Continuous Variable Transmission (CVT), transmission engagement is performed by a centrifugal clutch. Engagement may often take place at speeds higher than the low speed limit determined above. Similar to manual gearboxes, the manufacturer may decide to disable misfire monitoring under such events. This is already foreseen in point Annex XII, paragraph 3.2.2.1 of Regulation (EU) 44/2014. To explicitly include CVT gearboxes, we propose to extend the focus of this to include CVT by explicitly including "centrifugal clutch engagement" in the examples list.

<u>Enabling successful repair</u>

OBD Stage II introduces additionally functionalities that may enable enhanced repair capacity also to independent repair workshops. Most importantly, catalyst monitoring capability is important as catalyst malfunction can otherwise be possibly detected only by periodic environmental technical inspections (PTI), where these are mandatory. In case a vehicle fails the roadworthiness emission test, the existence or not of a relevant OBD-II trouble code may readily advice whether the reason of failure was the catalyst or not, respectively.

Misfire related trouble codes, together with trouble codes referring to other engine components can provide useful information on the source of a potential technical malfunction. However, reliable misfire diagnosis is necessary; as misfire is the result and not the reason of a malfunction, false misfire detections may lead to unnecessary and costly misguided troubleshooting with no real environmental benefit.

<u>OBD Stage II cost-benefit</u>

Due to the technical limitations identified, three alternative scenarios – on top of the baseline one - were executed to examine a cost-beneficial implementation of OBD Stage II:

i. OBD stage II introduction in 2020 as laid down in Regulation (EU) No 168/2013. This scenario is technically not feasible, but it has been simulated to examine the benchmark environmental benefit that would be achieved.

ii. OBD stage II introduction with OTL I with no catalyst monitoring in 2020 and OBD stage II with OTL II in 2024/25 for all malfunctions. This scenario allows some lead time to manufacturers to start enabling catalyst monitoring from 2024/25 (new/all types) on. In the period 2020-2023, OBD II is implemented for all other malfunctions, including misfire detection, assuming OTL I.

iii. OBD stage II introduction with OTL II with no catalyst monitoring in 2020 and OBD stage II in 2024/25 for all malfunctions. This scenario is similar to scenario ii, in terms of time periods applying OBD I and OBD II. However, in the period 2020-2023, OBD II is implemented with OTL II.

The scenarios executed showed that shifting the full implementation of OBD II with OTL II, including catalyst monitoring, to 2024/25 instead of the original 2020/21 time horizon can be proven both technically feasible and cost-beneficial. In order to make sure that net societal benefits are achieved, OBD II for all other malfunctions, including misfire detection, needs to be introduced from 2020/21 (new/all models). The OTL levels in the period 2020-2023 is of moderate importance. This is because malfunctions not related to catalyst performance and misfire lead to emissions increase that in any case exceeds OTL I. As a result, implementation of OBD II with OTL I in 2020-2023 (w/o catalyst monitoring) leads to the overall highest net benefit. OTL levels become critical when the catalyst monitoring is considered, in the post 2023 period.

The recommendation on OBD-II implementation would therefore be (dates applying to new types, one year later for existing types):

- 2020-2023: OBD II for all malfunctions with OTL I, excluding catalyst monitoring;
- 2024: Full implementation of OBD II with OTL II, including catalyst monitoring.

A further recommendation is that anti-tampering provisions for the downstream oxygen sensor are reviewed and, possibly further enhanced, and that guidance to personnel of periodic inspection test centres is given to reduce the possibility of catalyst monitoring system tampering.

Implementation of In Use Performance Ratios (IUPRs)

IUPRs make sure that OBD diagnosis occurs at frequent intervals in real world driving conditions. For effective IUPR and for reducing the probability of false malfunctions, a gradual implementation of IUPR is considered necessary. The following recommendations can be made to maximize the IUPR effectiveness:

i. Introduce IUPR functionalities with OBD-II in 2020/21 (new/all models) for demonstration to technical authorities, without the need to meet a minimum IUPR.

ii. Introduce a minimum IUPR of 0,1, as foreseen in Regulation (EU) 44/2014, in the 2024/25 (new/all types) time frame. This is in consideration of the 30 months required after first implementation to report results and time given to manufacturers to develop the next algorithmic version.

iii. Examine with a specific study the cost-benefit of introducing a more stringent minimum IUPR. Foresee in regulations that anonymized IUPR data can be made available for such a study.

OBD Stage II suitability for L-vehicle sub-categories

In the course of the analysis of this study, a number of items not initially foreseen were identified in terms of OBD Stage II applicability to individual sub-categories:

- OBD Stage II is expected to be also applying to L6e-A vehicles which are designed and built around moped specifications in rather small volumes. No OBD requirements are enforced for other moped categories. It is therefore

recommended to remove OBD Stage II (and even consider removing OBD Stage I) provisions from L6e-A vehicles.
- L4e vehicles are not included in OBD Stage II provisions, despite they have identical powertrains to the equivalent L3e motorcycles. Inclusion of this sub-category in OBD Stage II is therefore recommended.
- OBD Effectiveness for Enduro (L3e-AxE) and Trial (L3e-AxT) motorcycles in real terms is questionable due to overall low activity and short lifetime of these vehicles. As the relevant industry is dominated by SMEs with limited R&D expenditure, exclusion from OBD Stage II provisions for these vehicles is therefore advised not to significantly distort the market.

<u>OBD Stage II expansion to other UNECE regions</u>
Introduction of OBD-II in other UNECE regions has the potential to further increase the benefit over costs ratio of the calculations made for the EU. This is primarily due to cost compression by economies of scale and the decrease of model varieties for different parts of the world. The actual cost-benefit ratio needs to take into account users responsibility and environmental awareness to repair malfunctions in the different regions. In cases where this is expected low, enabling default modes or no-start of the vehicle after certain distance has been covered following a malfunction may be effective.

MEASURES BEYOND EURO 5

Assessment of off-cycle emission (OCE) requirement implementation beyond the Euro 5 step

The experimental results collected and the subsequent analysis led to the following conclusions related to the implementation of off-cycle requirements beyond the Euro 5 step:

i. PEMS is considered to be the most suitable method for controlling OCE
ii. OCE requirements are technically feasible. Further improvements of the accuracy of PEMS for application on L-category vehicles are expected, once OCE requirements become mandatory.
iii. Off-cycle emissions can substantially differ from WMTC emissions.
iv. Due to the large variety in vehicle characteristics, the determination of trip requirements and test conditions cannot be generalised for all vehicles within the L-category.
v. Because of many uncertainties on the effectivity of the Euro 5 measures, pending on how the recommendations from this study are transferred to adaptation of the Euro 5 measures, the baseline for robust CBA for OCE requirements is unstable. Therefore a robust CBA cannot be performed.
vi. However, it is expected that OCE requirements are a viable measure to safeguard low emissions of L-category vehicles during everyday operation. The expectation is that the benefits of OCE requirements will be significant and will outweigh the additional costs.

Based on these conclusions, the main recommendations are:

i. Retain the introduction of OCE requirements as a possible viable option to safeguard and control low emissions of L-category vehicles during everyday operation;
ii. Anticipate next steps to provide definitive evidence for OCE viability and to prepare for introduction of OCE requirements after 2020

The following accompanying recommendations are made for follow-up:

i. A robust CBA shall be performed when a robust baseline for the actual performance of Euro 5 vehicles can be determined.

ii. A detailed test protocol for OCE requirements shall be developed, tailored to the Euro 5 baseline. These requirements shall include at minimum:
   a. Trip requirements and test conditions, at minimum per WMTC class. For this purpose, collection of real world operation data of each individual L-category shall be initiated.
   b. Technical requirements for the PEMS.
   c. Data evaluation requirements that are specifically designed for L-category vehicles.
   d. The required level of the accompanying conformity factors shall be researched and determined.

Assessment of in-service conformity (ISC) emissions requirement implementation beyond the Euro 5 step

The experimental results collected and the subsequent analysis led to the following conclusions related to the implementation of in-service conformity requirements beyond the Euro 5 step:

i. There is a need for emission requirements for in-use vehicles, as some of the tested in-use properly maintained vehicles have excessively high emissions compared to their emission limits

ii. It is strongly suspected by the study team that many new mopeds are adjusted by dealerships before delivery to the first owner. Often a larger fuel nozzle is applied, to, according to multiple dealerships, meet the client expectations with regard to drivability and cold start behaviour. As a result, emissions of the vehicle that is delivered to the end-user may not comply to the emission requirements anymore. This large scale tampering cannot be detected with the current set of type approval procedures, and the questions is if the manufacturer can be held responsible for the adjustments made by the dealerships. It should be remarked that these vehicles are not type approved under the anti-tampering provisions of Regulation (EU) No 168/2013 as these were all Euro 2 and 3 vehicles. Moreover, the size of the issue might be different with introduction of Euro 5 technology.

iii. The introduction of ISC-requirements are proven to be technically feasible. During the study, a demonstration ISC programme was successfully performed with 5 vehicle models that are representative for sales in Europe. In total 15 in-use vehicles were located and tested according to the draft protocol within 8 days of testing.

iv. Implementation of ISC-requirements is an effective and cost-beneficial measure to safeguard proper emissions levels from in-use vehicles during their useful life.

v. Implementation of ISC-requirements delivers the highest net benefit when 28% of the vehicle families are subjected to ISC verification testing. In this scenario, the 20% share of the families with highest sales volume on the market are selected for ISC verification testing, and, of the remaining 80% of the families, 10% is checked on ISC by random selection.

vi. It shall be secured that in-use vehicles are randomly selected from the vehicle fleet that is in-service, in order to prevent the potential risk that 'prepared' or 'carefully selected' vehicles are tested.

Based on these conclusions, the main recommendation is to:

i. Introduce ISC requirements beyond Euro 5 for 28% of the vehicle families, where 20% of the selection of families is based on representativeness in terms of sales and 8% of the families is randomly selected from the remaining families.

The following accompanying recommendations are made:

i. A part of the ISC-verification testing should be performed under full responsibility of the TAA, including the selection of the vehicles.
ii. When off-cycle emission (OCE) requirements are implemented, it is recommended to perform a cost-benefit analysis on the possibility to perform ISC testing by using the OCE test. This will thoroughly secure real-world emission performance of in-use vehicles during their useful life.
iii. Measures to avoid ‘adjustment’ of emission related components of new vehicles by dealerships before they are delivered to their first owner, affecting the emission performance of the vehicles, are important. The effectivity of the anti-tampering measures according to Regulation (EU) No 168/2013 should be assessed, additional measures might be required in the future.

Assessment of the need to expand the PM limit scope to other vehicle categories than those already subject in the Euro 5 step and introduction of a PN limit

The experimental results collected and the subsequent analysis led to the following conclusions related to the regulation of PM and PN emissions from L-category vehicles:

1. PM limits introduced by Regulation (EU) 168/2013 for PI DI and diesel vehicles are de facto cost-beneficial. Such vehicles are not expected in high numbers at Euro 5 step and if new designs appear they will need to respect PM limits.
2. Introducing specific PN limits for any L-category vehicles first requires better understanding of the emissions performance of such vehicles, as new emission control technologies at Euro 5 step become available. In this direction, improvements or confirmation of the PN measuring protocol is first required, especially following current discussions on extending PN size limits, before establishing a number-based limit value.
3. It is not possible to assess the cost-benefit ratio of introducing PN emission limits for PFI vehicles, using equivalencies to passenger cars. PN emissions from L-category vehicles are mostly linked to lube oil consumption and upcoming stringent NMHC limits at Euro 5 may be proven effective to control PN emissions from such vehicles as well, without the need of mandating a separate PN standard.
4. Monitoring and experimental campaigns in assessing whether and to what extent PN emissions from L-category vehicles drop with increasing stringency of NMHC emission standards need to be put in place. In particular, the impact of using low SAPS lube oil on particle emissions (with focus to those below 23 nm) are necessary to better understand the potential of PN reduction by lube oil reformulation.

Based on these, the following recommendations can be made:

i. Provide some lead time (2024/25 – new/all types) for introduction of PM limits for L6e-B (diesel mini-cars) to allow new powertrain concepts development, in line with the lead time recommended to be given for the gaseous pollutants.
ii. Introduce PM limits for 2-S vehicles as well, despite these may be infrequent or not at all able to make it to Euro 5 step.

iii.	Better understand impacts of PN emissions of new emission control concepts at Euro 5 step before introducing specific limits. Understand the impact of lube oil on L-category vehicle PN emissions and consider advanced lube oil specifications to reduce PN emissions.

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A Test results: Drivability of the WMTC

This Appendix includes the detailed test results of the drivability of the WMTC, which are summarized in paragraph 3.1.2.

The vehicles that were tested under the WMTC drivability are the following:

- L1e-A: 1 vehicle
- L1e-B, low speed: 3 vehicles
- L1e-B, high speed: 6 vehicles
- L2e-U: 2 vehicles (1 validation vehicle)
- L5e-A: 2 vehicles
- L6e-BP: 1 vehicle
- L6e-BU: 1 vehicle
- L7e-B1: 3 vehicles (1 validation vehicle)
- L7e-B2: 1 vehicle
- L7e-CP: 1 vehicle

The Table 81 and Table 82 summarize the resulting data for WMTC and ECE R40/R47 driving cycles respectively. The examined metrics are the following:

- Speed Violations
    - Violation events in a test cycle
    - Duration of violations in a test cycle
- Maximum Achievable Speed
- Mean Positive Acceleration (MPA)
- Driven Distance
- Speed * MPA (approx. of instantaneous, mass-specific power)

With regard to the WMTC, the vehicles are split into categories according to their class, following the classification of Regulation (EU) No 134/2014, i.e., L1e vehicles with 25 km/h limit vehicles, the L1e and L6e ones with 45 km/h limit vehicles, and the L7e vehicles split into those falling under WMTC class 1 and WMTC class 2, respectively. In each set of columns indicating the different vehicles' classification, the first column illustrates the vehicles tests average, while the minimum and the maximum values measured are shown in parentheses. The second column shows the corresponding values derived from precise execution of the corresponding driving cycle in each case. The most significant pattern deviations are pointed out in red font, following the rules indicated in Table 80.

Table 80. Rules for indication of the most significant speed pattern deviations

		Most significant
Speed Pattern Deviations	Events	> 20
	Duration (s)	> 100
Maximum Speed (km/h)		< 85% of WMTC/ECE max speed
Mean Positive Acceleration – MPA (m/s^2)		< 85% of WMTC/ECE MPA
Driven Distance (m)		< 85% of WMTC/ECE driven distance
Speed * MPA (W/kg)		< 85% of WMTC/ECE speed*MPA

Table 81. Drivability of WMTC: summary results

		Vehicle tests L1e, 25 km/h limit, tests average (min-max) (4 vehicles)	WMTC-1 Reduced Speed: L1e, L2e, L5e-B, L6e	Vehicle tests L1e, 45 km/h limit, and L6e tests average (min-max) (7 vehicles)	WMTC-1: L1e, L2e, L5e-B, L6e	Vehicle tests L7e class 1, reduced speed, tests average (min-max) (1 vehicle)	WMTC-1 Reduced Speed: L3e, L4e, L5e-A, L7e	Vehicle tests L7e, reduced speed, vehicles tests average (min-max) (3 vehicles)	WMTC2-1 Reduced Speed: L3e, L4e, L5e-A, L7e
Speed Pattern Deviations	Events	6 (0 - 23)	-	7 (0 - 25)	-	8 (4 - 10)	-	7 (0 - 15)	-
	Duration (s)	65 (0 - 358)	-	49 (0 - 363)	-	19 (9 - 24)	-	48 (0 - 106)	-
Maximum Speed (km/h)		24.6 (20 – 27)	25	44.8 (38 - 47)	45	50.2 (50 - 50)	50	76.0 (64 - 85)	82.5
Mean Positive Acceleration – MPA (m/s^2)		0.65 (0.36 - 0.79)	0.76	0.45 (0.25 - 0.51)	0.46	0.47 (0.46 - 0.48)	0.43	0.41 (0.38 - 0.45)	0.43
Driven Distance (m)		5453 (4094 - 5902)	5883	7471 (6503 - 7673)	7600	7702 (7670 - 7725)	7676	12024 (11570 - 12320)	12287
Speed * MPA (W/kg)		2.70 (1.00 - 3.51)	3.19	2.76 (1.29 - 3.20)	2.87	3.06 (3 - 3.11)	2.82	3.86 (3.25 - 4.38)	4.17

Table 82. Drivability of ECE R40/R47: summary results

		Vehicle tests L1e, L2e, L6e (reduced speed) tests average (min-max) (4 vehicles)	ECE R47 Reduced Speed: L1e, L2e, L6e	Vehicle tests L1e, L2e, L6e tests average (min-max) (7 vehicles)	ECE R47: L1e, L2e, L6e	Vehicle tests L5e-B, L7e-B, L7e-C tests average (min-max) (4 vehicles)	ECE R40: L5e-B, L7e-B, L7e-C
Speed Pattern Deviations	Events	10 (7 - 15)	-	6 (1 - 10)	-	3 (0 - 12)	-
	Duration (s)	78 (28 -189)	-	53 (5 - 264)	-	10 (0 - 37)	-
Maximum Speed (km/h)		25.3 (21 - 27)	Max. vehicle speed	45.3 (47 - 47)	Max. vehicle speed	50.7 (50.3 - 51.1)	50
Mean Positive Acceleration – MPA (m/s^2)		0.65 (0.42 - 0.84)	Full throttle	0.78 (0.35 - 0.94)	Full throttle	0.59 (0.55 - 0.62)	0.61
Driven Distance (m)		4284 (3768 - 4457)	-	6041 (5078 - 6257)	-	5970 (5909 - 6019)	5993
Speed * MPA (W/kg)		2.48 (1.17 - 3.48)	-	5.21 (1.69 - 6.40)	-	3.37 (3.15 - 3.55)	3.66

In the following, detailed results are presented for each test vehicle. Figures for the vehicle speed and the vehicle acceleration along with figures with zoomed areas in which drivability problems are observed are drawn for each vehicle. Besides, the WMTC distribution of acceleration over speed is also illustrated towards the assessment of driver errors versus machine limits for each test vehicle. Also, summary tables follow for each test vehicle, presenting the results on each of the examined metrics, indicating the drivability issues.

Vehicle J05 (L1e-A)

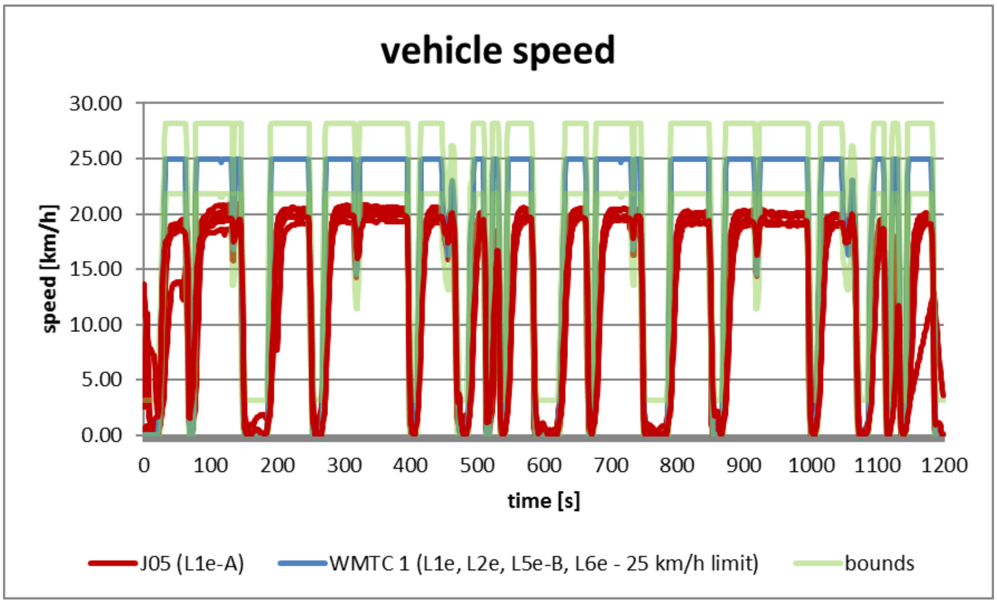

Figure 106. WMTC drivability of J05 (L1e-A) – vehicle speed

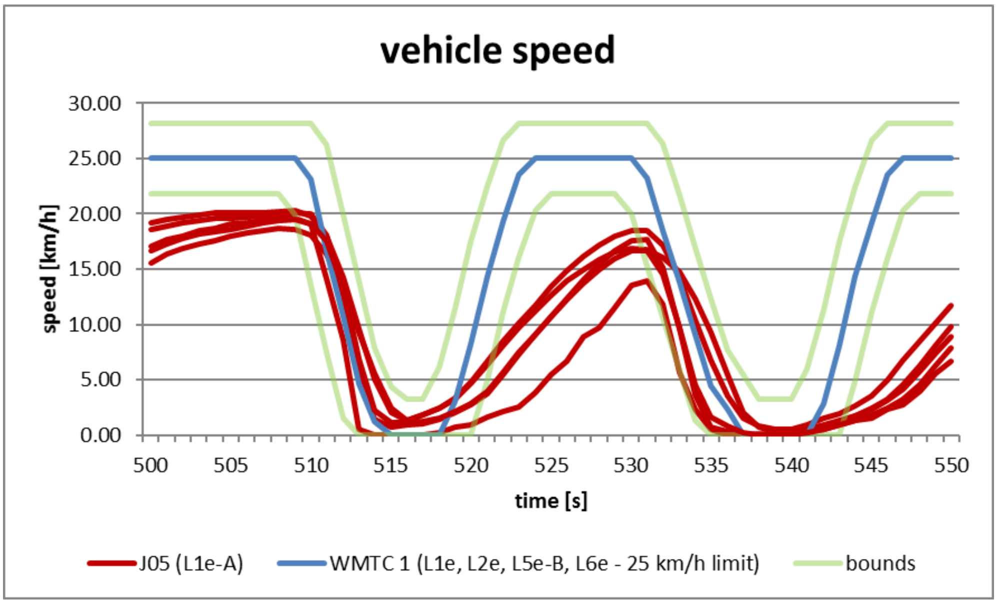

Figure 107. WMTC drivability of J05 (L1e-A) – vehicle speed zoom

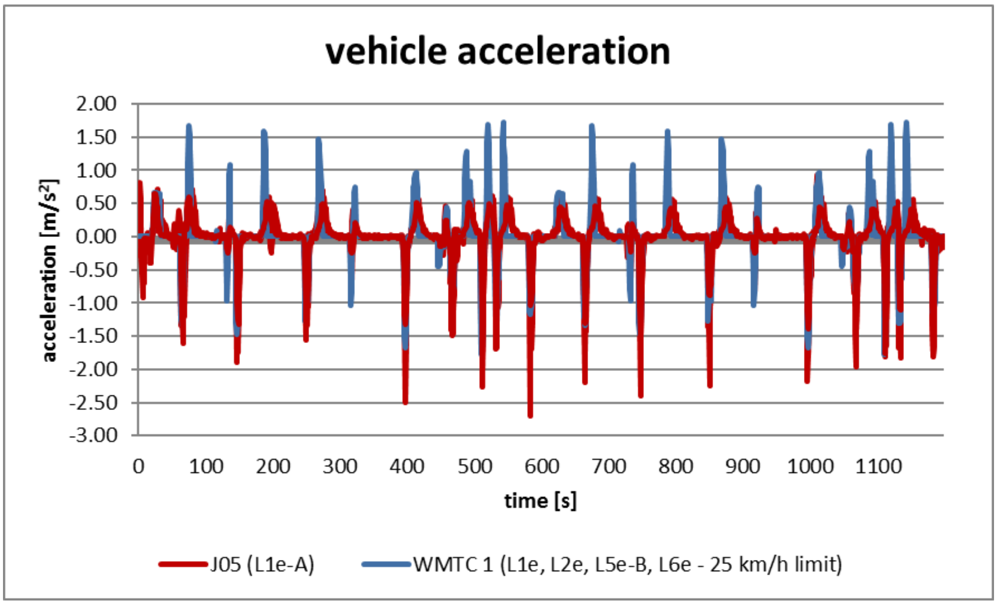

Figure 108. WMTC drivability of J05 (L1e-A) – vehicle acceleration

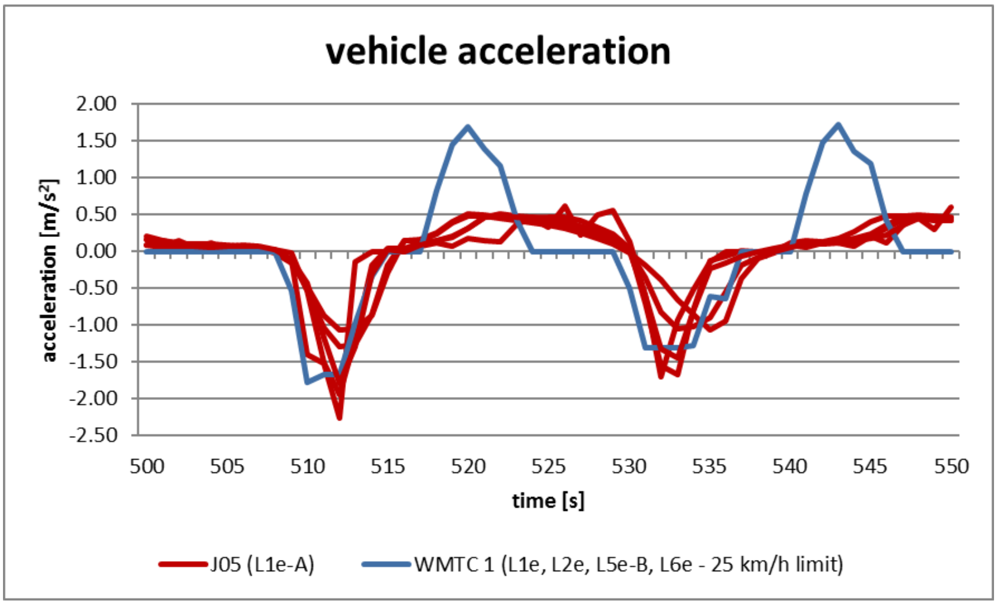

Figure 109. WMTC drivability of J05 (L1e-A) – vehicle acceleration zoom

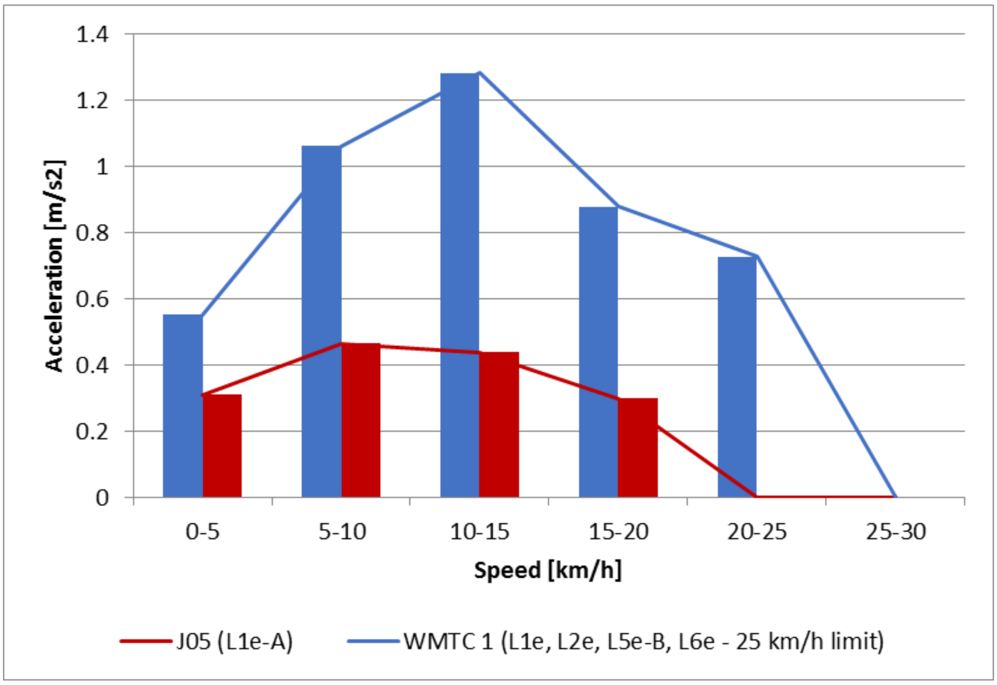

Figure 110. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J05 (L1e-A)

Table 83. Technical criteria for WMTC drivability assessment of J05 (L1e-A)

		J05 (L1e-A) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	20 (18 – 23)	-	-
	Duration (s)	251 (171 – 358)	-	-
Maximum Achievable Speed (km/h)		21 (20 – 21)	25	25
Mean Positive Acceleration (MPA) (m/s^2)		0.39 (0.36 – 0.41)	0.76	-
Driven Distance (m)		4305 (4092 – 4543)	5853	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		1.14 (1.03 – 25)	3.19	-

Vehicle J06 (L1e-B, low speed)

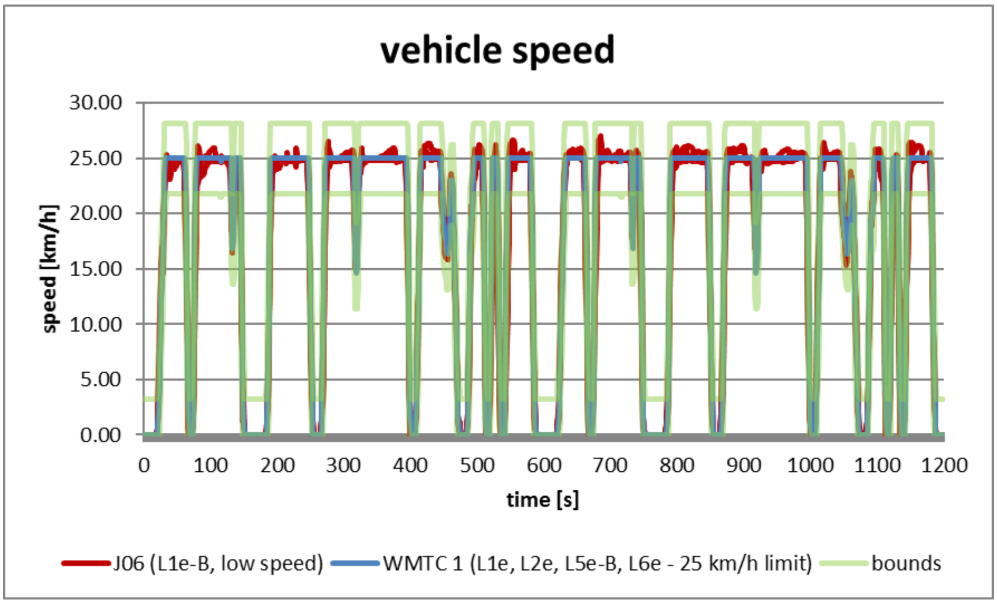

Figure 111. WMTC drivability of J06 (L1e-B, low speed) – vehicle speed

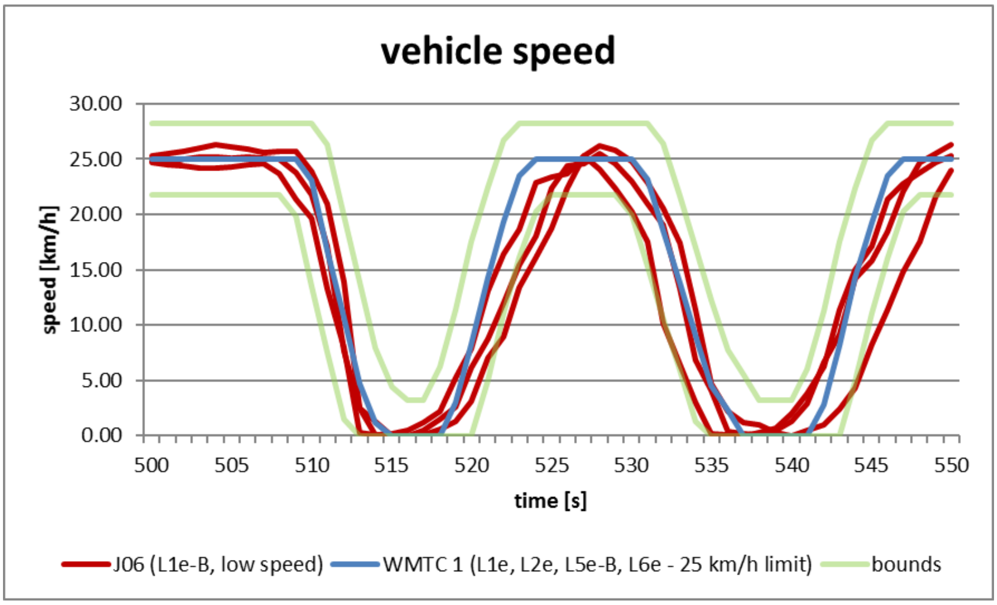

Figure 112. WMTC drivability of J06 (L1e-B, low speed) – vehicle speed zoom

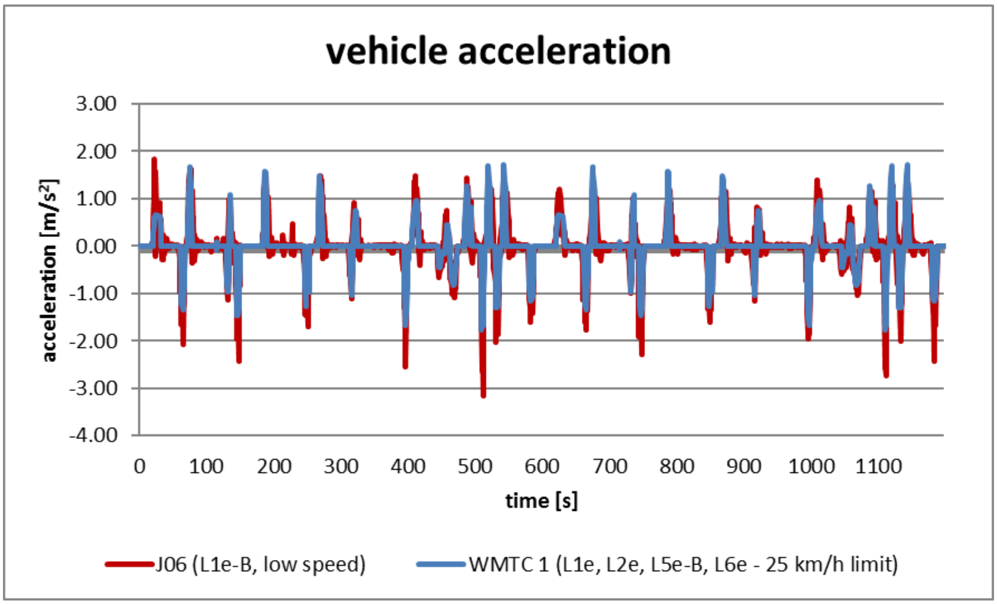

Figure 113. WMTC drivability of J06 (L1e-B, low speed) – vehicle acceleration

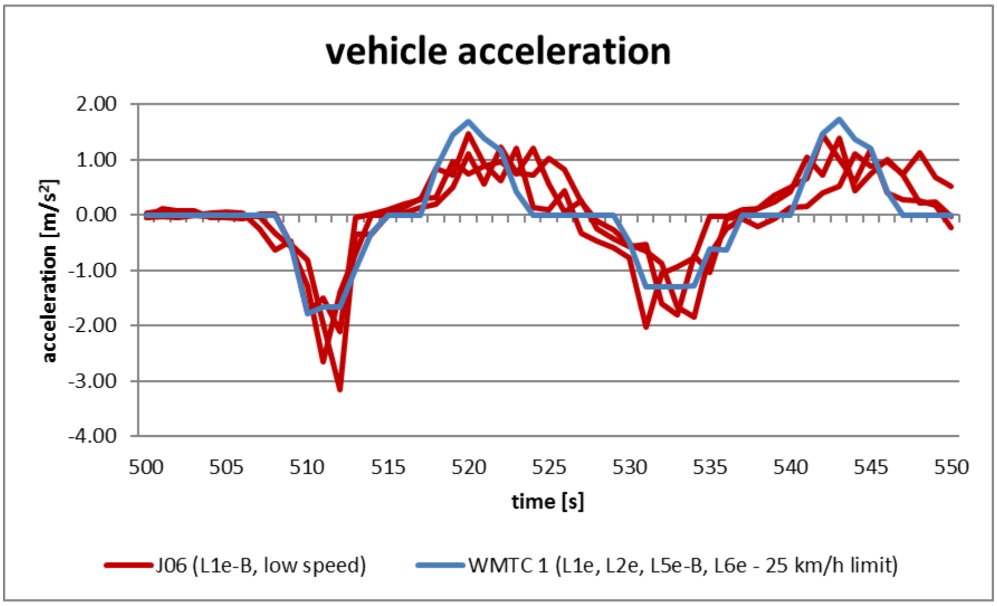

Figure 114. WMTC drivability of J06 (L1e-B, low speed) – vehicle acceleration zoom

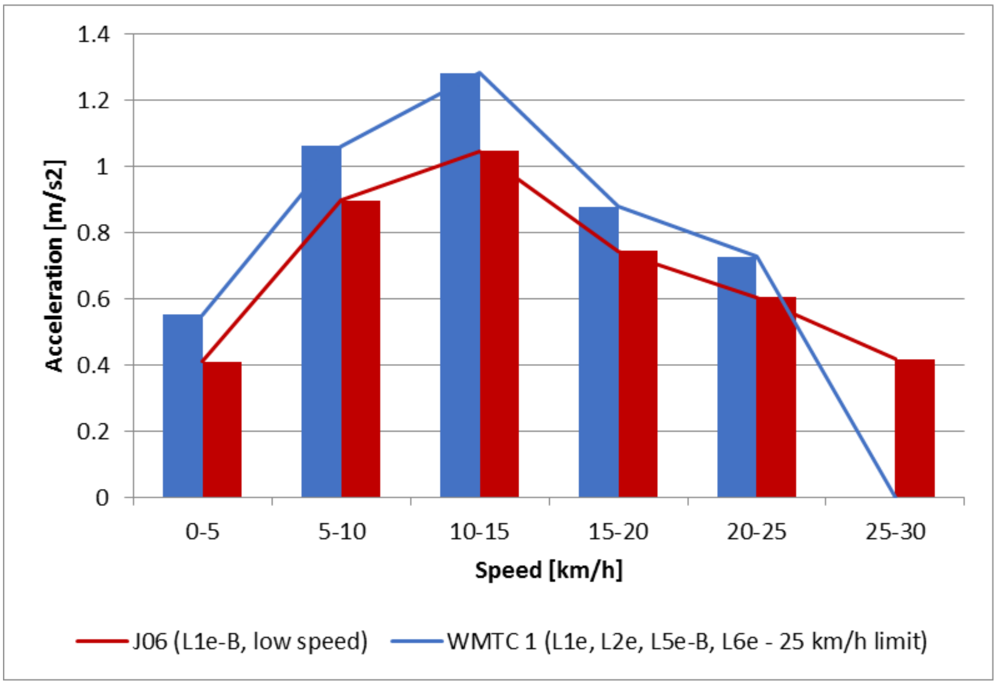

Figure 115. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J06 (L1e-B, low speed)

Table 84. Technical criteria for WMTC drivability assessment of J06 (L1e-B, low speed)

		J06 (L1e-B, low speed) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	2 (0 – 4)	-	-
	Duration (s)	5 (0 – 12)	-	-
Maximum Achievable Speed (km/h)		27 (26 – 27)	25	25
Mean Positive Acceleration (MPA) (m/s^2)		0.69 (0.67 – 0.70)	0.76	-
Driven Distance (m)		5786 (5769 – 5811)	5883	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		2.93 (2.86 – 2.98)	3.19	-

Vehicle J07 (L1e-B, low speed)

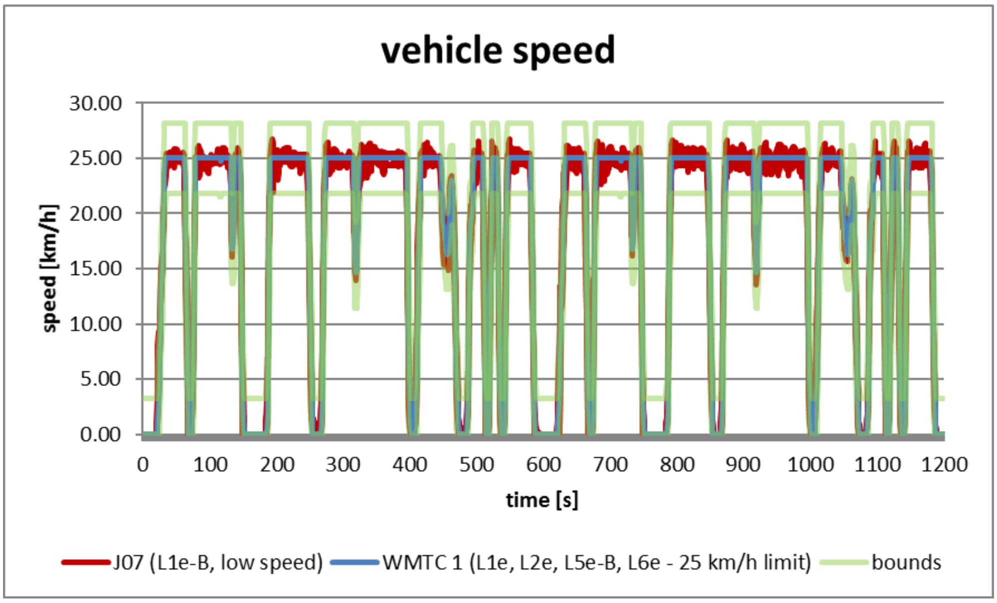

Figure 116. WMTC drivability of J07 (L1e-B, low speed) – vehicle speed

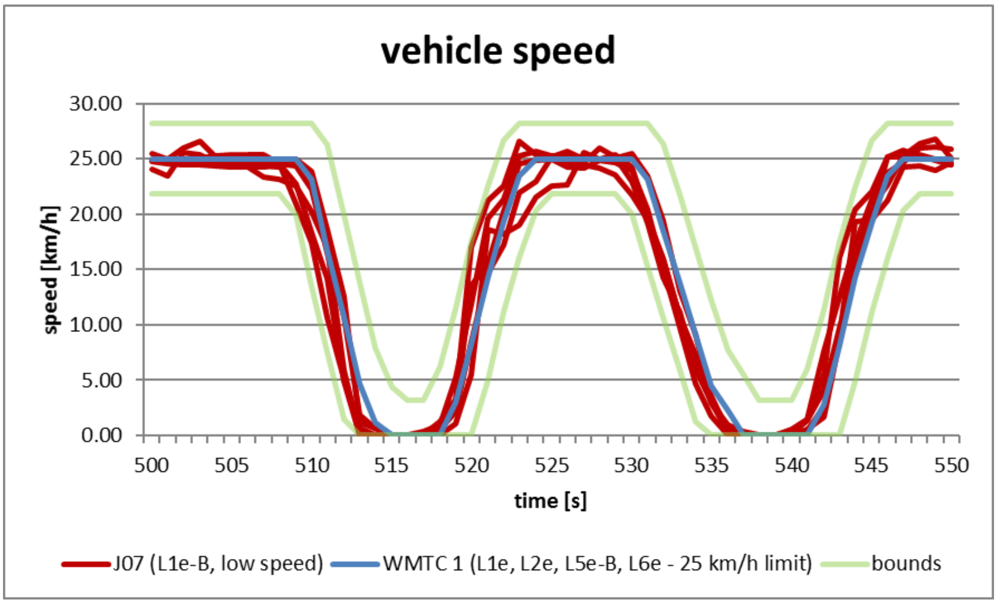

Figure 117. WMTC drivability of J07 (L1e-B, low speed) – vehicle speed zoom

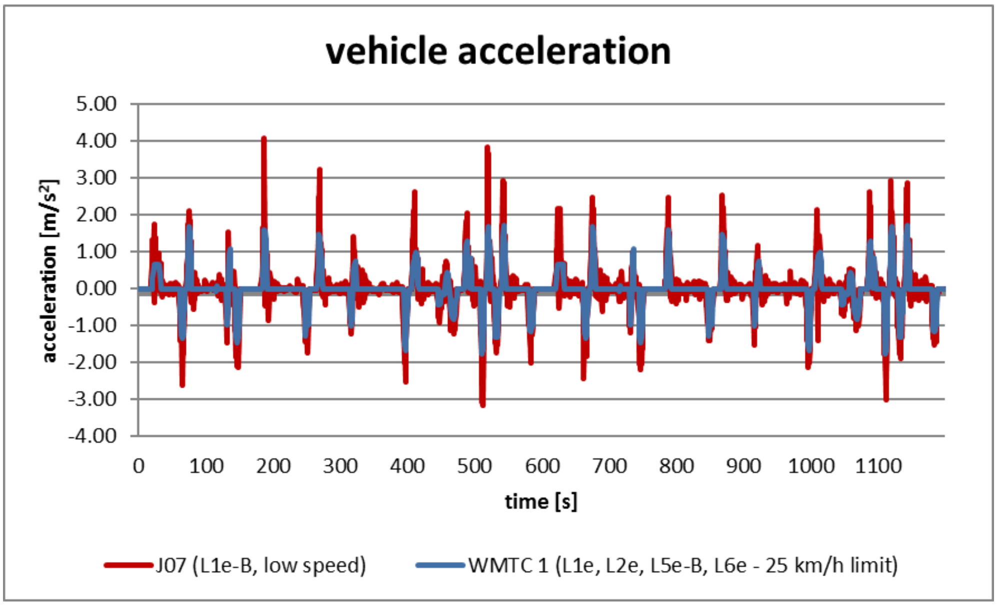

Figure 118. WMTC drivability of J07 (L1e-B, low speed) – vehicle acceleration

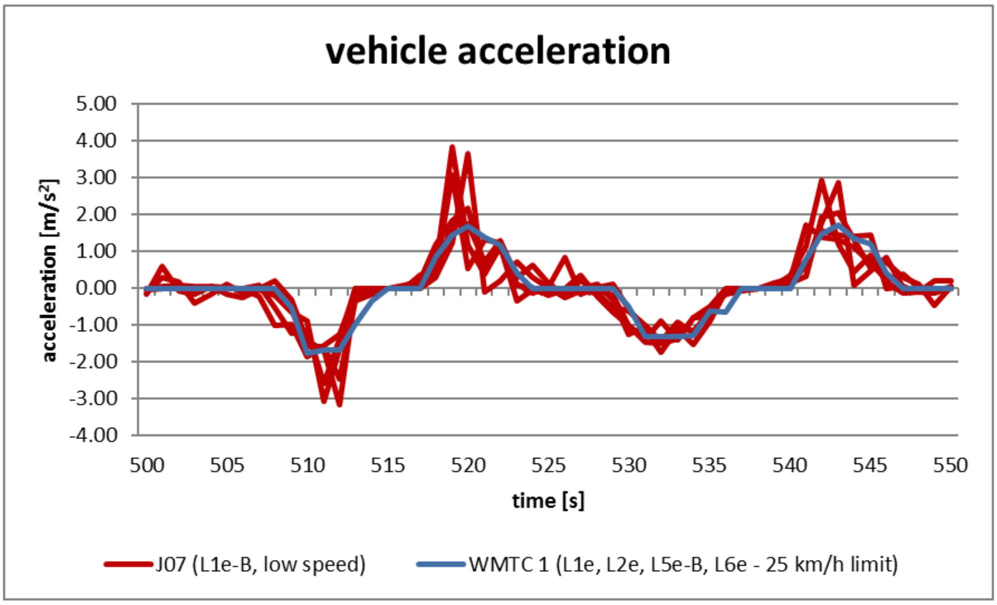

Figure 119. WMTC drivability of J07 (L1e-B, low speed) – vehicle acceleration zoom

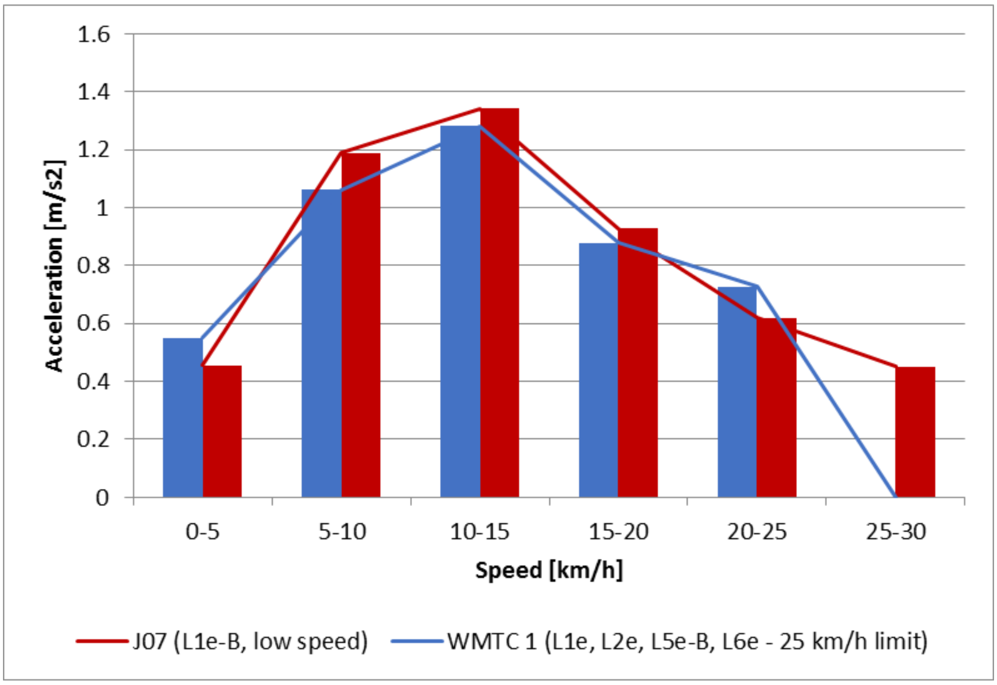

Figure 120. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J07 (L1e-B, low speed)

Table 85. Technical criteria for WMTC drivability assessment of J07 (L1e-B, low speed)

		J07 (L1e-B, low speed) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	0 (0 – 1)	-	-
	Duration (s)	0 (0 – 2)	-	-
Maximum Achievable Speed (km/h)		27 (27 – 27)	25	25
Mean Positive Acceleration (MPA) (m/s^2)		0.77 (0.71 – 0.79)	0. 76	-
Driven Distance (m)		5842 (5821 – 5861)	5883	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		3.44 (3.29 – 3.51)	3.19	-

Vehicle J10 (L1e-B, low speed)

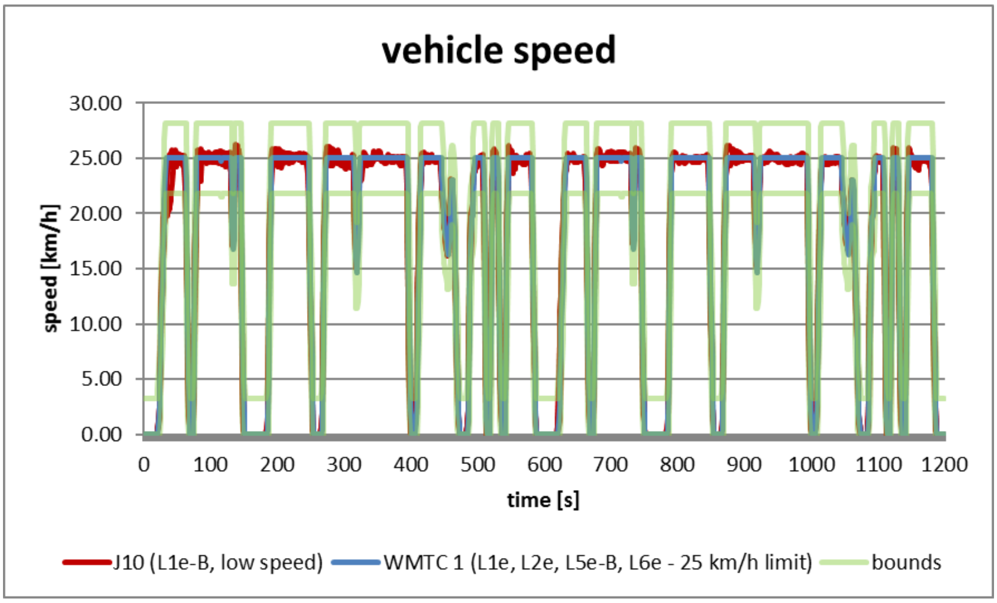

Figure 121. WMTC drivability of J10 (L1e-B, low speed) – vehicle speed

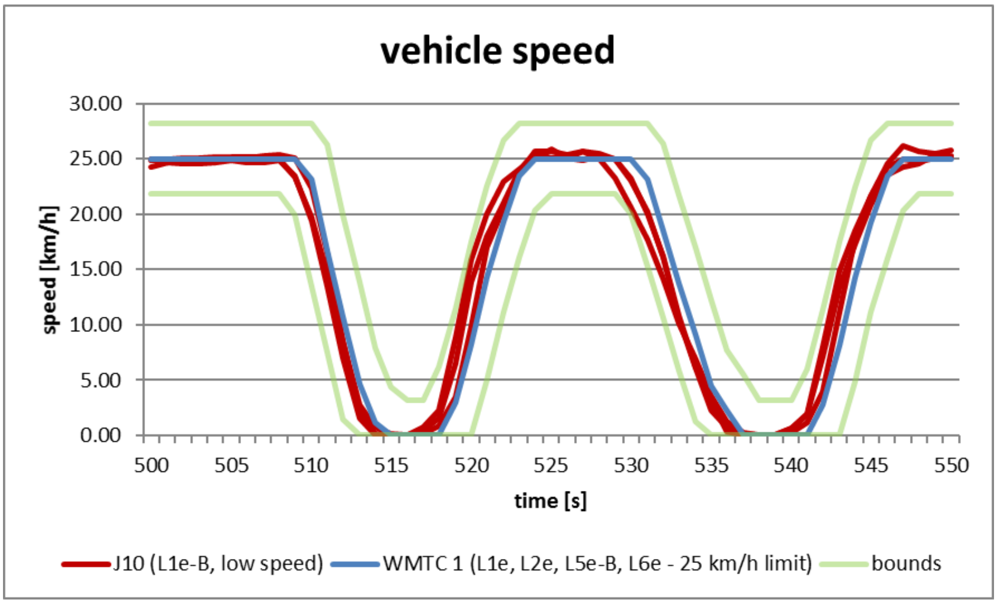

Figure 122. WMTC drivability of J10 (L1e-B, low speed) – vehicle speed zoom

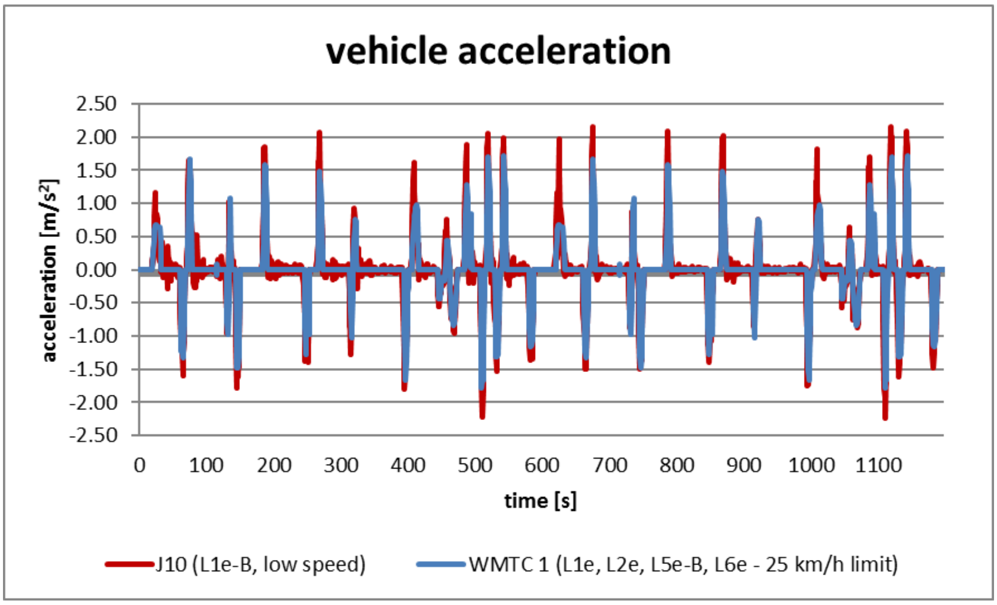

Figure 123. WMTC drivability of J10 (L1e-B, low speed) – vehicle acceleration

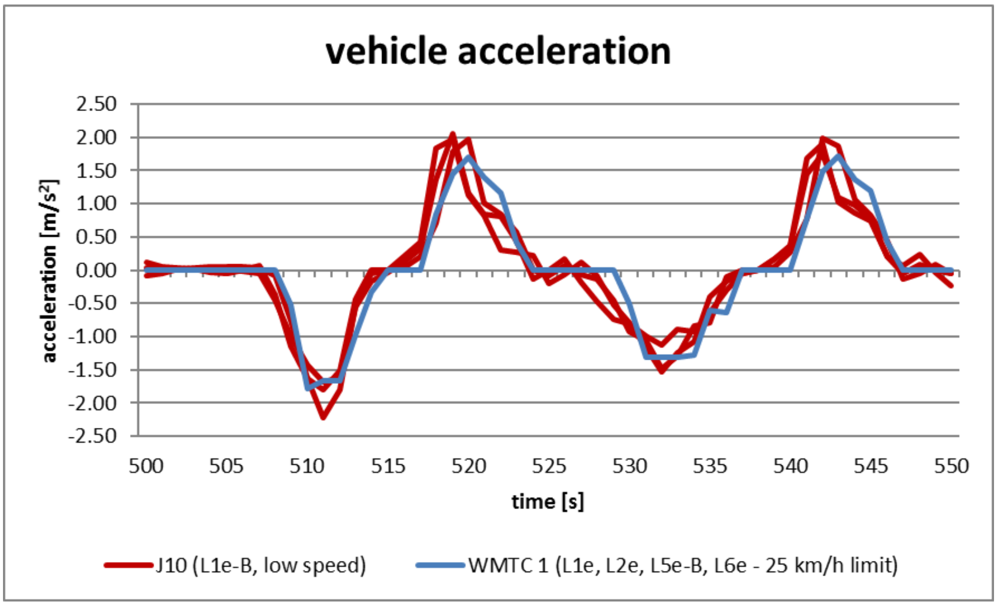

Figure 124. WMTC drivability of J10 (L1e-B, low speed) – vehicle acceleration zoom

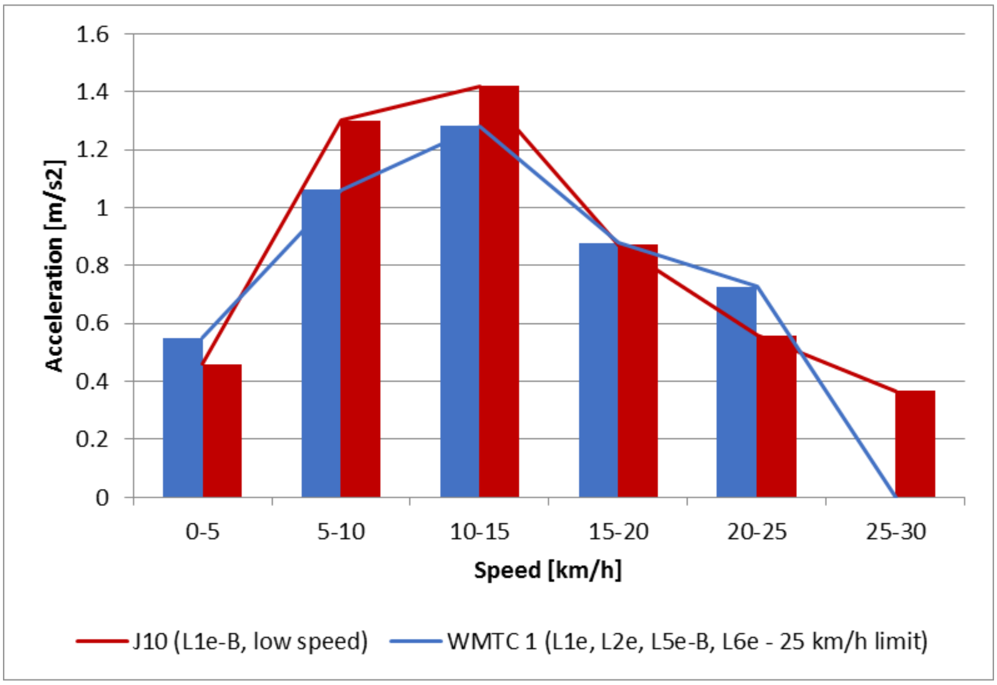

Figure 125. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J10 (L1e-B, low speed)

Table 86. Technical criteria for WMTC drivability assessment of J10 (L1e-B, low speed)

		J10 (L1e-B, low speed) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	1 (1 – 1)	-	-
	Duration (s)	3 (2 – 6)	-	-
Maximum Achievable Speed (km/h)		26 (26 – 26)	25	25
Mean Positive Acceleration (MPA) (m/s^2)		0.77 (0.76 – 0.78)	0. 76	-
Driven Distance (m)		5857 (5827 – 5897)	5883	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		3.30 (3.25 – 3.40)	3.19	-

Vehicle J02 (L1e-B, high speed moped)

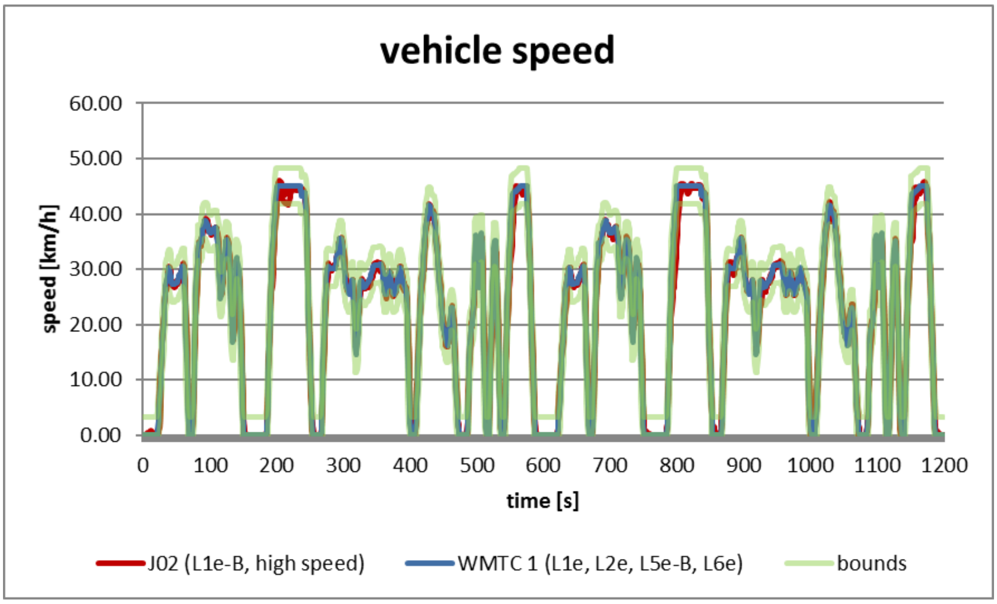

Figure 126. WMTC drivability of J02 (L1e-B, high speed moped) – vehicle speed

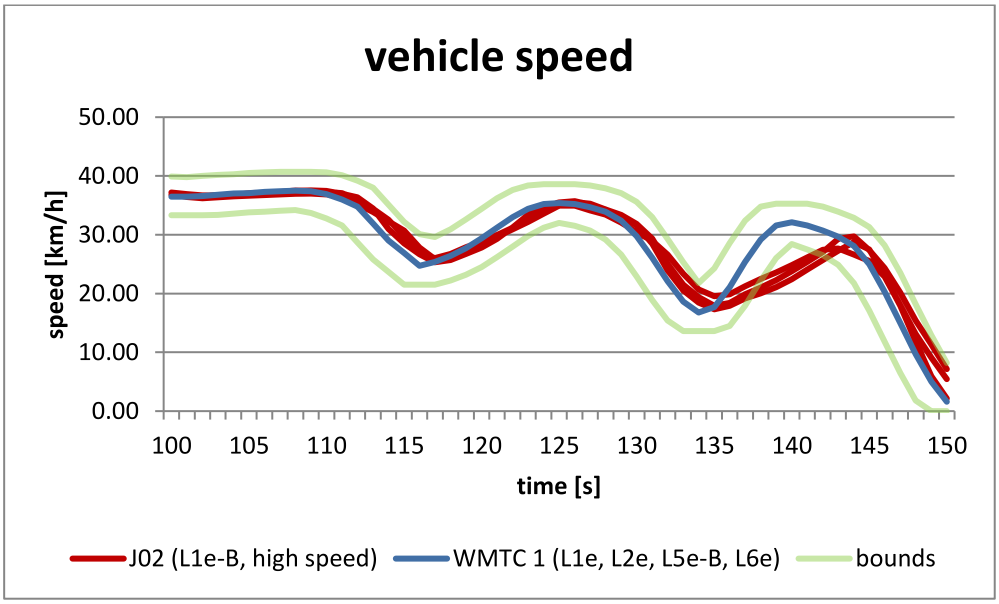

Figure 127. WMTC drivability of J02 (L1e-B, high speed moped) – vehicle speed zoom

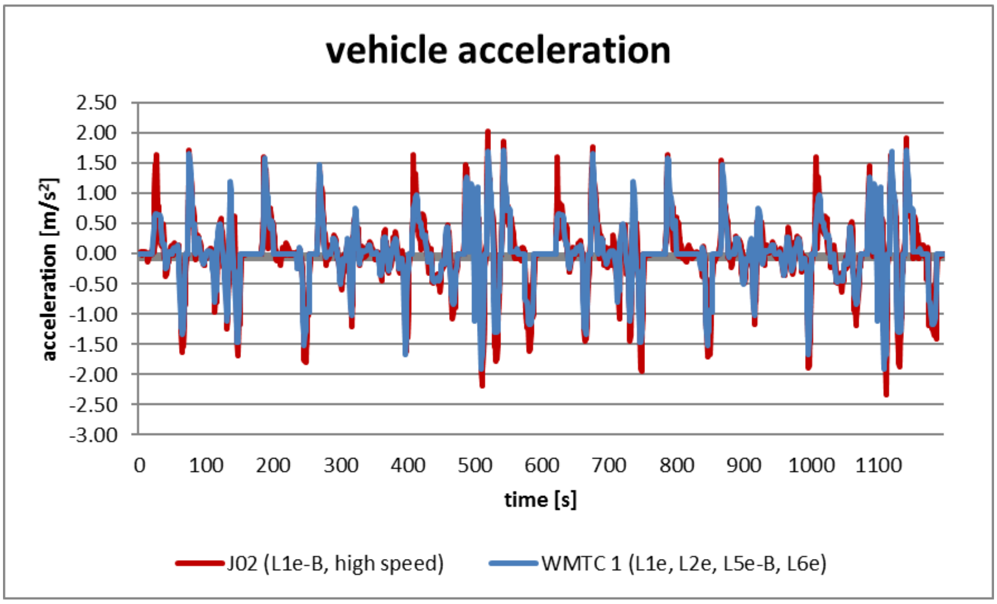

Figure 128. WMTC drivability of J02 (L1e-B, high speed moped) – vehicle acceleration

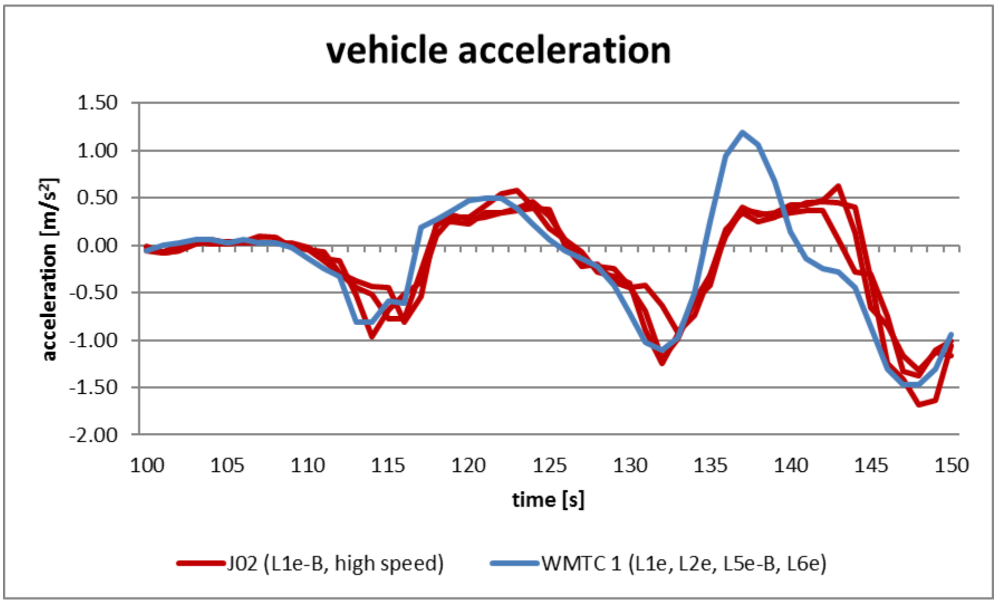

Figure 129. WMTC drivability of J02 (L1e-B, high speed moped) – vehicle acceleration zoom

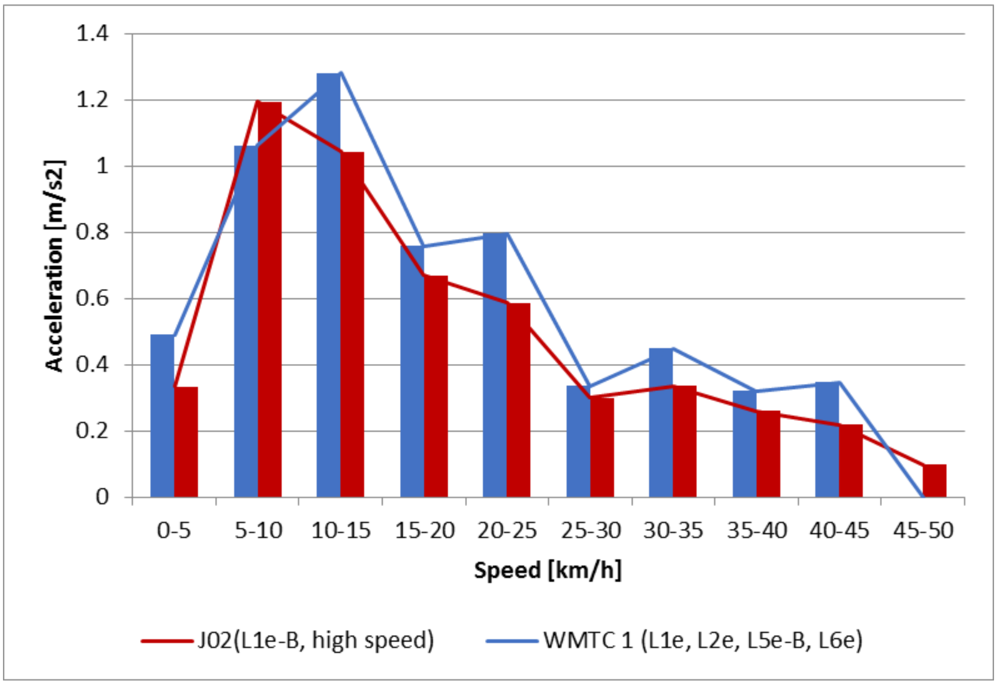

Figure 130. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J02 (L1e-B, high speed moped)

Table 87. Technical criteria for WMTC drivability assessment of J02 (L1e-B, high speed moped)

		J02 (L1e-B, high speed) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	5 (3 – 8)	-	-
	Duration (s)	18 (7 – 36)	-	-
Maximum Achievable Speed (km/h)		46 (45 – 46)	45	45
Mean Positive Acceleration (MPA) (m/s^2)		0.43 (0.41 – 0.44)	0.46	-
Driven Distance (m)		7561 (7517 – 7594)	7600	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		2.61 (2.54 – 2.66)	2.87	-

Vehicle J03 (L1e-B, high speed moped)

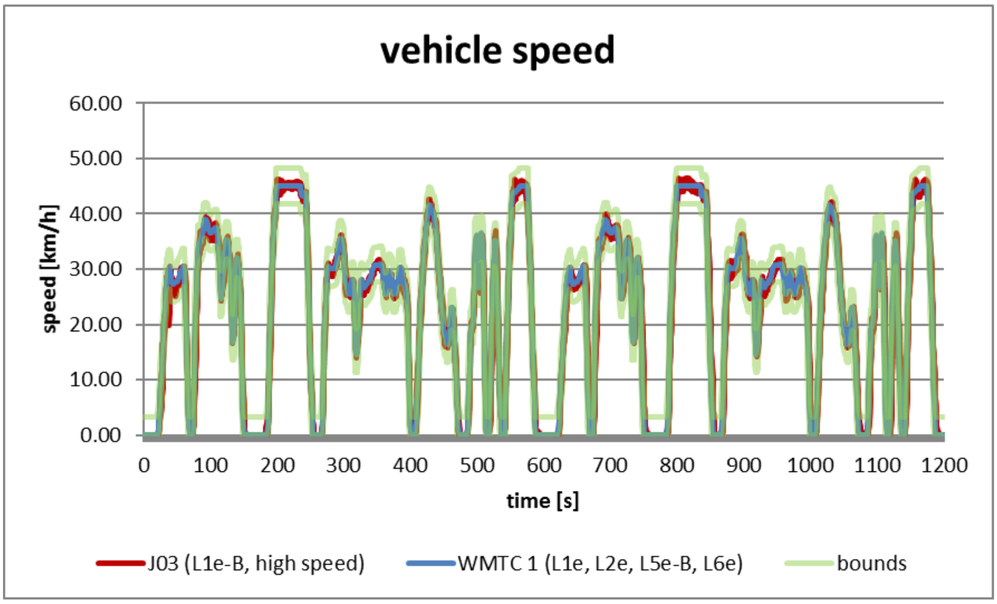

Figure 131. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle speed

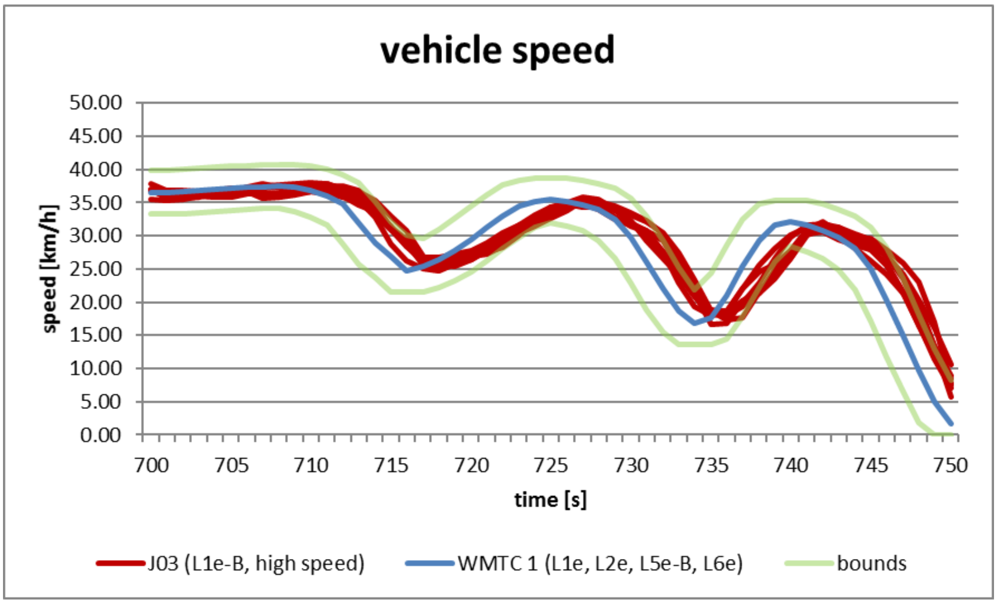

Figure 132. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle speed zoom

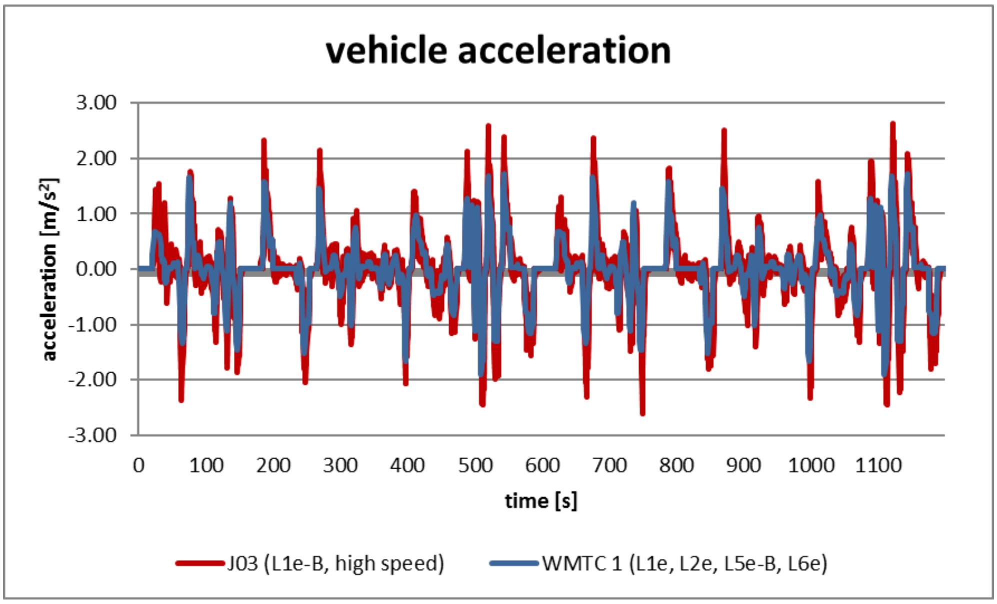

Figure 133. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle acceleration

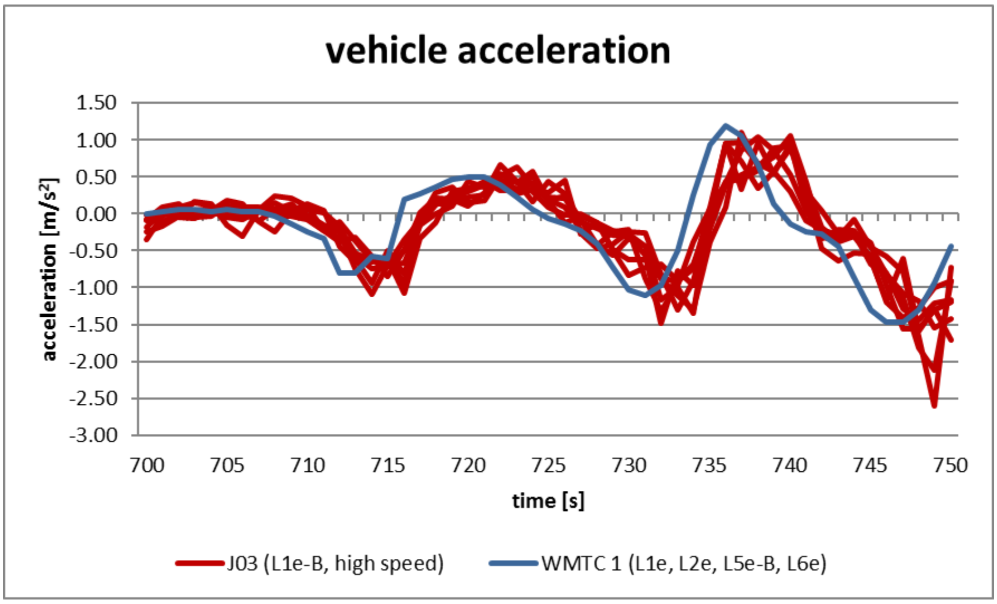

Figure 134. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle acceleration zoom

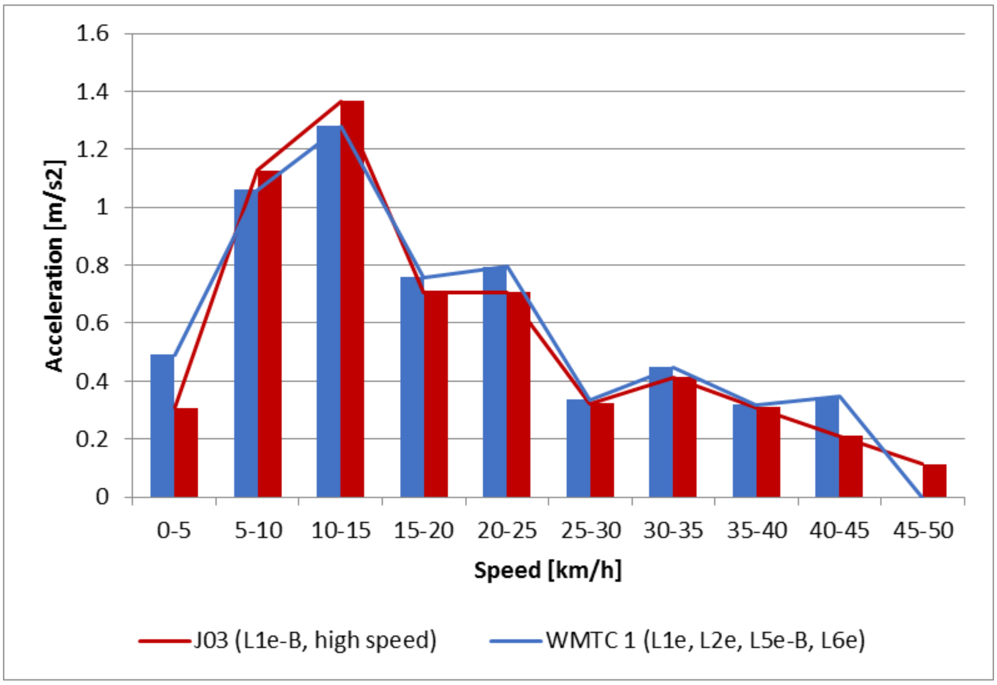

Figure 135. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J03 (L1e-B, high speed moped)

Table 88. Technical criteria for WMTC drivability assessment of J03 (L1e-B, high speed moped)

		J03 (L1e-B, high speed) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	5 (2 – 16)	-	-
	Duration (s)	16 (5 – 45)	-	-
Maximum Achievable Speed (km/h)		46 (46 – 46)	45	45
Mean Positive Acceleration (MPA) (m/s^2)		0.45 (0.45 – 0.46)	0.46	-
Driven Distance (m)		7553 (7532 – 7598)	7600	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		2.86 (2.79 – 2.96)	2.87	-

Vehicle J04 (L1e-B, high speed moped)

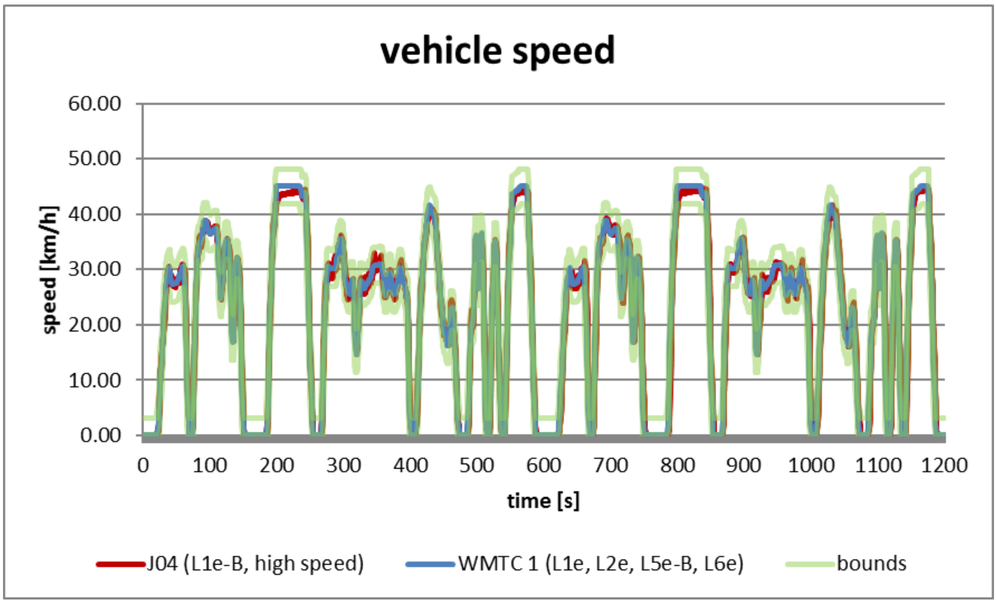

Figure 136. WMTC drivability of J04 (L1e-B, high speed moped) – vehicle speed

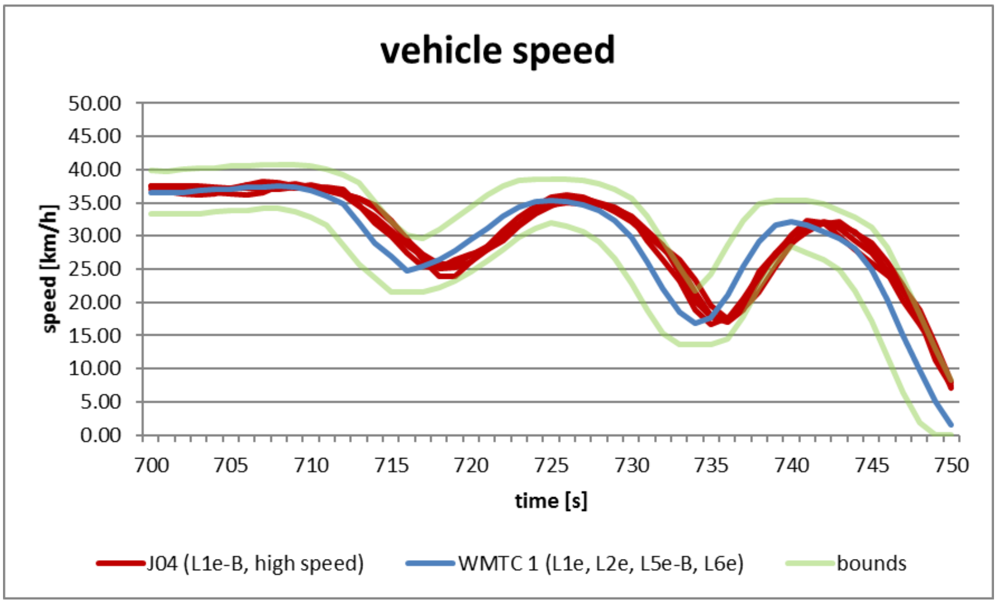

Figure 137. WMTC drivability of J04 (L1e-B, high speed moped) – vehicle speed zoom

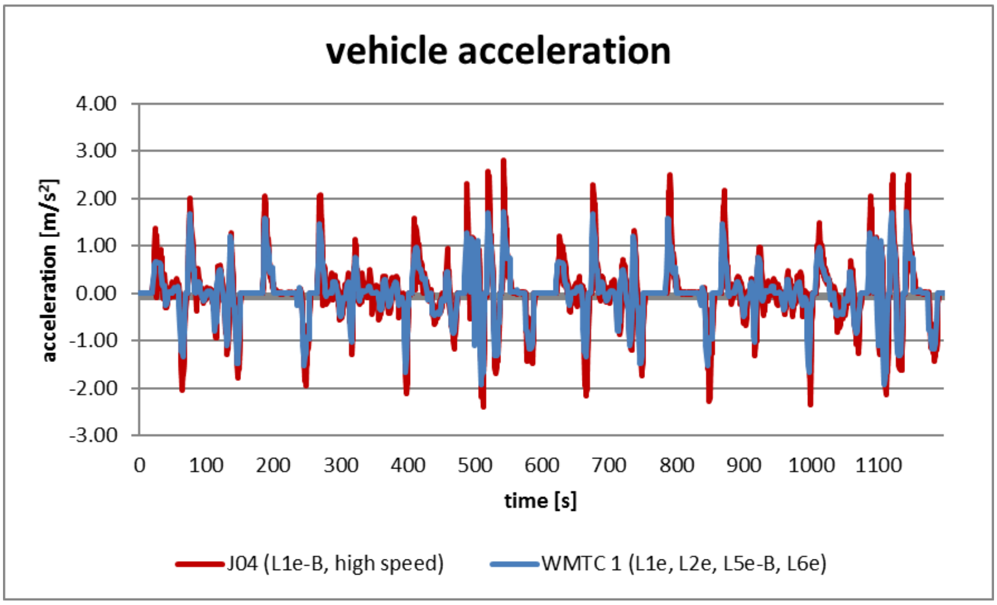

Figure 138. WMTC drivability of J04 (L1e-B, high speed moped) – vehicle acceleration

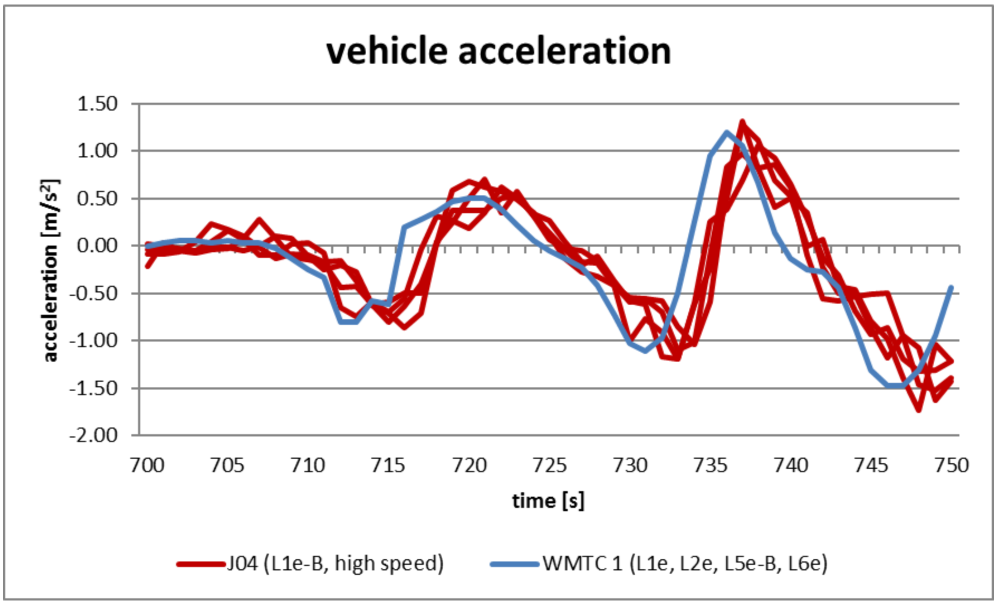

Figure 139. WMTC drivability of J04 (L1e-B, high speed moped) – vehicle acceleration zoom

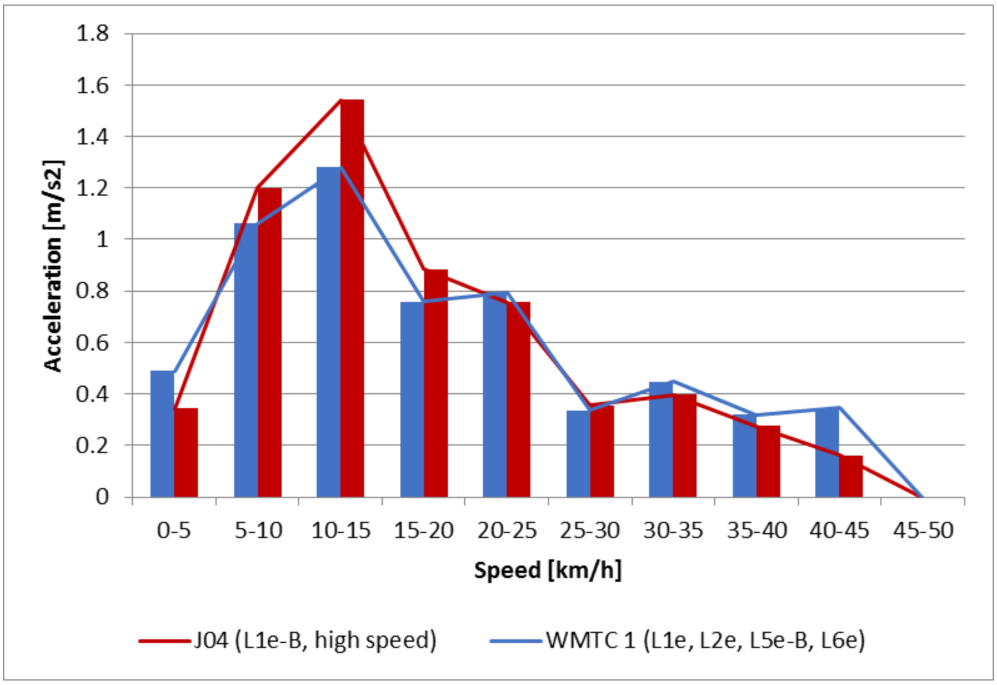

Figure 140. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J04 (L1e-B, high speed moped)

Table 89. Technical criteria for WMTC drivability assessment of J04 (L1e-B, high speed moped)

		J04 (L1e-B, high speed) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	4 (3 – 5)	-	-
	Duration (s)	9 (8 – 11)	-	-
Maximum Achievable Speed (km/h)		45 (44 – 45)	45	45
Mean Positive Acceleration (MPA) (m/s^2)		0.48 (0.45 – 0.50)	0.46	-
Driven Distance (m)		7595 (7562 – 7630)	7600	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		3.01 (2.83 – 3.18)	2.87	-

Vehicle J12 (L1e-B, high speed moped)

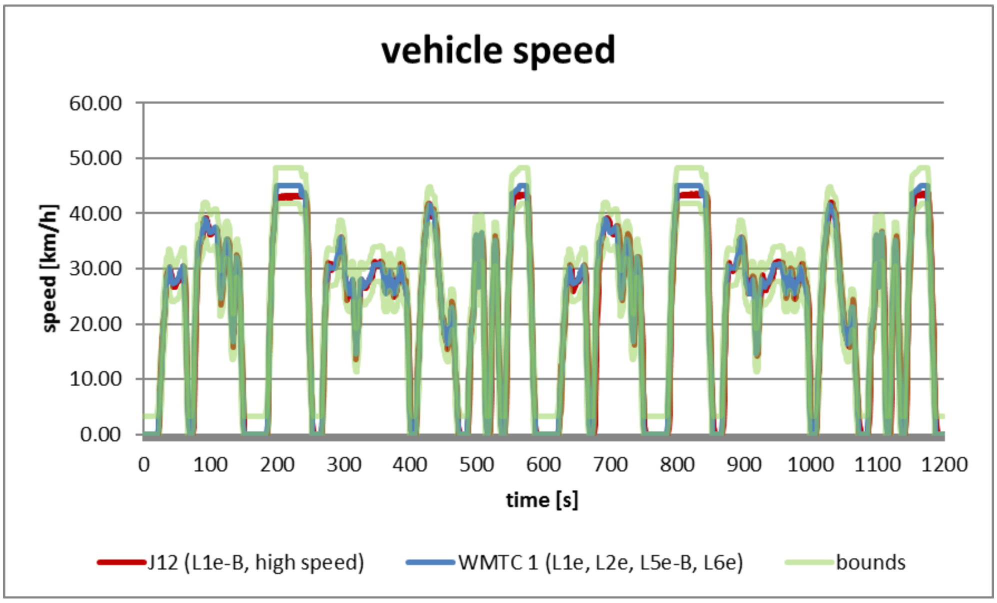

Figure 141. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle speed

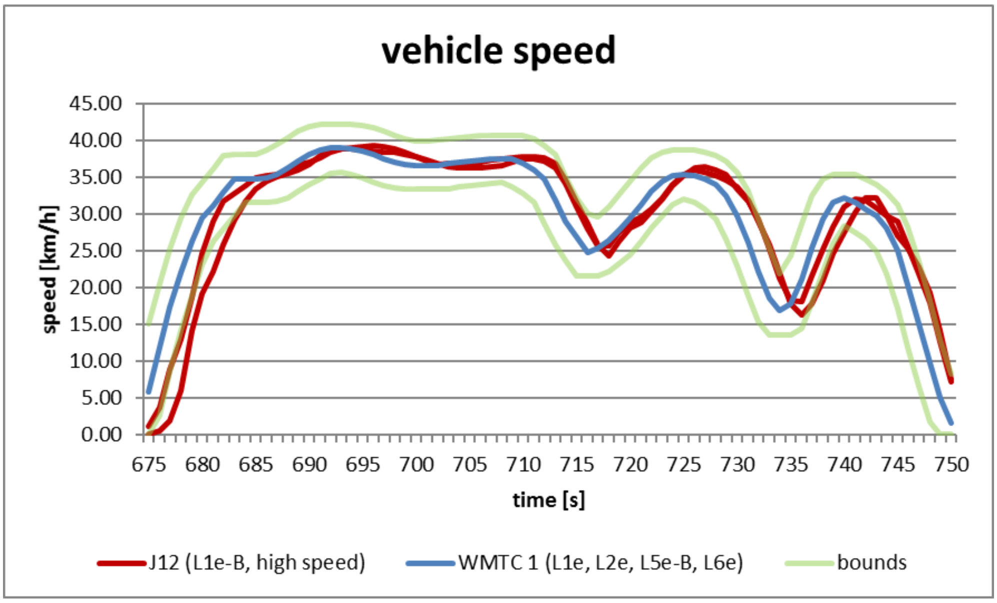

Figure 142. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle speed zoom

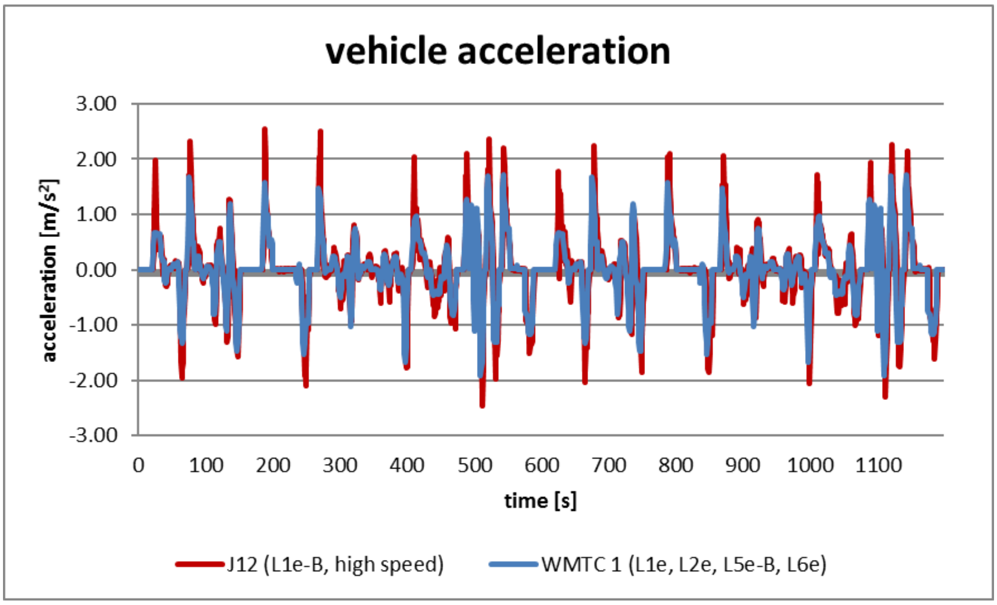

Figure 143. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle acceleration

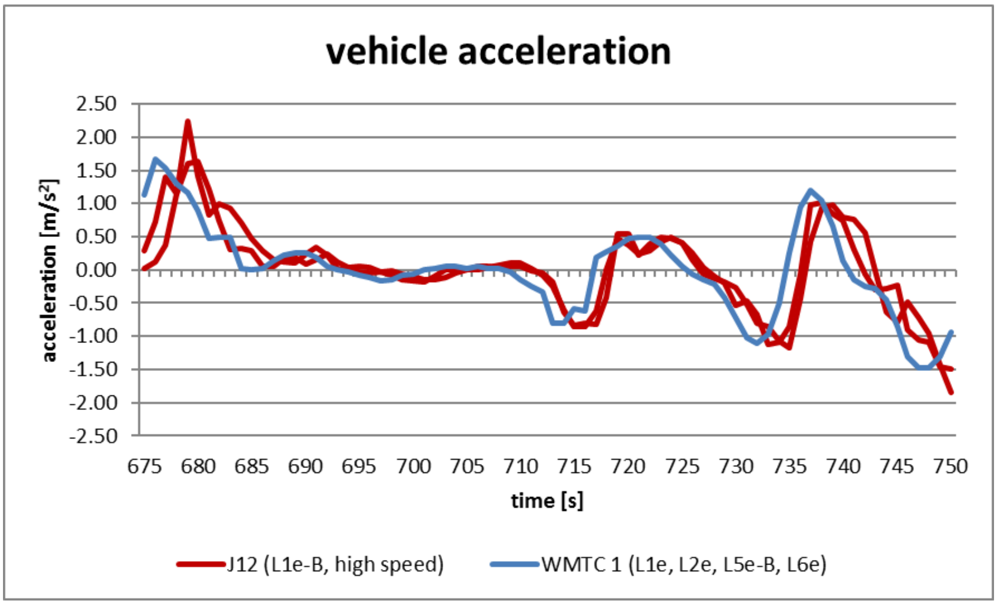

Figure 144. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle acceleration zoom

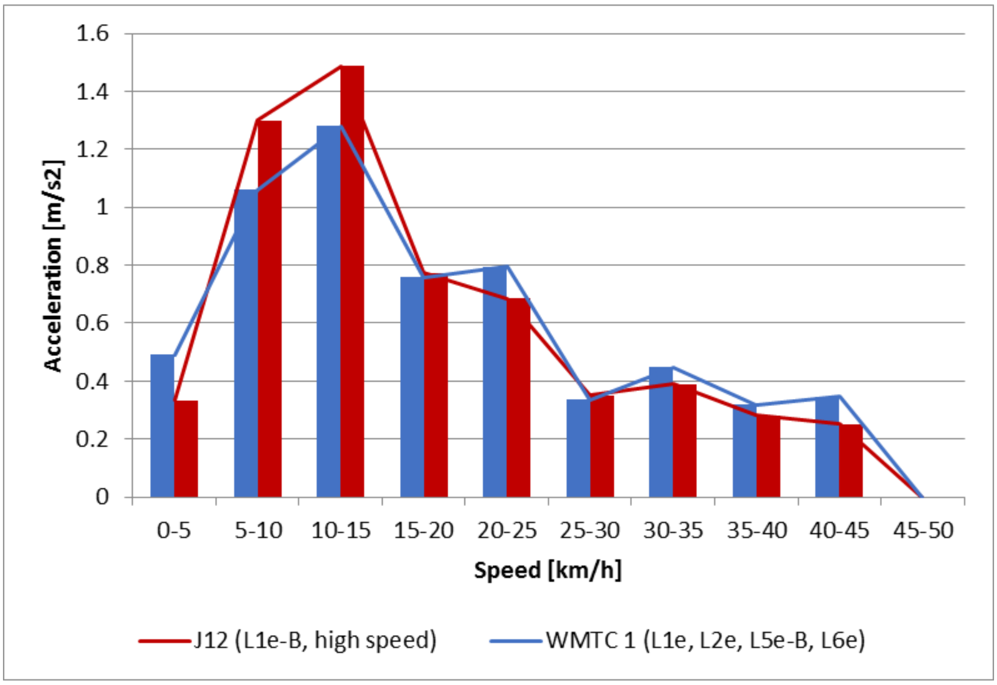

Figure 145. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J12 (L1e-B, high speed moped)

Table 90. Technical criteria for WMTC drivability assessment of J12 (L1e-B, high speed moped)

		J12 (L1e-B, high speed) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	6 (2 – 10)	-	-
	Duration (s)	17 (4 – 29)	-	-
Maximum Achievable Speed (km/h)		44 (43 – 44)	45	45
Mean Positive Acceleration (MPA) (m/s^2)		0.49 (0.48 – 0.50)	0.46	-
Driven Distance (m)		7558 (7571 – 7544)	7600	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		3.04 (2.96 – 3.12)	2.87	-

Vehicle J14 (L1e-B, high speed moped)

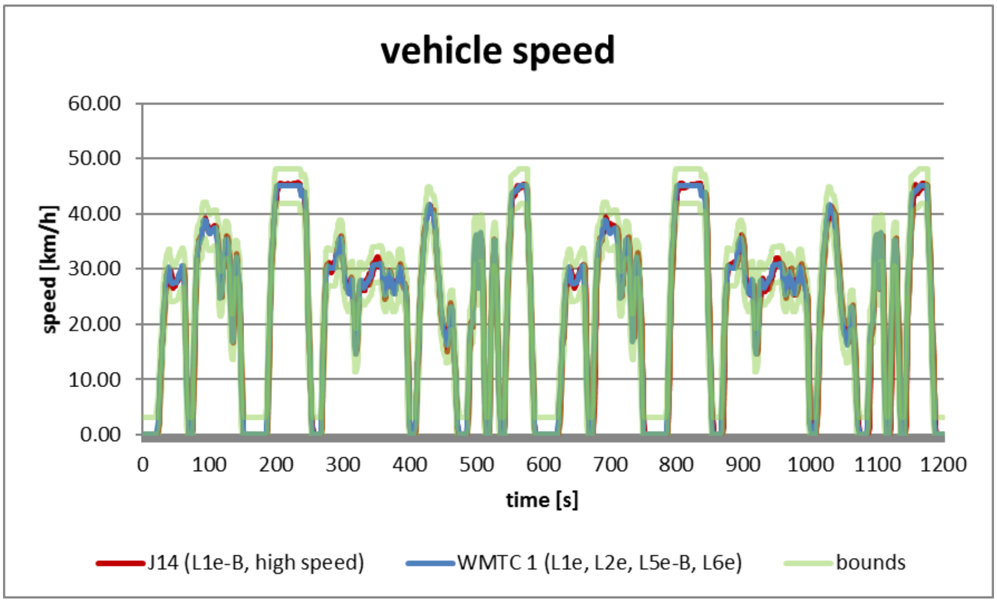

Figure 146. WMTC drivability of J14 (L1e-B, high speed moped) – vehicle speed

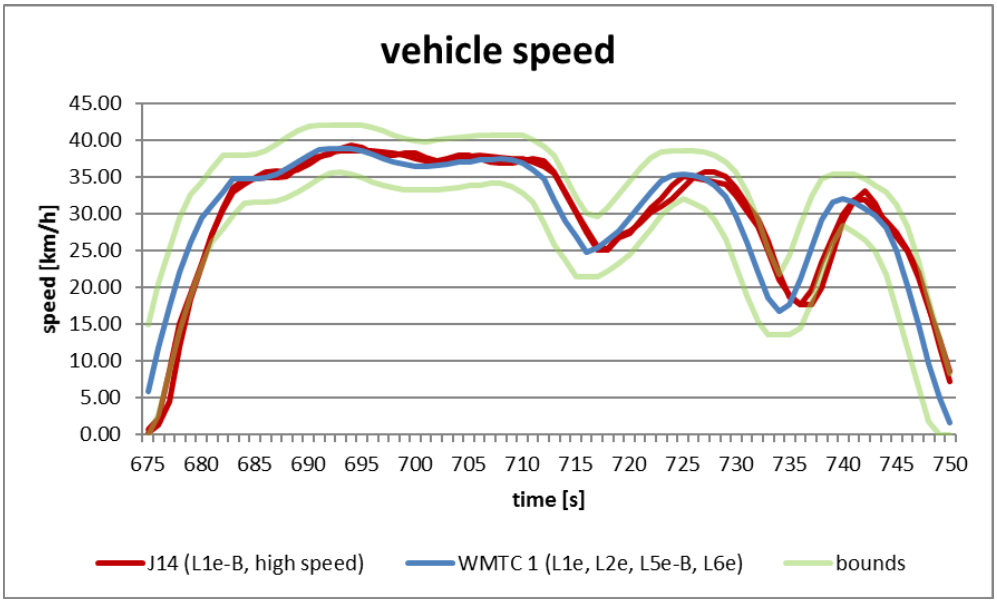

Figure 147. WMTC drivability of J14 (L1e-B, high speed moped) – vehicle speed zoom

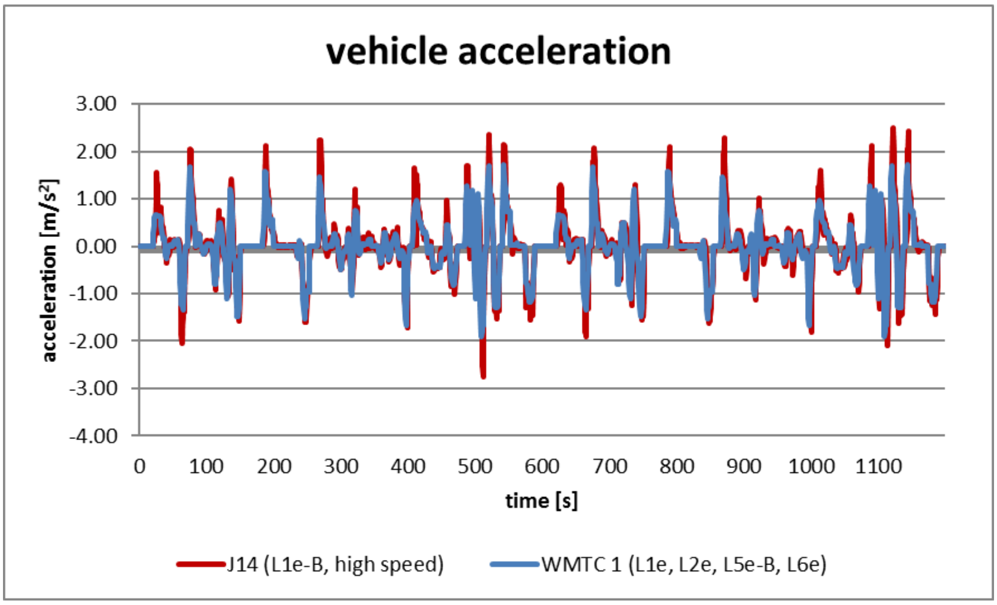

Figure 148. WMTC drivability of J14 (L1e-B, high speed moped) – vehicle acceleration

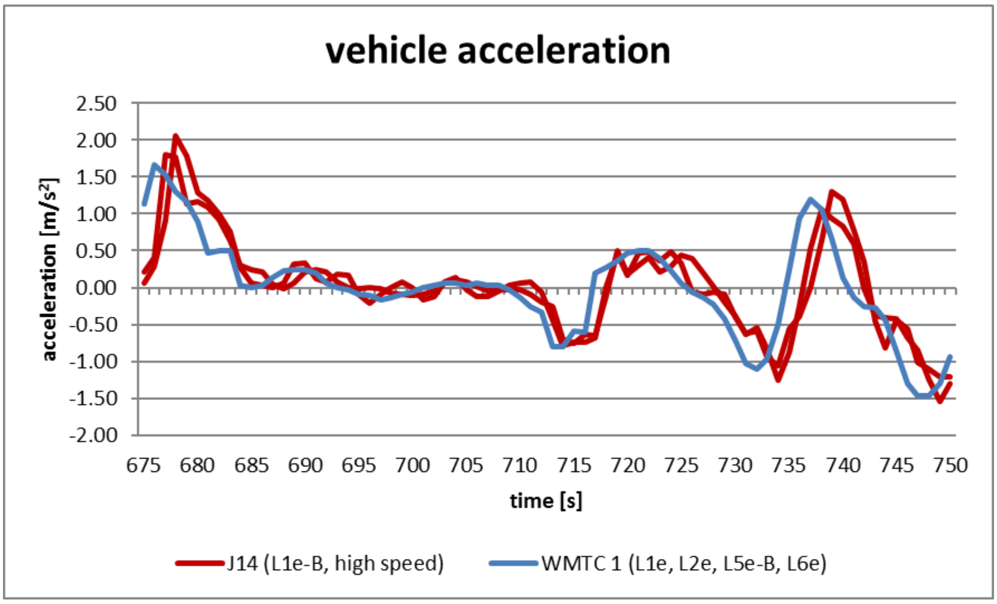

Figure 149. WMTC drivability of J14 (L1e-B, high speed moped) – vehicle acceleration zoom

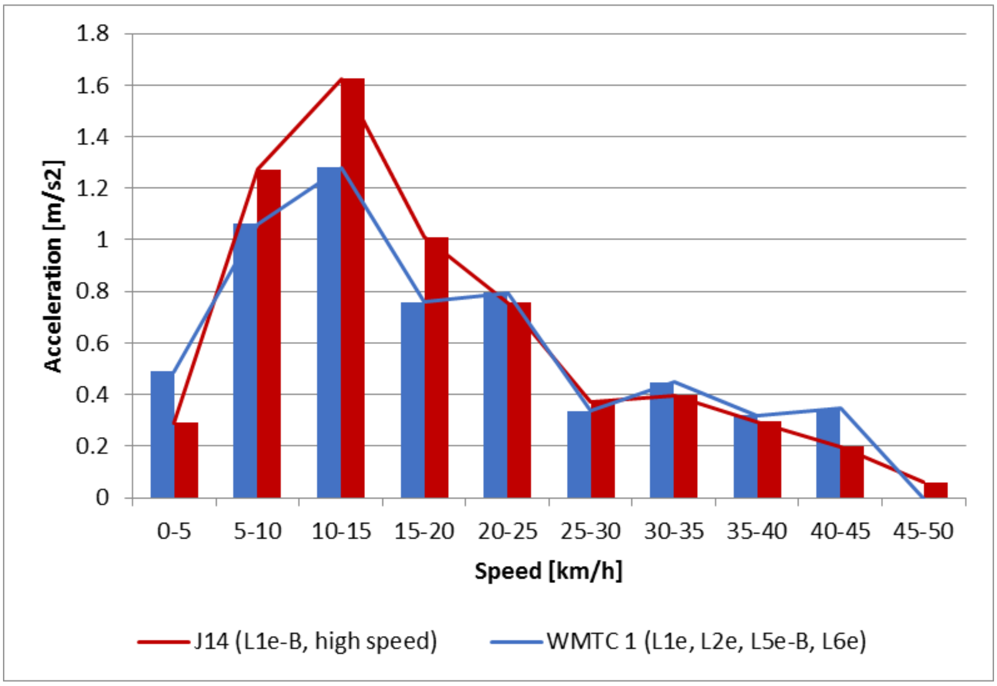

Figure 150. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J14 (L1e-B, high speed moped)

Table 91. Technical criteria for WMTC drivability assessment of J14 (L1e-B, high speed moped)

		J14 (L1e-B, high speed) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	6 (4 – 7)	-	-
	Duration (s)	15 (11 – 19)	-	-
Maximum Achievable Speed (km/h)		46 (45 – 46)	45	45
Mean Positive Acceleration (MPA) (m/s^2)		0.49 (0.48 – 0.50)	0.46	-
Driven Distance (m)		7566 (7549 – 7582)	7600	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		3.12 (3.04 – 3.20)	2.87	-

Vehicle J17 (L1e-B, high speed moped)

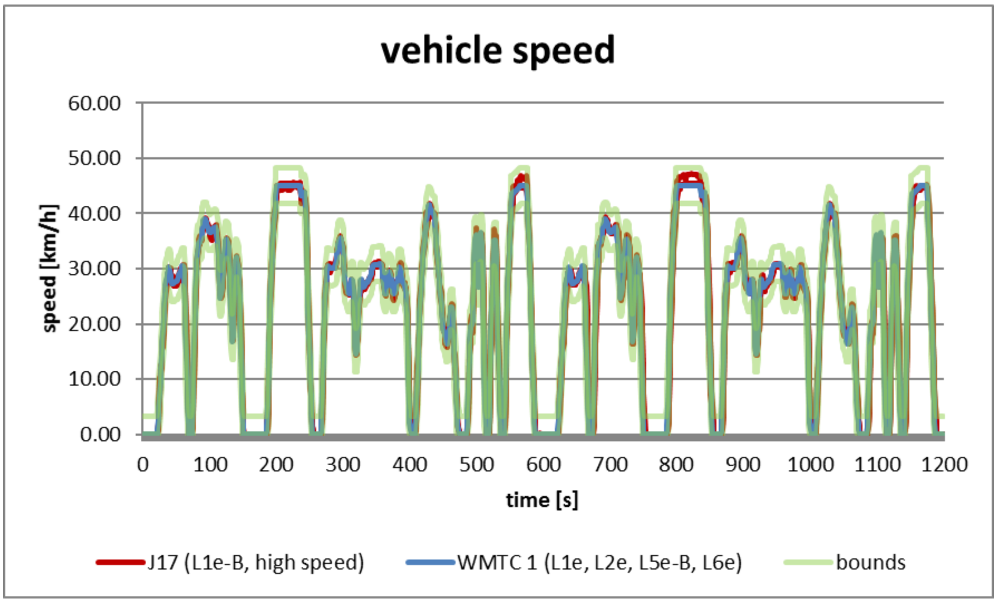

Figure 151. WMTC drivability of J17 (L1e-B, high speed moped) – vehicle speed

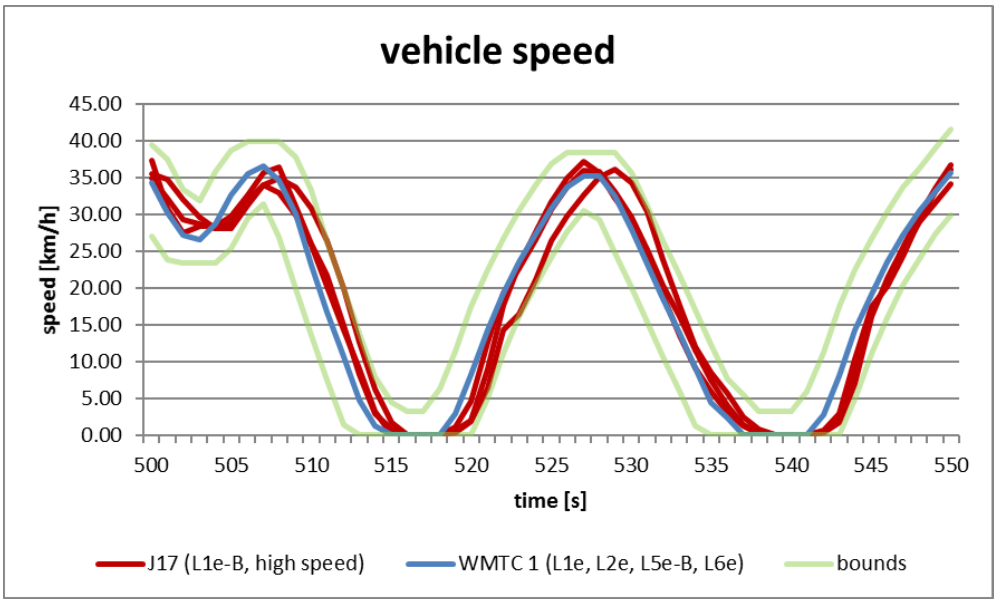

Figure 152. WMTC drivability of J17 (L1e-B, high speed moped) – vehicle speed zoom

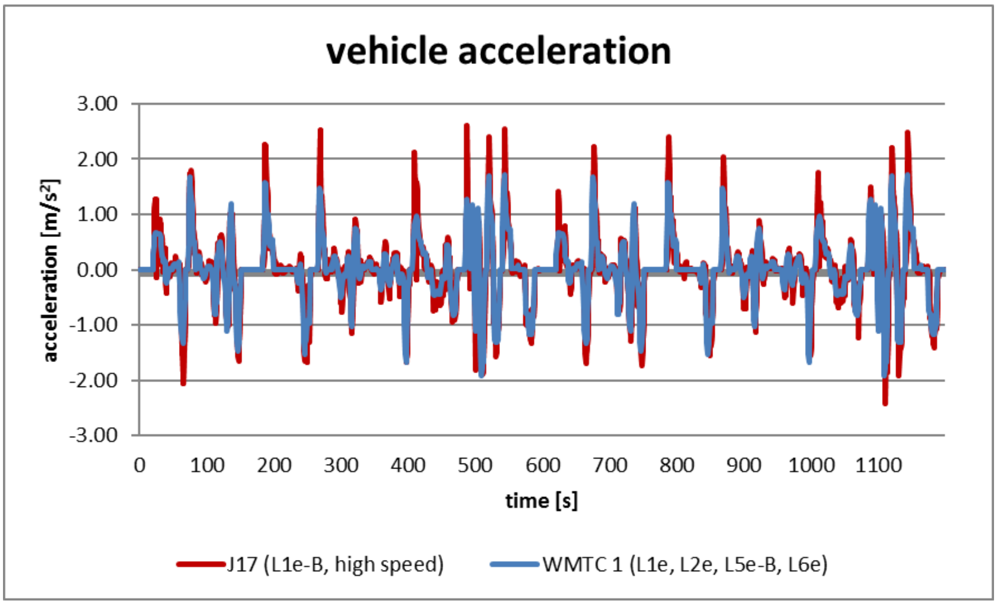

Figure 153. WMTC drivability of J17 (L1e-B, high speed moped) – vehicle acceleration

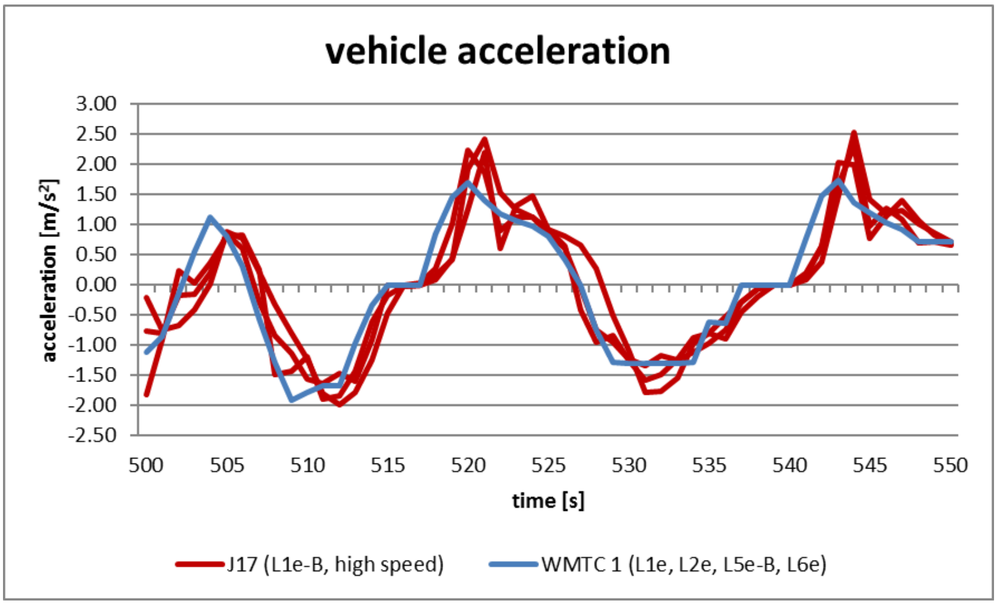

Figure 154. WMTC drivability of J17 (L1e-B, high speed moped) – vehicle acceleration zoom

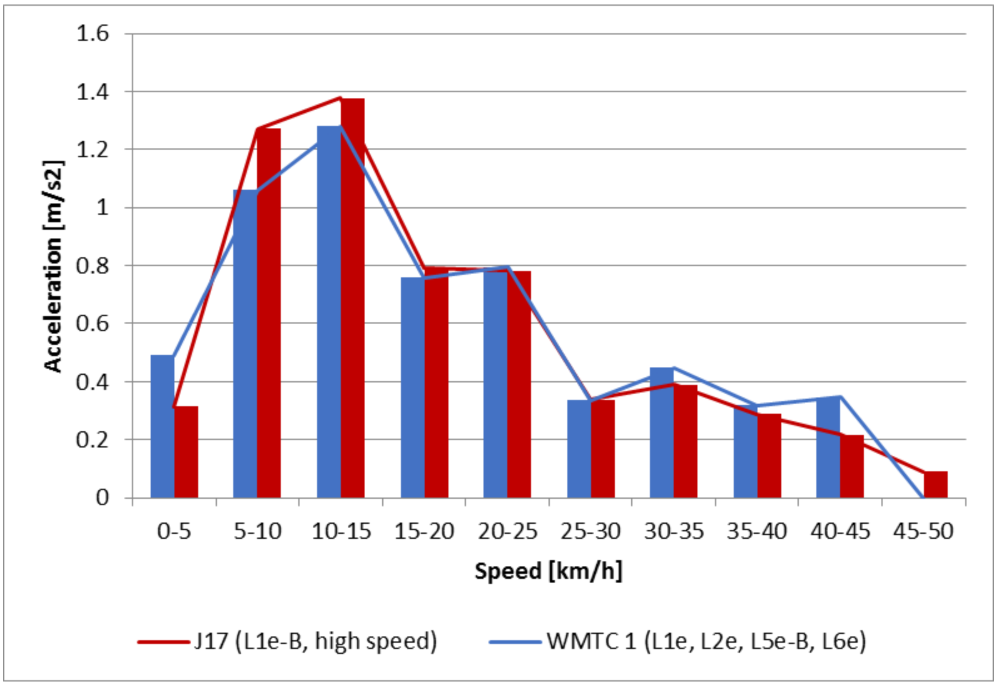

Figure 155. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J17 (L1e-B, high speed moped)

Table 92. Technical criteria for WMTC drivability assessment of J17 (L1e-B, high speed moped)

		J17 (L1e-B, high speed) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	2 (0 –7)	-	-
	Duration (s)	8 (0 – 25)	-	-
Maximum Achievable Speed (km/h)		46 (45 – 47)	45	45
Mean Positive Acceleration (MPA) (m/s^2)		0.47 (0.46 – 0.47)	0.46	-
Driven Distance (m)		7606 (7577 – 7647)	7600	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		2.94 (2.91 – 2.96)	2.87	-

Vehicle J26 (L2e-U)

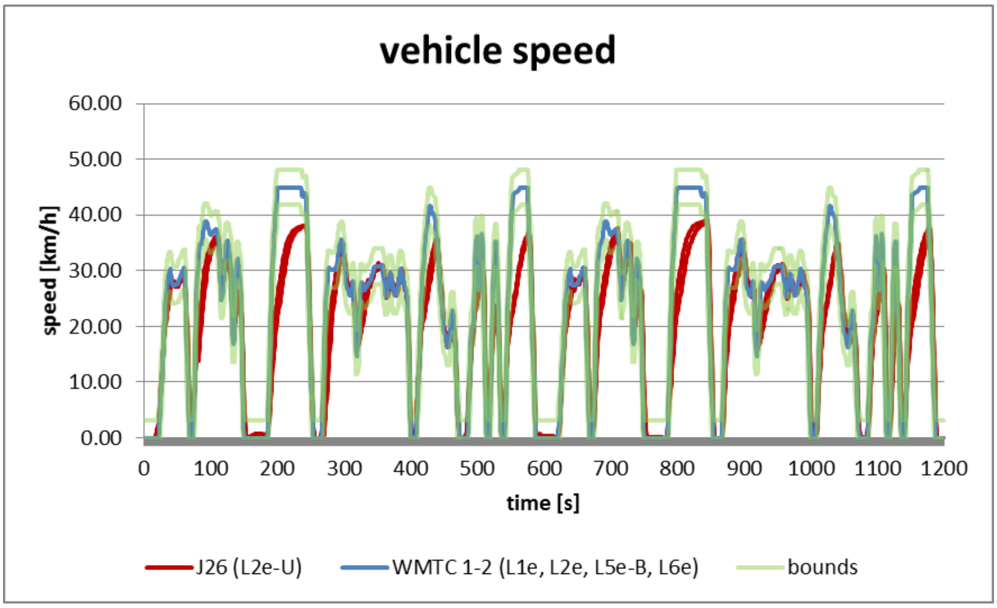

Figure 156. WMTC drivability of J26 (L2e-U) – vehicle speed

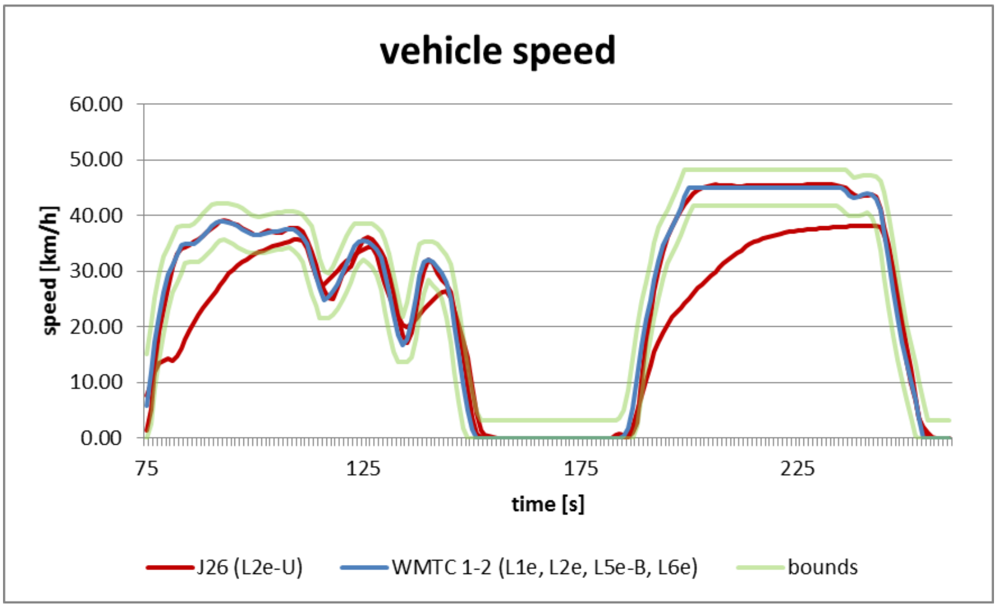

Figure 157. WMTC drivability of J26 (L2e-U) – vehicle speed zoom

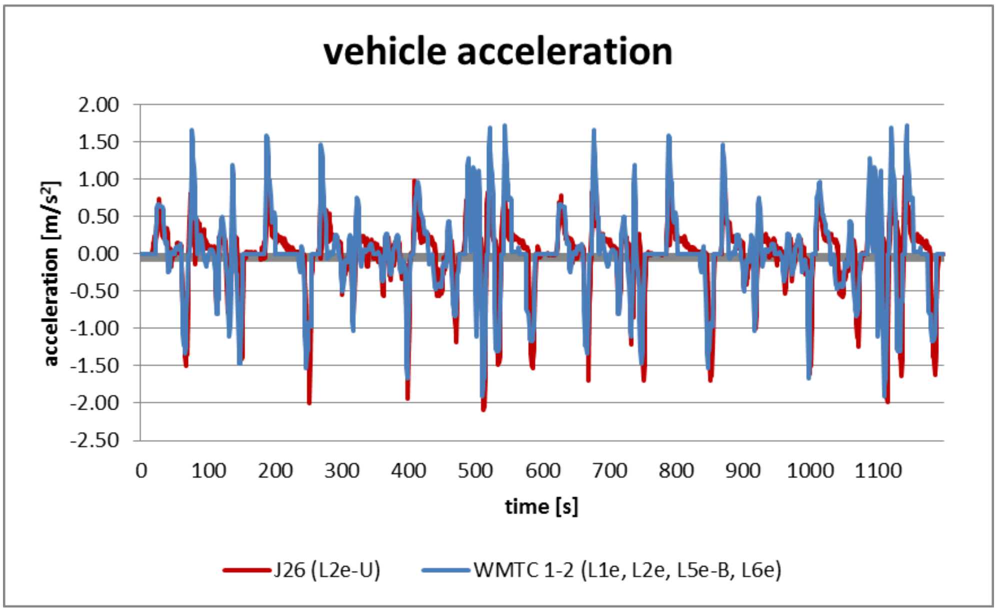

Figure 158. WMTC drivability of J26 (L2e-U) – vehicle acceleration

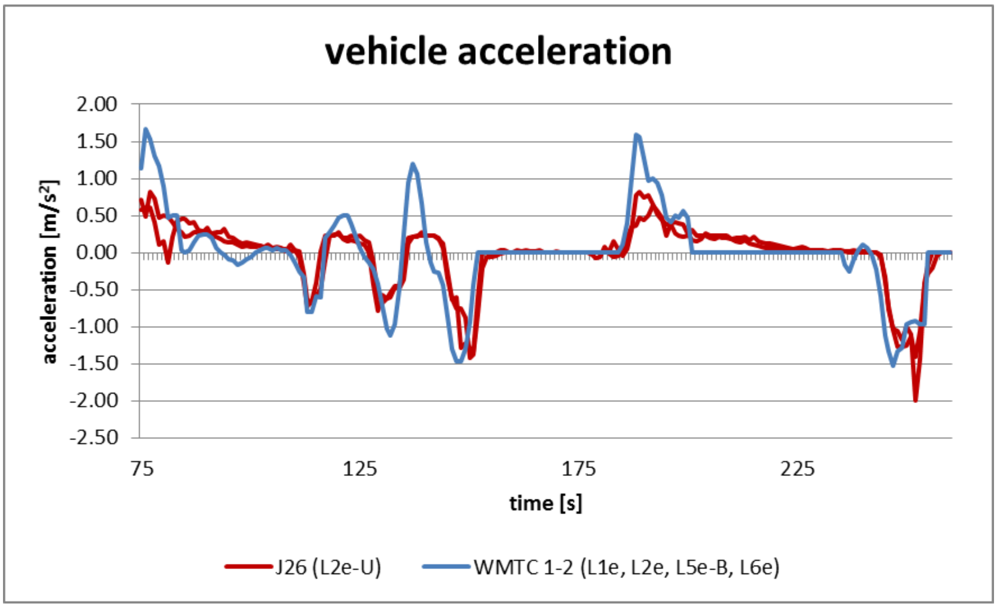

Figure 159. WMTC drivability of J26 (L2e-U) – vehicle acceleration zoom

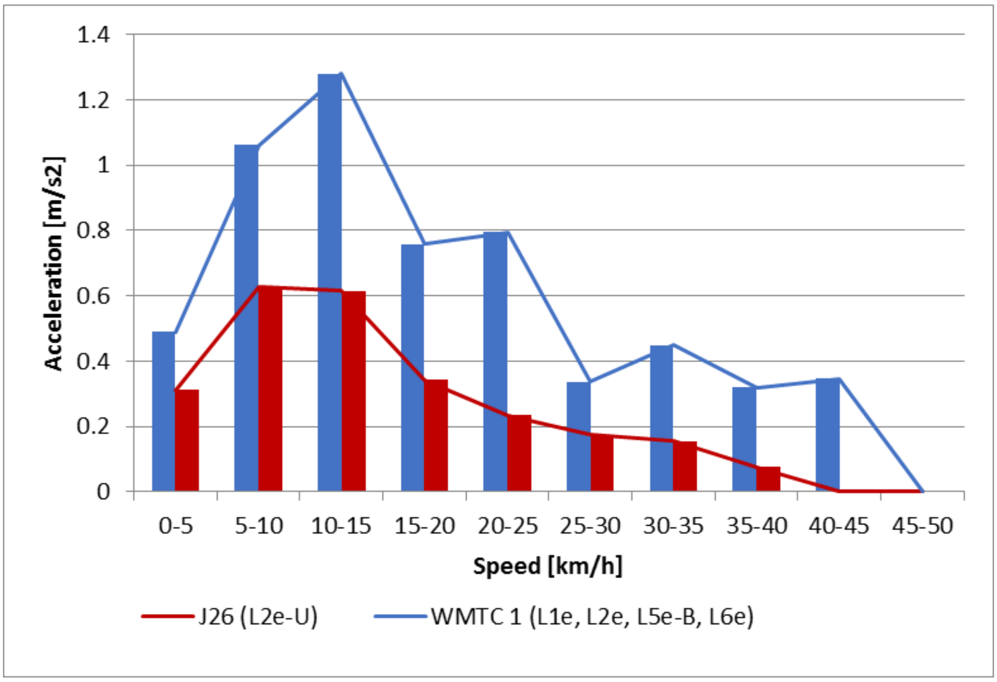

Figure 160. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J26 (L2e-U)

Table 93. Technical criteria for WMTC drivability assessment of J26 (L2e-U)

		J26 (L2e-U) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	25 (24 –25)	-	-
	Duration (s)	337 (310 – 363)	-	-
Maximum Achievable Speed (km/h)		39 (39 – 39)	45	38
Mean Positive Acceleration (MPA) (m/s^2)		0.25 (0.25 – 0.26)	0.46	-
Driven Distance (m)		6602 (6503 – 6702)	7600	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		1.32 (1.29 – 1.35)	2.87	-

Vehicle J27, valid. (L2e-U)

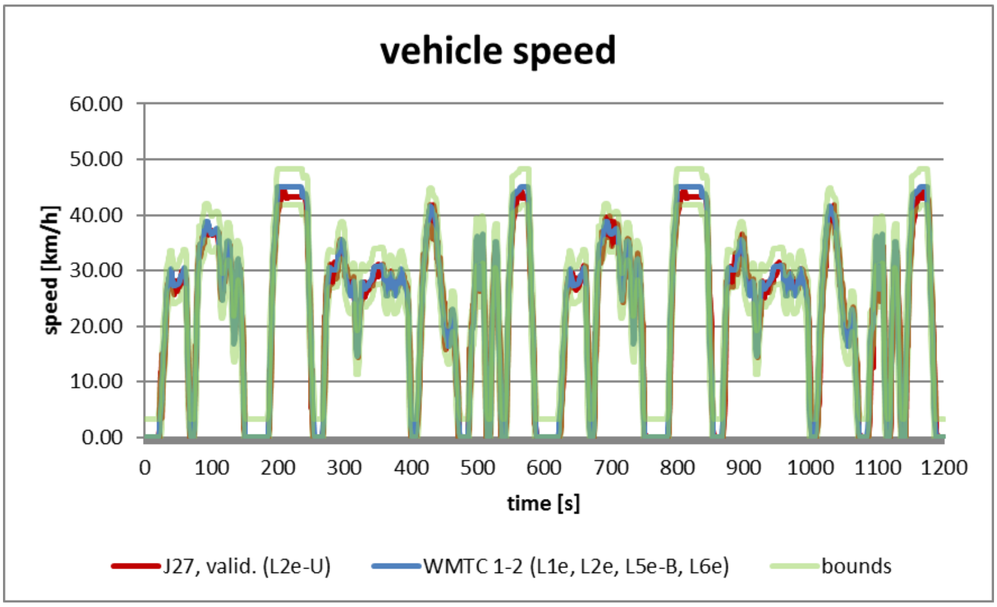

Figure 161. WMTC drivability of J27, valid. (L2e-U) – vehicle speed

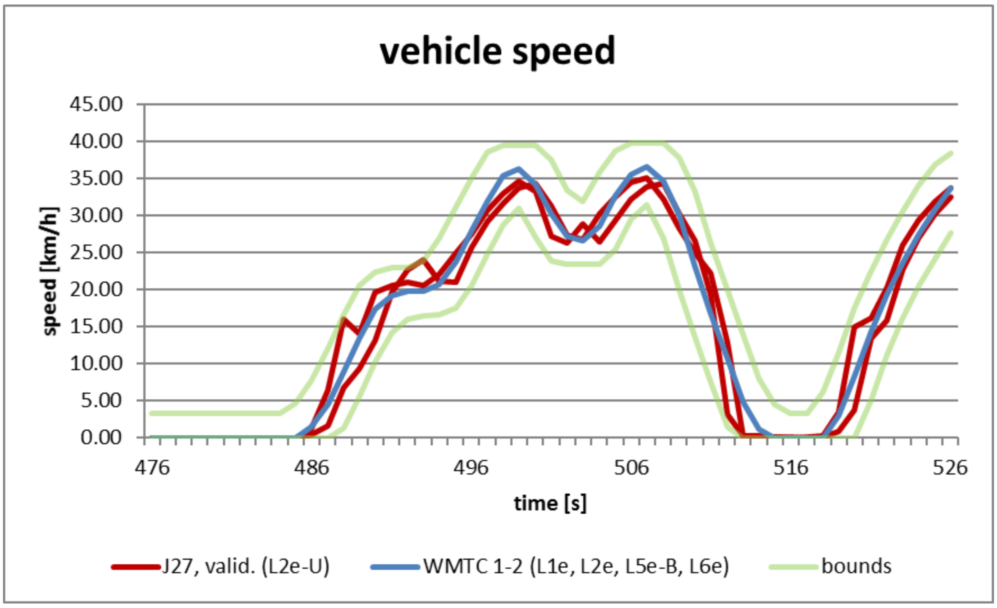

Figure 162. WMTC drivability of J27, valid. (L2e-U) – vehicle speed zoom

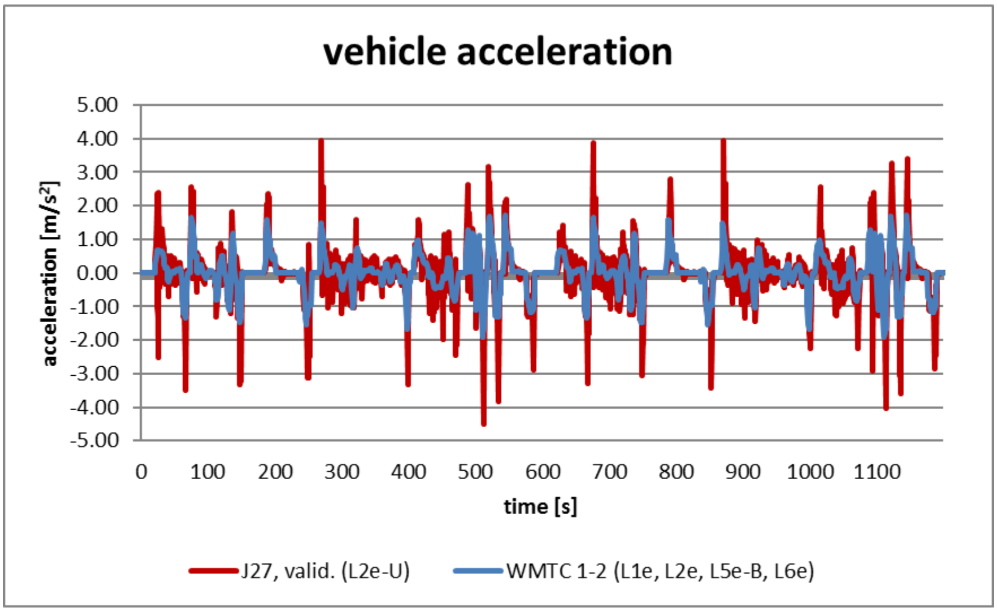

Figure 163. WMTC drivability of J27, valid. (L2e-U) – vehicle acceleration

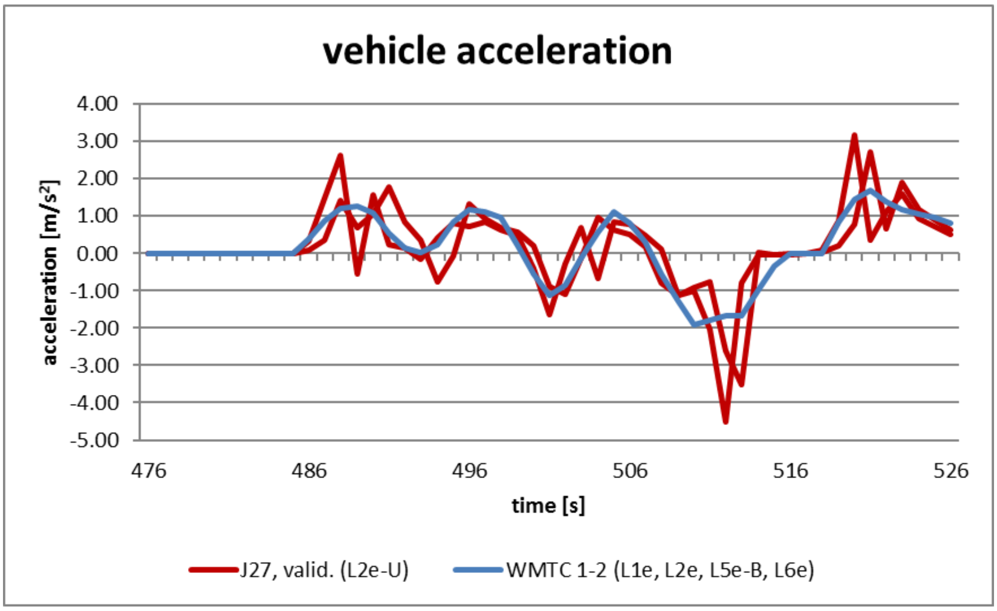

Figure 164. WMTC drivability of J27, valid. (L2e-U) – vehicle acceleration zoom

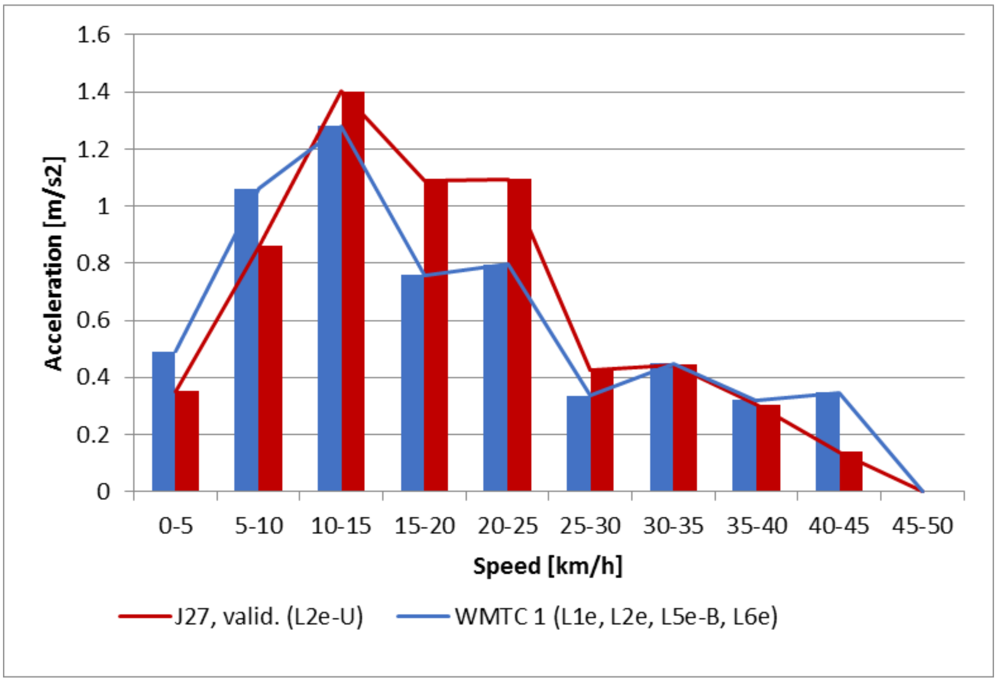

Figure 165. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J27, valid. (L2e-U)

Table 94. Technical criteria for WMTC drivability assessment of J27, valid. (L2e-U)

		J27, valid. (L2e-U) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	5 (4 –6)	-	-
	Duration (s)	11 (9 – 13)	-	-
Maximum Achievable Speed (km/h)		45 (45 – 45)	45	45
Mean Positive Acceleration (MPA) (m/s^2)		0.52 (0.51 – 0.53)	0.46	-
Driven Distance (m)		7470 (7461 – 7479)	7600	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		3.37 (3.31 – 3.42)	2.87	-

Vehicle J24 (L5e-A)

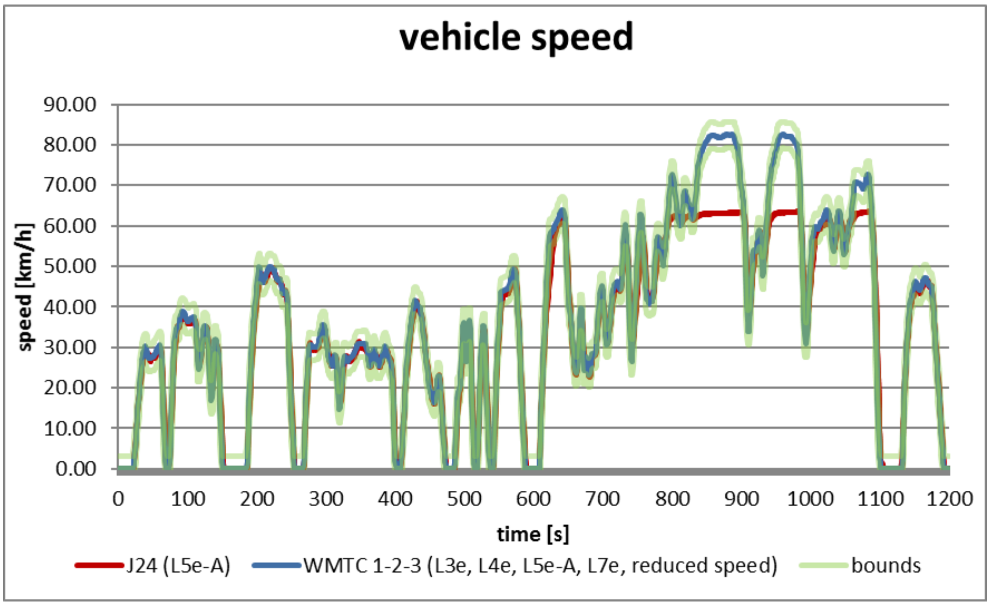

Figure 166. WMTC drivability of J24 (L5e-A) – vehicle speed

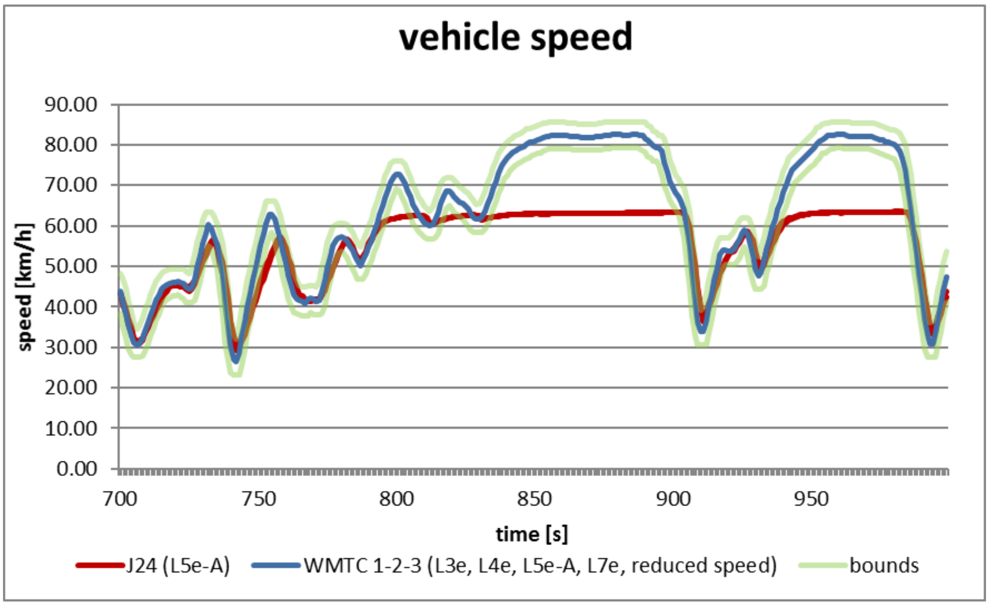

Figure 167. WMTC drivability of J24 (L5e-A) – vehicle speed zoom

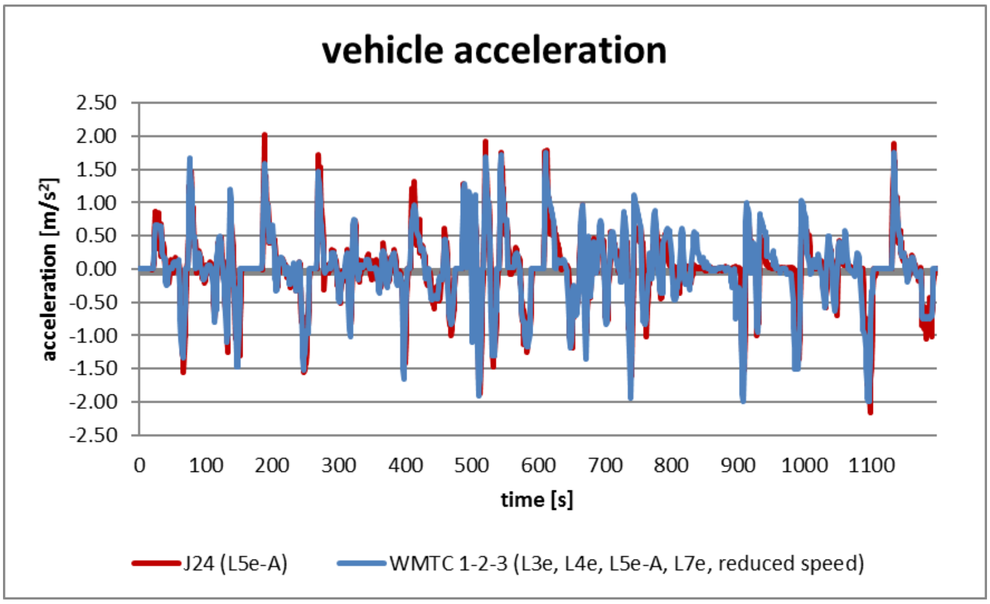

Figure 168. WMTC drivability of J24 (L5e-A) – vehicle acceleration

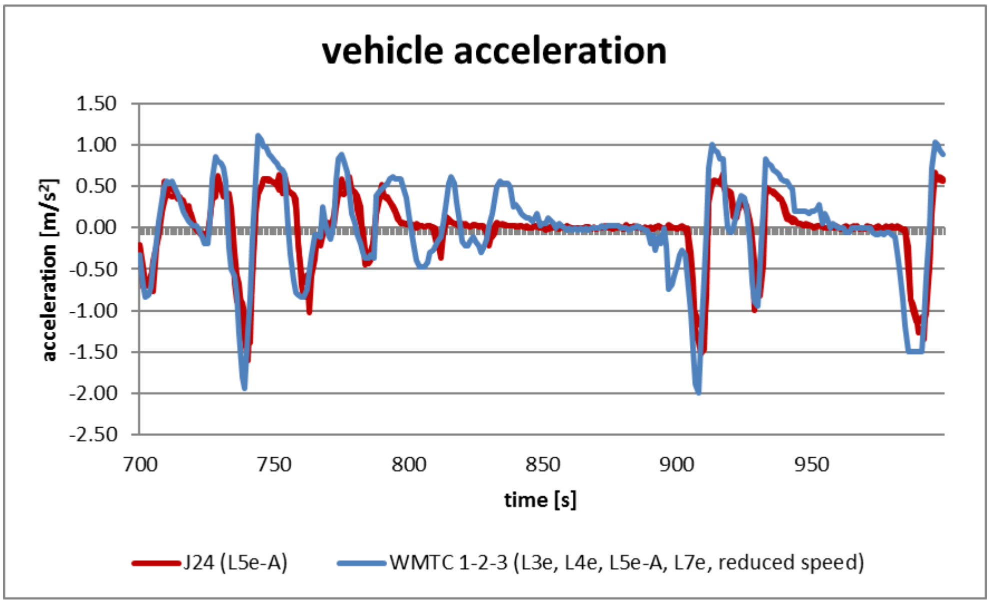

Figure 169. WMTC drivability of J24 (L5e-A) – vehicle acceleration zoom

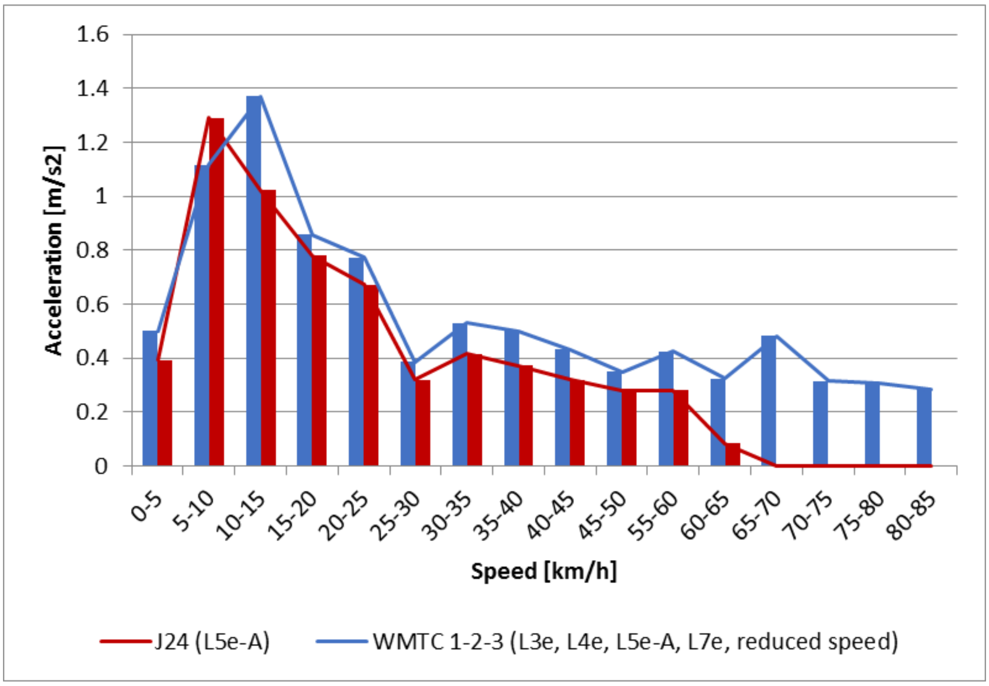

Figure 170. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J24 (L5e-A)

Table 95. Technical criteria for WMTC drivability assessment of J24 (L5e-A)

		J24 (L5e-A) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	8 (8 – 8)	-	-
	Duration (s)	43 (36 – 49)	-	-
Maximum Achievable Speed (km/h)		64 (64 – 64)	82.50	55
Mean Positive Acceleration (MPA) (m/s^2)		0.39 (0.38 – 0.40)	0.43	-
Driven Distance (m)		11577 (11570–11585)	12287	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		3.33 (3.25 – 3.40)	4.17	-

Vehicle L01 (L5e-A)

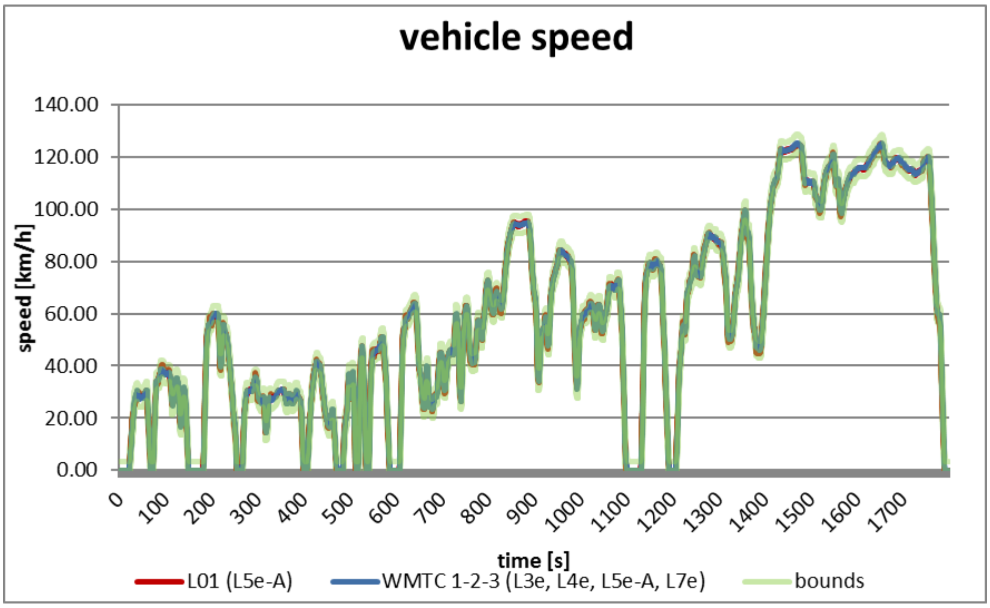

Figure 171. WMTC drivability of L01 (L5e-A) – vehicle speed

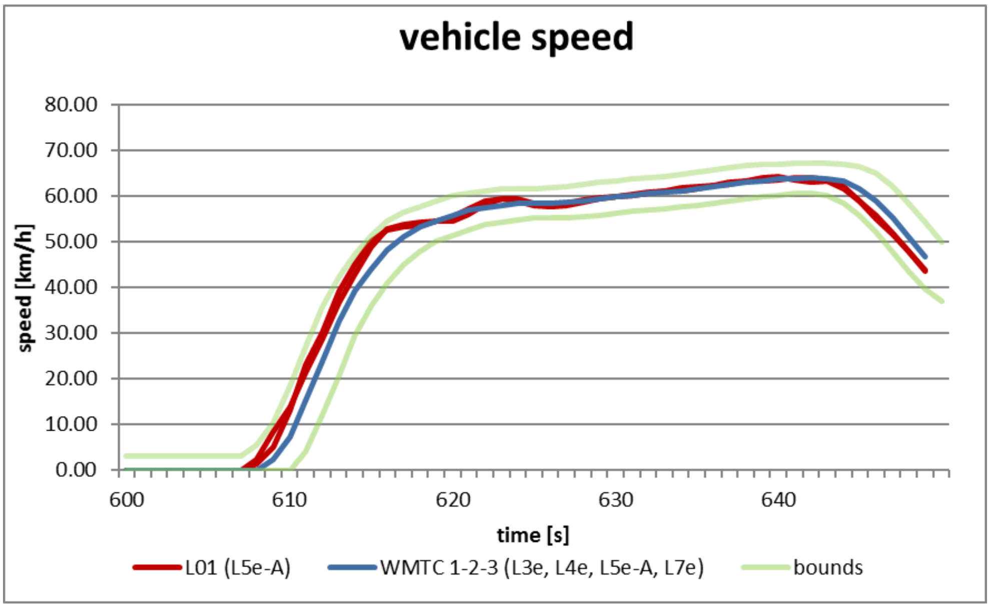

Figure 172. WMTC drivability of L01 (L5e-A) – vehicle speed zoom

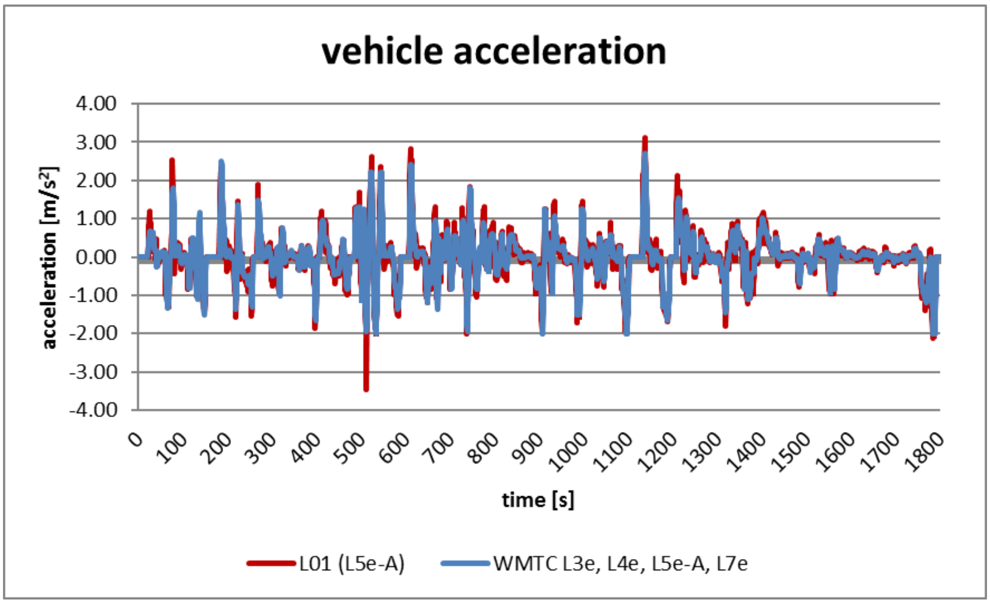

Figure 173. WMTC drivability of L01 (L5e-A) – vehicle acceleration

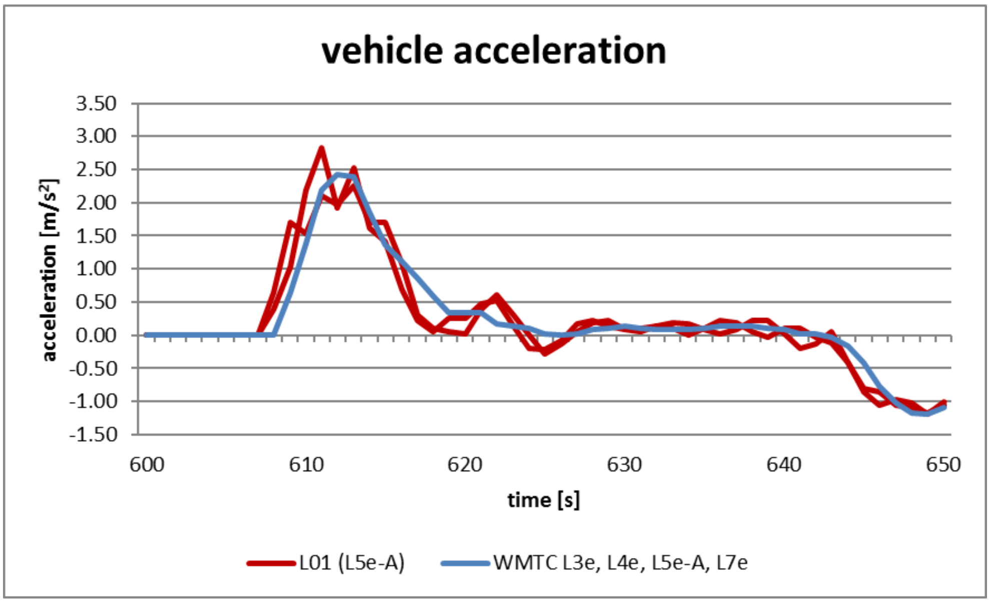

Figure 174. WMTC drivability of L01 (L5e-A) – vehicle acceleration zoom

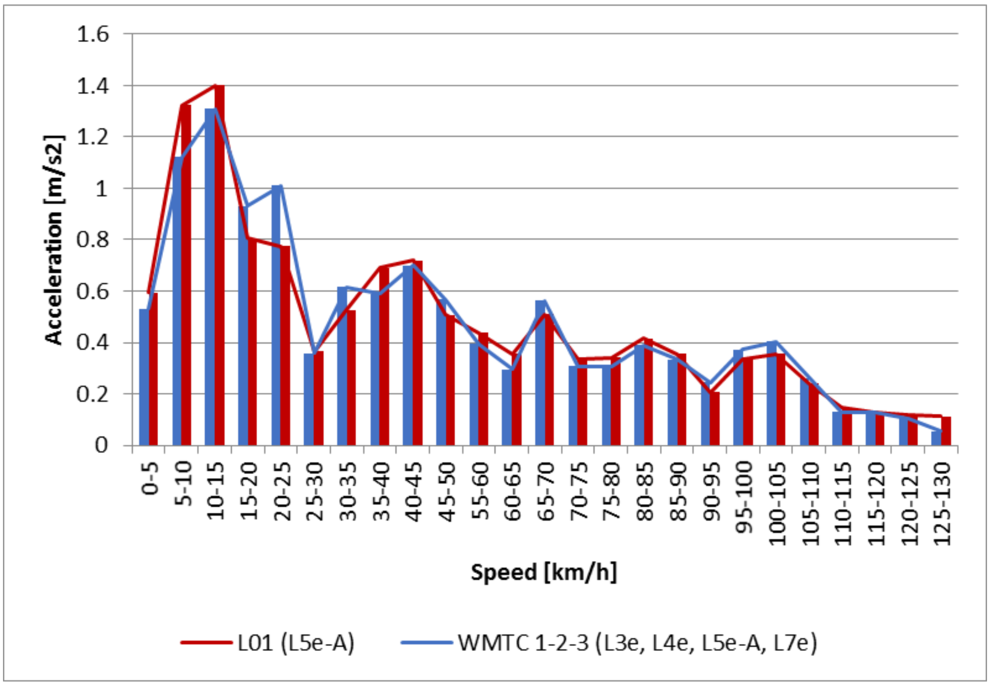

Figure 175. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of L01 (L5e-A)

Table 96. Technical criteria for WMTC drivability assessment of L01 (L5e-A)

		L01 (L5e-A) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	0 (0 – 0)	-	-
	Duration (s)	0 (0 – 0)	-	-
Maximum Achievable Speed (km/h)		125 (125 – 125)	125	180
Mean Positive Acceleration (MPA) (m/s^2)		0.44 (0.44 – 0.44)	0.39	-
Driven Distance (m)		28857 (28856–28859)	28915	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		5.98 (5.96 – 6.00)	5.18	-

Vehicle J01 (L6e-BP)

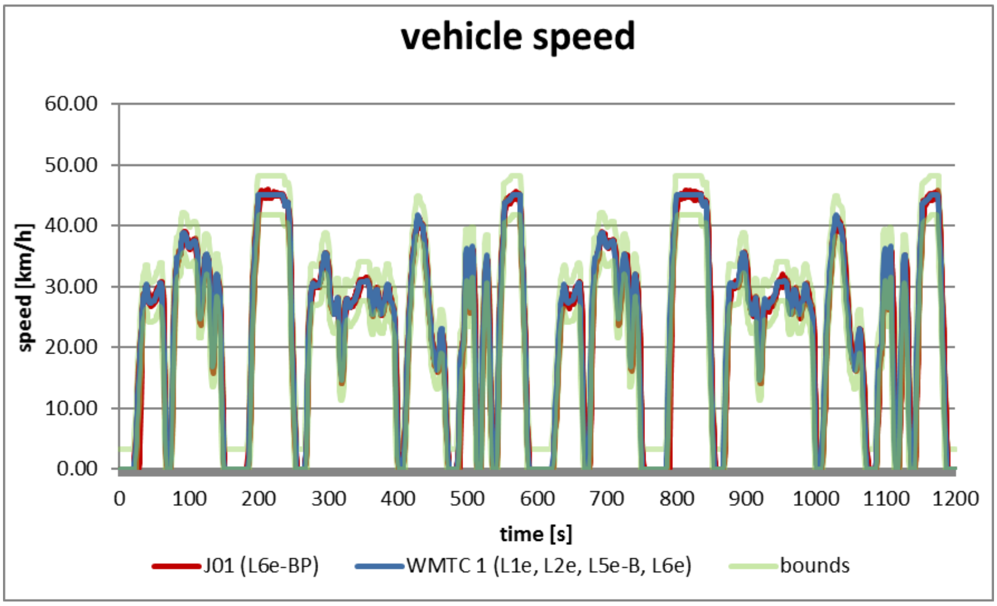

Figure 176. WMTC drivability of J01 (L6e-BP) – vehicle speed

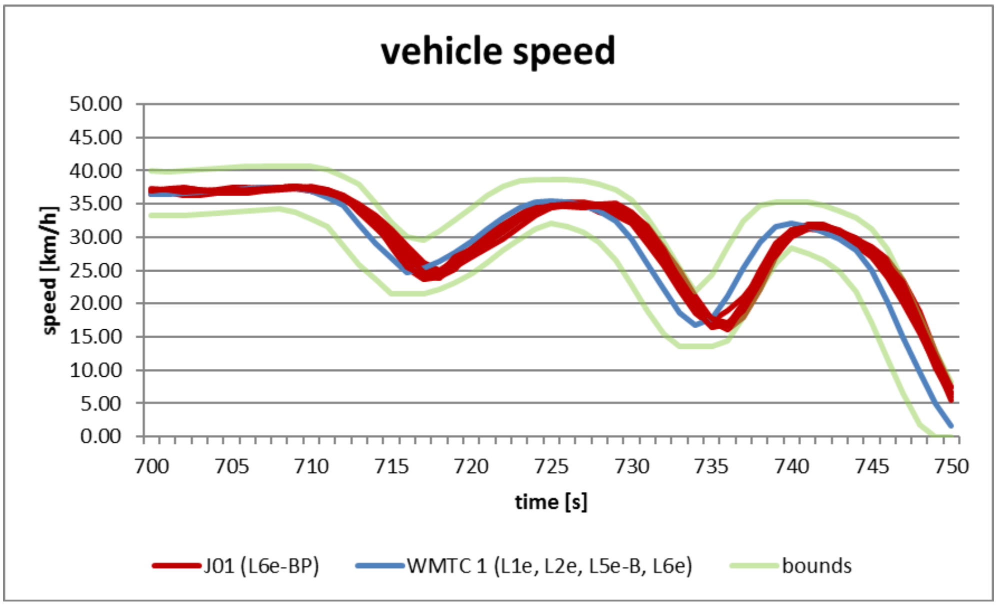

Figure 177. WMTC drivability of J01 (L6e-BP) – vehicle speed zoom

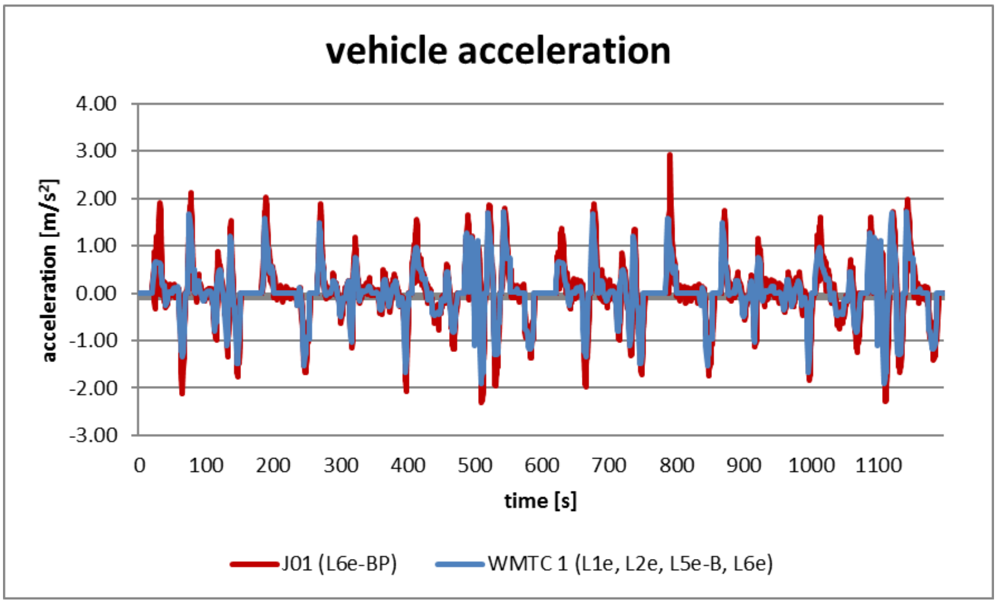

Figure 178. WMTC drivability of J01 (L6e-BP) – vehicle acceleration

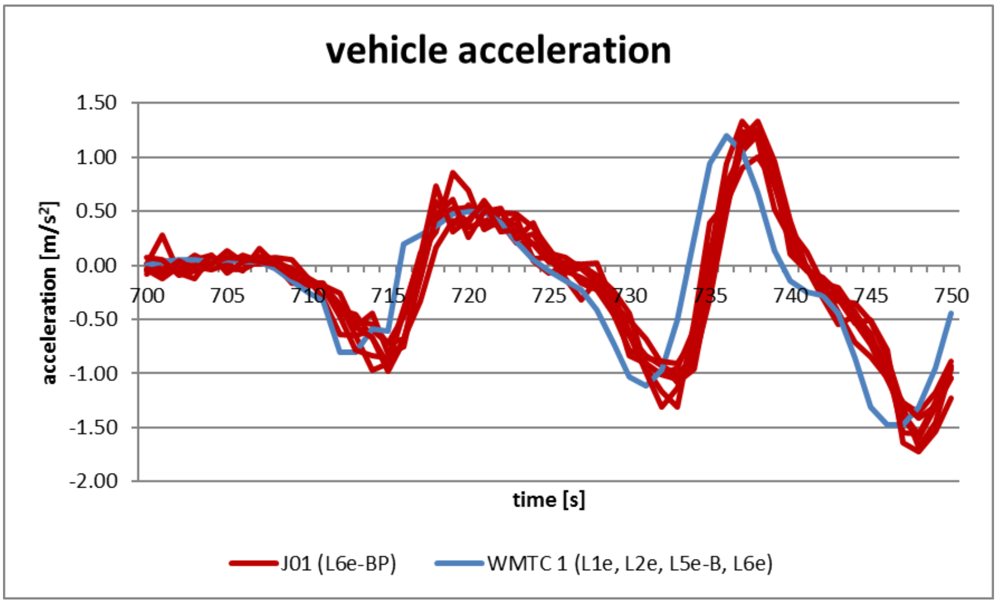

Figure 179. WMTC drivability of J01 (L6e-BP) – vehicle acceleration zoom

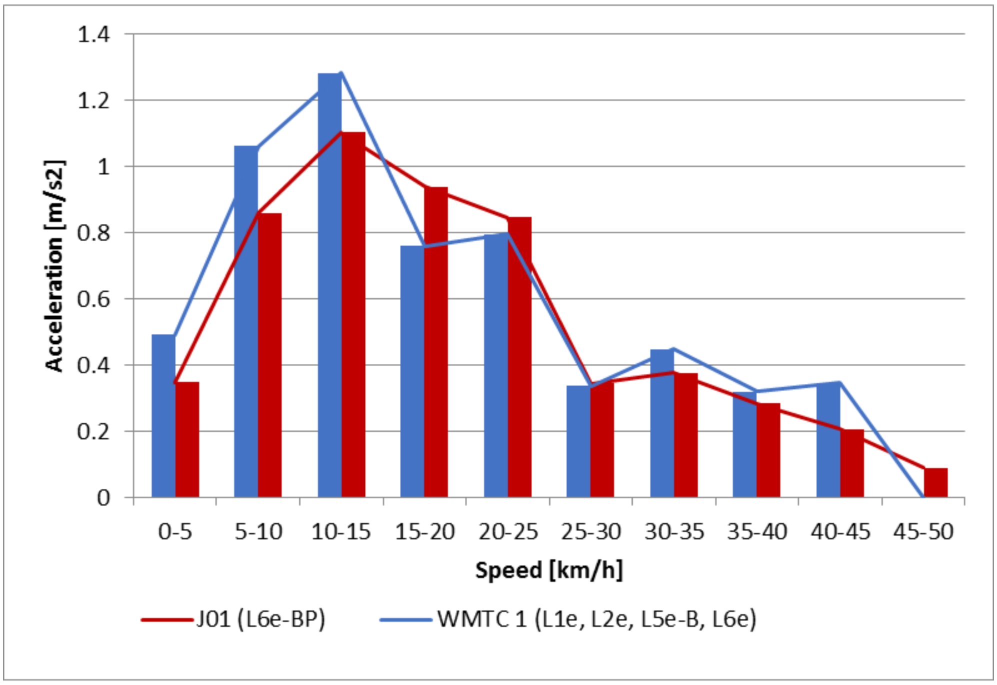

Figure 180. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J01 (L6e-BP)

Table 97. Technical criteria for WMTC drivability assessment of J01 (L6e-BP)

		J01 (L6e-BP) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	2 (0 – 5)	-	-
	Duration (s)	5 (0 – 16)	-	-
Maximum Achievable Speed (km/h)		46 (45 – 46)	45	45
Mean Positive Acceleration (MPA) (m/s^2)		0.46 (0.45 – 0.48)	0.46	-
Driven Distance (m)		7581 (7563 – 7603)	7600	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		2.89 (2.78 – 2.99)	2.87	-

Vehicle J22 (L6e-BU)

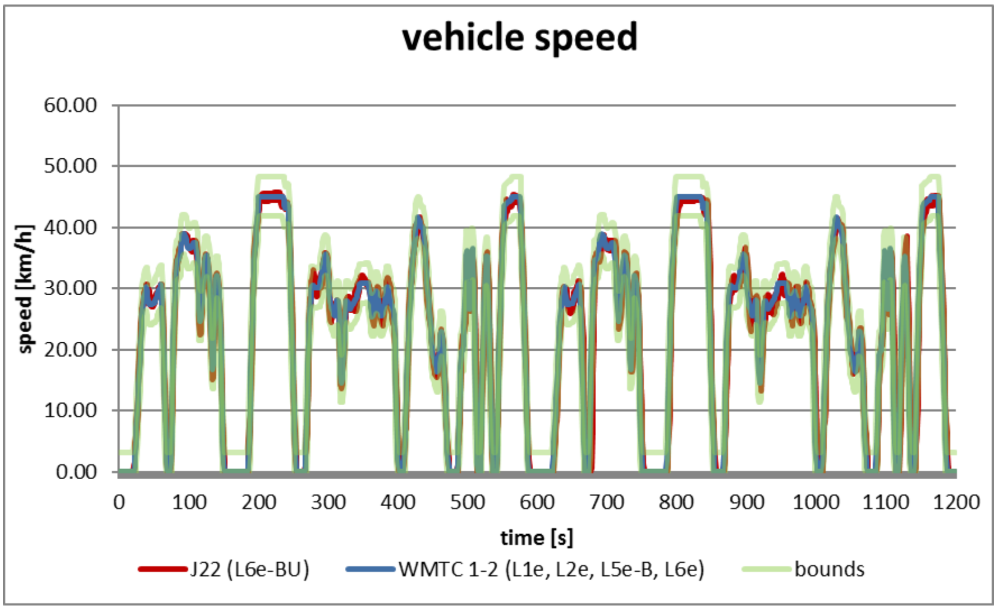

Figure 181. WMTC drivability of J22 (L6e-BU) – vehicle speed

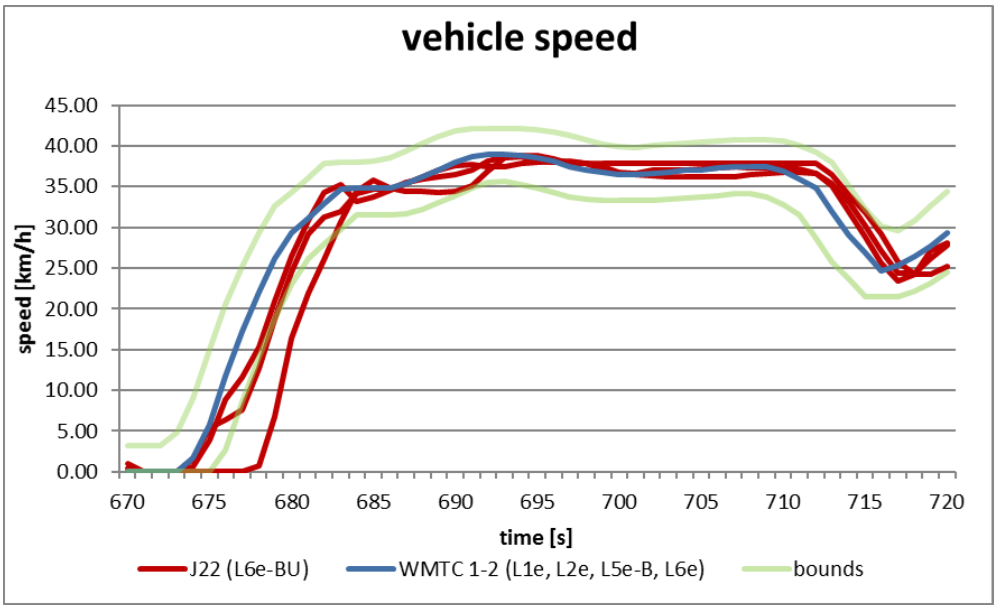

Figure 182. WMTC drivability of J22 (L6e-BU) – vehicle speed zoom

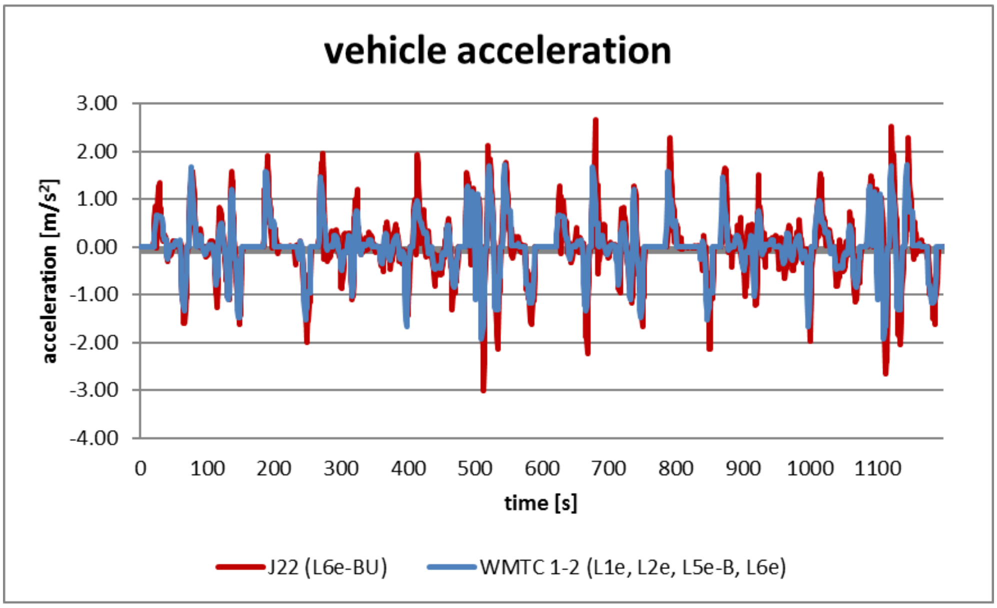

Figure 183. WMTC drivability of J22 (L6e-BU) – vehicle acceleration

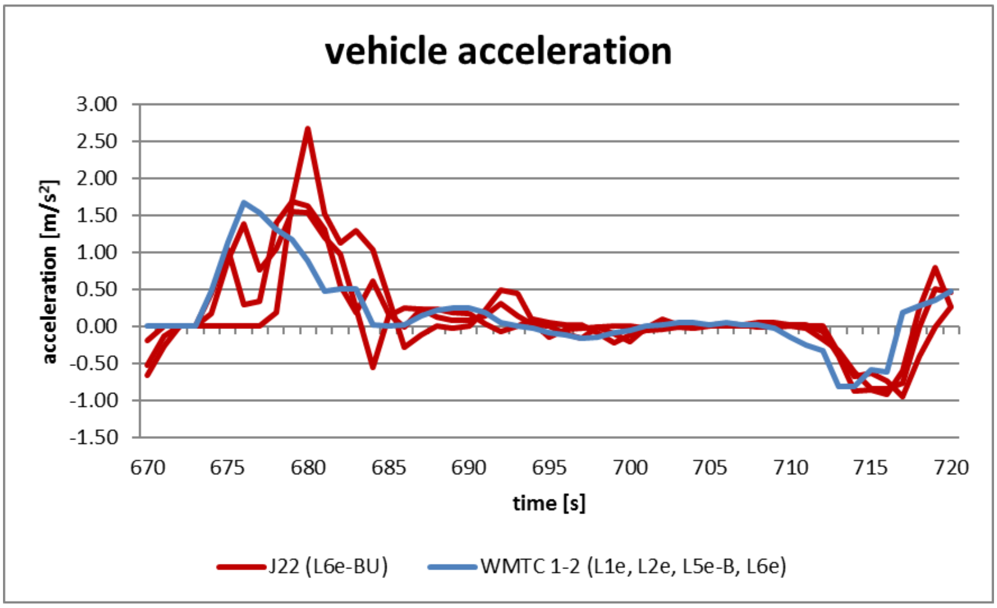

Figure 184. WMTC drivability of J22 (L6e-BU) – vehicle acceleration zoom

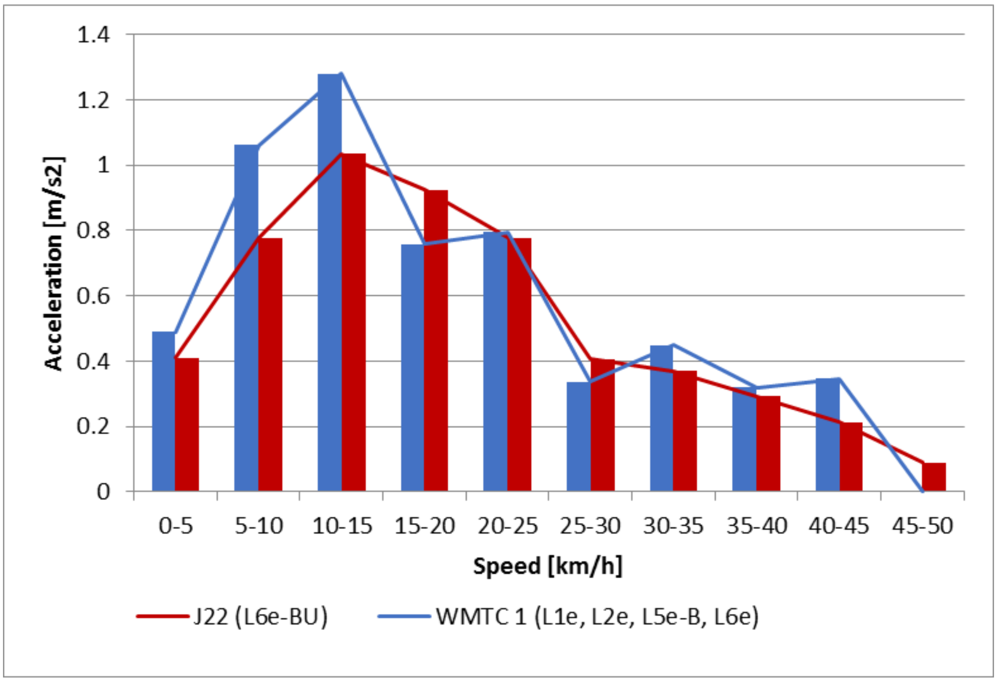

Figure 185. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J22 (L6e-BU)

Table 98. Technical criteria for WMTC drivability assessment of J22 (L6e-BU)

		J22 (L6e-BU) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	5 (5 – 6)	-	-
	Duration (s)	13 (11 – 16)	-	-
Maximum Achievable Speed (km/h)		45 (45 – 46)	45	45
Mean Positive Acceleration (MPA) (m/s^2)		0.49 (0.48 – 0.50)	0.46	-
Driven Distance (m)		7591 (7548 – 7673)	7600	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		3.06 (3.00 – 3.13)	2.87	-

Vehicle J08 (L7e-B1)

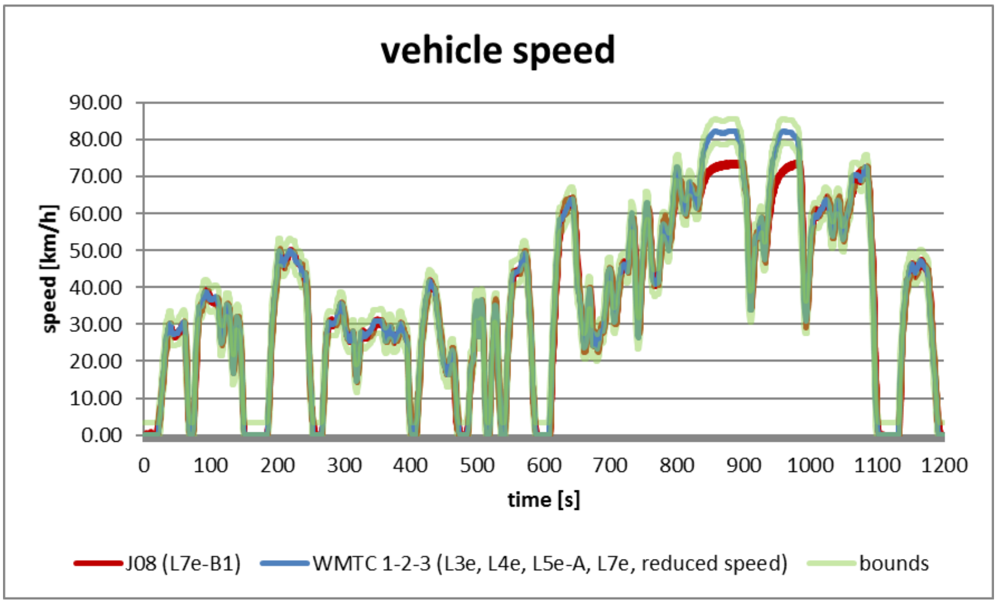

Figure 186. WMTC drivability of J08 (L7e-B1) – vehicle speed

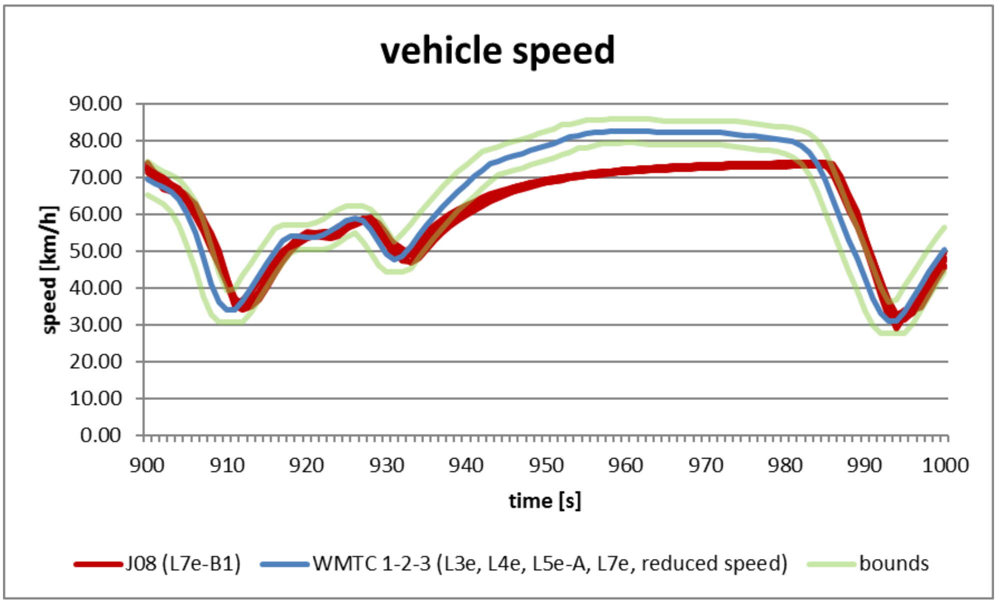

Figure 187. WMTC drivability of J08 (L7e-B1) – vehicle speed zoom

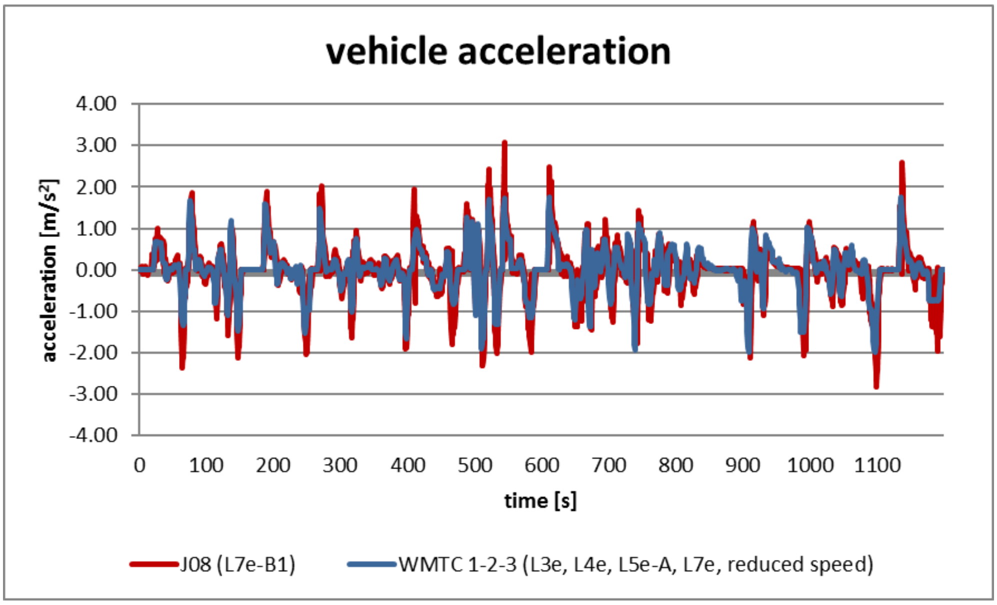

Figure 188. WMTC drivability of J08 (L7e-B1) – vehicle acceleration

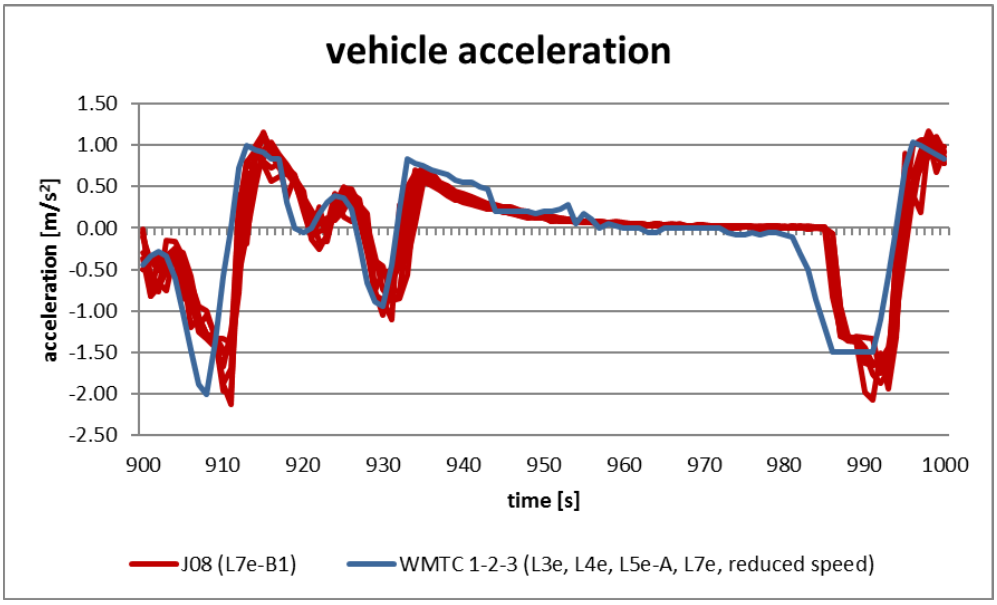

Figure 189. WMTC drivability of J08 (L7e-B1) – vehicle acceleration zoom

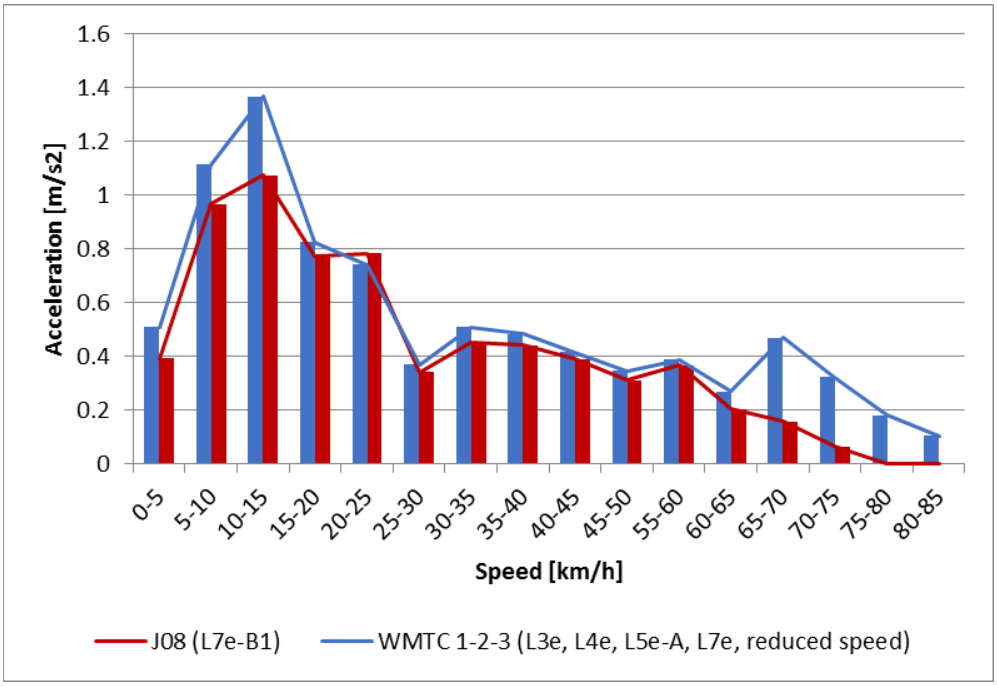

Figure 190. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J08 (L7e-B1)

Table 99. Technical criteria for WMTC drivability assessment of J08 (L7e-B1)

		J08 (L7e-B1) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	9 (6 – 11)	-	-
	Duration (s)	100 (22 – 158)	-	-
Maximum Achievable Speed (km/h)		74 (73 – 74)	82.50	70
Mean Positive Acceleration (MPA) (m/s^2)		0.40 m/s^2 (0.38m/s^2 – 0.43m/s^2)	0.43	-
Driven Distance (m)		12228 (11904 – 12707)	12287	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		3.92 (3.54 – 4.27)	4.17	-

Vehicle J16 (L7e-B1)

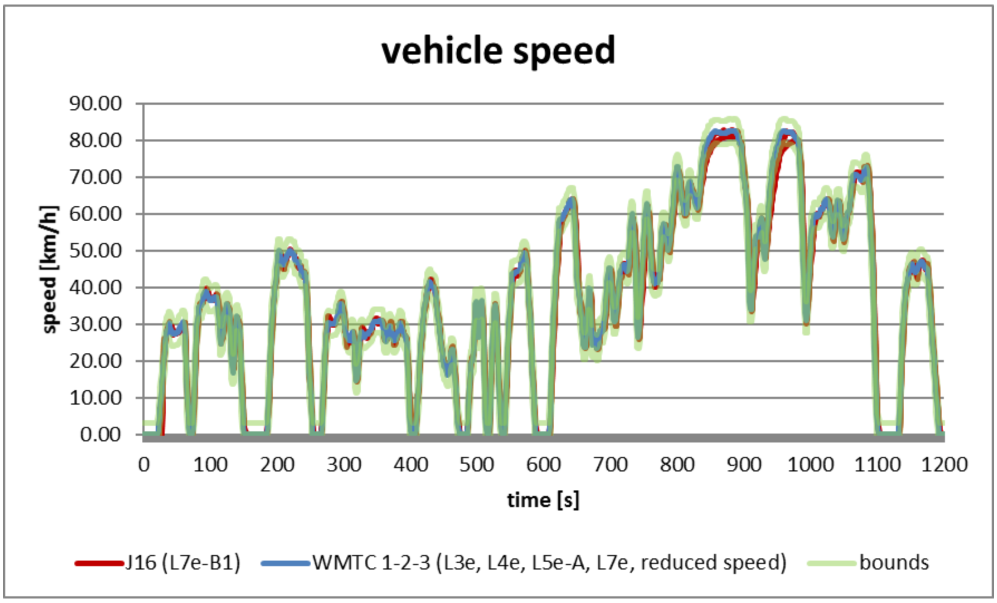

Figure 191. WMTC drivability of J16 (L7e-B1) – vehicle speed

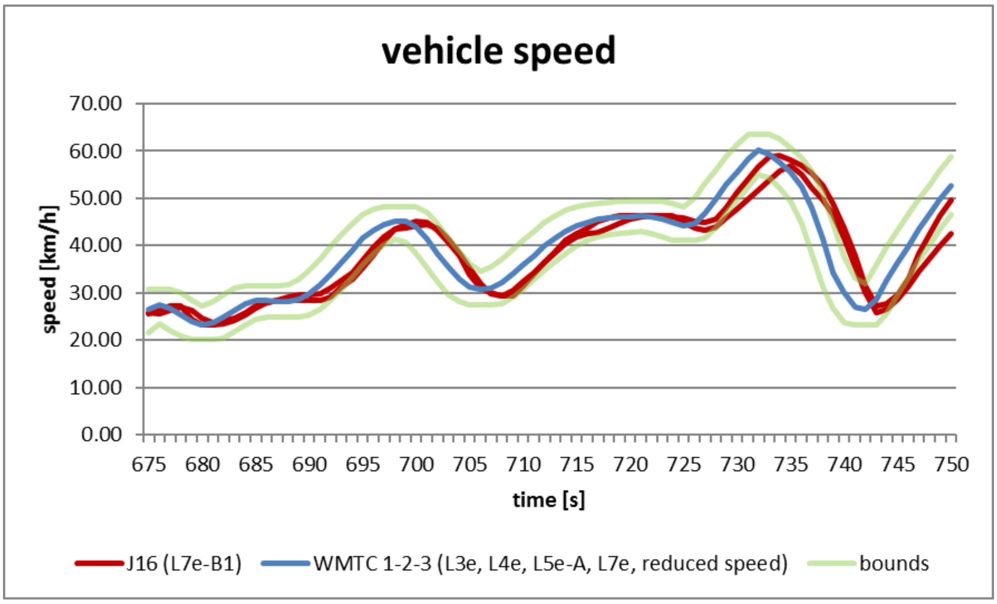

Figure 192. WMTC drivability of J16 (L7e-B1) – vehicle speed zoom

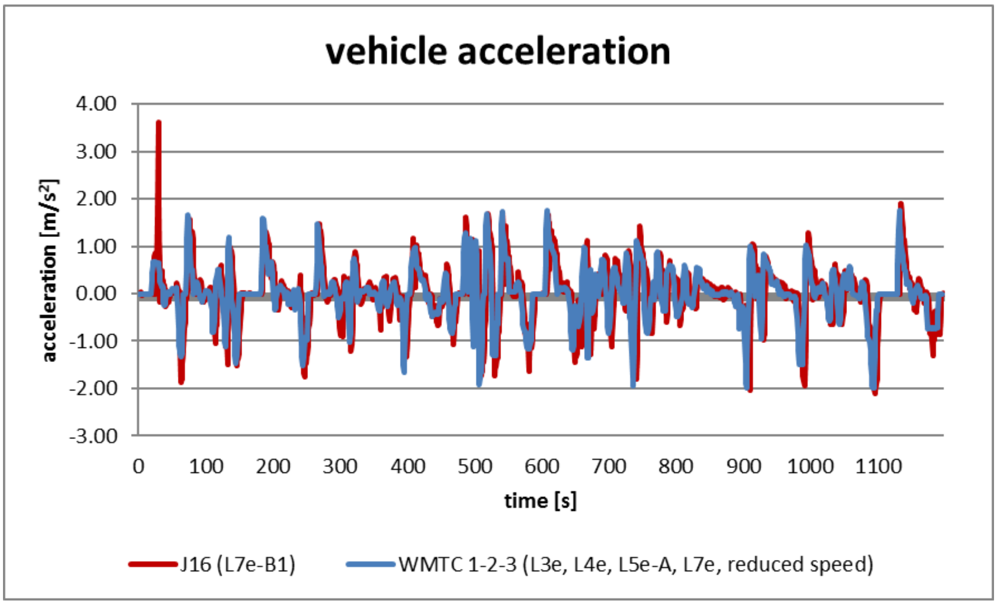

Figure 193. WMTC drivability of J16 (L7e-B1) – vehicle acceleration

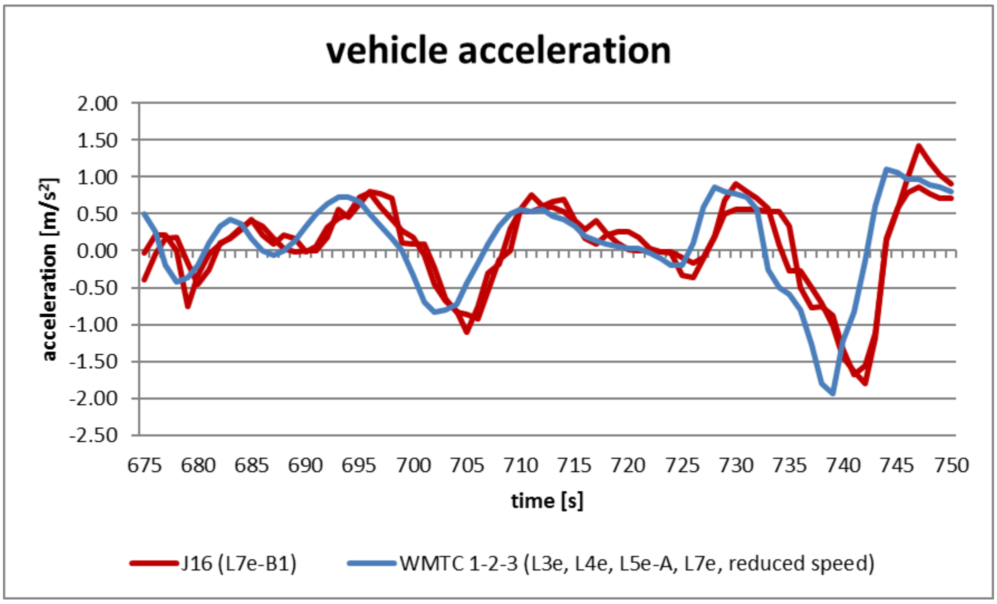

Figure 194. WMTC drivability of J16 (L7e-B1) – vehicle acceleration zoom

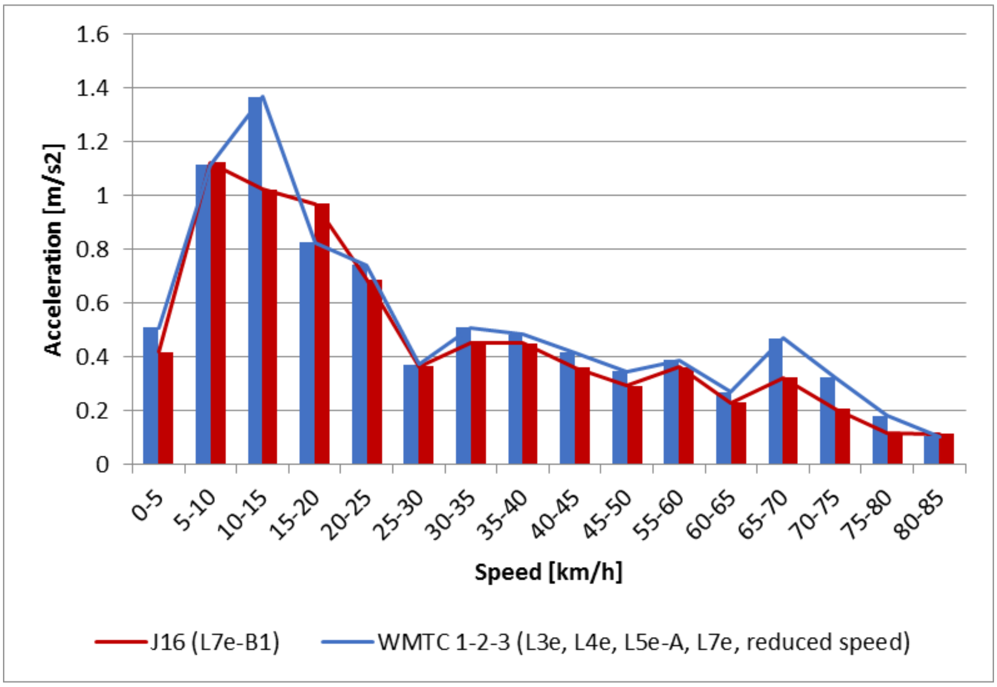

Figure 195. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J16 (L7e-B1)

Table 100. Technical criteria for WMTC drivability assessment of J16 (L7e-B1)

		J16 (L7e-B1) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	10 (5 – 15)	-	-
	Duration (s)	67 (54 – 80)	-	-
Maximum Achievable Speed (km/h)		82 (81 – 83)	82.50	65
Mean Positive Acceleration (MPA) (m/s^2)		0.42 (0.41 – 0.43)	0.43	-
Driven Distance (m)		12215 (12169 – 12260)	12287	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		4.06 (3.97 – 4.14)	4.17	-

Vehicle J25, valid. (L7e-B1)

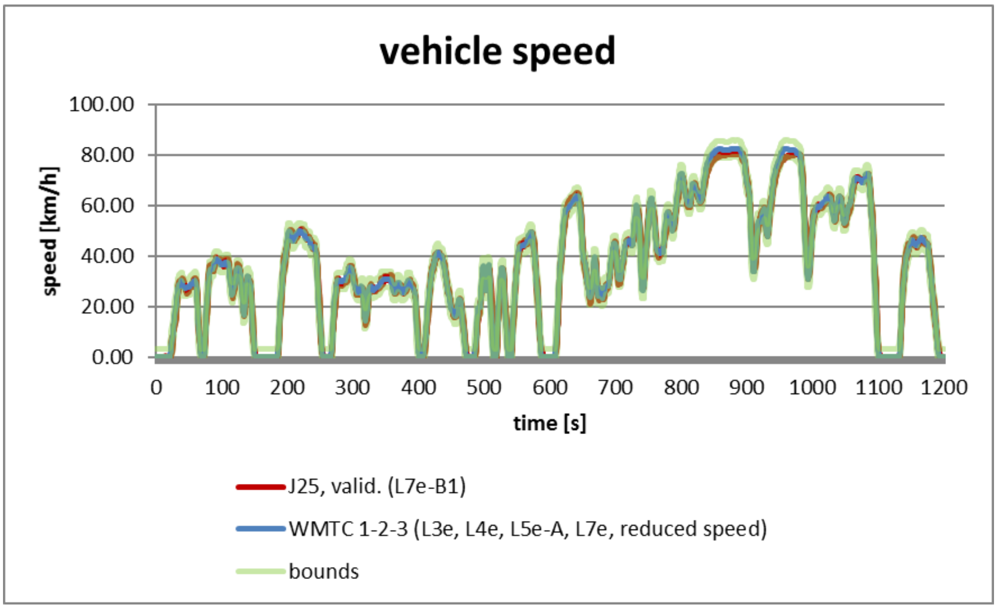

Figure 196. WMTC drivability of J25, valid. (L7e-B1) – vehicle speed

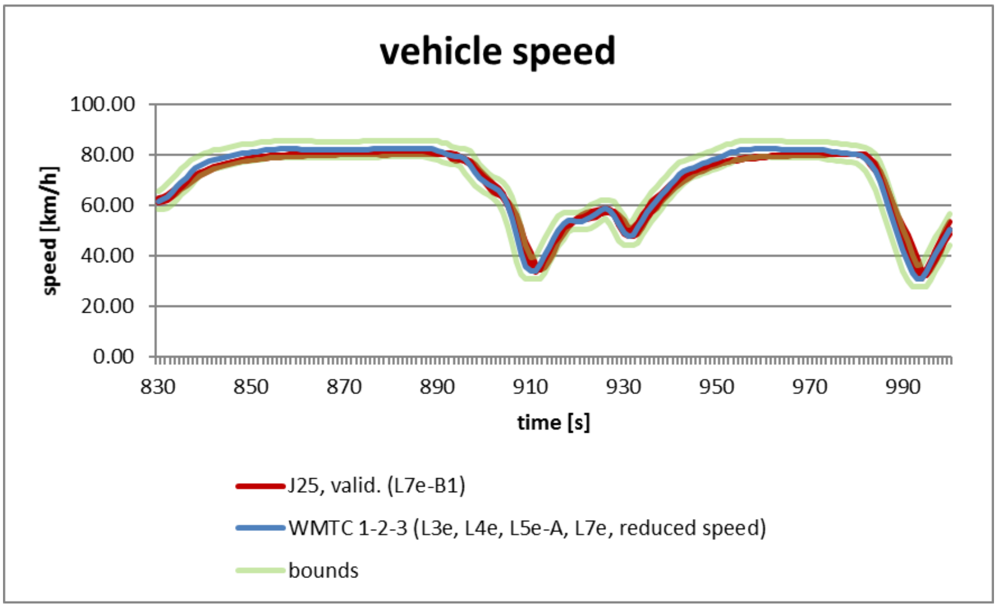

Figure 197. WMTC drivability of J25, valid. (L7e-B1) – vehicle speed zoom

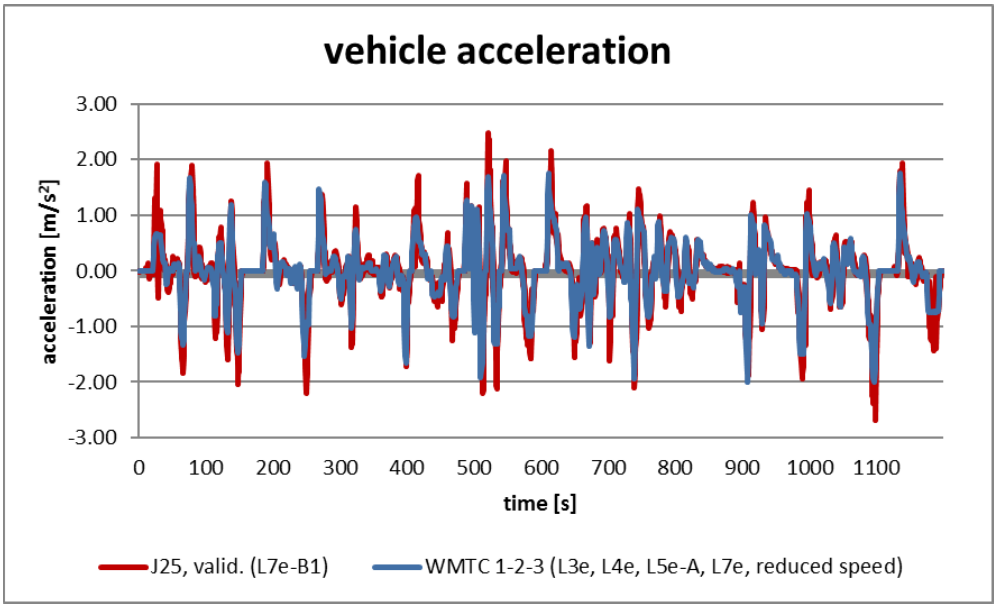

Figure 198. WMTC drivability of J25, valid. (L7e-B1) – vehicle acceleration

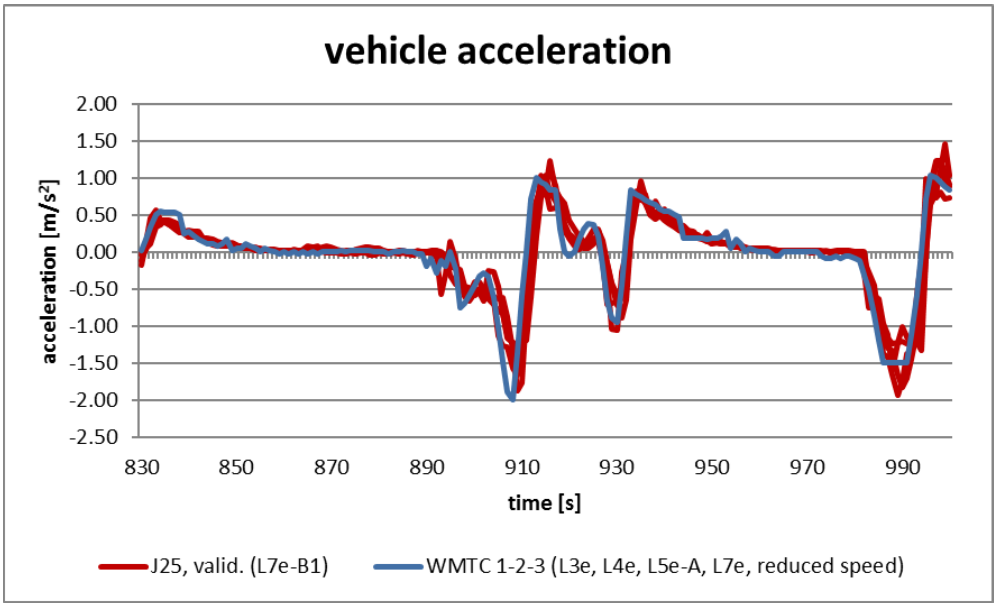

Figure 199. WMTC drivability of J25, valid. (L7e-B1) – vehicle acceleration zoom

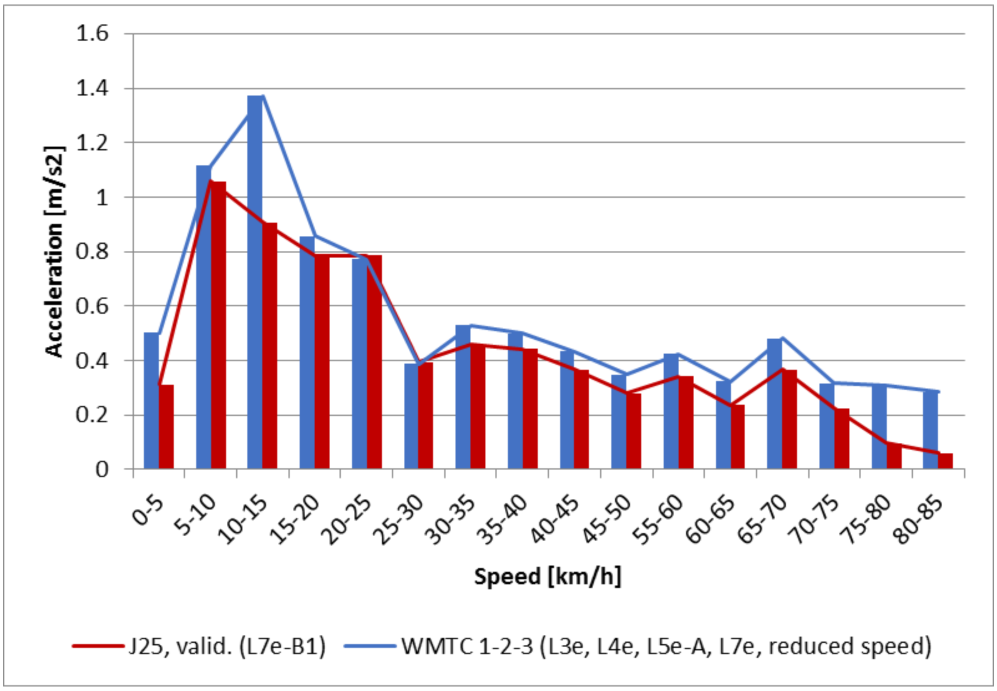

Figure 200. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J25, valid. (L7e-B1)

Table 101. Technical criteria for WMTC drivability assessment of J25, valid. (L7e-B1)

		J25, valid. (L7e-B1) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	1 (0 – 2)	-	-
	Duration (s)	5 (0 – 10)	-	-
Maximum Achievable Speed (km/h)		81 (80 – 81)	82.50	65
Mean Positive Acceleration (MPA) (m/s^2)		0.42 (0.41 – 0.42)	0.43	-
Driven Distance (m)		12218 (12199 – 12243)	12287	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		4.01 (3.96 – 4.02)	4.17	-

Vehicle J09 (L7e-B2)

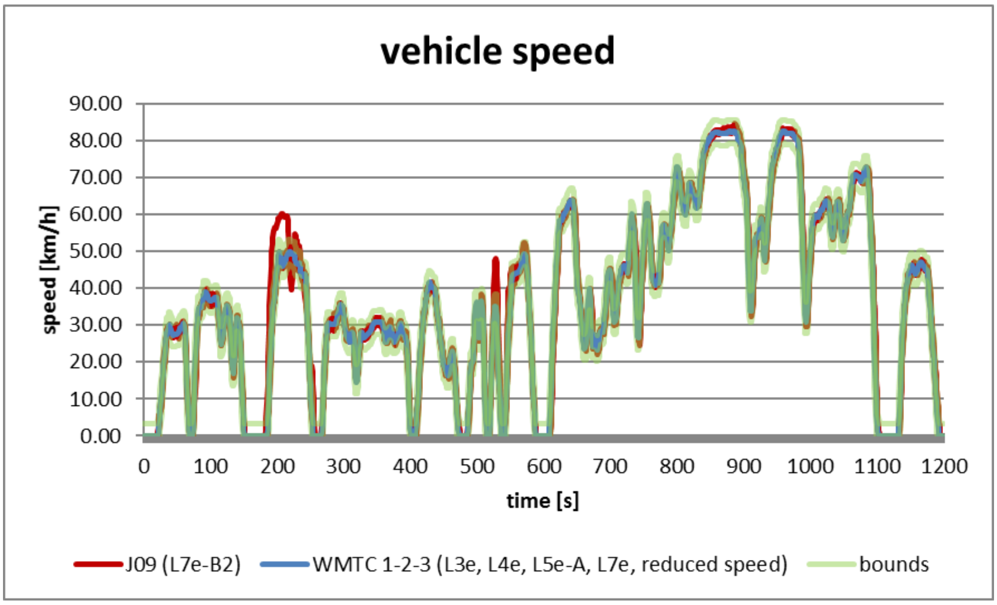

Figure 201. WMTC drivability of J09 (L7e-B2) – vehicle speed

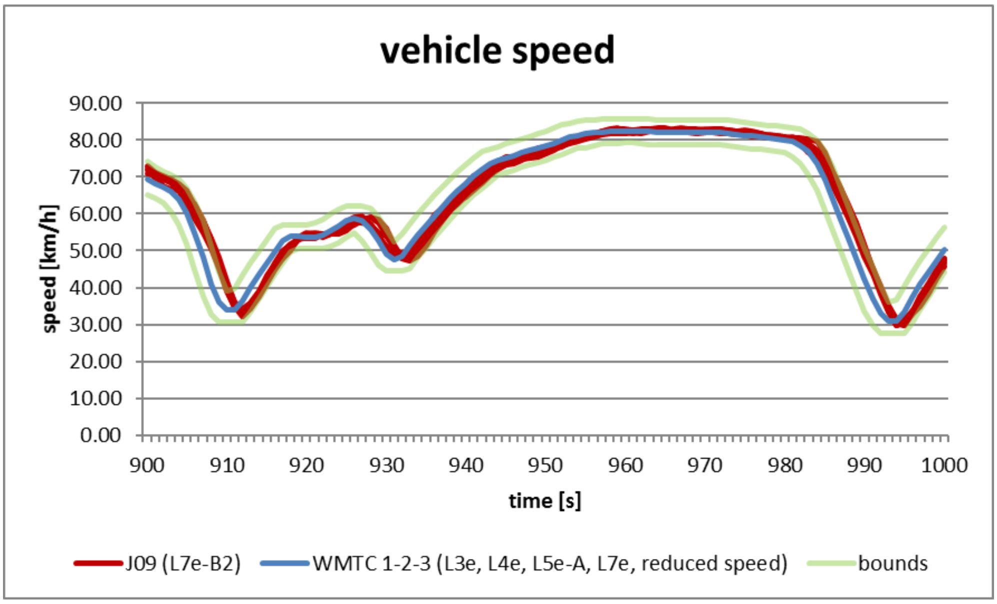

Figure 202. WMTC drivability of J09 (L7e-B2) – vehicle speed zoom

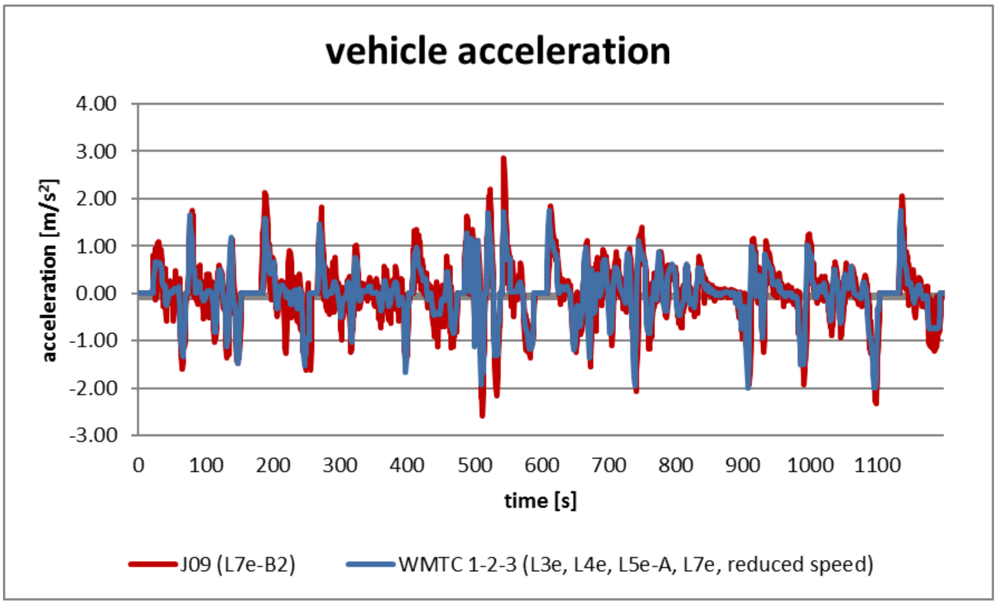

Figure 203. WMTC drivability of J09 (L7e-B2) – vehicle acceleration

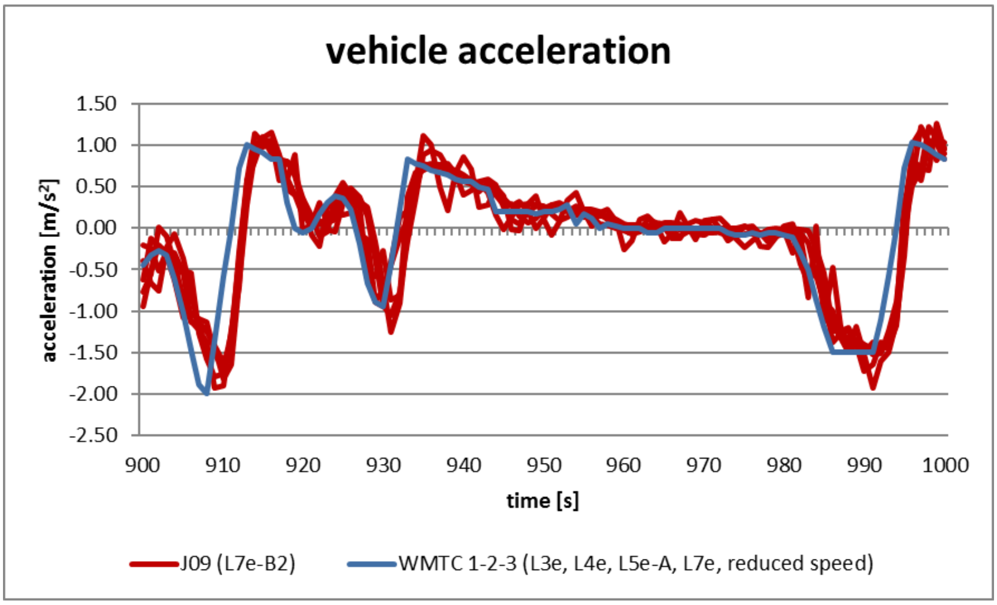

Figure 204. WMTC drivability of J09 (L7e-B2) – vehicle acceleration zoom

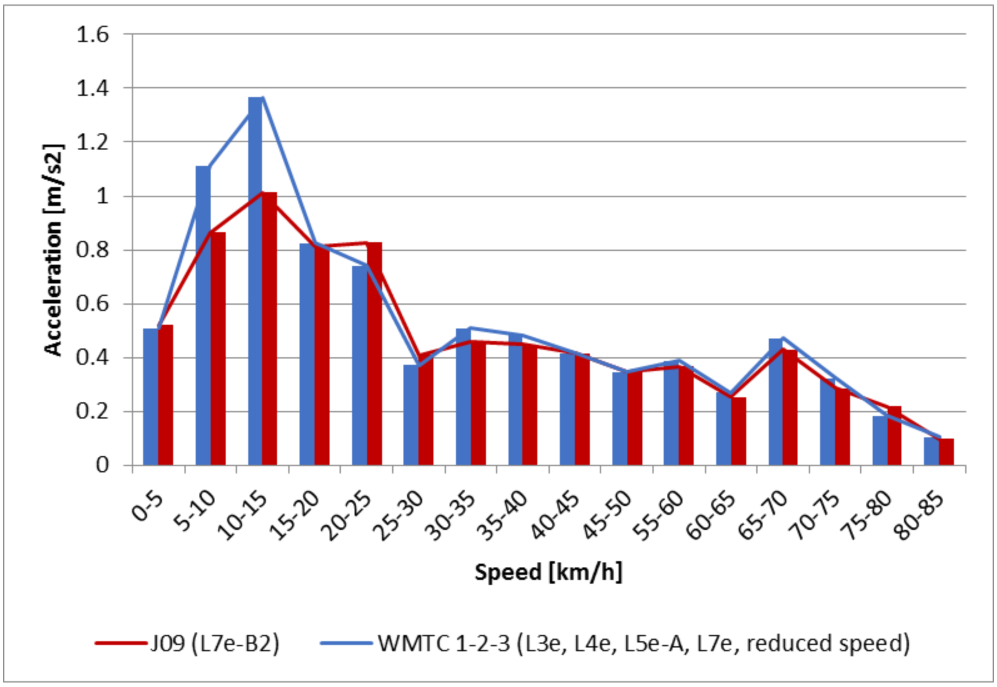

Figure 205. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J09 (L7e-B2)

Table 102. Technical criteria for WMTC drivability assessment of J09 (L7e-B2)

		J09 (L7e-B2) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	4 (0 – 11)	-	-
	Duration (s)	15 (0 – 53)	-	-
Maximum Achievable Speed (km/h)		84 (83 – 85)	82.50	78
Mean Positive Acceleration (MPA) (m/s^2)		0.44 (0.42 – 0.47)	0.43	-
Driven Distance (m)		12293 (12250 – 12314)	12287	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		4.39 (4.14 – 4.73)	4.17	-

Vehicle J20 (L7e-CP)

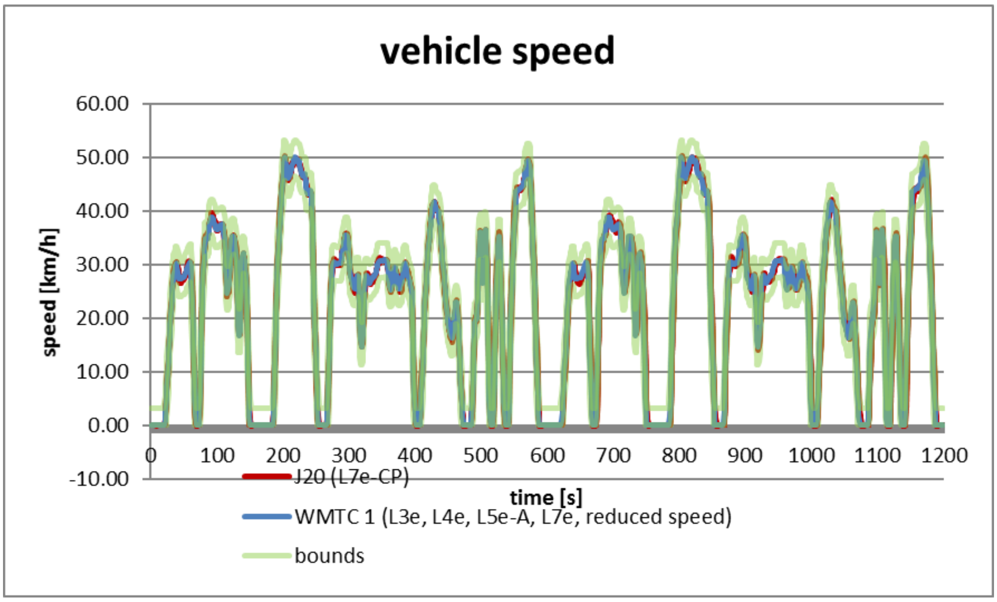

Figure 206. WMTC drivability of J20 (L7e-CP) – vehicle speed

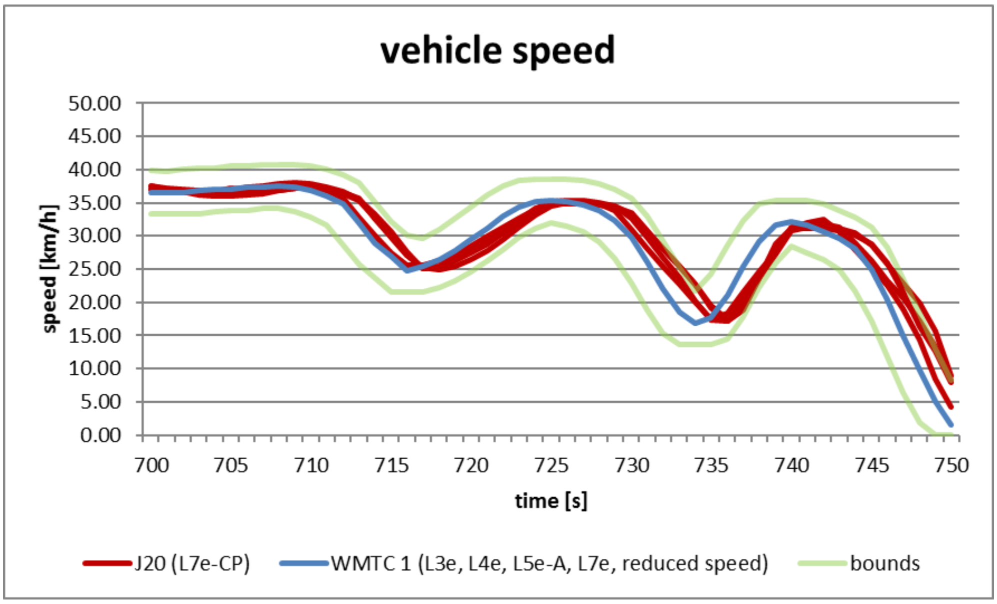

Figure 207. WMTC drivability of J20 (L7e-CP) – vehicle speed zoom

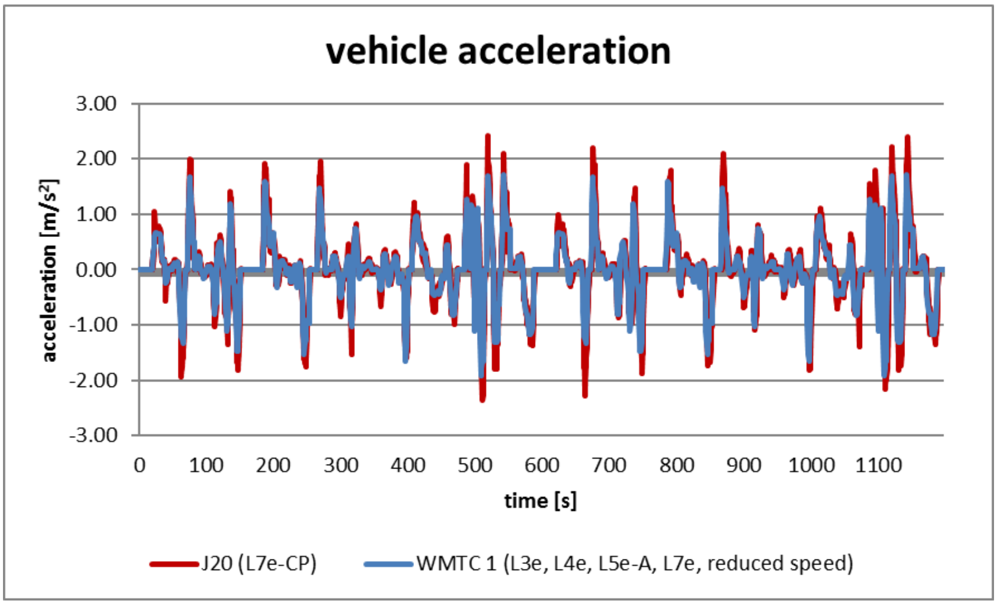

Figure 208. WMTC drivability of J20 (L7e-CP) – vehicle acceleration

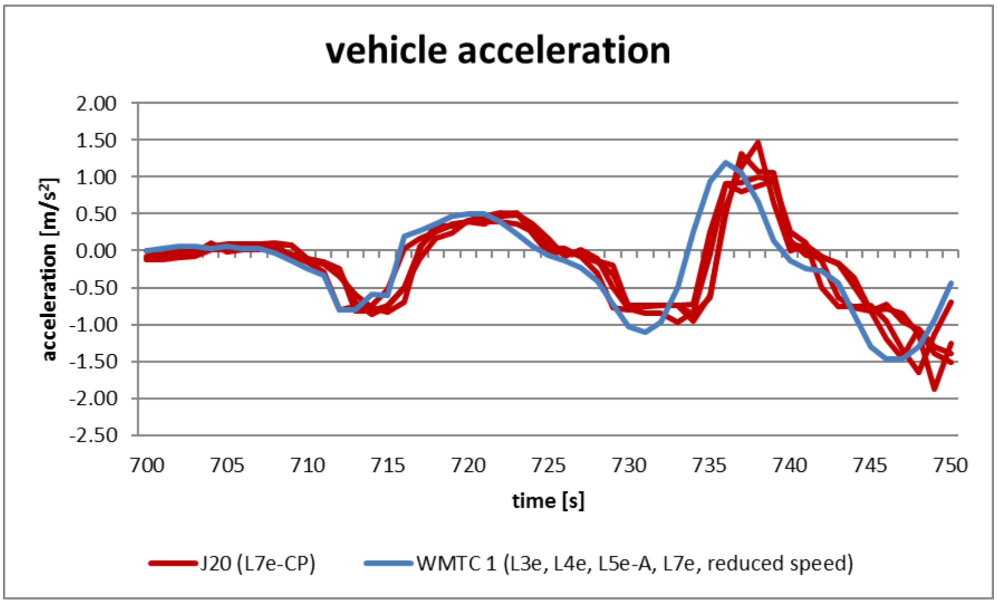

Figure 209. WMTC drivability of J20 (L7e-CP) – vehicle acceleration zoom

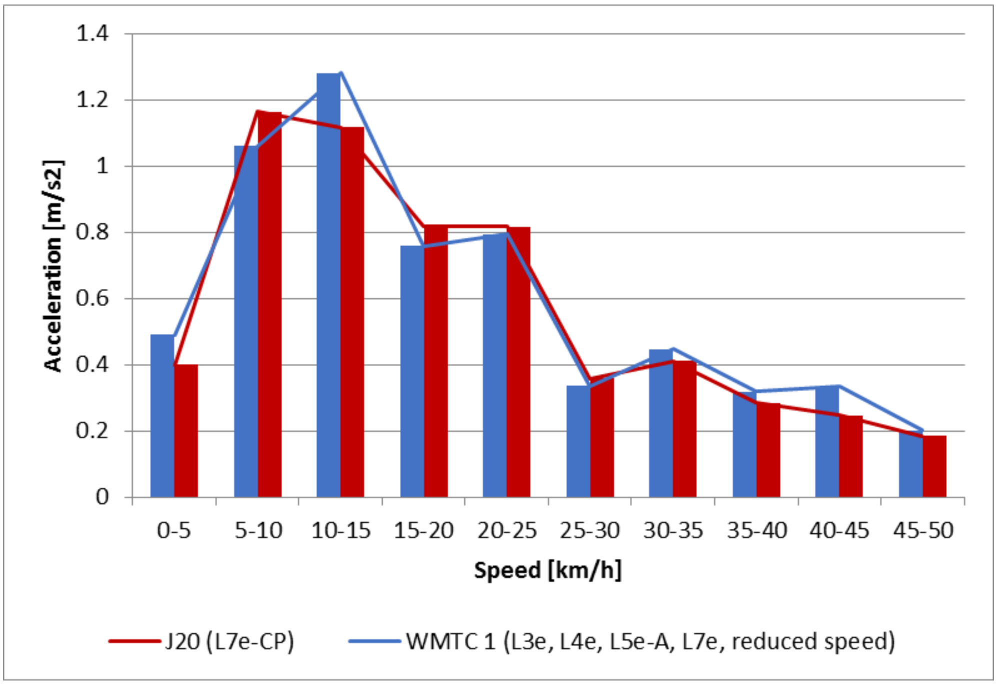

Figure 210. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J20 (L7e-CP)

Table 103. Technical criteria for WMTC drivability assessment of J20 (L7e-CP)

		J20 (L7e-CP) tests average (min-max)	REGULATION	MANUFACTURER
Speed Violations	Events	8 (4 – 10)	-	-
	Duration (s)	19 (9 – 24)	-	-
Maximum Achievable Speed (km/h)		50 (50 – 50)	50	80
Mean Positive Acceleration (MPA) (m/s^2)		0.47 (0.46 – 0.47)	0.43	-
Driven Distance (m)		7702 (7670 – 7725)	7676	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		3.06 (3.0 – 3.11)	2.82	-

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B Test results: Engine operation area of the different driving cycles

This Appendix includes the detailed engine map coverage results of each of the test cycles for each vehicle, which are summarized in paragraph 3.1.3. A scatter plot of the torque versus the engine speed is presented, along with the distribution of the torque for the WMTC and the ECE R40 / R47 cycles, for each vehicle. Besides, the engine map coverage density is investigated in gridded graphs. The extreme out of the range values are filtered in all graphs.

The vehicles tested and presented in the following figures are:

- L1e-A: 1 vehicle
- L1e-B, low speed: 3 vehicles
- L1e-B, high speed: 6 vehicles
- L2e-U: 1 vehicle
- L5e-A: 2 vehicles
- L6e-BP: 1 vehicle
- L6e-BU: 1 vehicle
- L7e-B1: 3 vehicles (1 validation vehicle)
- L7e-B2: 1 vehicle

Vehicle J05 (L1e-A)

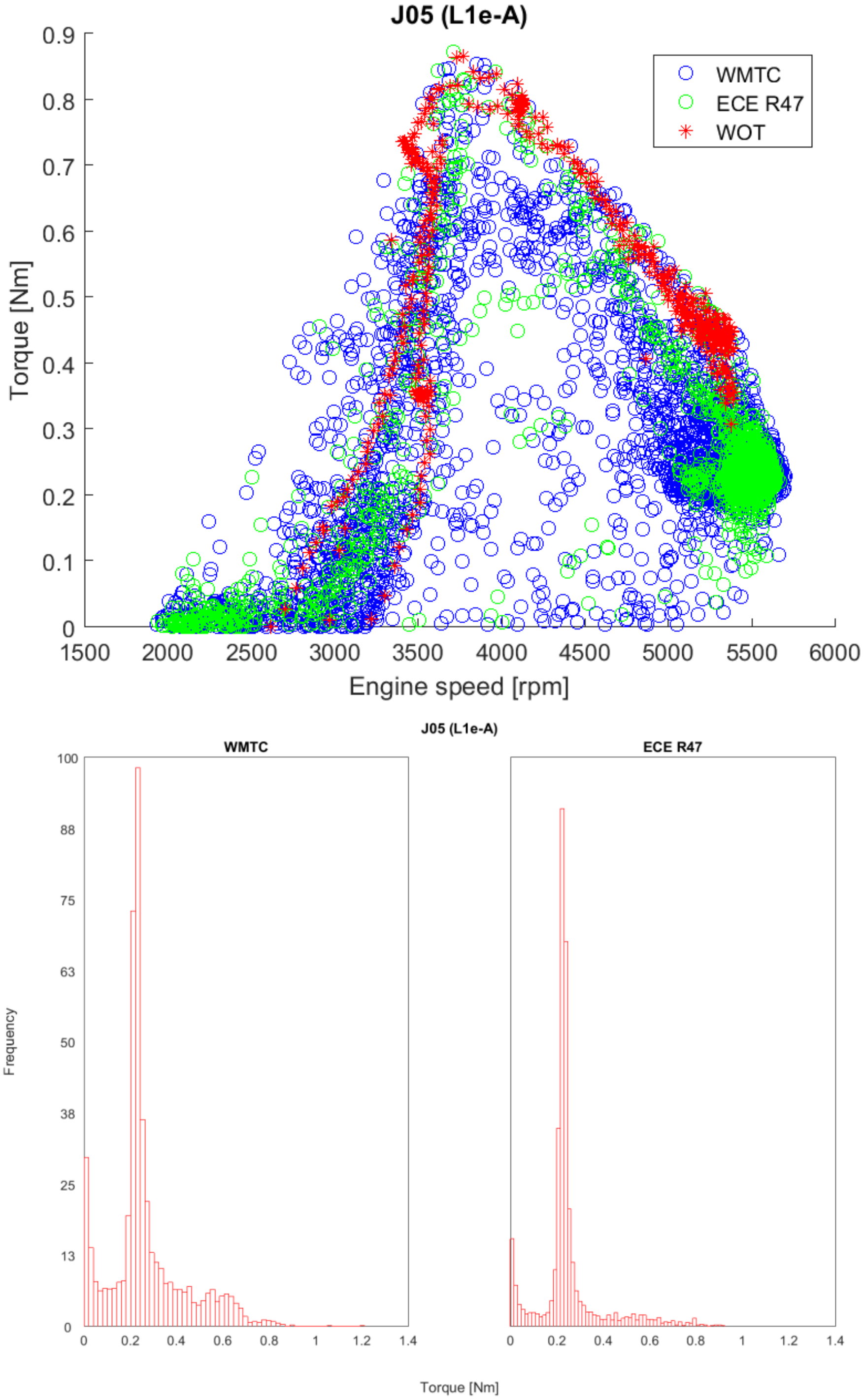


Figure 211. Engine map coverage of J05 (L1e-A) - torque

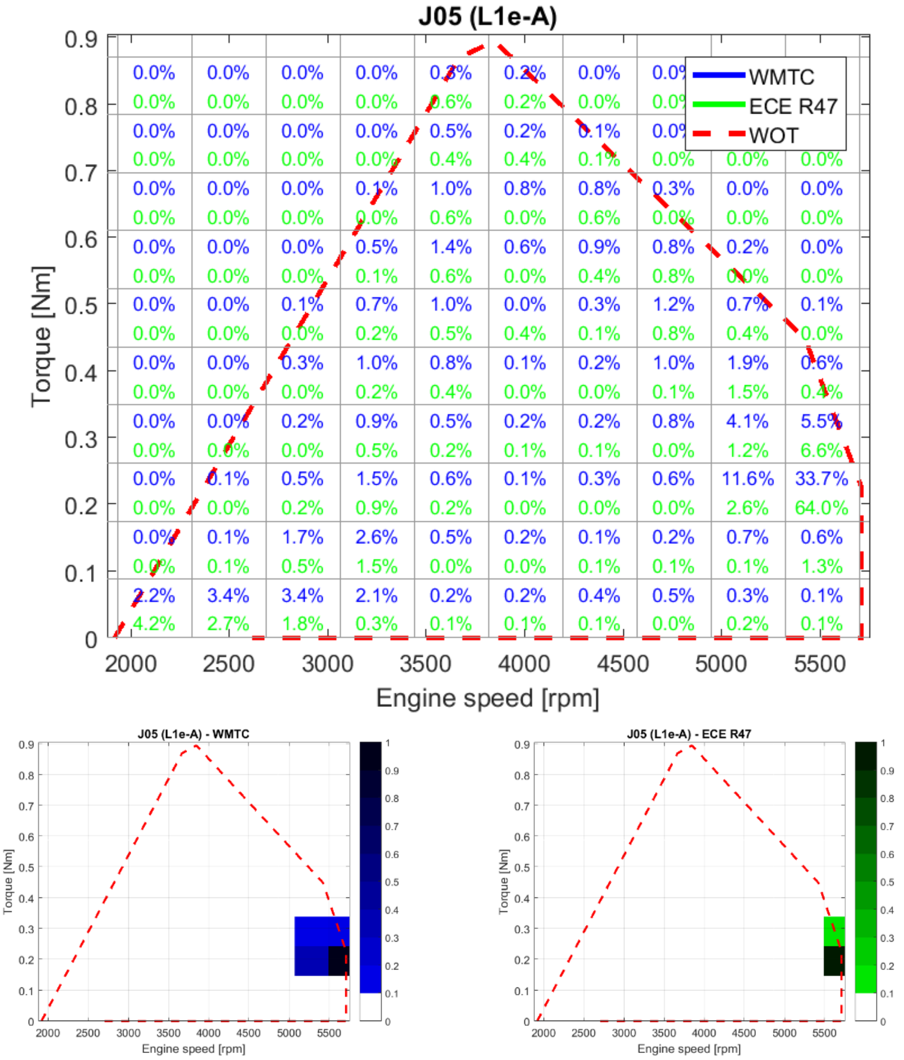


Figure 212. Engine map coverage density of J05 (L1e-A) – torque

Vehicle J06 (L1e-B, low speed)

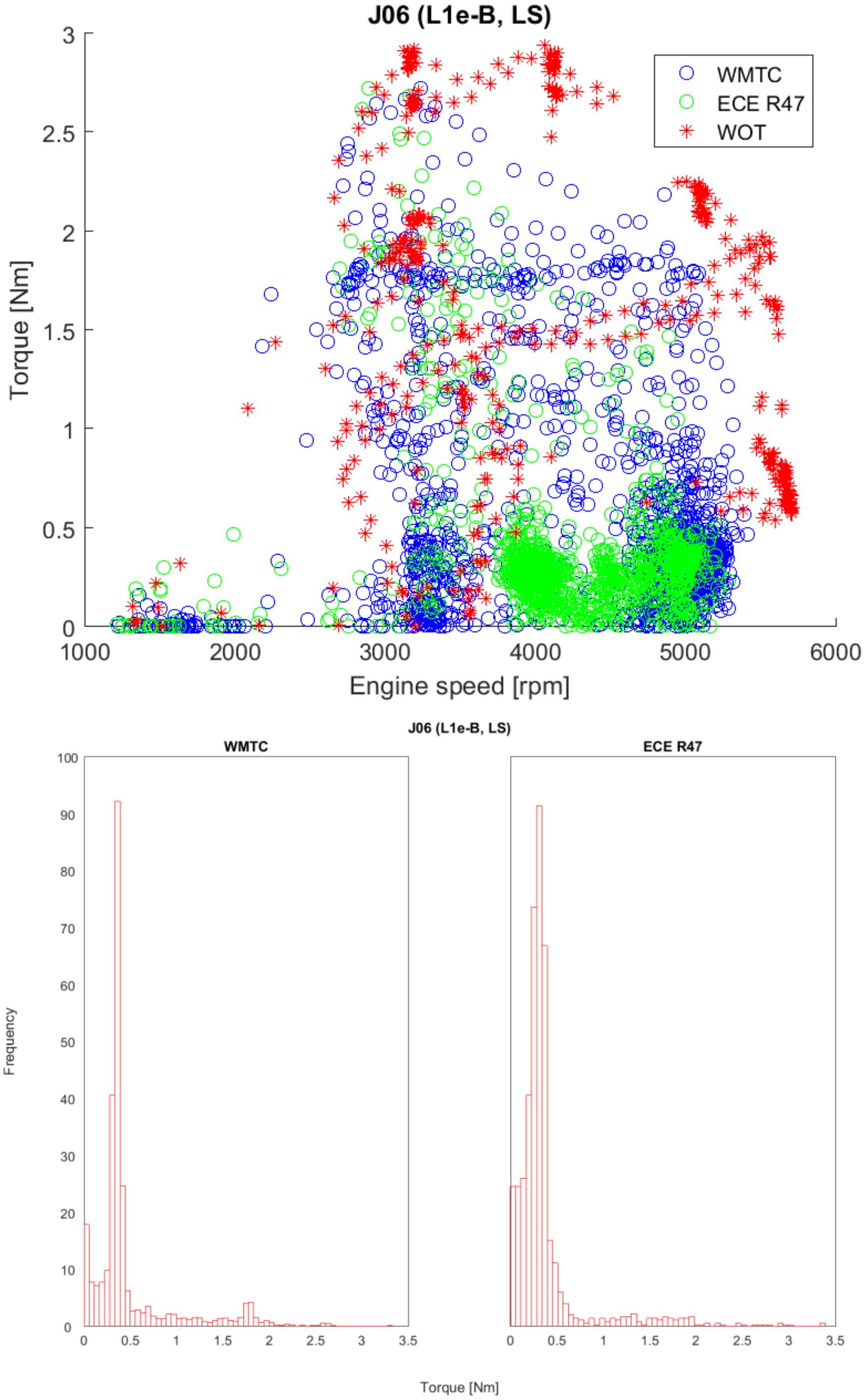


Figure 213. Engine map coverage of J06 (L1e-B, low speed) - torque

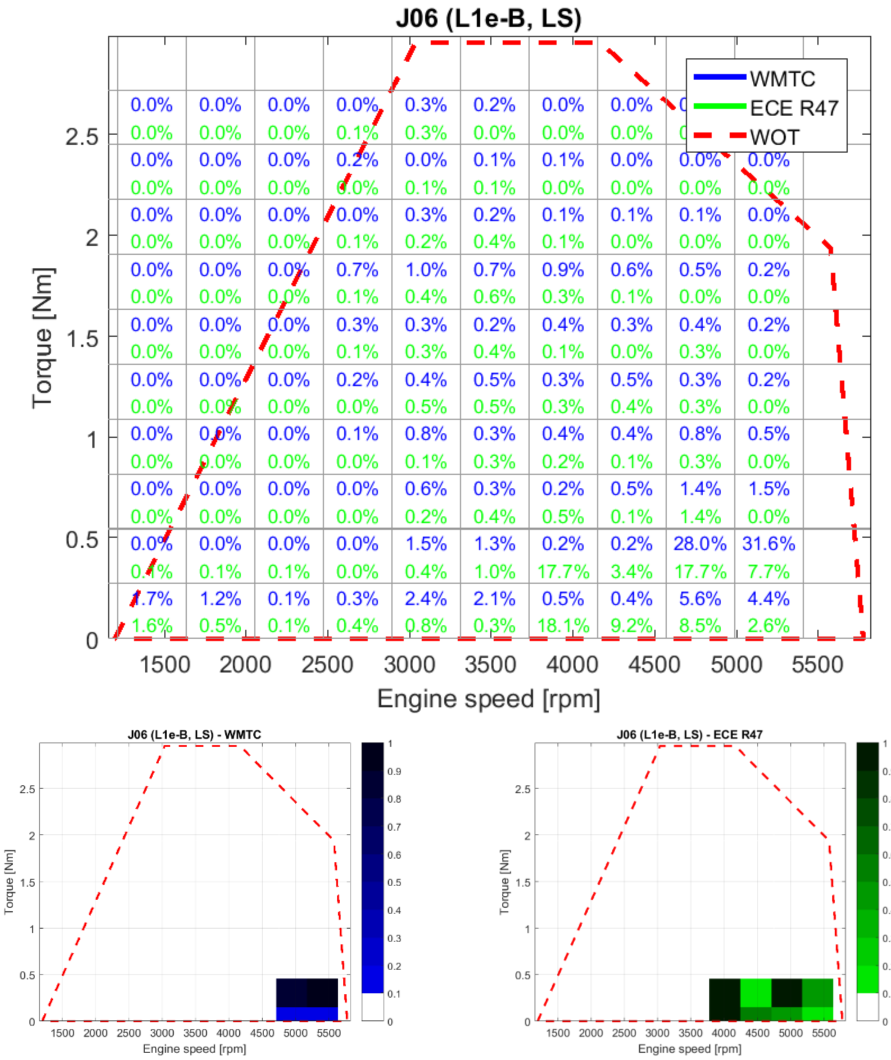


Figure 214. Engine map coverage density of J06 (L1e-B, low speed) - torque

Vehicle J07 (L1e-B, low speed)

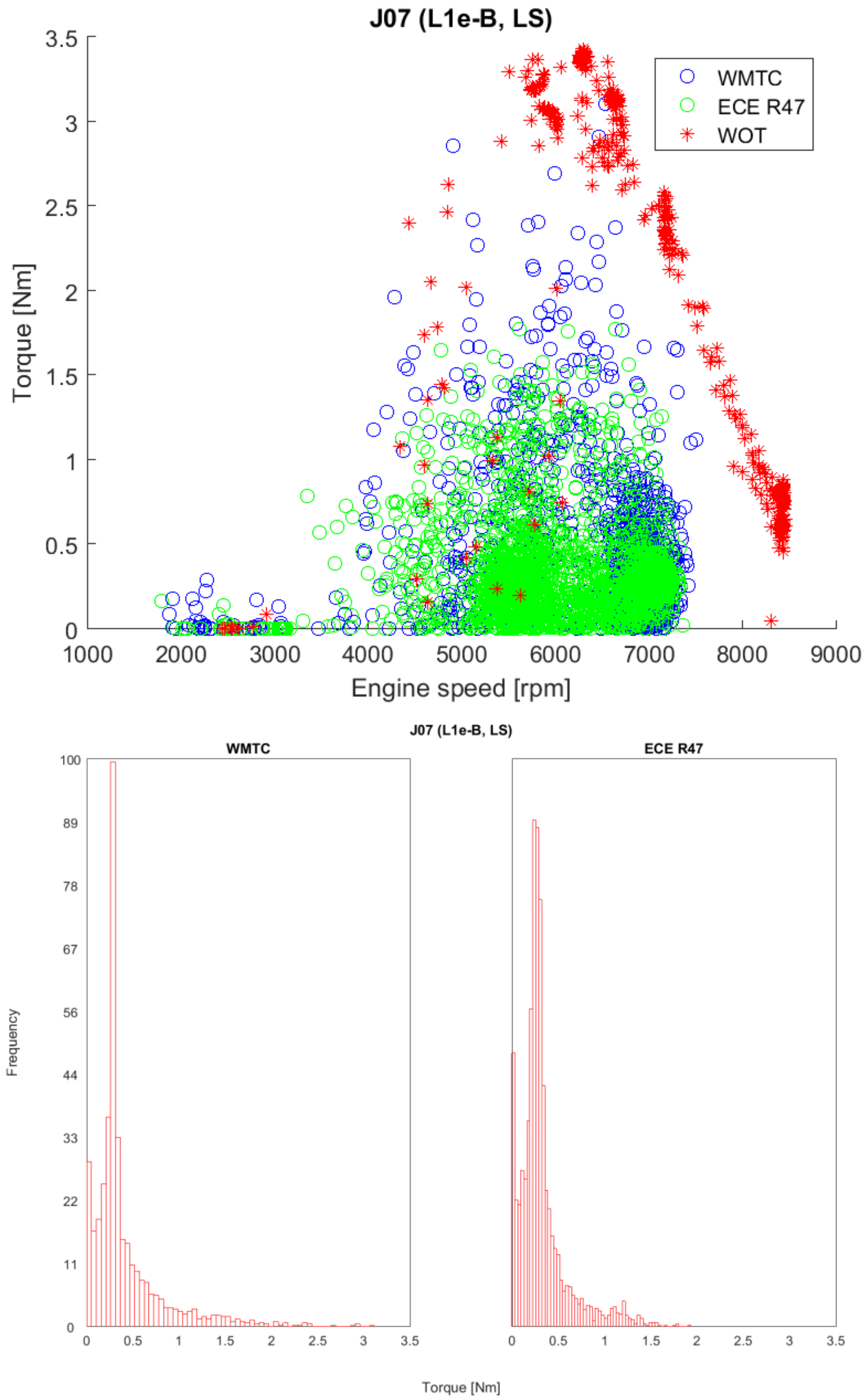


Figure 215. Engine map coverage of J07 (L1e-B, low speed) - torque

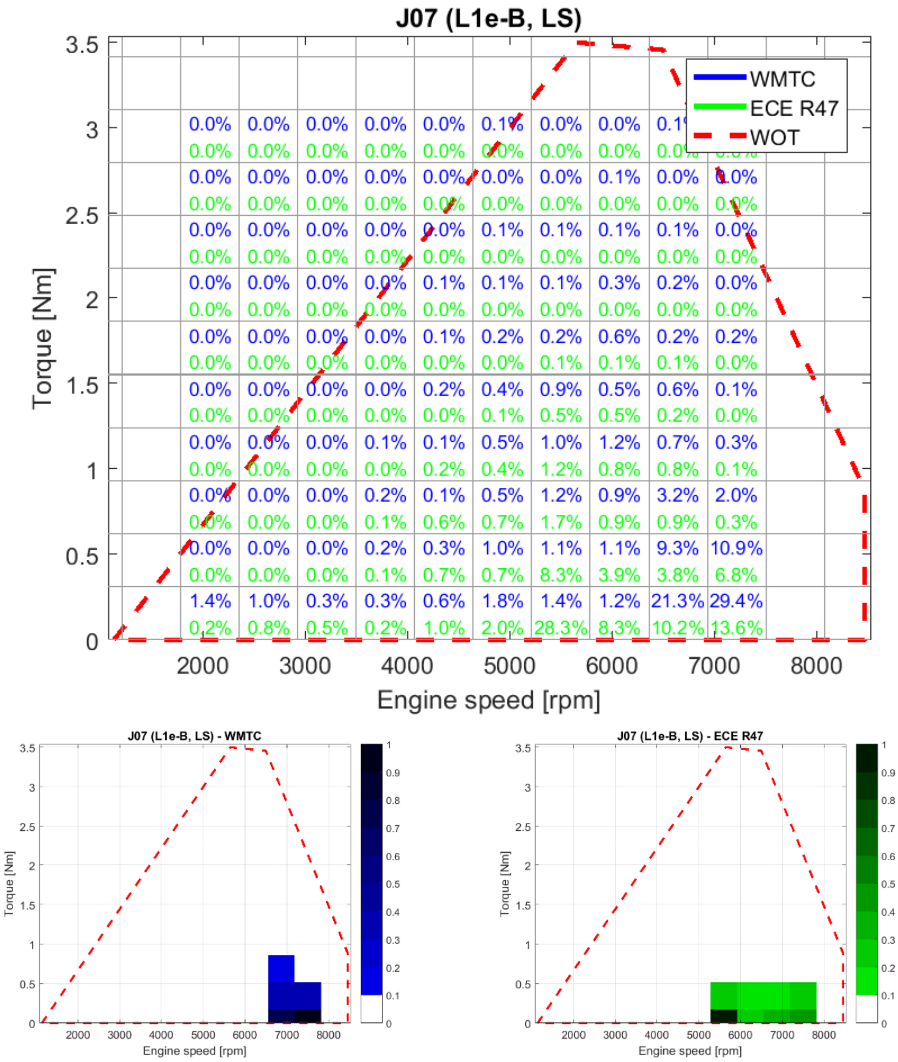


Figure 216. Engine map coverage density of J07 (L1e-B, low speed) - torque

Vehicle J10 (L1e-B, low speed)

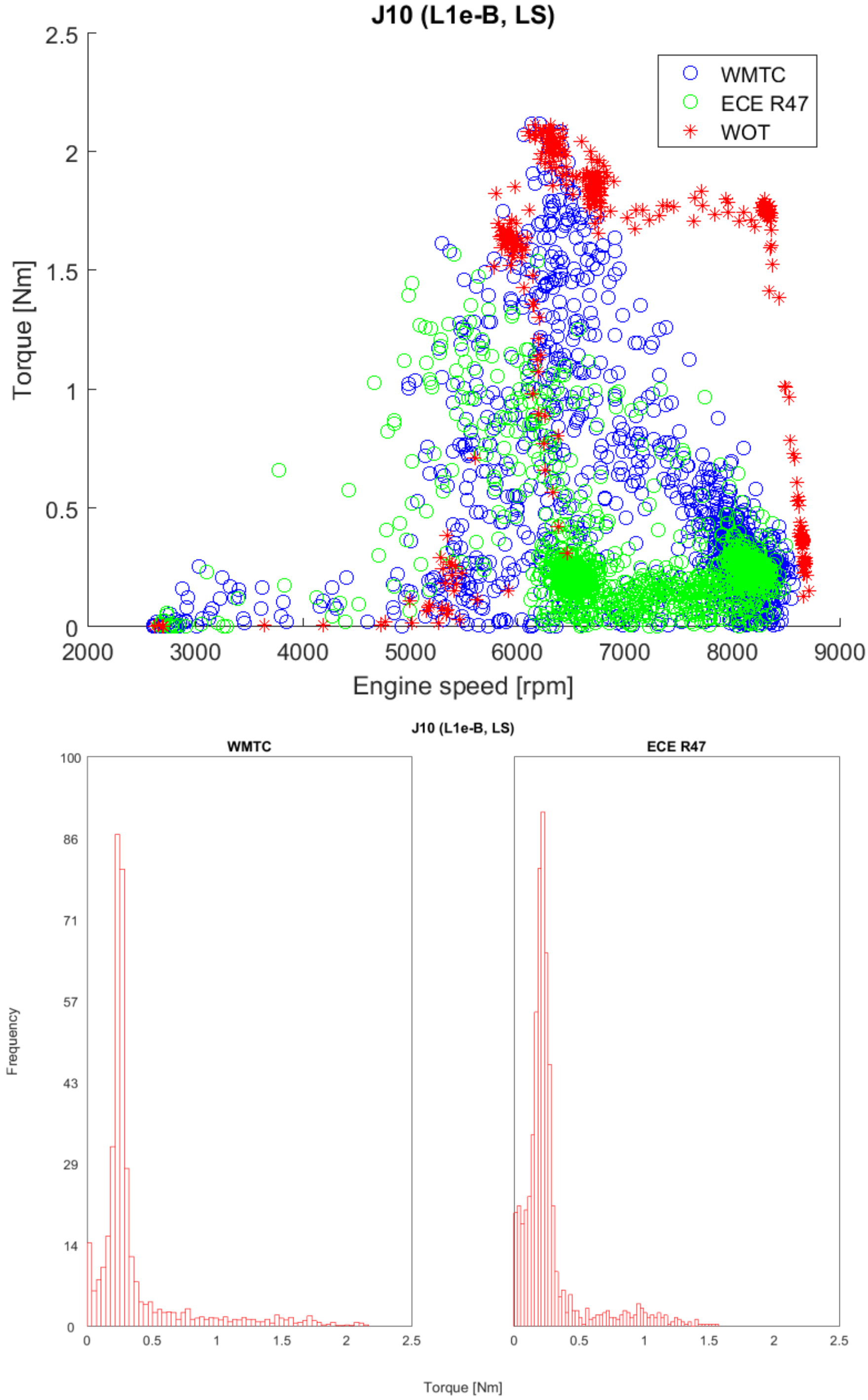


Figure 217. Engine map coverage of J10 (L1e-B, low speed) - torque

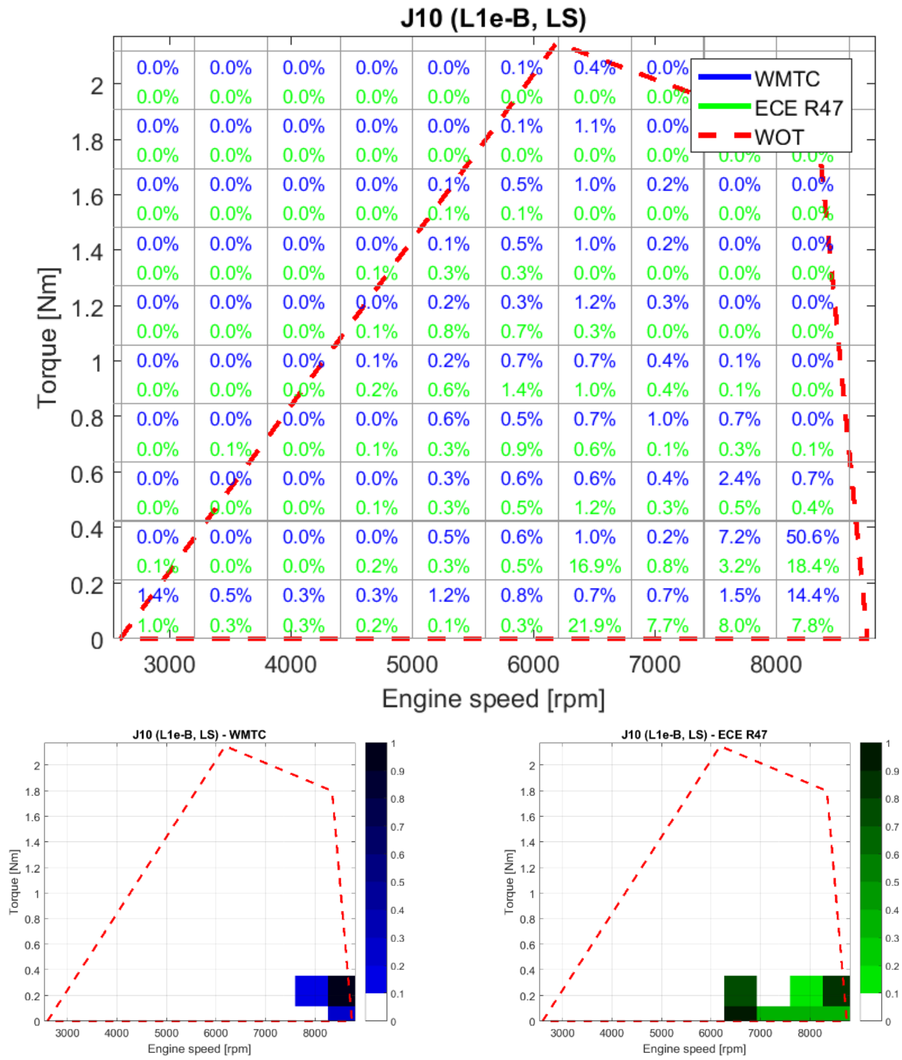


Figure 218. Engine map coverage density of J10 (L1e-B, low speed) - torque

Vehicle J02 (L1e-B, high speed)

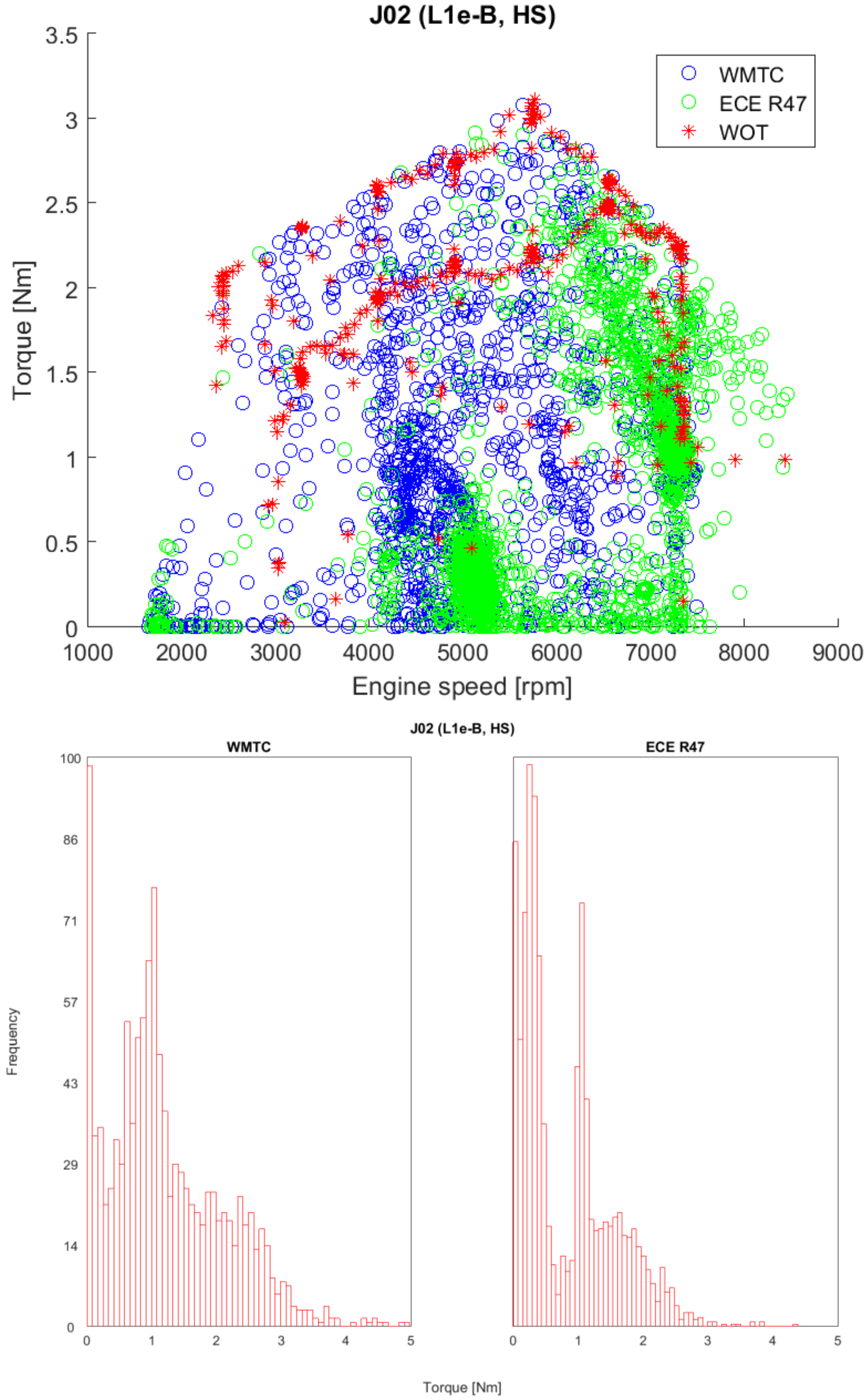


Figure 219. Engine map coverage of J02 (L1e-B, high speed) - torque

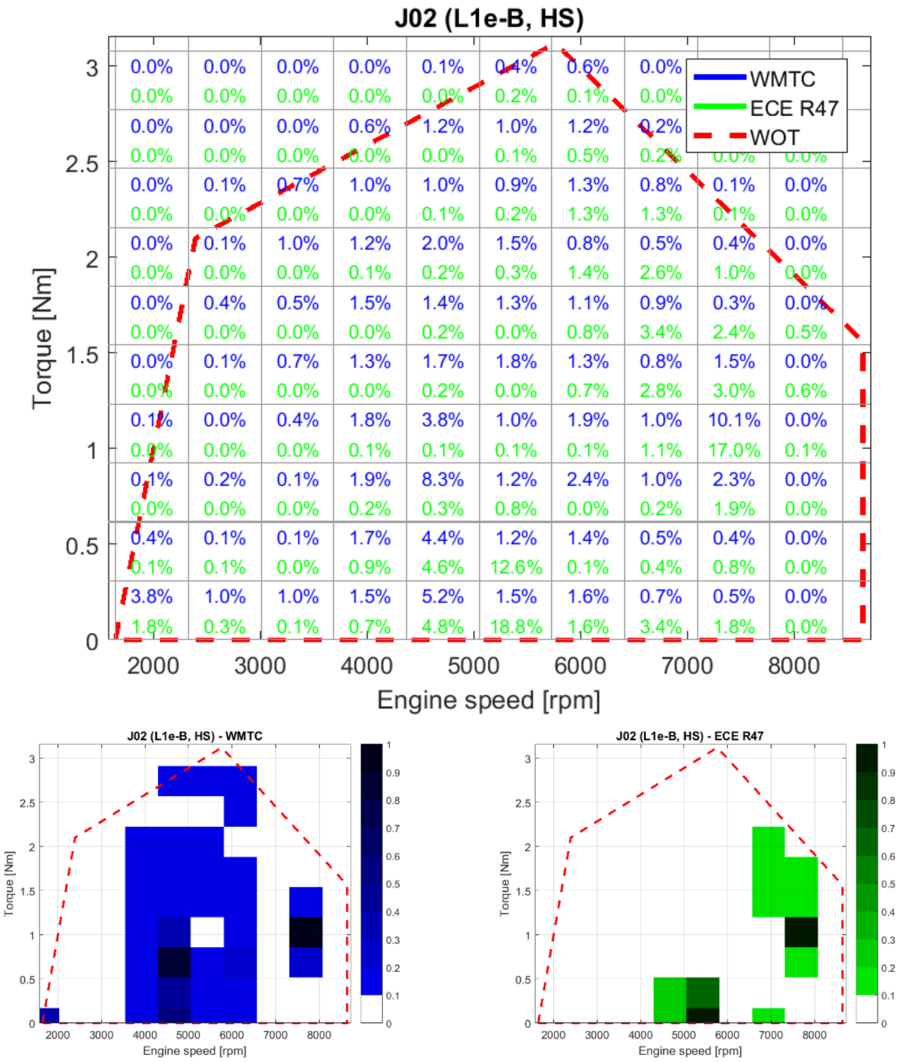


Figure 220. Engine map coverage density of J02 (L1e-B, high speed) - torque

Vehicle J03 (L1e-B, high speed)

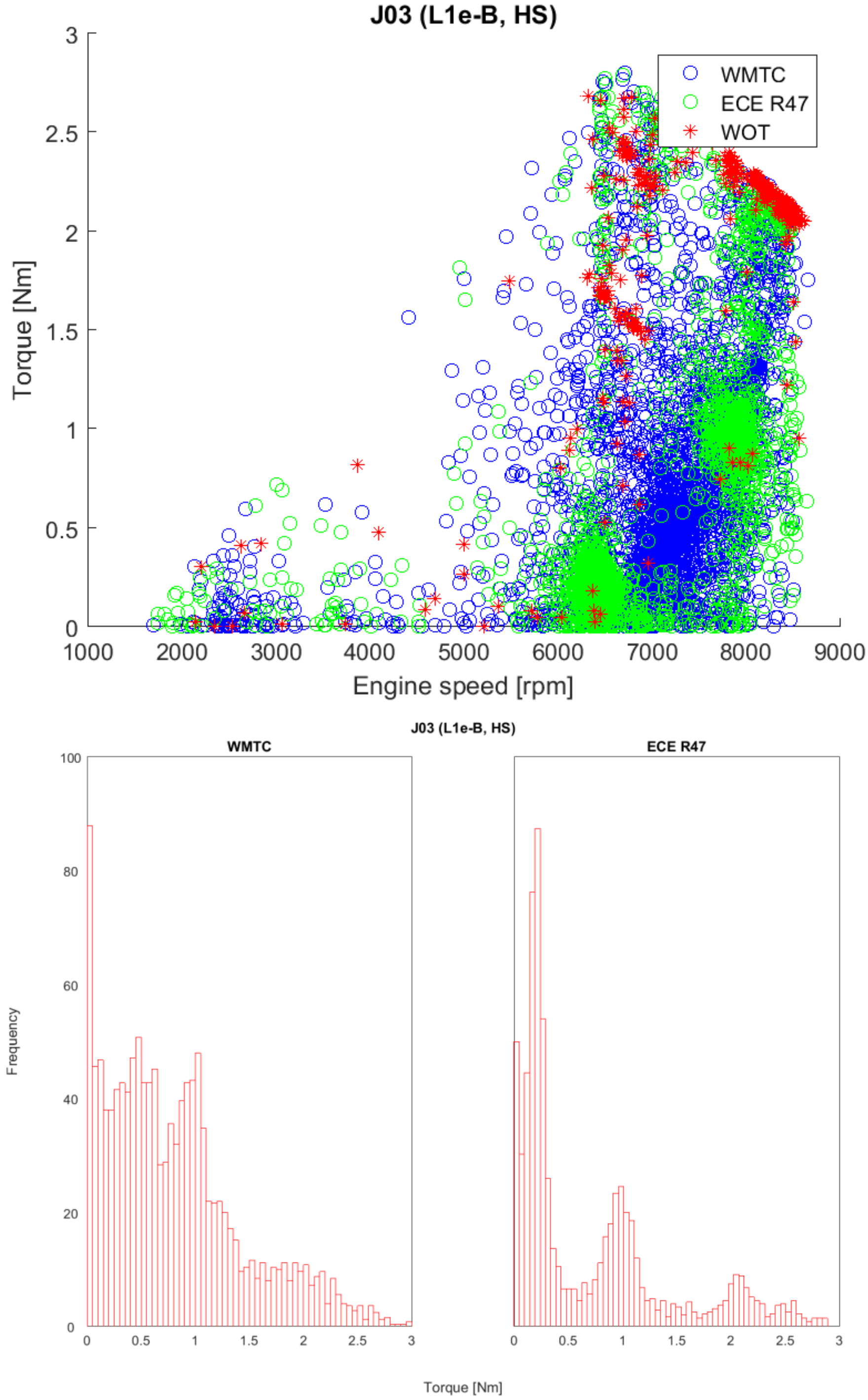


Figure 221. Engine map coverage of J03 (L1e-B, high speed) - torque

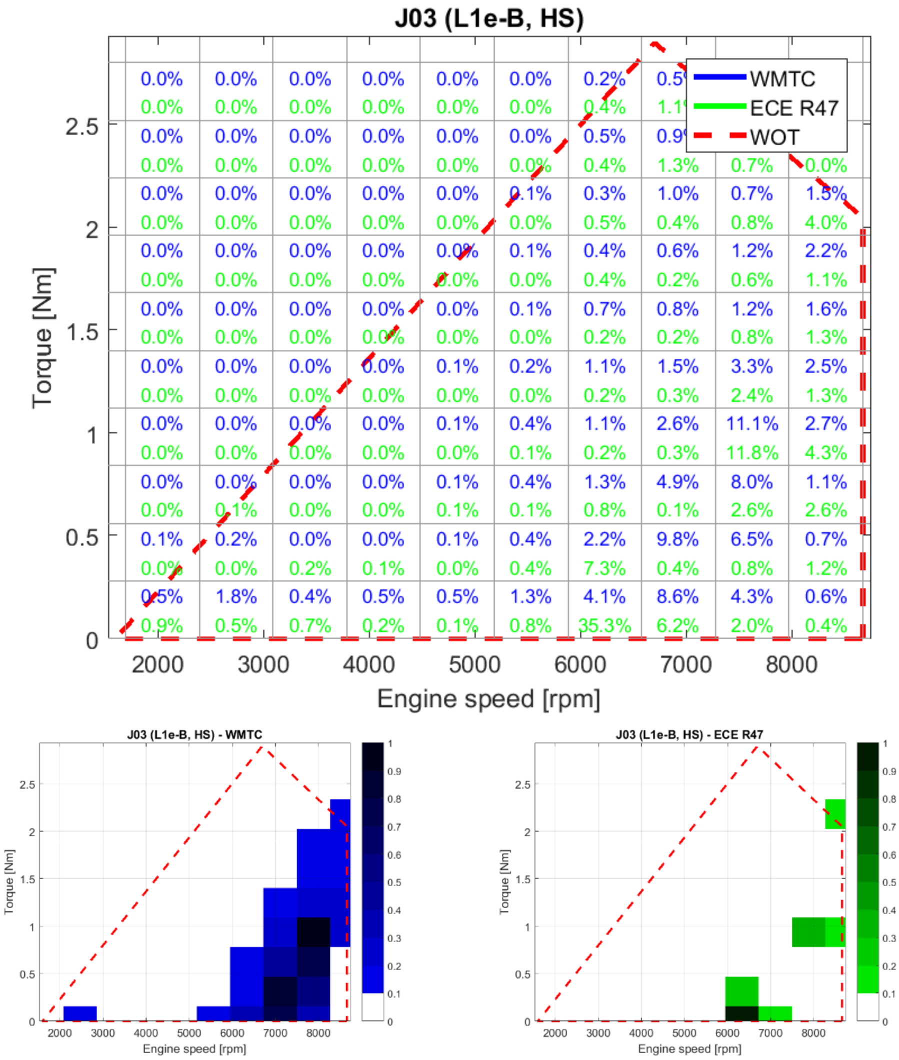


Figure 222. Engine map coverage density of J03 (L1e-B, high speed) - torque

Vehicle J04 (L1e-B, high speed)

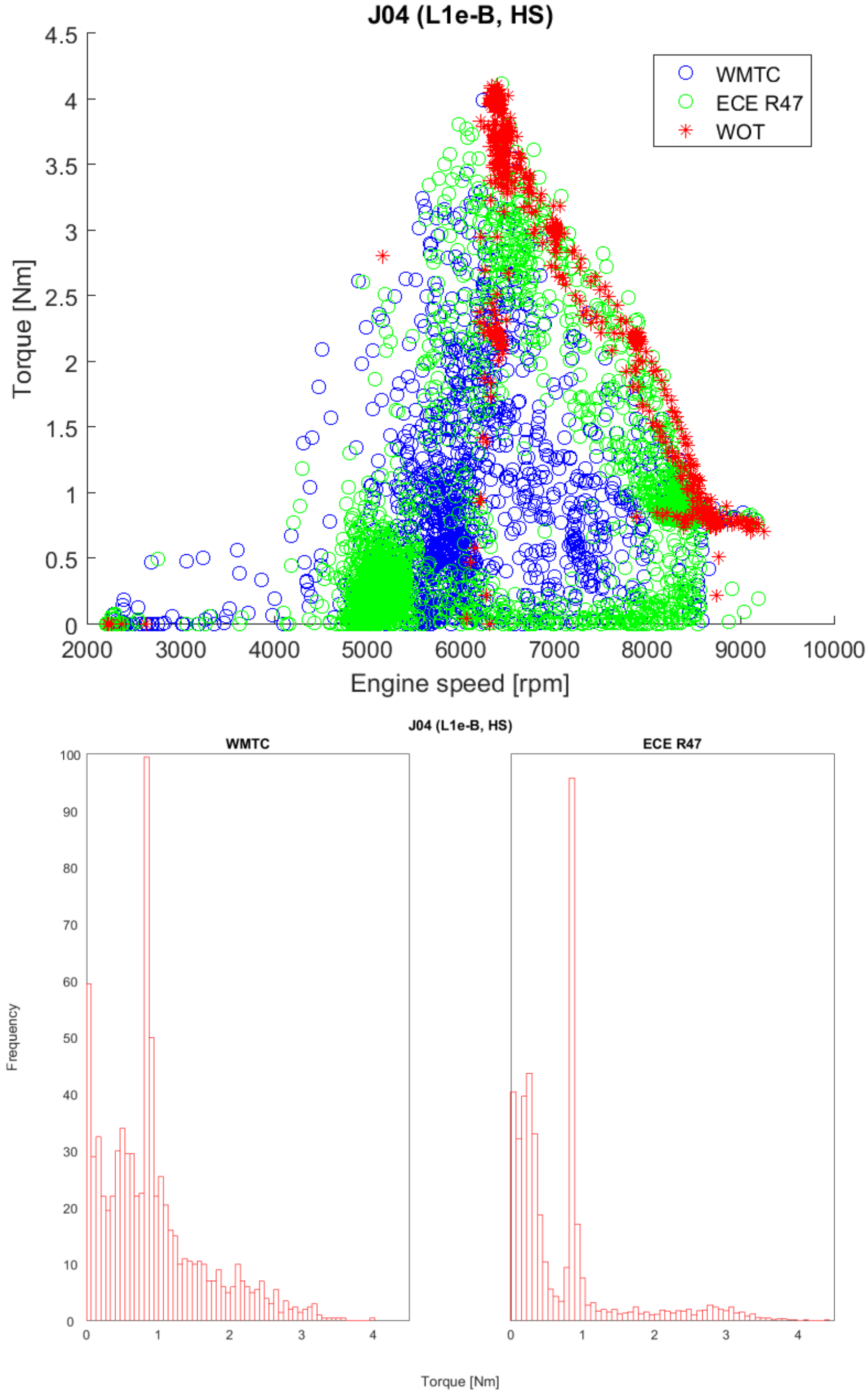


Figure 223. Engine map coverage of J04 (L1e-B, high speed) - torque

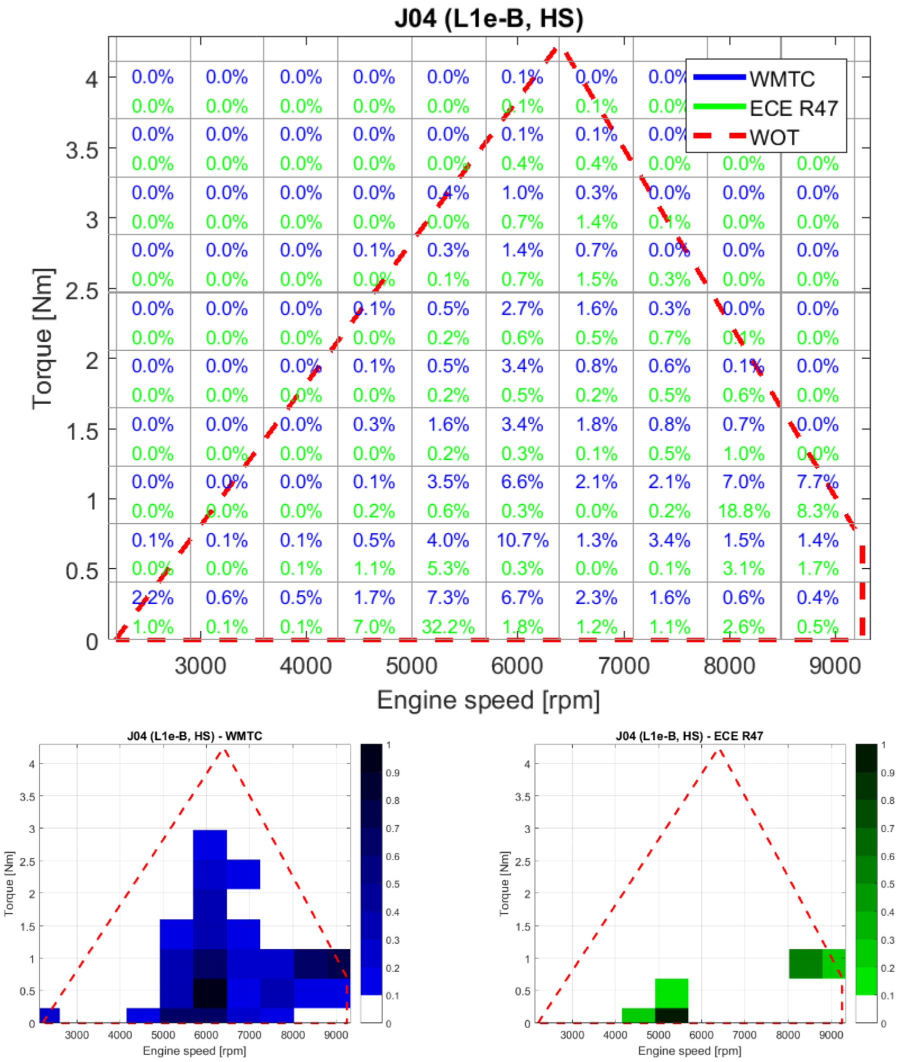


Figure 224. Engine map coverage density of J04 (L1e-B, high speed) - torque

Vehicle J12 (L1e-B, high speed)

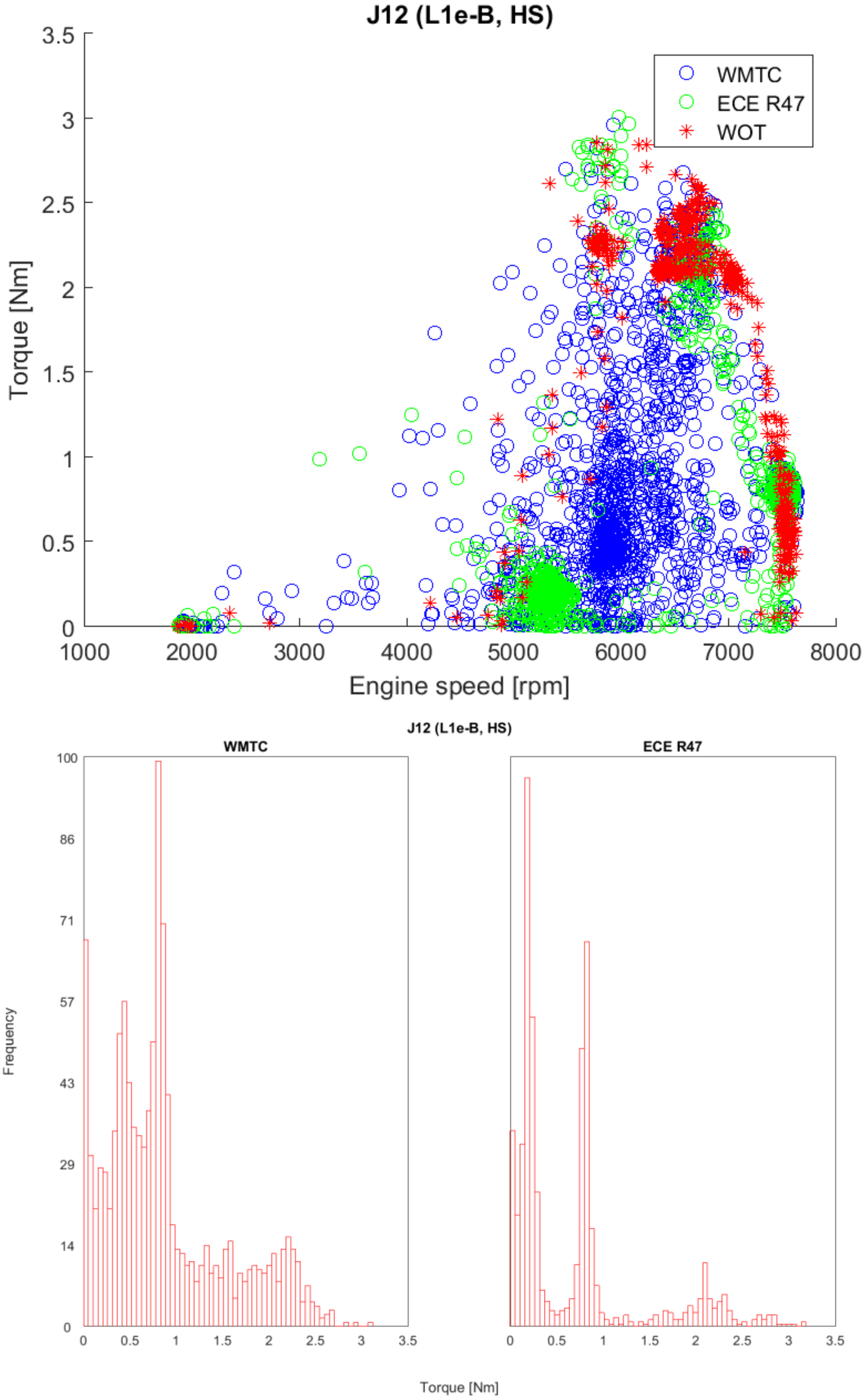


Figure 225. Engine map coverage of J12 (L1e-B, high speed) - torque

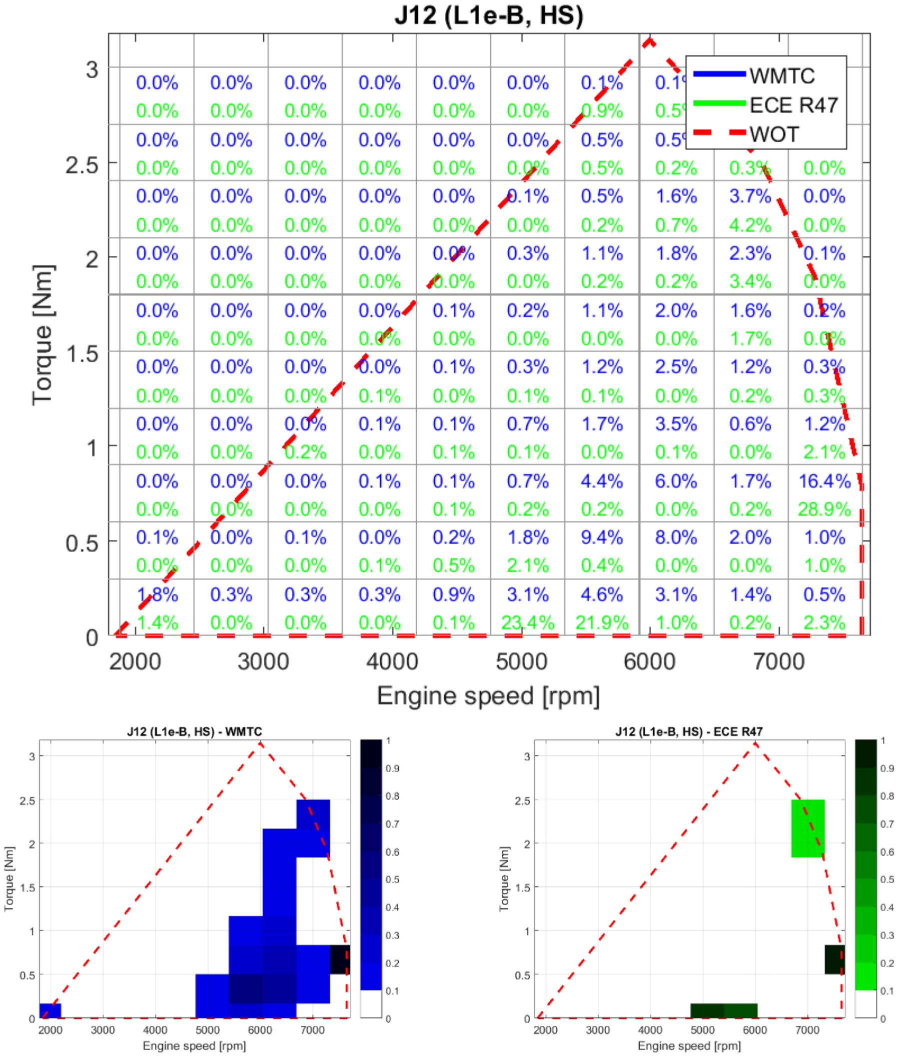


Figure 226. Engine map coverage density of J12 (L1e-B, high speed) - torque

Vehicle J14 (L1e-B, high speed)

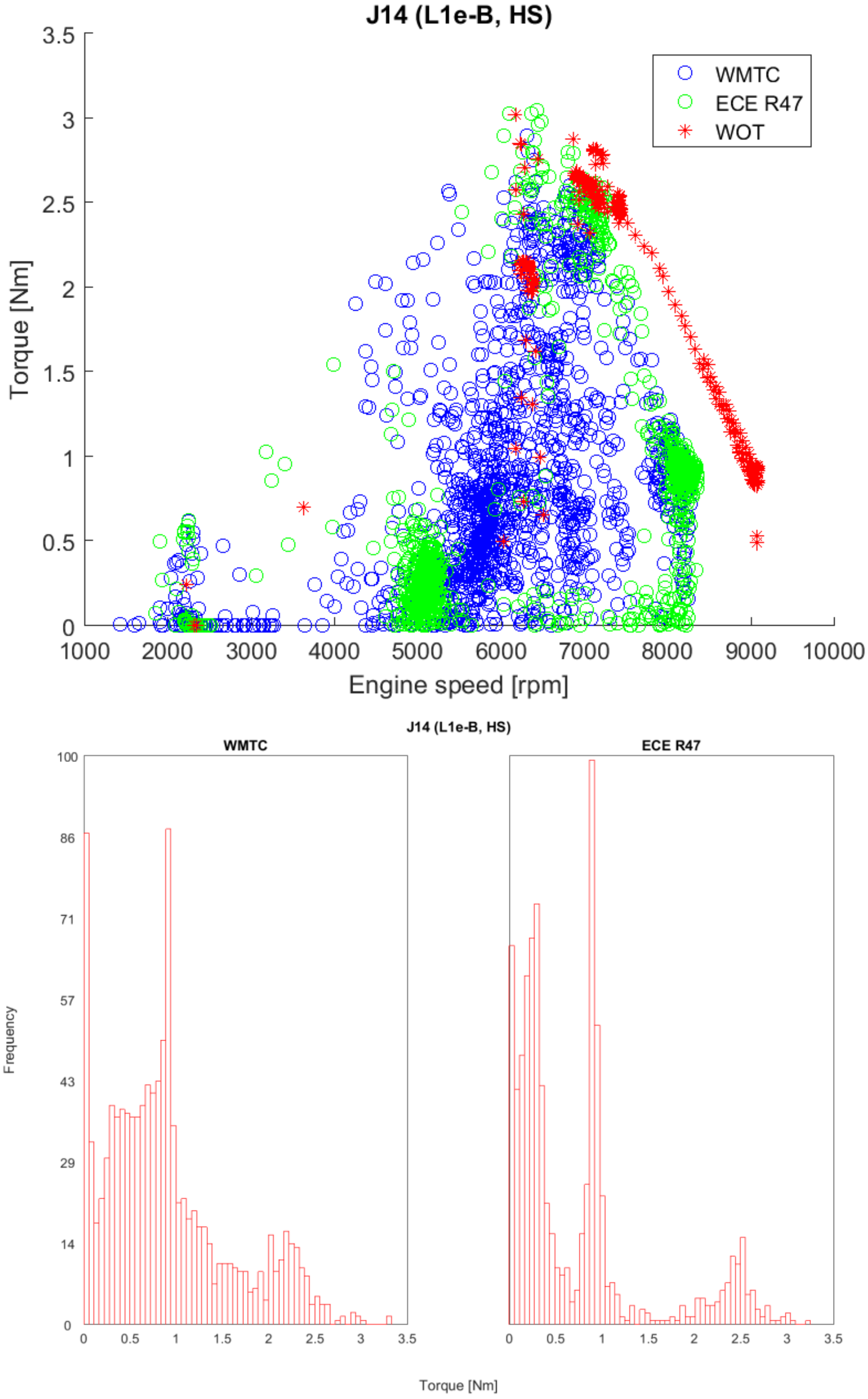


Figure 227. Engine map coverage of J14 (L1e-B, high speed) - torque

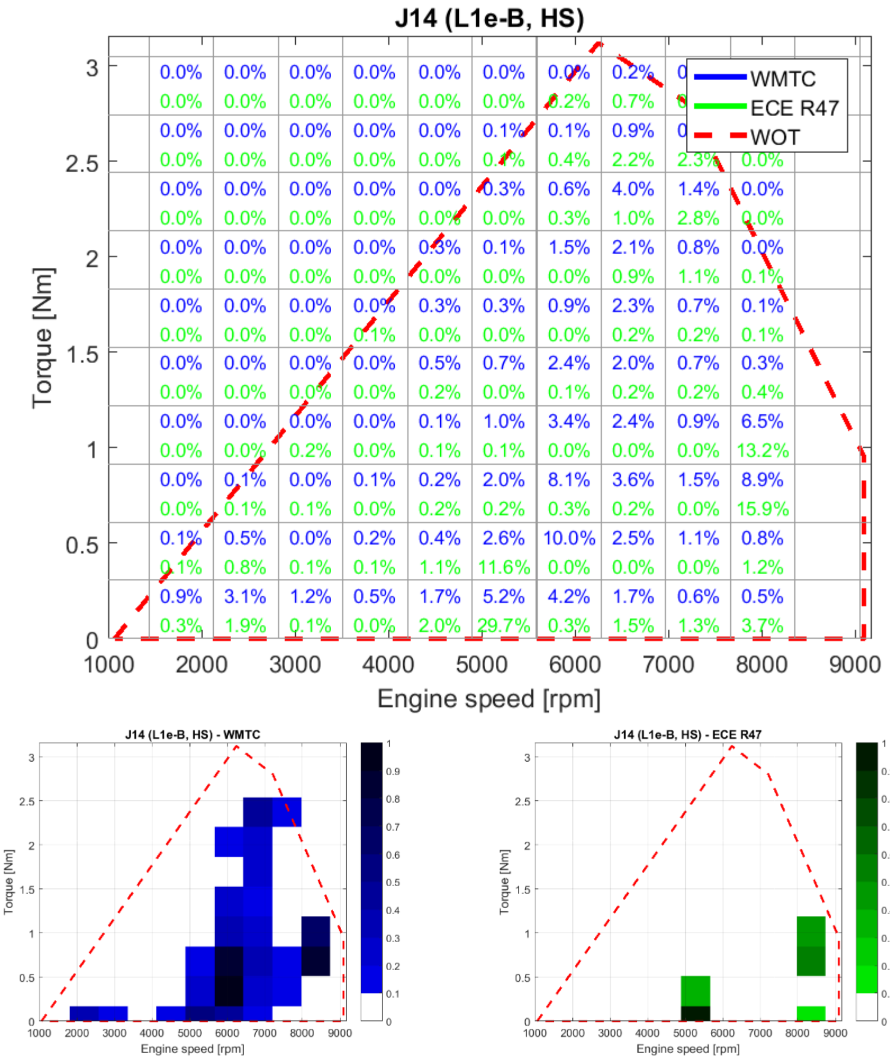


Figure 228. Engine map coverage density of J14 (L1e-B, high speed) - torque

Vehicle J17 (L1e-B, high speed)

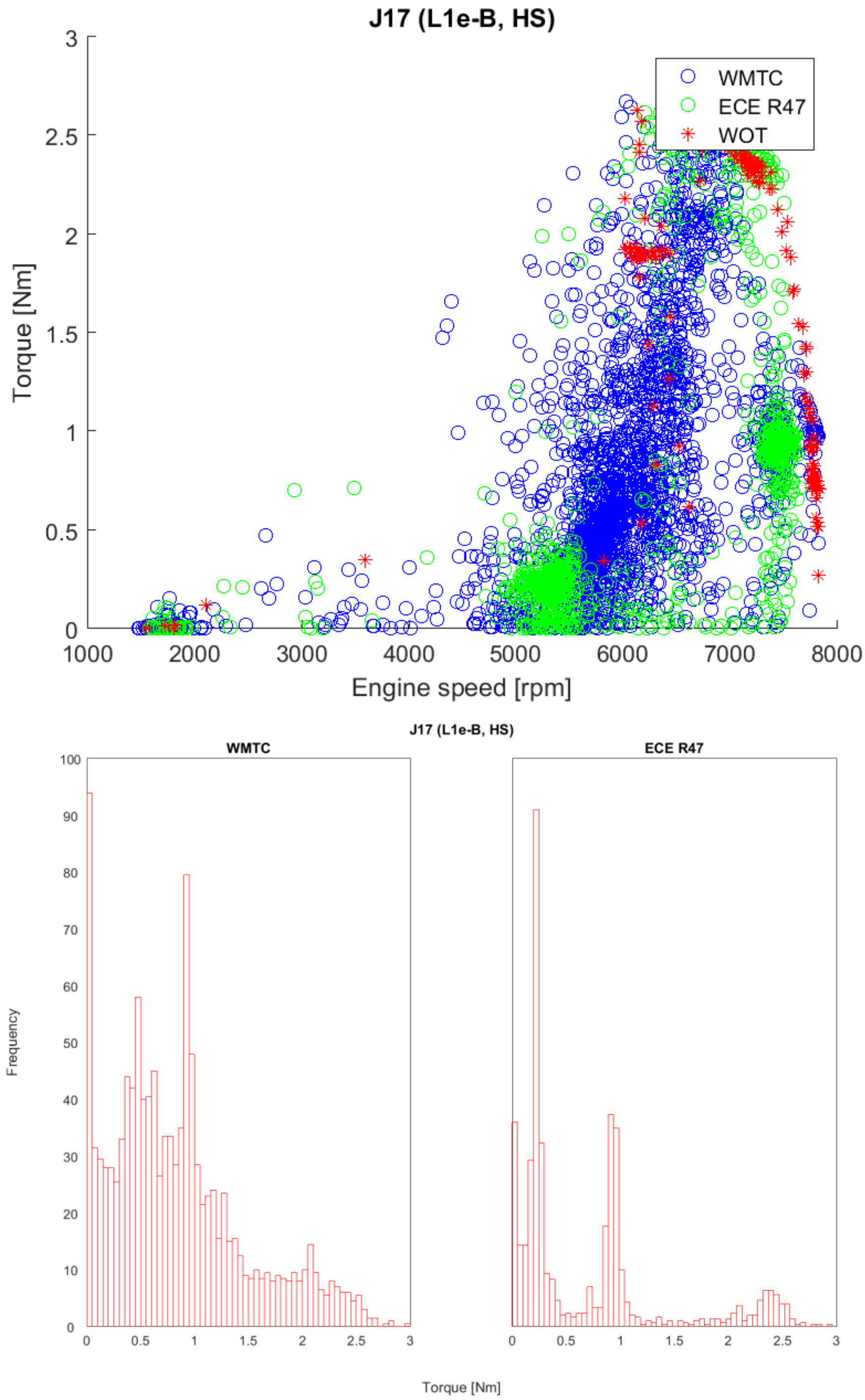


Figure 229. Engine map coverage of J17 (L1e-B, high speed) - torque

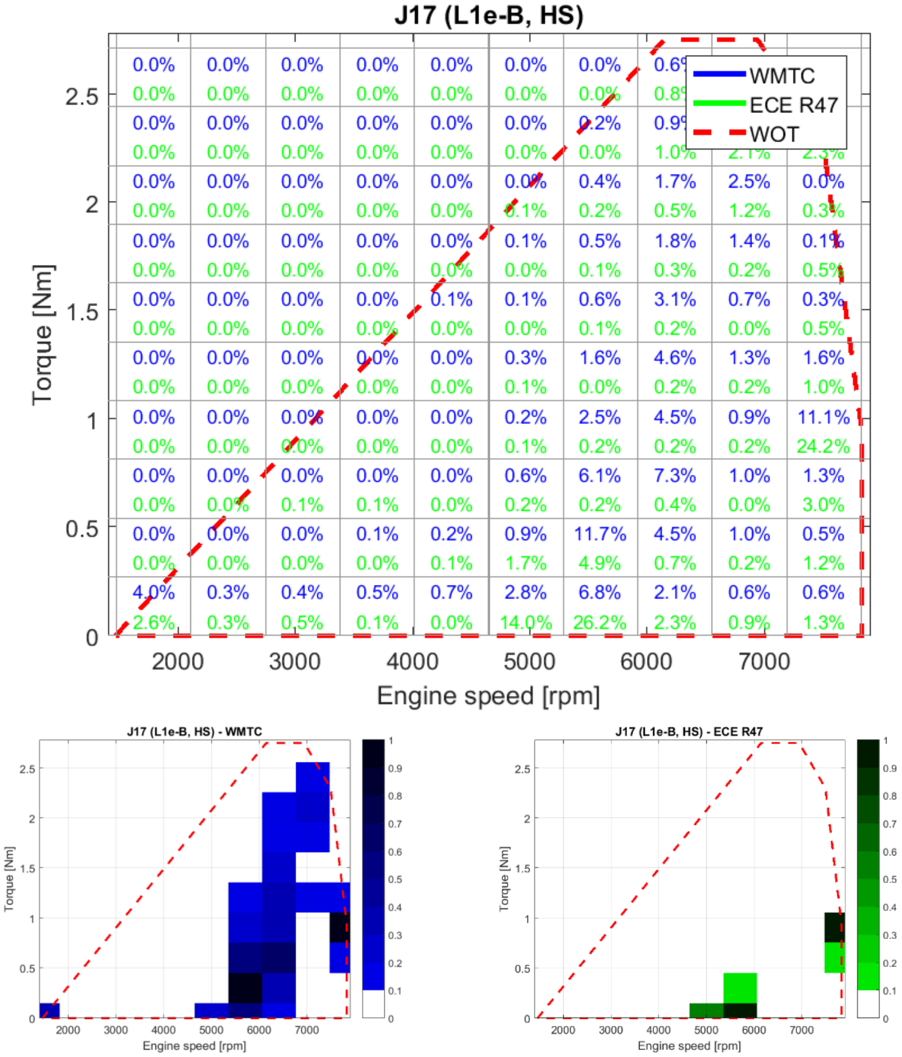


Figure 230. Engine map coverage density of J17 (L1e-B, high speed) - torque

Vehicle J26 (L2e-U)

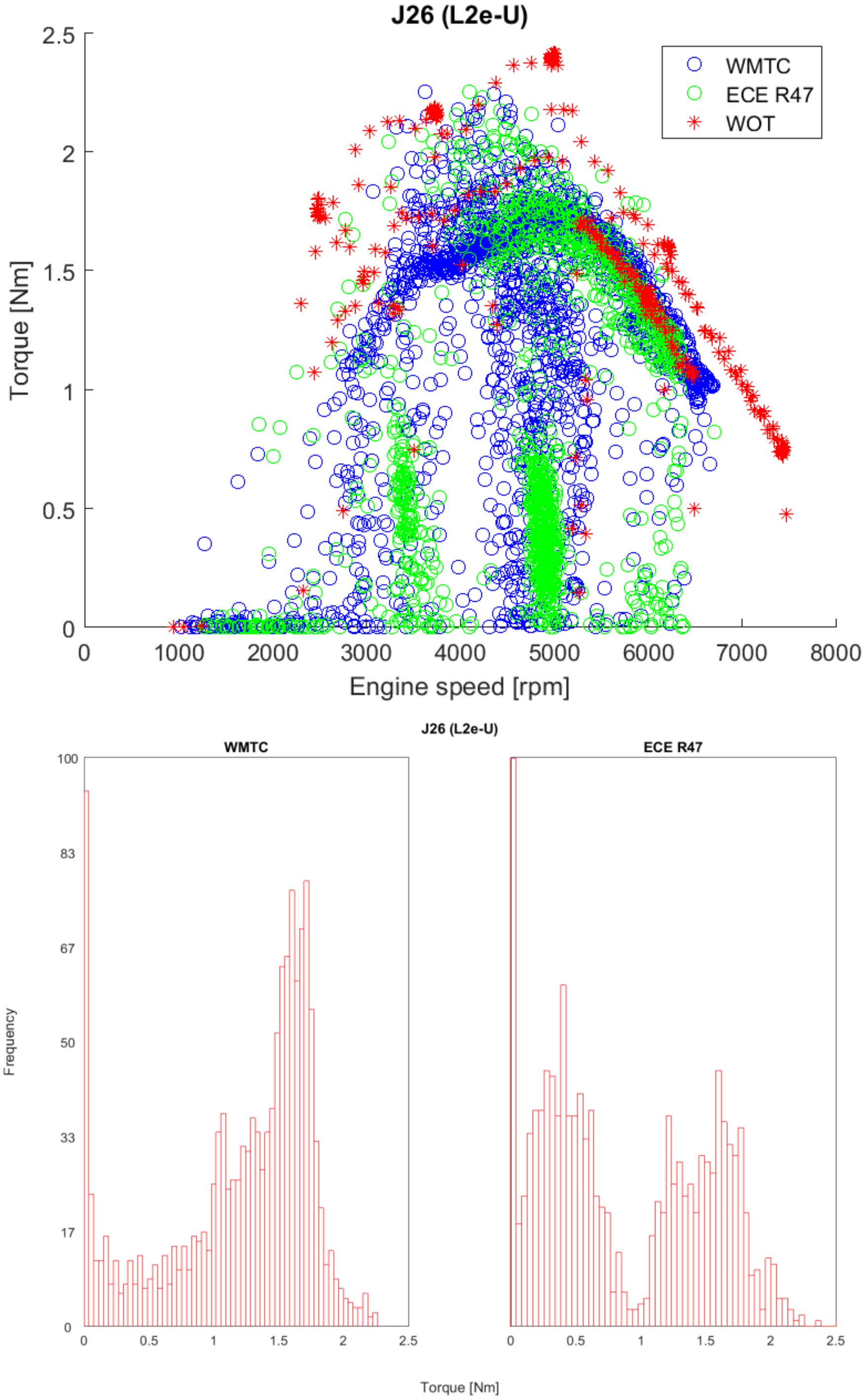


Figure 231. Engine map coverage of J26 (L2e-U) - torque

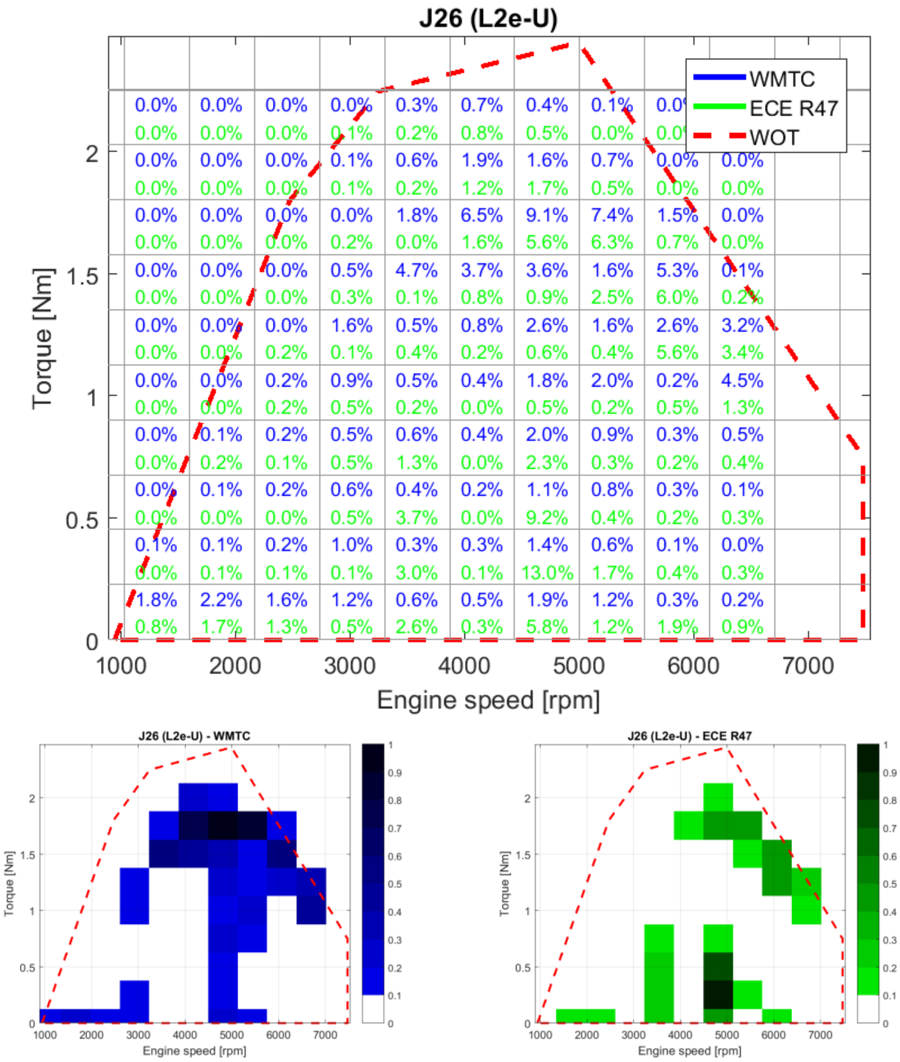


Figure 232. Engine map coverage density of J26 (L2e-U) - torque

Vehicle J24 (L5e-A)

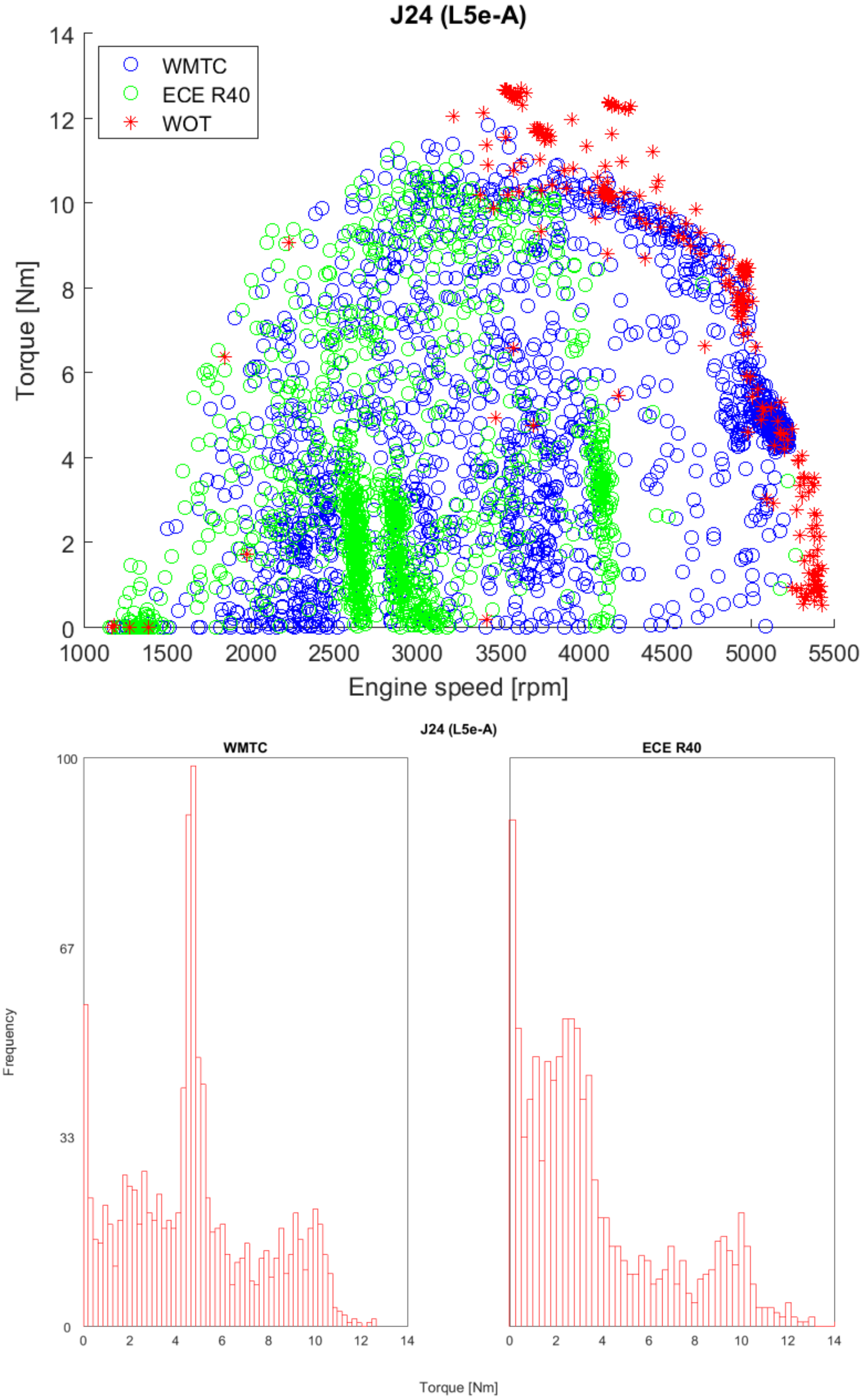


Figure 233. Engine map coverage of J24 (L5e-A) - torque

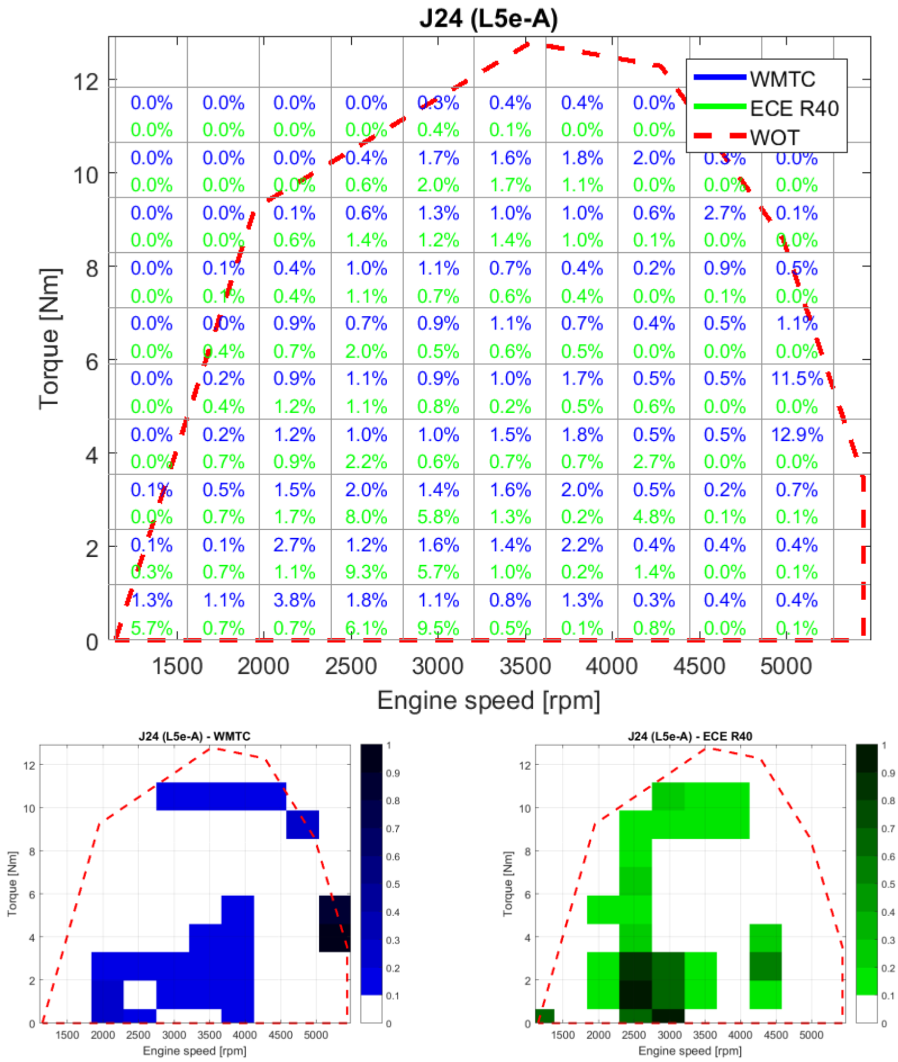


Figure 234. Engine map coverage density of J24 (L5e-A) - torque

Vehicle L01 (L5e-A)

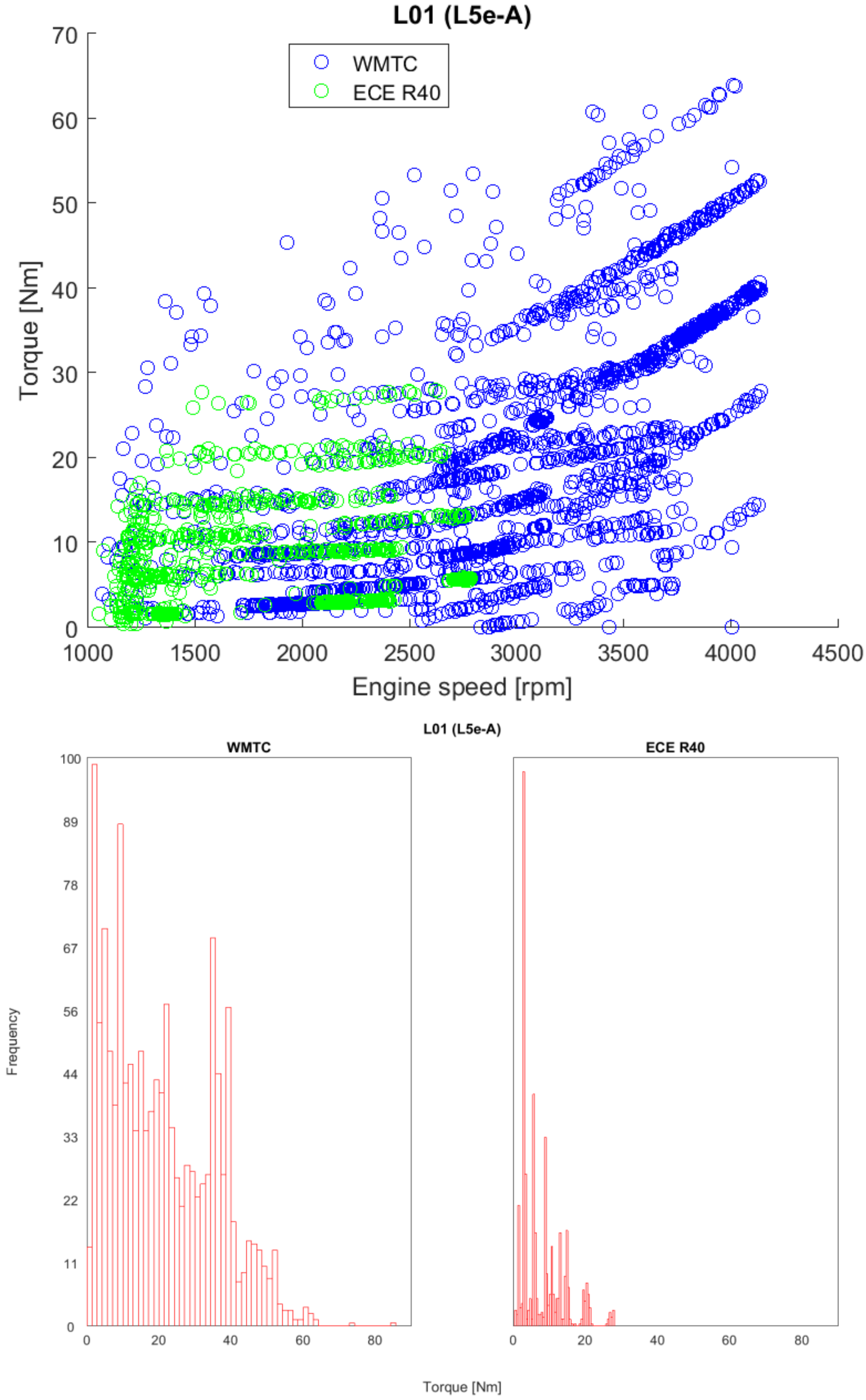


Figure 235. Engine map coverage of J24 (L5e-A) - torque

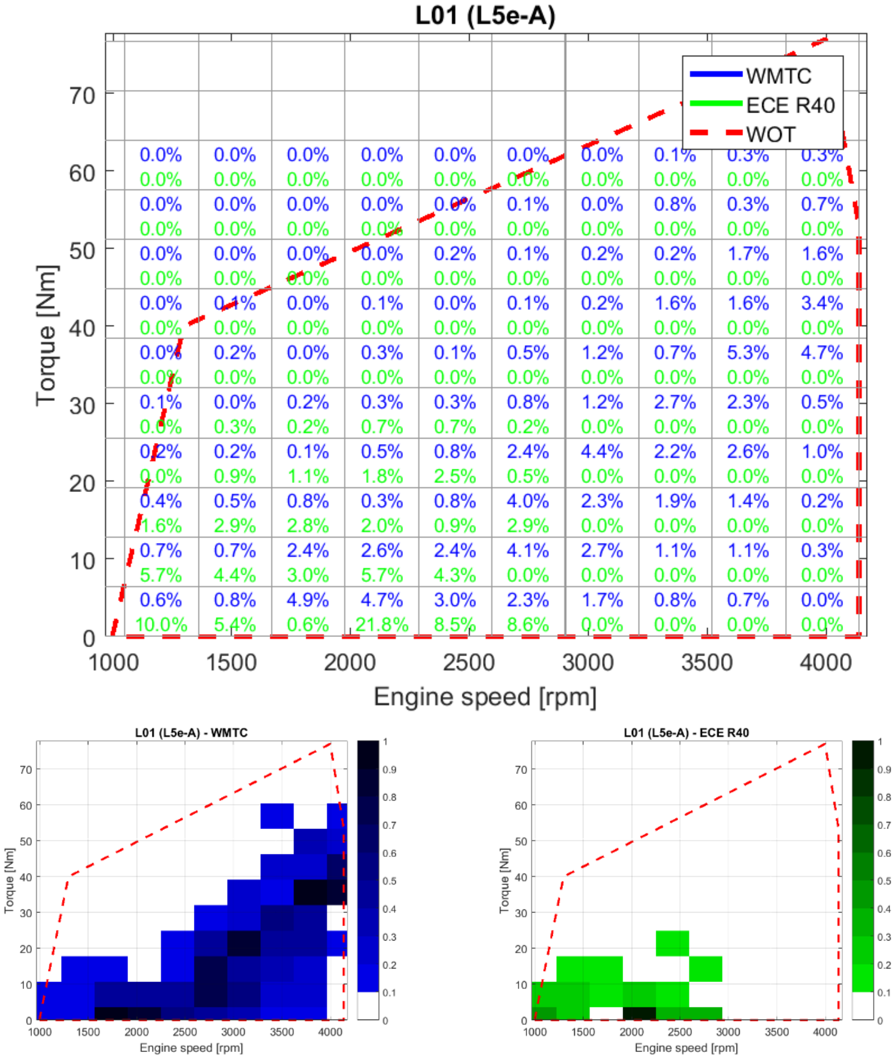


Figure 236. Engine map coverage density of L01 (L5e-A) - torque

Vehicle J01 (L6e-BP)

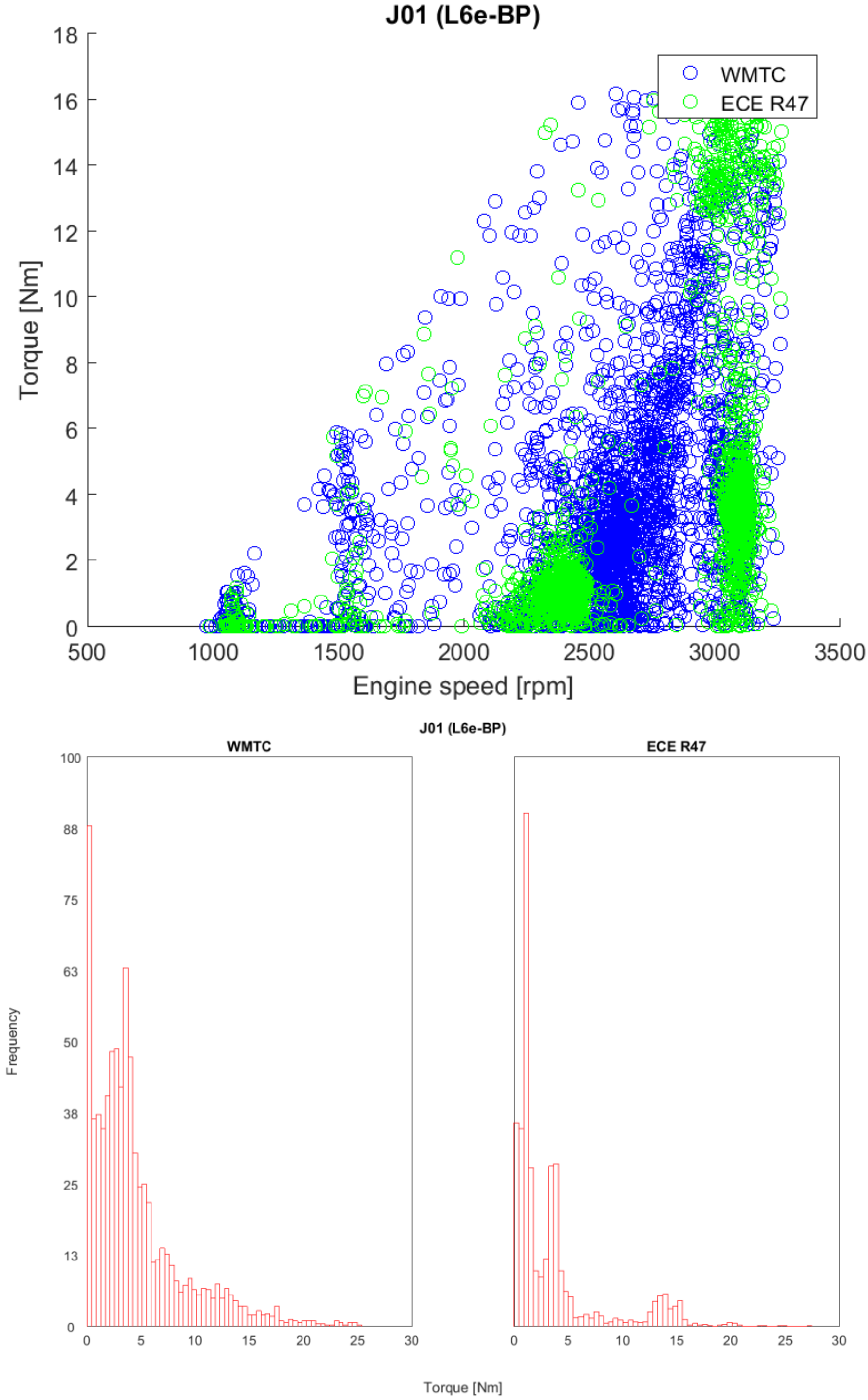


Figure 237. Engine map coverage of J01 (L6e-BP) - torque

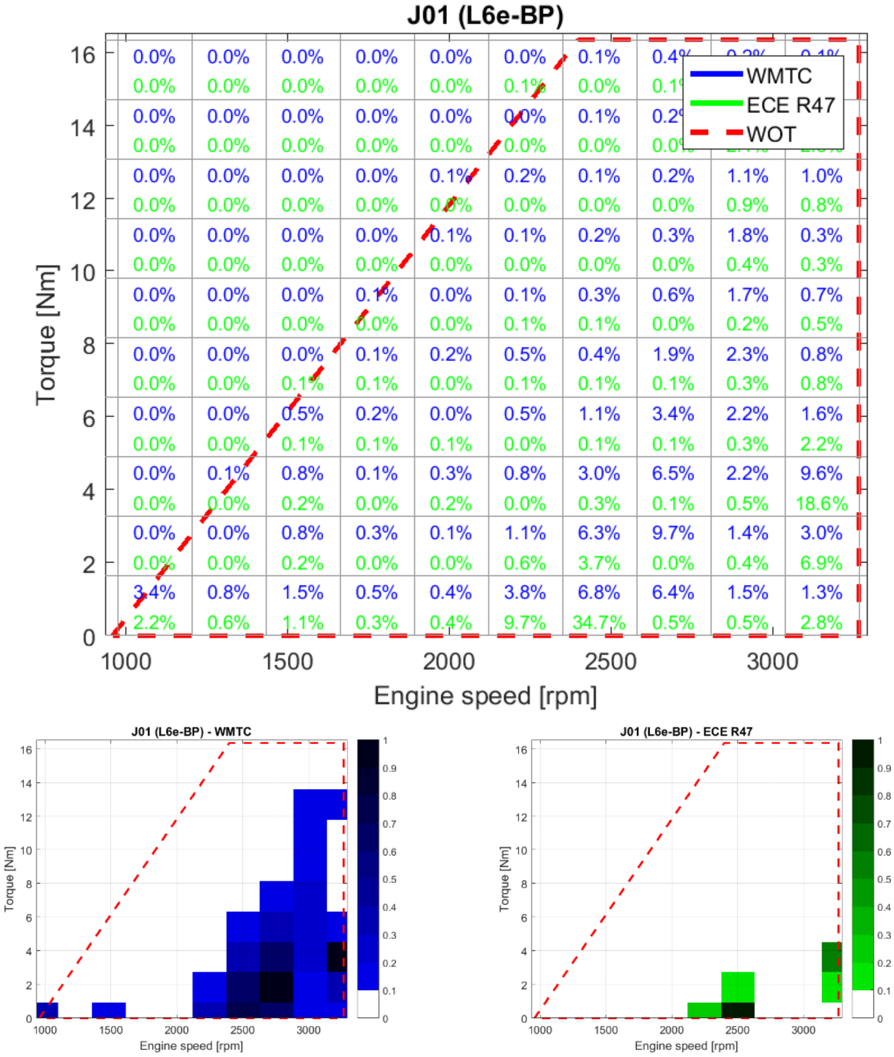


Figure 238. Engine map coverage density of J01 (L6e-BP) - torque

Vehicle J22 (L6e-BU)

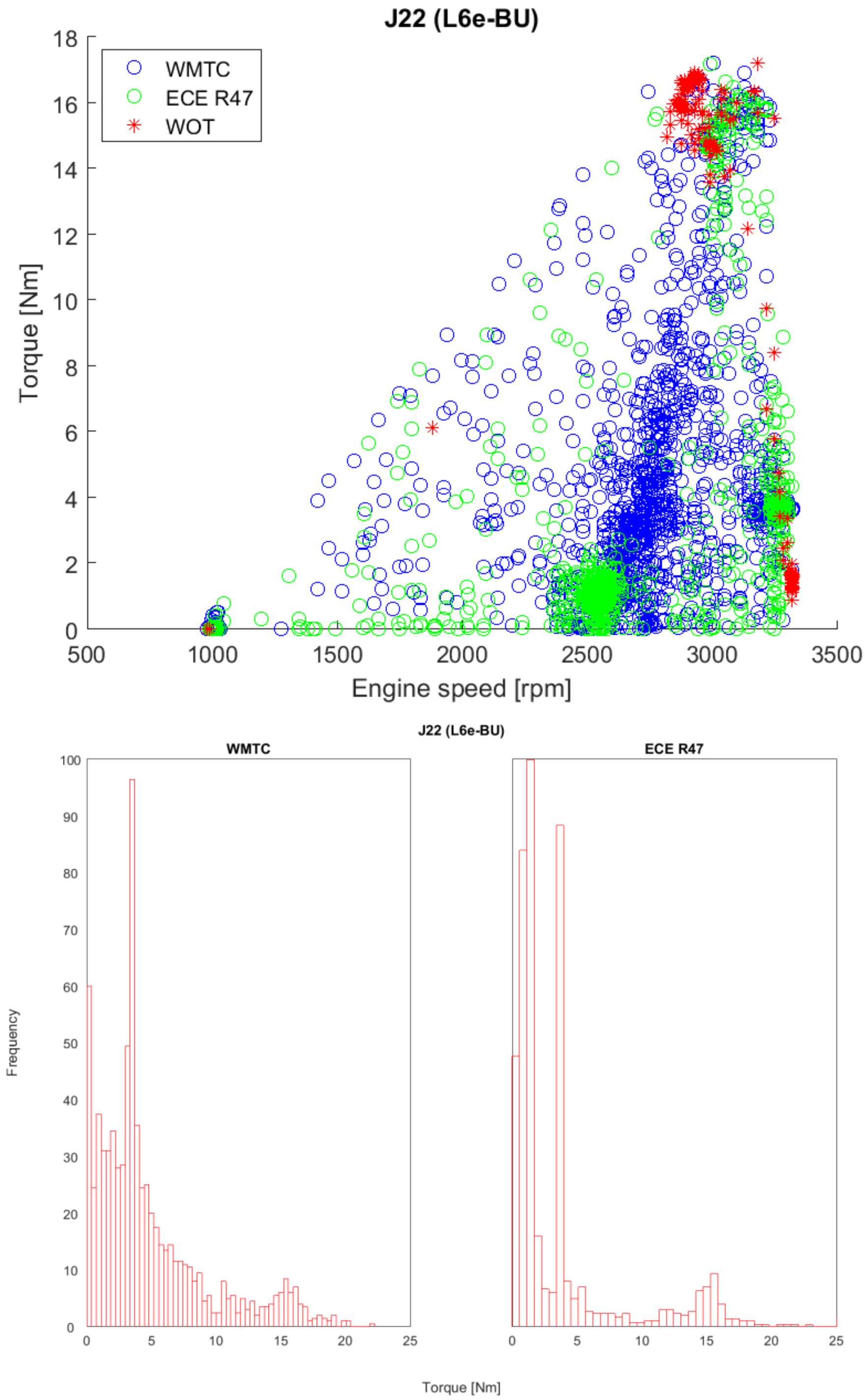


Figure 239. Engine map coverage of J22 (L6e-BU) - torque

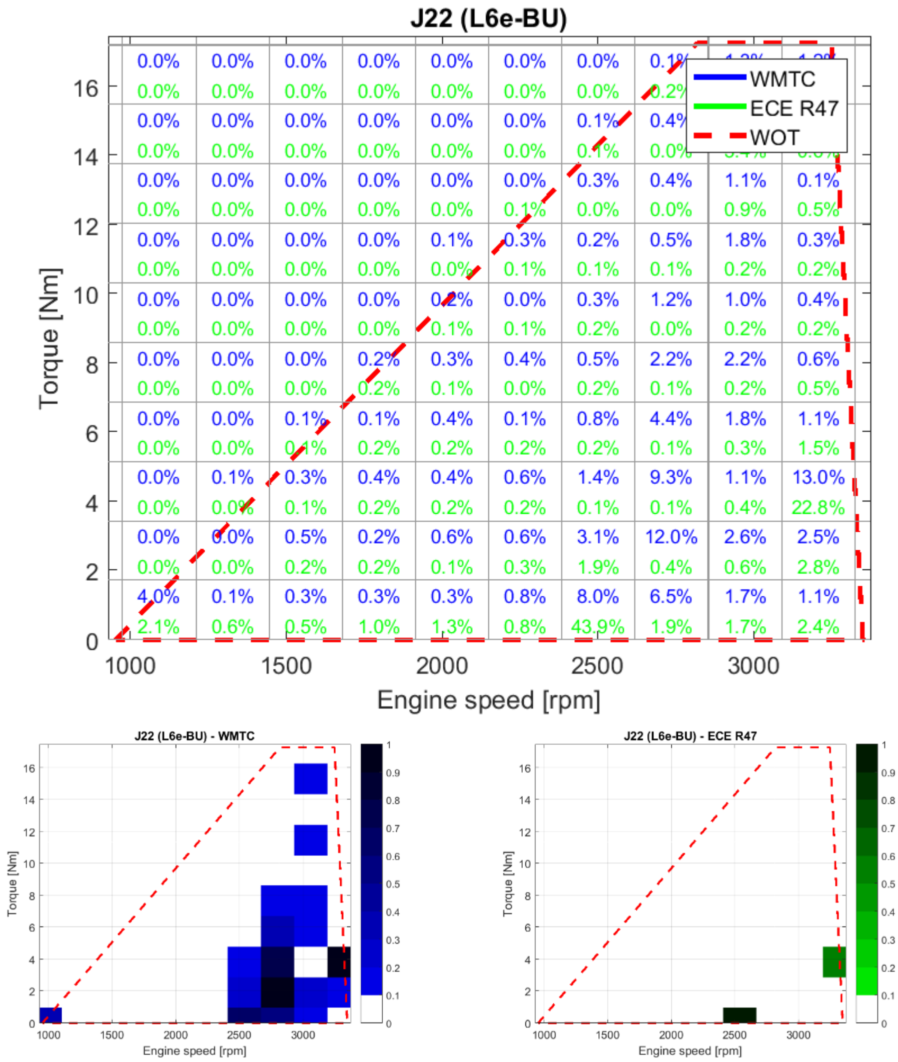


Figure 240. Engine map coverage density of J22 (L6e-BU) - torque

Vehicle J08 (L7e-B1)

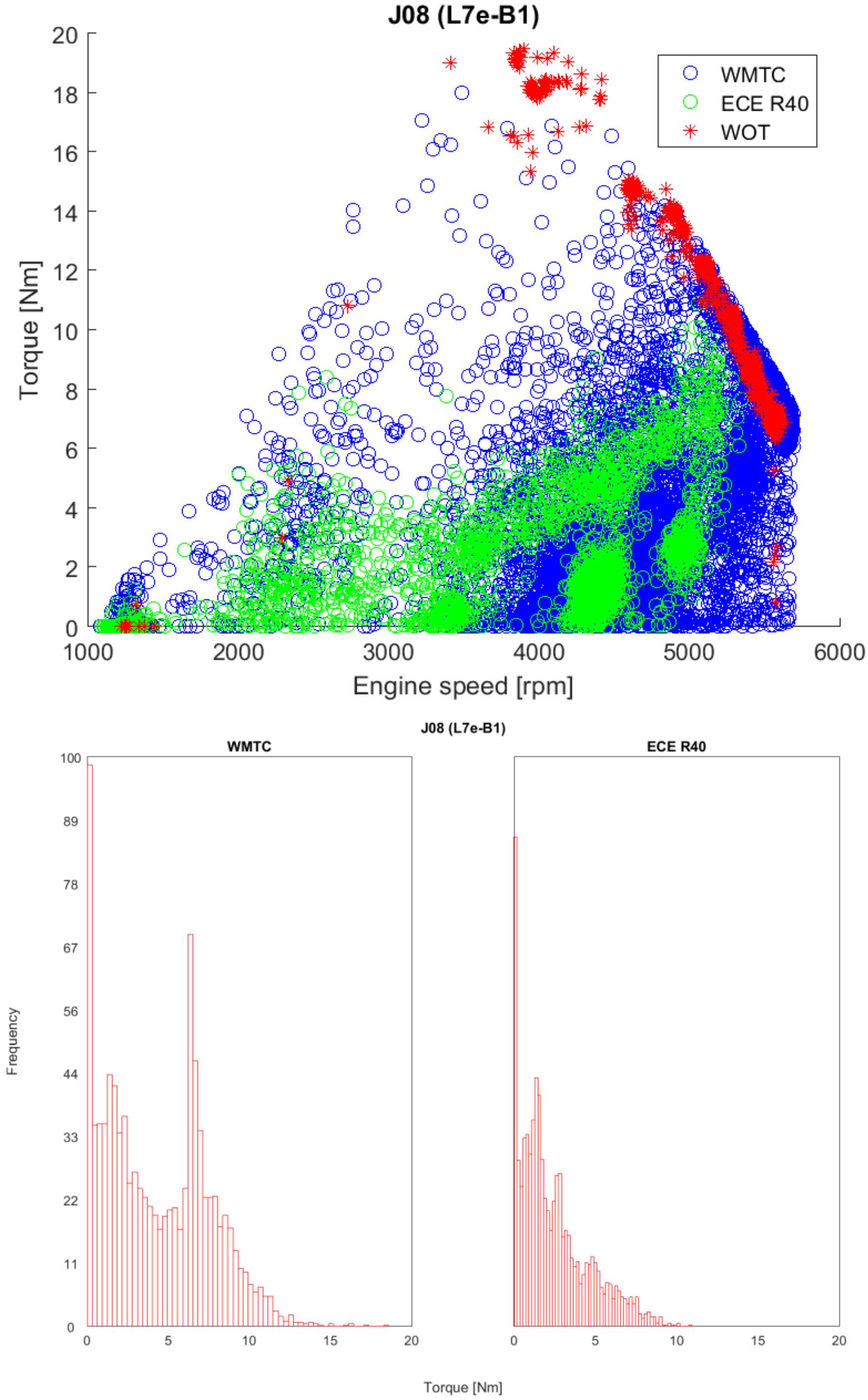
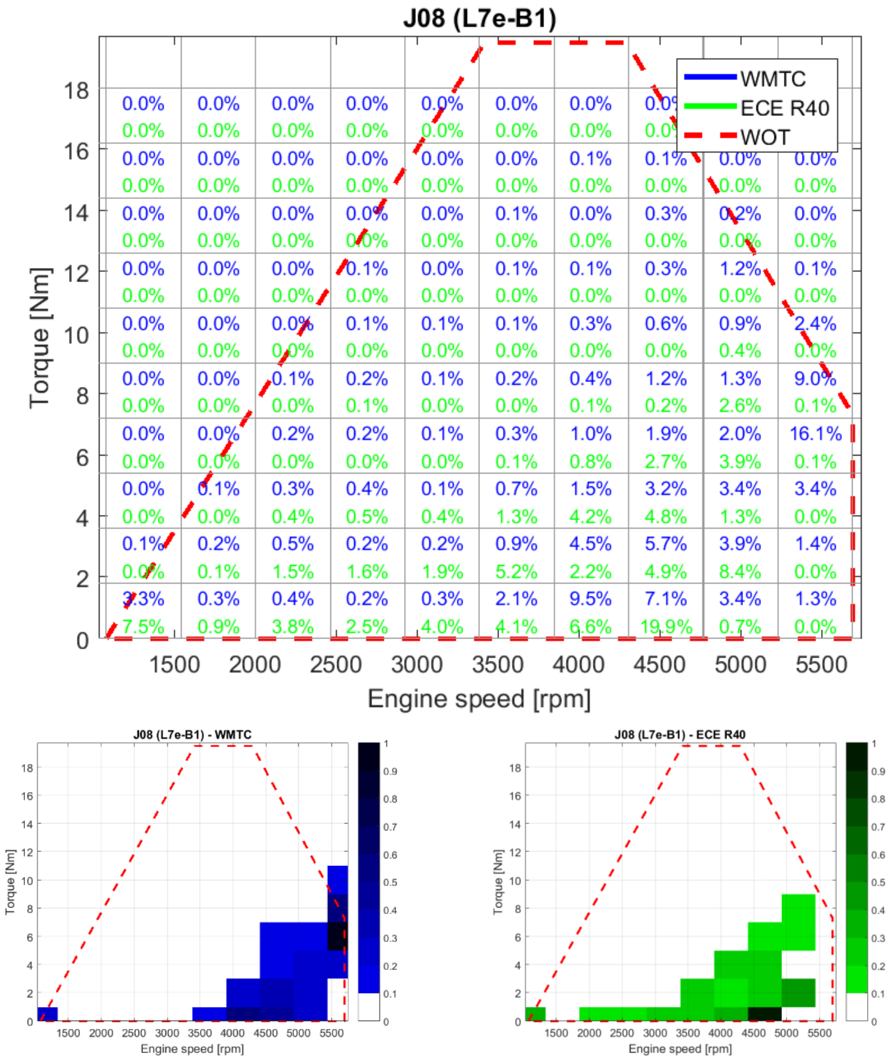


Figure 241. Engine map coverage of J08 (L7e-B1) - torque



6

Figure 242. Engine map coverage density of J08 (L7e-B1) - torque

Vehicle J16 (L7e-B1)

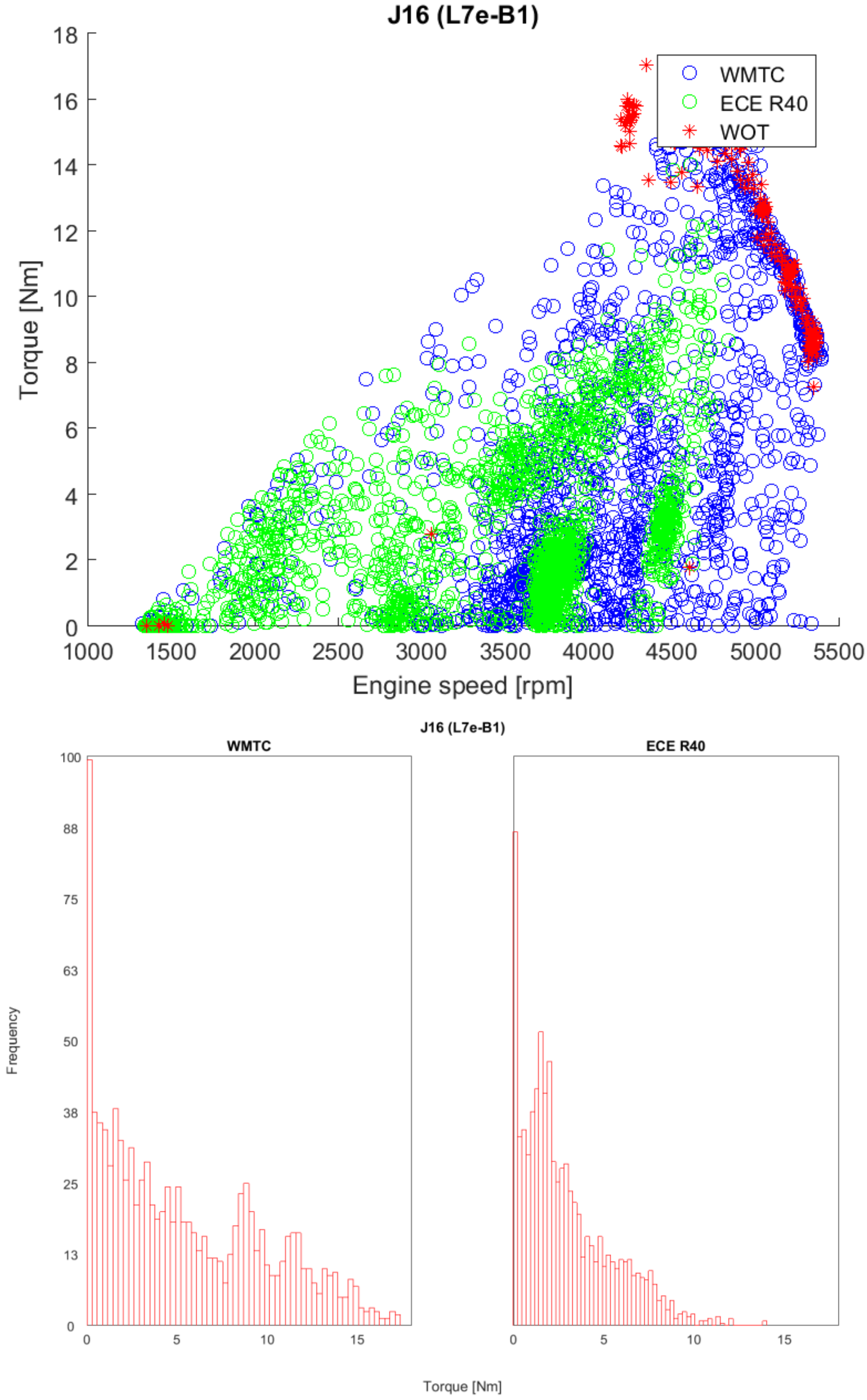


Figure 243. Engine map coverage of J16 (L7e-B1) - torque

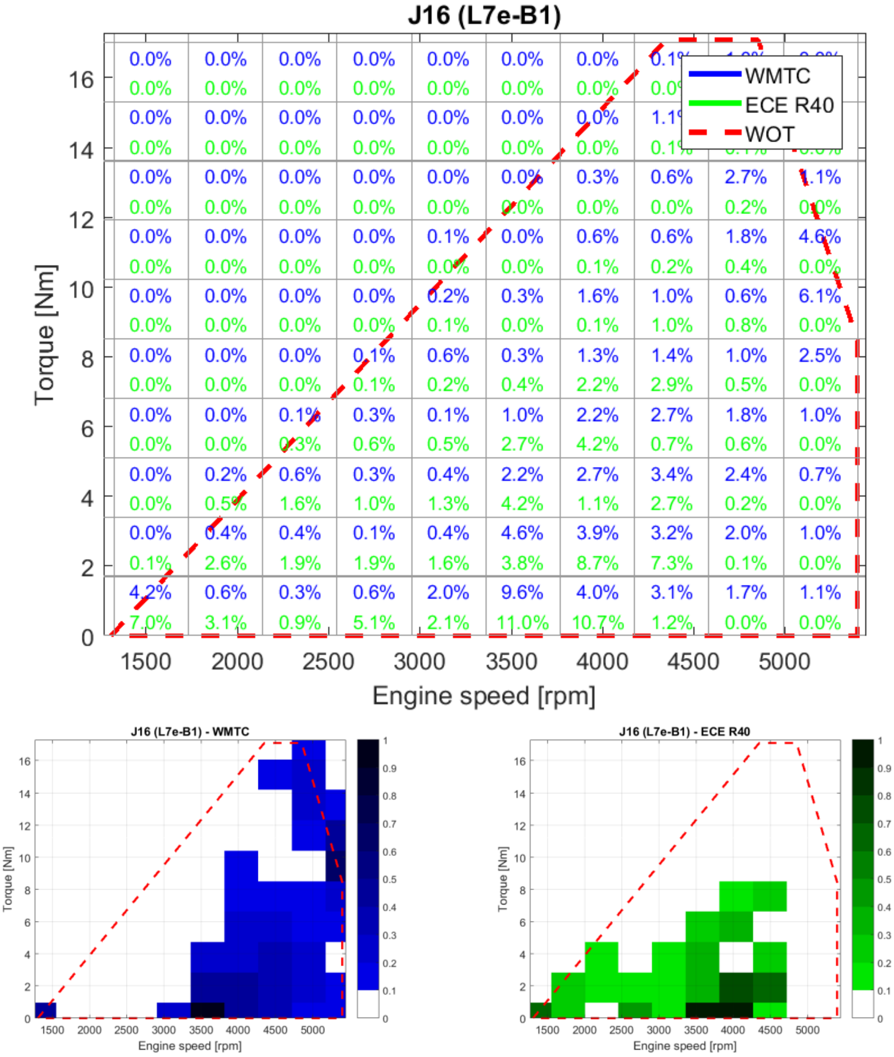


Figure 244. Engine map coverage density of J16 (L7e-B1) - torque

Vehicle J25, valid. (L7e-B1)

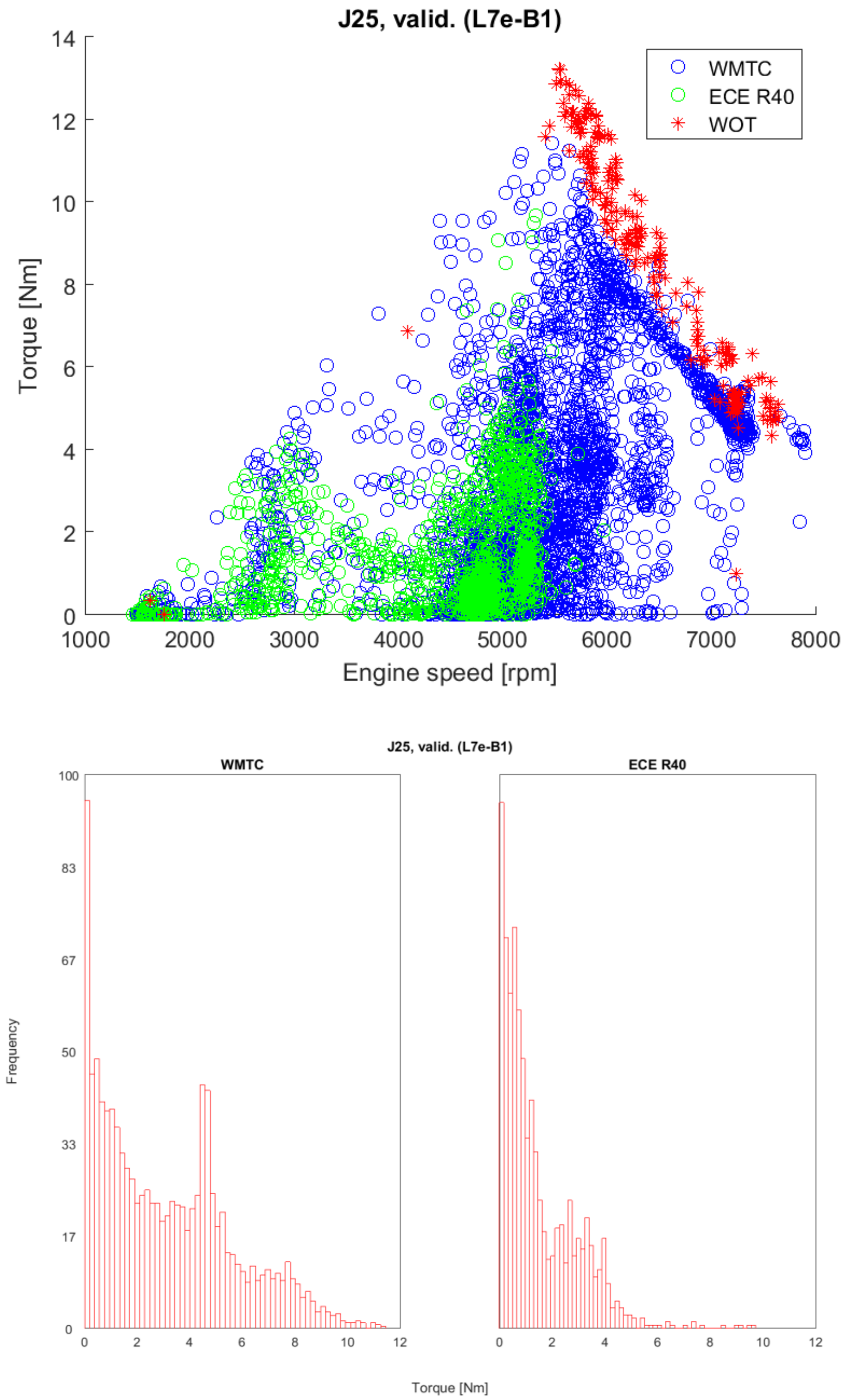


Figure 245. Engine map coverage of J25, valid. (L7e-B1) - torque

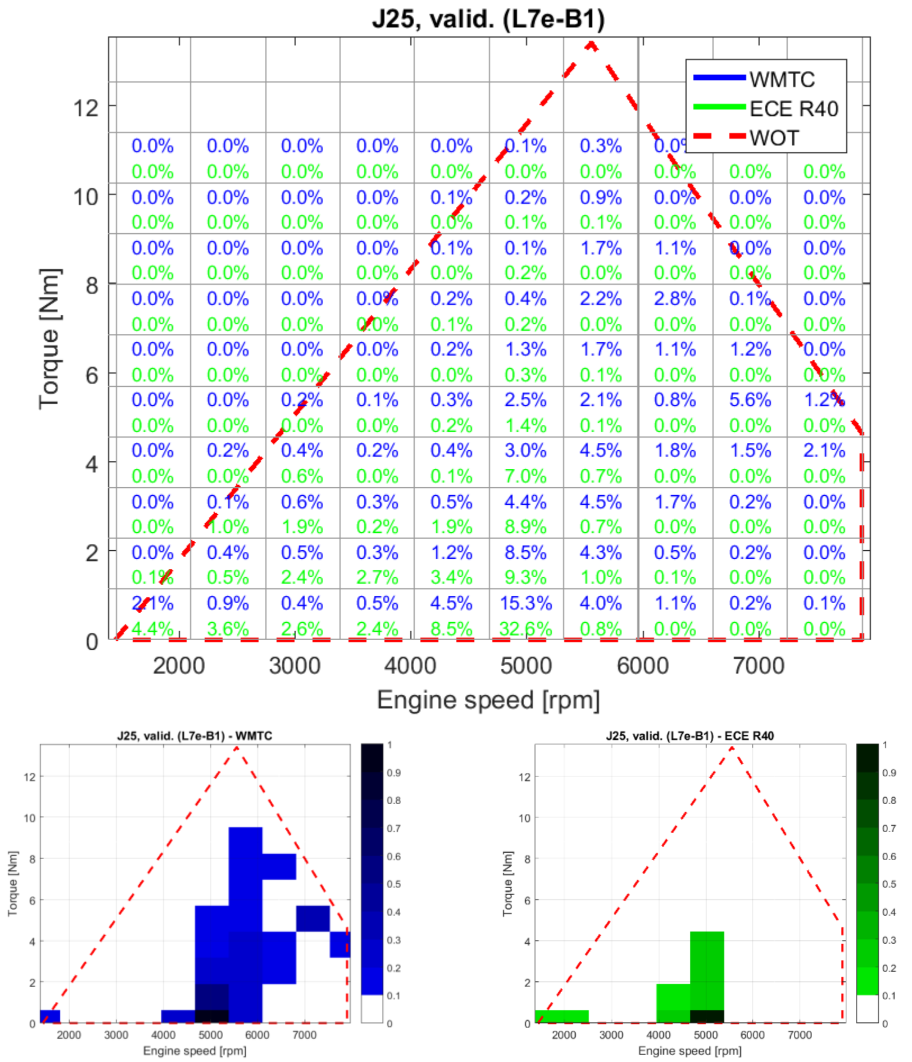


Figure 246. Engine map coverage density of J25, valid. (L7e-B1) - torque

Vehicle J09 (L7e-B2)

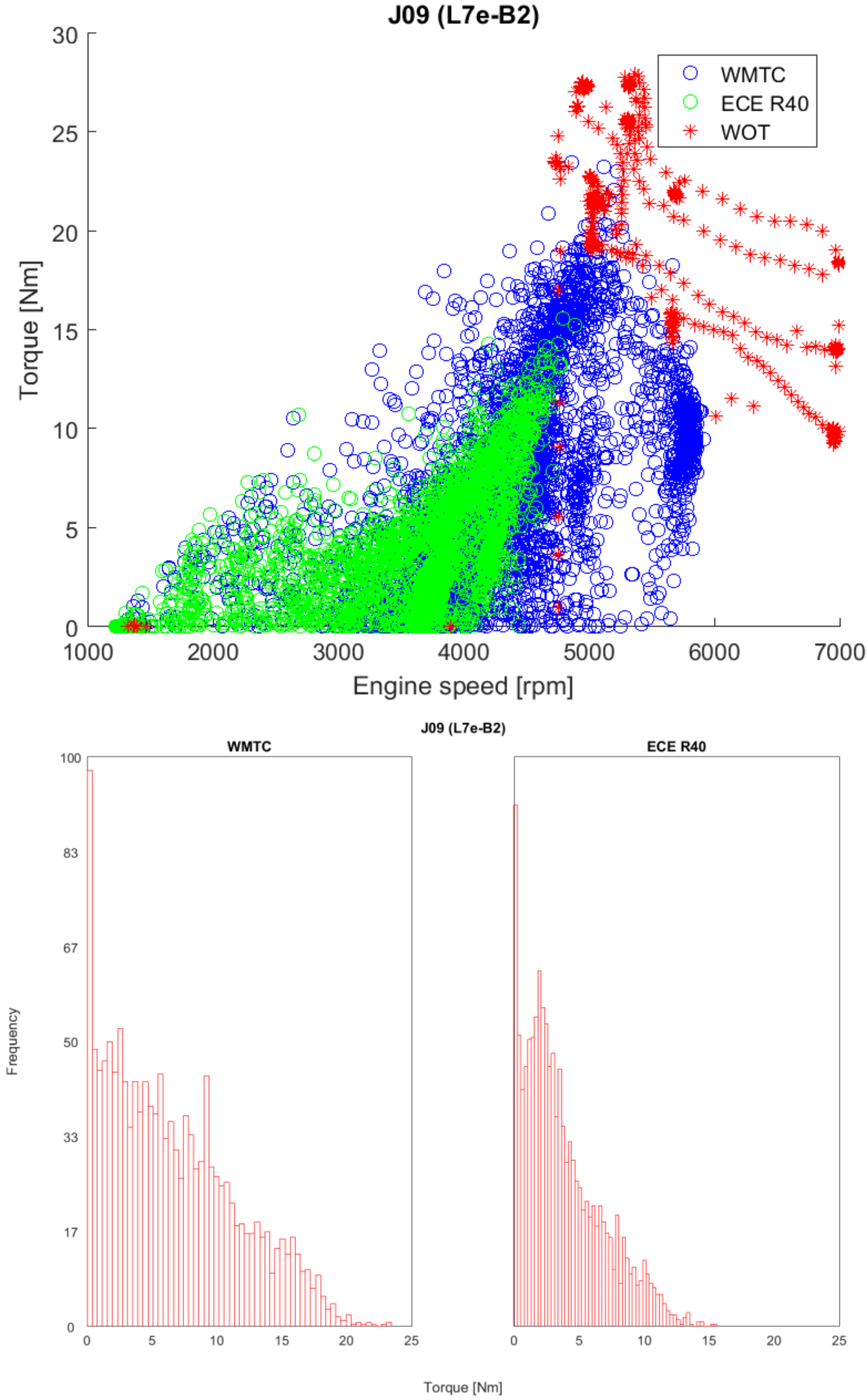


Figure 247. Engine map coverage of J09 (L7e-B2) - torque

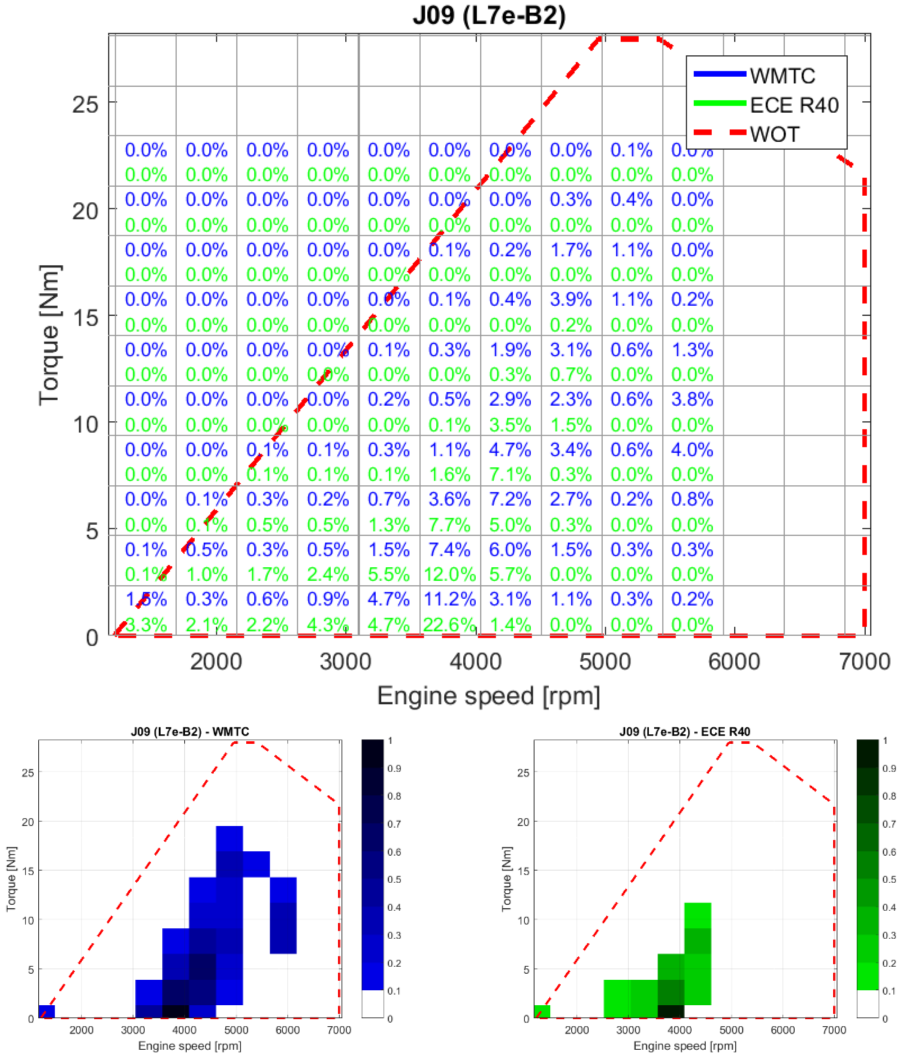


Figure 248. Engine map coverage density of J08 (L7e-B1) - torque

C Test results: Engine speed and engine load related parameters

The following figures present a scatter plot of the examined-recorded engine load parameters versus the engine speed for each vehicle, i.e., the accelerator position and the manifold absolute pressure (MAP), for the vehicles that MAP is recorded. Each figure is split in four areas. The main area is the scatter plot, illustrating the points for each of the examined driving cycle, WMTC, ECE, WOT. In the upper left and the lower right graphs, the accelerator/MAP and the engine speed distributions are illustrated in bars, respectively, while the mean value is also marked with a line, for each driving cycle. The lower left area contains the legend of each figure, also including the mean value for each driving cycle.

The vehicles tested and presented in the following figures are:

- L1e-A: 1 vehicle
- L1e-B, low speed: 3 vehicles
- L1e-B, high speed: 6 vehicles
- L5e-A: 2 vehicles
- L6e-BP: 1 vehicle
- L6e-BU: 1 vehicle
- L7e-B1: 2 vehicles
- L7e-B2: 1 vehicle

Disclaimer
The following figures are requested by the call and are presented without further commenting.

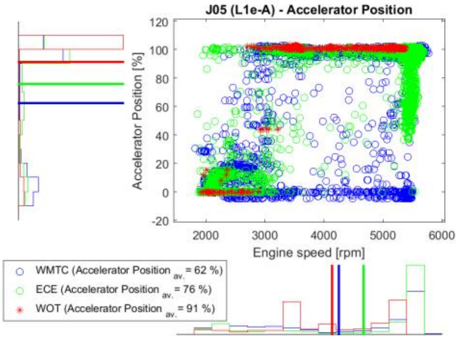


Figure 249. Engine speed and engine load related parameters – Vehicle J05 (L1e-A)

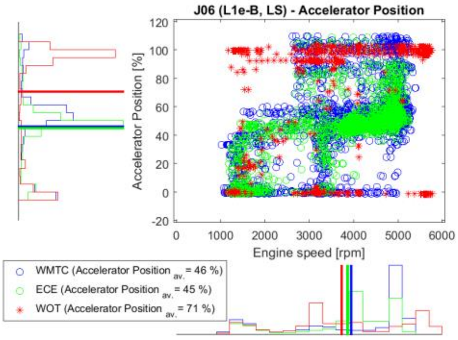


Figure 250. Engine speed and engine load related parameters – Vehicle J06 (L1e-B, low speed)

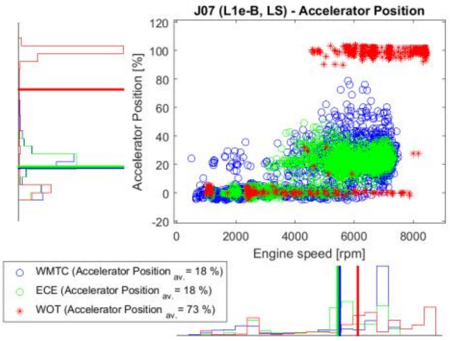


Figure 251. Engine speed and engine load related parameters – Vehicle J07 (L1e-B, low speed)

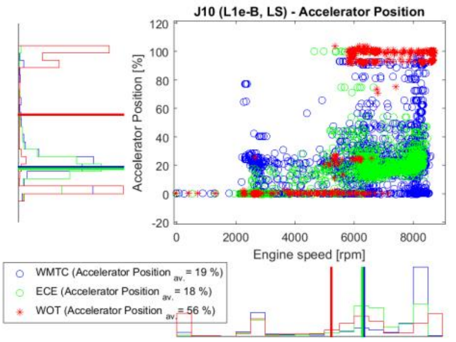


Figure 252. Engine speed and engine load related parameters – Vehicle J10 (L1e-B, low speed)

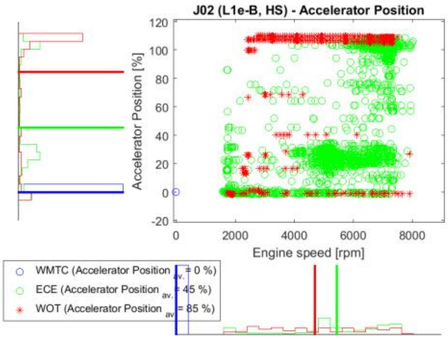


Figure 253. Engine speed and engine load related parameters – Vehicle J02 (L1e-B, high speed moped)

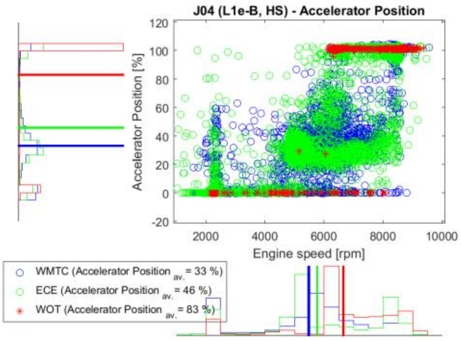


Figure 254. Engine speed and engine load related parameters – Vehicle J04 (L1e-B, high speed moped)

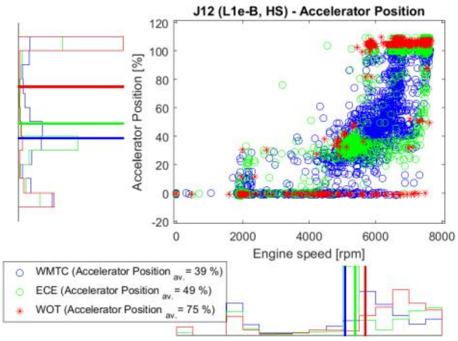


Figure 255. Engine speed and engine load related parameters – Vehicle J12 (L1e-B, high speed moped)

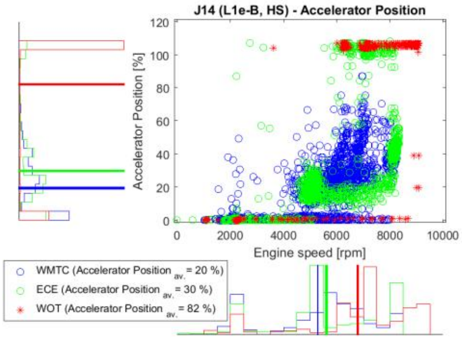


Figure 256. Engine speed and engine load related parameters – Vehicle J14 (L1e-B, high speed moped)

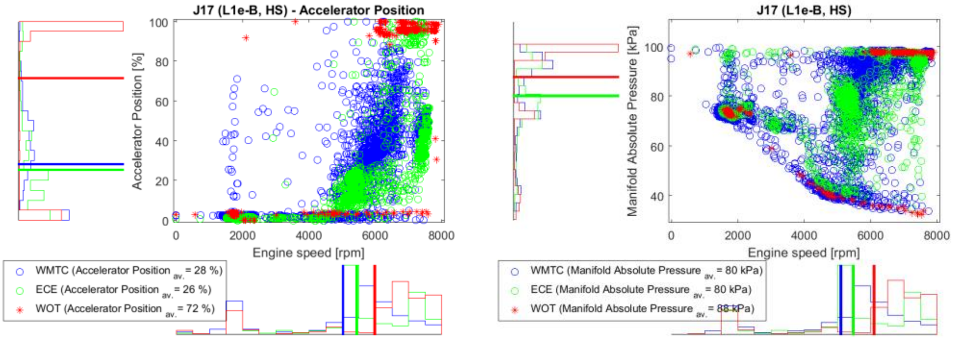


Figure 257. Engine speed and engine load related parameters – Vehicle J17 (L1e-B, high speed moped)

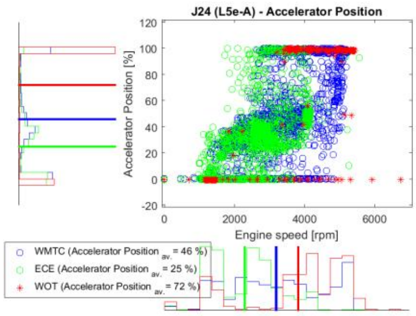


Figure 258. Engine speed and engine load related parameters – Vehicle J24 (L5e-A)

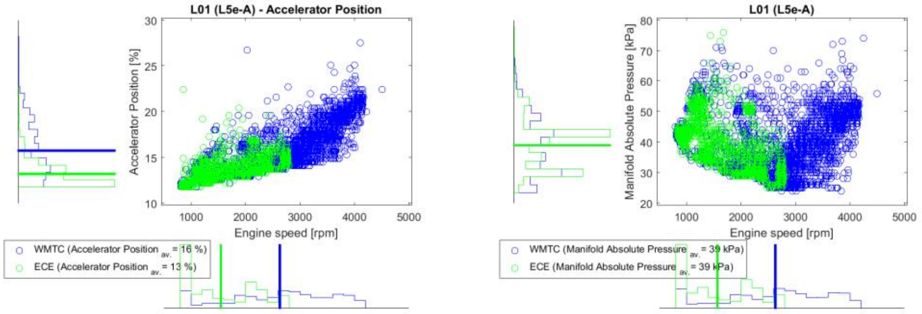


Figure 259. Engine speed and engine load related parameters – Vehicle L01 (L5e-A)

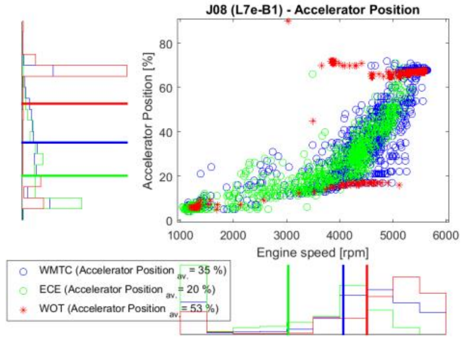


Figure 260. Engine speed and engine load related parameters – Vehicle J08 (L7e-B1)

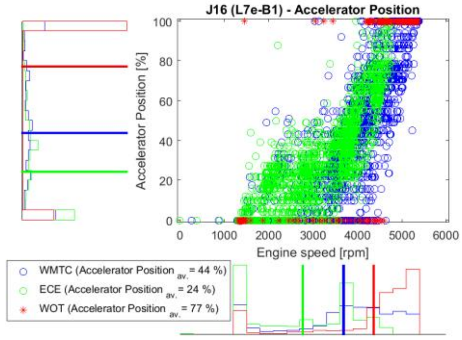


Figure 261. Engine speed and engine load related parameters – Vehicle J16 (L7e-B1)

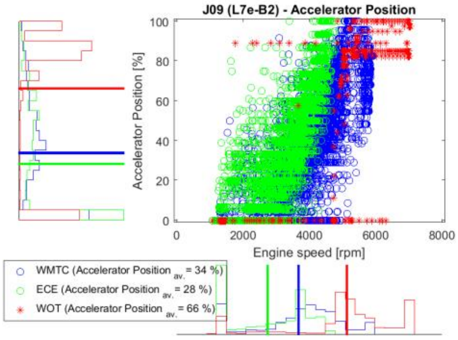


Figure 262. Engine speed and engine load related parameters – Vehicle J09 (L7e-B2)

D Test results: Pollutant emissions, fuel consumption and lambda sensor results

The base emission results are presented, as average of the bag results recorded during the tests, relative to the maximum value. The cold-warm phase weighting factors used to calculate the final values follow the Euro 5 weighting factors of Table 1-10 of Regulation (EU) No 134/2014. The results are grouped in the following figures by their L- vehicle category.
The tested vehicles are the following:

- L1e-A: 1 vehicle
- L1e-B, low speed: 3 vehicles
- L1e-B, high speed: 6 vehicles
- L2e-U: 1 vehicle
- L5e-A: 2 vehicles
- L6e-BP: 1 vehicle
- L6e-BU: 1 vehicle
- L7e-B1: 3 vehicles (1 validation vehicle)
- L7e-B2: 1 vehicle

The recorded and examined pollutants are the NO_x, CO, CO_2, THC, CH_4, NMHC and FC. The error bar presented in each bar of the graphs shows the standard deviation of the variability of the results, coming after running multiple times the examined driving cycles.

L1e vehicles

In the following figures the bag results of the emission pollutants for the L1e test vehicles are presented. It must be noted that all L1e tested vehicles are Euro 2 homologated.

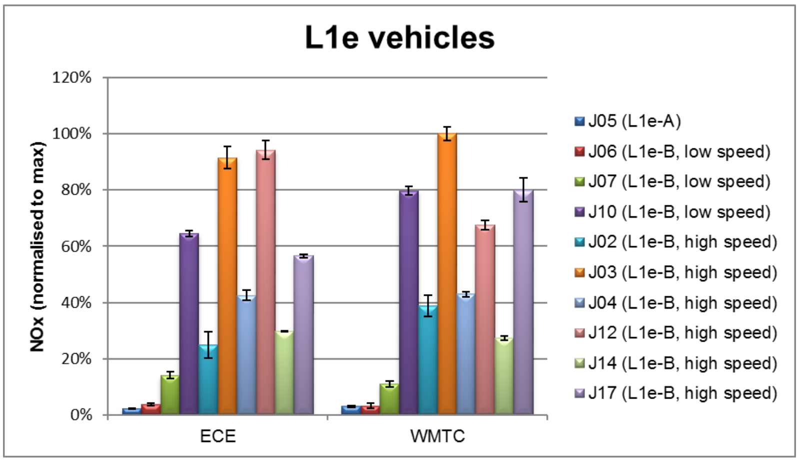


Figure 263. Average bag emission results of L1e vehicles – NO_x

The NO_x emissions are presented in this figure. NO_x emissions are lower for the 2-stroke mopeds (J05, J06, J07, J02, J04 and J14) than the 4-stroke ones (J10, J03, J12 and J17). This observation is even clearer when examining the low speed mopeds. As expected, the low speed mopeds emit lower NO_x levels than the high speed ones. The most important conclusion coming from this figure is that the two driving cycles' results show exactly the same behaviour in terms of the engine technology used in the examined vehicles, though, the WMTC presents little higher emissions than the ECE cycle. The variability of the results is very low in both driving cycles, while the highest variability is presented for J02 (L1e-B, low speed moped), which is the only vehicle with manual transmission.

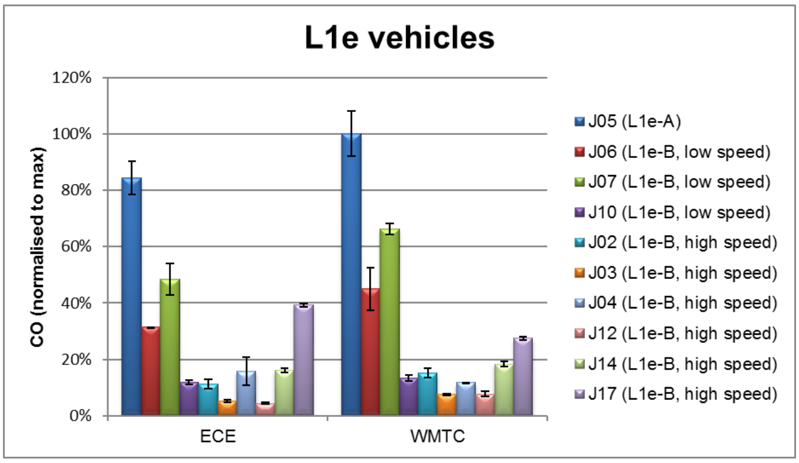


Figure 264. Average bag emission results of L1e vehicles – CO

On the other hand, CO emissions are generally lower for the 4-stroke mopeds than the 2-stroke ones. Besides, the low speed mopeds emit higher CO levels than the high speed vehicles. The comparison of the driving cycles' results shows no major differences, with the WMTC presenting little higher emissions than the ECE cycle in most of the test vehicles.

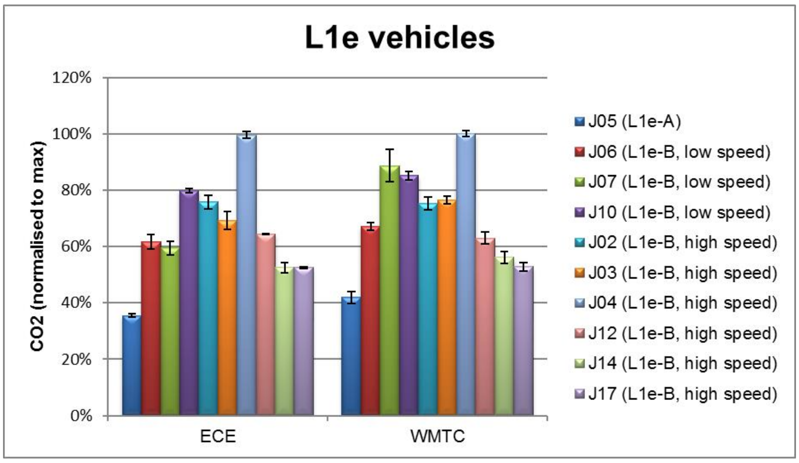


Figure 265. Average bag emission results of L1e vehicles – CO_2

Figure 265 presents the CO_2 bag emission results. The engine technology seems to have no clear effect on the CO_2 emissions, while the same stands for the driving cycles examined.

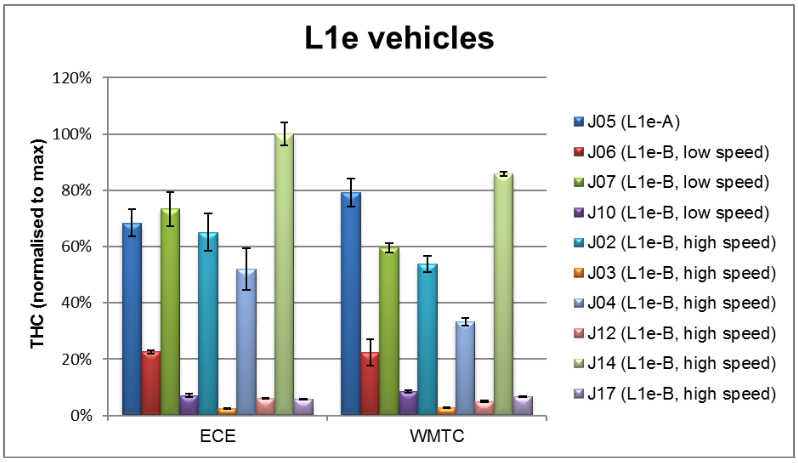


Figure 266. Average bag emission results of L1e vehicles – THC

With regard to the THC pollutant examined, the engine technology seems to play a very significant role to the emissions level. No clear conclusion can be drawn when comparing the different driving cycles, since in some vehicles the WMTC shows lower emissions, while ECE behaves better than WMTC in some other tested vehicles.

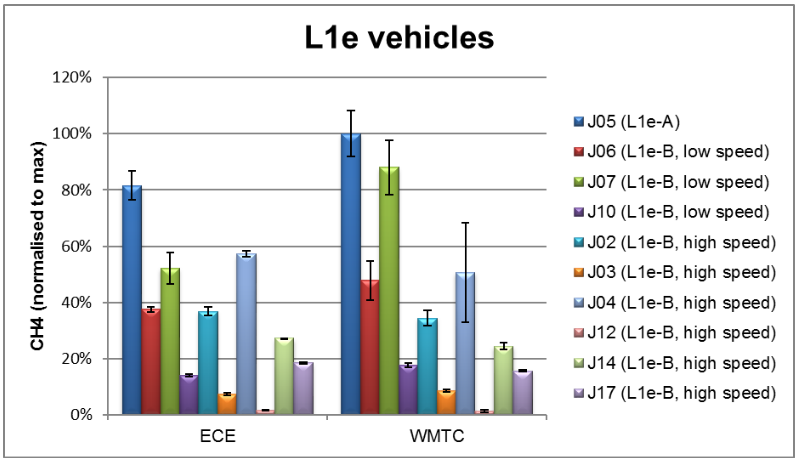


Figure 267. Average bag emission results of L1e vehicles – CH_4

CH_4 bag results are presented in Figure 267. WMTC perform almost the same as ECE, with a little worst behavior, in terms of the CH_4 emissions. The variability of the results seems higher than the rest of the examined pollutants, especially for the 4-stroke vehicles, though, this can be explained because of the very low mass levels recorded for the CH_4 pollutant.

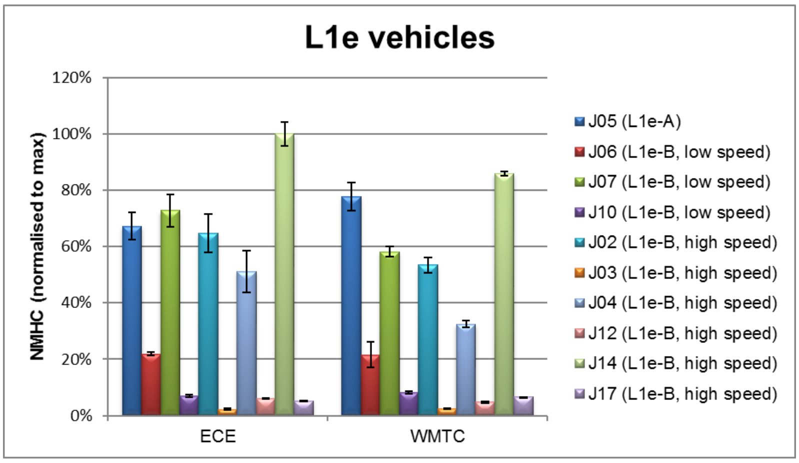


Figure 268. Average bag emission results of L1e vehicles – NMHC

The examination of the NMHC pollutant follows exactly the same behavior as the THC pollutant. This is expected, since the percentage of CH_4 mass contained in the THC pollutant is very low when compared to the NMHC mass.

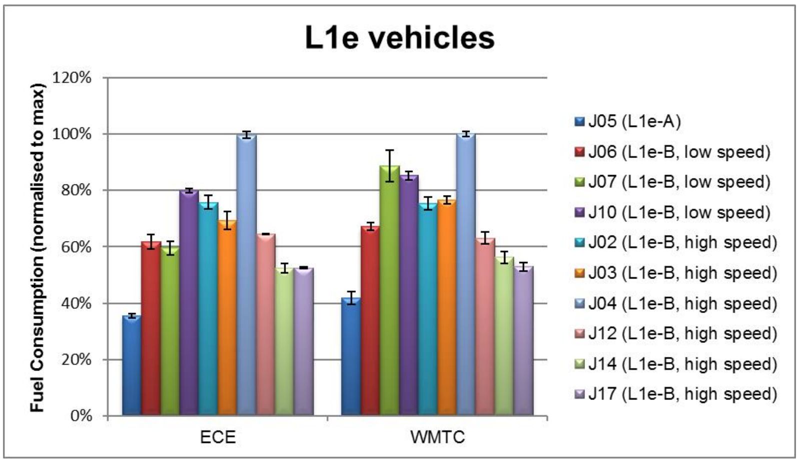


Figure 269. Average bag emission results of L1e vehicles – FC

The last examined parameter is the fuel consumption. As expected, the behavior of this graph follows the behavior of Figure 265 where CO_2 is examined. No clear effect of the engine technology or the examined driving cycles are observed.

L2e vehicles
In the following figures the bag results of the emission pollutants for the L2e-A test vehicles are presented. It must be noted that J26 is Euro 2 homologated tricycle.

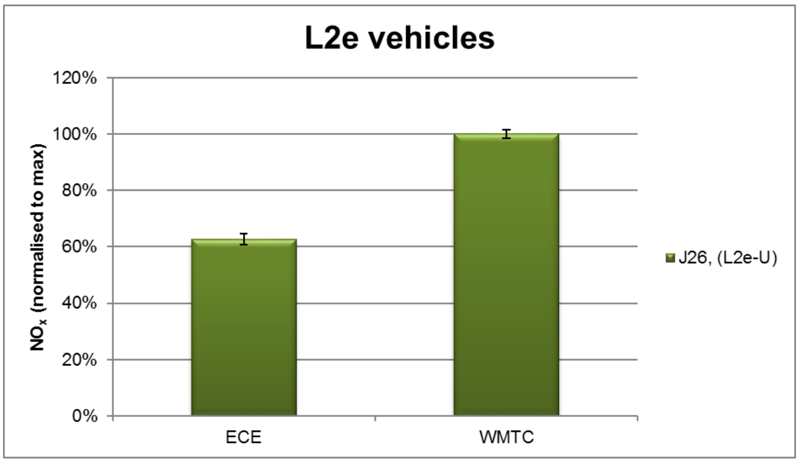


Figure 270. Average bag emission results of L2e vehicles – NO_x

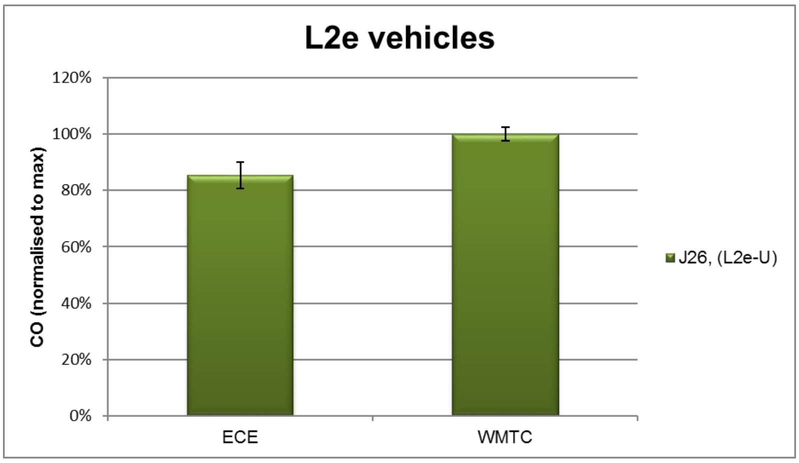


Figure 271. Average bag emission results of L2e vehicles – CO

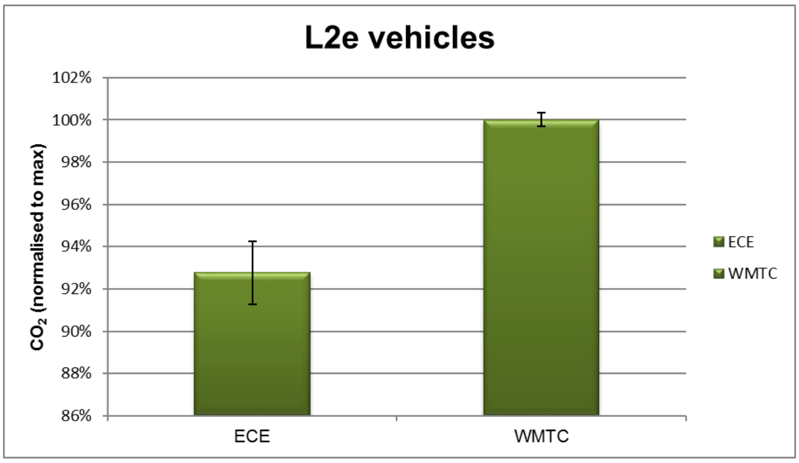


Figure 272. Average bag emission results of L2e vehicles – CO_2

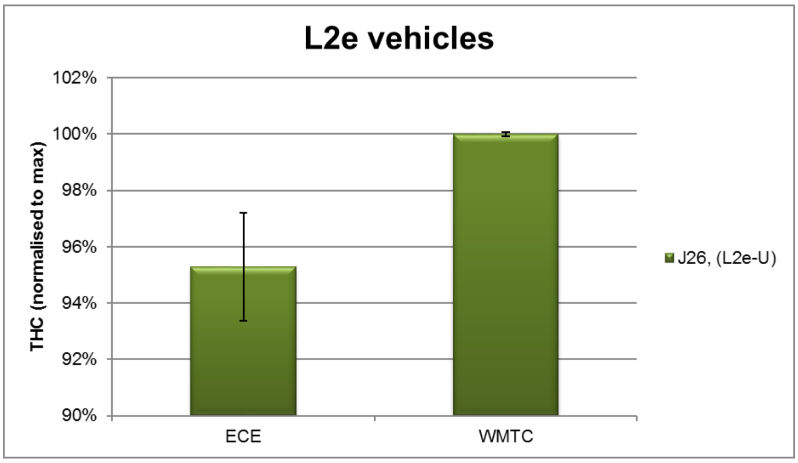


Figure 273. Average bag emission results of L2e vehicles – THC

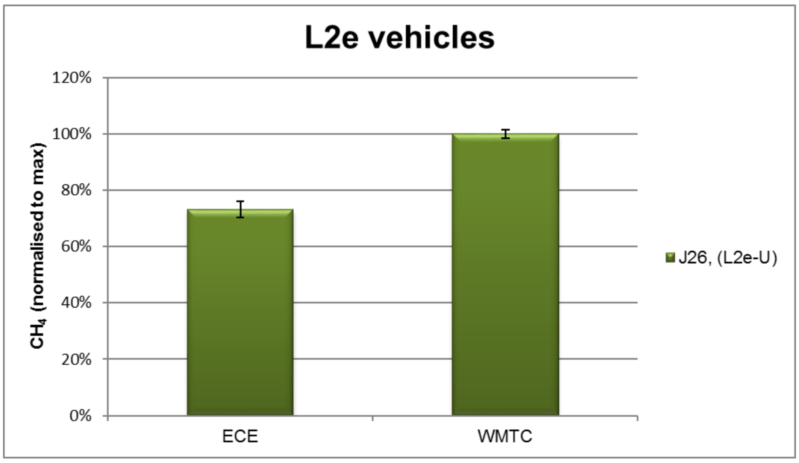


Figure 274. Average bag emission results of L2e vehicles – CH_4

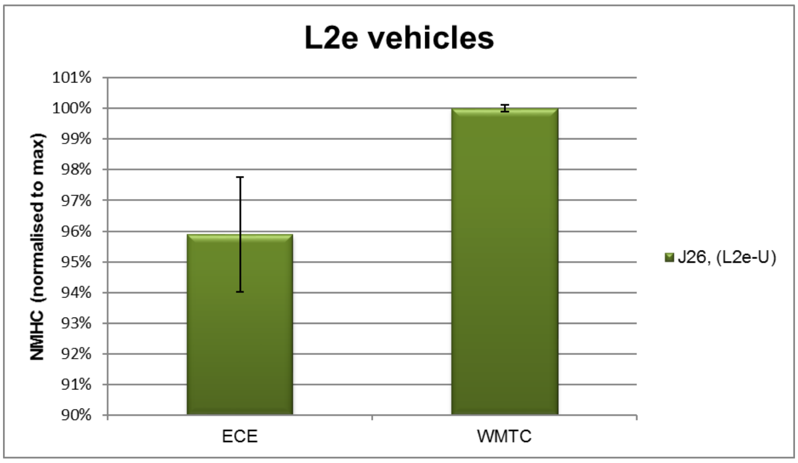


Figure 275. Average bag emission results of L2e vehicles – NMHC

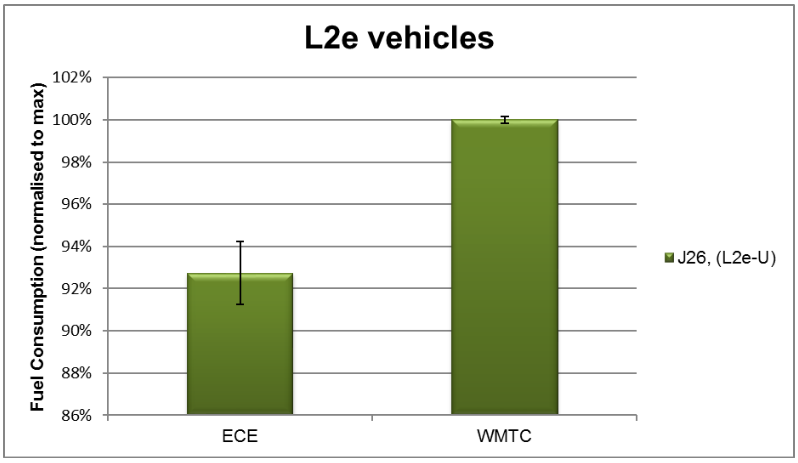


Figure 276. Average bag emission results of L2e vehicles – fuel consumption

L5e vehicles

In the following figures the bag results of the emission pollutants for the L5e-A test vehicles are presented. It must be noted that J24 is Euro 2 homologated low power (7.5 kW) tricycle, while L01 is Euro 4 homologated high power (84 kW) tricycle.

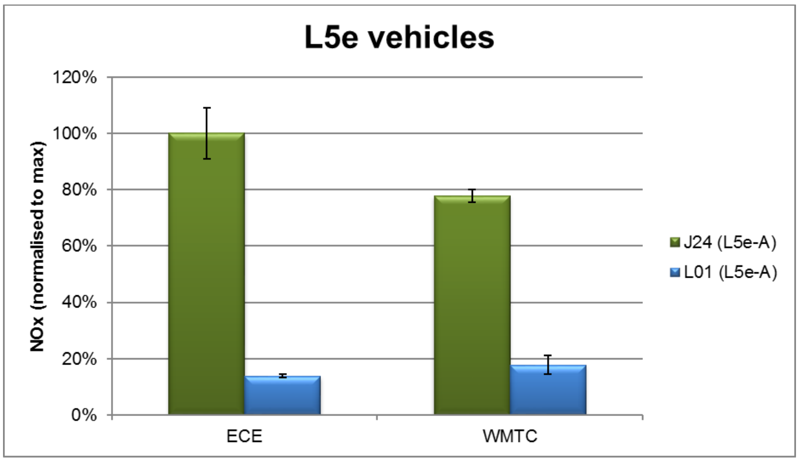


Figure 277. Average bag emission results of L5e vehicles – NO_x

Figure 277 presents the NO_x emissions of the L5e vehicles. As expected, the L01 vehicle presents lower emissions than the J24 one, because of their Euro standard. No clear comparison for the variability of emissions can be concluded.

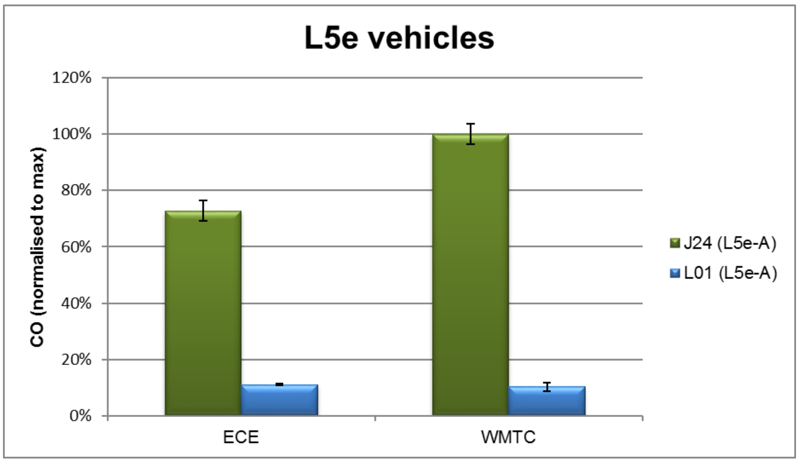


Figure 278. Average bag emission results of L5e vehicles – CO

Similarly, no clear comparison for the variability of emissions can be concluded from Figure 278, where the CO emissions are presented.

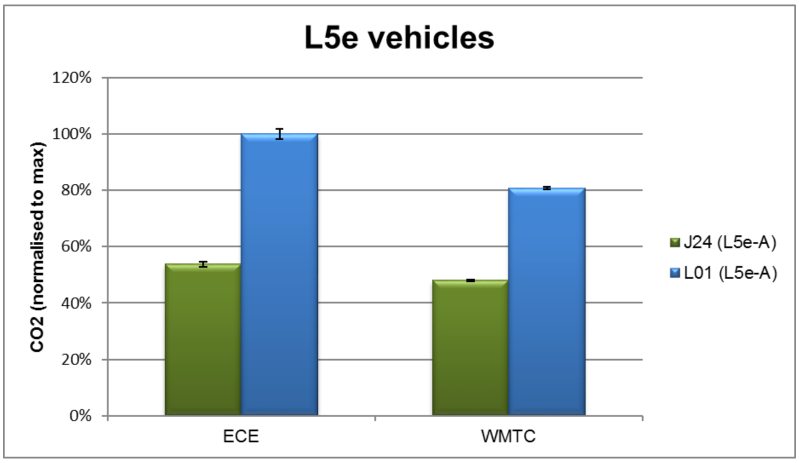


Figure 279. Average bag emission results of L5e vehicles – CO_2

In Figure 279 the CO_2 emissions are presented. The L01 tricycle presents much higher emissions than the J24, because the former uses an engine of 1330cc demanding high fuel consumption, while the latter vehicle uses an engine of 200cc with lower fuel consumption. The variability of emissions is very low.

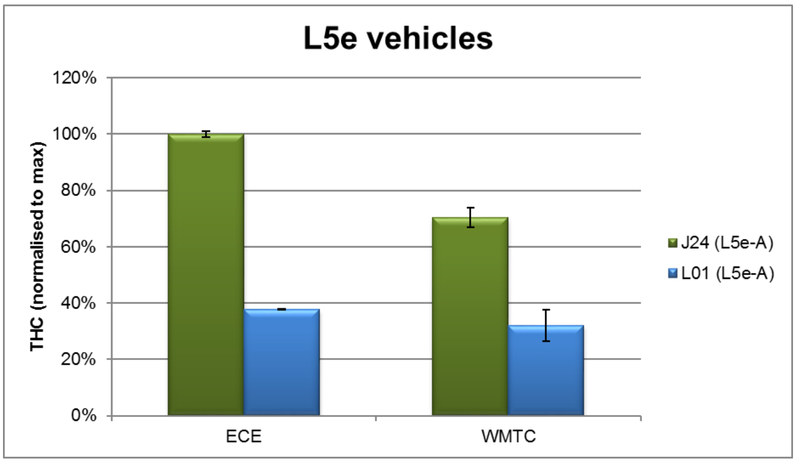


Figure 280. Average bag emission results of L5e vehicles – THC

The THC, the CH_4 and the NMHC bag results are presented in Figure 280, Figure 281 and Figure 282, respectively. Though, CH_4 as well as NMHC emission results are not recorded for the L01 tricycle. WMTC presents lower emissions than the ECE, though, WMTC presents higher variability of emissions than ECE for the THC, and lower variability of emissions for the CH_4 pollutant.

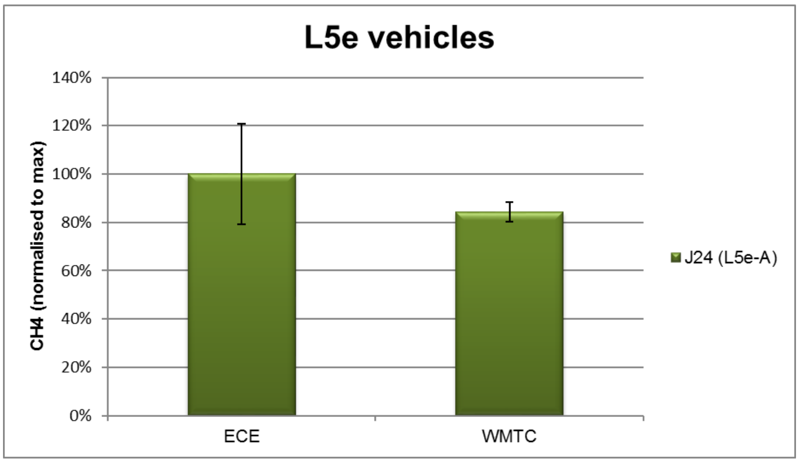


Figure 281. Average bag emission results of L5e vehicles – CH_4

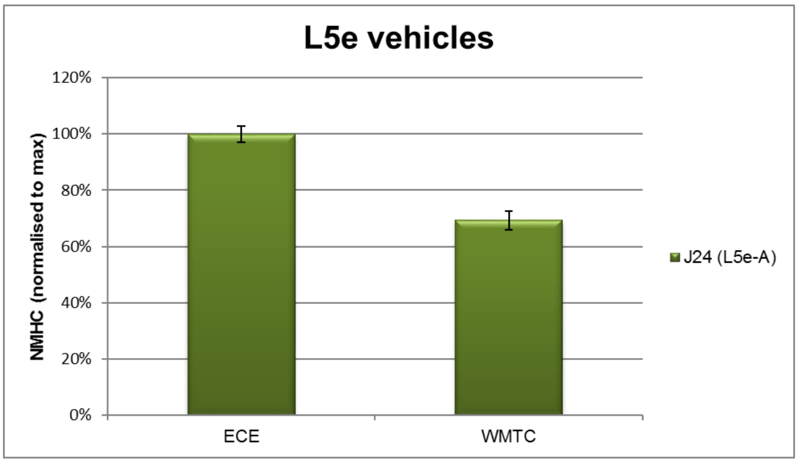


Figure 282. Average bag emission results of L5e vehicles – NMHC

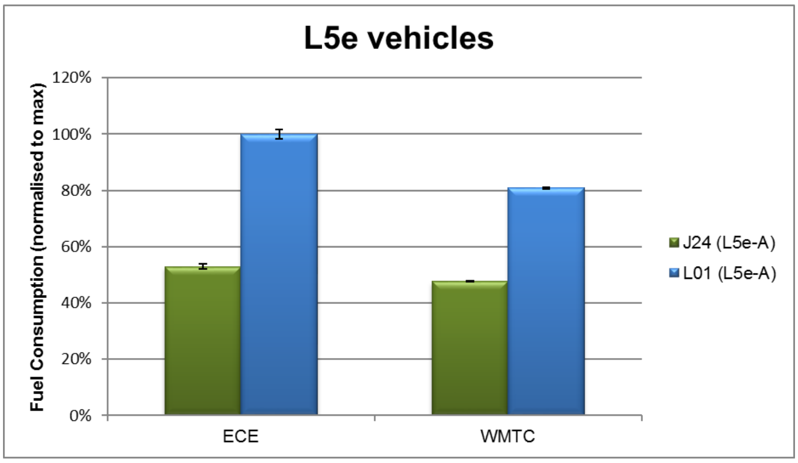


Figure 283. Average bag emission results of L5e vehicles – fuel consumption

The fuel consumption presented in Figure 283 follows the trend of Figure 279, where CO_2 is examined.

L6e vehicles

In the following figures the bag results of the emission pollutants for the L6e test vehicles are presented. It must be noted that all of the following tested vehicles are Euro 2 homologated.

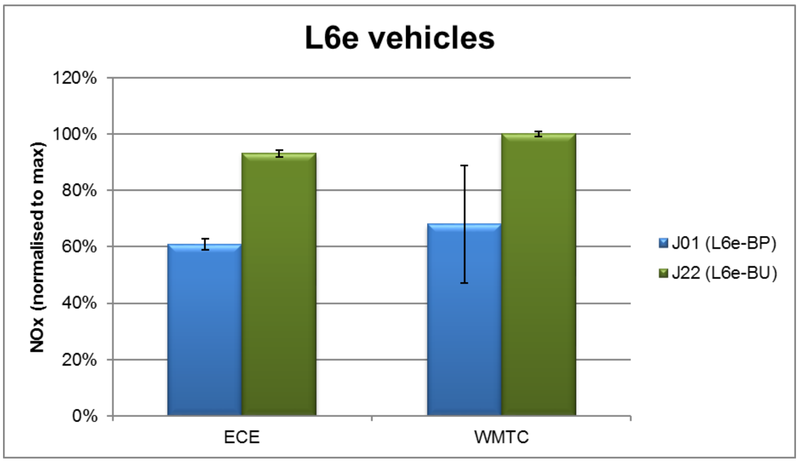


Figure 284. Average bag emission results of L6e vehicles – NO_x

In Figure 284 the NO_x emissions are presented. When WMTC is under test, higher emissions are presented when compared to the ECE driving cycle. Also, the J01 (L6e-BP) presents great variability in the various WMTC runs that have been performed.

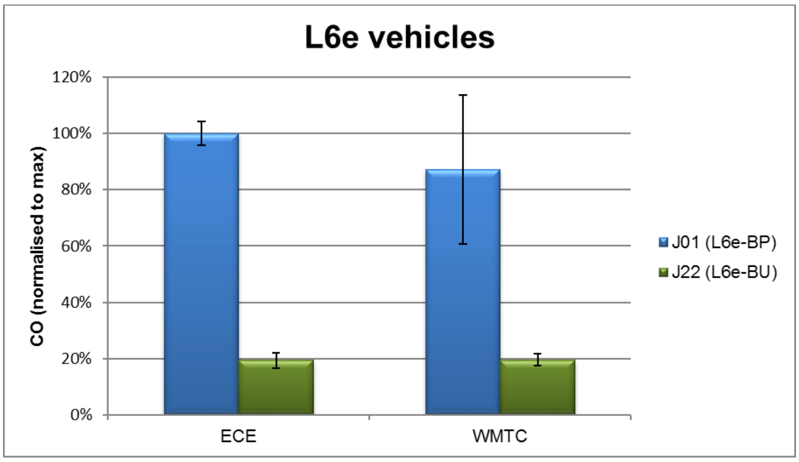


Figure 285. Average bag emission results of L6e vehicles – CO

Both the CO and CO2 emission results presented in Figure 285 and Figure 286, respectively, do not lead to clear conclusions in the tested driving cycle. The J01 vehicle presents significant variability in the various WMTC runs that have been performed.

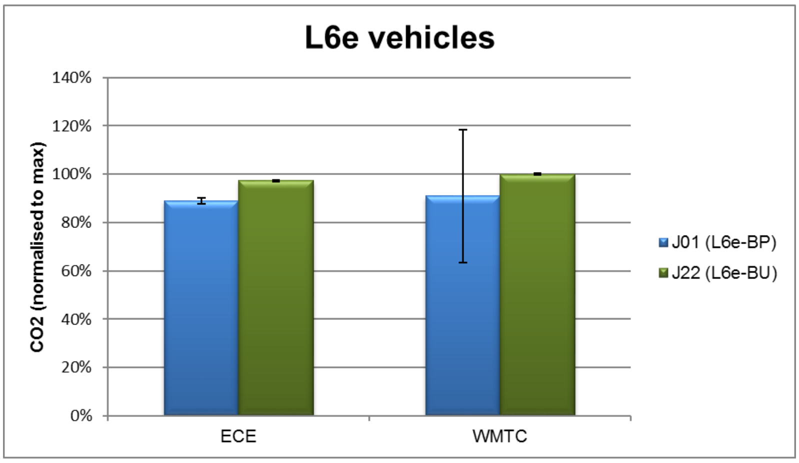


Figure 286. Average bag emission results of L6e vehicles – CO_2

The THC, the CH_4 and the NMHC bag results are presented in Figure 287, Figure 288 and Figure 289, respectively. The variability of emissions of J01 is higher than J22 in all examined cases. The NMHC results follow the trend of the THC results, as expected.

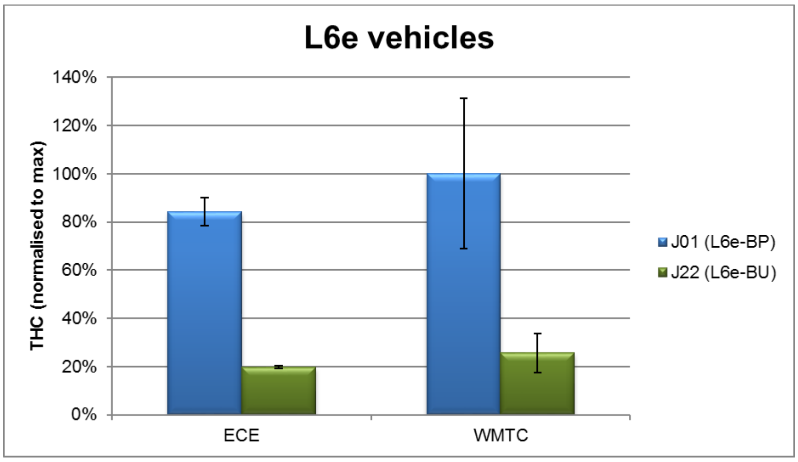


Figure 287. Average bag emission results of L6e vehicles – THC

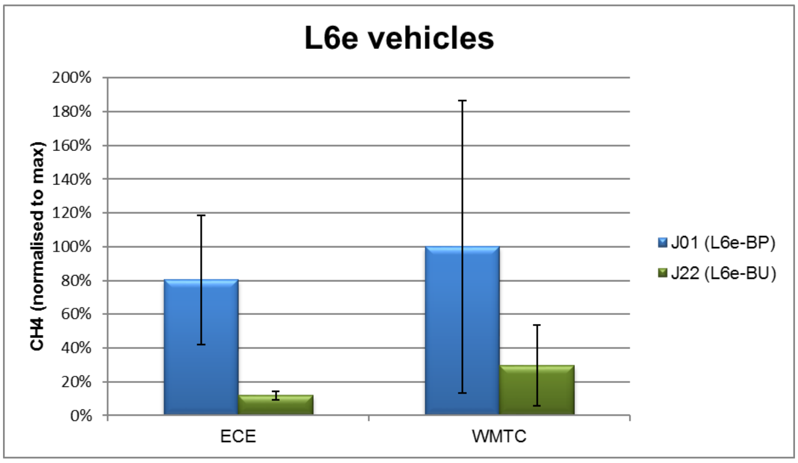


Figure 288. Average bag emission results of L6e vehicles – CH_4

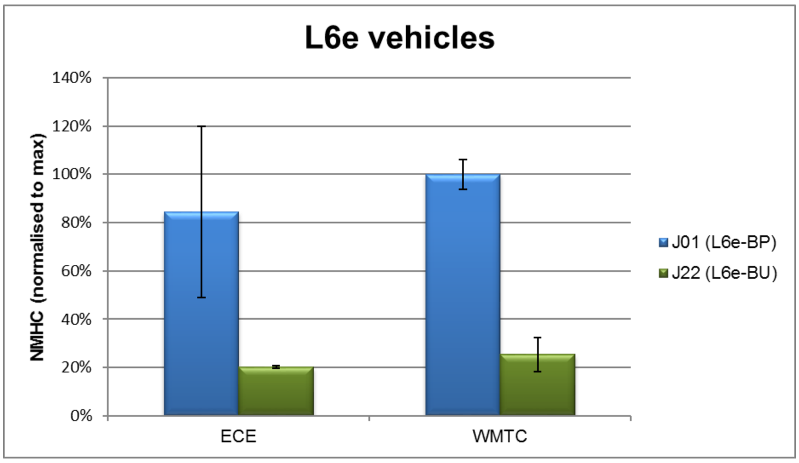


Figure 289. Average bag emission results of L6e vehicles – NMHC

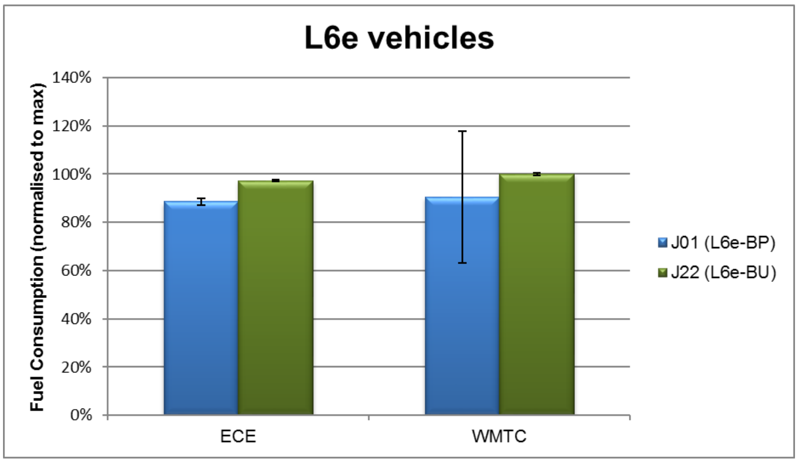


Figure 290. Average bag emission results of L6e and L7e vehicles – FC

The fuel consumption presented in Figure 290 follows the trend of Figure 286, where CO_2 is examined.

L7e vehicles

In the following figures the bag results of the emission pollutants for the L7e test vehicles are presented. It must be noted that all of the following tested vehicles are Euro 2 homologated. Vehicle J25 is considered as the validation vehicle, tested in the validation phase of the study.

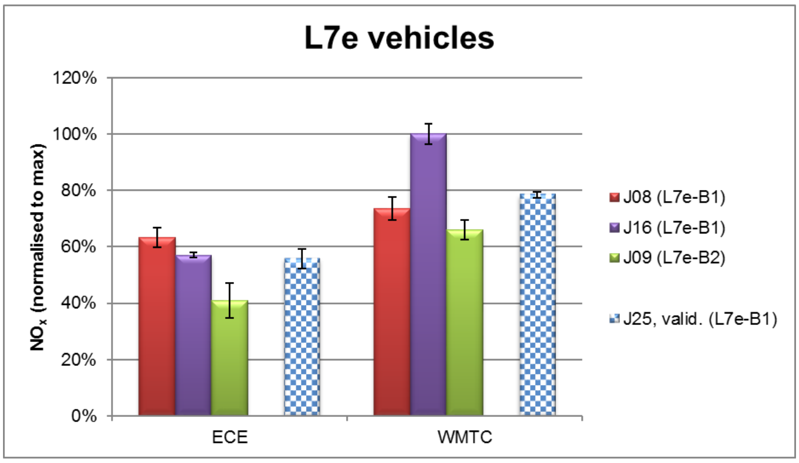


Figure 291. Average bag emission results of L7e vehicles – NO_x

In Figure 291 the NO_x emissions are presented. When WMTC is under test, higher emissions are presented when compared to the ECE driving cycle. With regard to the variability it seems that the L7e-B2 vehicle presents higher variability than the L7e-B1 vehicles, while no clear conclusion can be drawn when comparing the results of the driving cycles.

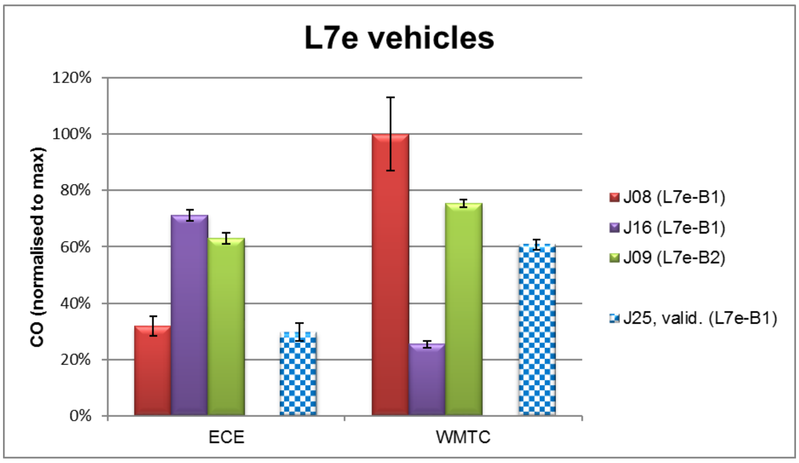


Figure 292. Average bag emission results of L7e vehicles – CO

Both the CO and CO2 emission results presented in Figure 292 and Figure 293, respectively, do not lead to clear conclusions.

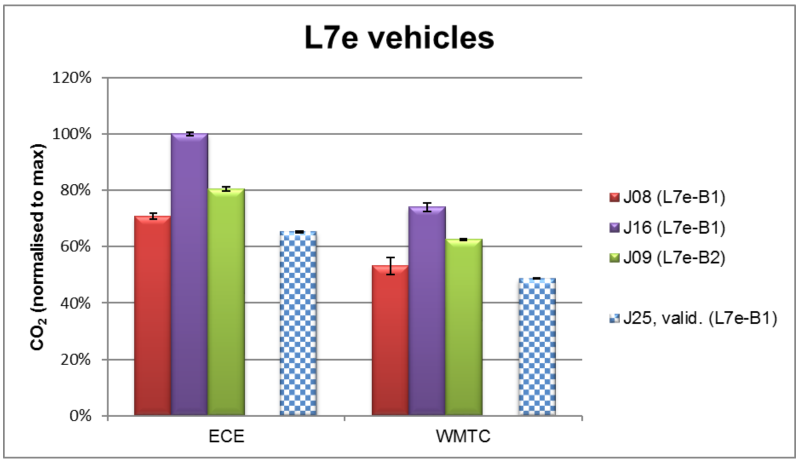


Figure 293. Average bag emission results of L7e vehicles – CO_2

The THC, the CH_4 and the NMHC bag results are presented in Figure 294, Figure 295 and Figure 296.

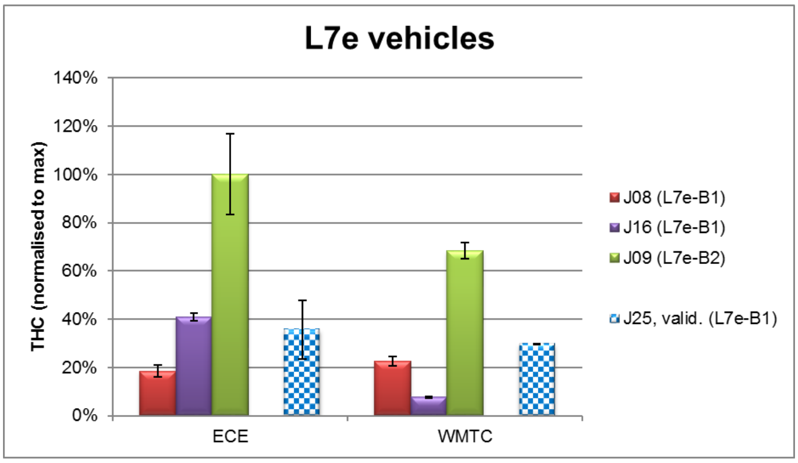


Figure 294. Average bag emission results of L7e vehicles – THC

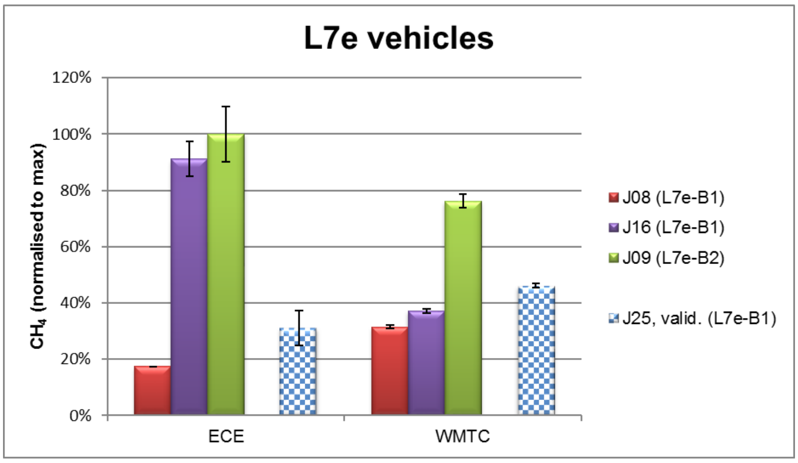


Figure 295. Average bag emission results of L7e vehicles – CH_4

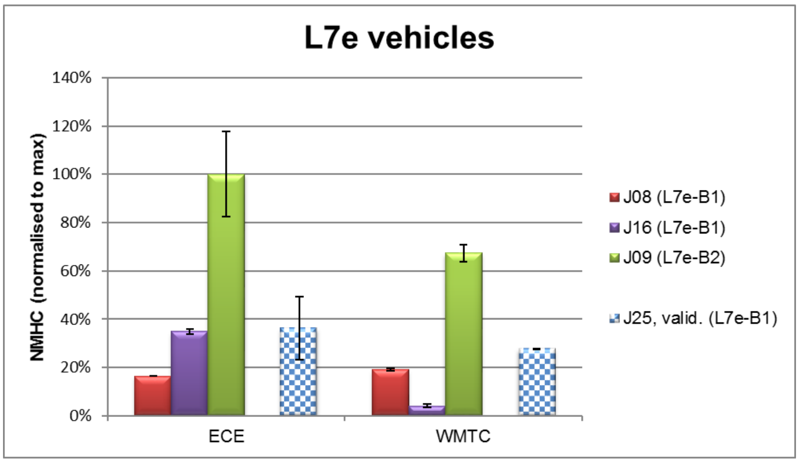


Figure 296. Average bag emission results of L7e vehicles – NMHC

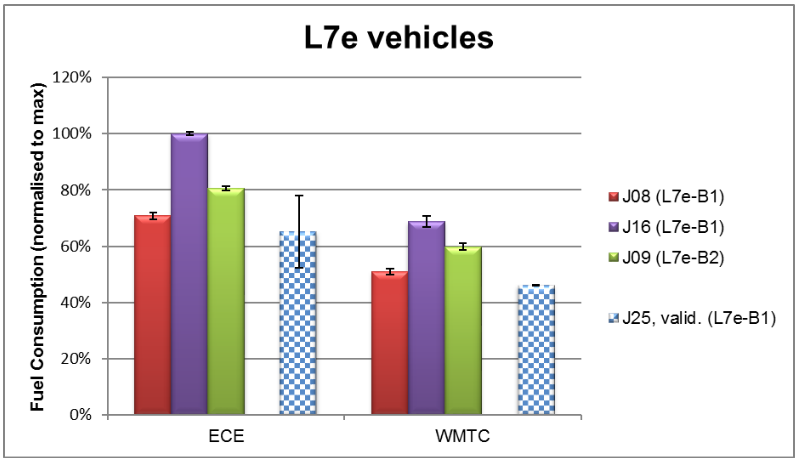


Figure 297. Average bag emission results of L7e vehicles – FC

The fuel consumption presented in Figure 297 follows the trend of Figure 293, where CO_2 is examined, as expected.

The **variability of emissions** is also examined for the WMTC and for the ECE R40 / R47 driving cycles in the following figures. The variability of emissions criterion is examined by calculating the coefficient of variation (CV) metric for each of the examined pollutants. The coefficient of variation is defined as

$$CV = \sigma/\mu$$

where σ is the standard deviation and μ is the mean of the emission bag results of the multiple runs of each test cycle.

The tested vehicles and the examined pollutants are the same as previously in this Appendix.

L1e vehicles

In the following figures the coefficient of variation of the emission pollutants for the L1e test vehicles are presented. It should be noted that all L1e tested vehicles are Euro 2 homologated.

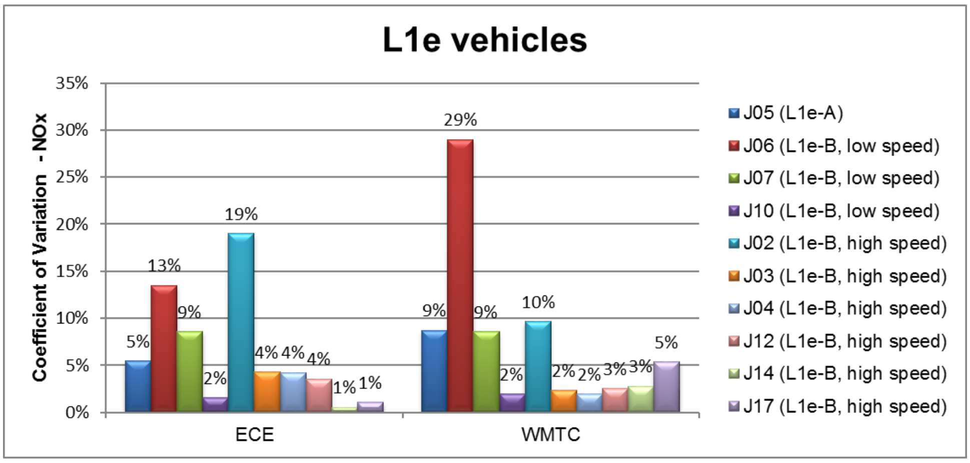


Figure 298. Coefficient of Variation of L1e vehicles – NO_x

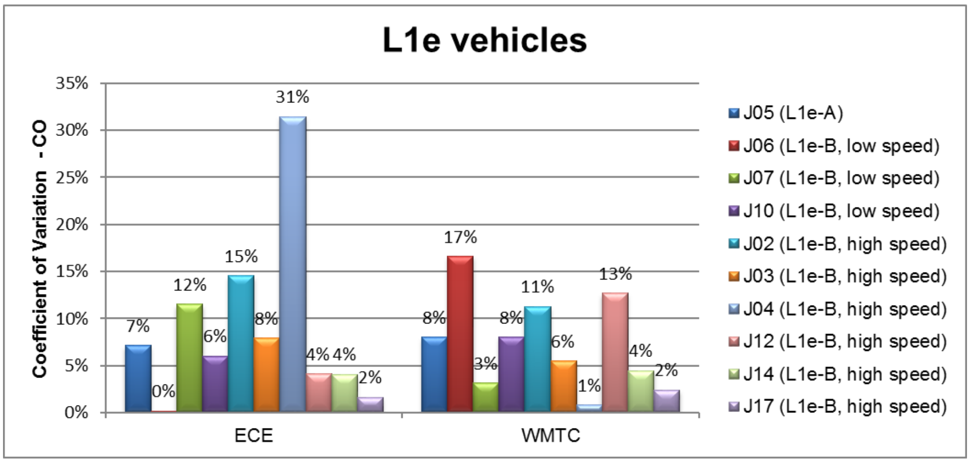


Figure 299. Coefficient of Variation of L1e vehicles – CO

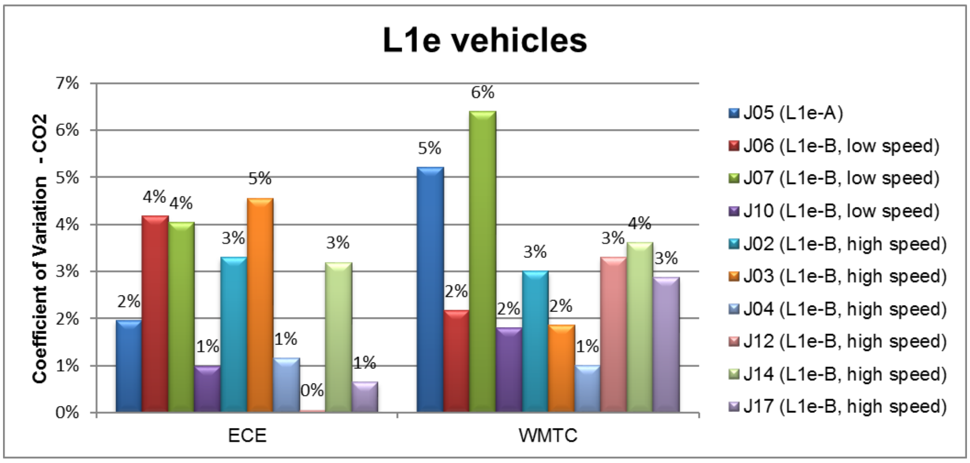


Figure 300. Coefficient of Variation of L1e vehicles – CO_2

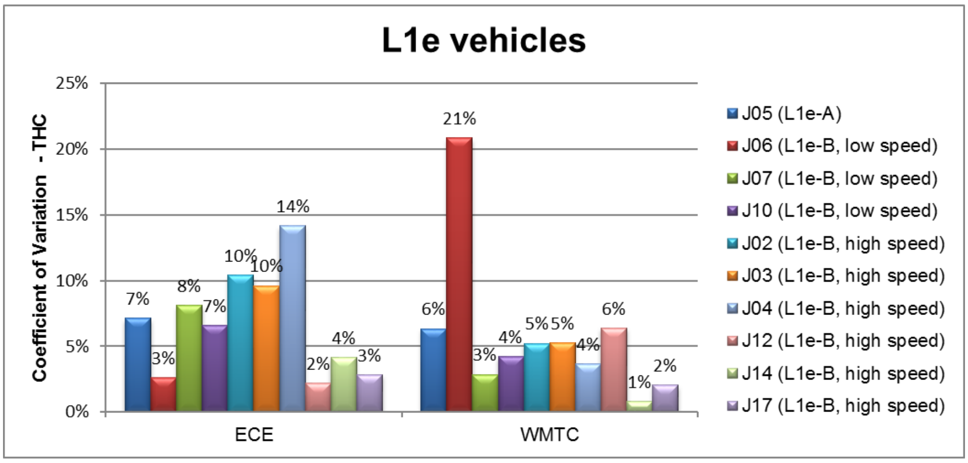


Figure 301. Coefficient of Variation of L1e vehicles – THC

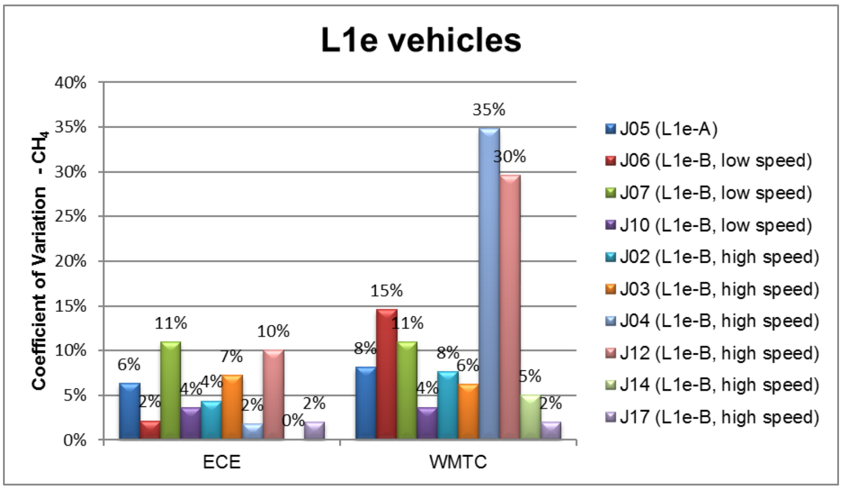


Figure 302. Coefficient of Variation of L1e vehicles – CH_4

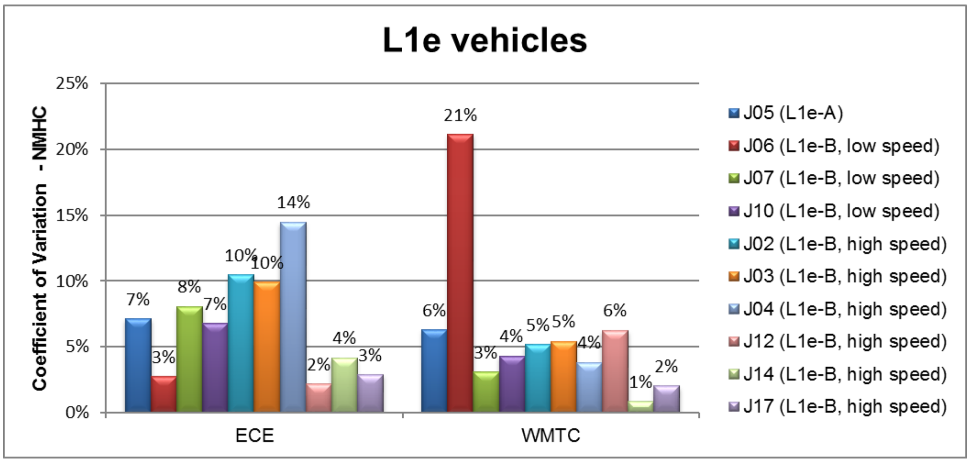


Figure 303. Coefficient of Variation of L1e vehicles – NMHC

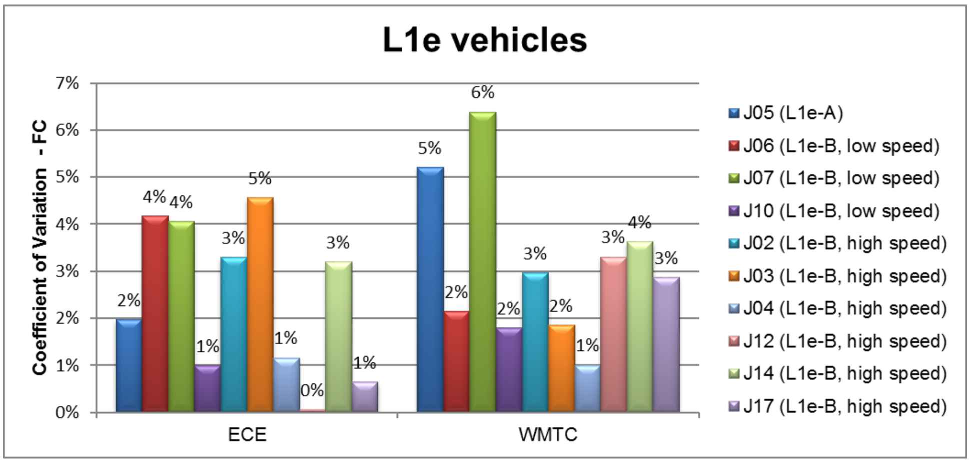


Figure 304. Coefficient of Variation of L1e vehicles – FC

As shown, low speed mopeds mostly present higher coefficient of variation of the examined emission pollutants when running the WMTC than when running the ECE R47 driving cycle. On the other hand, high speed mopeds mostly present lower coefficient of variation of the emissions when running the WMTC than when the ECE R47 driving cycle is being examined.

L2e vehicles

In the following figures the coefficient of variation of the emission pollutants for the L2e test vehicles are presented. It must be noted that J26 is Euro 2 homologated tricycle.

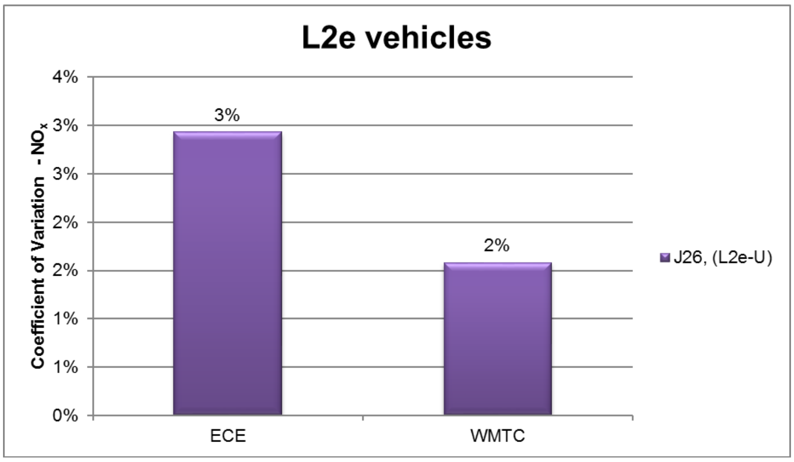


Figure 305. Coefficient of Variation of L2e vehicles – NO_x

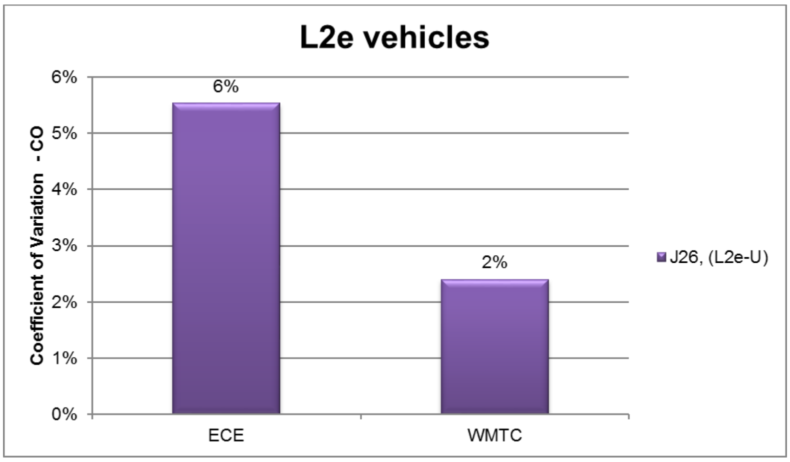


Figure 306. Coefficient of Variation of L2e vehicles – CO

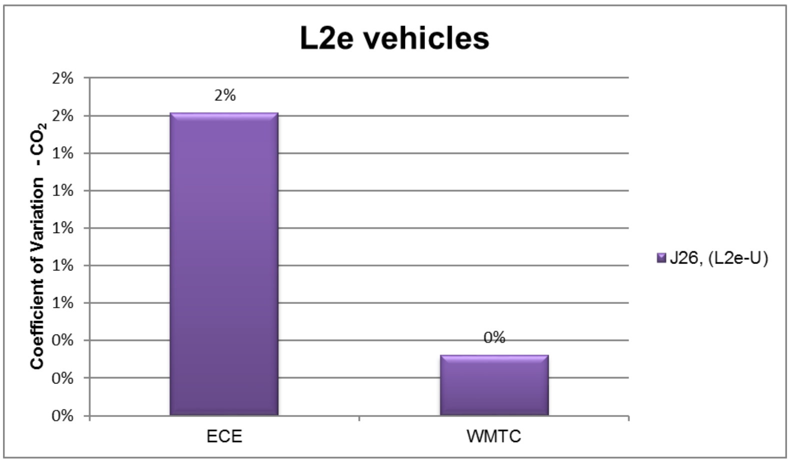


Figure 307. Coefficient of Variation of L2e vehicles – CO_2

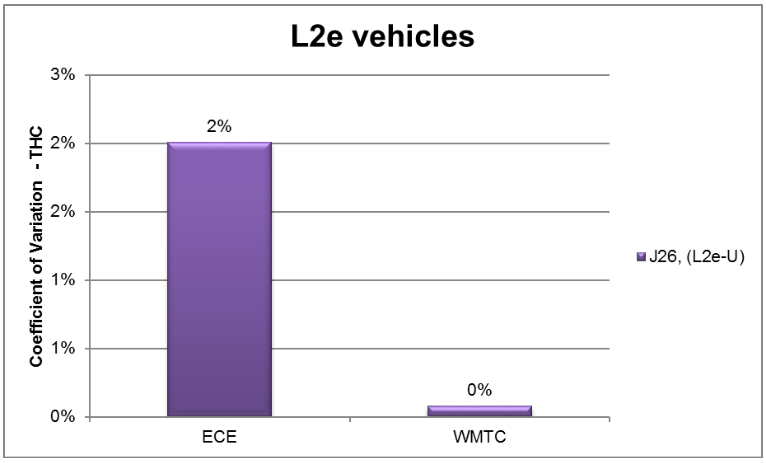


Figure 308. Coefficient of Variation of L2e vehicles – THC

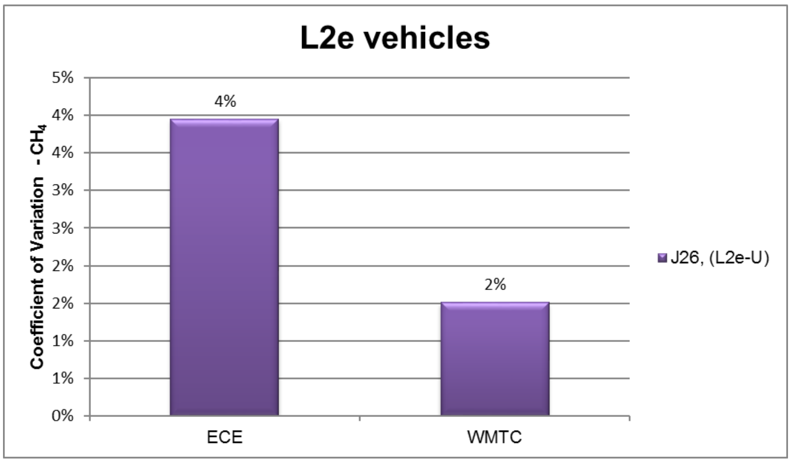


Figure 309. Coefficient of Variation of L2e vehicles – CH_4

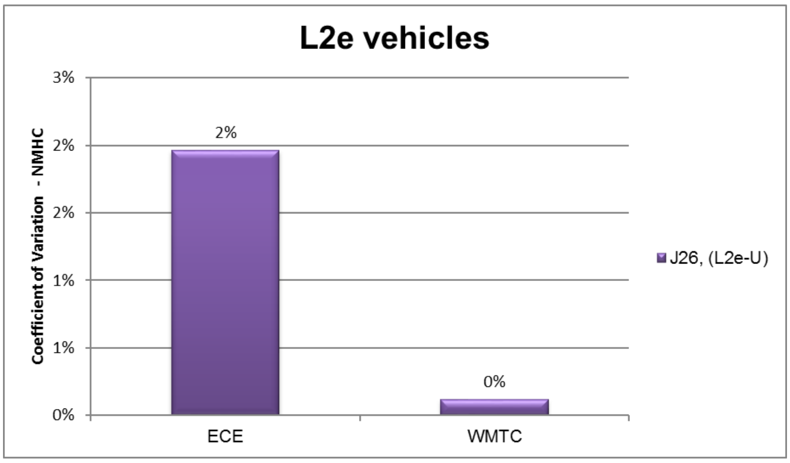


Figure 310. Coefficient of Variation of L2e vehicles – NMHC

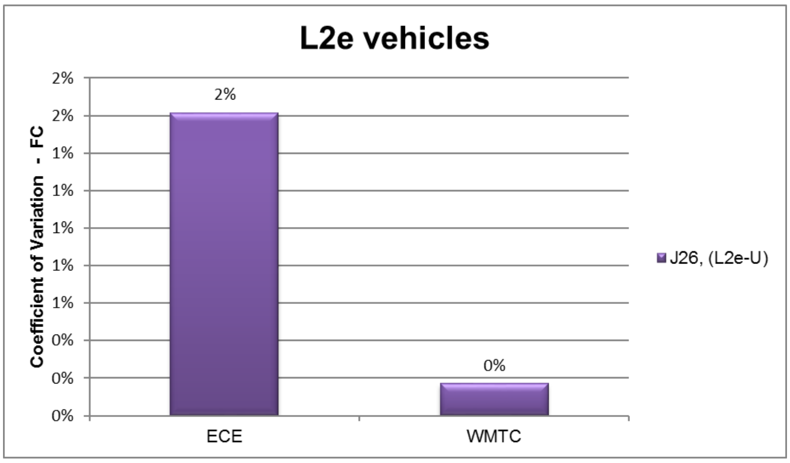


Figure 311. Coefficient of Variation of L2e vehicles – FC

L5e vehicles

In the following figures the coefficient of variation of the emission pollutants for the L5e test vehicles are presented. It must be noted that J24 is Euro 2 homologated low power (7.5 kW) tricycle, while L01 is Euro 4 homologated high power (84 kW) tricycle.

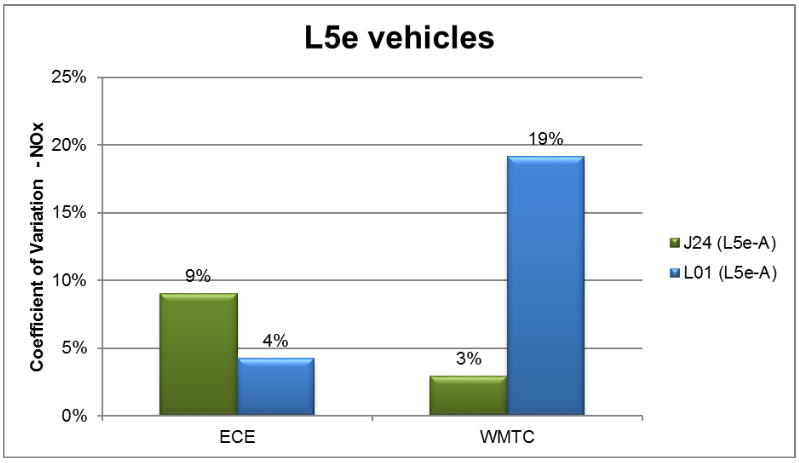


Figure 312. Coefficient of Variation of L5e vehicles – NO_x

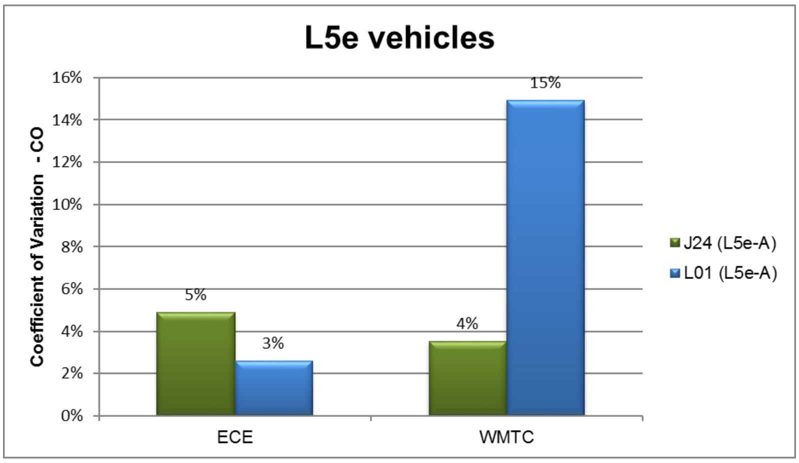


Figure 313. Coefficient of Variation of L5e vehicles – CO

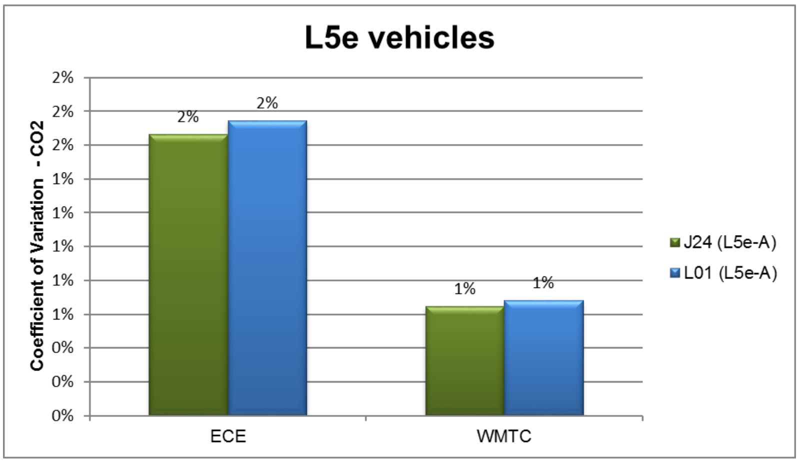


Figure 314. Coefficient of Variation of L5e vehicles – CO_2

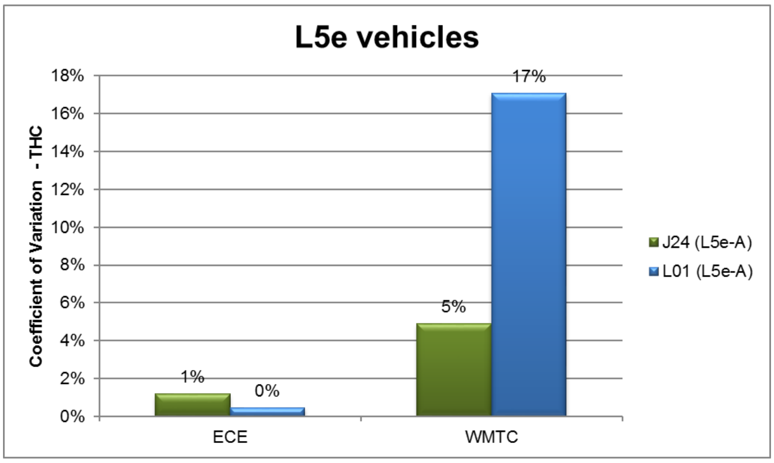


Figure 315. Coefficient of Variation of L5e vehicles – THC

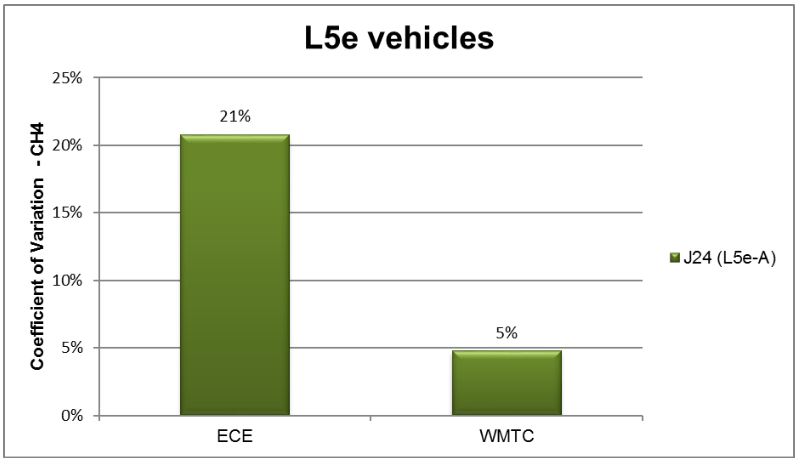


Figure 316. Coefficient of Variation of L5e vehicles – CH_4

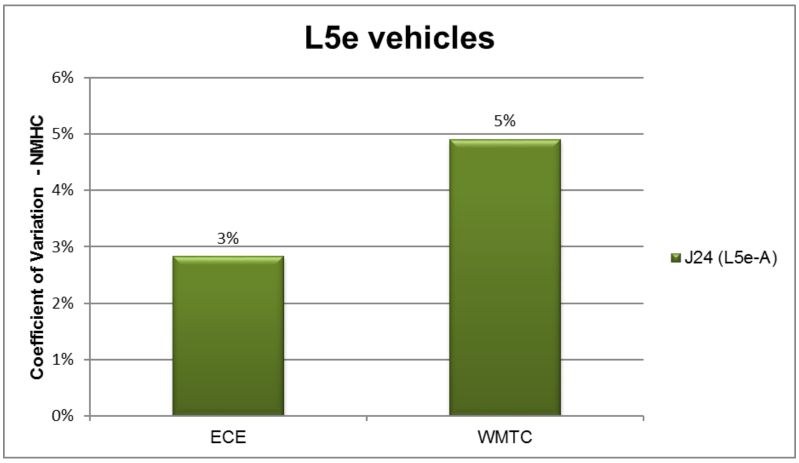


Figure 317. Coefficient of Variation of L5e vehicles – NMHC

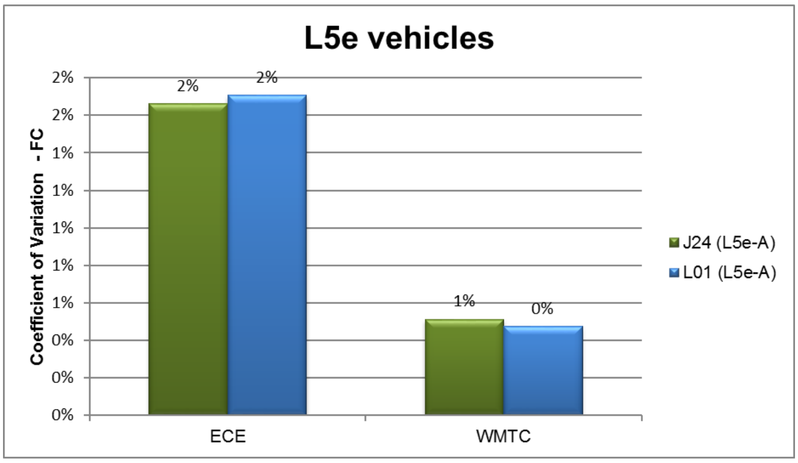


Figure 318. Coefficient of Variation of L5e vehicles – FC

L6e vehicles

In the following figures the coefficient of variation of the emission pollutants for the L6e test vehicles are presented. It must be noted that all of the following tested vehicles are Euro 2 homologated.

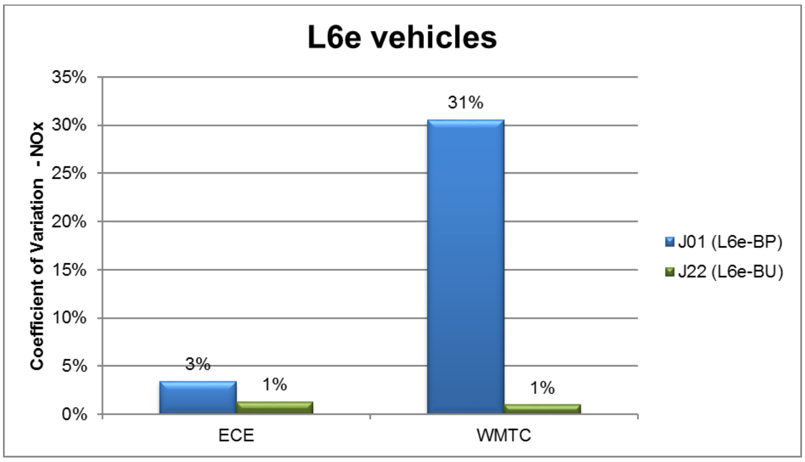


Figure 319. Coefficient of Variation of L6e vehicles – NO_x

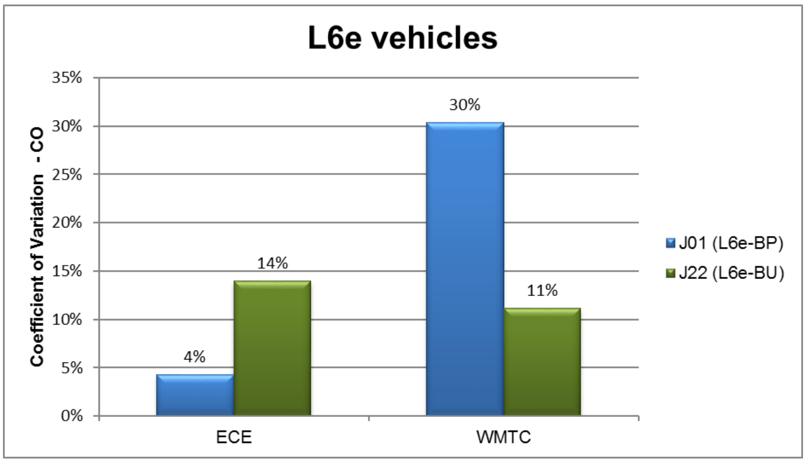


Figure 320. Coefficient of Variation of L6e vehicles – CO

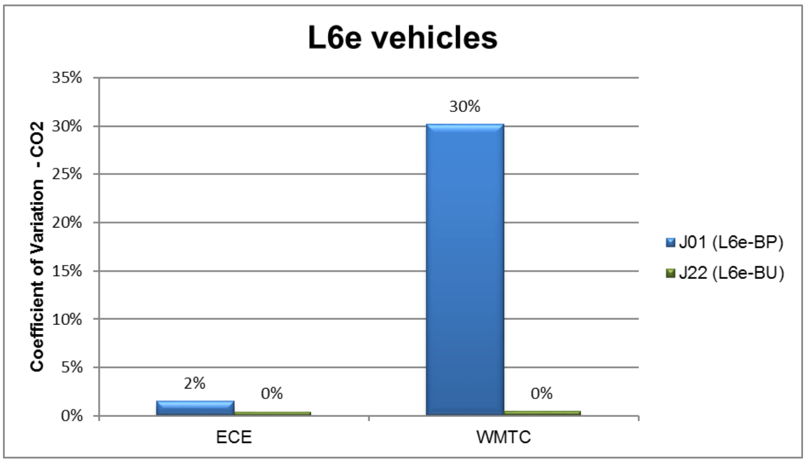


Figure 321. Coefficient of Variation of L6e vehicles – CO_2

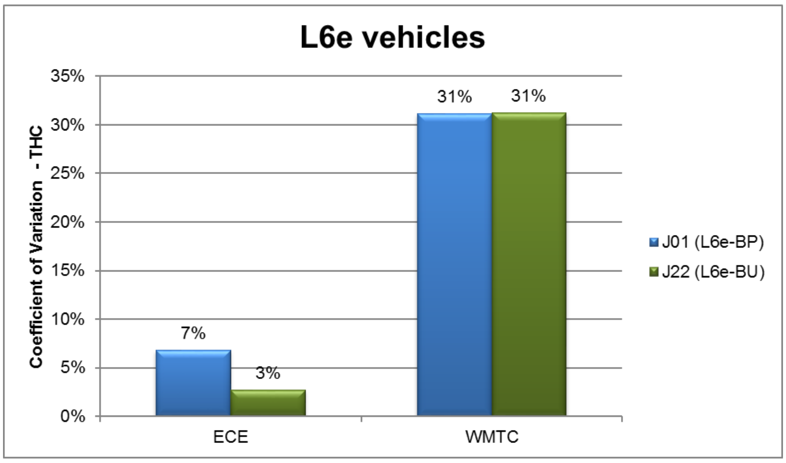


Figure 322. Coefficient of Variation of L6e vehicles – THC

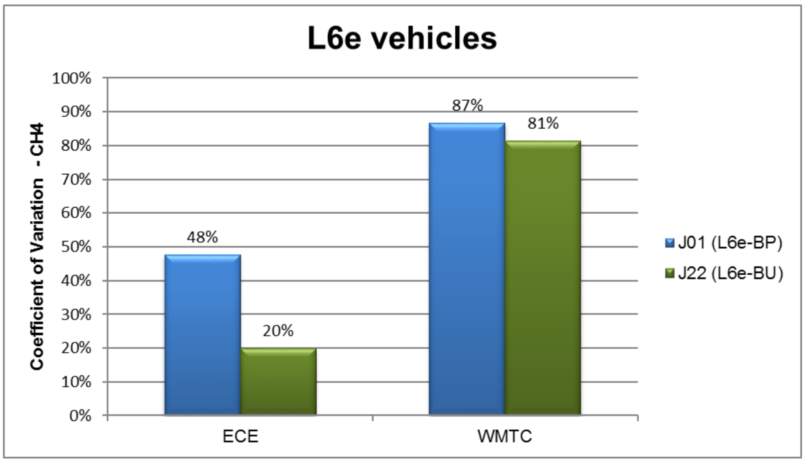


Figure 323. Coefficient of Variation of L6e and L7e vehicles – CH_4

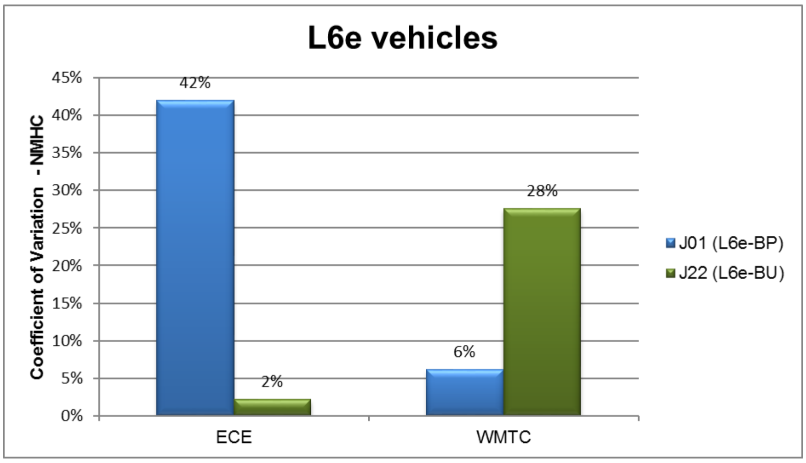


Figure 324. Coefficient of Variation of L6e vehicles – NMHC

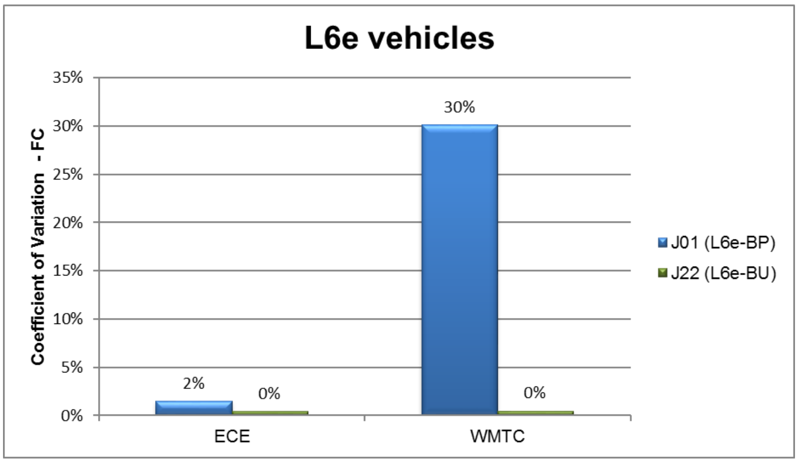


Figure 325. Coefficient of Variation of L6e vehicles – FC

The examined vehicles present higher or similar coefficient of variation in all of the examined pollutants when running the WMTC than when running the ECE R47 driving cycle, except for the case that the NMHC pollutant is examined for the J01.

L7e vehicles

In the following figures the coefficient of variation of the emission pollutants for the L7e test vehicles are presented. It must be noted that all of the following tested vehicles are Euro 2 homologated.

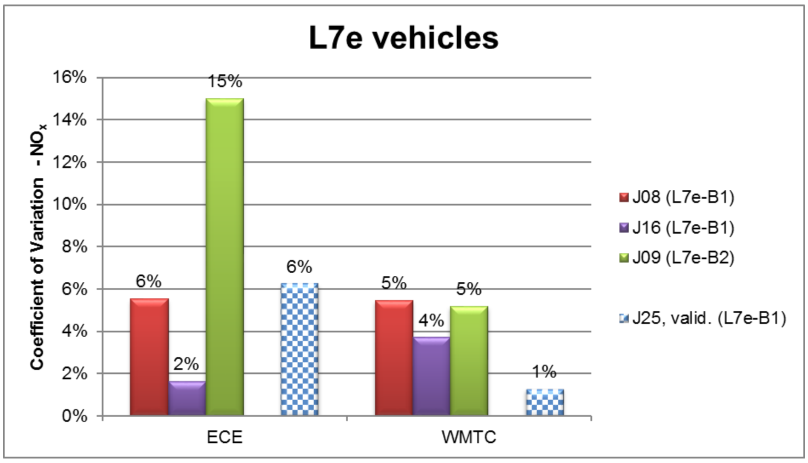


Figure 326. Coefficient of Variation of L7e vehicles – NO_x

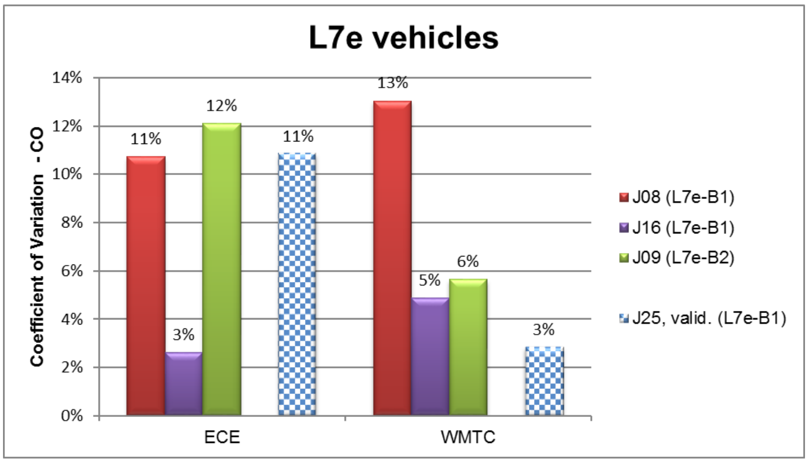


Figure 327. Coefficient of Variation of L7e vehicles – CO

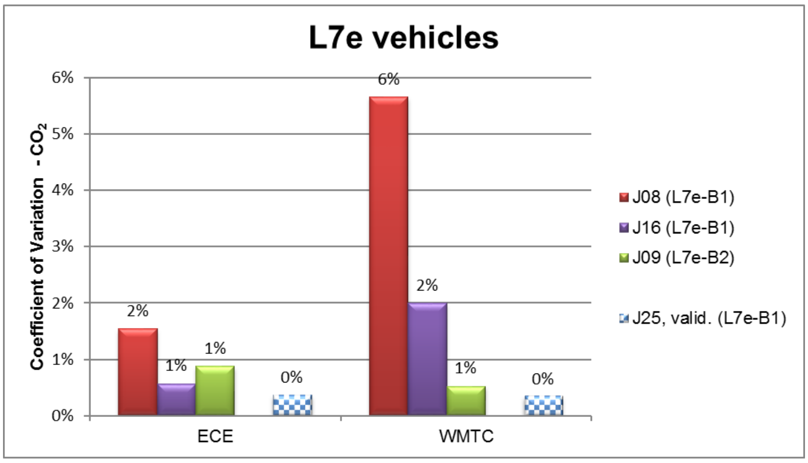


Figure 328. Coefficient of Variation of L7e vehicles – CO_2

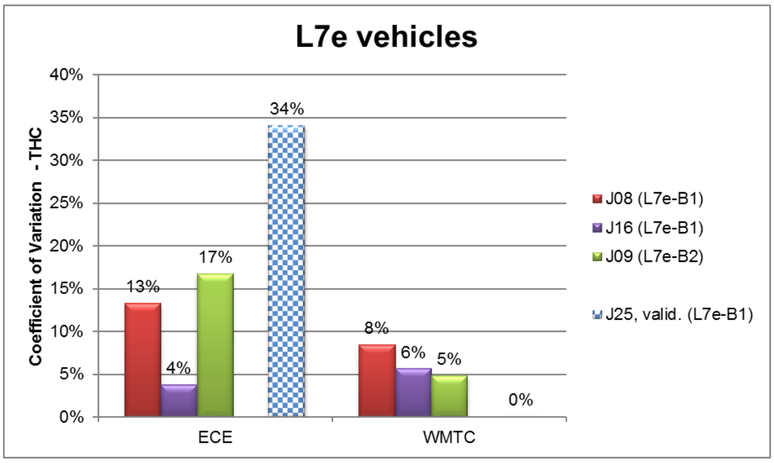


Figure 329. Coefficient of Variation of L7e vehicles – THC

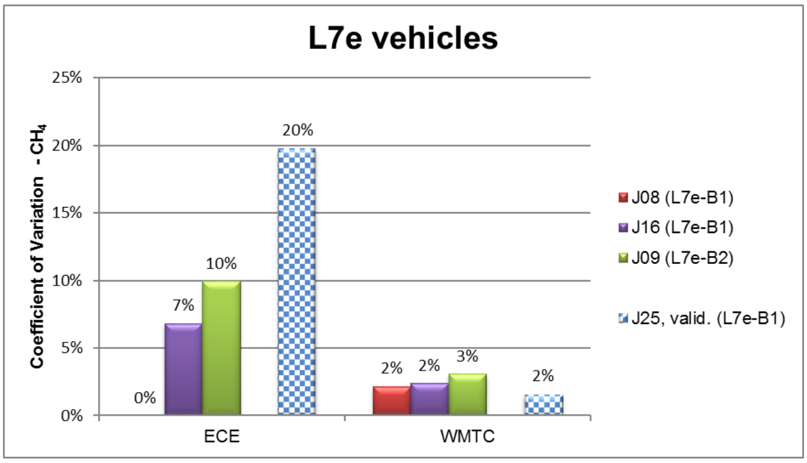


Figure 330. Coefficient of Variation of L7e vehicles – CH_4

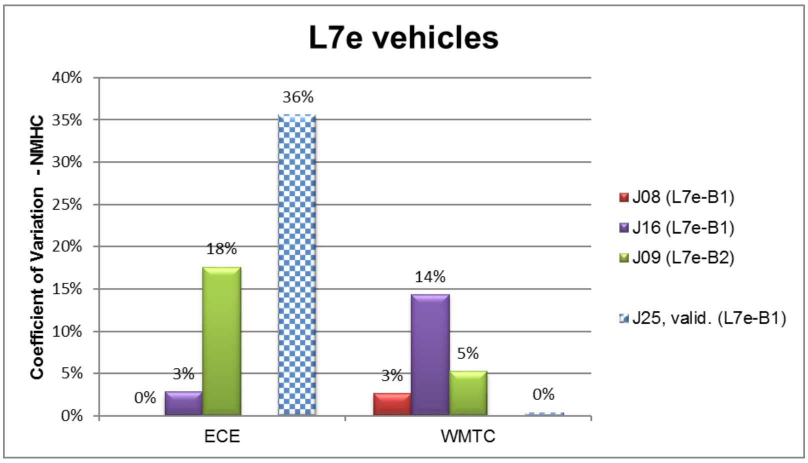


Figure 331. Coefficient of Variation of L7e vehicles – NMHC

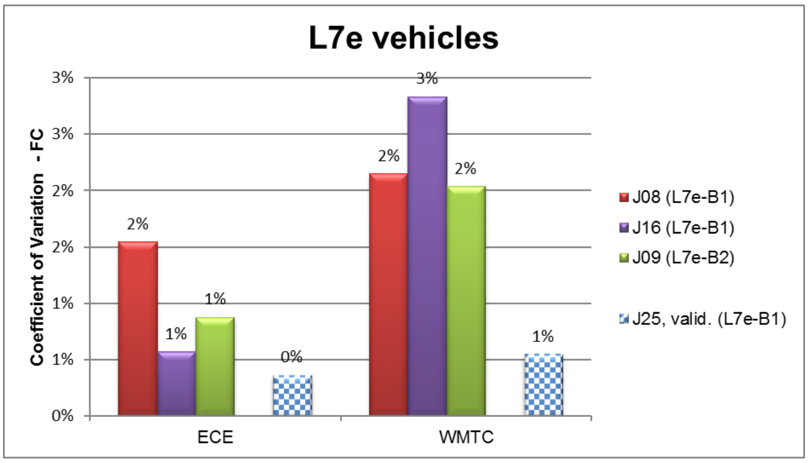


Figure 332. Coefficient of Variation of L7e vehicles – FC

Generally higher or similar coefficient of variation of the examined pollutants is presented when running the ECE R40 driving cycle than when running the WMTC.

The following figures shows a scatter plot of the examined-recorded pollutants versus the engine speed, i.e., CO, CO2, THC, CH4, NMHC, NO and NO_x, as well as exhaust flow rate, fuel consumption and lambda. Each figure is split in four areas. The main area is the scatter plot, illustrating the points for each of the examined driving cycle, WMTC, ECE, WOT. In the upper left and the lower right graphs, the examined parameter (pollutant emission / fuel consumption / lambda sensor) and the engine speed distributions are illustrated in bars, respectively, while the mean value is also marked with a line, for each driving cycle. The lower left area contains the legend of each figure, also including the mean value for each driving cycle. It must be noted that the pollutant emission scatter plots are produced after averaging the raw modal data every 5 seconds, in order to assure the synchronization of the pollutants with the engine speed.

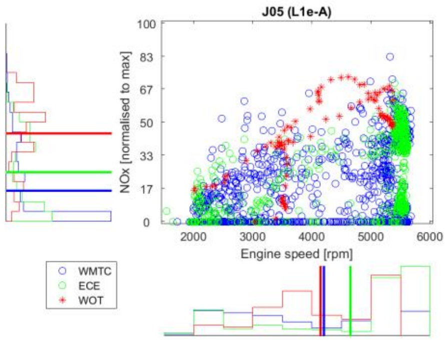
Besides, cumulative emission plots illustrating the normalized empirical cumulative distribution function (ECDF) of the sample data for each test cycle are also presented in this Appendix. The curves are normalized both in terms of time (horizontal axis) and in terms of examined pollutant mass (vertical axis).

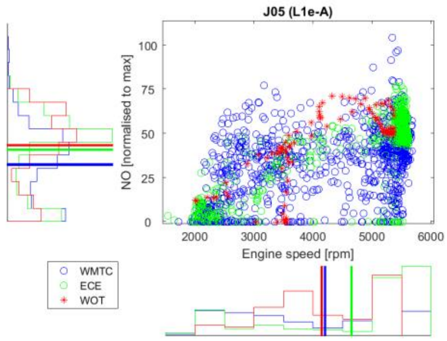
The vehicles tested and presented in the following figures are:

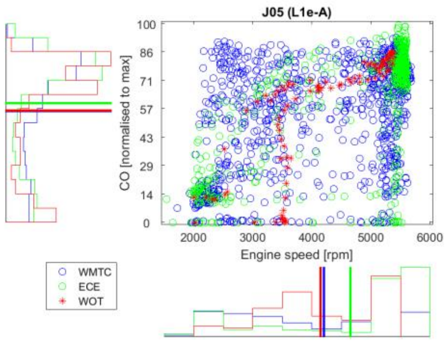
- L1e-A: 1 vehicle
- L1e-B, low speed: 3 vehicles
- L1e-B, high speed: 6 vehicles
- L2e-U: 1 vehicle
- L5e-A: 2 vehicles
- L6e-BP: 1 vehicle
- L6e-BU: 1 vehicle
- L7e-B1: 3 vehicles (1 validation vehicle)
- L7e-B2: 1 vehicle

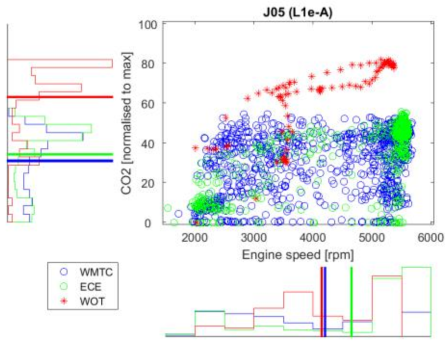
Disclaimer

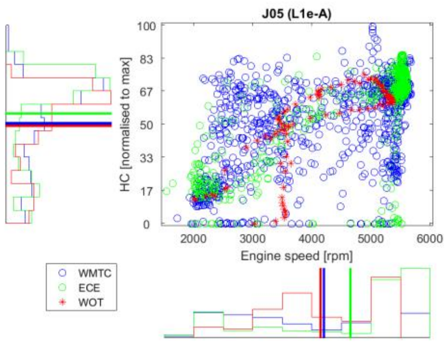
The following figures are requested by the call and are presented without further commenting.

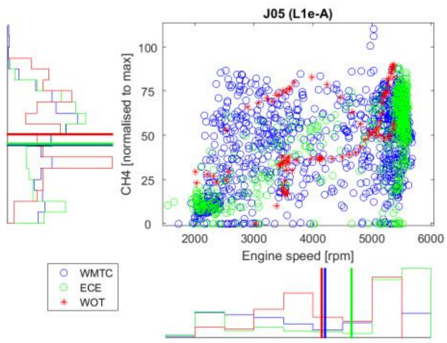

J05 (L1e-A)
NOx [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

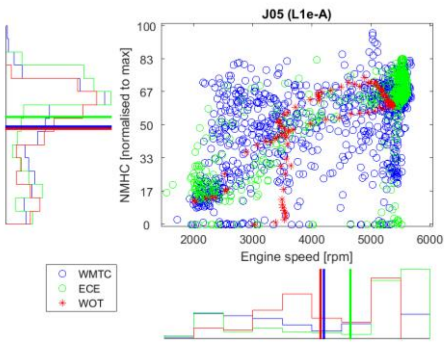

J05 (L1e-A)
NO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

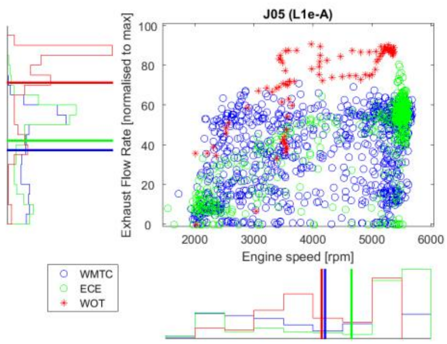

J05 (L1e-A)
CO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J05 (L1e-A)
CO2 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J05 (L1e-A)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J05 (L1e-A)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J05 (L1e-A)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J05 (L1e-A)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

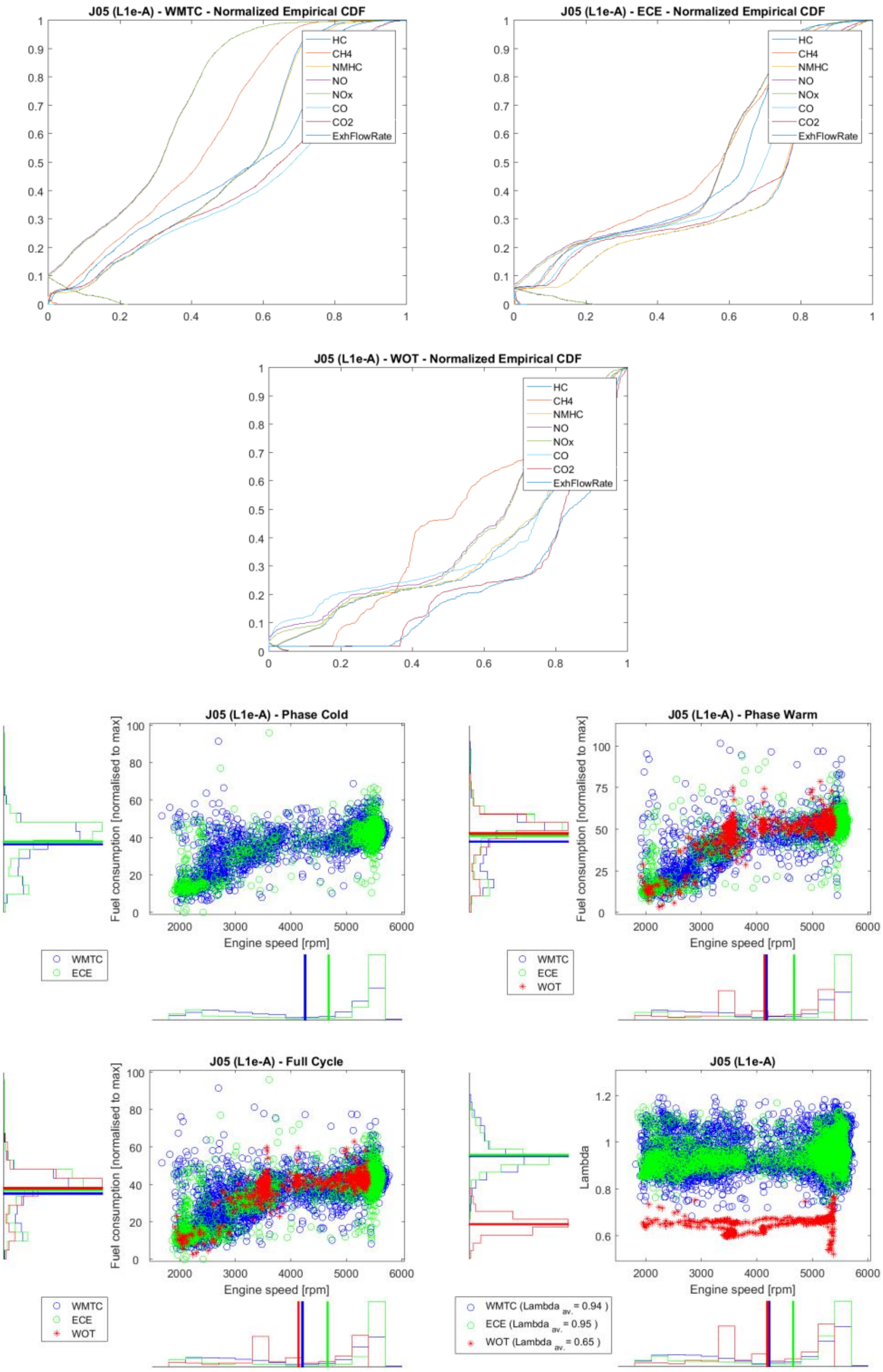
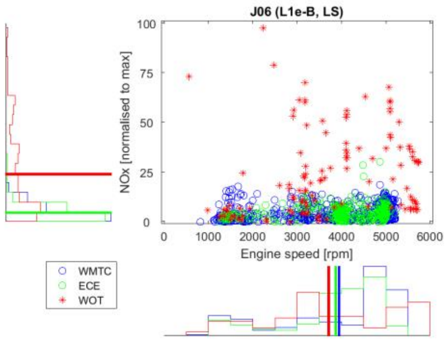
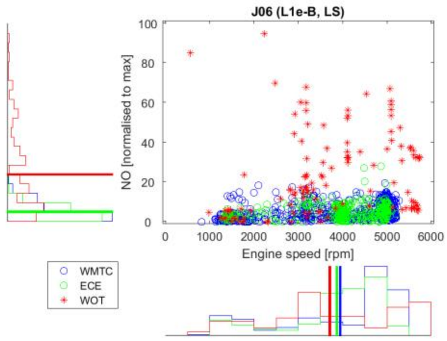
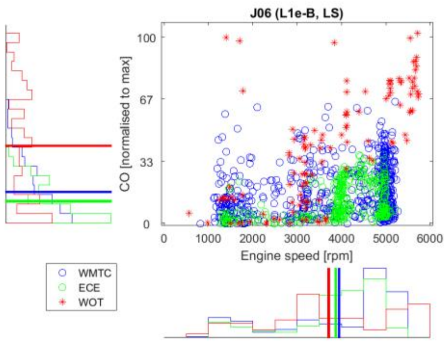
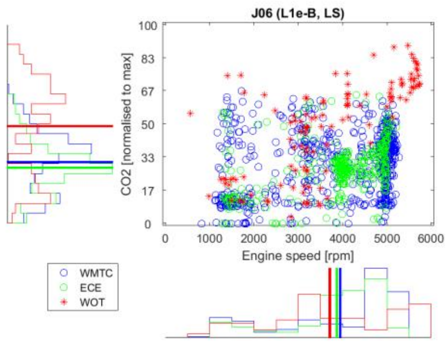


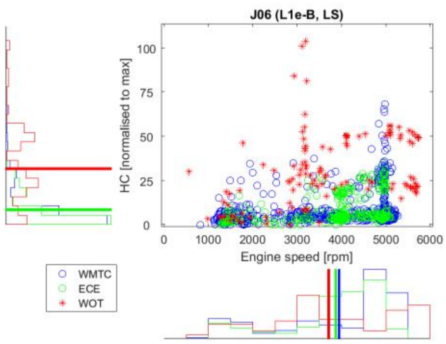
Figure 333. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J05 (L1e-A)

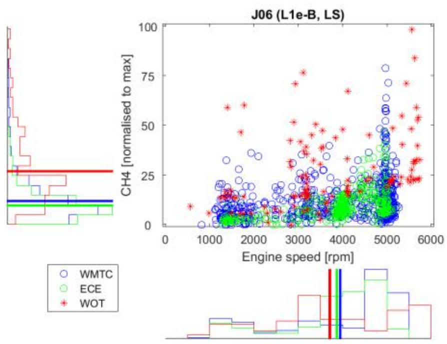

J06 (L1e-B, LS)
NOx [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

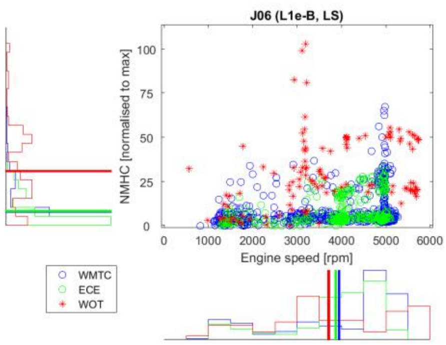

J06 (L1e-B, LS)
NO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

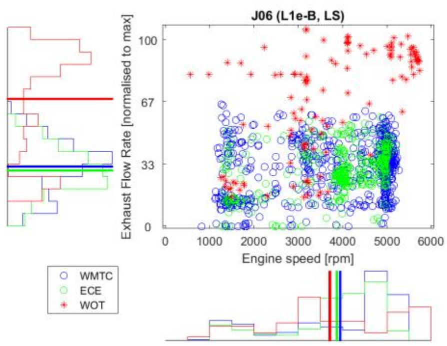

J06 (L1e-B, LS)
CO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J06 (L1e-B, LS)
CO2 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J06 (L1e-B, LS)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J06 (L1e-B, LS)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J06 (L1e-B, LS)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J06 (L1e-B, LS)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

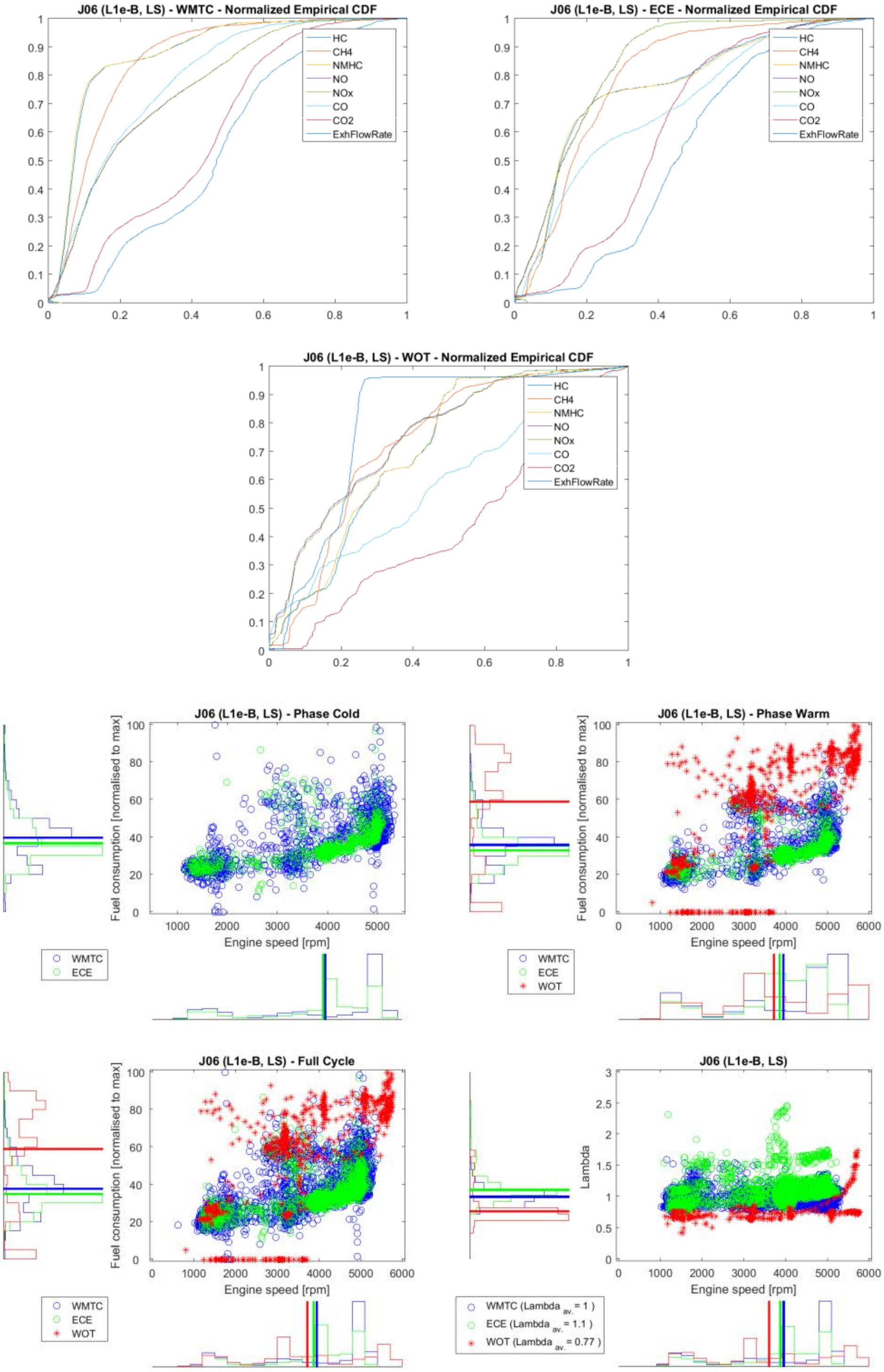
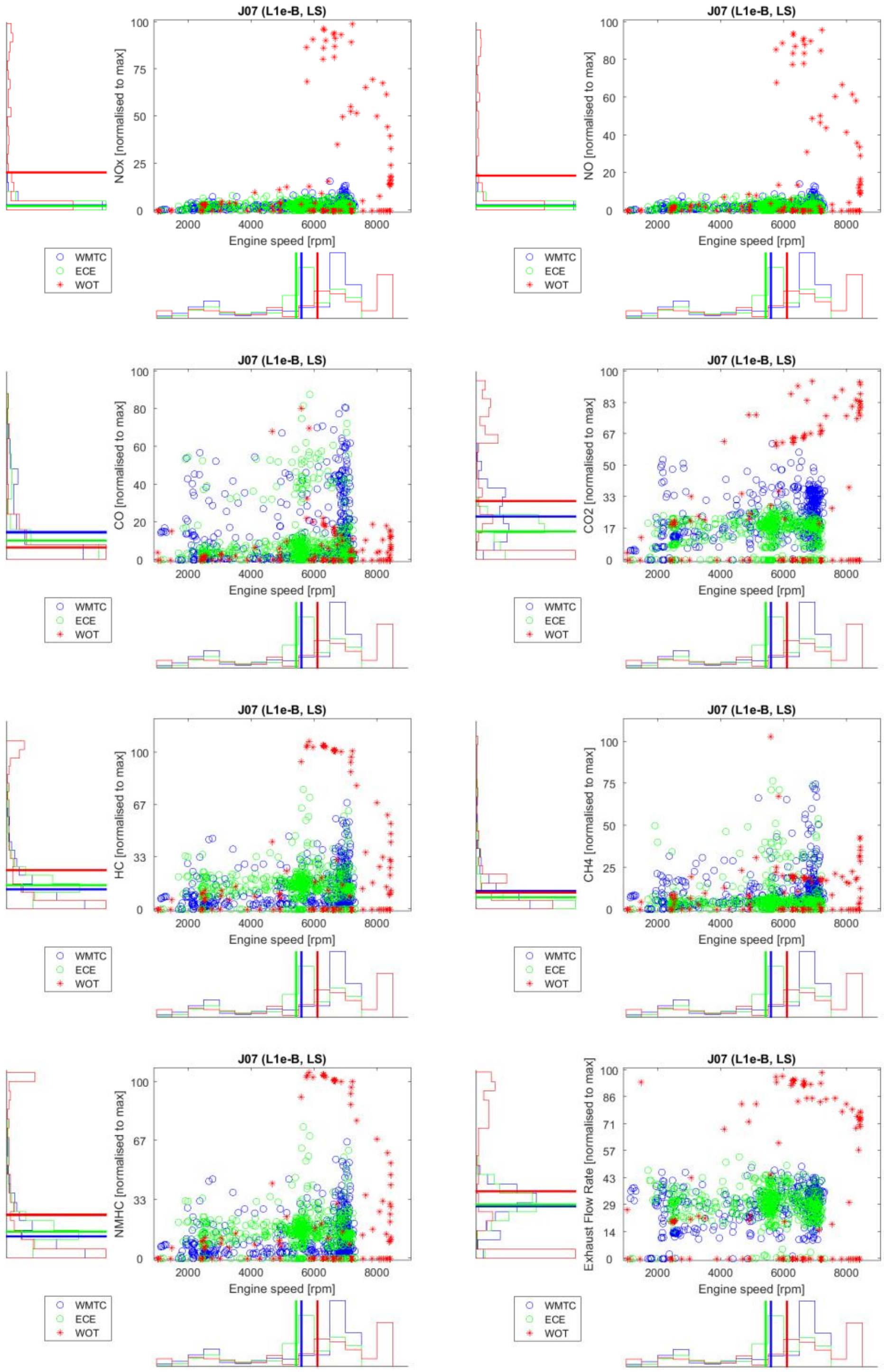


Figure 334. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J06 (L1e-B, low speed)


J07 (L1e-B, LS)
NOx [normalised to max]
NO [normalised to max]
CO [normalised to max]
CO2 [normalised to max]
HC [normalised to max]
CH4 [normalised to max]
NMHC [normalised to max]
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

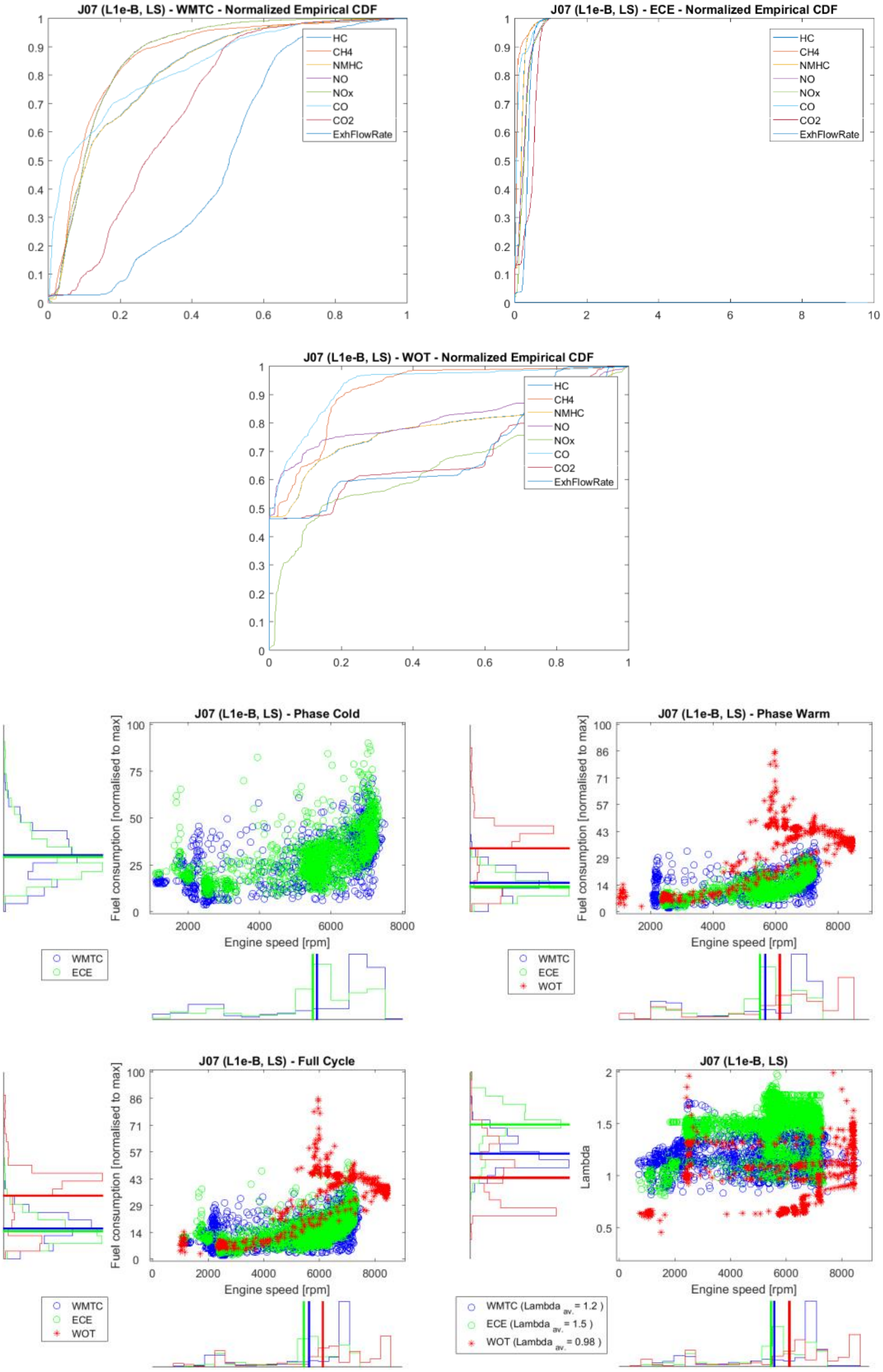
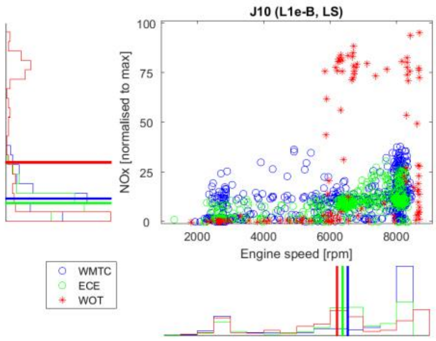
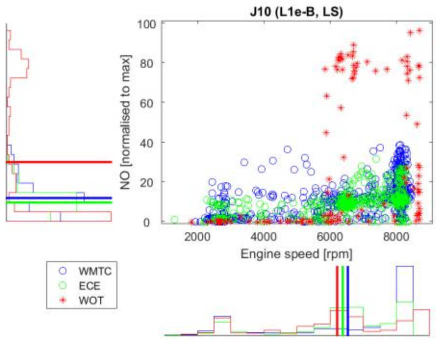
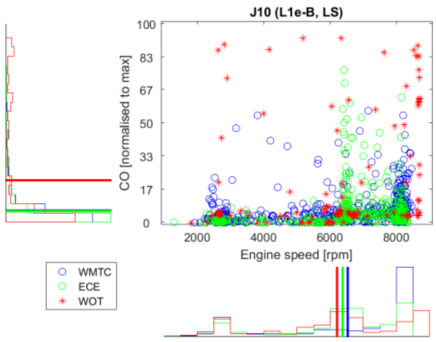
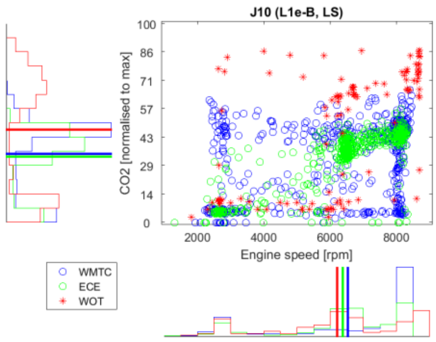


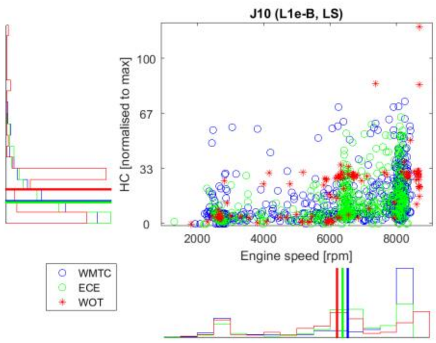
Figure 335. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J07 (L1e-B, low speed)

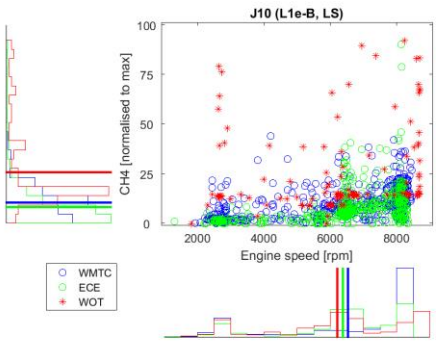

J10 (L1e-B, LS)
NOx [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

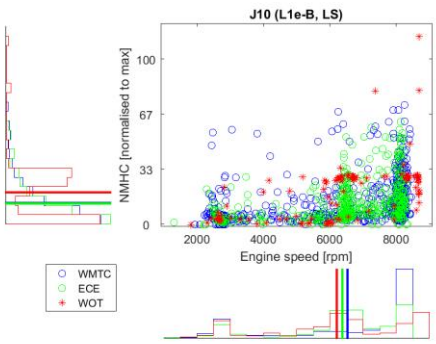

J10 (L1e-B, LS)
NO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

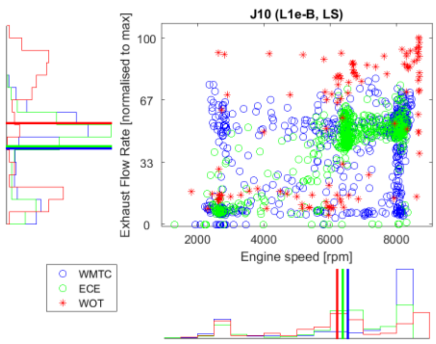

J10 (L1e-B, LS)
CO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J10 (L1e-B, LS)
CO2 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J10 (L1e-B, LS)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J10 (L1e-B, LS)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J10 (L1e-B, LS)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J10 (L1e-B, LS)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

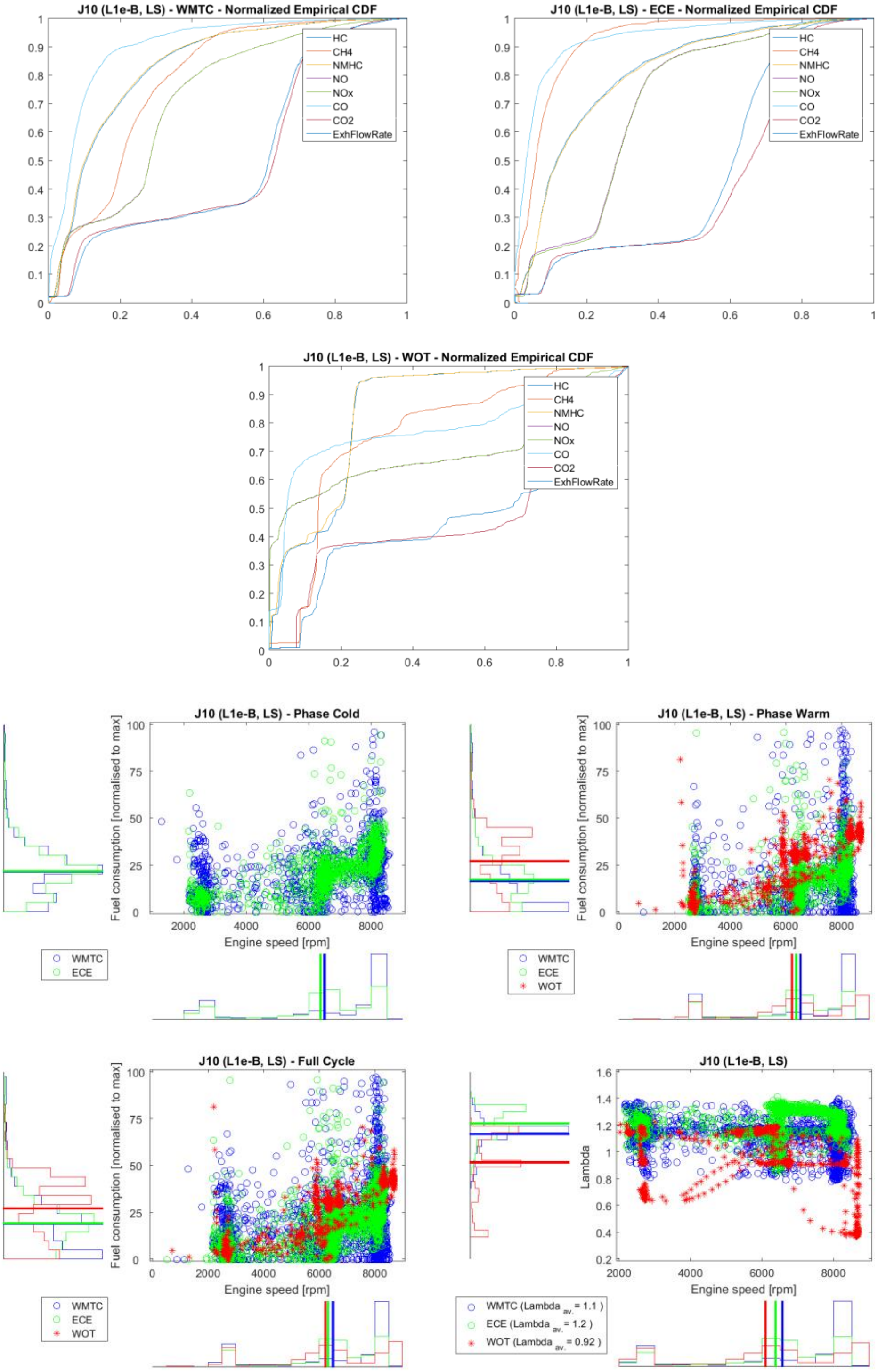
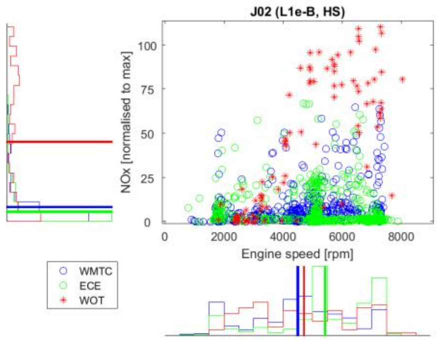
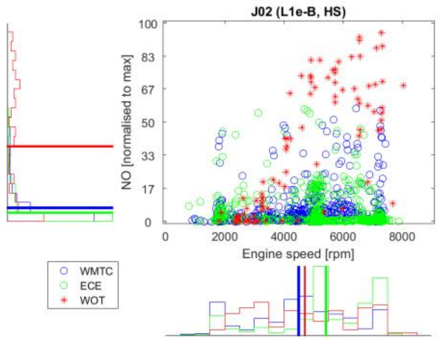
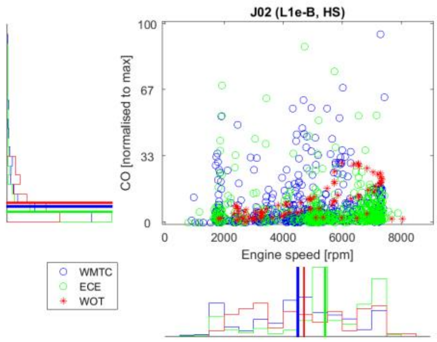
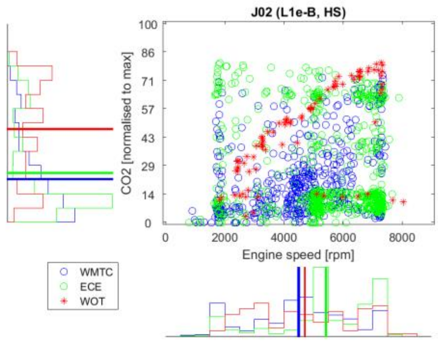


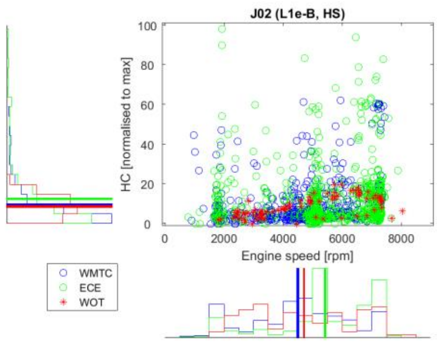
Figure 336. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J10 (L1e-B, low speed)

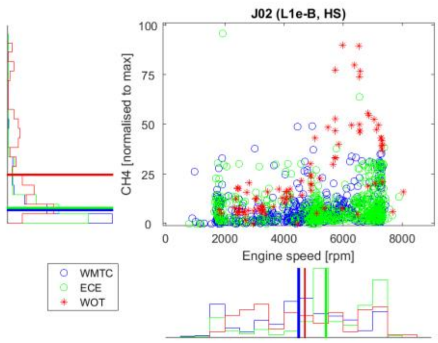

J02 (L1e-B, HS)
NOx [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

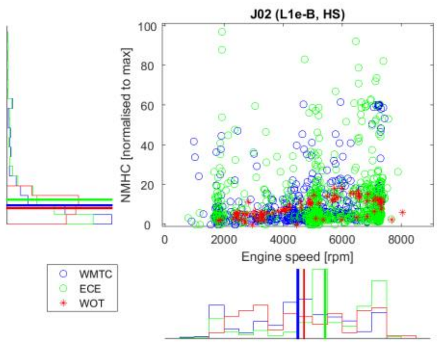

J02 (L1e-B, HS)
NO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

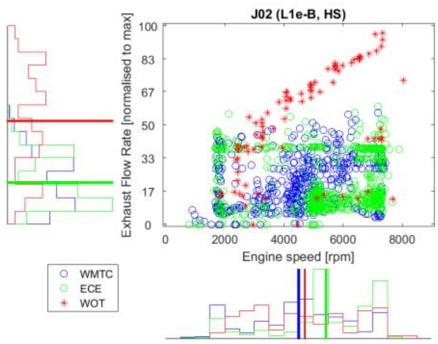

J02 (L1e-B, HS)
CO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J02 (L1e-B, HS)
CO2 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J02 (L1e-B, HS)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J02 (L1e-B, HS)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J02 (L1e-B, HS)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J02 (L1e-B, HS)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

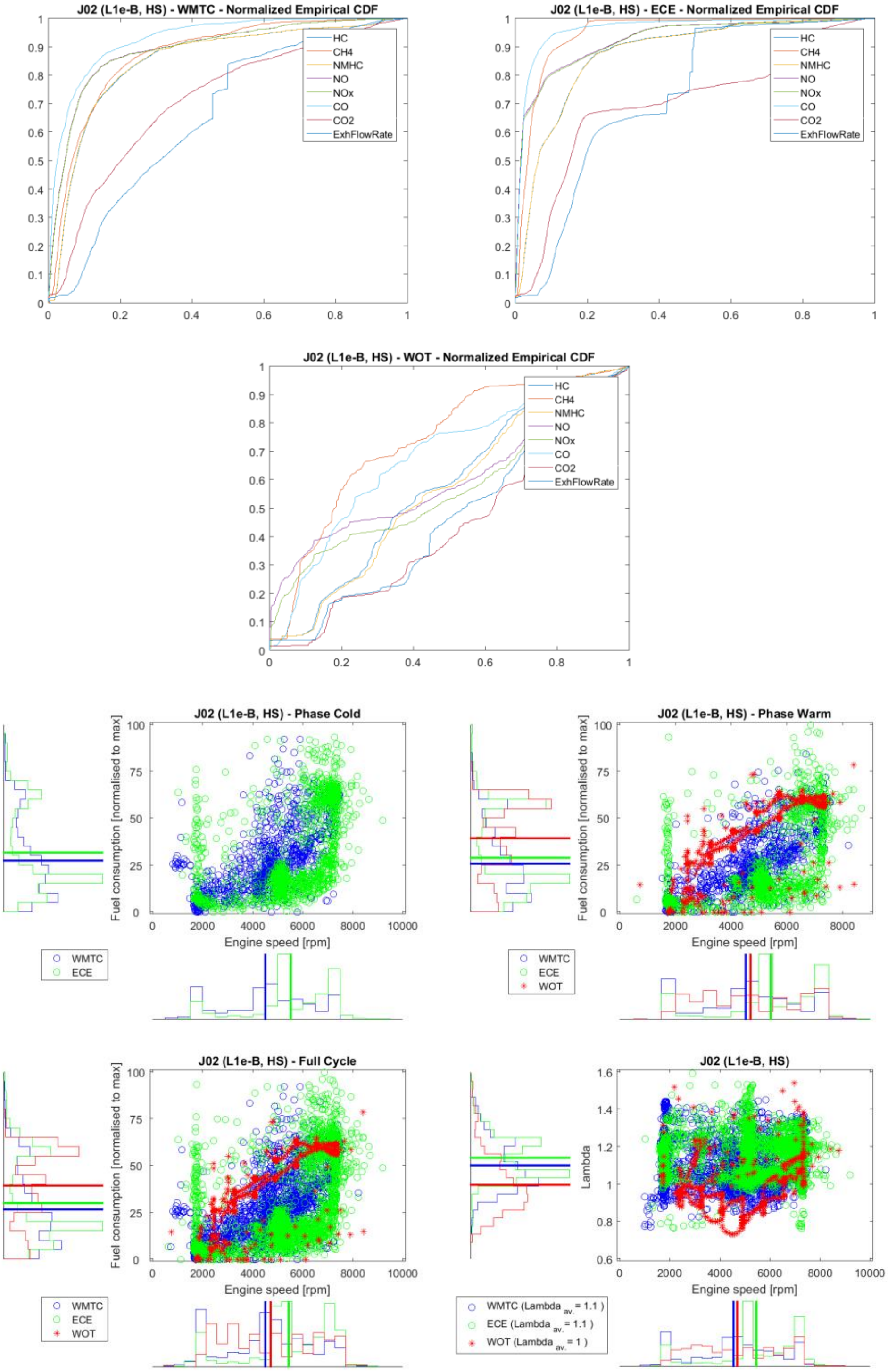
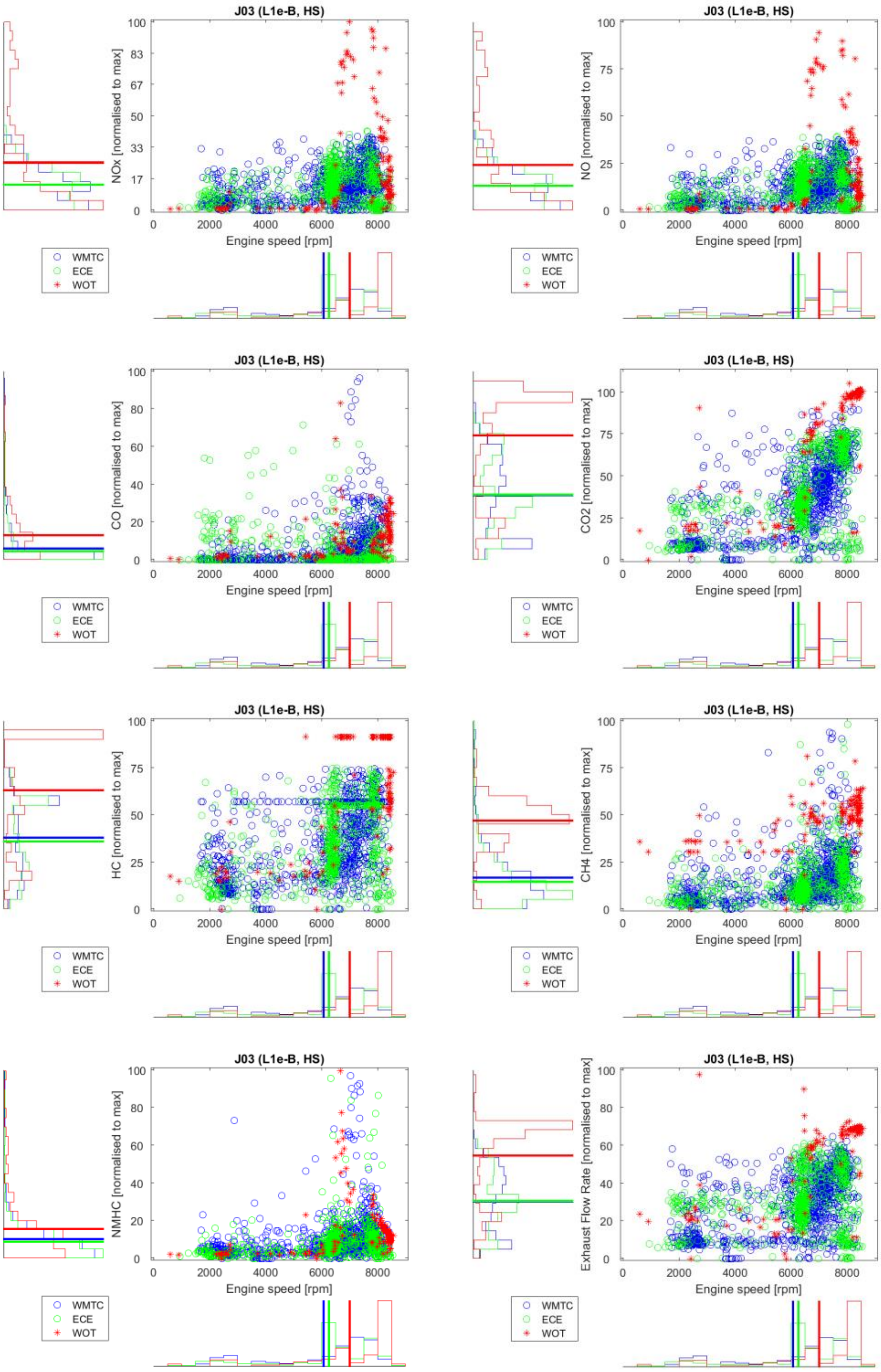


Figure 337. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J02 (L1e-B, high speed moped)


J03 (L1e-B, HS)
NOx [normalised to max]
NO [normalised to max]
CO [normalised to max]
CO2 [normalised to max]
HC [normalised to max]
CH4 [normalised to max]
NMHC [normalised to max]
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

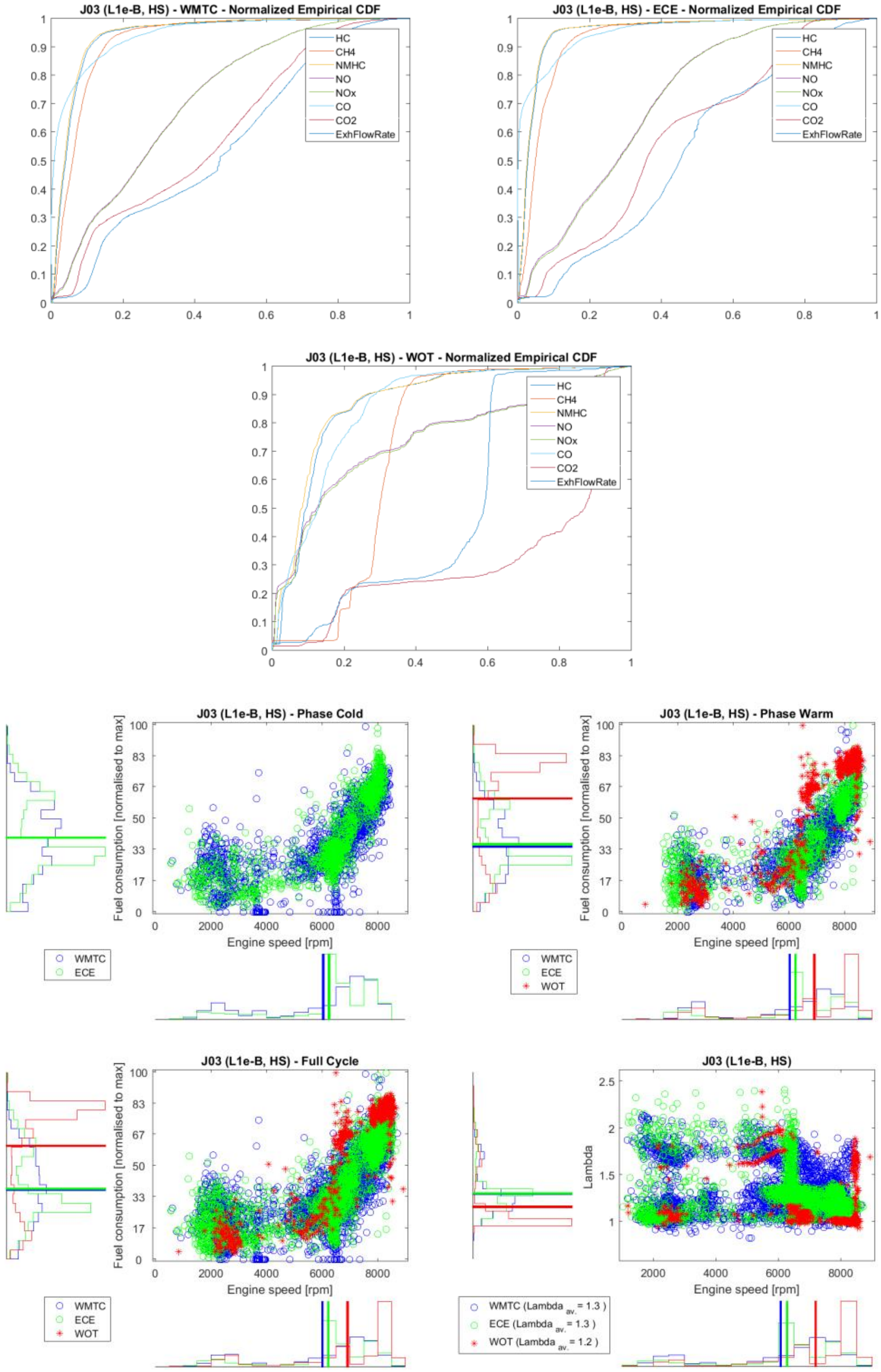
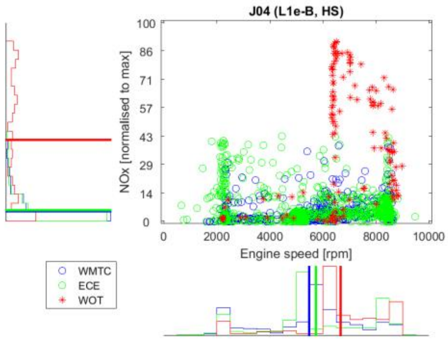
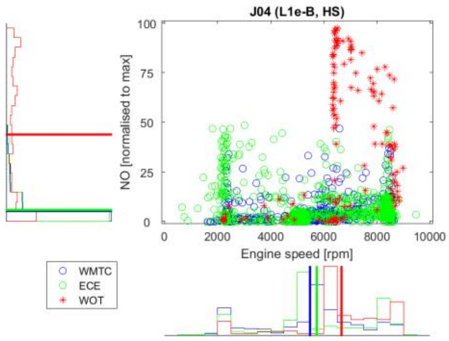
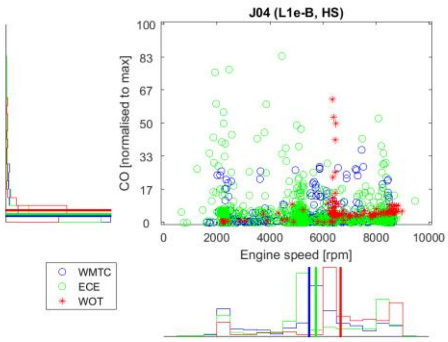
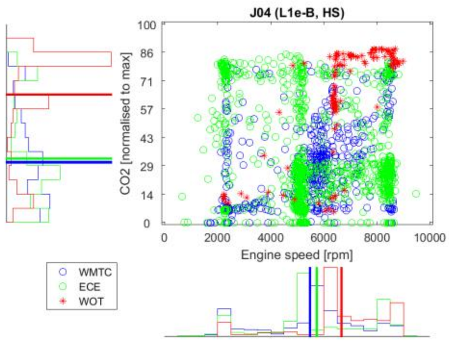


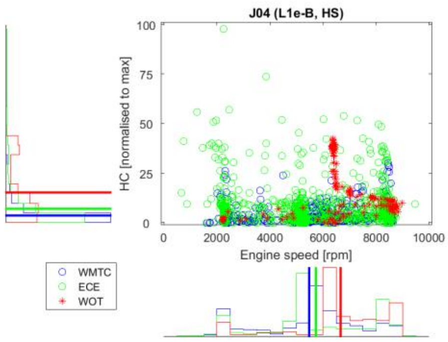
Figure 338. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J03 (L1e-B, high speed moped)

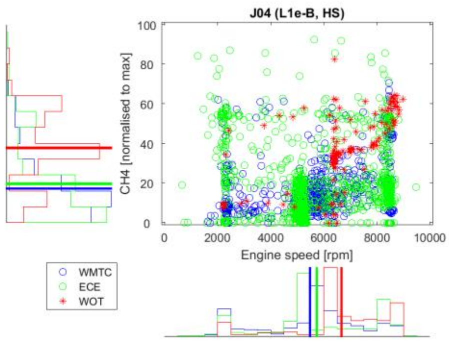

J04 (L1e-B, HS)
NOx [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

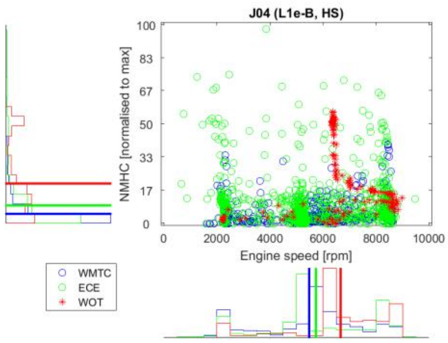

J04 (L1e-B, HS)
NO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

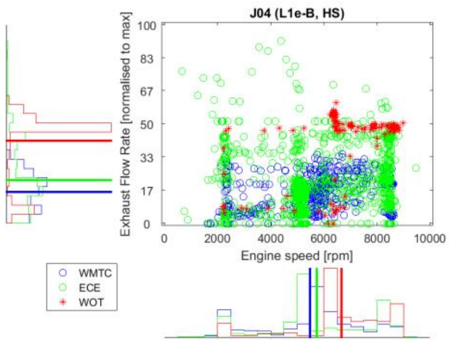

J04 (L1e-B, HS)
CO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J04 (L1e-B, HS)
CO2 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J04 (L1e-B, HS)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J04 (L1e-B, HS)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J04 (L1e-B, HS)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J04 (L1e-B, HS)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

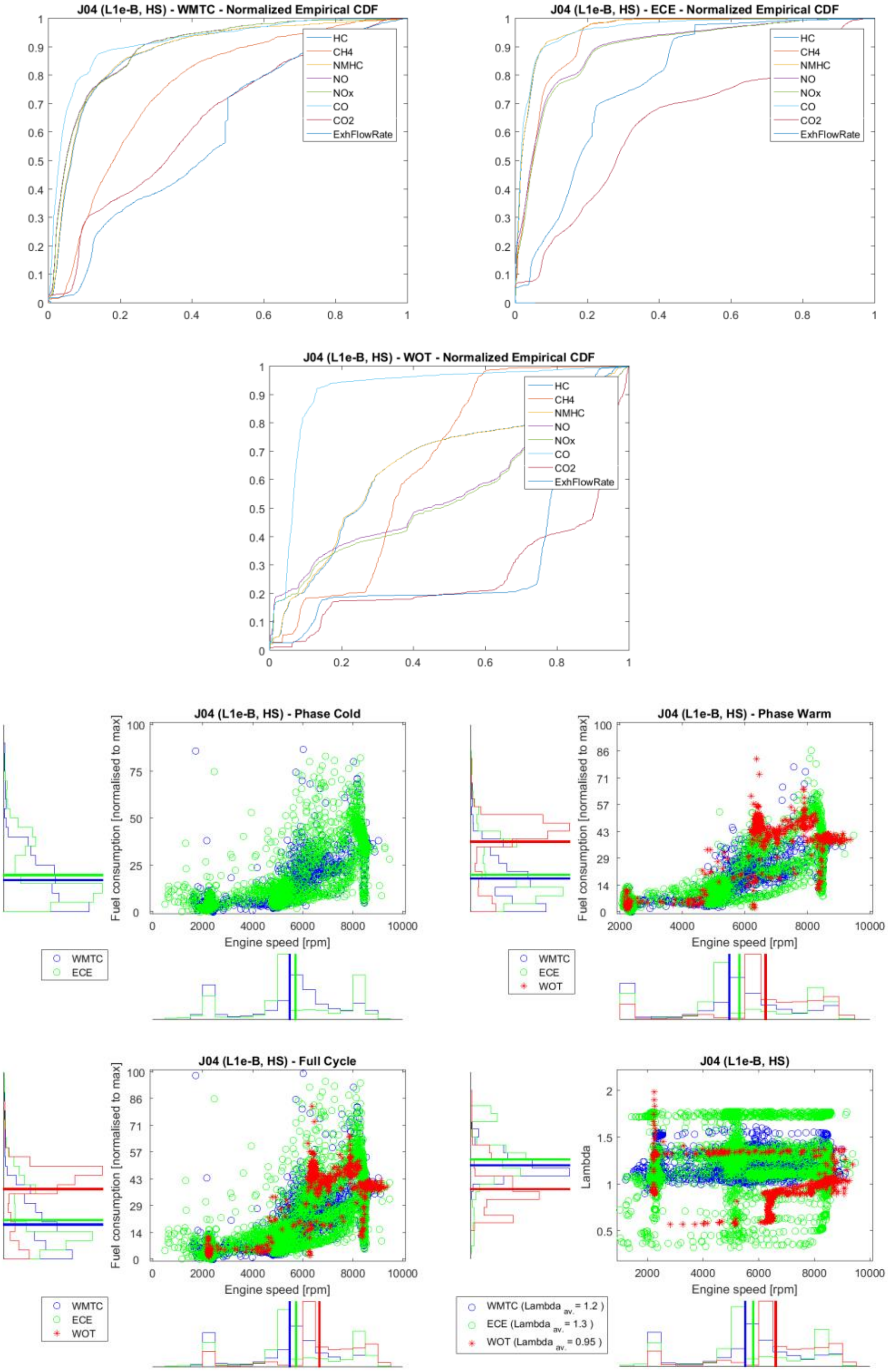
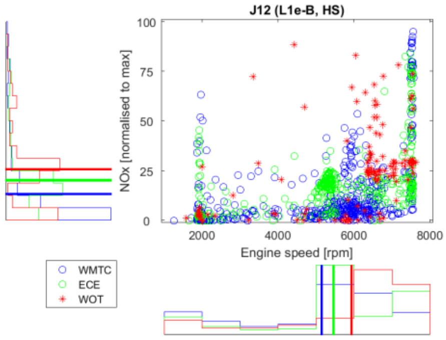
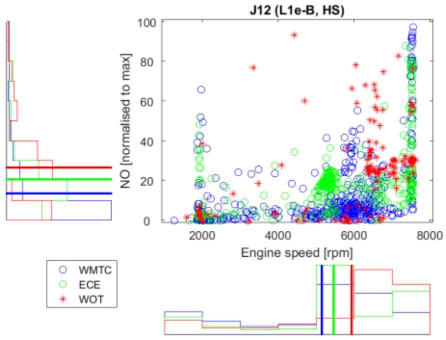
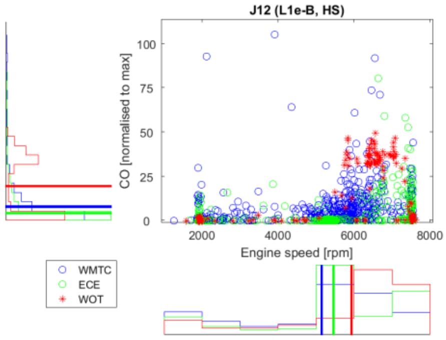
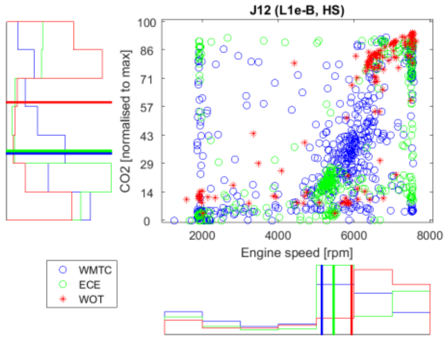


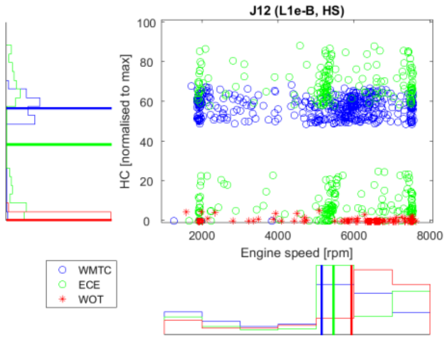
Figure 339. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J04 (L1e-B, high speed moped)

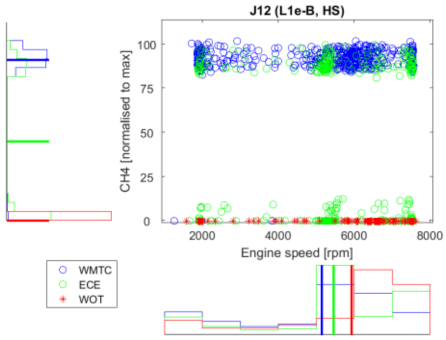

J12 (L1e-B, HS)
NOx [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

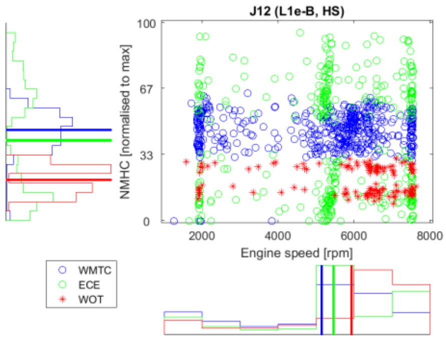

J12 (L1e-B, HS)
NO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

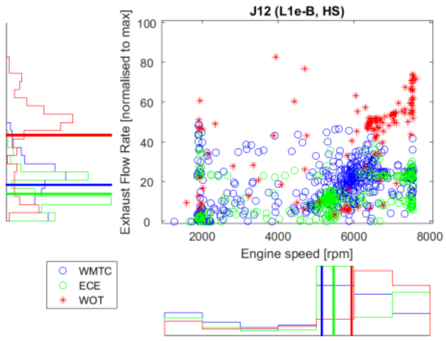

J12 (L1e-B, HS)
CO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J12 (L1e-B, HS)
CO2 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J12 (L1e-B, HS)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J12 (L1e-B, HS)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J12 (L1e-B, HS)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J12 (L1e-B, HS)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

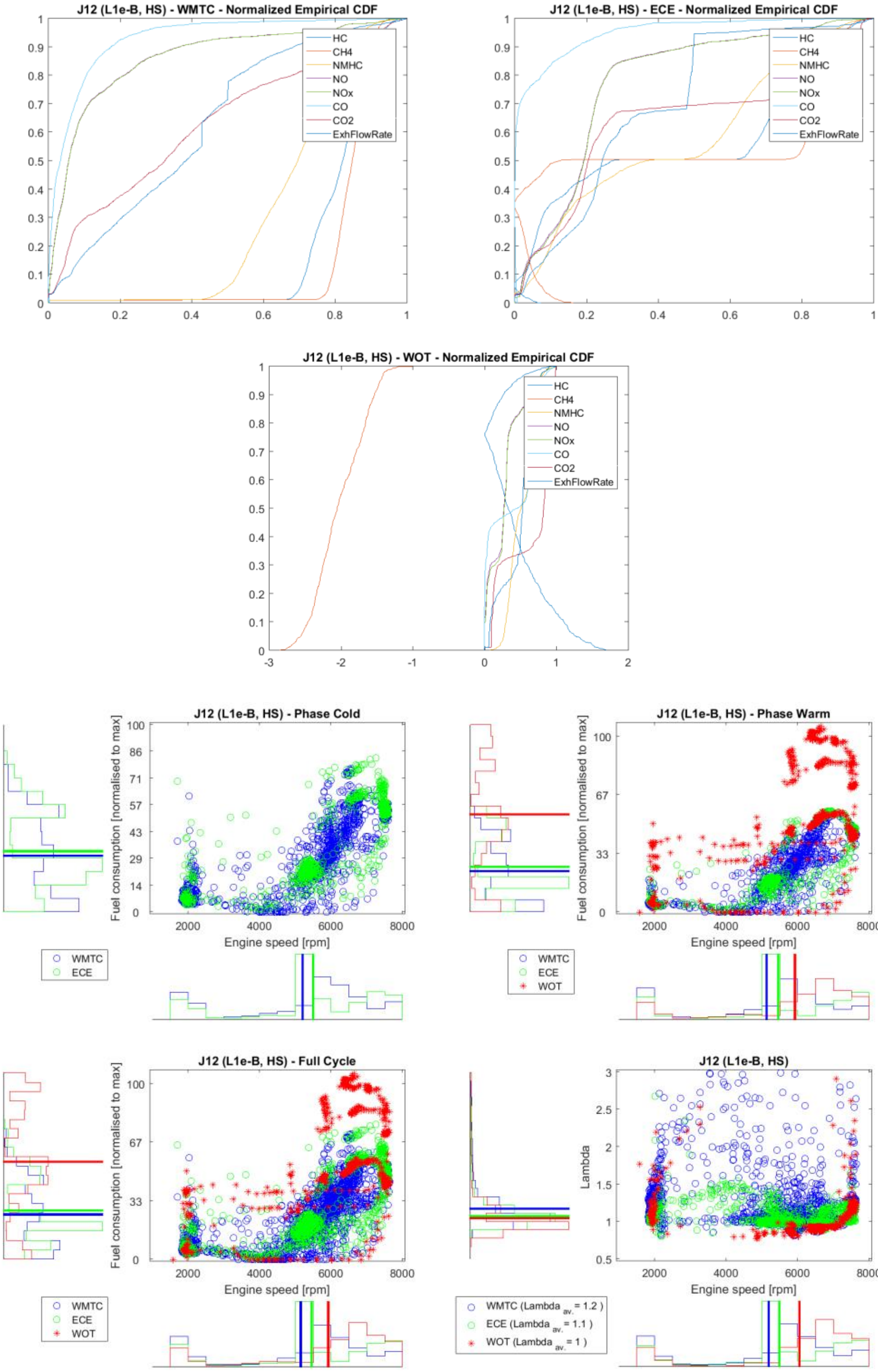
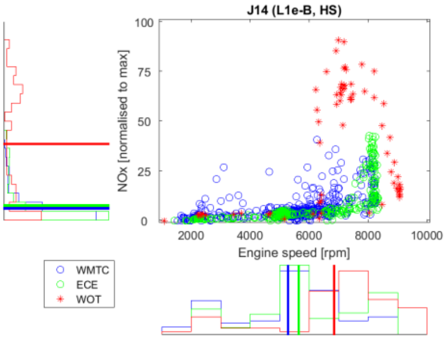
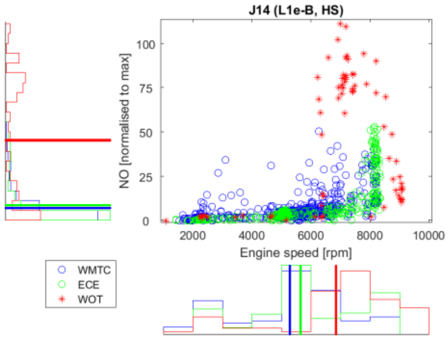
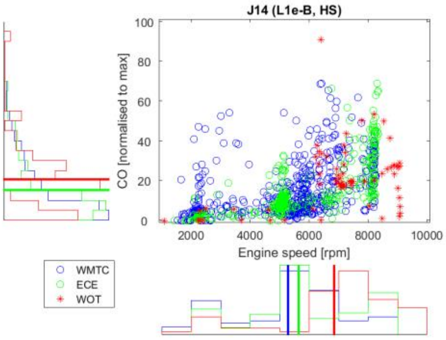
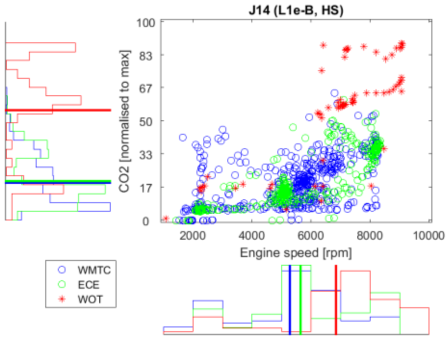


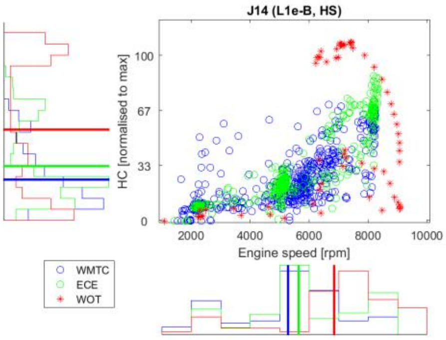
Figure 340. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J12 (L1e-B, high speed moped)

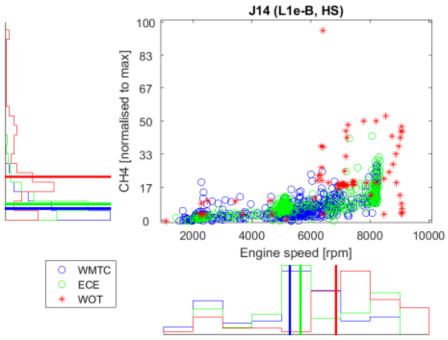

J14 (L1e-B, HS)
NOx [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

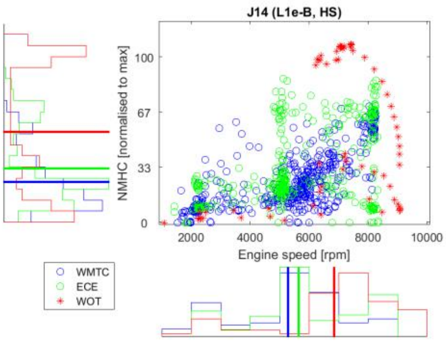

J14 (L1e-B, HS)
NO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

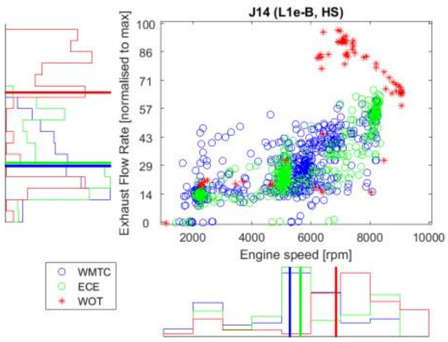

J14 (L1e-B, HS)
CO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J14 (L1e-B, HS)
CO2 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J14 (L1e-B, HS)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J14 (L1e-B, HS)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J14 (L1e-B, HS)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J14 (L1e-B, HS)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

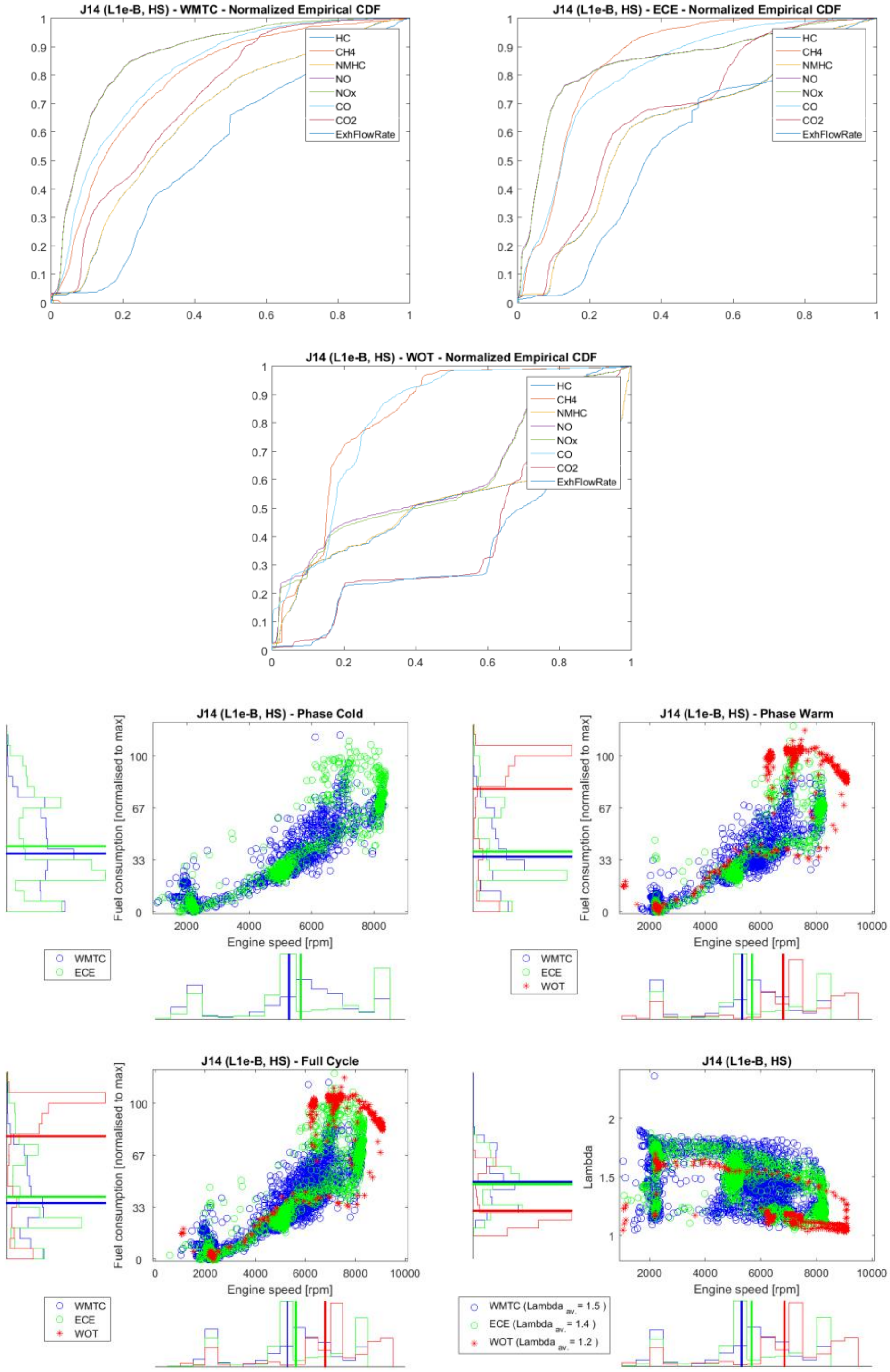
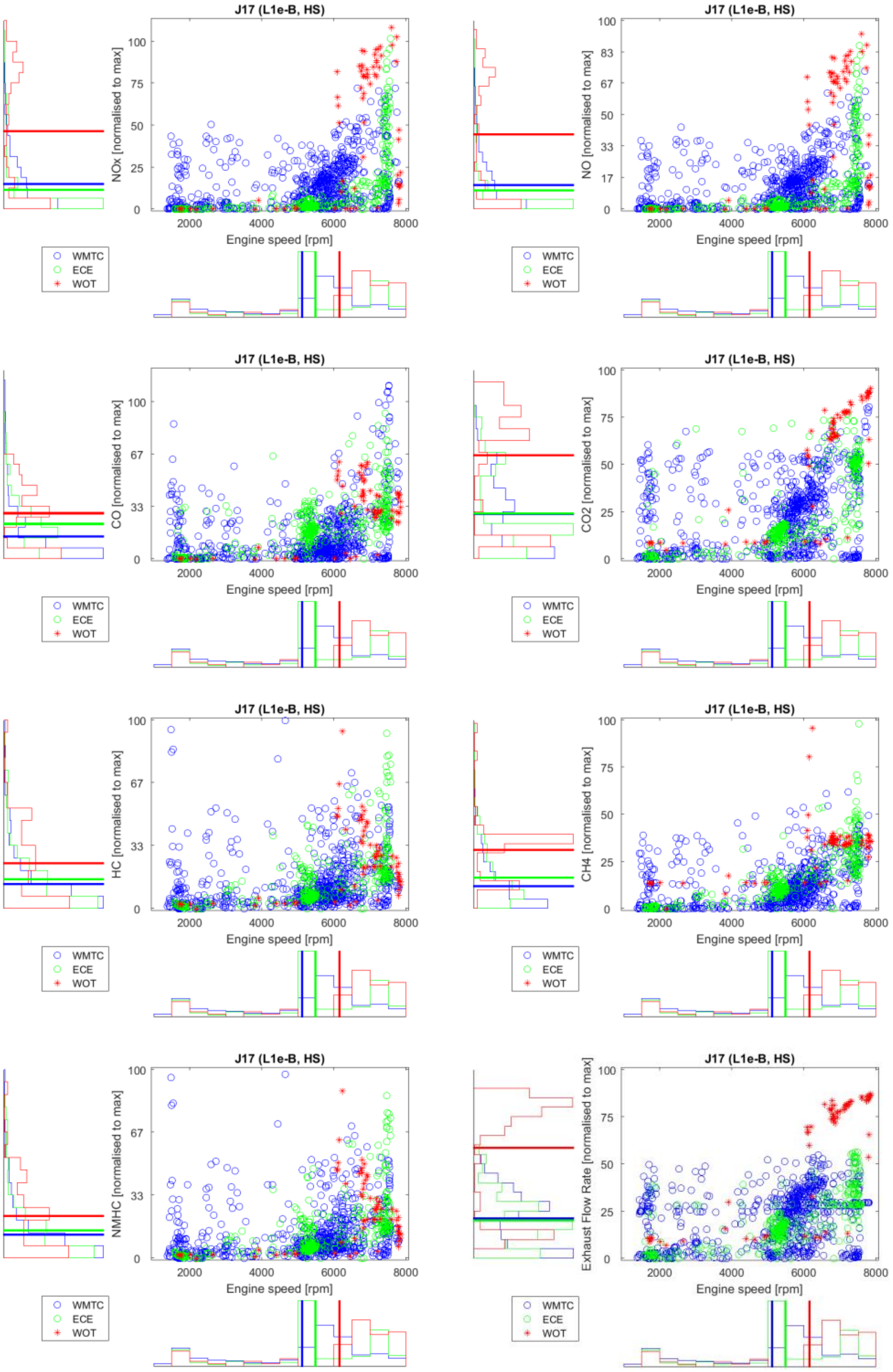


Figure 341. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J14 (L1e-B, high speed moped)


J17 (L1e-B, HS)
NOx [normalised to max]
NO [normalised to max]
CO [normalised to max]
CO2 [normalised to max]
HC [normalised to max]
CH4 [normalised to max]
NMHC [normalised to max]
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

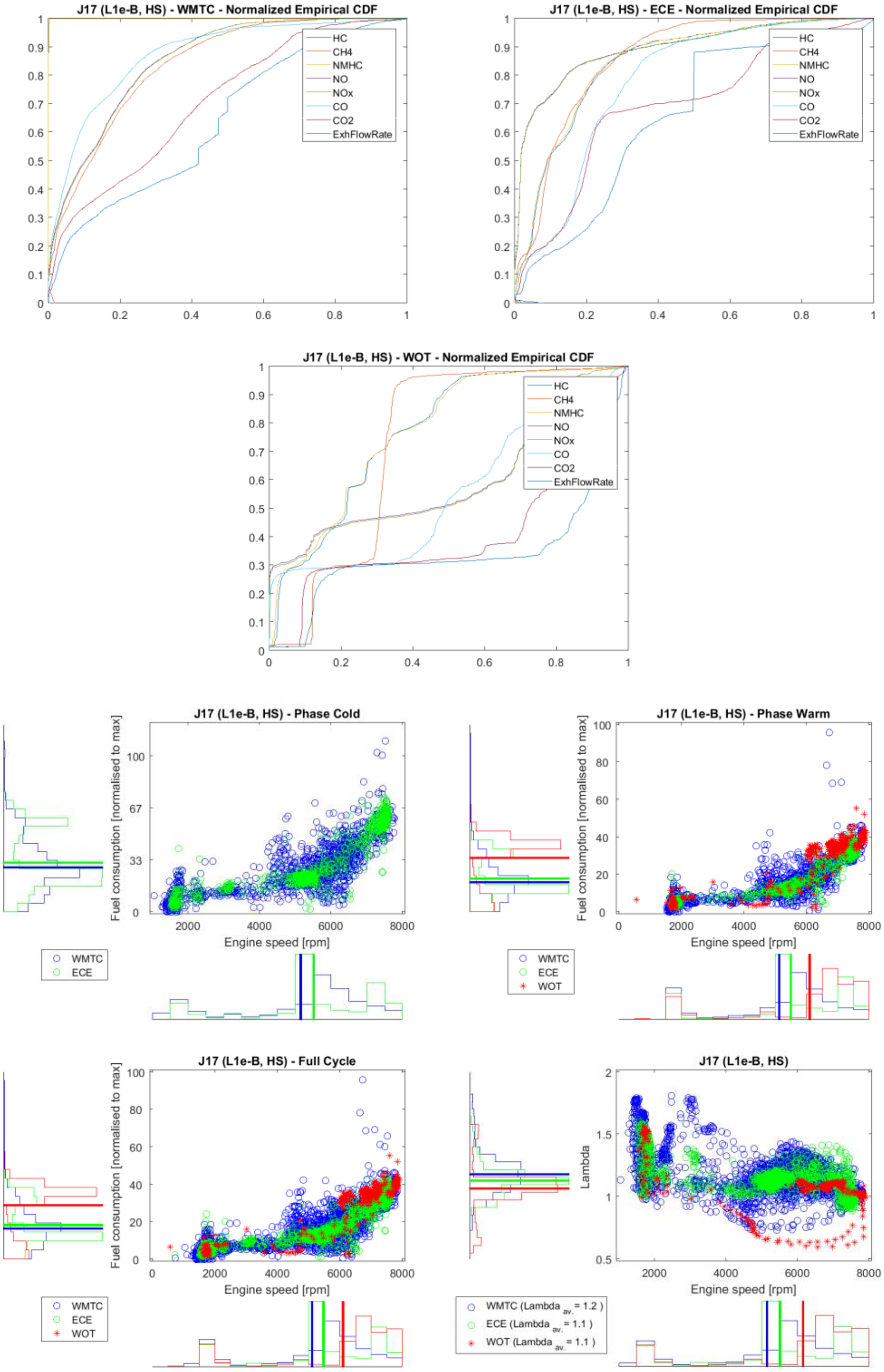
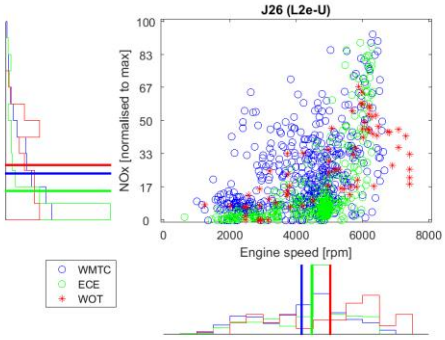
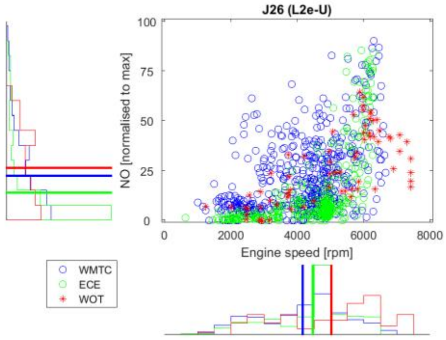
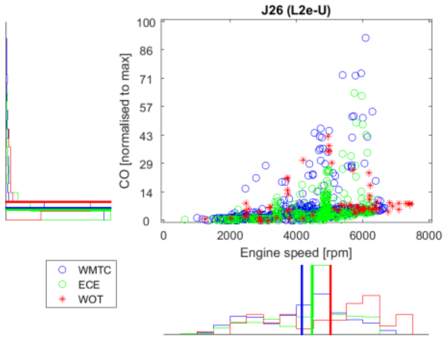
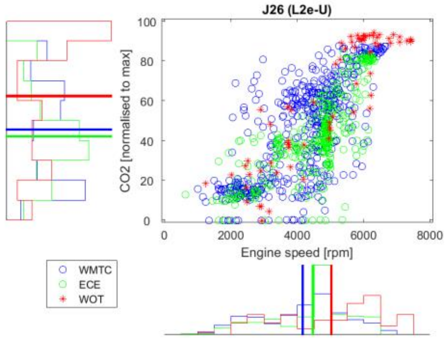


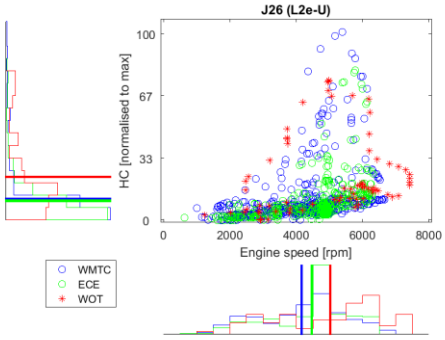
Figure 342. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J17 (L1e-B, high speed moped)

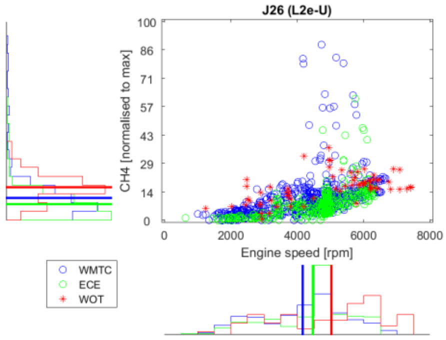

J26 (L2e-U)
NOx [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

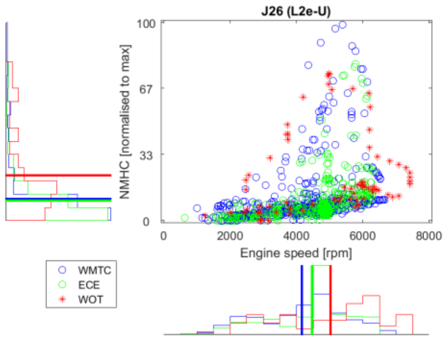

J26 (L2e-U)
NO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

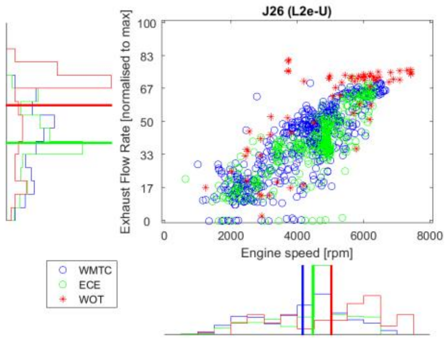

J26 (L2e-U)
CO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J26 (L2e-U)
CO2 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J26 (L2e-U)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J26 (L2e-U)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J26 (L2e-U)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J26 (L2e-U)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

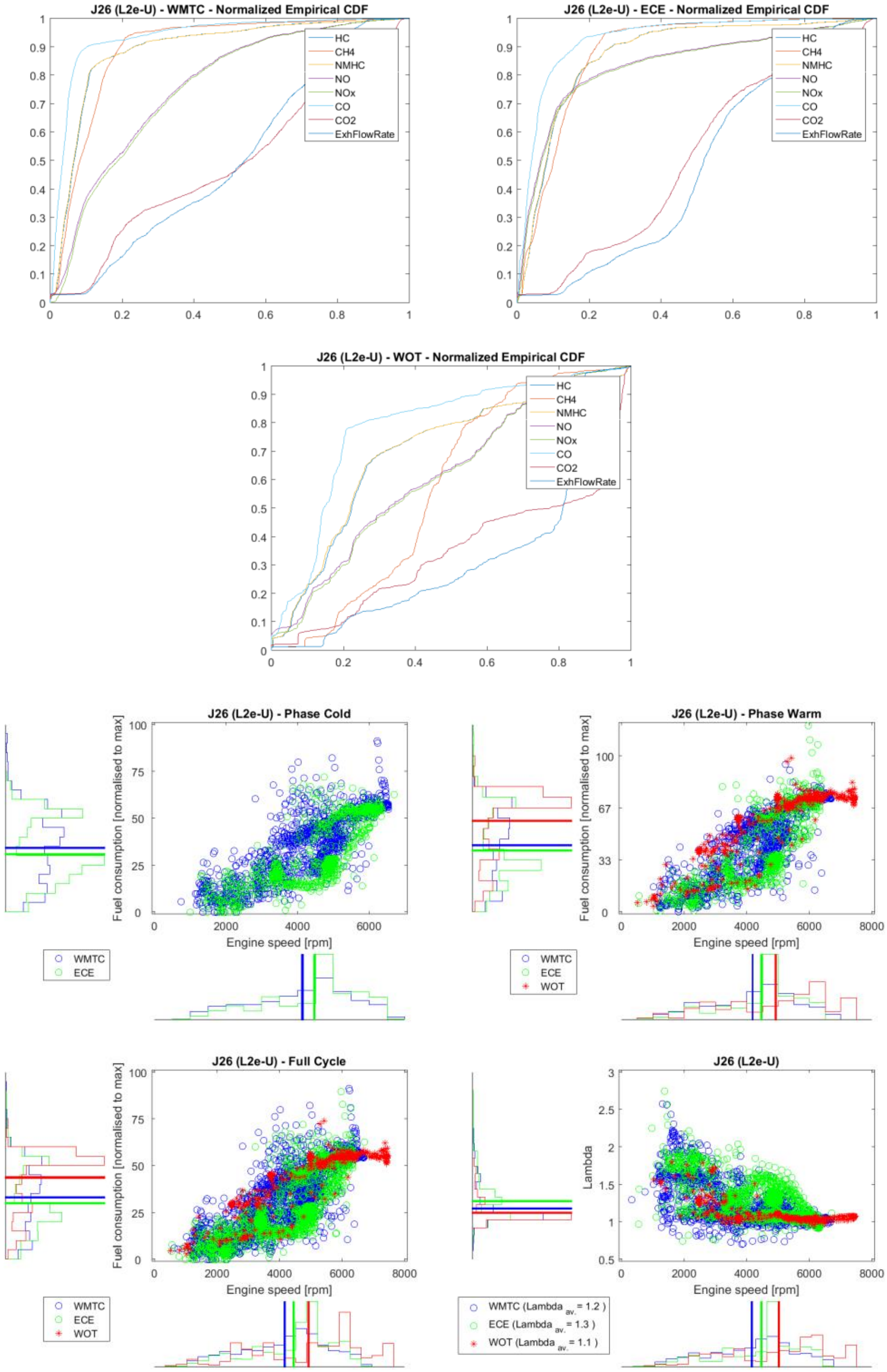
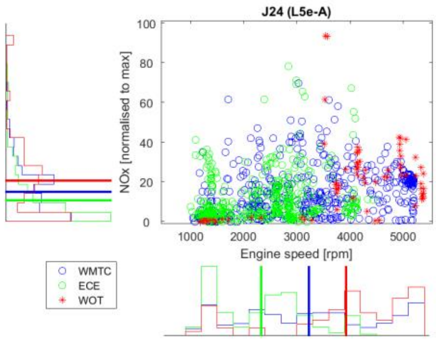
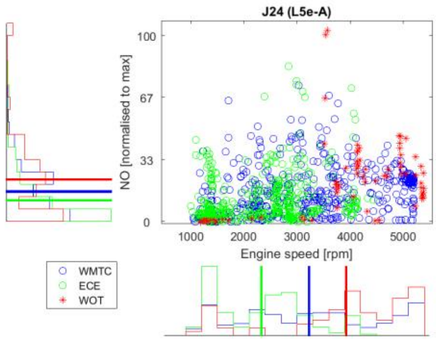
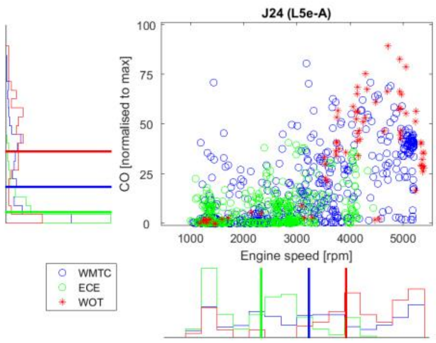
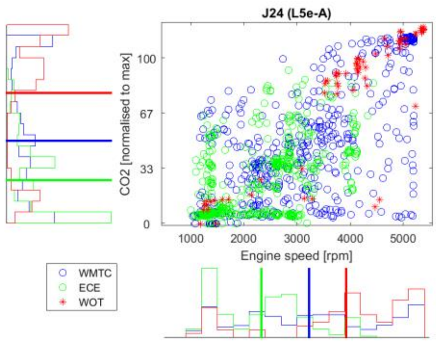


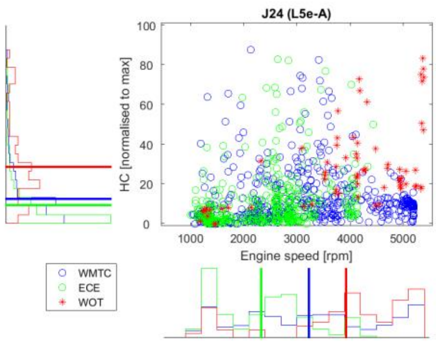
Figure 343. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J26 (L2e-U)

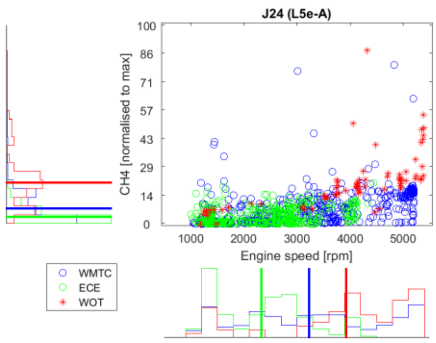

J24 (L5e-A)
NOx [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

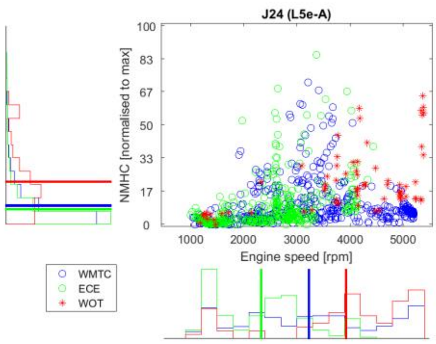

J24 (L5e-A)
NO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

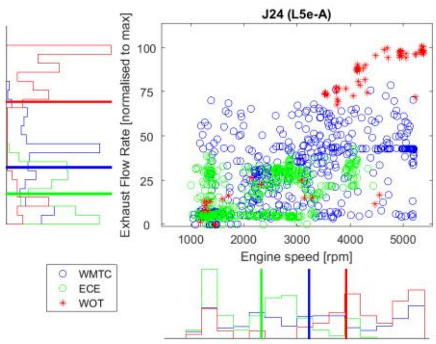

J24 (L5e-A)
CO [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J24 (L5e-A)
CO2 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J24 (L5e-A)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J24 (L5e-A)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J24 (L5e-A)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J24 (L5e-A)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

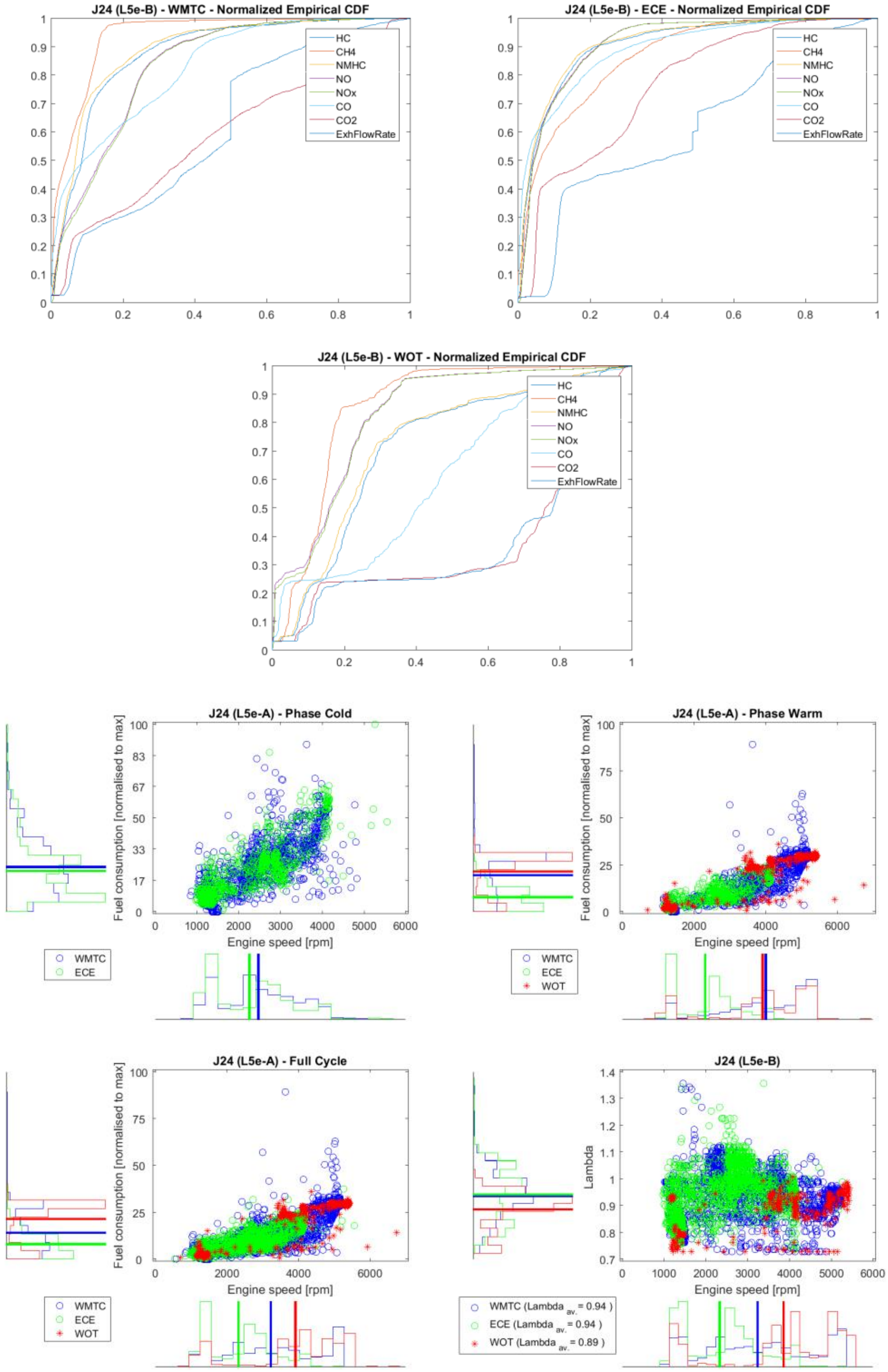
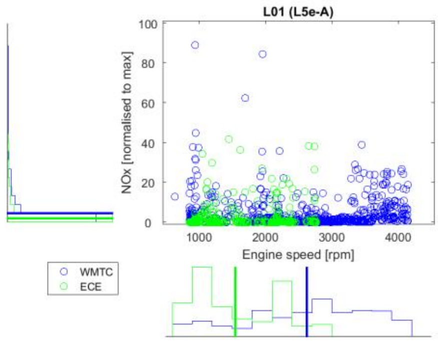
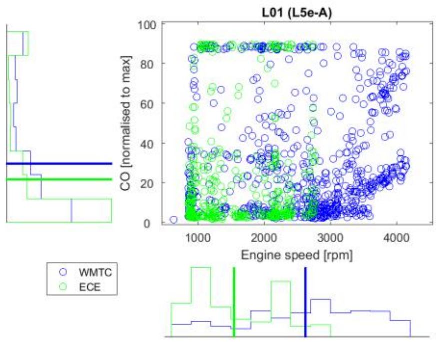
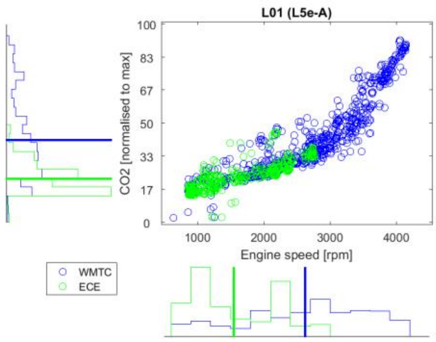
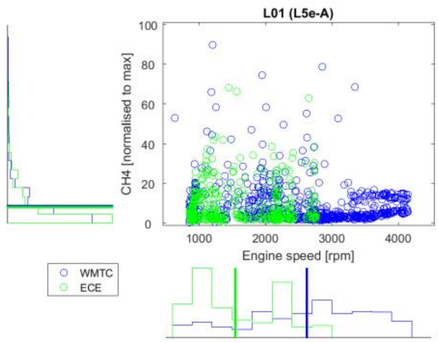


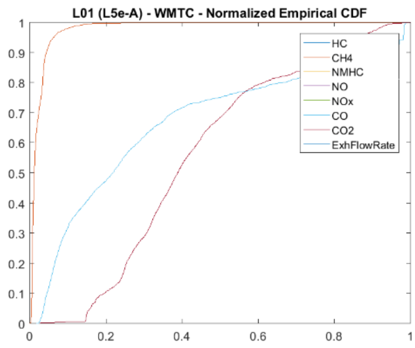
Figure 344. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J24 (L5e-A)

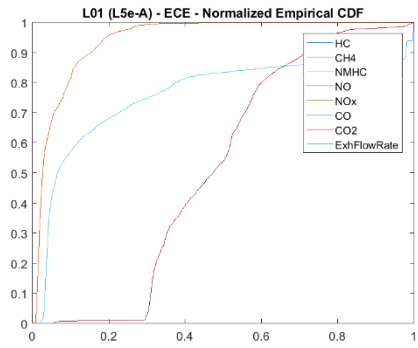

L01 (L5e-A)
NOx [normalised to max]
Engine speed [rpm]
WMTC
ECE


L01 (L5e-A)
CO [normalised to max]
Engine speed [rpm]
WMTC
ECE


L01 (L5e-A)
CO2 [normalised to max]
Engine speed [rpm]
WMTC
ECE


L01 (L5e-A)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE


L01 (L5e-A) - WMTC - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


L01 (L5e-A) - ECE - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate

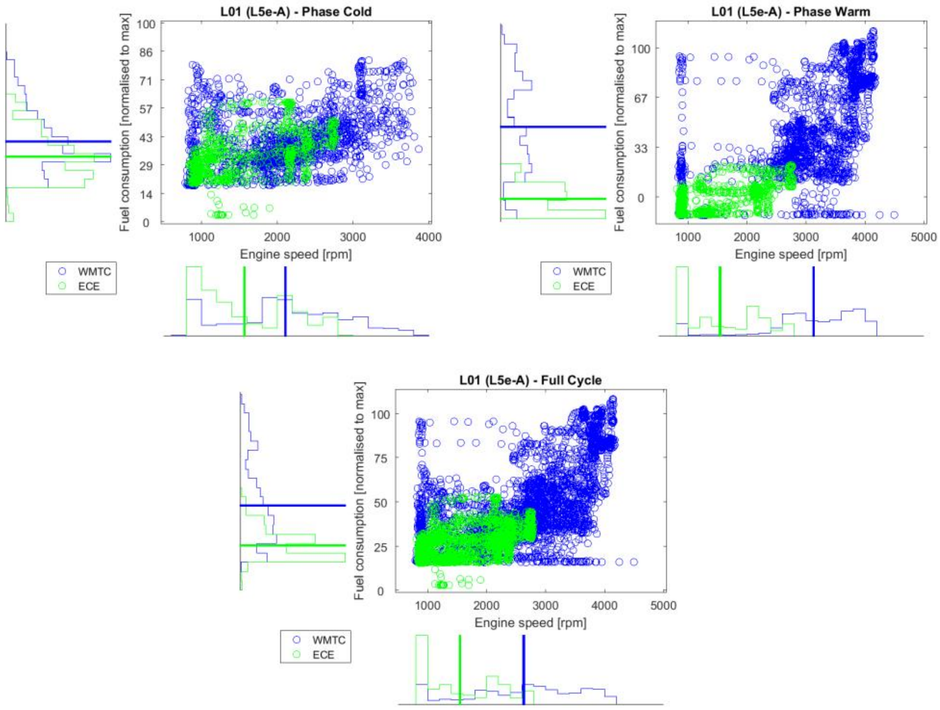
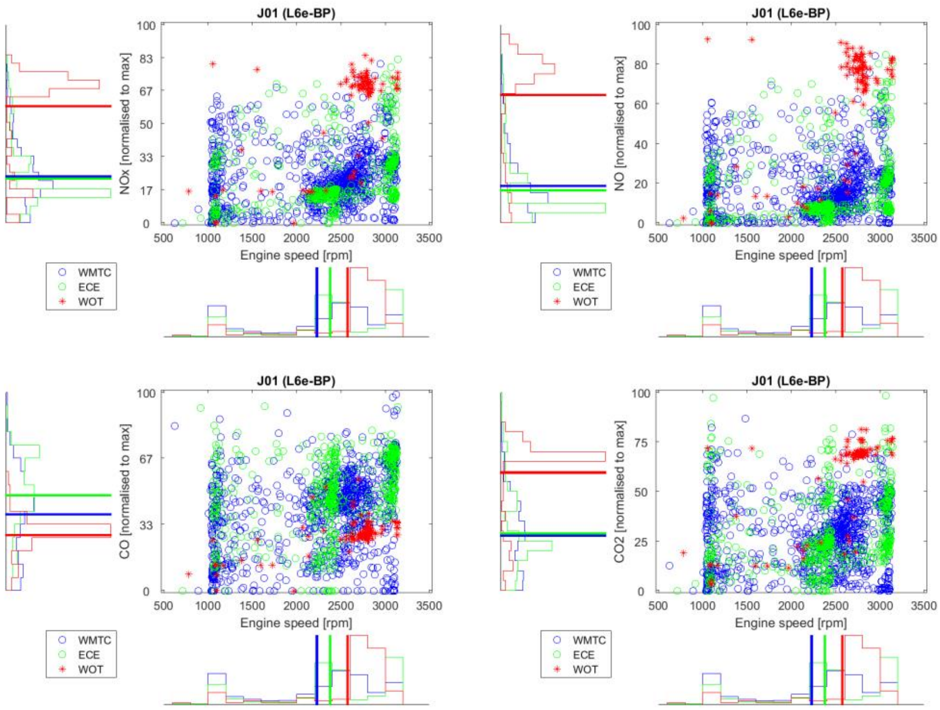
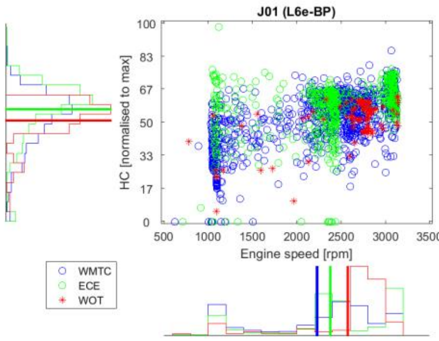
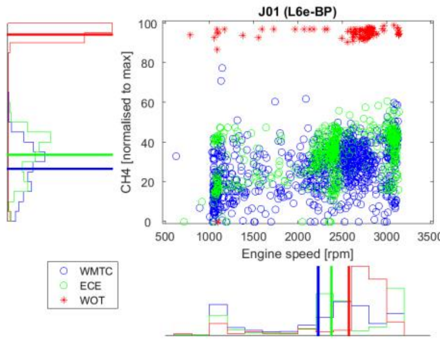
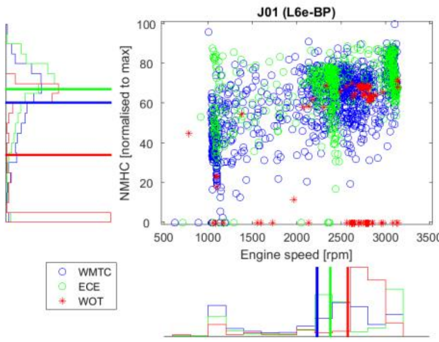


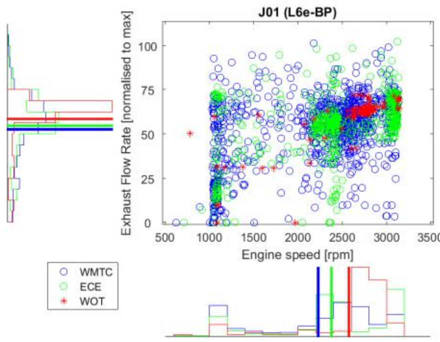
Figure 345. Pollutant emissions, fuel consumption and lambda sensor – Vehicle L01 (L5e-A)

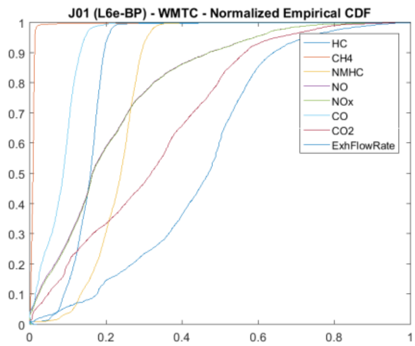


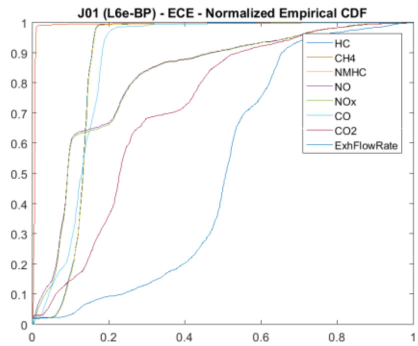

J01 (L6e-BP)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

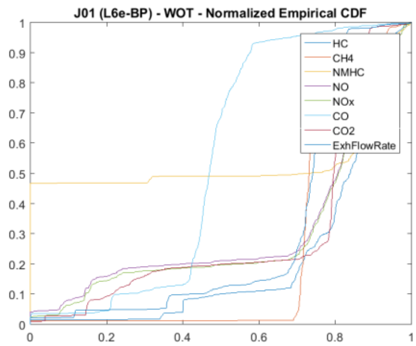

J01 (L6e-BP)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J01 (L6e-BP)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J01 (L6e-BP)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J01 (L6e-BP) - WMTC - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


J01 (L6e-BP) - ECE - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


J01 (L6e-BP) - WOT - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate

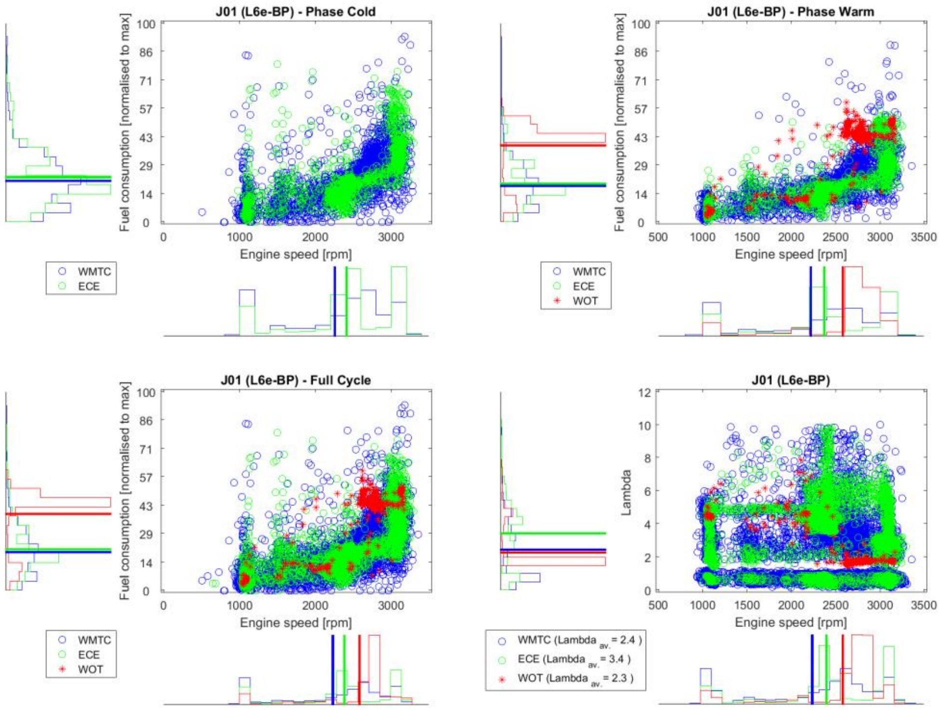
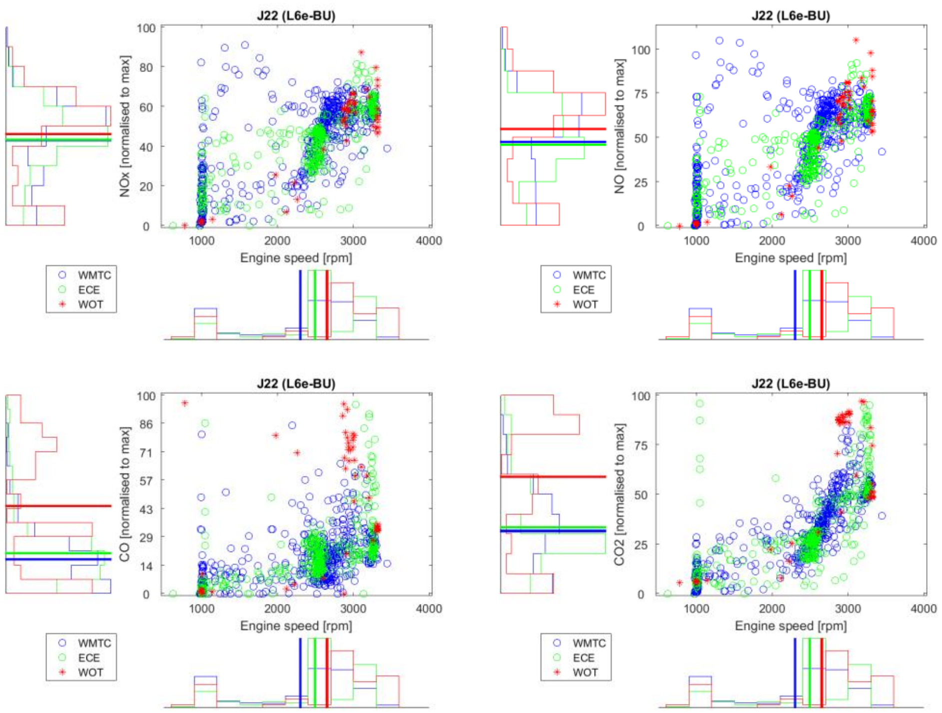
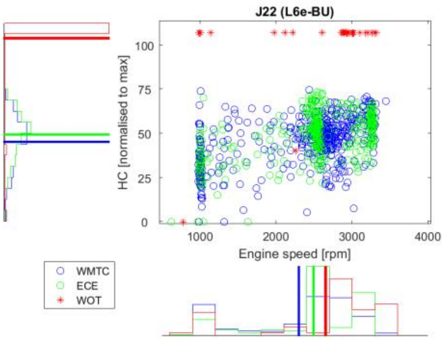
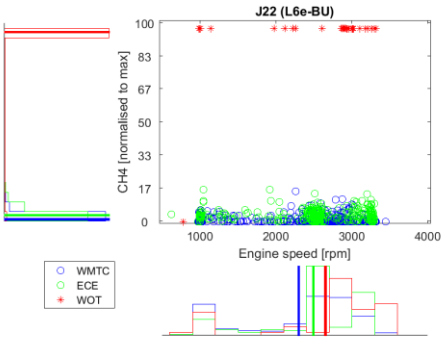
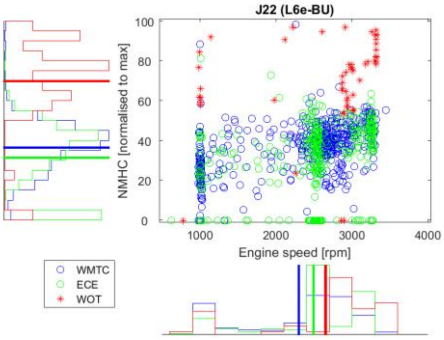


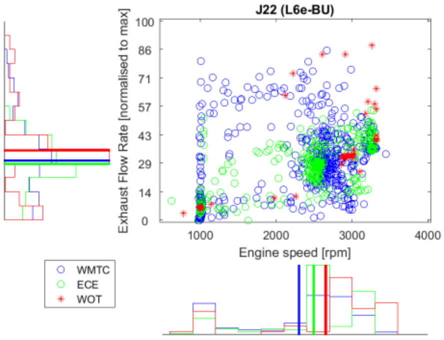
Figure 346. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J01 (L6e-BP)

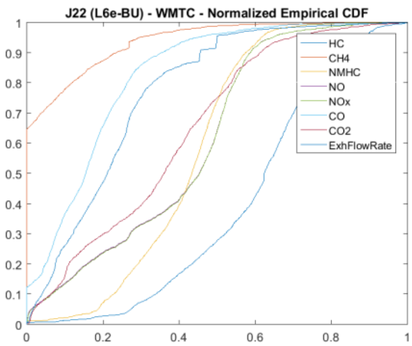


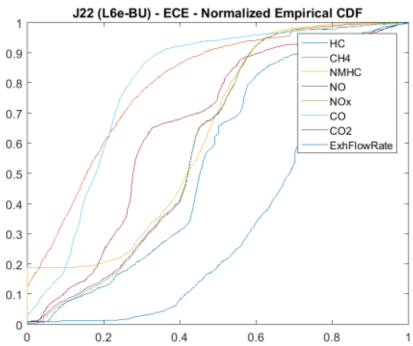

J22 (L6e-BU)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

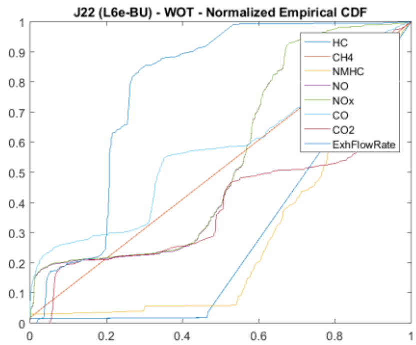

J22 (L6e-BU)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J22 (L6e-BU)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J22 (L6e-BU)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J22 (L6e-BU) - WMTC - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


J22 (L6e-BU) - ECE - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


J22 (L6e-BU) - WOT - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate

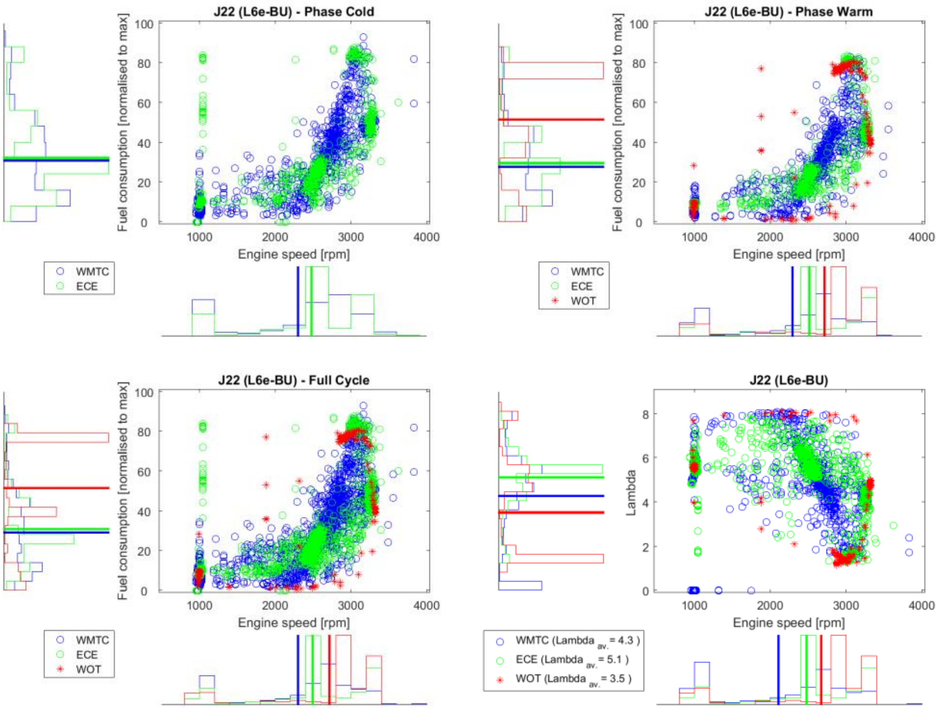
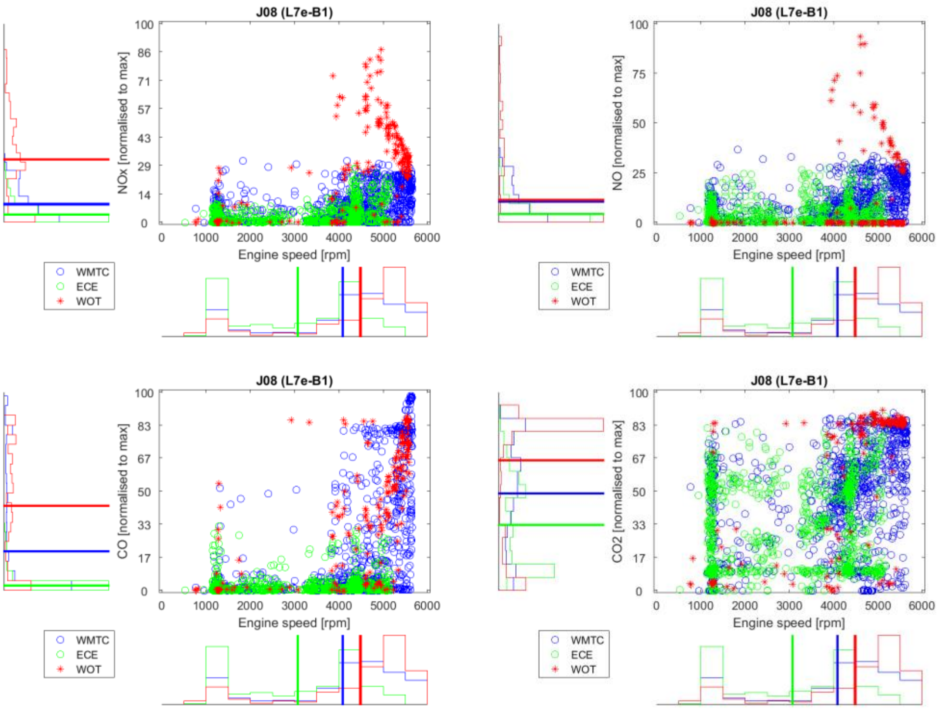
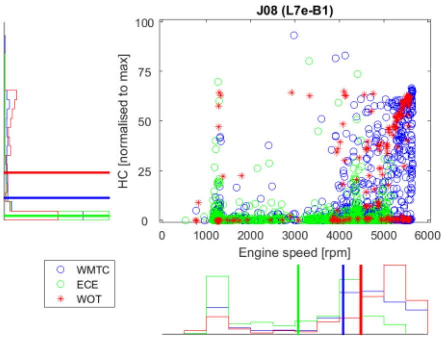
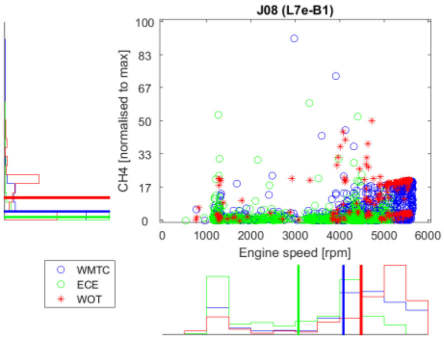
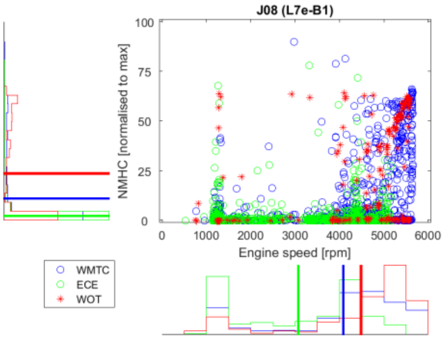


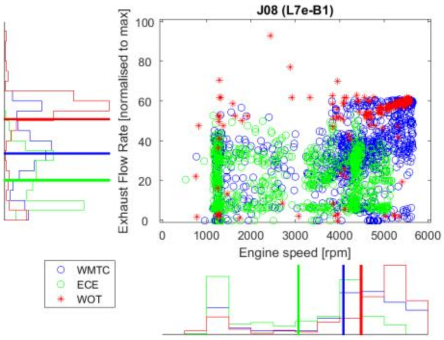
Figure 347. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J22 (L6e-BU)

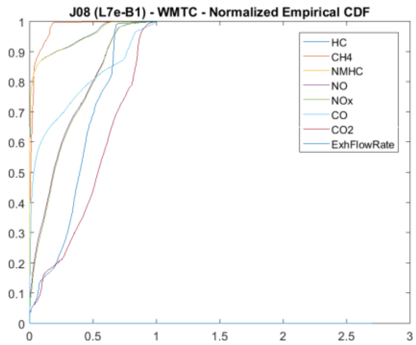


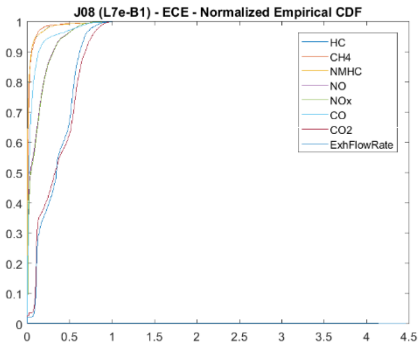

J08 (L7e-B1)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

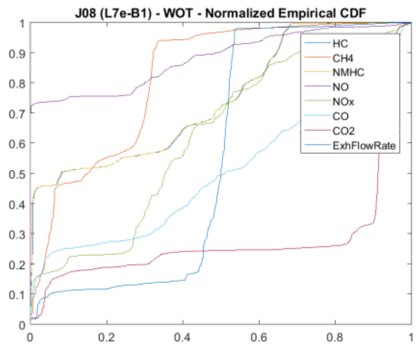

J08 (L7e-B1)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J08 (L7e-B1)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J08 (L7e-B1)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J08 (L7e-B1) - WMTC - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


J08 (L7e-B1) - ECE - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


J08 (L7e-B1) - WOT - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate

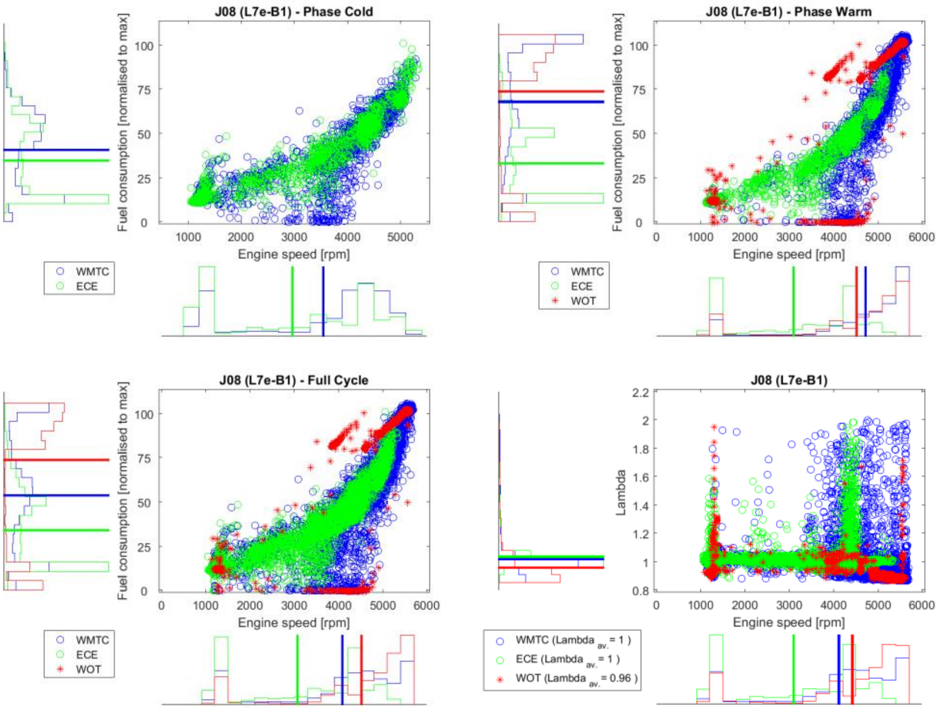
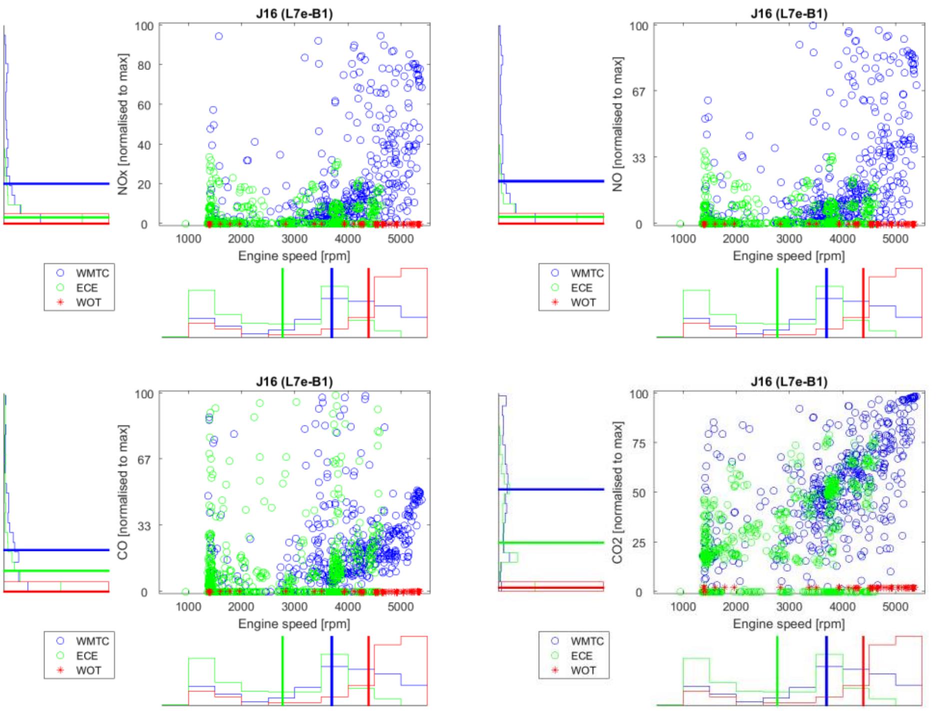
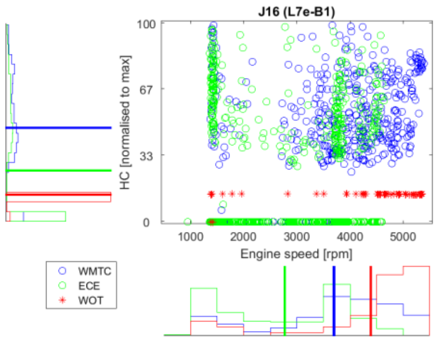
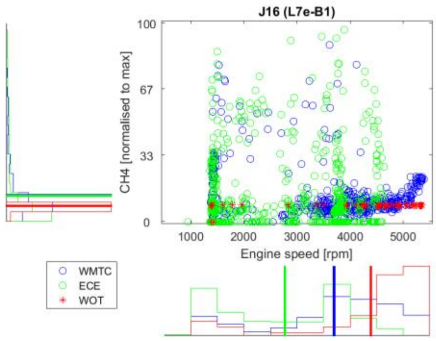
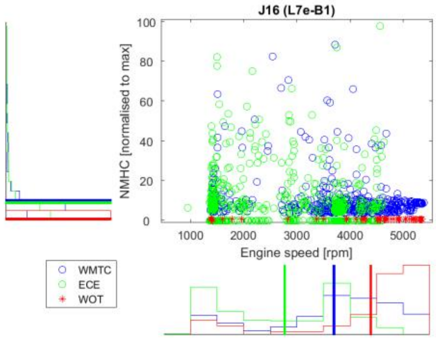


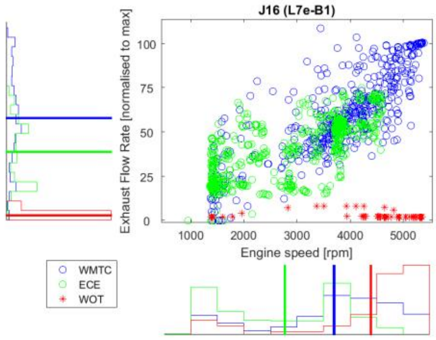
Figure 348. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J08 (L7e-B1)

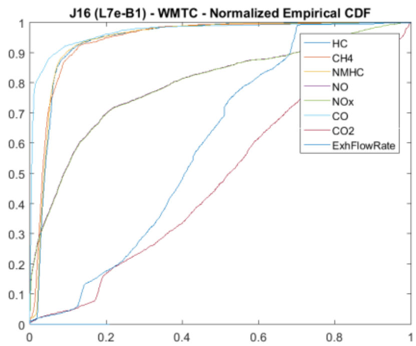


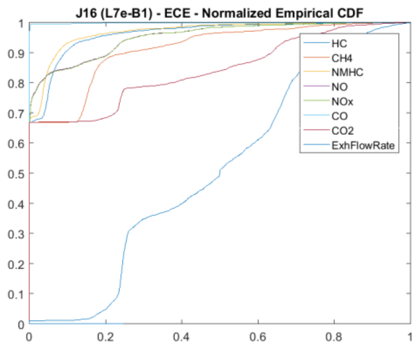

J16 (L7e-B1)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

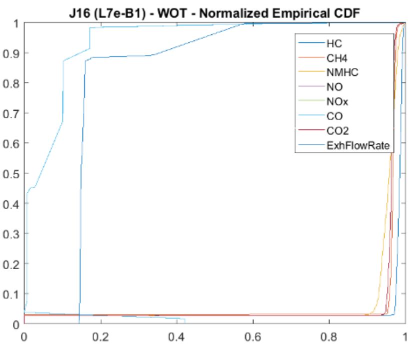

J16 (L7e-B1)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J16 (L7e-B1)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J16 (L7e-B1)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J16 (L7e-B1) - WMTC - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


J16 (L7e-B1) - ECE - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


J16 (L7e-B1) - WOT - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate

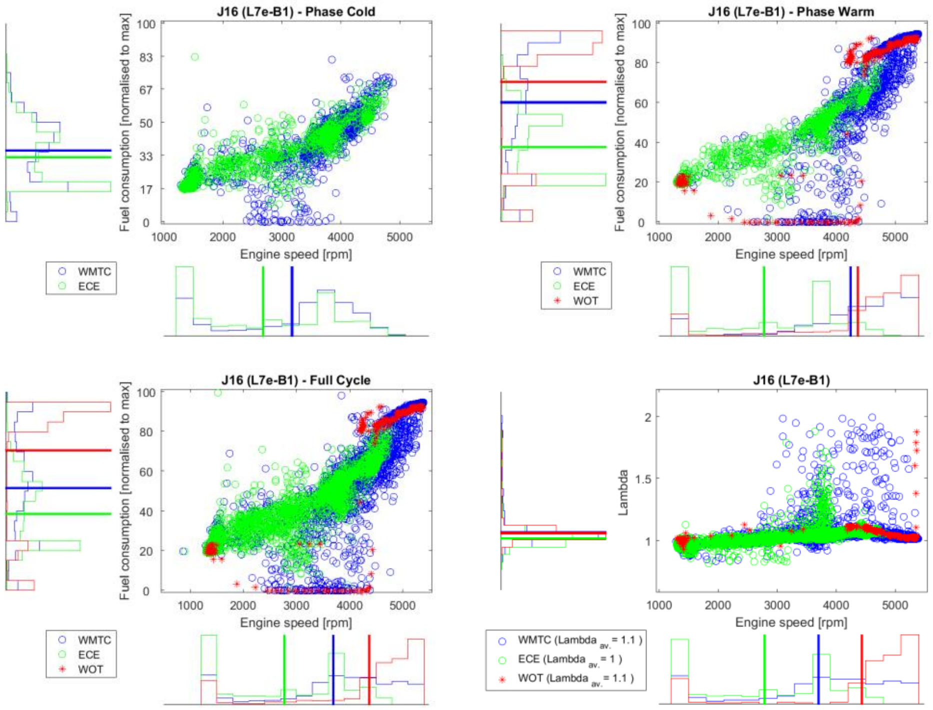
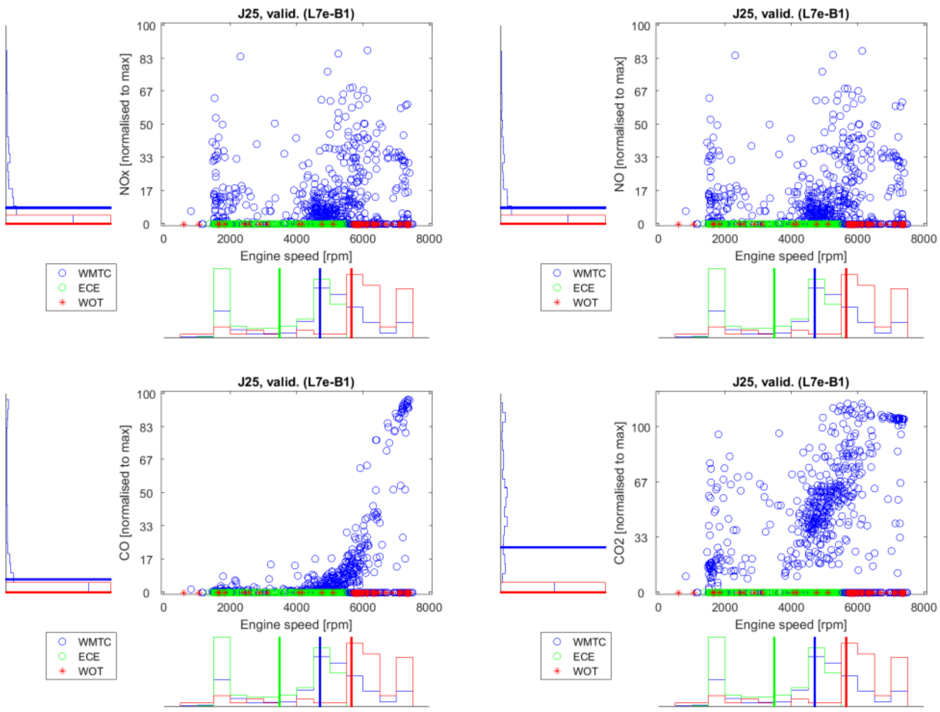
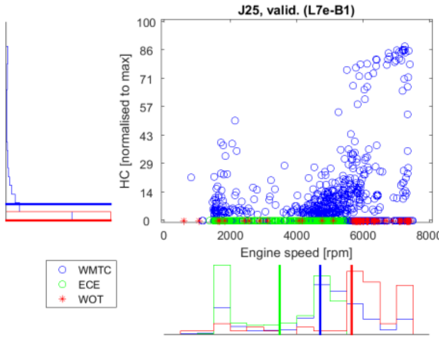
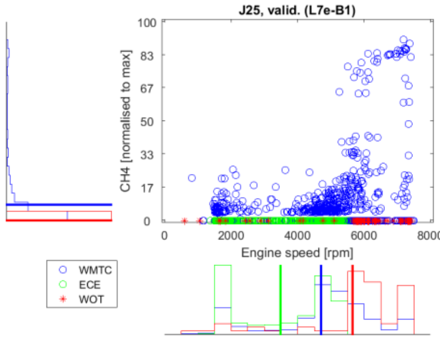
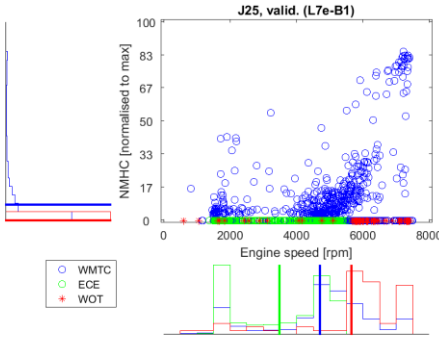


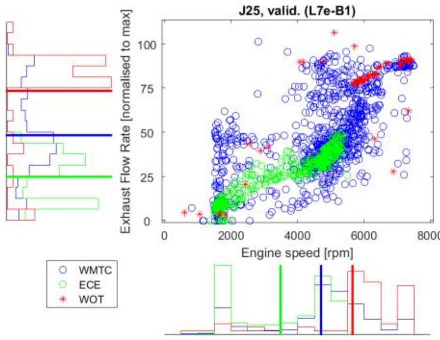
Figure 349. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J16 (L7e-B1)

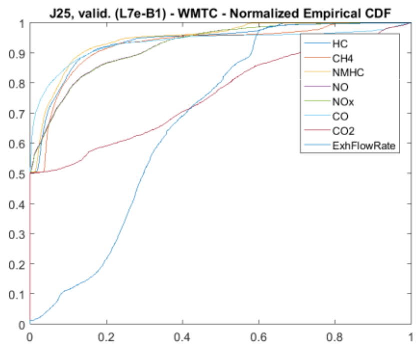


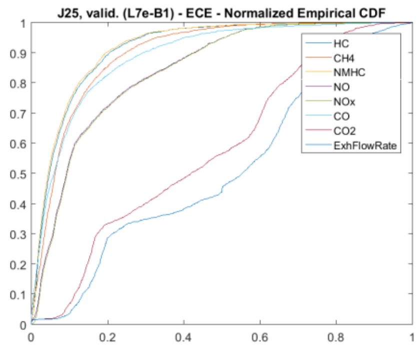

J25, valid. (L7e-B1)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

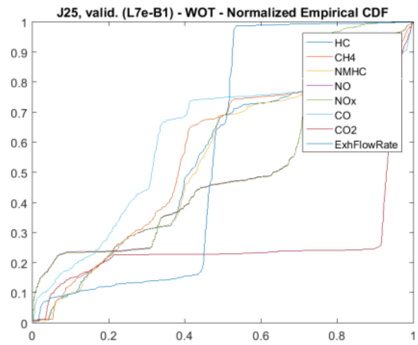

J25, valid. (L7e-B1)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J25, valid. (L7e-B1)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J25, valid. (L7e-B1)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J25, valid. (L7e-B1) - WMTC - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


J25, valid. (L7e-B1) - ECE - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


J25, valid. (L7e-B1) - WOT - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate

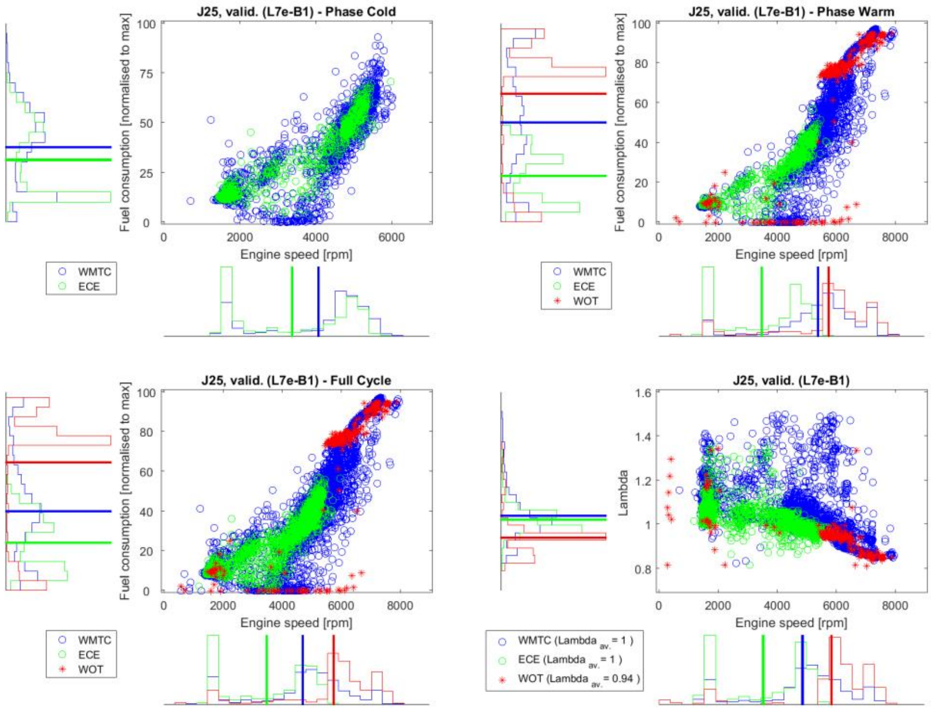
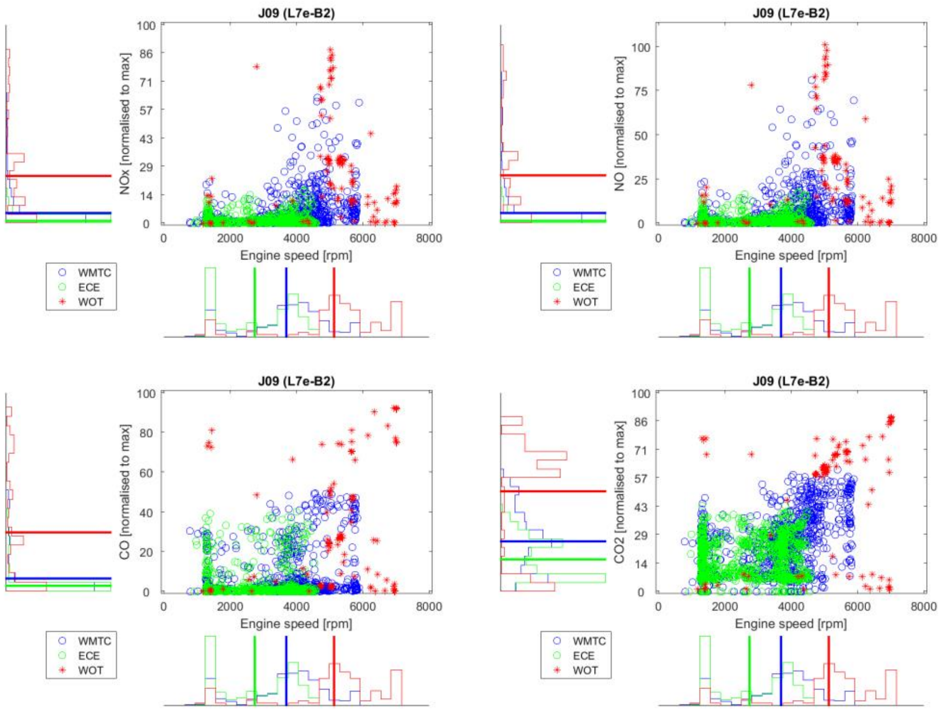
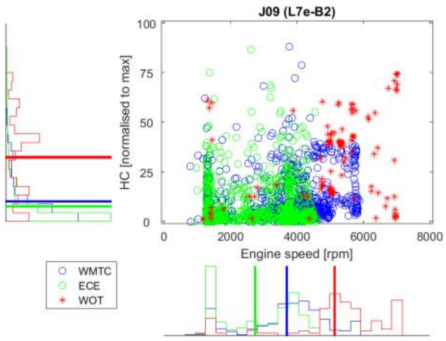
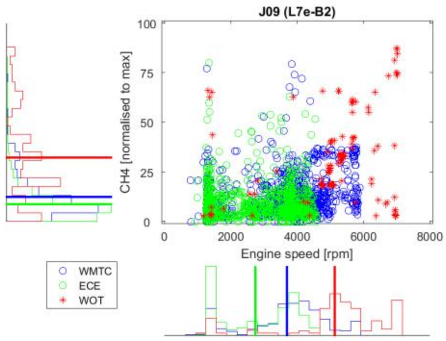
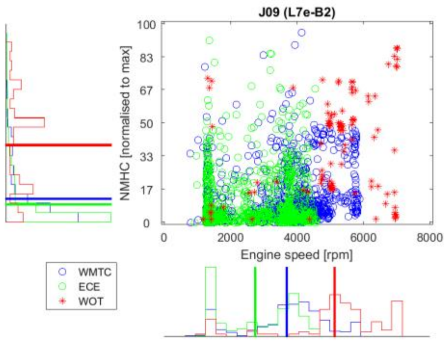


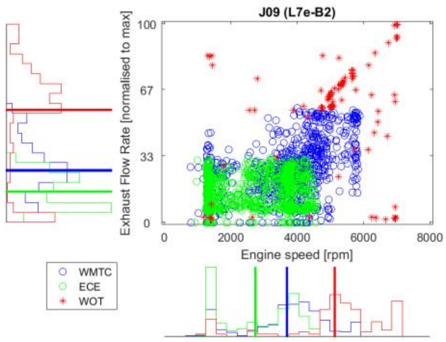
Figure 350. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J25, valid. (L7e-B1)

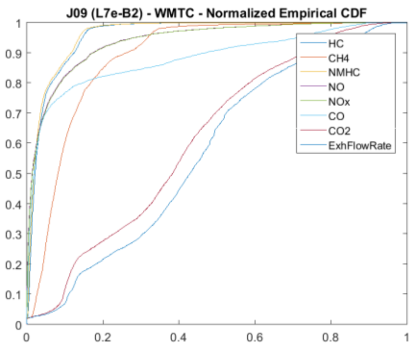


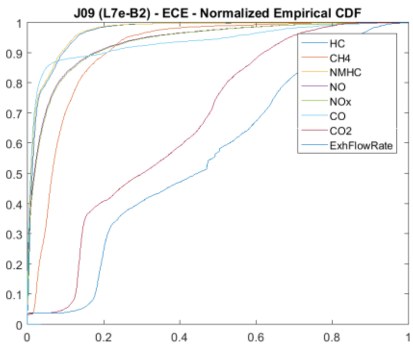

J09 (L7e-B2)
HC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT

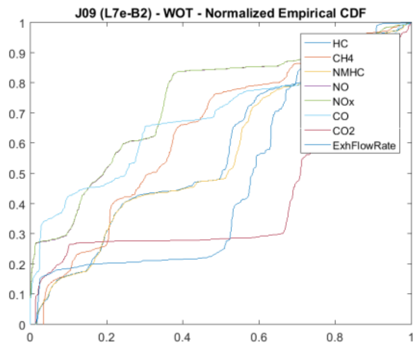

J09 (L7e-B2)
CH4 [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J09 (L7e-B2)
NMHC [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J09 (L7e-B2)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
WMTC
ECE
WOT


J09 (L7e-B2) - WMTC - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


J09 (L7e-B2) - ECE - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate


J09 (L7e-B2) - WOT - Normalized Empirical CDF
HC
CH4
NMHC
NO
NOx
CO
CO2
ExhFlowRate

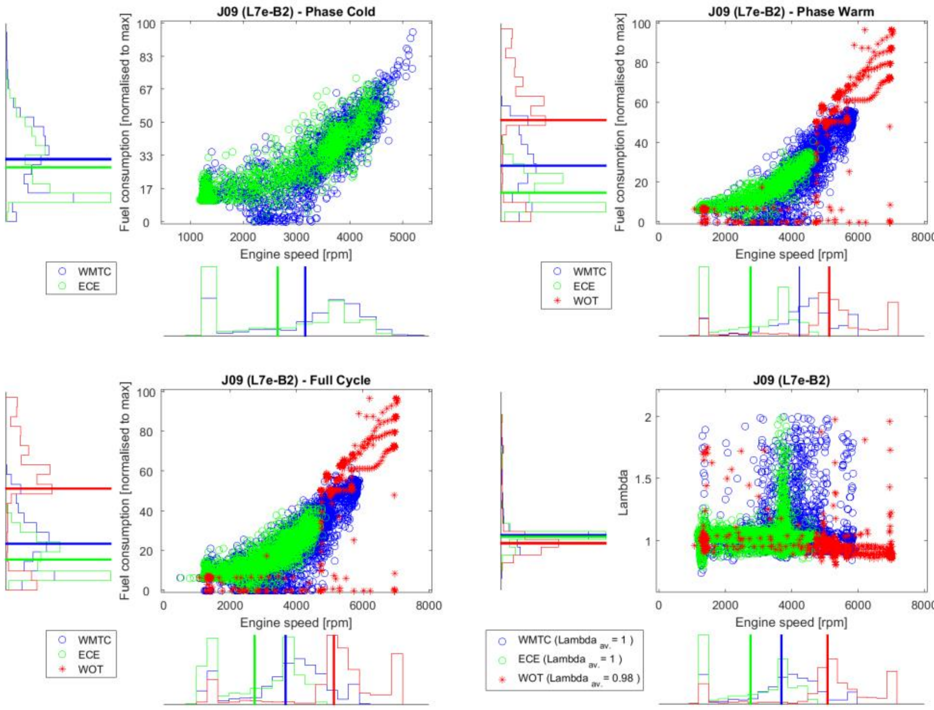


Figure 351, Pollutant emissions, fuel consumption and lambda sensor – Vehicle J09 (L7e-B2)

E Cost analysis for the Cost-Benefit model

Table 104. Costs for the CBA Type I emission limits

Vehicle category			Mopeds	Motorcycles	ATVs	Mini-cars (scenario with conventional diesel vehicles)	Mini-cars (scenario with advanced vehicles)
Introduction date			Euro 5 in 2020	Euro 5 in 2020	Euro 5 in 2020	Euro 5 in 2020	Euro 5 in 2024
Imple-mentation costs		basic investment [€/manuf.]	2,000,000	1,000,000	375,000	3,000,000	25,000,000
	R&D	development [€/engine family]	2,000,000	500,000	187,500	3,000,000	3,000,000
		calibration [€/model]	200,000	100,000	130,000	300,000	100,000
		residual calibration cost	100,000	40,000	65,000	210,000	0.00
		H/W [€/veh.]	100.00	44.00	57.20	800.00	-620.00
		residual H/W cost	70.00	22.00	40.04	680.00	-713.00
	T.A.	new facilities build [#]	0.00	0.00	0.00	0.00	0.00
		cost/facility [€/facility]	0.00	0.00	0.00	0.00	0.00
		cost/new model [€]	0.00	0.00	0.00	2,000	0.00
repair	labour	repair freq. [#/lifetime]	0.00	0.00	0.00	0.20	0.00
		repair freq. [#/year/lifetime]	0.00	0.00	0.00	0.03	0.00
		labour cost [€/h]	0.00	0.00	0.00	28.00	0.00
		hours of repair [h]	0.00	0.00	0.00	3.00	0.00
	parts	parts [€/veh.]	0.00	0.00	0.00	300.00	0.00
other costs		maintenance [% veh. Value cost / lifetime]	0.30%	0.1%	0.2%	1.00%	1.00%
		fuel penalty [% of FC]	0.00%	0.0%	0.0%	0.00%	0.00%
		fuel consumption [g/km]	15.03	27.99	37.61	23.87	23.87
		cost/lt of fuel	1.50	1.50	1.50	1.50	1.50
		warranty [% veh value cost/lifetime]	0.10%	0.05%	0.10%	0.10%	0.10%

Table 105. Costs for the CBA Type I separate NMHC limit

Vehicle category			Mopeds	Motorcycles	Mini-cars	ATVs
Scenario			Fixed ratio for CH_4	Fixed ratio for CH_4	Fixed ratio for CH_4	Fixed ratio for CH_4
Imple-mentation costs		basic investment [€/manuf.]	-120,000	-230,000	-230,000	-120,000
	R&D	development [€/engine family]	0.00	0.00	0.00	0.00
		calibration [€/model]	0.00	0.00	0.00	0.00
		residual calibration cost	0.00	0.00	0.00	0.00
		H/W [€/veh.]	0.00	0.00	0.00	0.00
		residual H/W cost	0.00	0.00	0.00	0.00
	T.A.	new facilities build [#]	0.00	3.00	0.00	0.00
		cost/facility [€/facility]	0.00	-70,000	0.00	0.00
		cost/new model [€]	0.00	0.00	0.00	0.00
repair	labour	repair freq. [#/lifetime]	0.00	0.00	0.00	0.00
		repair freq. [#/year/lifetime]	0.00	0.00	0.00	0.00
		labour cost [€/h]	0.00	0.00	0.00	0.00
		hours of repair [h]	0.00	0.00	0.00	0.00
	parts	parts [€/veh.]	0.00	0.00	0.00	0.00
other costs		maintenance [% veh. Value cost / lifetime]	0.00	0.00	0.00	0.00
		fuel penalty [% of FC]	0.00%	0.00%	0.00%	0.00%
		fuel consumption [g/km]	0.00	0.00	0.00	0.00
		cost/lt of fuel	0.00	0.00	0.00	0.00
		warranty [% veh value cost/lifetime]	0.00%	0.00%	0.00%	0.00%

Table 106. Costs for the CBA Type IV evaporative emissions

Vehicle category			Mopeds		Motorcycles			Mini-cars		ATVs	
Scenario			Permeation test	SHED test	Permeation test	SHED test	Lower Euro 5 limit	Permeation test	SHED test	Permeation test	Scenario: SHED test
Imple-mentation costs	R&D	basic investment [€/manuf.]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		development [€/engine family]	0.00	0.00	0.00	8.00	50,000	0.00	4,000	0.00	200,000
		calibration [€/model]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		residual calibration cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		H/W [€/veh.]	20.00	0.00	0.05	0.00	6.00	0.50	1.20	25.00	60.00
		residual H/W cost	6.00	0.00	0.04	0.00	1.80	0.40	0.96	7.50	18.00
	T.A.	new facilities build [#]	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
		cost/facility [€/facility]	0.00	600,000	0.00	0.00	0.00	0.00	0.00	0.00	600,000
		cost/new model [€]	3,000	3,000	6.00	0.12	0.00	60.00	60.00	3,000	3,000
repair	labour	repair freq. [#/lifetime]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		repair freq. [#/year/lifetime]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		labour cost [€/h]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		hours of repair [h]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	parts	parts [€/veh.]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
other costs		maintenance [% veh. Value cost / lifetime]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		fuel penalty [% of FC]	-1.00%	0.00%	0.00%	0.00%	-0.02%	-0.02%	-0.01%	-6.00%	-2.50%
		fuel consumption [g/km]	15.03	15.03	27.99	27.99	27.99	23.87	23.87	37.61	37.61
		cost/lt of fuel	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
		warranty [% veh value cost/lifetime]	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 107. Costs for the CBA Type V durability scenarios

Vehicle category			Mopeds		Motorcycles		Mini-cars		ATVs	
Scenario			Stringent physical degradation	Physical degradation	Stringent physical degradation	Physical degradation	Stringent physical degradation	Physical degradation	Stringent physical degradation	Physical degradation
Imple-mentation costs		basic investment [€/manuf.]	1,800,000	1,800,000	2,625,000	2,625,000	0.00	0.00	0.00	0.00
	R&D	development [€/engine family]	200,000	150,000	250,000	250,000	500,000	500,000	120,000	120,000
		calibration [€/model]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		residual calibration cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		H/W [€/veh.]	12.00	8.00	18.00	12.00	0.00	0.00	15.00	10.00
		residual H/W cost	9.60	6.40	14.40	9.60	0.00	0.00	12.00	8.00
	T.A.	new facilities build [#]	5.00	5.00	5.00	5.00	0.00	0.00	0.00	0.00
		cost/facility [€/facility]	300,000	300,000	437,500	437,500	0.00	0.00	0.00	0.00
		cost/new model [€]	5,625	5,000	18,286	13,714	13,333	13,333	5,625	7,500
repair	labour	repair freq. [#/lifetime]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		repair freq. [#/year/lifetime]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		labour cost [€/h]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		hours of repair [h]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	parts	parts [€/veh.]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
other costs		maintenance [% veh. Value cost / lifetime]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		fuel penalty [% of FC]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		fuel consumption [g/km]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		cost/lt of fuel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		warranty [% veh value cost/lifetime]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 108. Implementation costs for the CBA Type VIII OBD scenarios

Vehicle category			Motorcycles	Motorcycles	Motorcycles	Motorcycles
Scenario			2020-2023: OBD II, OTL I, CAT: N	2024-on: OBD II, OTL II, CAT: Y [incremental costs]	2020-2023: OBD II, OTL II, CAT: N	2024-on: OBD II, OTL II, CAT: Y [incremental costs]
Imple-mentation costs		basic investment [€/manuf.]	0.00	0.00	0.00	0.00
	R&D	development [€/engine family]	100,000	50,000	100,000	50,000
		calibration [€/model]	10,000	10,000	20,000	10,000
		residual calibration cost	7,500	5,000	7,500	5,000
		H/W [€/veh.]	40.00	10.00	40,00	10.00
		residual H/W cost	17.00	8.00	17,00	8.00
	T.A.	new facilities build [#]	0.00	0.00	0.00	0.00
		cost/facility [€/facility]	0.00	0.00	0.00	0.00
		cost/new model [€]	500.00	0.00	500.00	0.00
repair	labour	repair freq. [#/lifetime]	Repair costs are calculated by detailed model			
		repair freq. [#/year/lifetime]				
		labour cost [€/h]				
		hours of repair [h]				
	parts	parts [€/veh.]				
other costs		maintenance [% veh. Value cost / lifetime]	0.00	0.00	0.00	0.00
		fuel penalty [% of FC]	0.00%	0.00%	0.00%	0.00%
		fuel consumption [g/km]	0.00	0.00	0.00	0.00
		cost/lt of fuel	0.00	0.00	0.00	0.00
		warranty [% veh value cost/lifetime]	0.05%	0.05%	0.2%	0.05%

Table 109. Implementation costs for the ISC scenarios

Vehicle category	All vehicle categories					
Scenario	no Euro 5 exceedances in real world, ISC in all models	no Euro 5 exceedances in real world, ISC in high production volume models	some Euro 5 models incompliant with Euro 5, ISC in all models	some Euro 5 models incompliant with Euro 5, ISC in high production volume models	failure of Euro 5 limits, ISC in all models	failure of Euro 5 limits, ISC in high production volume models
cost/new model [€]	12,825.00	3,591.00	12,825.00	3,591.00	12,825.00	3,591.00

F Environmental benefit for all scenarios

Type I – Tailpipe emissions after cold start

Table 110: Environmental benefit (emission savings) due to the introduction of Euro 5 emission limits (Type I) for all L-category vehicles (0.5/0.5 cold/warm weighting factors)

Emission savings (kt) for specific pollutant (2020-2040)	HC	NO_x	PM	CO
Fleet scenario: baseline Euro 5 introduction: 2020	509	141	6.6	776
Fleet scenario: baseline Euro 5 introduction: 2024	355	99	4.7	537
Fleet scenario: high growth Euro 5 introduction: 2020	609	165	7.5	918
Fleet scenario: high growth Euro 5 introduction: 2024	431	117	5.4	643
Fleet scenario: low growth Euro 5 introduction: 2020	433	122	5.9	665
Fleet scenario: low growth Euro 5 introduction: 2024	297	84	4.1	453

Table 111: Environmental benefit (emission savings) due to the introduction of Euro 5 emission limits (Type I) for all L-category vehicles (0.3/0.7 cold/warm weighting factors)

Emission savings (kt) for specific pollutant (2020-2040)	HC	NO_x	PM	CO
Fleet scenario: baseline Euro 5 introduction: 2020	460	133	6	622
Fleet scenario: baseline	320	93	4.2	428

Euro 5 introduction: 2024				
Fleet scenario: high growth Euro 5 introduction: 2020	550	156	6.7	734
Fleet scenario: high growth Euro 5 introduction: 2024	389	111	4.8	512
Fleet scenario: low growth Euro 5 introduction: 2020	390	115	5.3	533
Fleet scenario: low growth Euro 5 introduction: 2024	267	80	3.7	362

Table 112: Environmental benefit (emission savings) due to the replacement of diesel mini-cars with advanced (gasoline series hybrid) Euro 5 and pure electric vehicles in 2024

Emission savings (kt) for specific pollutant (2020-2040)	HC	NO_x	PM	CO
Fleet scenario: high growth Euro 5 introduction: 2024	2.7	22	2.3	26.4

Table 113: Environmental benefit (emission savings) due to the concept of having a fixed ratio for NMHC/THC (compared to separate Euro 5 limits) for all L-category vehicles

Emission savings (kt) (2020-2040)	HC
All fleet scenarios and Euro 5 introduction dates	0

Type IV – Evaporative emissions

Table 114: Environmental benefit (emission savings) due to the introduction of Euro 5 permeation test

Emission savings (kt) (2020-2040)	HC

Fleet scenario: baseline Permeation test introduction: 2020	39.0
Fleet scenario: baseline Permeation test introduction: 2024	26.7
Fleet scenario: high growth Permeation test introduction: 2020	51.6
Fleet scenario: high growth Permeation test introduction: 2024	36.6
Fleet scenario: low growth Permeation test introduction: 2020	30.4
Fleet scenario: low growth Permeation test introduction: 2024	20.0

Table 115: Environmental benefit (emission savings) due to the introduction of Euro 5 SHED test

Emission savings (kt) (2020-2040)	HC
Fleet scenario: baseline SHED test introduction: 2020	3.6
Fleet scenario: baseline SHED test introduction: 2024	2.4
Fleet scenario: high growth SHED test introduction: 2020	4.2
Fleet scenario: high growth SHED test introduction: 2024	2.8
Fleet scenario: low growth SHED test introduction: 2020	3.0
Fleet scenario: low growth SHED test introduction: 2024	2.0

Table 116: Environmental benefit (emission savings) due to the introduction of lower Euro 5 evaporative emission limits

Emission savings (kt) (2020-2040)	HC
Fleet scenario: baseline Lower Euro 5 evaporative emission limits introduction: 2020	3.9
Fleet scenario: baseline Lower Euro 5 evaporative emission limits introduction: 2024	2.6
Fleet scenario: high growth Lower Euro 5 evaporative emission limits introduction: 2020	4.6
Fleet scenario: high growth Lower Euro 5 evaporative emission limits introduction: 2024	3.1
Fleet scenario: low growth Lower Euro 5 evaporative emission limits introduction: 2020	3.3
Fleet scenario: low growth Lower Euro 5 evaporative emission limits introduction: 2024	2.2

Type V – Durability of pollution-control devices

Table 117: Environmental benefit (emission savings) due to the introduction of Euro 5 mandatory physical degradation for all L-category vehicles (compared to the mathematical method)

Emission savings (kt) for specific pollutant (2020-2040)	HC	NO_x	PM	CO
Fleet scenario: baseline Physical degradation introduction: 2020	50	33	0.68	787
Fleet scenario: baseline Physical degradation introduction: 2024	34	23	0.47	542
Fleet scenario: high growth Physical degradation introduction: 2020	58	38	0.78	910
Fleet scenario: high growth Physical degradation introduction: 2024	40	26	0.54	631
Fleet scenario: low growth Physical degradation introduction: 2020	43	28	0.59	684
Fleet scenario: low growth Physical degradation introduction: 2024	29	19	0.41	467

Table 118: Environmental benefit (emission savings) due to the introduction of Euro 5 stringent physical degradation for all L-category vehicles (compared to the mathematical method)

Emission savings (kt) for specific pollutant (2020-2040)	HC	NO_x	PM	CO
Fleet scenario: baseline Stringent physical degradation introduction: 2020	62	41	0.85	982
Fleet scenario: baseline Stringent physical degradation introduction: 2024	44	29	0.61	696
Fleet scenario: high growth Stringent physical degradation introduction: 2020	72	48	0.98	1,136

Fleet scenario: high growth Stringent physical degradation introduction: 2024	51	34	0.70	810
Fleet scenario: low growth Stringent physical degradation introduction: 2020	54	36	0.74	853
Fleet scenario: low growth Stringent physical degradation introduction: 2024	38	25	0.52	600

Table 119: Environmental benefit (emission savings) due to the introduction of Euro 5 physical degradation with bench ageing for all L-category vehicles (compared to the mathematical method)

Emission savings (kt) for specific pollutant (2020-2040)	HC	NO_x	PM	CO
	Values equal to physical degradation (Table 117), depending on fleet scenario and introduction year.			

Type VIII – OBD environmental tests

Table 120: Environmental benefit (emission savings) for the examined OBD scenarios

Emission savings (kt) (2020-2040)	HC	NO_x	PM	CO
Scenario 1: OBD stage II introduction in 2020 in the EU as laid down in Regulation (EU) No 168/2013	83	206	1.1	458
Scenario 2: OBD stage I introduction in the EU in 2020 without catalyst monitoring and OBD stage II in 2024 for catalyst monitoring also	61	152	0.8	341
Scenario 3: OBD stage II introduction in the EU in 2020 without catalyst monitoring and in 2024 for catalyst monitoring also	61	153	0.8	348

In-Service Conformity

Table 121: Environmental benefit (emission savings) due to ISC for scenario “some of the Euro 5 models are incompliant with the Euro 5 limits”

Emission savings (kt) for specific pollutant (2020-2040)	HC	NO_x	PM	CO
Fleet scenario: baseline Euro 5 introduction: 2020	28	0	0.39	890

Fleet scenario: baseline Euro 5 introduction: 2024	19	0	0.27	616
Fleet scenario: high growth Euro 5 introduction: 2020	32	0	0.45	1,029
Fleet scenario: high growth Euro 5 introduction: 2024	23	0	0.31	719
Fleet scenario: low growth Euro 5 introduction: 2020	24	0	0.34	772
Fleet scenario: low growth Euro 5 introduction: 2024	17	0	0.23	531

Table 122: Environmental benefit (emission savings) due to ISC for scenario "total failure of the Euro 5 limits"

Emission savings (kt) for specific pollutant (2020-2040)	HC	NO_x	PM	CO
Fleet scenario: baseline Euro 5 introduction: 2020	50	33	0.68	787
Fleet scenario: baseline Euro 5 introduction: 2024	34	23	0.47	542
Fleet scenario: high growth Euro 5 introduction: 2020	58	38	0.78	910
Fleet scenario: high growth Euro 5 introduction: 2024	40	26	0.54	631
Fleet scenario: low growth Euro 5 introduction: 2020	43	28	0.59	684

Fleet scenario: low growth Euro 5 introduction: 2024	29	19	0.41	467

G Test results: Impact of EtOH on Type I test emission levels

This Appendix includes the detailed test results of the assessment of the impact of ethanol blended fuels on the Type I test. The investigated parameters-metrics used for the assessment of the ethanol impact are the same as the ones used for the assessment of the applicability of the “revised” WMTC. These are the following, presented in the following paragraphs:

- Drivability of the “revised” WMTC
- Engine operation area of the different driving cycles
- Engine speed and engine load related parameters
- Pollutant emissions, fuel consumption and lambda sensor results

The tested vehicles are the following:

- L1e-B, high speed: 2 vehicles
- L3e-A2: 3 vehicles
- L3e-A3: 1 vehicle

The results of the reference fuel (E5) tests for the mopeds are also presented above in the assessment of the WMTC applicability, though, they are also presented in this Appendix in order to assure direct comparison to the results of the tests performed with different ethanol blended fuels (E0 and E10).

G.1 Impact of EtOH on the drivability of the “revised” WMTC

The examined vehicles on the ethanol impact on the drivability of the “revised” WMTC are the mopeds, i.e. the 2 L1e-B, high speed mopeds. The examined metrics for the assessment of the drivability are the same as the ones presented in Appendix A.

Figures for the vehicle speed and the vehicle acceleration along with figures with zoomed areas in which drivability problems are observed are drawn for each vehicle. Besides, the WMTC distribution of acceleration over speed is also illustrated towards the assessment of driver errors versus machine limits for each test vehicle.

Disclaimer

The figures of this Appendix are requested by the call and are presented without further commenting.

Vehicle J03 (L1e-B, high speed moped)

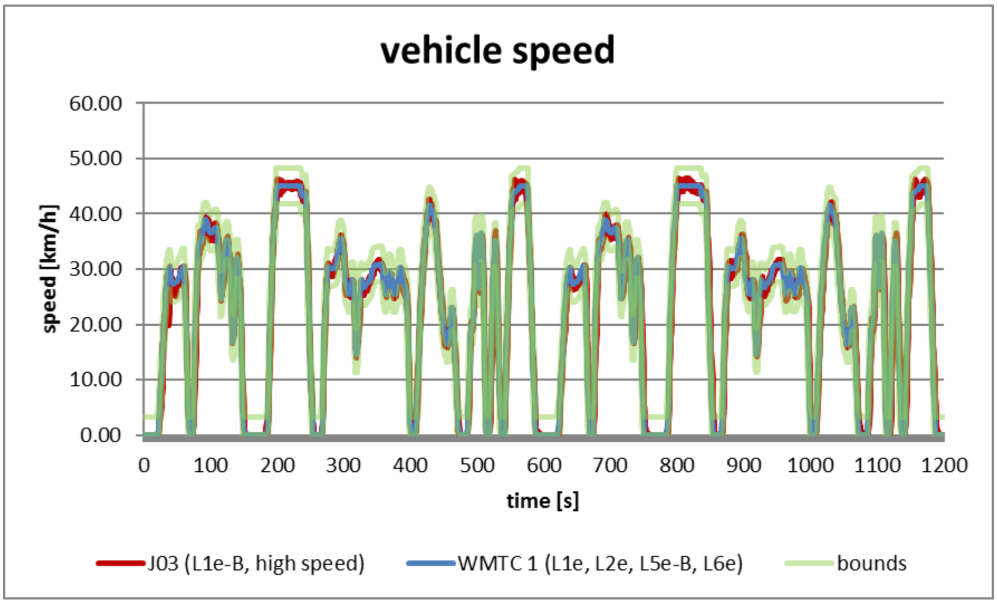


Figure 352. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle speed – E5

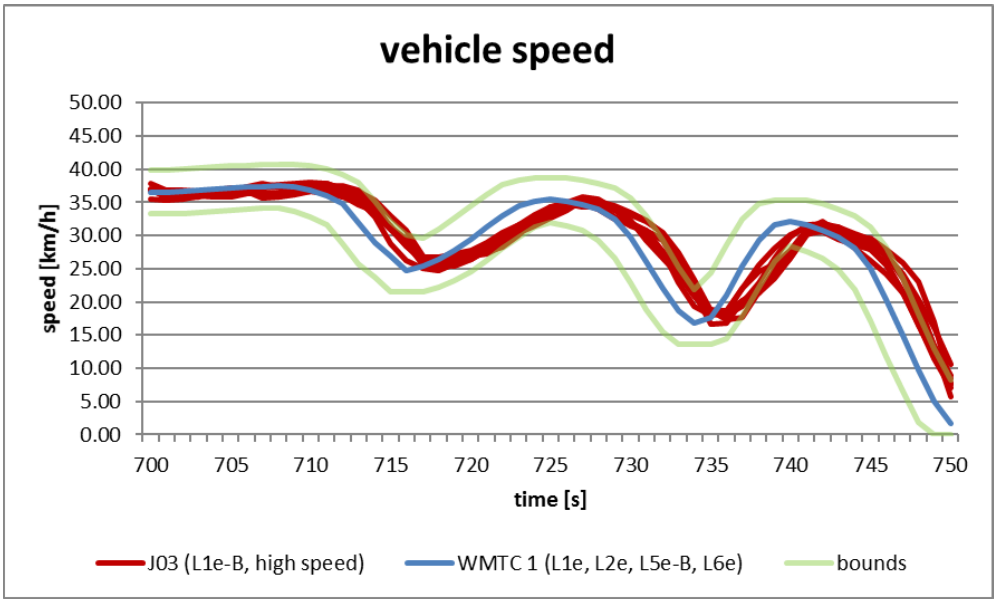


Figure 353. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle speed zoom – E5

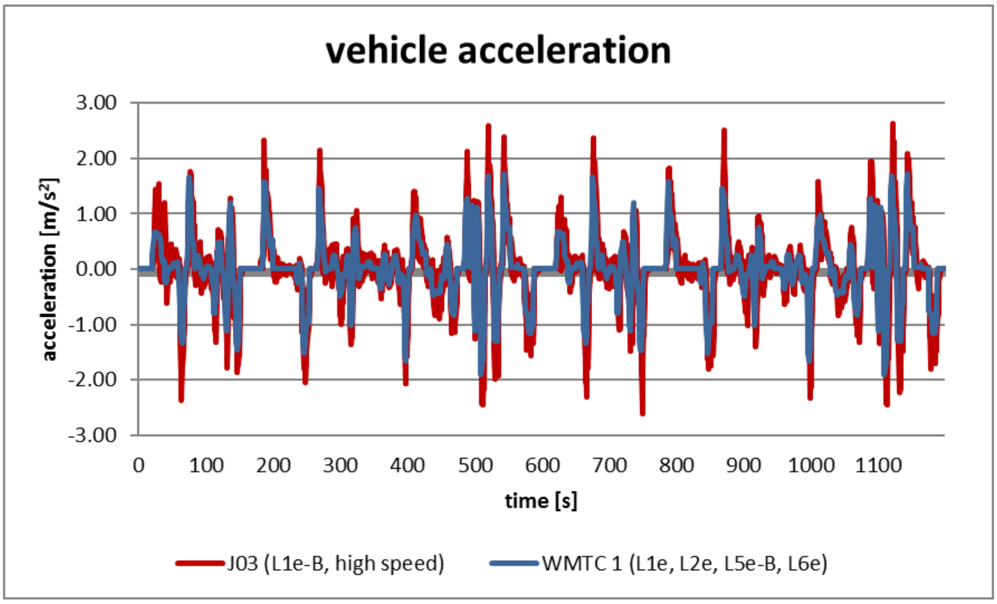


Figure 354. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle acceleration – E5

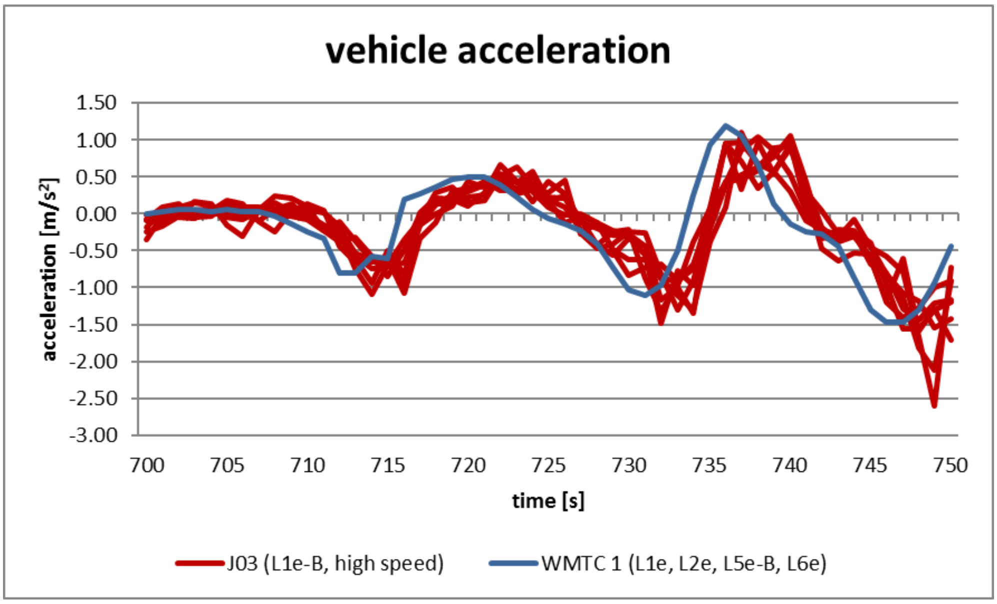


Figure 355. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle acceleration zoom – E5

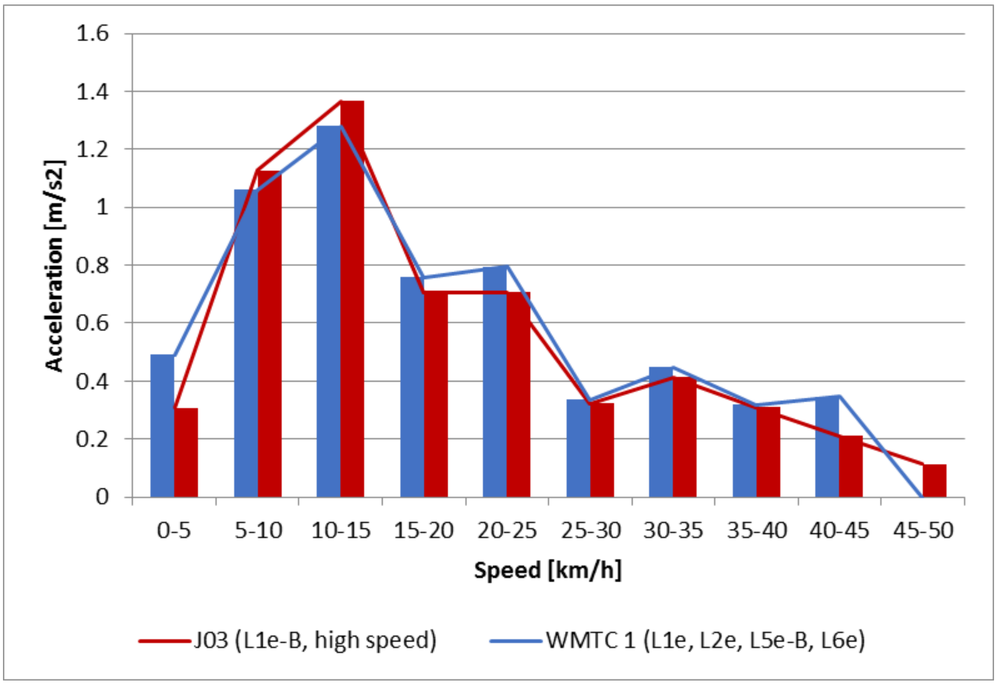


Figure 356. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J03 (L1e-B, high speed moped) – E5

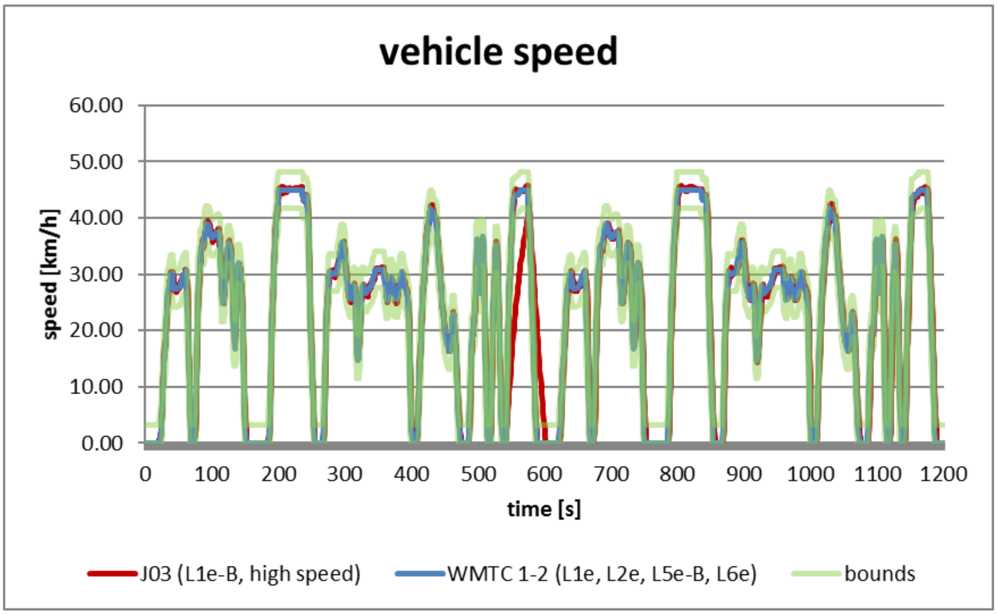


Figure 357. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle speed – E0

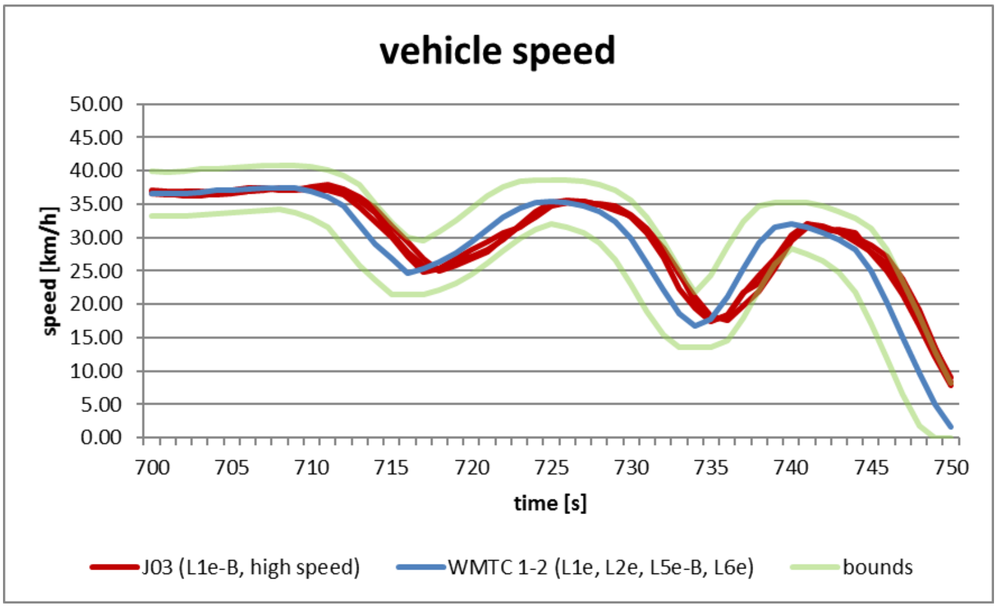


Figure 358. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle speed zoom – E0

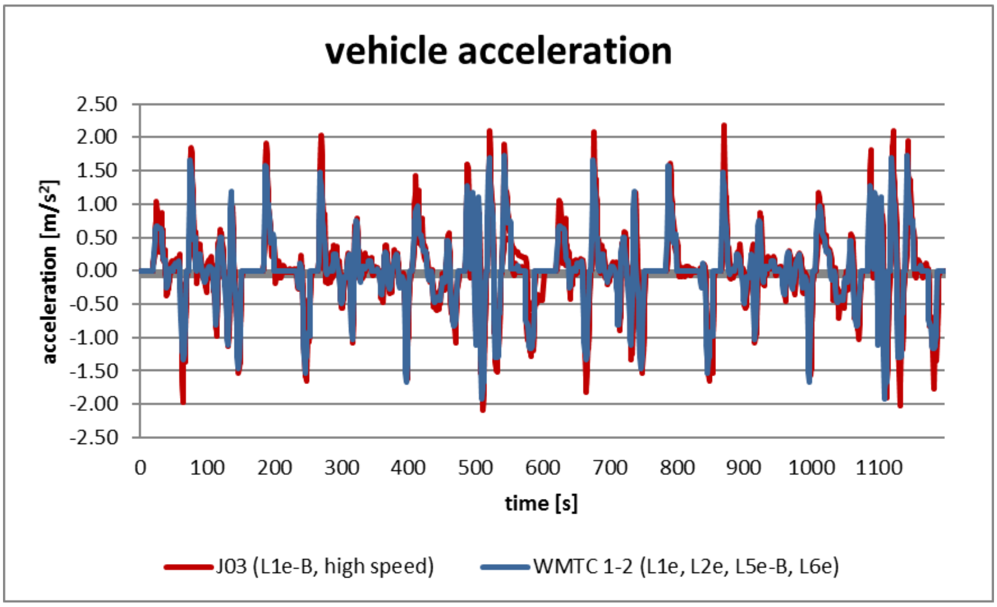


Figure 359. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle acceleration – E0

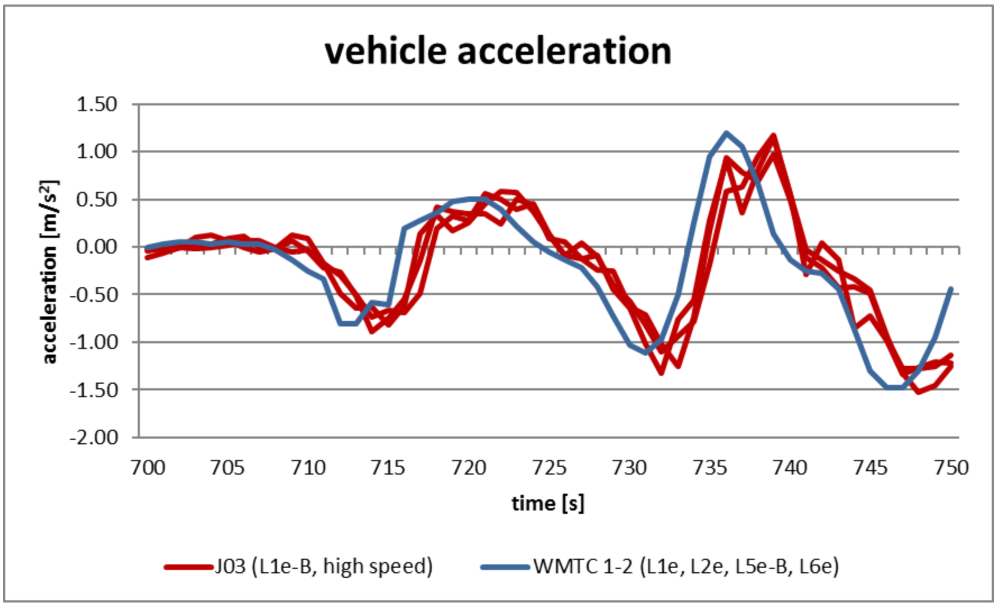


Figure 360. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle acceleration zoom – E0

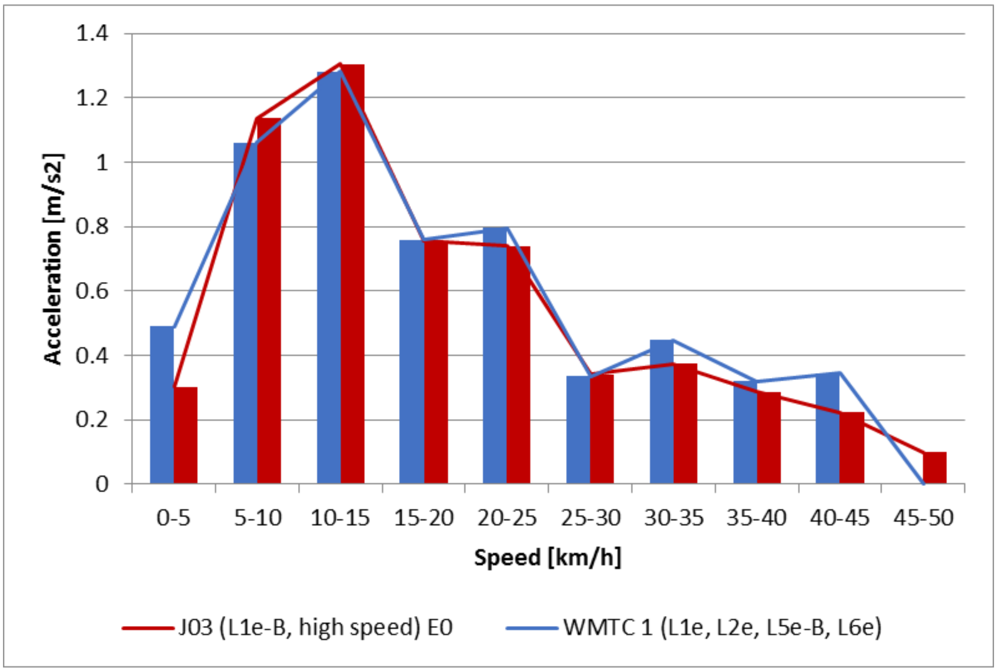


Figure 361. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J03 (L1e-B, high speed moped) – E0

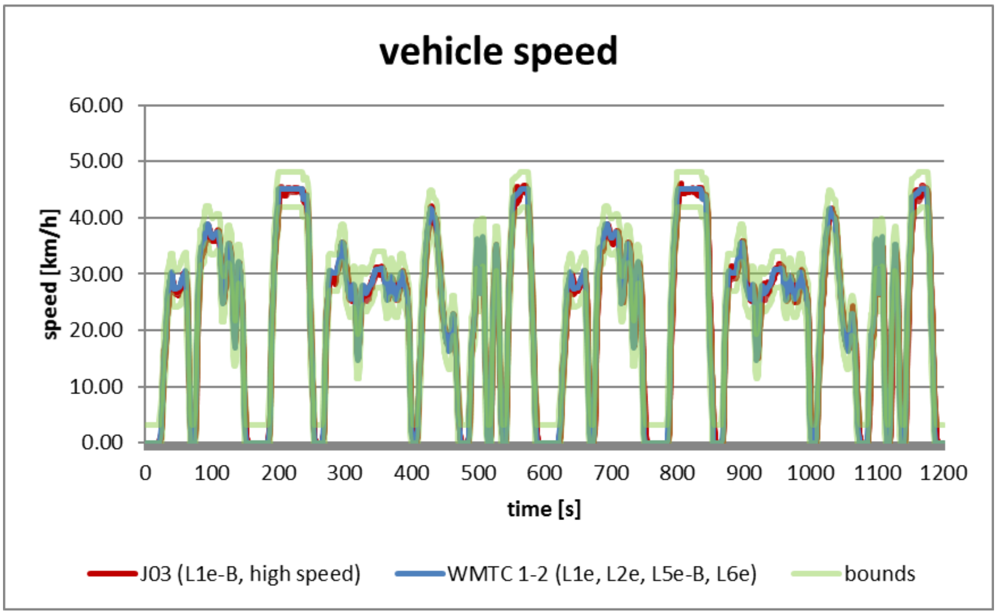


Figure 362. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle speed – E10

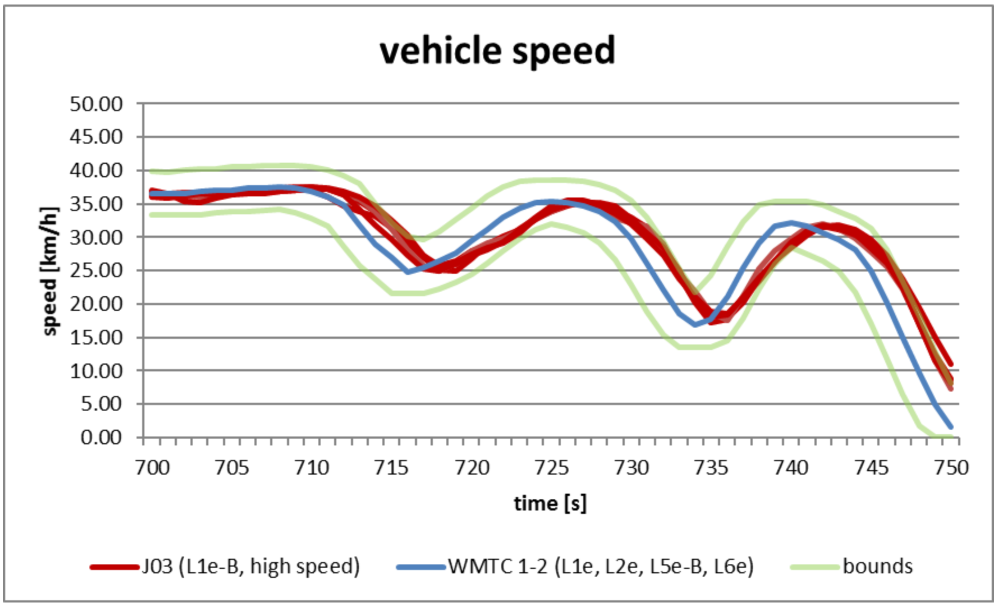


Figure 363. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle speed zoom – E10

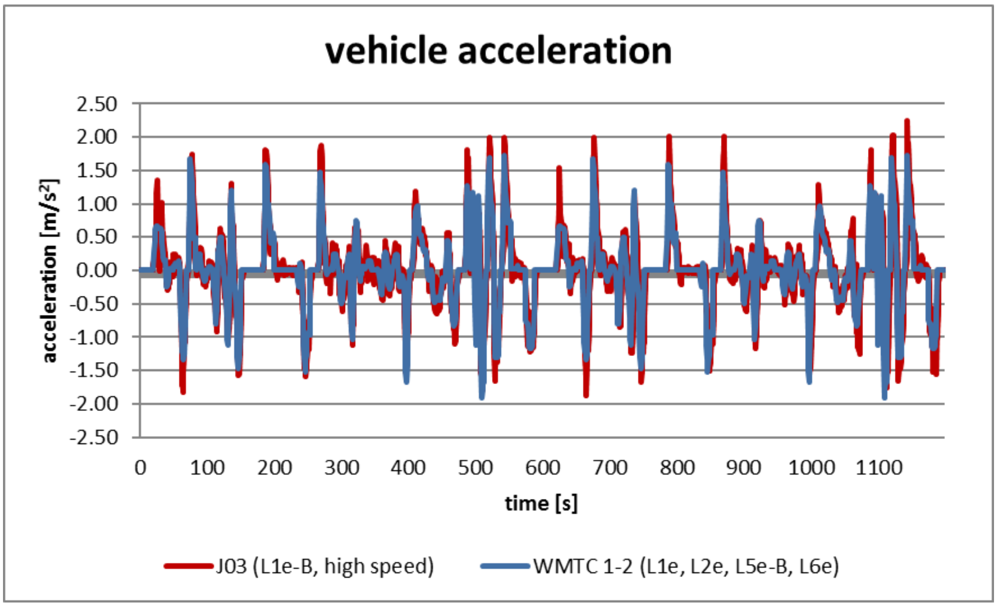


Figure 364. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle acceleration – E10

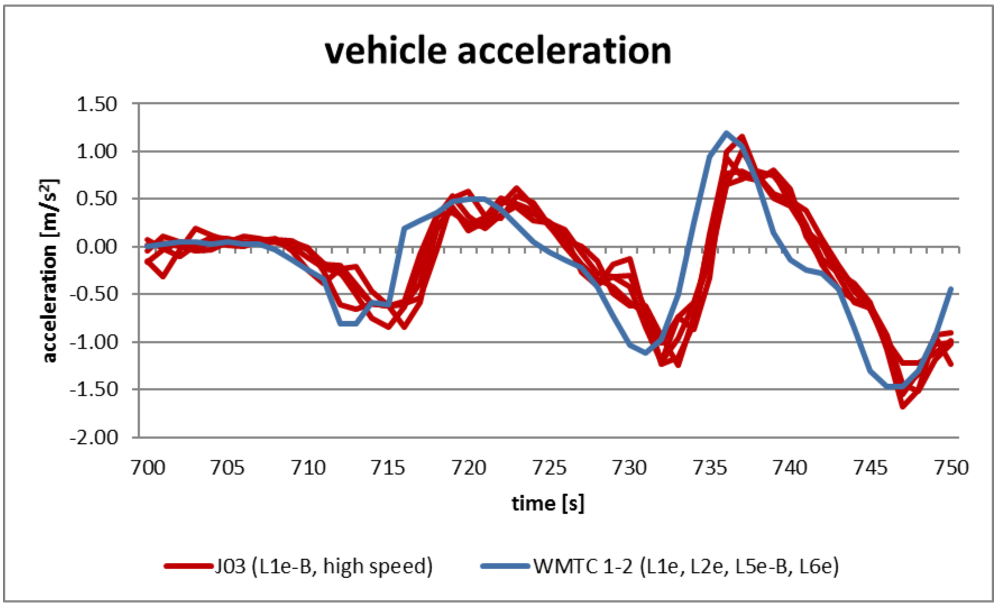


Figure 365. WMTC drivability of J03 (L1e-B, high speed moped) – vehicle acceleration zoom – E10

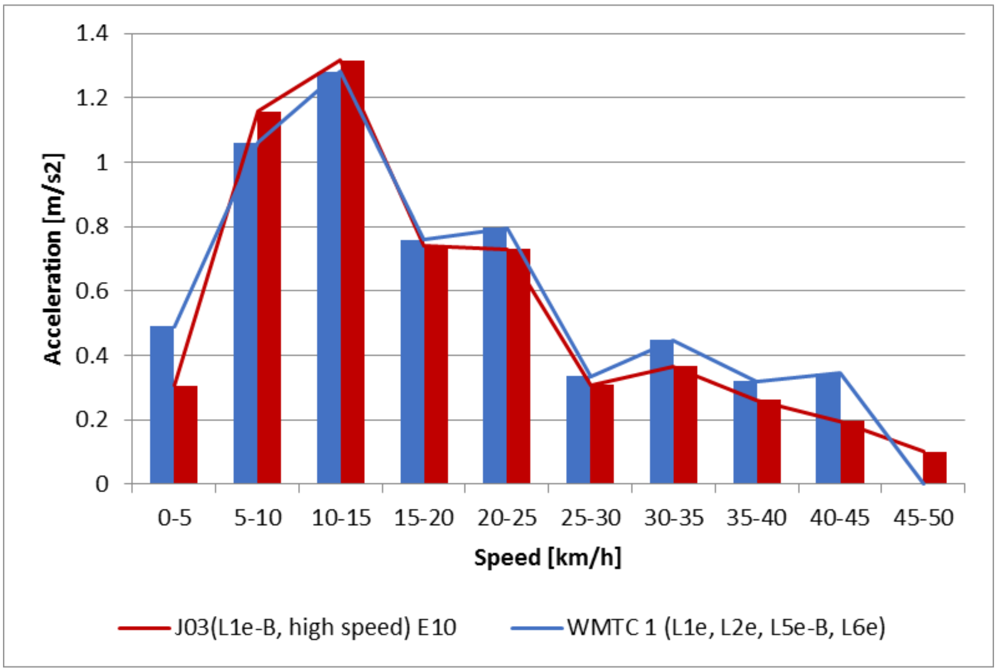


Figure 366. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J03 (L1e-B, high speed moped) – E10

Table 123. Technical criteria for WMTC drivability assessment of J03 (L1e-B, high speed moped)

WMTC		tests average (min-max)			REGULATION	MANUFACTURER
		E5	E0	E10		
Speed Violations	Events	5 (2 – 16)	3 (1 – 4)	3 (2 – 5)	-	-
	Duration (s)	16 (5 – 45)	15 (2 – 33)	10 (4 – 15)	-	-
Maximum Achievable Speed (km/h)		46 (46 – 46)	46 (46 – 46)	46 (45 – 46)	45	45
Mean Positive Acceleration (MPA) (m/s^2)		0.45 (0.45 – 0.46)	0.46 (0.44 – 0.47)	0.44 (0.43 – 0.45)	0.46	-
Driven Distance (m)		7553 (7532–7598)	7619 (7584–7651)	7525 (7497–7552)	7600	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		2.86 (2.79 – 2.96)	2.86 (2.72 – 2.97)	2.74 (2.68 – 2.78)	2.87	-

Vehicle J12 (L1e-B, high speed moped)

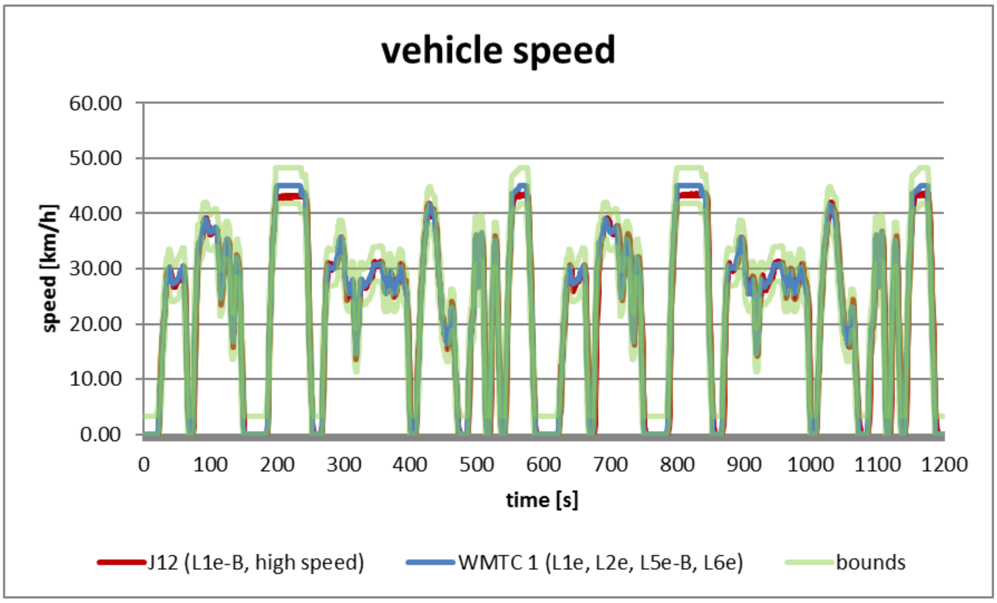


Figure 367. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle speed – E5

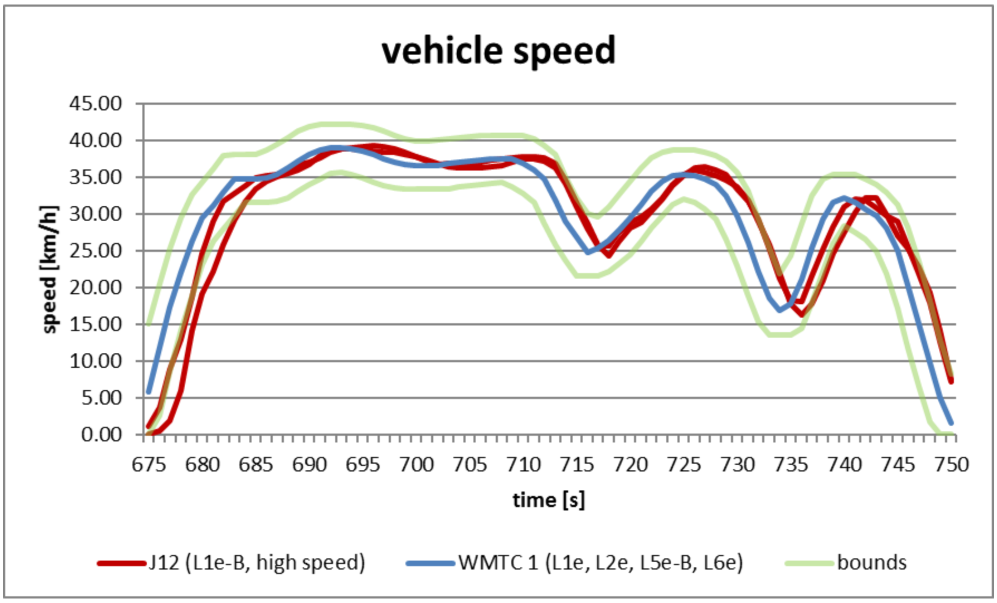


Figure 368. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle speed zoom – E5

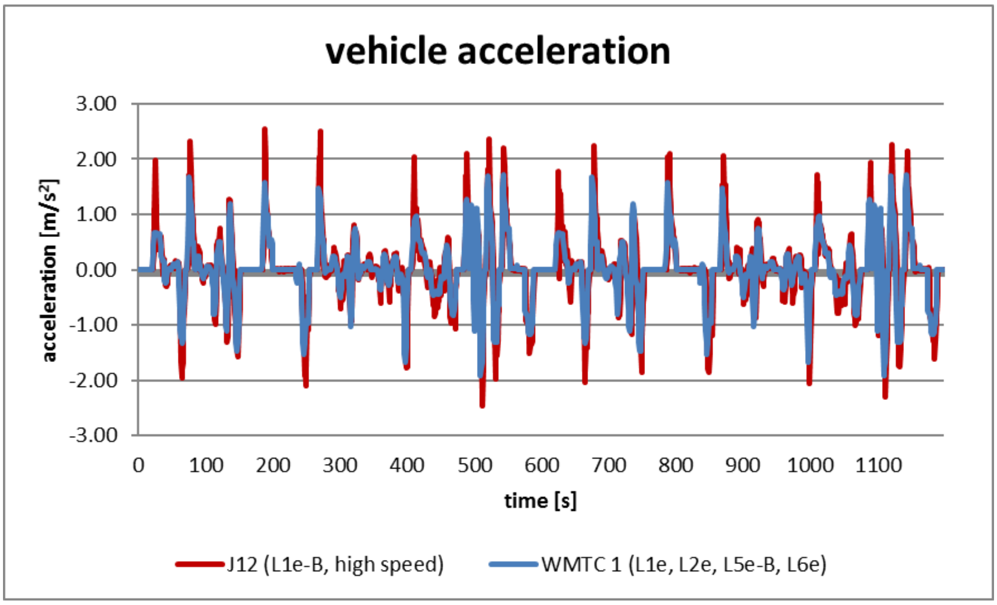


Figure 369. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle acceleration – E5

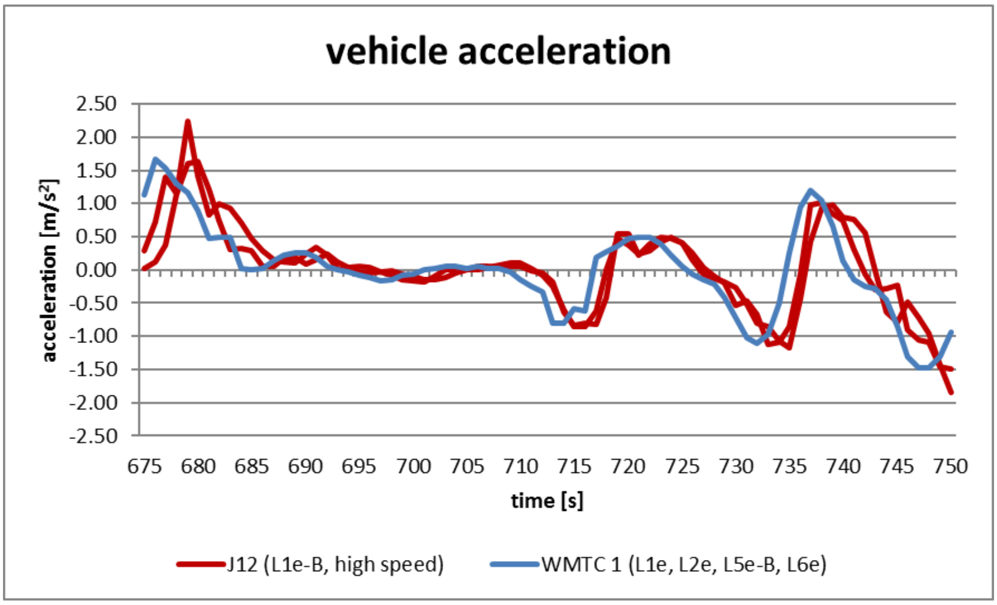


Figure 370. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle acceleration zoom – E5

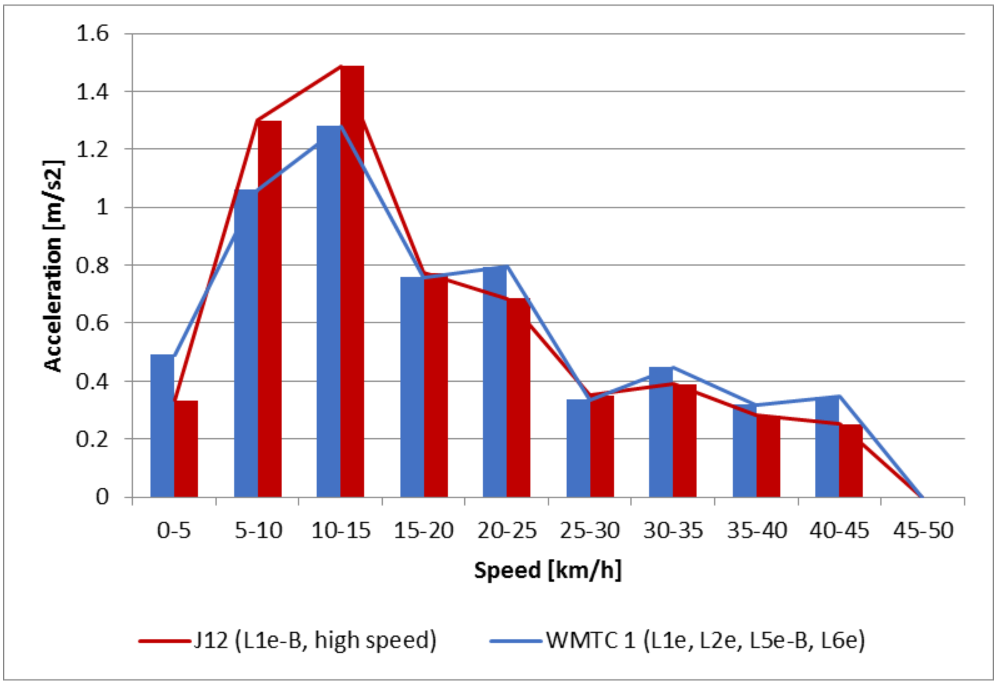


Figure 371. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J12 (L1e-B, high speed moped) – E5

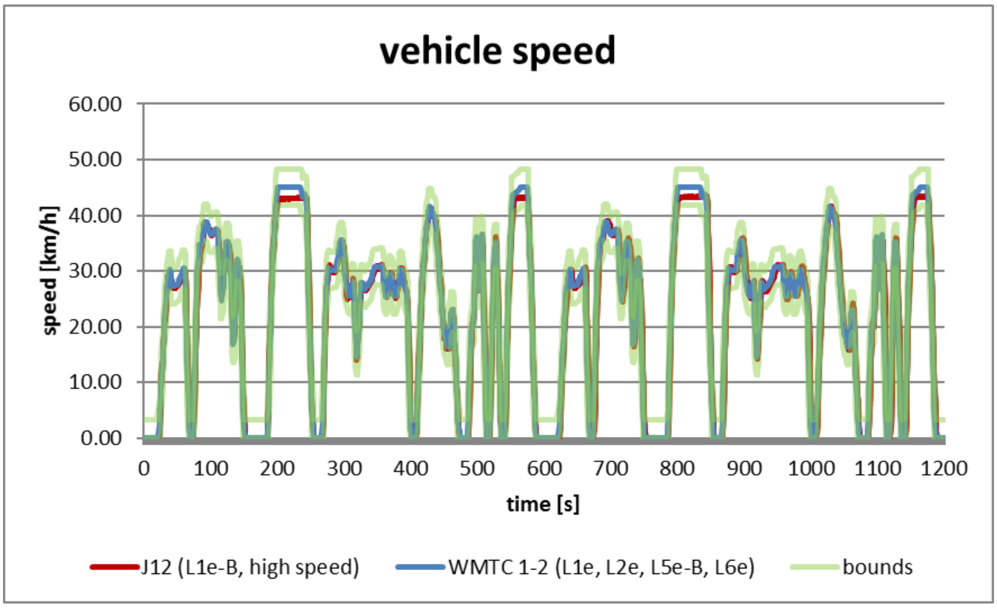


Figure 372. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle speed – E0

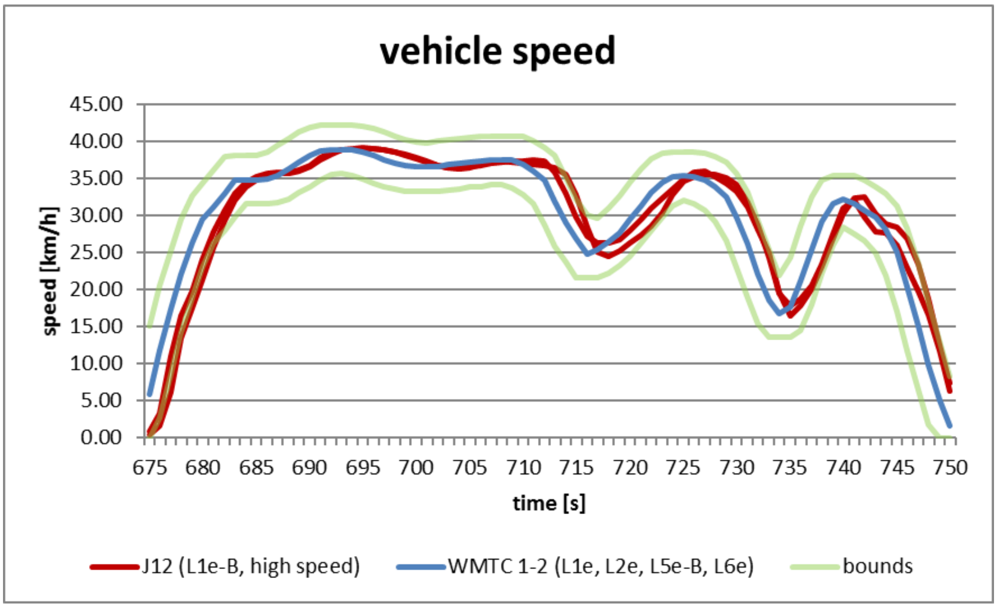


Figure 373. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle speed zoom – E0

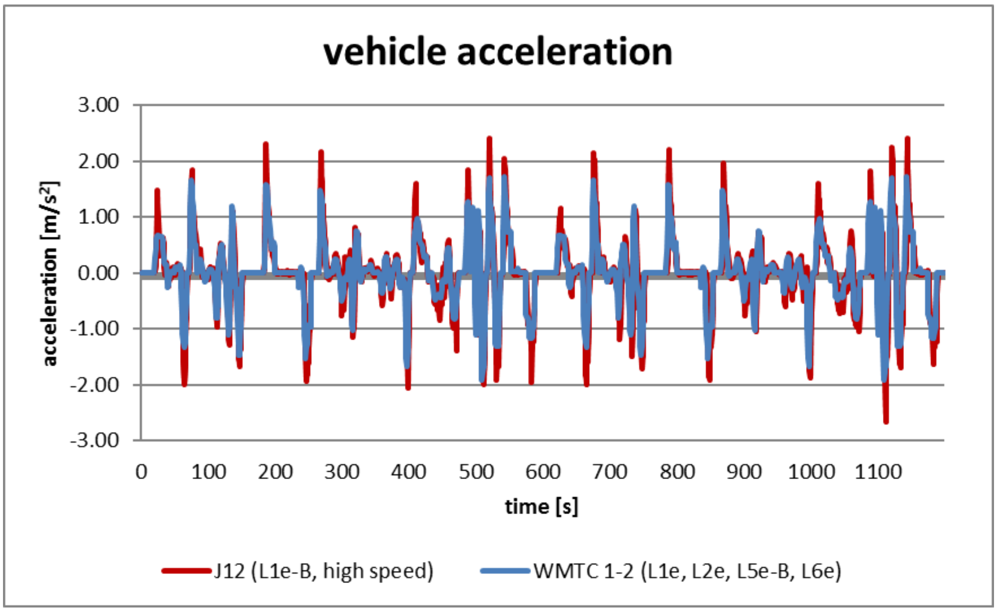


Figure 374. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle acceleration – E0

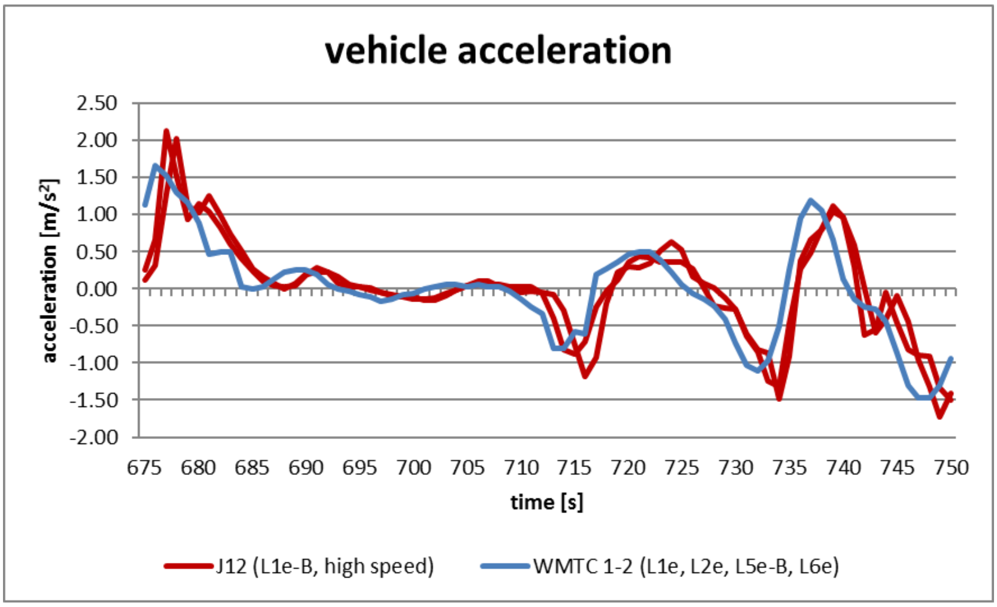


Figure 375. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle acceleration zoom – E0

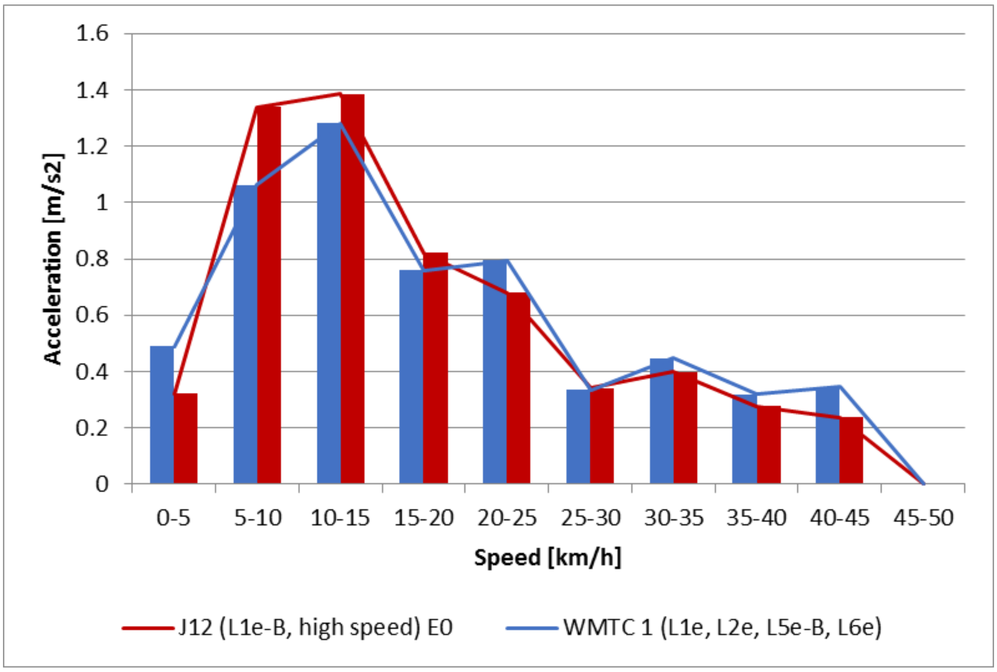


Figure 376. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J12 (L1e-B, high speed moped) – E0

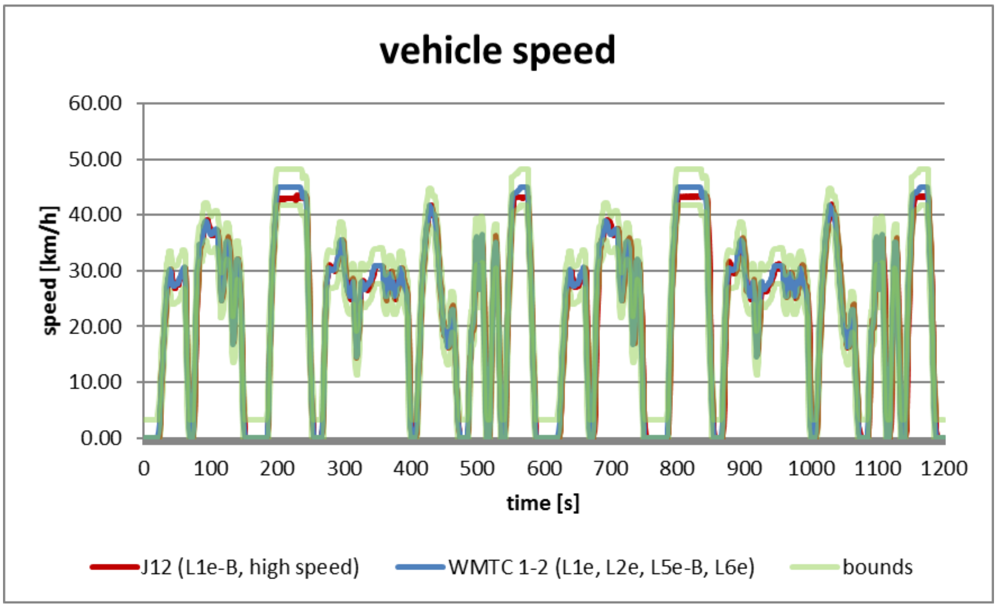


Figure 377. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle speed – E10

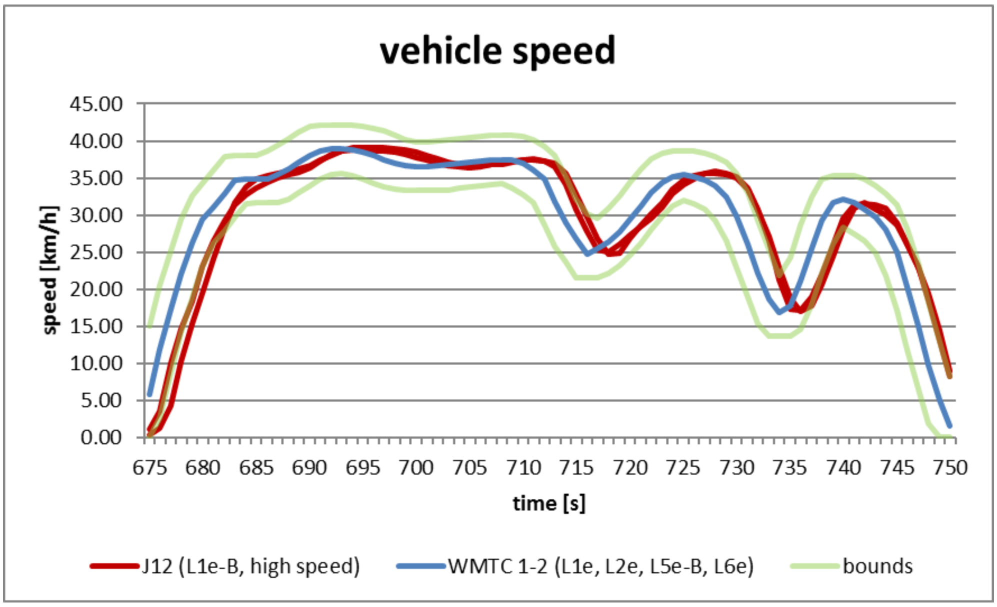


Figure 378. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle speed zoom – E10

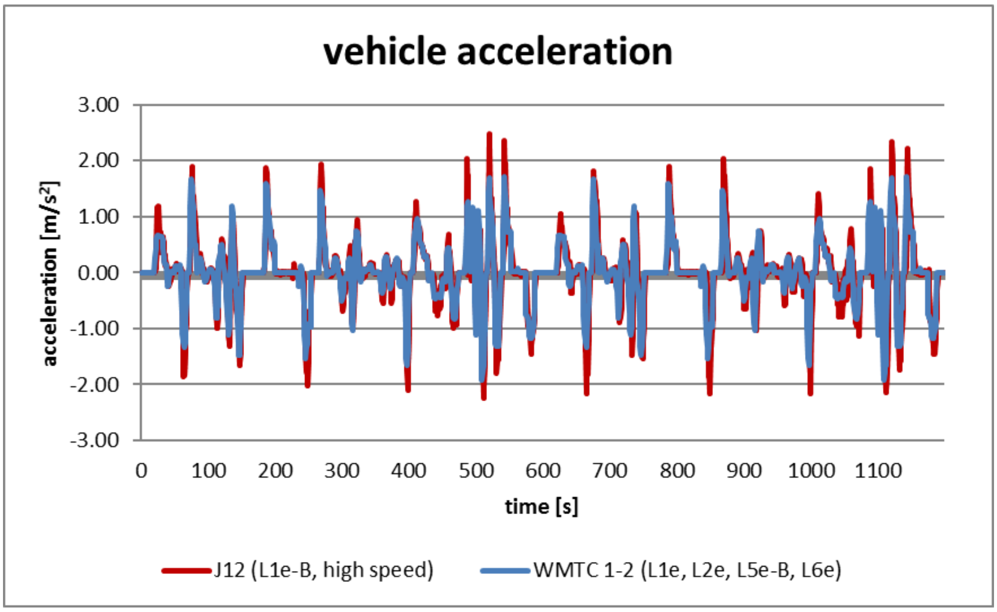


Figure 379. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle acceleration – E10

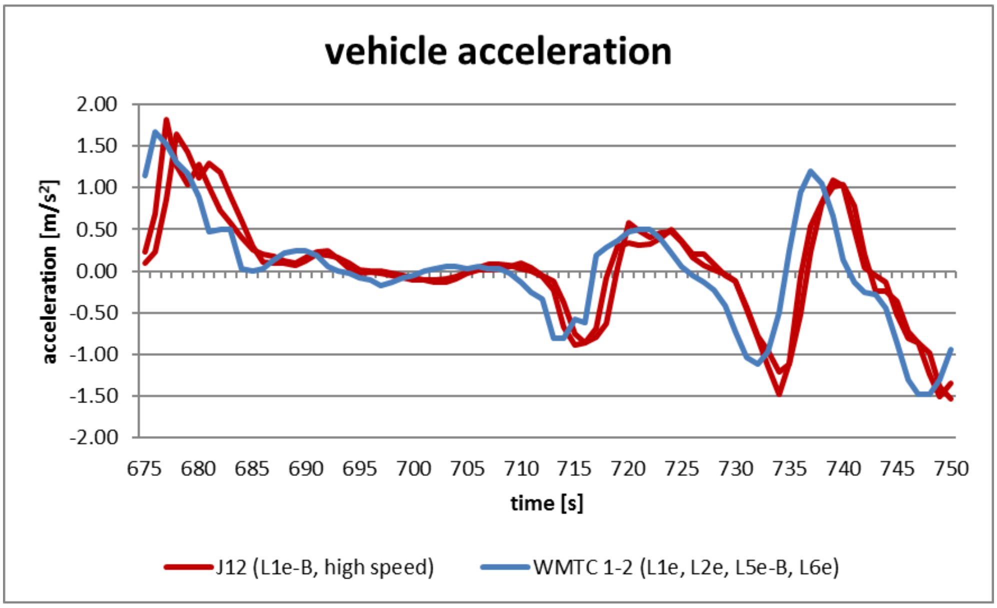


Figure 380. WMTC drivability of J12 (L1e-B, high speed moped) – vehicle acceleration zoom – E10

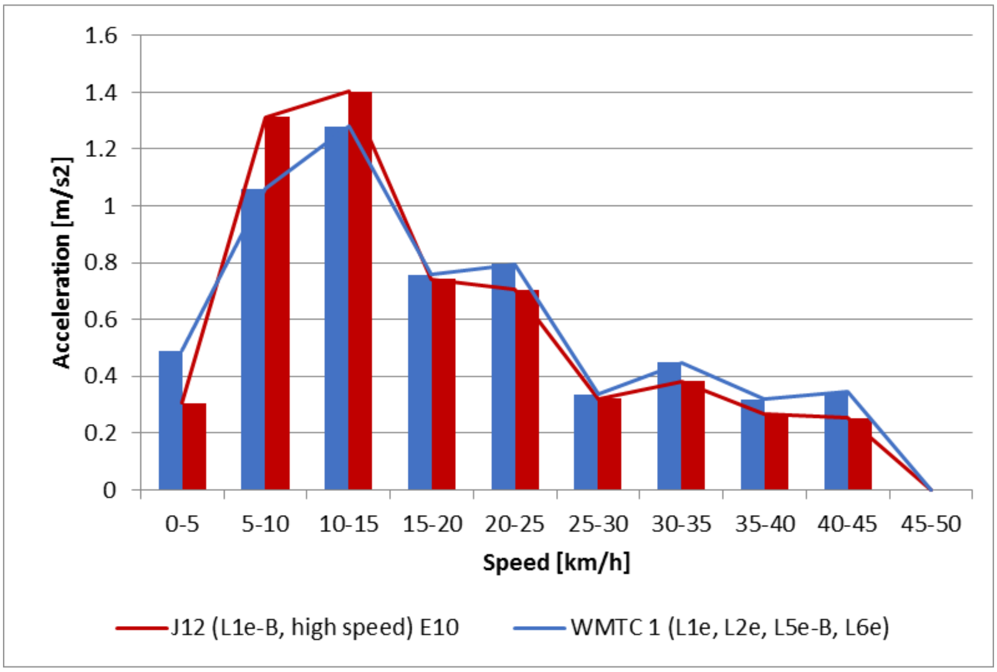


Figure 381. WMTC distribution of acceleration over speed to assess driver errors vs machine limits of J12 (L1e-B, high speed moped) – E10

Table 124. Technical criteria for WMTC drivability assessment of J12 (L1e-B, high speed moped)

WMTC		tests average (min-max)			REGULATION	MANUFACTURER
		E5	E0	E10		
Speed Violations	Events	6 (2 – 10)	3 (3 – 3)	6 (5 – 7)	-	-
	Duration (s)	17 (4 – 29)	10 (9 – 10)	21 (17 – 24)	-	-
Maximum Achievable Speed (km/h)		44 (43 – 44)	43 (43 – 43)	44 (43 – 44)	45	45
Mean Positive Acceleration (MPA) (m/s^2)		0.49 (0.48 – 0.50)	0.49 (0.48 – 0.49)	0.47 (0.46 – 0.47)	0.46	-
Driven Distance (m)		7558 (7544–7571)	7542 (7535–7548)	7560 (7551–7569)	7600	-
Speed * MPA (approx. of instantaneous, mass-specific power) (W/kg)		3.04 (2.96 – 3.12)	2.99 (2.97 – 3.01)	2.89 (2.86 – 2.93)	2.87	-

G.2 Impact of EtOH on the engine operation area of the different driving cycles

The examined vehicles on the ethanol impact on the engine operation area of the different driving cycles are all 6 vehicles examined under the ethanol impact task:

- L1e-B, high speed: 2 vehicles
- L3e-A2: 4 vehicles (1 validation vehicle)
- L3e-A3: 1 vehicle

This Appendix includes the engine map coverage results of the WMTC when run with each of the examined fuels, i.e. E5 (reference), E0 and E10. A scatter plot of the torque versus the engine speed is presented, along with the distribution of the torque for each vehicle. The extreme out of the range values are filtered in all graphs.

Disclaimer

The figures of this Appendix are requested by the call and are presented without further commenting.

Vehicle J03 (L1e-B, high speed)

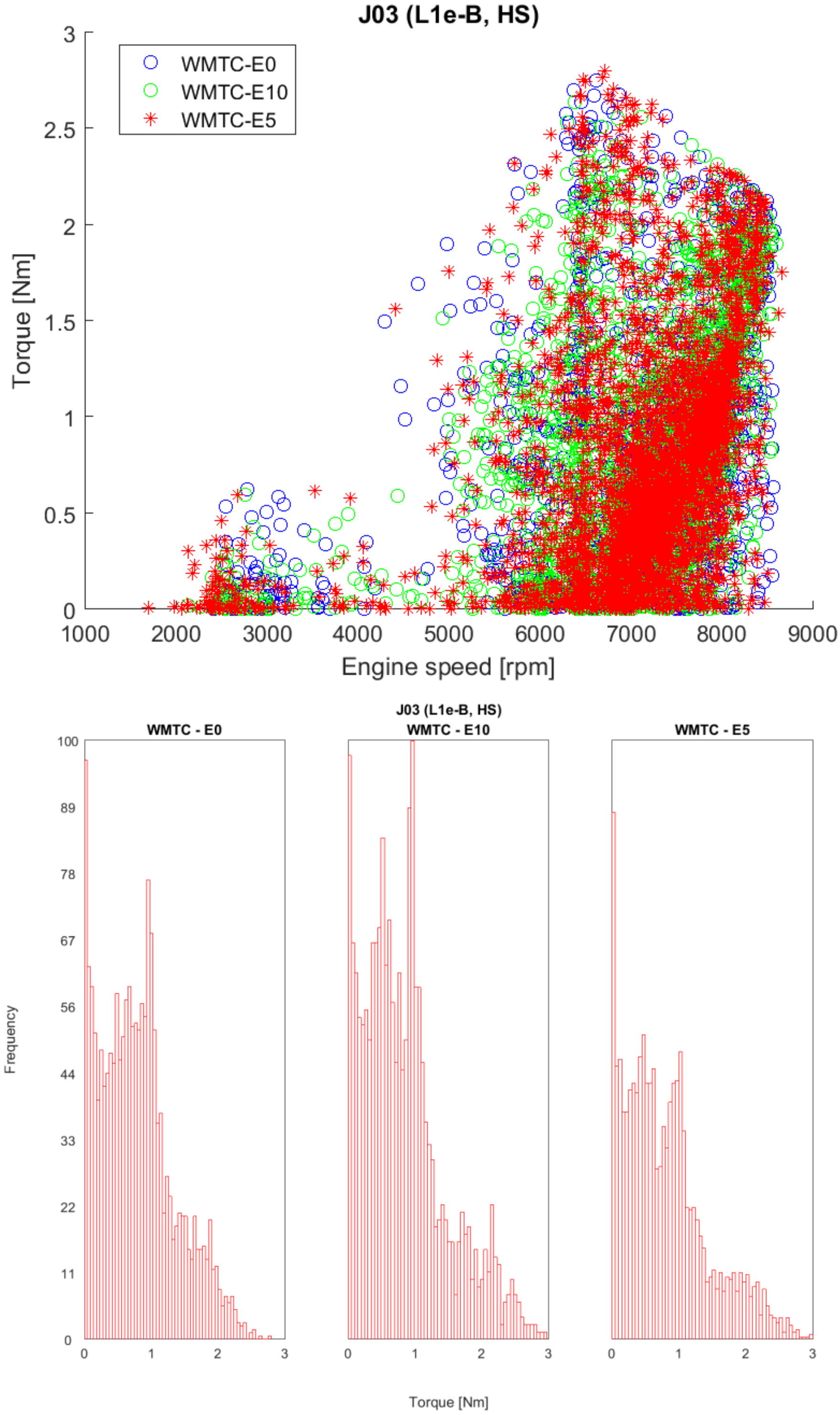


Figure 382. Engine map coverage of J03 (L1e-B, high speed) – torque – ethanol impact

Vehicle J12 (L1e-B, high speed)

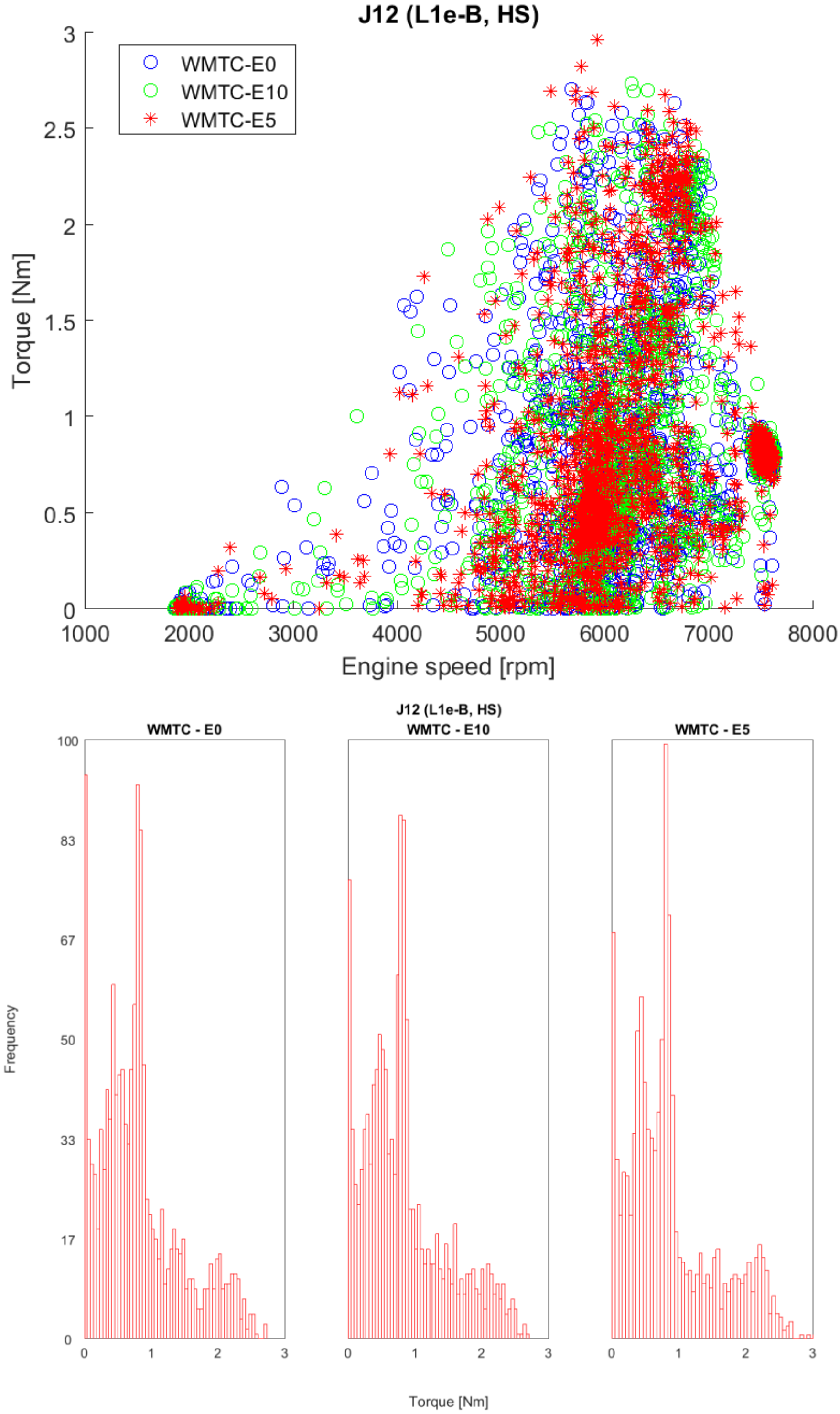


Figure 383. Engine map coverage of J12 (L1e-B, high speed) – torque – ethanol impact

Vehicle J11 (L3e-A2)

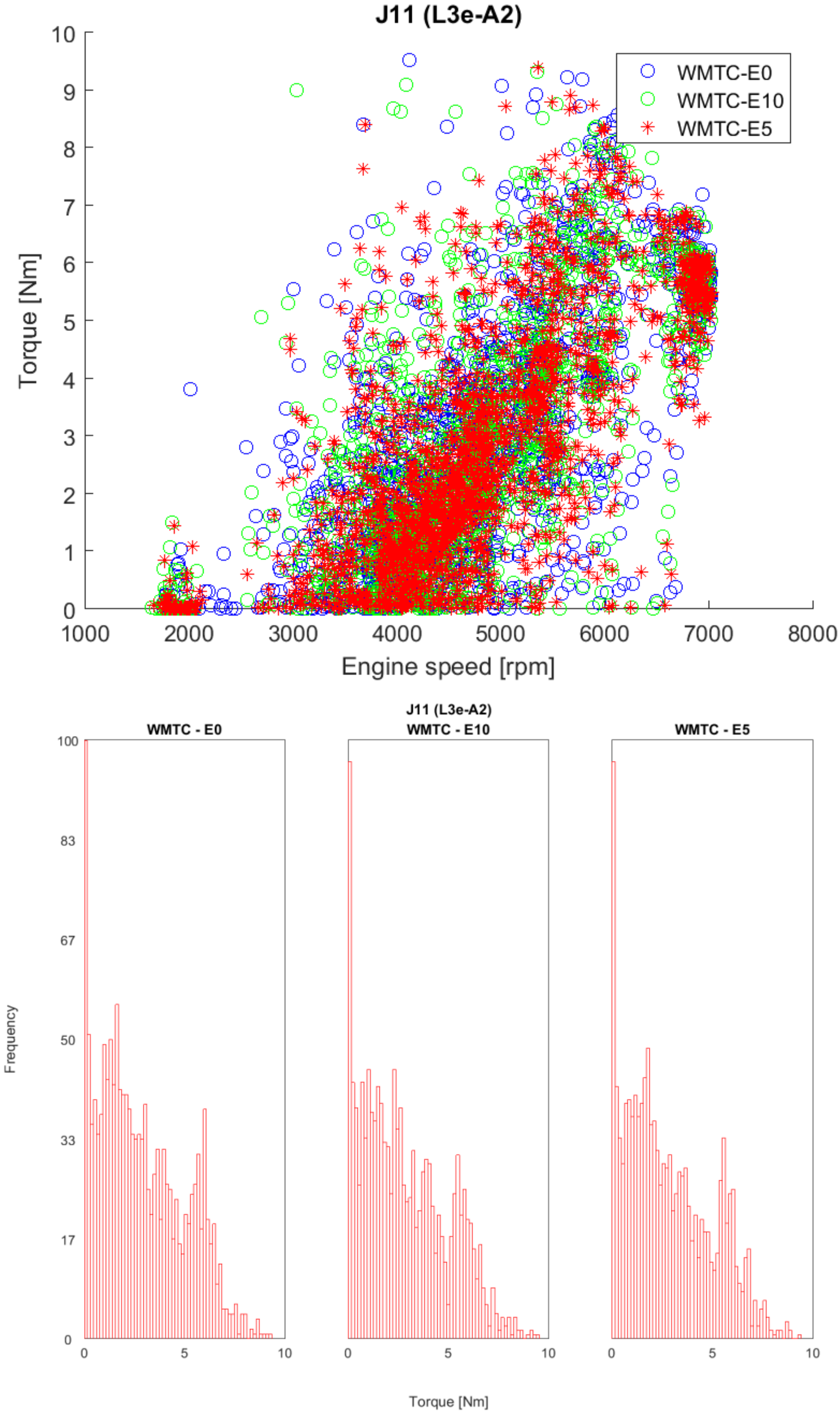


Figure 384. Engine map coverage of J11 (L3e-A2) – torque – ethanol impact

Vehicle J13 (L3e-A2)

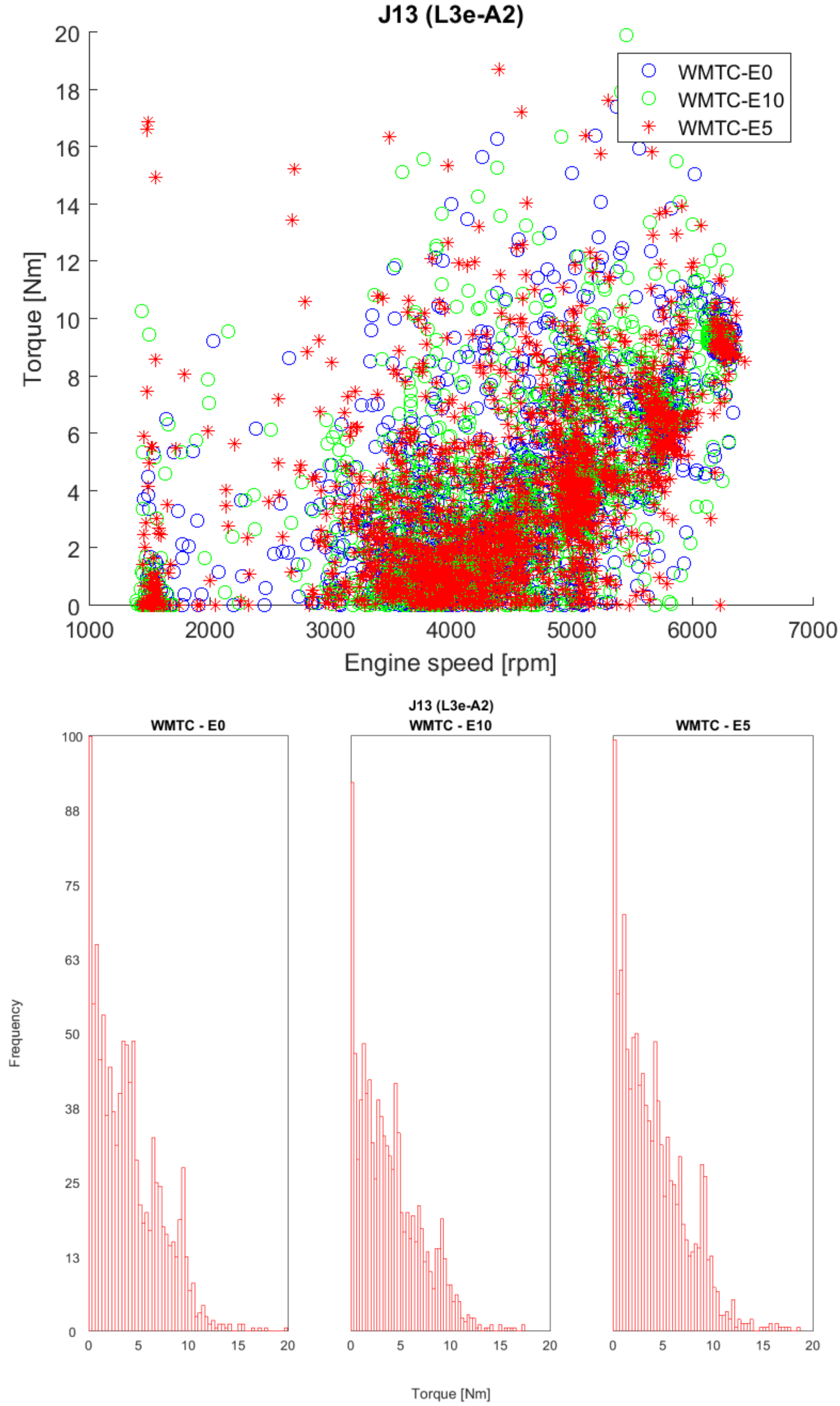


Figure 385. Engine map coverage of J13 (L3e-A2) – torque – ethanol impact

Vehicle J15 (L3e-A2)

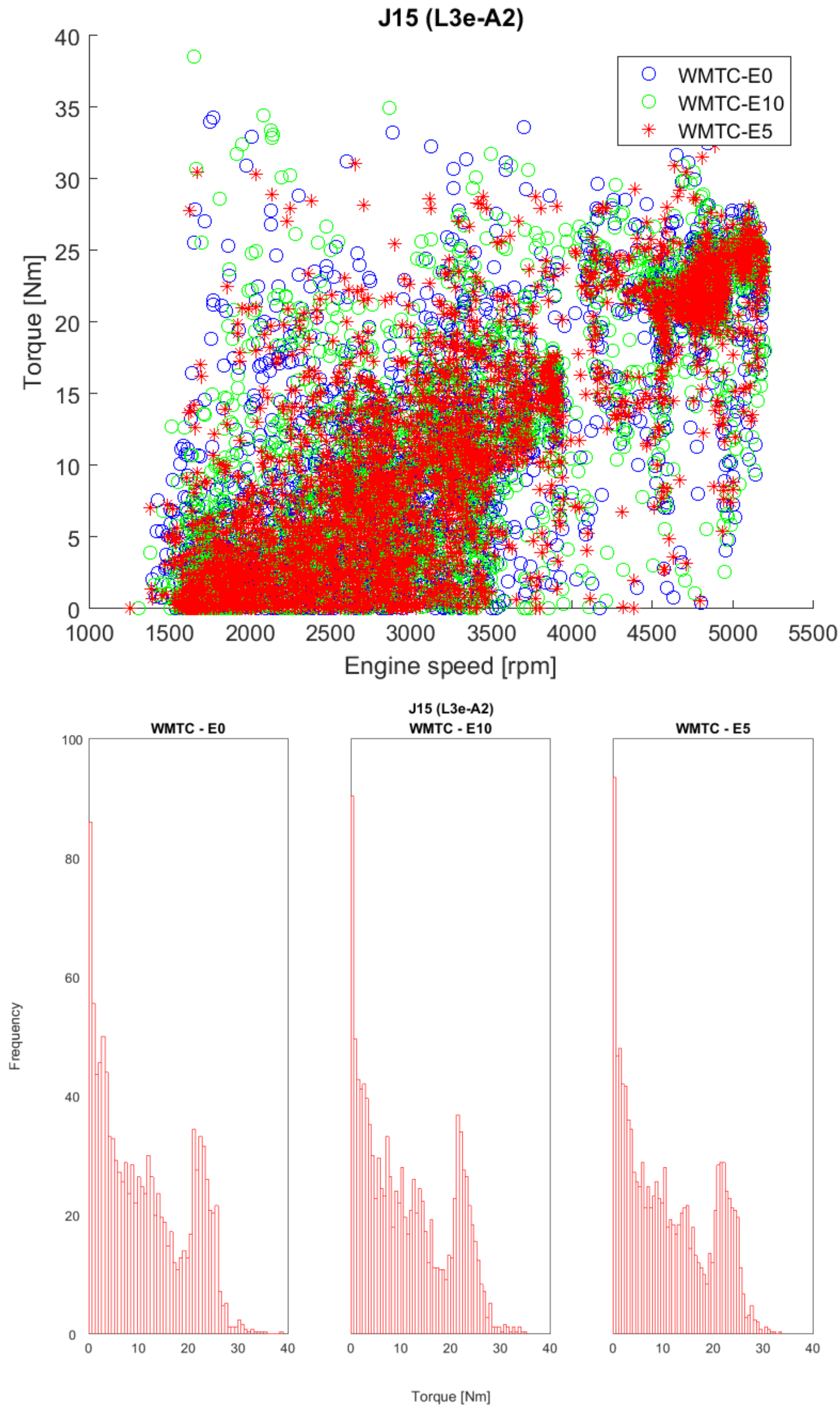
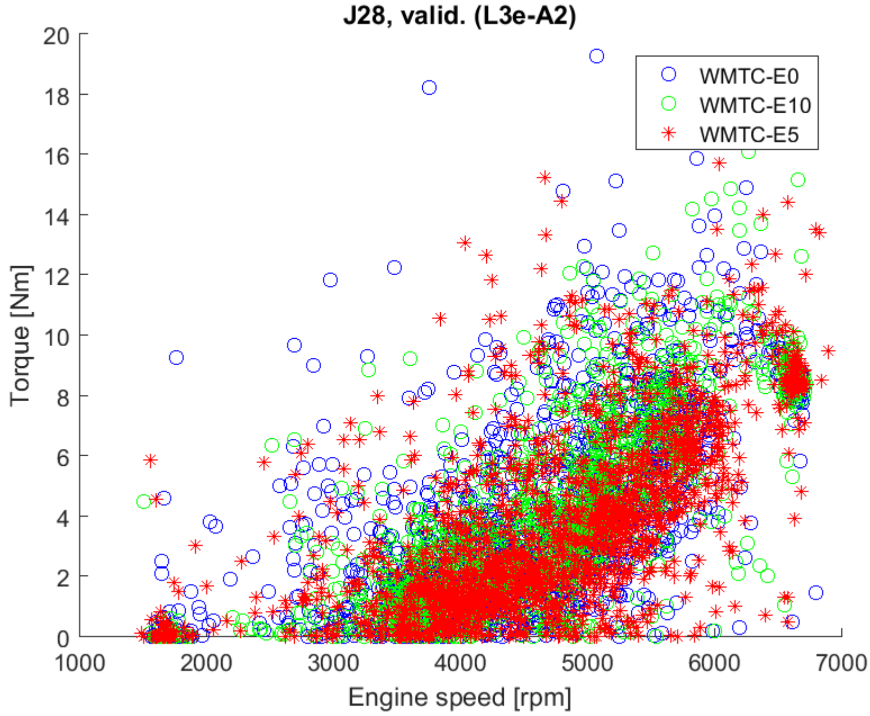


Figure 386. Engine map coverage of J15 (L3e-A2) – torque – ethanol impact

Vehicle J28, valid. (L3e-A2)



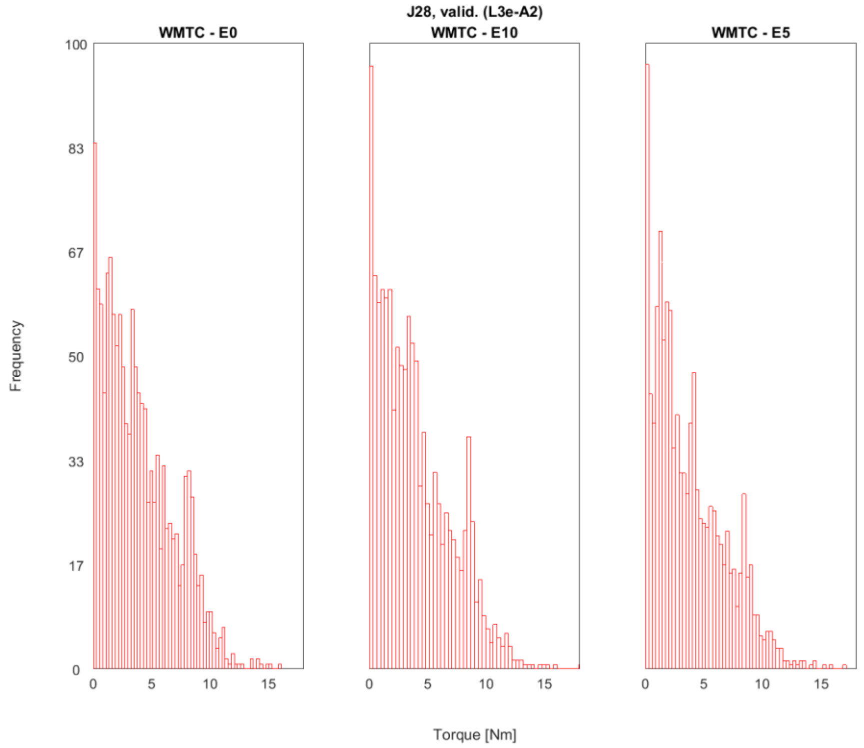


Figure 387. Engine map coverage of J28, valid.(L3e-A2) – torque – ethanol impact

Vehicle J18 (L3e-A3)

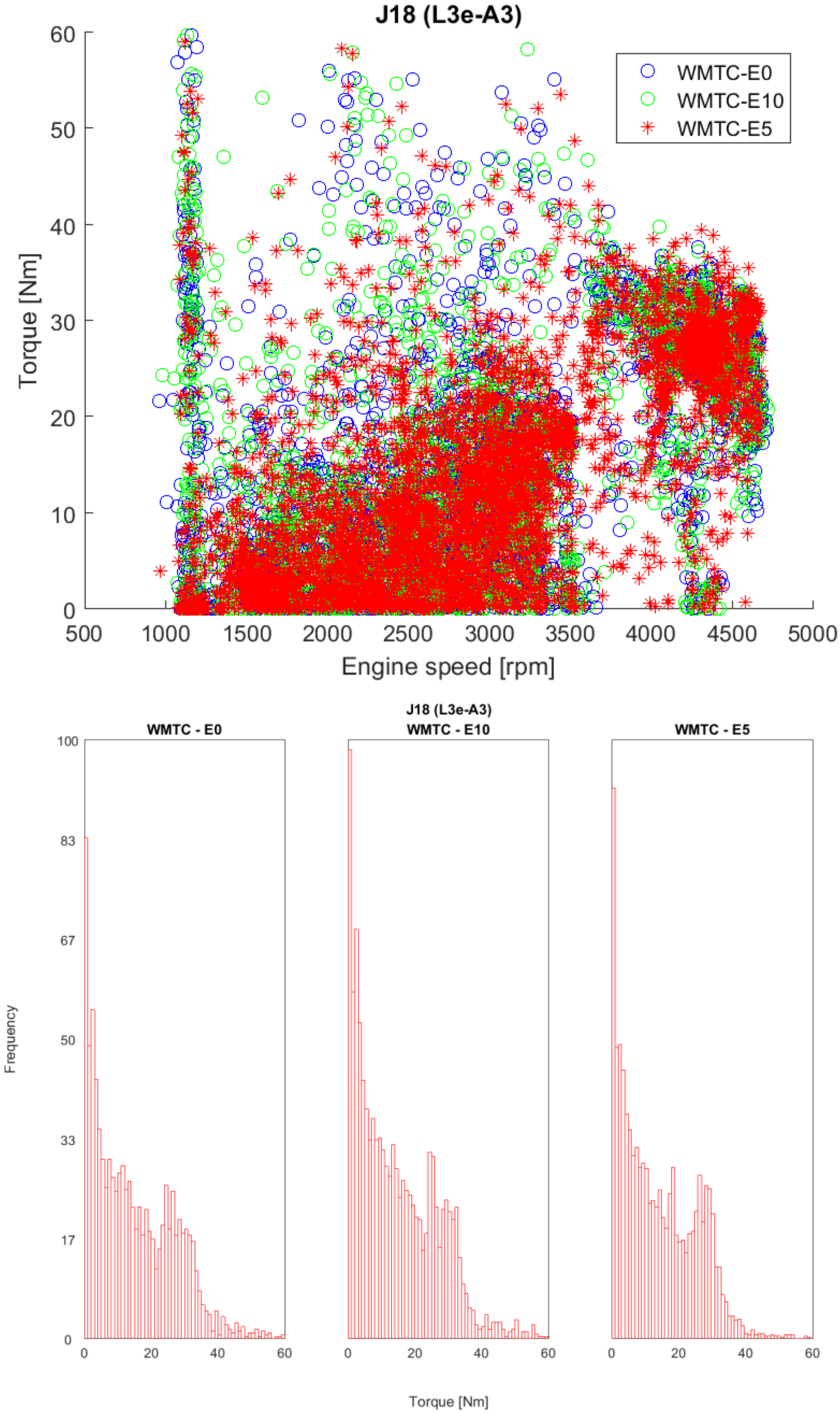


Figure 388. Engine map coverage of J18 (L3e-A3) – torque – ethanol impact

G.3 Impact of EtOH on the engine speed and engine load related parameters

The following figures present a scatter plot of the examined-recorded engine load parameters versus the engine speed for each vehicle, i.e., the accelerator position and the manifold absolute pressure (MAP), for the vehicles that MAP is recorded. Each figure is split in four areas. The main area is the scatter plot, illustrating the points for each of the examined ethanol blend fuel, i.e. E0, E10 and E5 (reference fuel). In the upper left and the lower right graphs, the accelerator/MAP and the engine speed distributions are illustrated in bars, respectively, while the mean value is also marked with a line, for each examined fuel. The lower left area contains the legend of each figure, also including the mean value for each fuel.

The vehicles tested and presented in the following figures are:

- L1e-B, high speed: 2 vehicles
- L3e-A2: 4 vehicles (1 validation vehicle)
- L3e-A3: 1 vehicle

Disclaimer

The figures of this Appendix are requested by the call and are presented without further commenting.

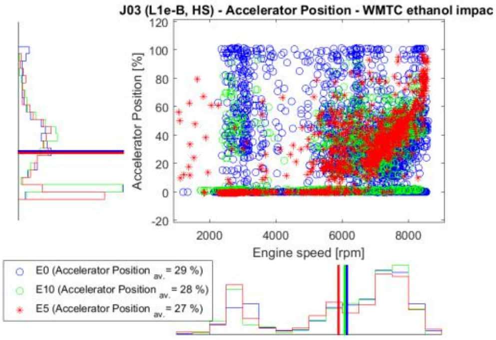


Figure 389. Engine speed and engine load related parameters – Vehicle J03 (L1e-B, high speed) – ethanol impact

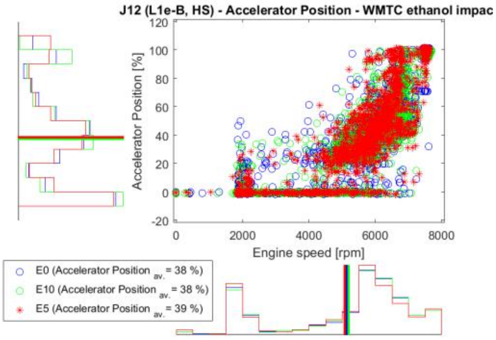


Figure 390. Engine speed and engine load related parameters – Vehicle J12 (L1e-B, high speed) – ethanol impact

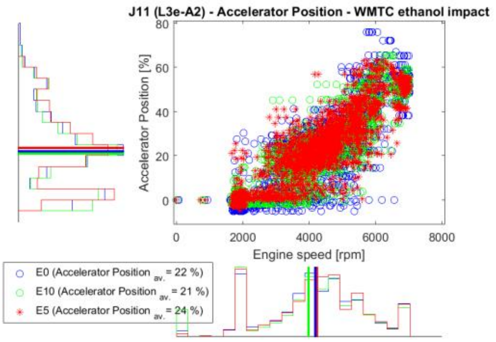


Figure 391. Engine speed and engine load related parameters – Vehicle J11 (L3e-A2) – ethanol impact

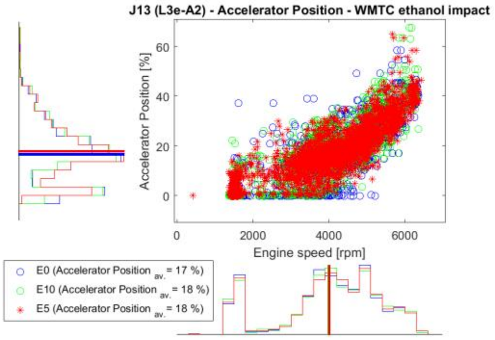


Figure 392. Engine speed and engine load related parameters – Vehicle J13 (L3e-A2) – ethanol impact

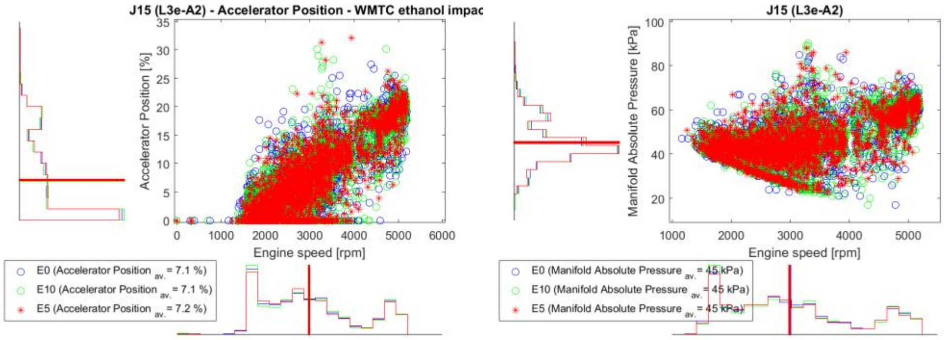


Figure 393. Engine speed and engine load related parameters – Vehicle J15 (L3e-A2) – ethanol impact

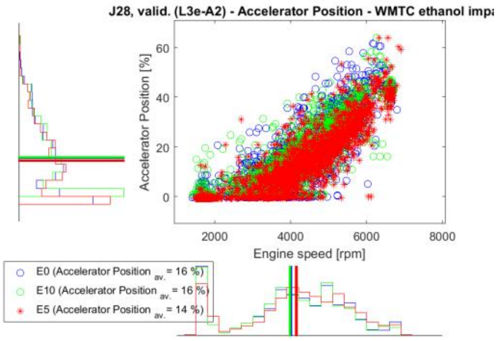


Figure 394. Engine speed and engine load related parameters – Vehicle J28, valid. (L3e-A2) – ethanol impact

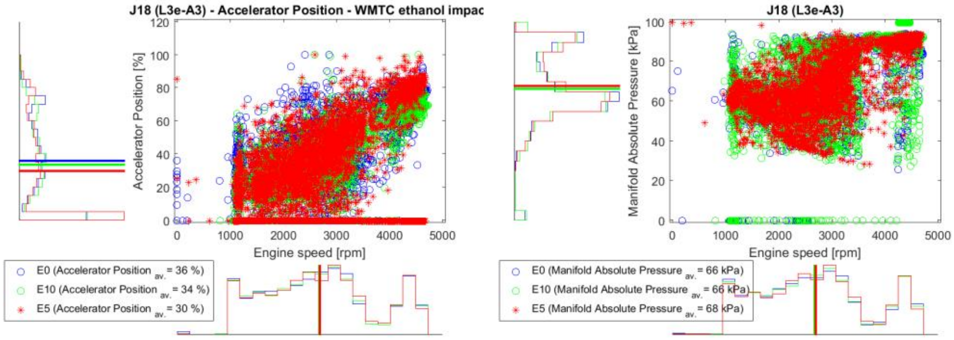


Figure 395. Engine speed and engine load related parameters – Vehicle J18 (L3e-A3) – ethanol impact

G.4 Impact of EtOH on the pollutant emissions, fuel consumption and lambda sensor results

In this paragraph the average emission results of the tests are presented for the tests run with E0 and E10 fuels as relative differences to the average emission results of the tests with E5 fuel presented in Appendix C. Subsequently, the average emission results of the tests run on E5 are put to 100% and the relative differences with the emission results run on E0 and E10 are normalised to the results with E5. The error bars indicate the minimum and the maximum relative difference of each test with E0 or E10 fuel, normalised to the results of the tests performed with E5.

The cold-warm phase weighting factors used to calculate the final values follow the Euro 5 weighting factors of Table 1-10 in Annex II of Regulation (EU) No 134/2014. The tested vehicles are the following:

- L1e-B, high speed: 2 vehicles
- L3e-A2: 4 vehicles (1 validation vehicle)
- L3e-A3: 1 vehicle

The recorded and examined pollutants are the NO_x, CO, CO_2, THC, CH_4, NMHC and FC.

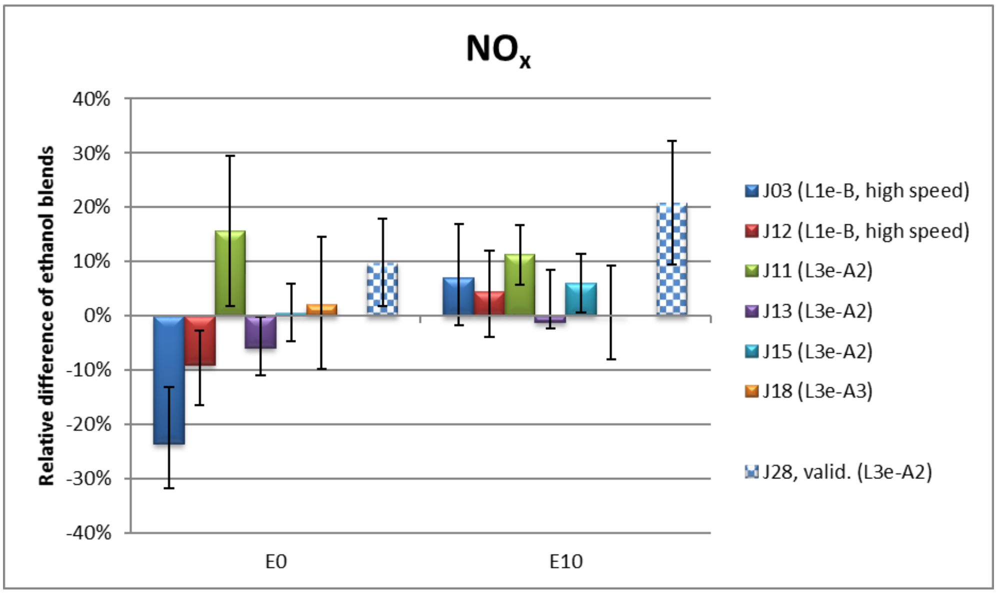


Figure 396. Emissions relative difference of ethanol blends normalised to the emissions with reference fuel (E5) – NO_x

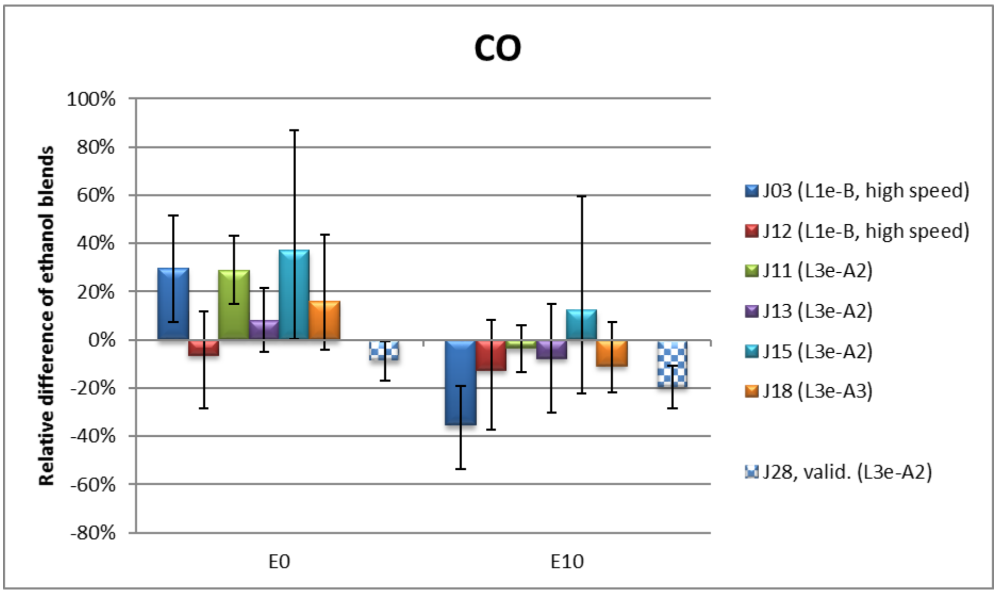


Figure 397. Emissions relative difference of ethanol blends normalised to the emissions with reference fuel (E5) – CO

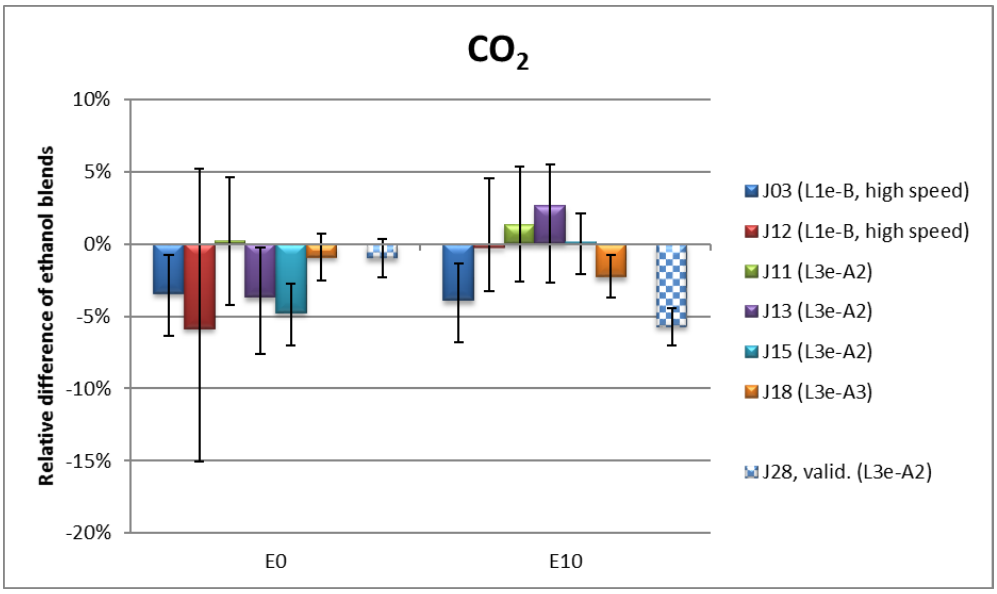


Figure 398. Emissions relative difference of ethanol blends normalised to the emissions with reference fuel (E5) – CO_2

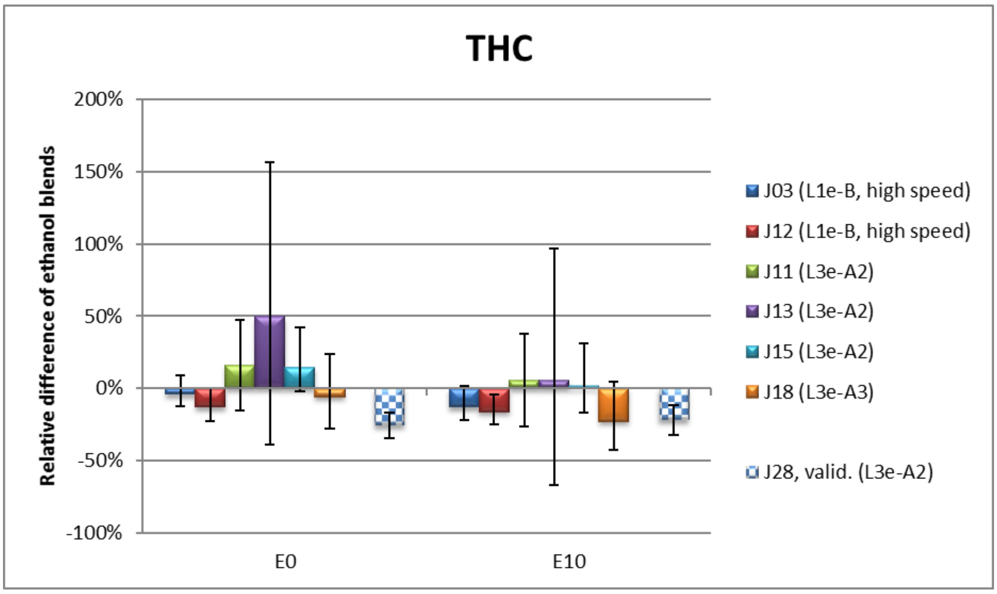


Figure 399. Emissions relative difference of ethanol blends normalised to the emissions with reference fuel (E5) – THC

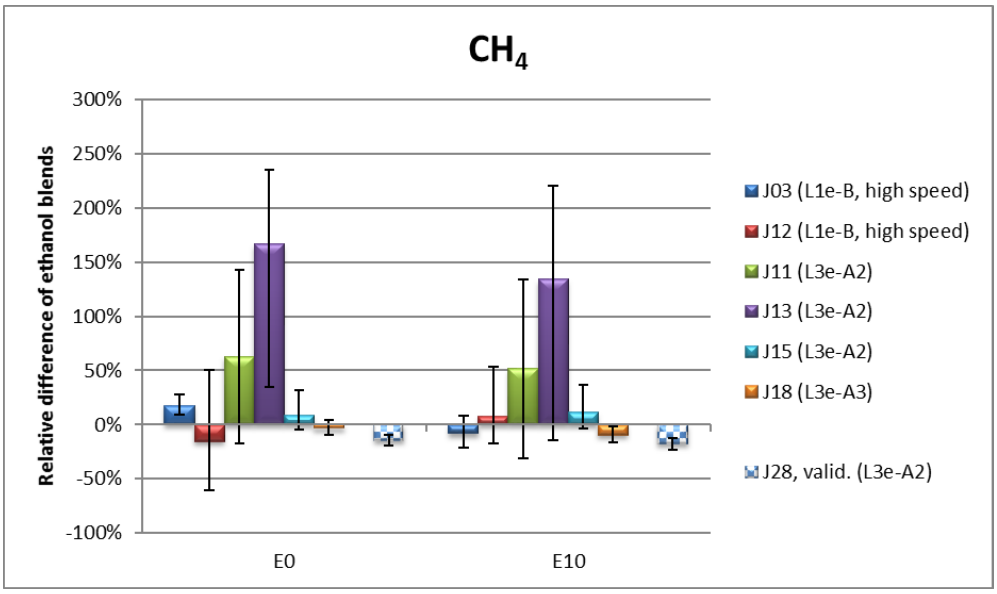


Figure 400. Emissions relative difference of ethanol blends normalised to the emissions with reference fuel (E5) – CH_4

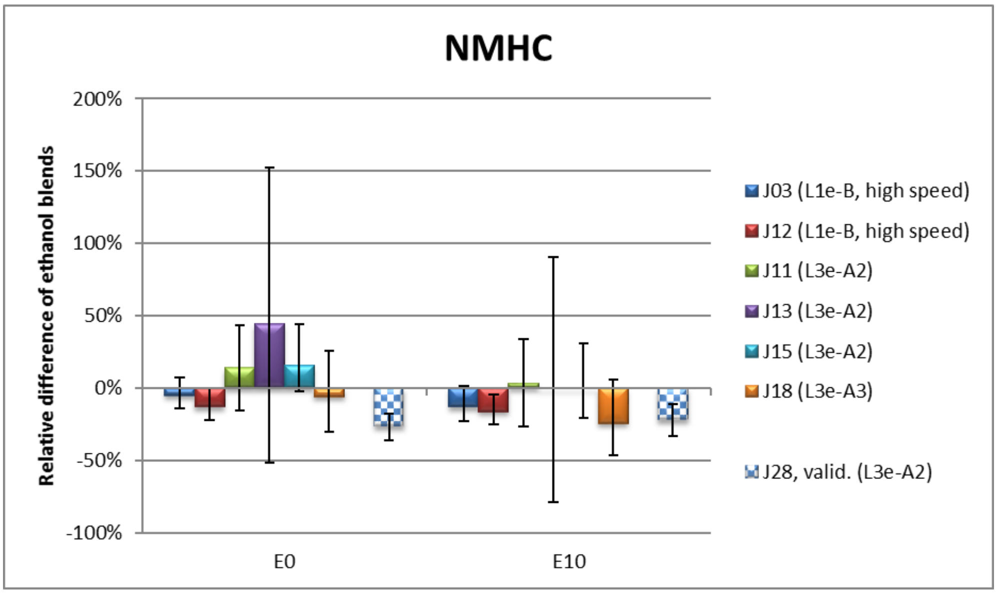


Figure 401. Emissions relative difference of ethanol blends normalised to the emissions with reference fuel (E5) – NMHC

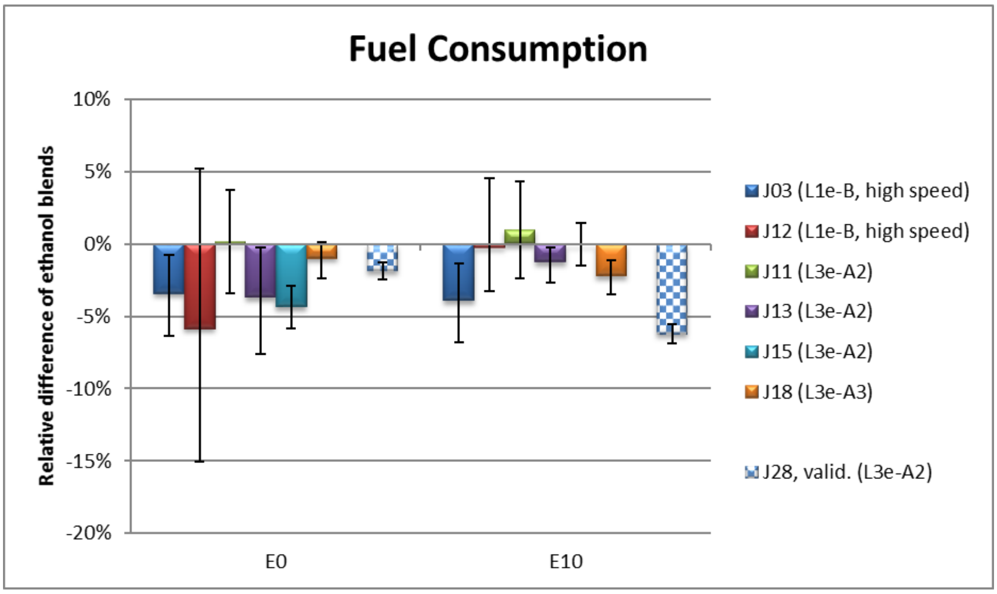
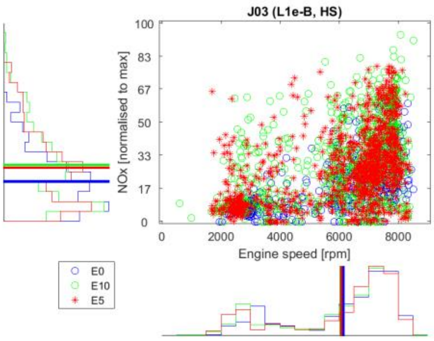


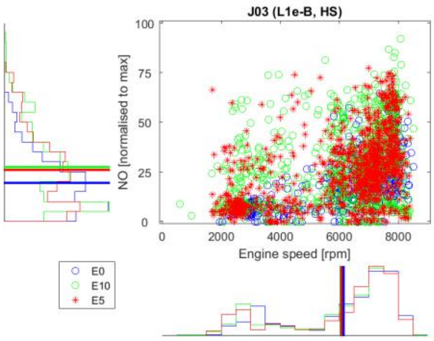
Figure 402. Emissions relative difference of ethanol blends normalised to the emissions with reference fuel (E5) – FC

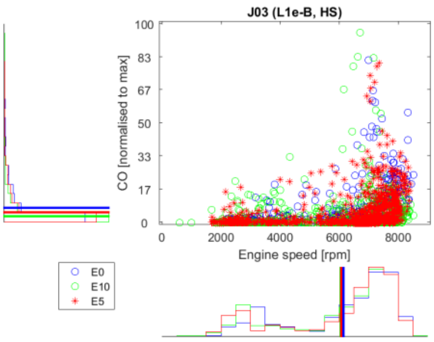
Additionally, the following figures show a scatter plot of the examined-recorded pollutants versus the engine speed, i.e., NO_x, NO, CO, CO2, THC, CH4 and NMHC as well as exhaust flow rate, fuel consumption and lambda. Each figure is split in four areas. The main area is the scatter plot, illustrating the points for each of the examined ethanol fuel blends, i.e. E0, E10 and E5 (reference fuel). In the upper left and the lower right graphs, the examined parameter (pollutant emission / fuel consumption / lambda sensor) and the engine speed distributions are illustrated in bars, respectively, while the mean value is also marked with a line, for each examined fuel. The lower left area contains the legend of each figure, also including the mean value for each examined fuel. It must be noted that the pollutant emission scatter plots are produced after averaging the raw modal data every 5 seconds, in order to assure the synchronization of the pollutants with the engine speed.

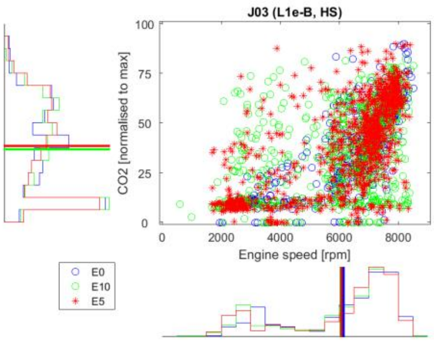
Besides, cumulative emission plots illustrating the normalized empirical cumulative distribution function (ECDF) of the sample data for each of the examined fuels are also presented in this Appendix. The curves are normalized both in terms of time (horizontal axis) and in terms of examined pollutant mass (vertical axis).

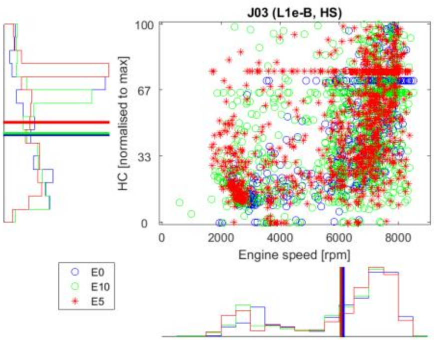
Disclaimer
The following figures are requested by the call and are presented without further commenting.

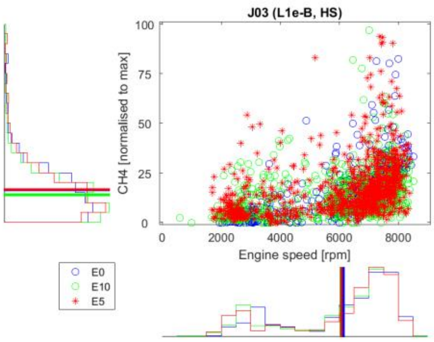

J03 (L1e-B, HS)
NOx [normalised to max]
100
83
67
50
33
17
0
0
2000
4000
6000
8000
Engine speed [rpm]
E0
E10
E5

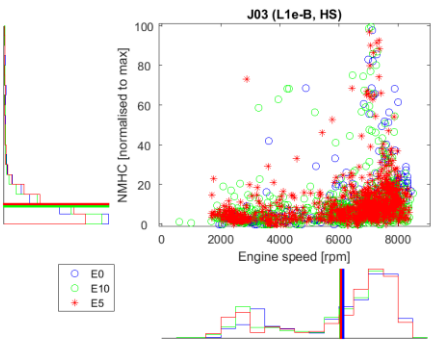

J03 (L1e-B, HS)
NO [normalised to max]
100
75
50
25
0
0
2000
4000
6000
8000
Engine speed [rpm]
E0
E10
E5

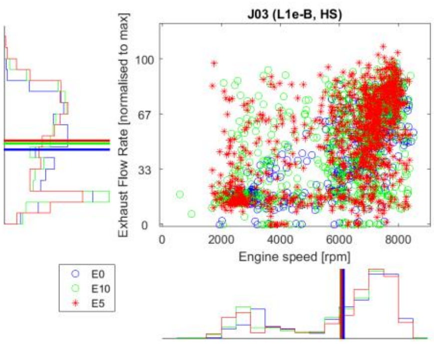

J03 (L1e-B, HS)
CO [normalised to max]
100
83
67
50
33
17
0
0
2000
4000
6000
8000
Engine speed [rpm]
E0
E10
E5


J03 (L1e-B, HS)
CO2 [normalised to max]
100
75
50
25
0
0
2000
4000
6000
8000
Engine speed [rpm]
E0
E10
E5


J03 (L1e-B, HS)
HC [normalised to max]
100
67
33
0
0
2000
4000
6000
8000
Engine speed [rpm]
E0
E10
E5


J03 (L1e-B, HS)
CH4 [normalised to max]
100
75
50
25
0
0
2000
4000
6000
8000
Engine speed [rpm]
E0
E10
E5


J03 (L1e-B, HS)
NMHC [normalised to max]
100
80
60
40
20
0
0
2000
4000
6000
8000
Engine speed [rpm]
E0
E10
E5


J03 (L1e-B, HS)
Exhaust Flow Rate [normalised to max]
100
67
33
0
0
2000
4000
6000
8000
Engine speed [rpm]
E0
E10
E5

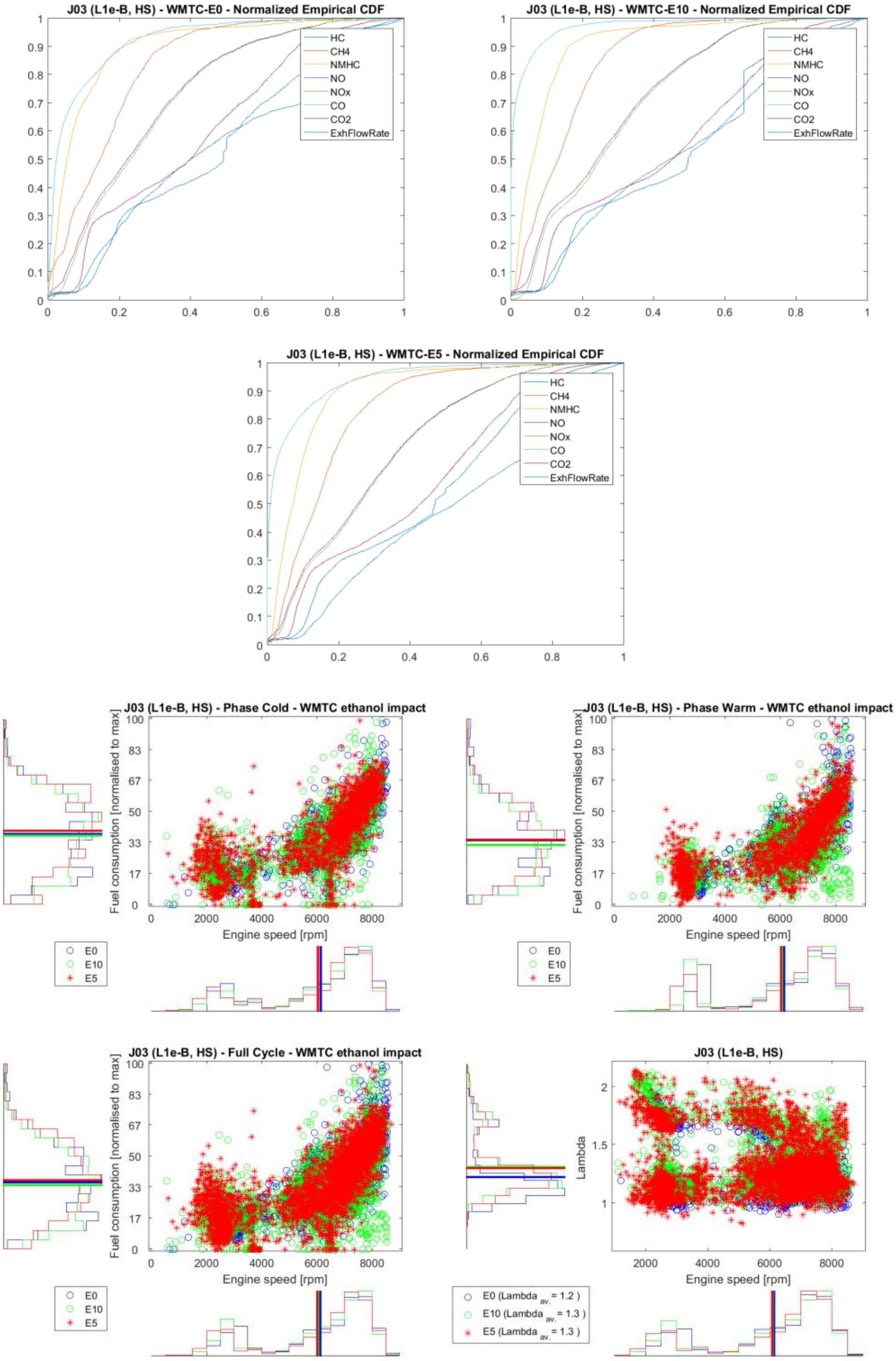
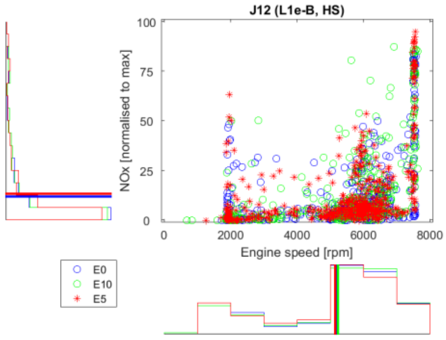
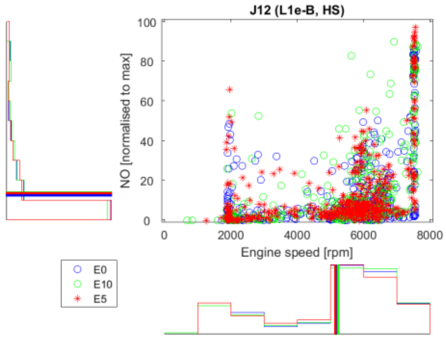
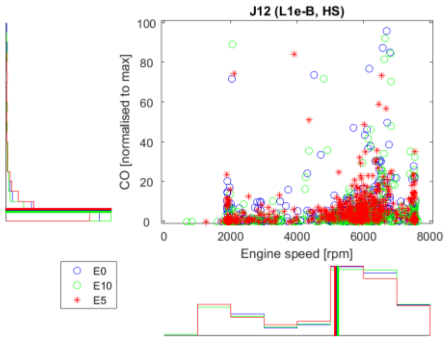
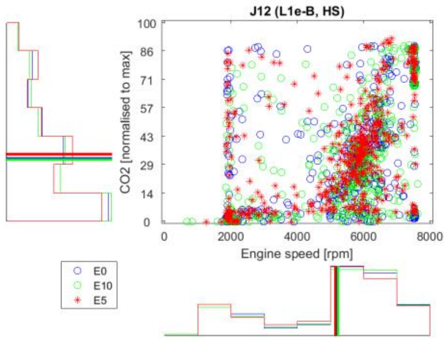


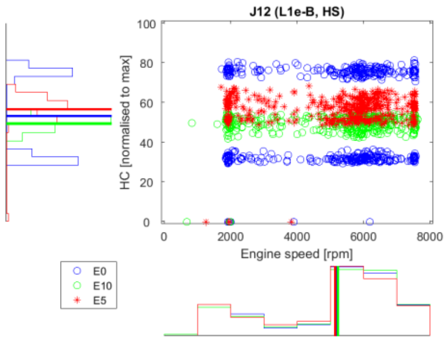
Figure 403. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J03 (L1e-B, high speed) – ethanol impact

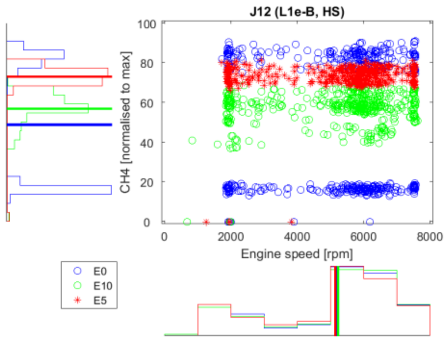

J12 (L1e-B, HS)
NOx [normalised to max]
Engine speed [rpm]
E0
E10
E5

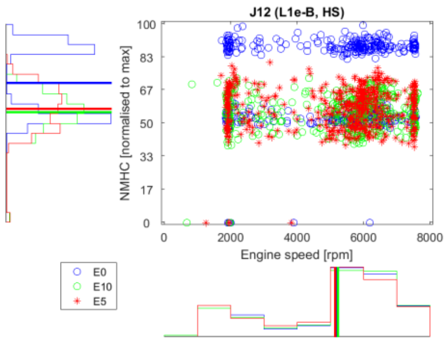

J12 (L1e-B, HS)
NO [normalised to max]
Engine speed [rpm]
E0
E10
E5

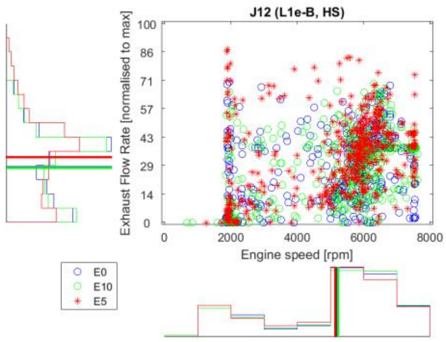

J12 (L1e-B, HS)
CO [normalised to max]
Engine speed [rpm]
E0
E10
E5


J12 (L1e-B, HS)
CO2 [normalised to max]
Engine speed [rpm]
E0
E10
E5


J12 (L1e-B, HS)
HC [normalised to max]
Engine speed [rpm]
E0
E10
E5


J12 (L1e-B, HS)
CH4 [normalised to max]
Engine speed [rpm]
E0
E10
E5


J12 (L1e-B, HS)
NMHC [normalised to max]
Engine speed [rpm]
E0
E10
E5


J12 (L1e-B, HS)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
E0
E10
E5

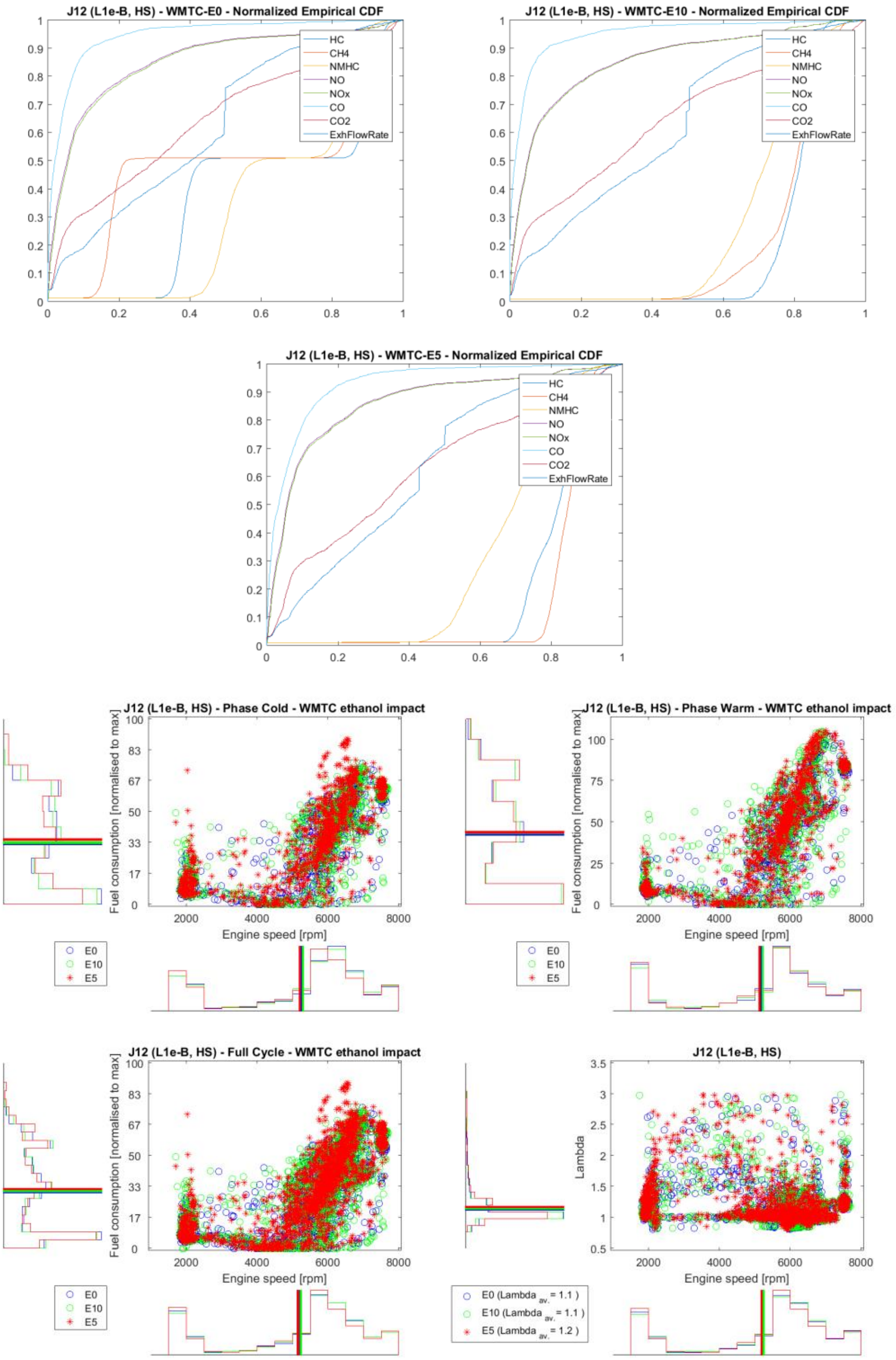
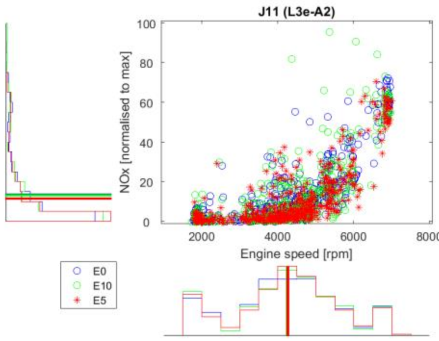
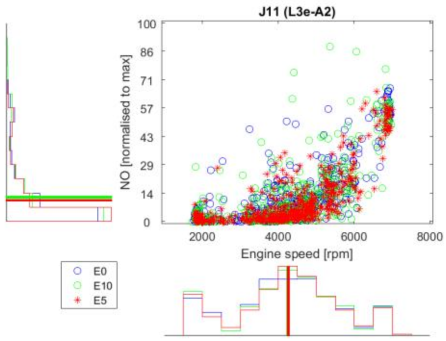
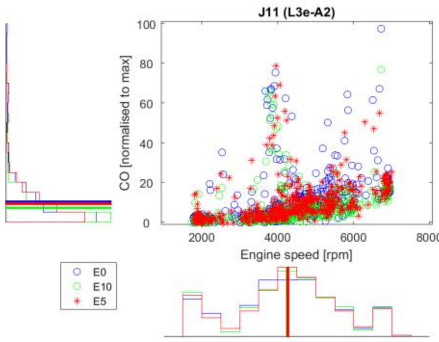
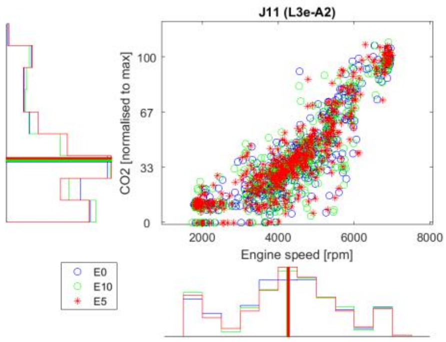


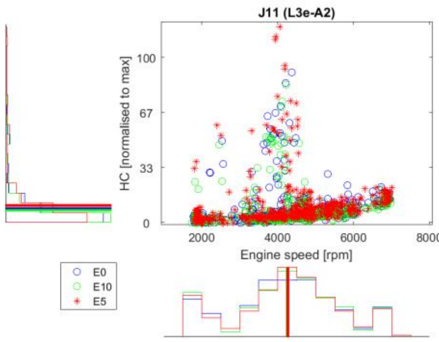
Figure 404. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J12 (L1e-B, high speed) – ethanol impact

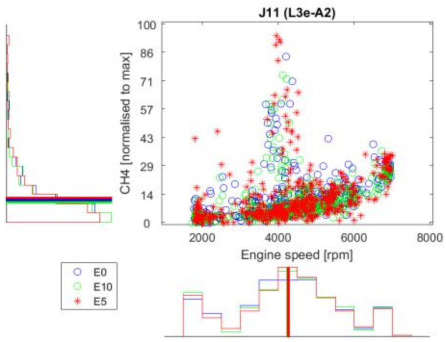

J11 (L3e-A2)
NOx [normalised to max]
Engine speed [rpm]
E0
E10
E5

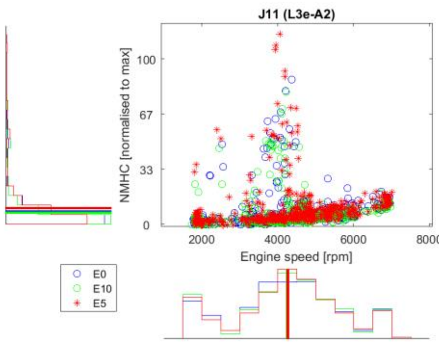

J11 (L3e-A2)
NO [normalised to max]
Engine speed [rpm]
E0
E10
E5

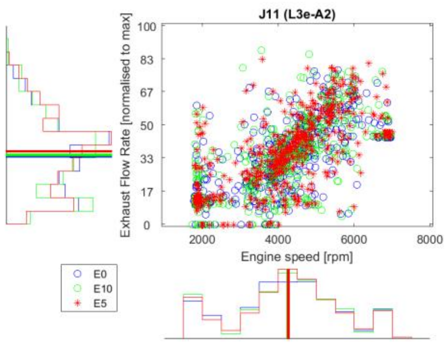

J11 (L3e-A2)
CO [normalised to max]
Engine speed [rpm]
E0
E10
E5


J11 (L3e-A2)
CO2 [normalised to max]
Engine speed [rpm]
E0
E10
E5


J11 (L3e-A2)
HC [normalised to max]
Engine speed [rpm]
E0
E10
E5


J11 (L3e-A2)
CH4 [normalised to max]
Engine speed [rpm]
E0
E10
E5


J11 (L3e-A2)
NMHC [normalised to max]
Engine speed [rpm]
E0
E10
E5


J11 (L3e-A2)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
E0
E10
E5

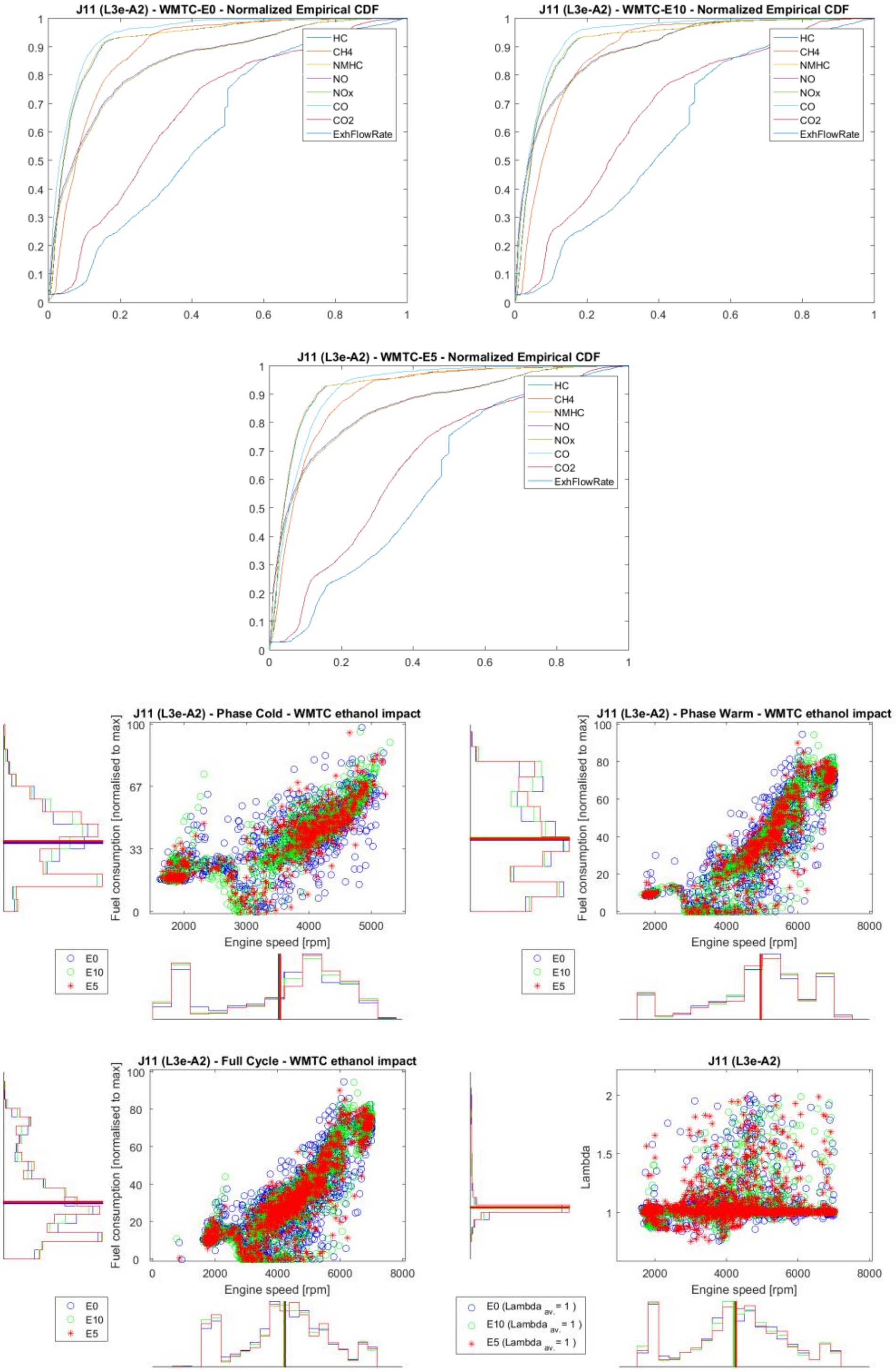
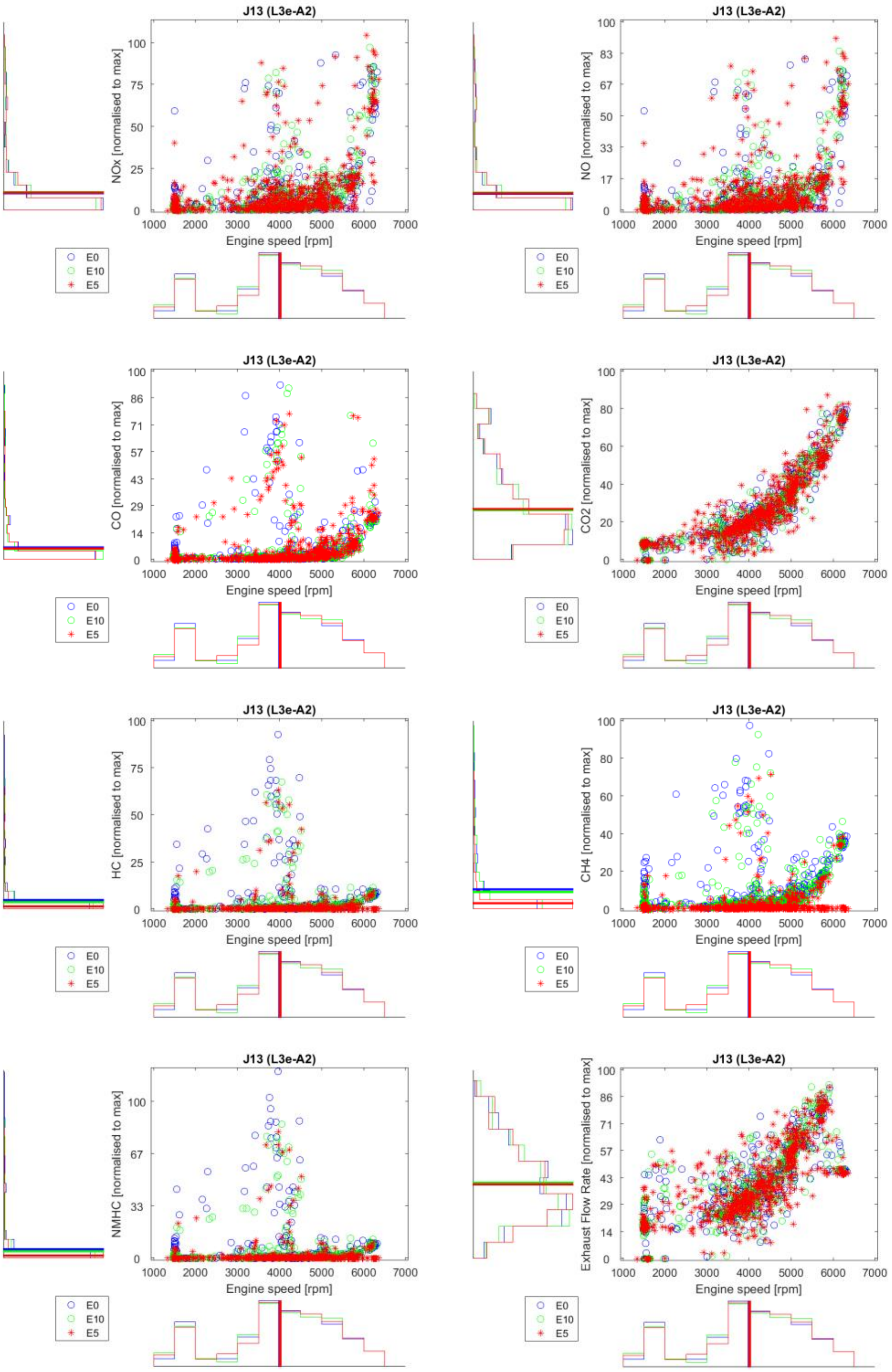


Figure 405. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J11 (L3e-A2) – ethanol impact


J13 (L3e-A2)
NOx [normalised to max]
NO [normalised to max]
CO [normalised to max]
CO2 [normalised to max]
HC [normalised to max]
CH4 [normalised to max]
NMHC [normalised to max]
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
E0
E10
E5

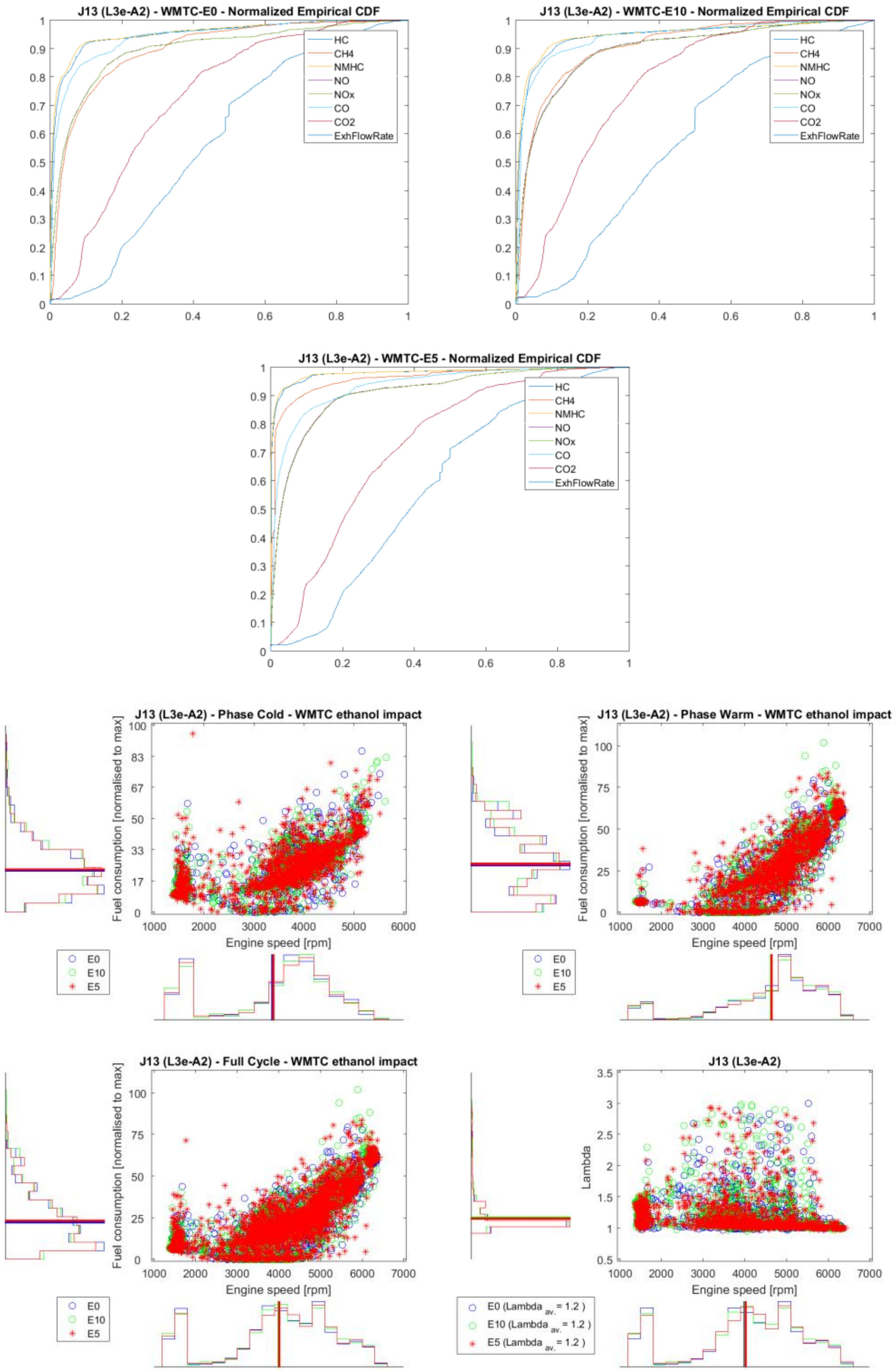
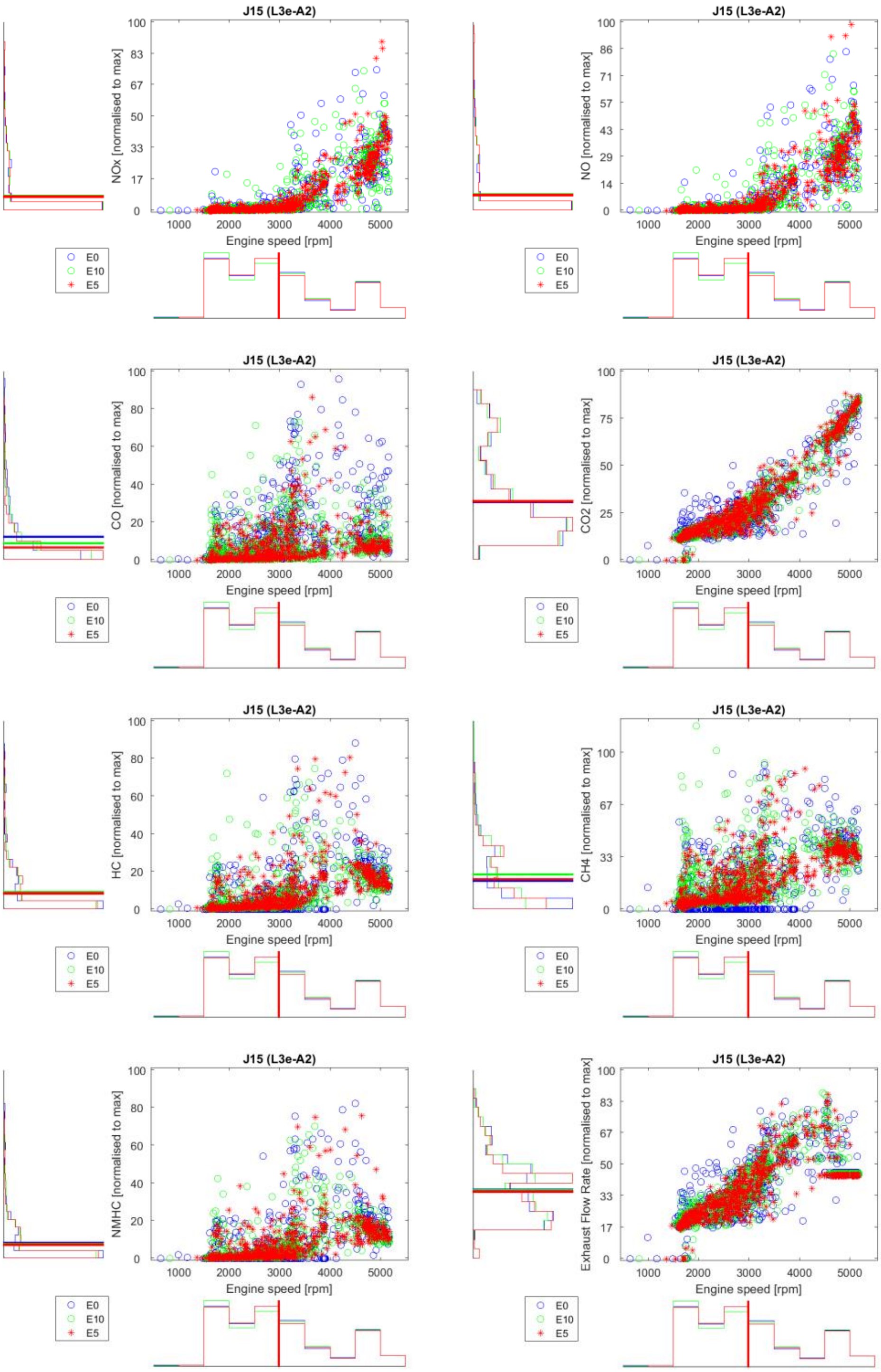


Figure 406. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J13 (L3e-A2) – ethanol impact


J15 (L3e-A2)
NOx [normalised to max]
NO [normalised to max]
CO [normalised to max]
CO2 [normalised to max]
HC [normalised to max]
CH4 [normalised to max]
NMHC [normalised to max]
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
E0
E10
E5

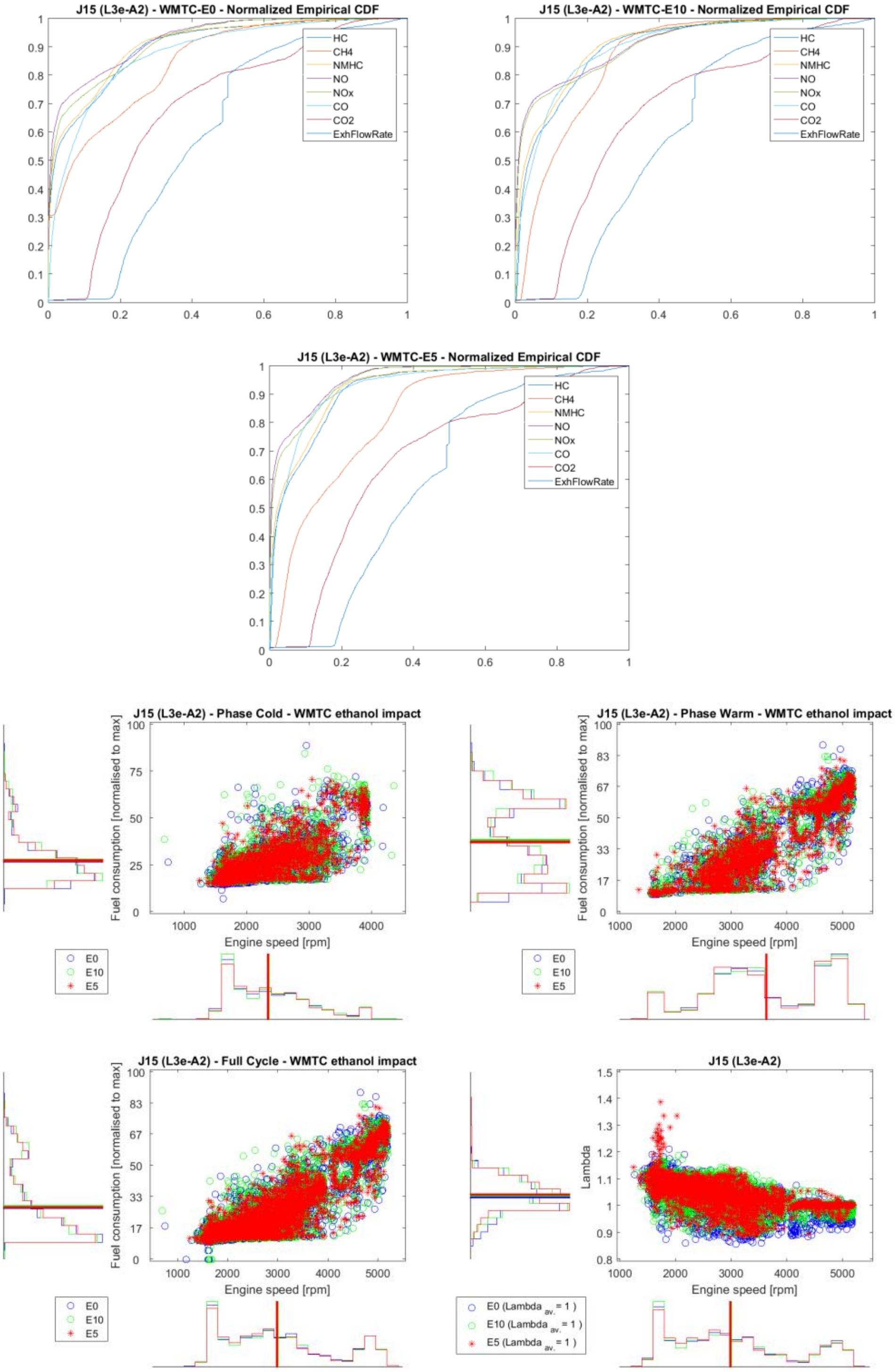
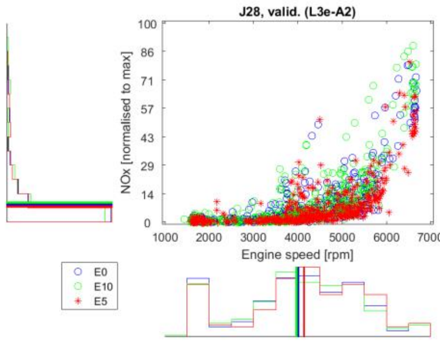
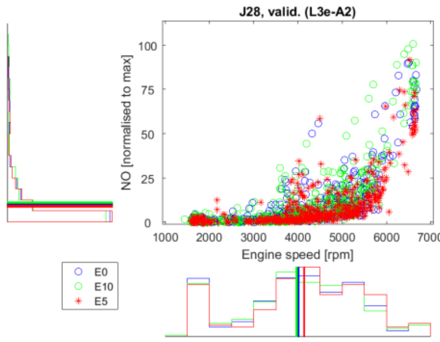
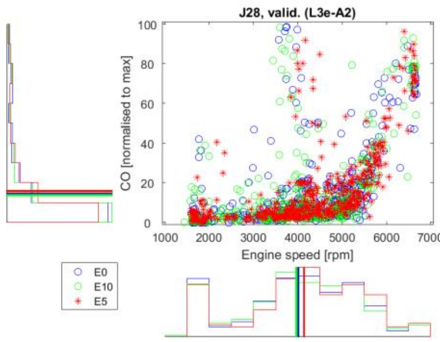
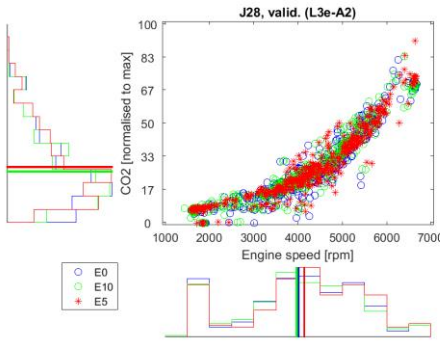


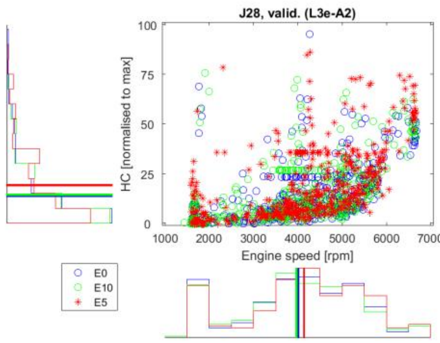
Figure 407. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J15 (L3e-A2) – ethanol impact

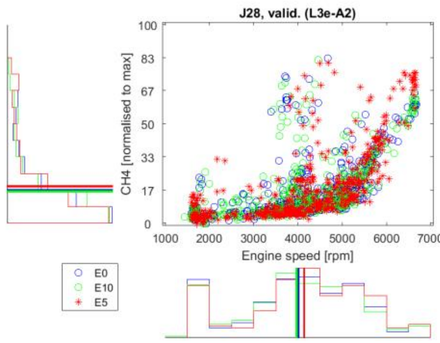

J28, valid. (L3e-A2)
NOx [normalised to max]
Engine speed [rpm]
E0
E10
E5

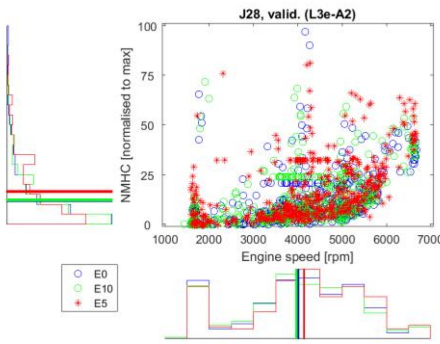

J28, valid. (L3e-A2)
NO [normalised to max]
Engine speed [rpm]
E0
E10
E5

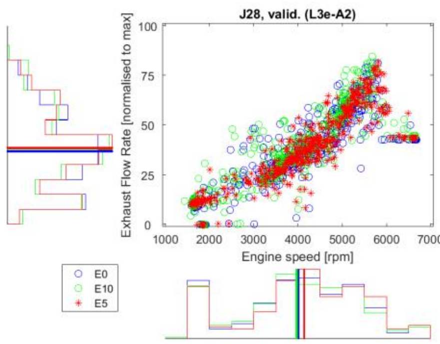

J28, valid. (L3e-A2)
CO [normalised to max]
Engine speed [rpm]
E0
E10
E5


J28, valid. (L3e-A2)
CO2 [normalised to max]
Engine speed [rpm]
E0
E10
E5


J28, valid. (L3e-A2)
HC [normalised to max]
Engine speed [rpm]
E0
E10
E5


J28, valid. (L3e-A2)
CH4 [normalised to max]
Engine speed [rpm]
E0
E10
E5


J28, valid. (L3e-A2)
NMHC [normalised to max]
Engine speed [rpm]
E0
E10
E5


J28, valid. (L3e-A2)
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
E0
E10
E5

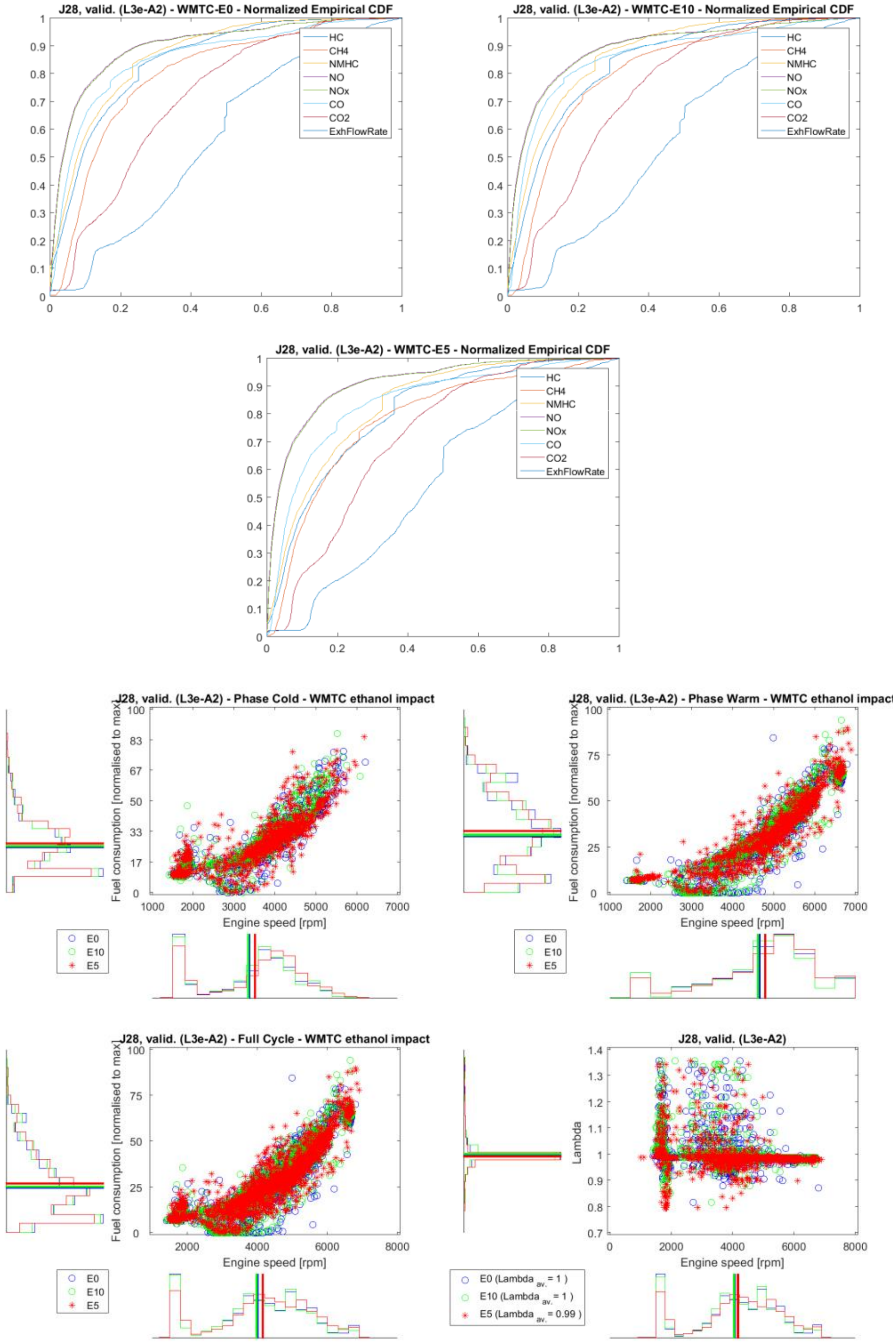
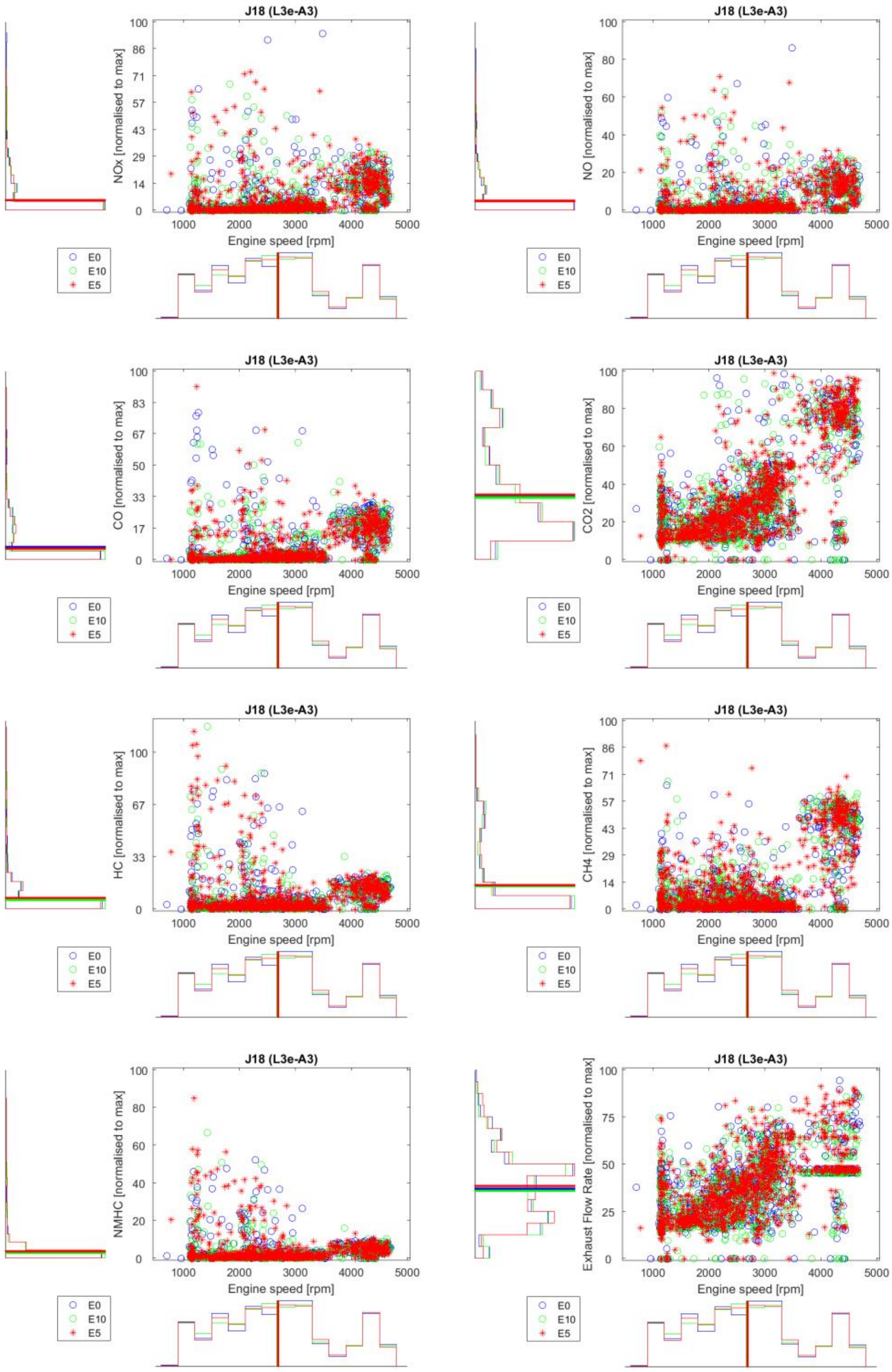


Figure 408. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J28, valid. (L3e-A2) – ethanol impact


J18 (L3e-A3)
NOx [normalised to max]
NO [normalised to max]
CO [normalised to max]
CO2 [normalised to max]
HC [normalised to max]
CH4 [normalised to max]
NMHC [normalised to max]
Exhaust Flow Rate [normalised to max]
Engine speed [rpm]
E0
E10
E5

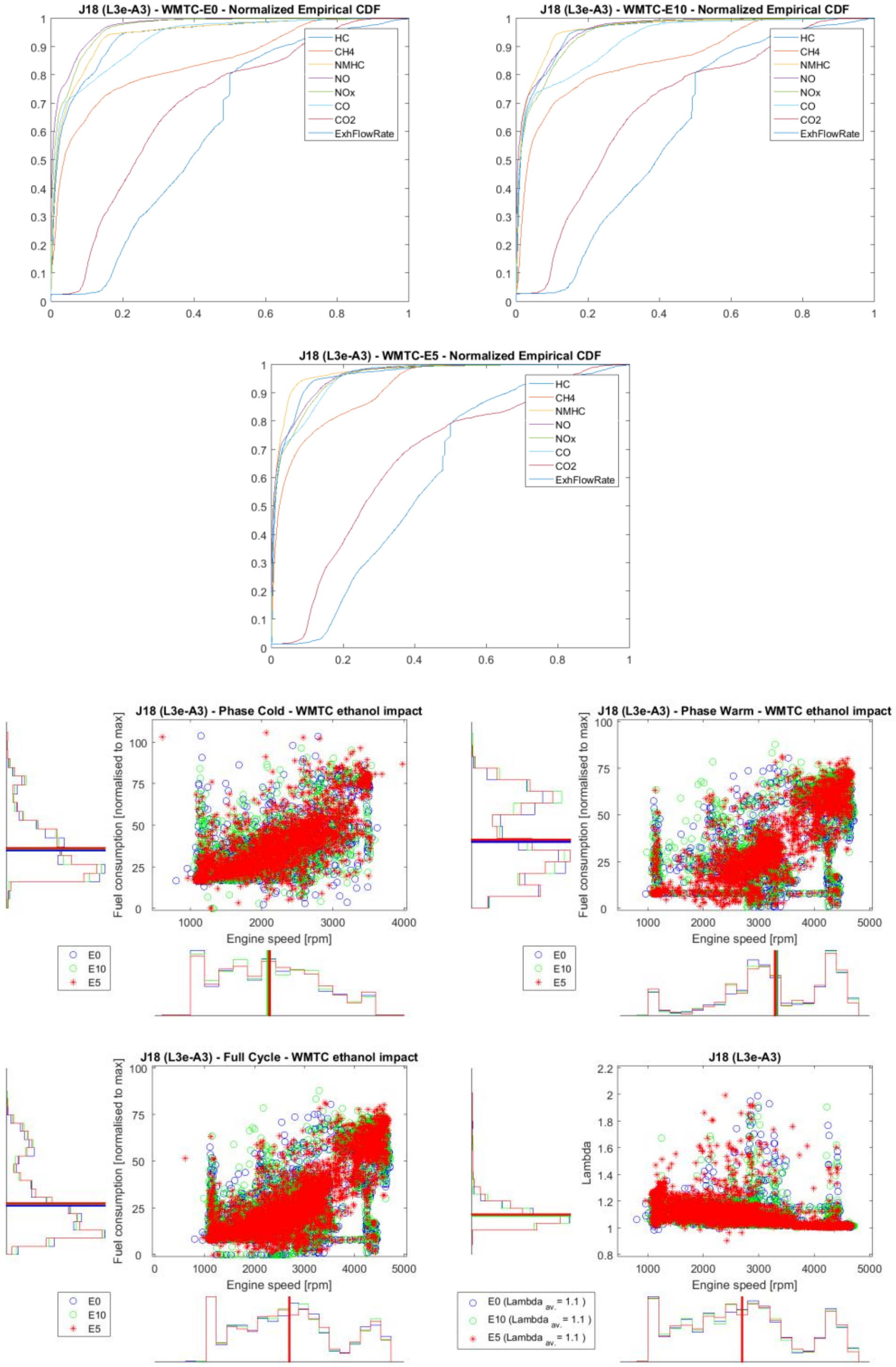


Figure 409. Pollutant emissions, fuel consumption and lambda sensor – Vehicle J18 (L3e-A3) – ethanol impact

H Type II: Unofficial working procedure and test instructions

TYPE II test procedure (PI engines)

1. Determine (normal) idle engine speed

Can the (normal) idle speed be adjusted by simple using bare hands, screwdrivers, spanners, allen keys or a generic scan tool?

YES

Determine **low limit value** for (normal) idle speed. It is the **highest value** of:

- The lowest engine speed the engine can reach by adjusting the idle speed components.
- The speed recommended by the manufacturer -/- 100 rpm

Determine **high limit value** for (normal) idle speed. It is the **lowest value** of:

- Highest idling speed the engine can reach by adjusting the idle speed components
- The speed recommended by the manufacturer +/+ 250 rpm
- The cut-in rotation speed of the automatic clutch

Choose any (normal) idling speed such that:

low limit value < (normal) idle speed < high limit value

NO

Normal idle speed = idle speed at 0% throttle

3. Determine high idle engine speed

High idle speed is:

- either the speed defined by the manufacturer
- or any speed above 2000 rpm

NOTE: **high idle speed shall always be above 2000 rpm**

2. Execute the test

1. Drive to warm-up the vehicle to conditions that match the conditions of the vehicle at the end of the type I test with regard to coolant temperature, oil temperature and exhaust gas temperature
2. Go to idle speed and maintain idle speed for > 60s
3. Go to high idle speed and maintain high idle speed for > 60s

TYPE II test LAB OPERATOR SHEET (PI engines)

1. Determine (normal) idle engine speed

Can the (normal) idle speed be adjusted by simple using bare hands, screwdrivers, spanners, allen keys or a generic scan tool?

YES

1a: declared idle speed -/- 100 rpm	rpm
1b: lowest speed before engine shuts down	rpm
Highest value of 1a and 1b = **low limit value (1)**	**rpm**

2a: declared idle speed +/+ 250 rpm	rpm
2b: highest adjustable idle speed	rpm
2c: cut-in rotation speed of automatic clutch	rpm
Lowest value of 2a, 2b and 2c = **high limit value (2)**	**rpm**

Low limit value (1) < (normal) idle speed < high limit value (2)

rpm

NO

Speed at 0% throttle

rpm

2. Determine high idle engine speed

Either declared high idle speed	rpm
Or any speed above 2000 rpm	rpm
NOTE: **high idle speed shall always be above 2000 rpm**	

High idle speed:

rpm

3. Execute the test

Date / time	
Vehicle code	
File Vela	
Idle speed	rpm
Time vela	s
High idle speed	rpm
Time vela	s

I Test results: Type II test results

Table 125: Vehicles, test conditions and measured values for type II test

Vehicle	Equipment	Engine speed [rpm]		HC [ppm]		NO_x [ppm]		CO [ppm]	
		Idle	High idle	Idle	High idle	Idle	High idle	Idle	High idle
J05 (L1e-A)	JRC VELA 1	1244	2047	15162	9909	2	1	3598	1327
J06 (L1e-B, LS)	JRC VELA 1	1198	2679	1430	544	2	1	5512	186
J07 (L1e-B, LS)	JRC VELA 1	1270	2300	62586	51515	12	11	25287	28387
J10 (L1e-B, LS)	JRC VELA 1	1524	2832	3123	797	4	75	12801	3469
J31, valid. (L1e-B, LS)	4-gas analyser	1762	2028	247	149	-	-	600	600
J03 (L1e-B, HS)	JRC VELA 1	1634	2727	416	1417	86	58	970	2264
J04 (L1e-B, HS)	JRC VELA 1	1437	2179	263	325	5	9	180	477
J12 (L1e-B, HS)	JRC VELA 1	1927	2845	617	1463	2	4	198	258
J14 (L1e-B, HS)	JRC VELA 1	1567	2288	1168	1472	8	8	1388	2171
J17 (L1e-B, HS)	JRC VELA 1	1786	2363	2269	1726	33	52	798	3749
J34, valid. (L1e-B, HS)	4-gas analyser	1528	2286	54	41	-	-	1000	500
J26 (L2e-U)	JRC VELA 1	1189	3154	4118	19358	5	3	1244	65234
J11 (L3e-A2)	JRC VELA 1	1838	2818	575	208	2	2	3481	1288
J13 (L3e-A2)	JRC VELA 1	1504	2125	71	16	19	62	20	13
J15 (L3e-A2)	JRC VELA 1	1648	2076	93	22	20	0	8	53
J40, valid. (L3e-A2)	4-gas analyser	770	2020	-	-	-	-	800	100
J18 (L3e-A3)	JRC VELA 1	1147	3175	253	49	0	0	37	93
J24 (L5e-A)	JRC VELA 1	1420	2100	2290	1793	12	46	30878	31079
J22 (L6e-BU)	JRC VELA 1	1011	2079	113	139	572	303	98	202
J08 (L7e-B1)	JRC VELA 1	1254	2002	65	99	34	7	360	1687
J16 (L7e-B1)	JRC VELA 1	1410	2344	820	181	2	1	4502	1731
J25, valid. (L7e-B1)	JRC VELA 1	1561	2741	272	169	75	105	146	121
J09 (L7e-B2)	JRC VELA 1	1311	2279	3813	288	1	1	2064	64

J Type III: Unofficial working procedure and test instructions

TYPE III test procedure (4S-engines), emissions of crankcase gases

1. Test method nr. 1: 'Basic method'; type III test method; crankcase pressure measurement on the chassis dyno with data logger

Preparation

1. Measurement equipment and installation;
   a. *Install a manometer on the crankcase of the vehicle at an appropriate location, for instance on the dip-stick hole (figure 1);*
   b. *Install a manometer on the intake manifold (figure 2);*
   c. *Install a manometer in the test cell for the ambient pressure;*
   d. *The manometers used for the crankcase and ambient pressure should have an accuracy of ± 0,1 kPa. The manometer used for the intake manifold should have an accuracy of ± 1 kPa;*
   e. *The sampling rate shall be ≥ 1 Hz;*
   f. *Speed shall be measured to within ± 2 km/h.*
2. Preparation of test vehicle: The engine's apertures shall be left as found;
3. Install vehicle on the chassis dynamometer.

Test

The functioning of the crankcase ventilation system shall be checked for the operation conditions as described in Table 1. The sample duration per condition is ≥ 60 seconds when the conditions are continuously operated and stabilized.

Table 1: Test conditions

Condition number	vehicle speed (km/h)	Power absorbed by the brake
1.	Idling (in conformity with the manufacturer's recommendations)	Nil
2.	Highest of: (a) 50 ±2 (in 3rd gear or 'drive') or (b) if (a) not achievable, 50 % of max. design vehicle speed.	That corresponding to the setting for type I test at 50 km/h or if not achievable type I test at 50 % of max. design vehicle speed.
3.		As for condition 2, multiplied by a factor of 1,7

Pass/fail

The vehicle shall be deemed satisfactory if, in every condition of the measurement, the pressure measured in the crankcase does not exceed the atmospheric pressure prevailing at the time of measurement.

If, in one or more conditions the highest pressure value measured in the crankcase within the used time period exceeds the atmospheric pressure, an additional test as defined in **'test method nr. 2'**. or **'test method nr. 3'** (as chosen by the manufacturer) shall be performed to the satisfaction of the approval authority.

2. Test method nr. 2: 'Additional type III test method (No 1)'; crankcase pressure measurement on the chassis dyno with a flexible bag

Preparation	1. Measurement equipment and installation a. *A flexible bag shall be connected to the dipstick hole.* i. *The easiest way for preparation is to use the connection tube of test method nr. 1;* ii. *Install a valve which can be used for opening en closing of the connection to the crankcase (figure 3);* iii. *Install the flexible bag to the valve.* b. *If the structural layout of the engine is such that the test cannot be performed by the method as described in point (a), the measurements shall be effected by the following method:* i. *All apertures other than that required for the recovery of the gases shall be closed;* ii. *The flexible bag shall be placed on a suitable take-off which does not introduce any additional loss of pressure and is installed on the recycling circuit of the device directly at the engine-connection aperture.* c. *The used flexible bag needs to be impervious to crankcase gases and having a capacity of approximately five litres* d. *Speed shall be measured to within ± 2 km/h* 4. Preparation of test vehicle: The engine's apertures shall be left as found. 5. Install vehicle on the chassis dynamometer
Test	The functioning of the crankcase ventilation system shall be checked for the operation conditions as described in Table 1. • *The bag shall be closed before each measurement. It shall be opened to the crankcase for five minutes for each condition of measurement;* • *The sample duration per condition is five minutes when the conditions are continuously operated and stabilized.*
Pass/fail	The vehicle shall be deemed satisfactory if, in every condition of measurement defined in Table 1, no visible inflation of the bag occurs.

3. Test method nr. 3: 'Alternative additional type III test method (No 2)'; Crankcase leak check measurement with sealed engin

Preparation

1. Measurement equipment and installation
   a. *Prepare a connection to pressurize the crankcase (figure 1);*
   b. *Install a manometer on the crankcase of the vehicle at an appropriate location, for instance on the dip-stick hole, the oil fill cap, drain plug (figure 4) or level check port*
      i. *This should be another location than where the crankcase is pressurized;*
      ii. *All seals between the screw-thread, gaskets, O-rings and other (pressure) seals of the engine shall remain intact and representative of the engine type;*
      iii. *If needed, remove the crankcase oil.*
   c. *Install a manometer in the test cell for the ambient pressure;*
   d. *Use a pressure reducer to avoid too high pressures (figure 7)*
2. Engine sealing
   a. *The engine of the vehicle may be installed on a test rig*
   b. *Remove the intake manifold (or carburetor) and exhaust manifold;*
   c. *Hermetically seal the air intake and exhaust evacuation openings (including the crankcase ventilation opening) of the engine with plugs (figure 5 and 6);*
   d. *Alternatively, the intake and exhaust systems may be plugged on a representative test vehicle on locations chosen by the manufacturer and to the satisfaction of the technical service and approval authority;*
   e. *The crankshaft may be rotated to optimise the position of the pistons, minimising pressure loss to the combustion chamber(s).*

Test

1. Pressure the crankcase system with compressed air to:
   a. *The maximum recorded peak pressure as monitored during the three test conditions in test method nr. 1 and at least to a pressure of 5 kPa over ambient pressure, or;*
   b. *To a higher pressure at the choice of the manufacturer.*
   c. *The minimum pressure of 5 kPa shall be allowed only if it can be demonstrated by means of traceable calibration that test equipment has accurate resolution for testing at that pressure. A higher test pressure shall be used otherwise, according to the equipment's calibrated resolution.*
2. Determine the correct pressure with the installed manometer;
3. Ambient temperature and pressure shall remain constant throughout the test;
4. The compressed air source inducing the overpressure shall be closed and the pressure in the crankcase shall be monitored for 300 seconds. See figure 7 for an installation overview.

Pass/fail

The test pass condition shall be: crankcase pressure ≥ 0,95 times the initial overpressure for 300 seconds after closure of the compressed air source.

Figure 1: Connection at dip-stick hole

Figure 2: MAP sensor

Figure 3: Connection at dip-stick hole with installed valve

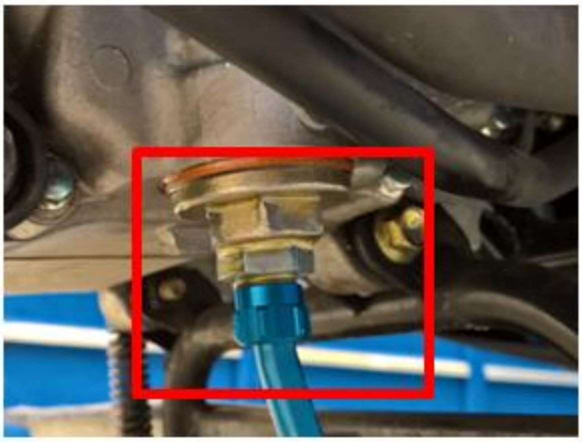


Figure 4: Connection at oil drain plug

Figure 5: Intake manifold plugged

Figure 6: Exhaust opening plugged

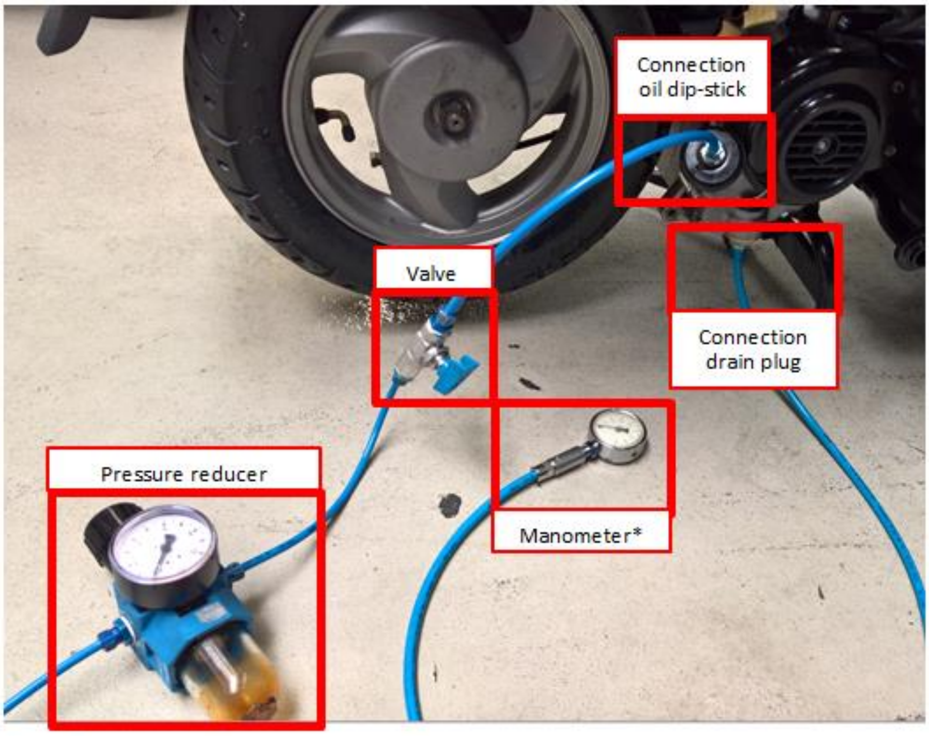


Figure 7: Overview installation for test method nr. 3
* This should be a digital manometer

K Type III: vehicle specific test results

Vehicle specific test results sheet | crankcase tests

Vehicle specifications

Vehicle ID no.	**J03**
category	**L1e-B**
category name	**high speed moped**
engine capacity class [cc]	**50**
rated power [kW]	**3**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**45**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**carburettor**
SAS	**Yes**
catalyst**	**2w**
reference mass class [kg]	**160**
year	**2015**
mileage [km]***	**0**

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

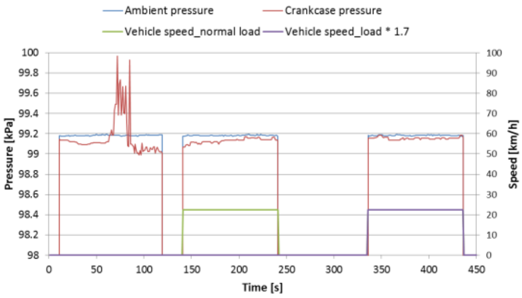
*** mileage at vehicle take-in, before any applied degreening

Type III test results	Pass/Fail
Basic method	X
Additional method No 1	✓
Alternative additional method No 2	X

Pressure sensor specifications

Sensor	1	2
Used for	Amb. /crankcase	Crankcase / MAP
Brand	Keller	Keller
Type	PAA33/80794	PAA33/08794
Input range	80-120kPa	0-200kPa
Output range	0-10V	0-10V
Error at 100kPa	-0.0009 kPa	0.0008 kPa

Basic test with crankcase and ambient pressure

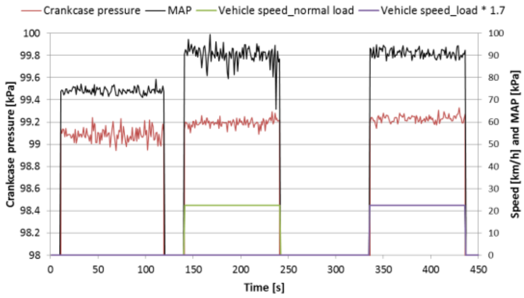


Condition 1: Idle

Condition 2: 50% of max. vehicle speed

Condition 3: load of condition 2 multiplied with 1,7

Basic test repetition with crankcase pressure and MAP



Condition 1: Idle

Condition 2: 50% of max. vehicle speed

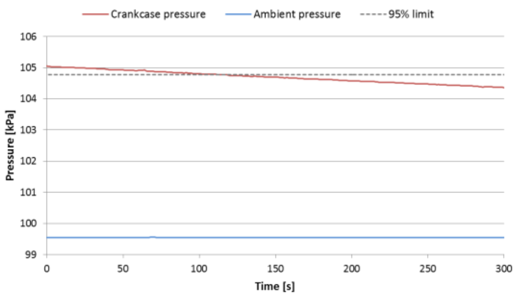
Condition 3: load of condition 2 multiplied with 1,7

Additional test method No 1: Bag inflation at load points

Used bag volume	*1 L*
Test result overall	***Pass***
Condition 1	*No visible inflation*
Condition 2	*No visible inflation*
Condition 3	*No visible inflation*

``

Alternative additional test method No 2



The crankcase pressure does not remain at ≥ 95% of the initial pressure for at least 300 seconds.

Vehicle specific test results sheet | crankcase tests

Vehicle specifications	
Vehicle ID no.	**J17**
category	**L1e-B**
category name	**high speed moped**
engine capacity class [cc]	**50**
rated power [kW]	**3**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**45**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**carburettor**
SAS	**Yes**
catalyst**	**2w**
reference mass class [kg]	**170**
year	**2013**
mileage [km]***	**4926**

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

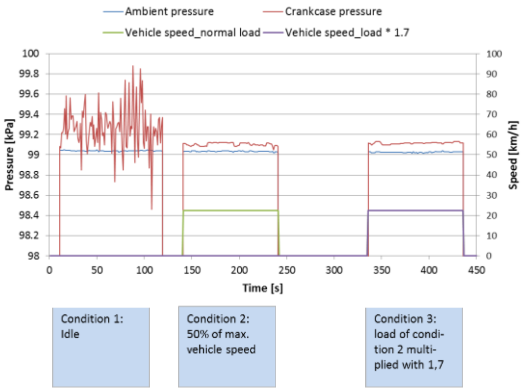
*** mileage at vehicle take-in, before any applied degreening

Type III test results	Pass/Fail
Basic method	X
Additional method No 1	✓
Alternative additional method No 2	✓

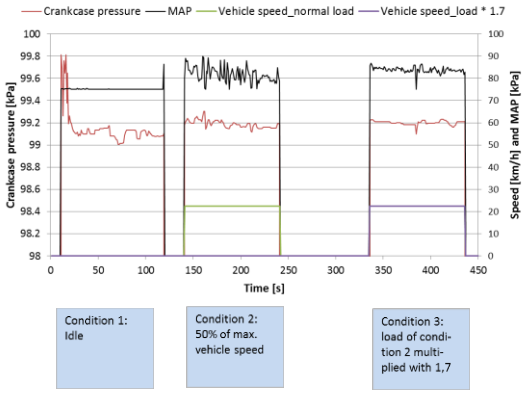
Pressure sensor specifications

Sensor	1	2
Used for	Ambient / MAP	Crankcase
Brand	Keller	Keller
Type	PAA33/80794	PAA33/08794
Input range	80-120kPa	0-200kPa
Output range	0-10V	0-10V
Error at 100kPa	-0.0009 kPa	0.0008 kPa

Basic test with crankcase and ambient pressure



Basic test repetition with crankcase pressure and MAP

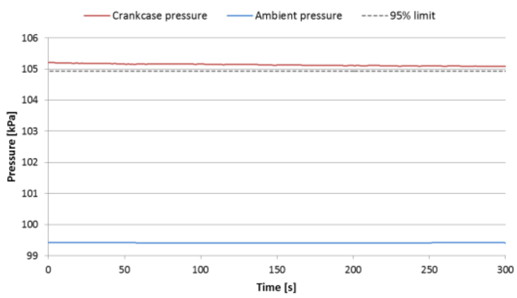


Additional test method No 1: Bag inflation at load points

Used bag volume	*1 L*
Test result overall	***Pass***
Condition 1	*No visible inflation*
Condition 2	*No visible inflation*
Condition 3	*No visible inflation*

``

Alternative additional test method No 2



The crankcase pressure remains at ≥ 95% of the initial pressure for at least 300 seconds.

Vehicle specific test results sheet | crankcase tests

Vehicle specifications	
Vehicle ID no.	**J19**
category	**L3e-A1**
category name	**low perf. motorcycle**
engine capacity class [cc]	**130**
rated power [kW]	**7**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**90**
Transmission	**CVT**
Euro class	**Euro 3**
Fuel delivery system	**carburettor**
SAS	**No**
catalyst**	**2w**
reference mass class [kg]	**180**
year	**2012**
mileage [km]***	**1372**

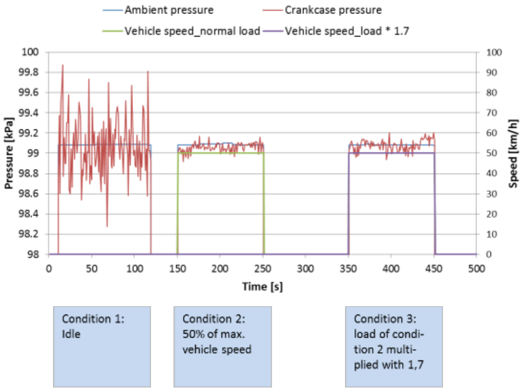
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

Type III test results	Pass/Fail
Basic method	X
Additional method No 1	✓
Alternative additional method No 2	✓

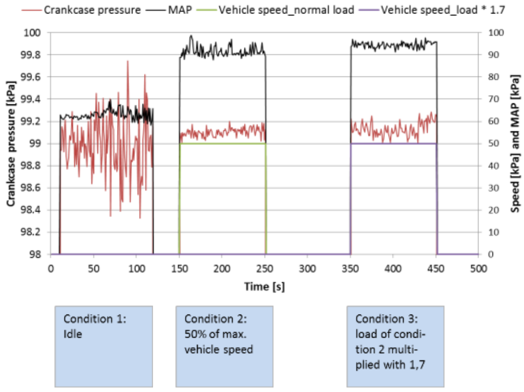
Pressure sensor specifications

Sensor	1	2
Used for	Crankcase	Ambient / MAP
Brand	Keller	Keller
Type	PAA33/80794	PAA33/08794
Input range	80-120kPa	0-200kPa
Output range	0-10V	0-10V
Error at 100kPa	-0.0009 kPa	0.0008 kPa

Basic test with crankcase and ambient pressure



Basic test repetition with crankcase pressure and MAP

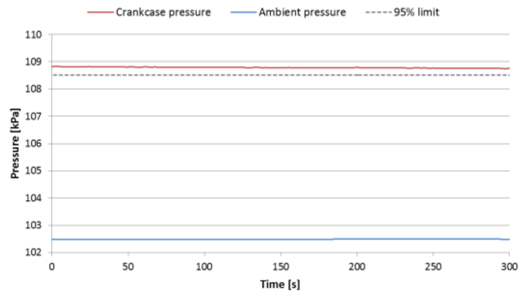


Additional test method No 1: Bag inflation at load points

Used bag volume	*1 L*
Test result overall	***Pass***
Condition 1	*No visible inflation*
Condition 2	*No visible inflation*
Condition 3	*No visible inflation*

``

Alternative additional test method No 2



The crankcase pressure remains at ≥ 95% of the initial pressure for at least 300 seconds.

Vehicle specific test results sheet | crankcase tests

Vehicle specifications	
Vehicle ID no.	**J15**
category	**L3e-A2**
category name	**medium perf. motorcycle**
engine capacity class [cc]	**690**
rated power [kW]	**32**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**>150**
Transmission	**Manual**
Euro class	**Euro 4**
Fuel delivery system	**injection**
SAS	**Yes**
catalyst**	**3w**
reference mass class [kg]	**230**
year	**2016**
mileage [km]***	**1000**

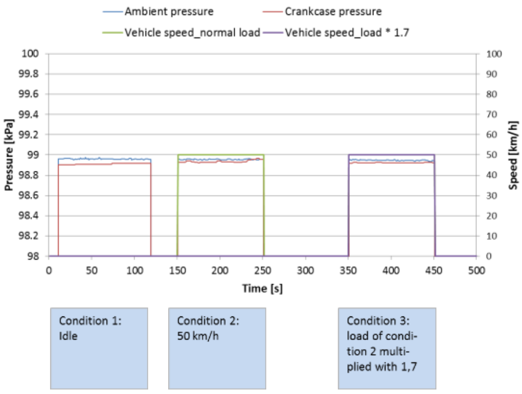
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

Type III test results	Pass/Fail
Basic method	X
Additional method No 1	✓
Alternative additional method No 2	X

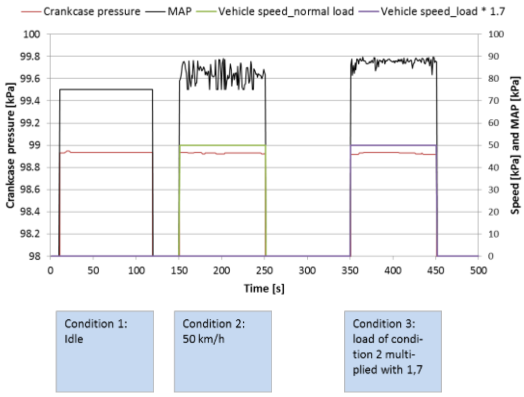
Pressure sensor specifications

Sensor	1	2
Used for	Ambient / MAP	Crankcase
Brand	Keller	Keller
Type	PAA33/80794	PAA33/08794
Input range	80-120kPa	0-200kPa
Output range	0-10V	0-10V
Error at 100kPa	-0.0009 kPa	0.0008 kPa

Basic test with crankcase and ambient pressure



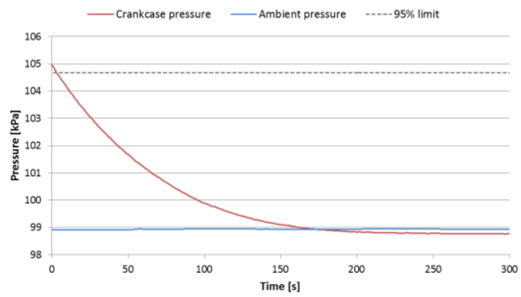
Basic test repetition with crankcase pressure and MAP



Additional test method No 1: Bag inflation at load points

Used bag volume	*1 L*
Test result overall	***Pass***
Condition 1	*No visible inflation*
Condition 2	*No visible inflation*
Condition 3	*No visible inflation*

Alternative additional test method No 2



The crankcase pressure does not remain at ≥ 95% of the initial pressure for at least 300 seconds.
Possibly the test failed due to incomplete engine sealing before the test

Vehicle specific test results sheet | crankcase tests

Vehicle specifications	
Vehicle ID no.	**J18**
category	**L3e-A3**
category name	**high perf. motorcycle**
engine capacity class [cc]	**1170**
rated power [kW]	**92**
engine combustion type*	**G-4S**
# of cylinders	**2**
Maximum design speed [km/h]	**>150**
Transmission	**Manual**
Euro class	**Euro 4**
Fuel delivery system	**injection**
SAS	**No**
catalyst**	**3w**
reference mass class [kg]	**300**
year	**2015**
mileage [km]***	**1156**

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

*** mileage at vehicle take-in, before any applied degreening

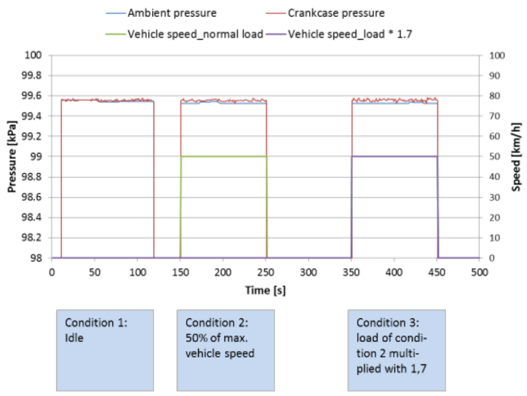
Type III test results	**Pass/Fail**
Basic method	X
Additional method No 1	X
Alternative additional method No 2	*

Pressure sensor specifications

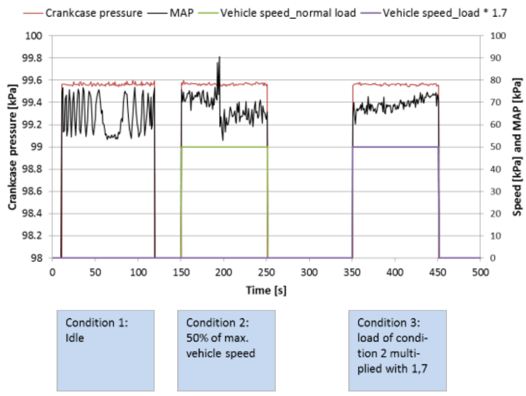
Sensor	1	2
Used for	Crankcase	Ambient / MAP
Brand	Keller	Keller
Type	PAA33/80794	PAA33/08794
Input range	80-120kPa	0-200kPa
Output range	0-10V	0-10V
Error at 100kPa	-0.0009 kPa	0.0008 kPa

* Not performed

Basic test with crankcase and ambient pressure



Basic test repetition with crankcase pressure and MAP



Additional test method No 1: Bag inflation at load points

Used bag volume	*1 L*
Test result overall	***Fail***
Condition 1	*No visible inflation*
Condition 2	*Visible inflation*
Condition 3	*Visible inflation*

``

Alternative additional test method No 2

Not performed

Vehicle specific test results sheet | crankcase tests

Vehicle specifications

Vehicle ID no.	**J22**
category	**L6e-BU**
category name	**light quadri-mobile**
engine capacity class [cc]	**400**
rated power [kW]	**4**
engine combustion type*	**D-4S**
# of cylinders	**2**
Maximum design speed [km/h]	**45**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**injection**
SAS	**No**
catalyst**	**n.a.**
reference mass class [kg]	**0**
year	**n/a**
mileage [km]***	**988**

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

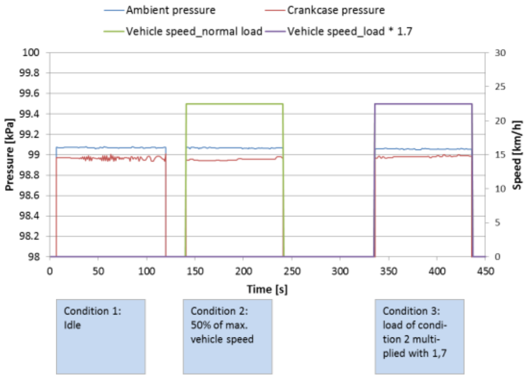
Type III test results	**Pass/Fail**
Basic method	✓
Additional method No 1	✓
Alternative additional method No 2	**

Pressure sensor specifications

Sensor	1	2
Used for	Ambient	Crankcase
Brand	Keller	Keller
Type	PAA33/80794	PAA33/08794
Input range	80-120kPa	0-200kPa
Output range	0-10V	0-10V
Error at 100kPa	-0.0009 kPa	0.0008 kPa

** No valid test data

Basic test



Additional test method No 1: Bag inflation at load points

Used bag volume	*5 L*
Test result overall	***Pass***
Condition 1	*No visible inflation*
Condition 2	*No visible inflation*
Condition 3	*No visible inflation*

``

Alternative additional test method No 2

Test data not valid

Vehicle specific test results sheet | crankcase tests

Vehicle specifications	
Vehicle ID no.	**J08**
category	**L7e-B1**
category name	**heavy all terrain quad**
engine capacity class [cc]	**570**
rated power [kW]	**11**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**70**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**injection**
SAS	**No**
catalyst**	**2w**
reference mass class [kg]	**450**
year	**2015**
mileage [km]***	**900**

Type III test results	Pass/Fail
Basic method	✓
Additional method No 1	✓
Alternative additional method No 2	X

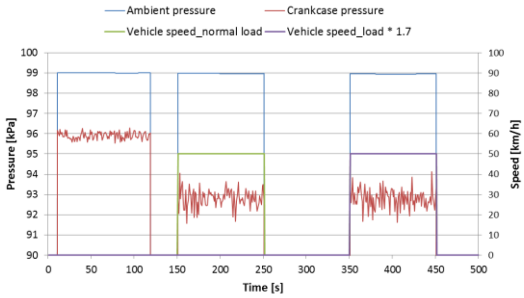
Pressure sensor specifications		
Sensor	1	2
Used for	Crankcase	Ambient / MAP
Brand	Keller	Keller
Type	PAA33/80794	PAA33/08794
Input range	80-120kPa	0-200kPa
Output range	0-10V	0-10V
Error at 100kPa	-0.0009 kPa	0.0008 kPa

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

*** mileage at vehicle take-in, before any applied degreening

Basic test with crankcase and ambient pressure



Condition 1: Idle

Condition 2: 50% of max. vehicle speed

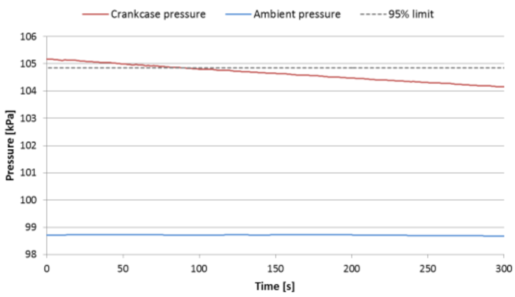
Condition 3: load of condition 2 multiplied with 1,7

Additional test method No 1: Bag inflation at load points

Used bag volume	*1 L*
Test result overall	***Pass***
Condition 1	*No visible inflation*
Condition 2	*No visible inflation*
Condition 3	*No visible inflation*

``

Alternative additional test method No 2



The crankcase pressure does not remain at ≥ 95% of the initial pressure for at least 300 seconds.

L SHED verification procedure

The SHED verification test procedure is based on the procedure prescribed in Annex V, Appendix 4 to Regulation (EU) No 134/2014 and consists of the following parts:

- Check of thermocouples based on reference traceable thermocouple.
- Check of HC FID analyzer with reference gas cylinders*
- Retention test (check of HC losses during a specific time period)

*This check was not performed due to unavailability of gas cylinders. Nevertheless, the zero and span checks performed before each SHED test show that there aren't any high deviations between the bottle concentration and the recordings of the HC analyzer. This is a strong indication that the HC analyzer of the SHED functions properly.

1. Thermocouple check

During each diurnal test carried out in the SHED two thermocouples (type K) were used, as shown in Figure 410, Figure 411 in order to record:

- The liquid fuel temperature in the fuel tank
- The fuel vapor temperature in the fuel tank

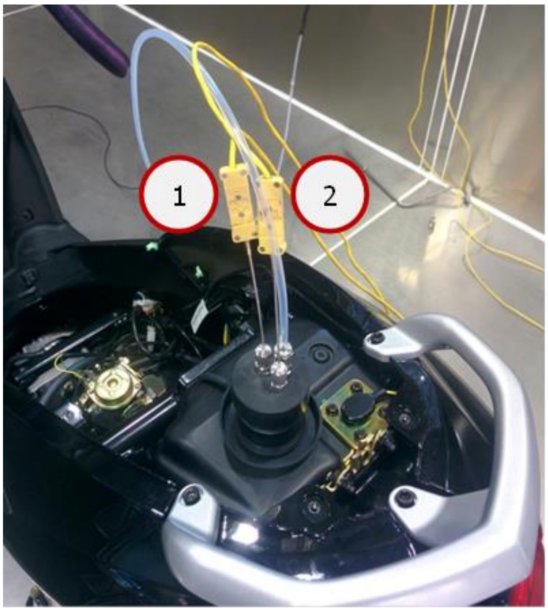


Figure 410: Thermocouples (1 for liquid fuel temperature recording, 2 for fuel vapor temperature recording) installed on fuel tank cap.

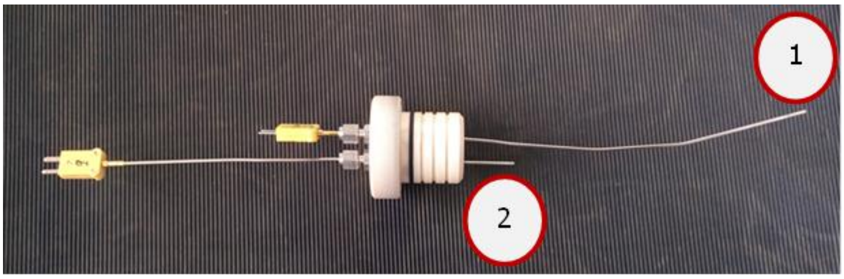


Figure 411: Detailed view of fuel tank cap with thermocouples (1 for liquid fuel temperature recording, 2 for fuel vapor temperature recording).

In all SHED tests carried out, 4 different thermocouples were used due to different size and dimensions of the fuel tank of each vehicle. All of them were verified against a reference thermocouple provided by the JRC. The tests were performed in a temperature controlled enclosure, as shown in
Figure 412, under various temperatures. The temperature recording of the type K thermocouples was done by the same data acquisition device used in the SHED tests while the reference thermocouple is a stand-alone device (Figure 413).

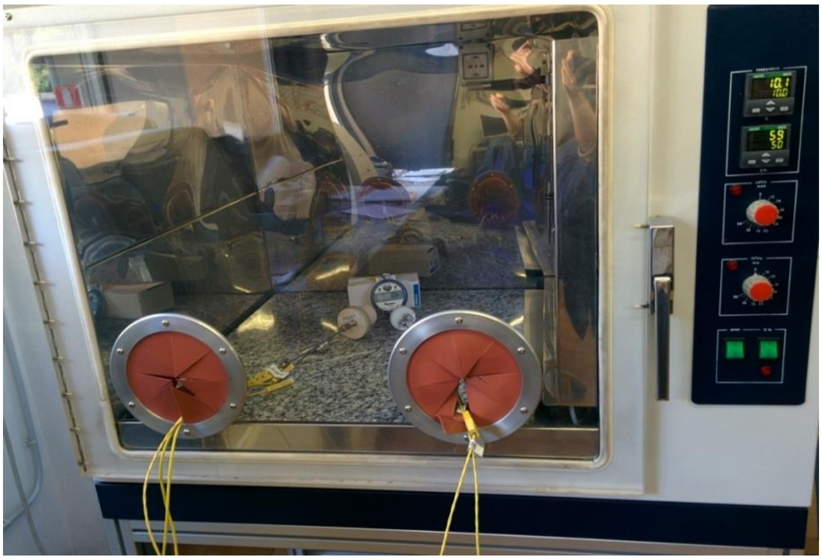


Figure 412: Temperature-controlled enclosure used for thermocouples check.

Figure 413: Reference (1) and under-test (2) thermocouples

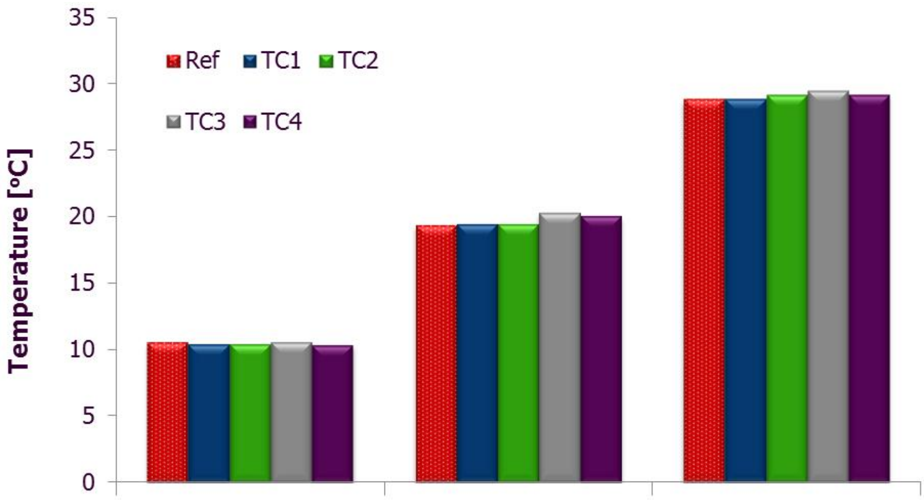


Figure 414: Thermocouple check results

Based on Regulation 134/2014 the accuracy of the temperature recording system should be within ±1.7 K. The results of the Figure 414 show that in all cases the thermocouple recordings are within the specified limits (max deviation from reference 0.9 K), thus all the thermocouples are verified.

2. Retention test

The test procedure followed for the determination of SHED enclosure losses is based on the process prescribed by the EU Legislation 134/2014. The basic steps of this test are the following:

i. Injection of 4g of propane inside the SHED
ii. Mixing in the chamber for at least 4 h

iii. Determination of the HC losses after this period. Based on legislation the HC losses during this period should be less than 4%.

Instruments used (shown in Figure 415 and Figure 416):

- Critical Flow Orifice (CFO) device in order to inject the desired propane amount
- Propane bottle (concentration 100%)
- 

Figure 415: CFO device and propane bottle used for the retention test

Figure 416: CFO device control panel

Table 126: Retention test results and legislation limit

	HC concentration [ppm]	HC mass [g]
Start of the test	133.9	3.94
End of the test	132.9	3.90
Difference	**-1.0**	**-0.04**
Difference [%]	**-0.75**	**-1.02**
Legislation limit [%]	**-**	**-4.0**

The results presented in Table 126 show that the HC losses during the 4-hour period are within the limits determined by the legislation. Thus, the SHED enclosure passes this test and is also verified.

3. Conclusions

Based on the above analysis, the JRC SHED facilities are verified according to the procedures prescribed in the EU Legislation 134/2014.
Thus, the results from the SHED test measurements can be used for the evaluation of evaporative emissions for the present study and there is no need for any corrections or adjustments to the SHED test emissions results.

M Type V test and modelling results

Vehicle specific test results sheet | durability test cycles

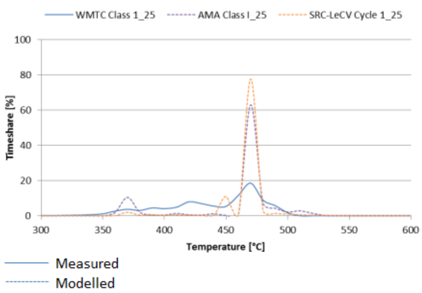
Vehicle specifications	
Vehicle ID no.	**J05**
category	**L1e-A**
category name	**powered cycle**
engine capacity class [cc]	**30**
rated power [kW]	**1**
engine combustion type*	**G-2S**
# of cylinders	**1**
Maximum design speed [km/h]	**25**
Transmission	**Fixed**
Euro class	**Euro 1**
Fuel delivery system	**carburettor**
SAS	**No**
catalyst**	**n.a.**
reference mass class [kg]	**100**
year	**2009**
mileage [km]***	**200**

test cycles		Tested	Modelled
WMTC	Class 1 25km/h	✓	✓
AMA	Class I 25km/h		✓
SRC-LeCV	Cycle 1 25km/h		✓

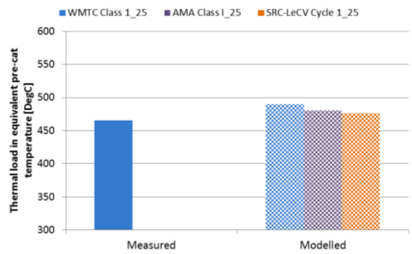
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

Thermal Load Comparison

Temperature distribution per test cycle



Thermal load per test cycle



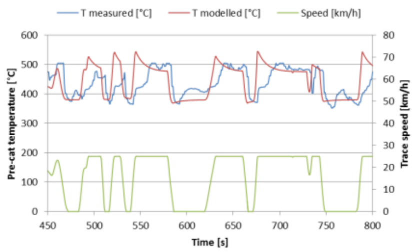
Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 1 25km/h	71%
AMA Class I 25km/h	86%
SRC-LeCV Cycle 1 25km/h	95%

Thermal pre-cat model specifications

Model formula:
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:
A= 379.706
B= 3.814
C= 56.441



Vehicle specific test results sheet | durability test cycles

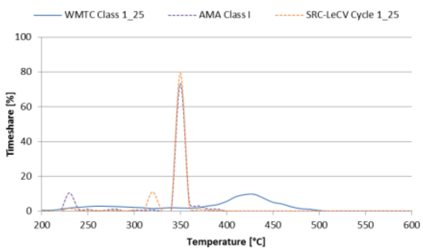
Vehicle specifications	
Vehicle ID no.	**J06**
category	**L1e-B**
category name	**low speed moped**
engine capacity class [cc]	**50**
rated power [kW]	**3**
engine combustion type*	**G-2S**
# of cylinders	**1**
Maximum design speed [km/h]	**25**
Transmission	**Fixed**
Euro class	**Euro 2**
Fuel delivery system	**carburettor**
SAS	**Yes**
catalyst**	**2w**
reference mass class [kg]	**120**
year	**2010**
mileage [km]***	**200**

test cycles		Tested	Modelled
WMTC	Class 1 25km/h	✓	✓
AMA	Class I 25km/h		✓
SRC-LeCV	Cycle 1 25km/h		✓

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

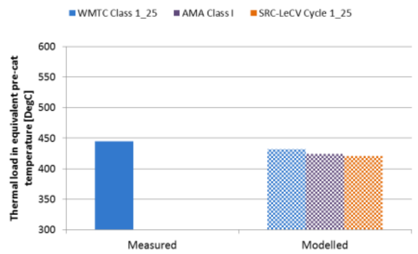
Thermal Load Comparison

Temperature distribution per test cycle



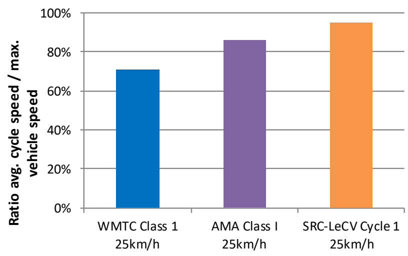
Measured
Modelled

Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

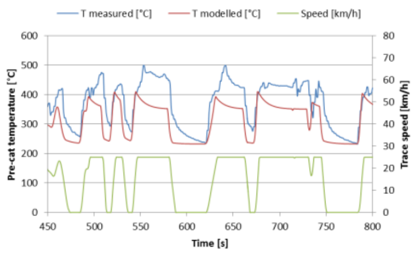
Cycle	Ratio
WMTC Class 1 25km/h	71%
AMA Class I 25km/h	86%
SRC-LeCV Cycle 1 25km/h	95%



Thermal pre-cat model specifications

Model formula:
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:
A= 283.665
B= 5.508
C= 61.298



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J07**
category	**L1e-B**
category name	**low speed moped**
engine capacity class [cc]	**50**
rated power [kW]	**3**
engine combustion type*	**G-2S**
# of cylinders	**1**
Maximum design speed [km/h]	**25**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**carburettor**
SAS	**No**
catalyst**	**2w**
reference mass class [kg]	**170**
year	**2010**
mileage [km]***	**200**

test cycles		Tested	Modelled
WMTC	Class 1 25km/h	✓	✓
AMA	Class I 25km/h		✓
SRC-LeCV	Cycle 1 25km/h		✓

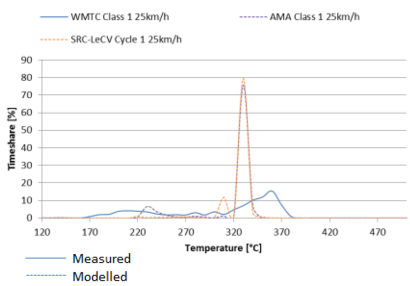
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

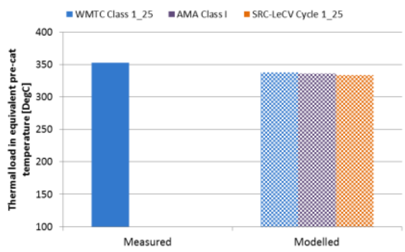
*** mileage at vehicle take-in, before any applied degreening

Thermal Load Comparison

Temperature distribution per test cycle

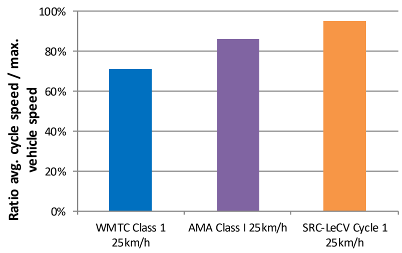


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 1 25km/h	71%
AMA Class I 25km/h	86%
SRC-LeCV Cycle 1 25km/h	95%



Thermal pre-cat model specifications

Model formula:

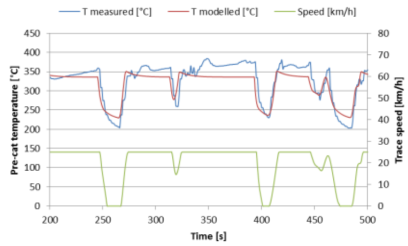
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

A= 223.576

B= 4.491

C= 38.833



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J10**
category	**L1e-B**
category name	**low speed moped**
engine capacity class [cc]	**50**
rated power [kW]	**3**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**25**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**carburettor**
SAS	**Yes**
catalyst**	**2w**
reference mass class [kg]	**160**
year	**2010**
mileage [km]***	**n/a**

test cycles		Tested	Modelled
WMTC	Class 1 25km/h	✓	✓
AMA	Class I 25km/h		✓
SRC-LeCV	Cycle 1 25km/h		✓

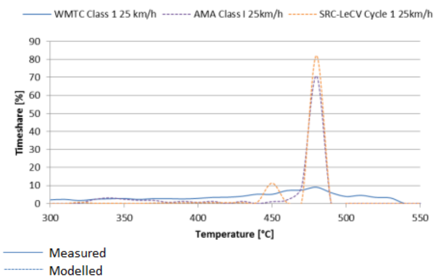
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

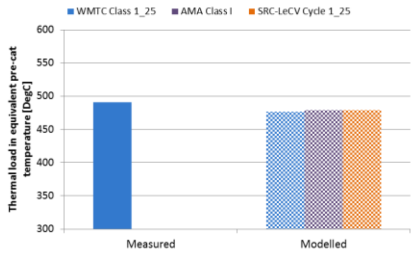
*** mileage at vehicle take-in, before any applied degreening

Thermal Load Comparison

Temperature distribution per test cycle

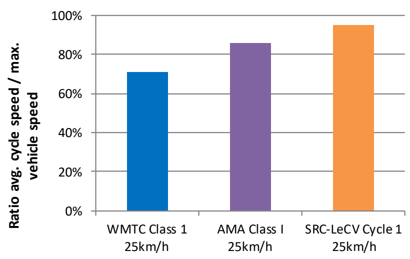


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 1 25km/h	71%
AMA Class I 25km/h	86%
SRC-LeCV Cycle 1 25km/h	95%



Thermal pre-cat model specifications

Model formula:

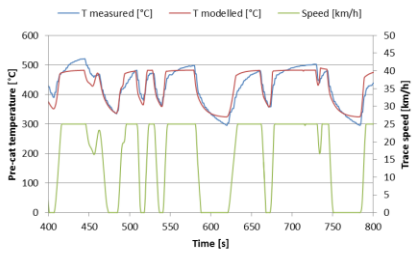
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

A= 322.245

B= 6.404

C= 36.686



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J02**
category	**L1e-B**
category name	**high speed moped**
engine capacity class [cc]	**50**
rated power [kW]	**2**
engine combustion type*	**G-2S**
# of cylinders	**1**
Maximum design speed [km/h]	**45**
Transmission	**Manual**
Euro class	**Euro 2**
Fuel delivery system	**injection**
SAS	**Yes**
catalyst**	**2w**
reference mass class [kg]	**190**
year	**2015**
mileage [km]***	**0**

test cycles		**Tested**	**Modelled**
WMTC	Class 1 45km/h	✓	✓
AMA	Class I 45km/h		✓
SRC-LeCV	Cycle 1 45km/h		✓

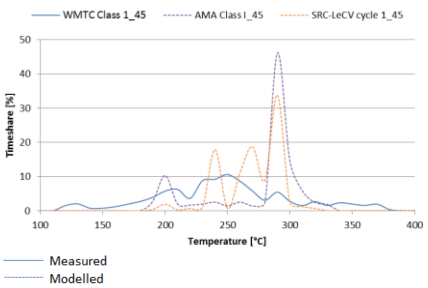
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

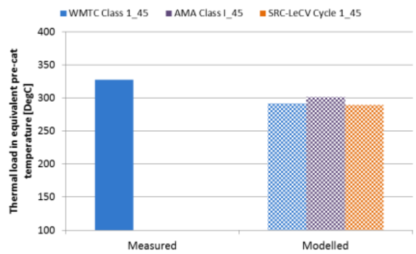
*** mileage at vehicle take-in, before any applied degreening

Thermal Load Comparison

Temperature distribution per test cycle

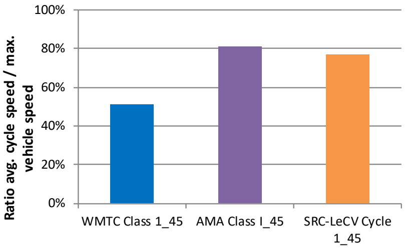


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 1_45	51%
AMA Class I_45	81%
SRC-LeCV Cycle 1_45	77%



Thermal pre-cat model specifications

Model formula:

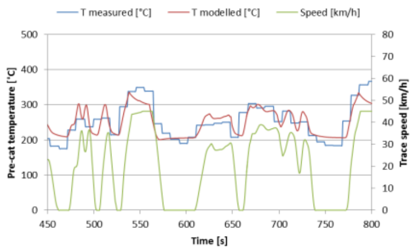
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

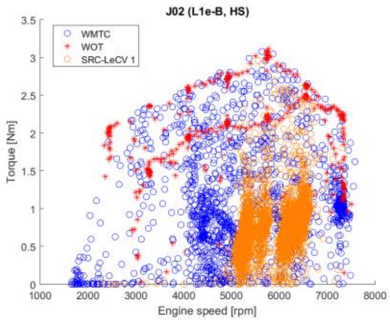
A= 205.797

B= 1.981

C= 16.172



Engine operation area per test cycle



* Torque data of AMA not available

Vehicle specific test results sheet | durability test cycles

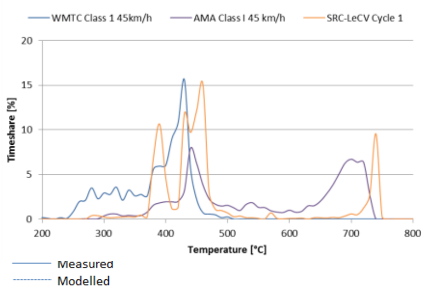
Vehicle specifications	
Vehicle ID no.	**J03**
category	**L1e-B**
category name	**high speed moped**
engine capacity class [cc]	**50**
rated power [kW]	**3**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**45**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**carburettor**
SAS	**Yes**
catalyst**	**2w**
reference mass class [kg]	**160**
year	**2015**
mileage [km]***	**0**

test cycles		Tested	Modelled
WMTC	Class 1 45km/h	✓	✓
AMA	Class I 45km/h	✓	✓
SRC-LeCV	Cycle 1	✓	✓

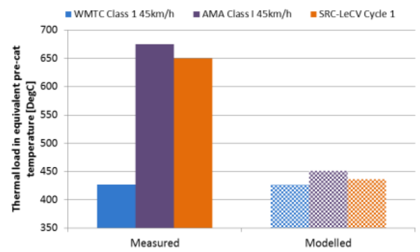
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

Thermal Load Comparison

Temperature distribution per test cycle



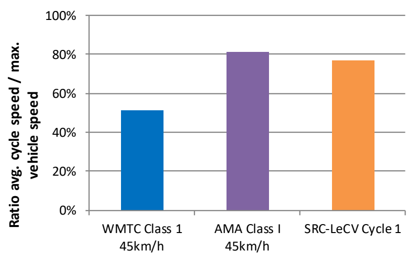
Thermal load per test cycle



Speed limiter effects are not well predicted by the model

Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 1 45km/h	51%
AMA Class I 45km/h	81%
SRC-LeCV Cycle 1	77%



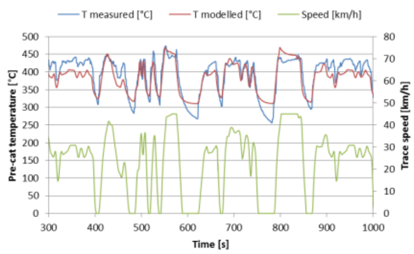
Thermal pre-cat model specifications

Model formula:

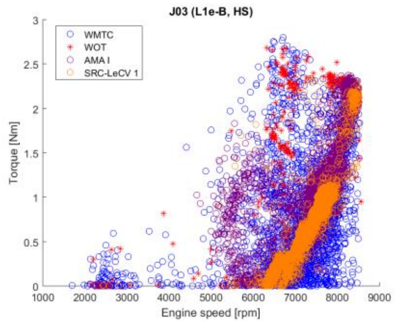
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

A= 316.224
B= 2.945
C= 15.837



Engine operation area per test cycle



Vehicle specific test results sheet | durability test cycles

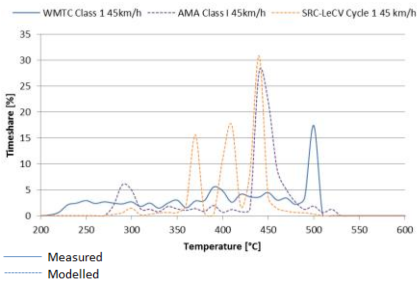
Vehicle specifications	
Vehicle ID no.	**J04**
category	**L1e-B**
category name	**high speed moped**
engine capacity class [cc]	**50**
rated power [kW]	**3**
engine combustion type*	**G-2S**
# of cylinders	**1**
Maximum design speed [km/h]	**45**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**carburettor**
SAS	**Yes**
catalyst**	**2w**
reference mass class [kg]	**160**
year	**2015**
mileage [km]***	**0**

test cycles		Tested	Modelled
WMTC	Class 1 45km/h	✓	✓
AMA	Class I 45km/h		✓
SRC-LeCV	Cycle 1 45km/h		✓

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

Thermal Load Comparison

Temperature distribution per test cycle

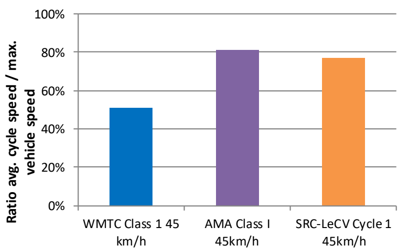


Thermal load per test cycle

Measurement data is truncated at 500 degrees Celsius

Ratio: average cycle speed / maximum vehicle design speed

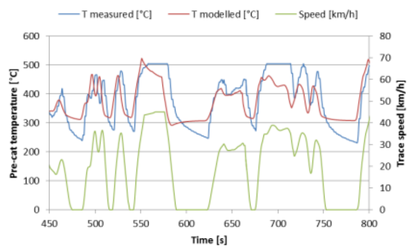
Cycle	Ratio
WMTC Class 1 45 km/h	51%
AMA Class I 45km/h	81%
SRC-LeCV Cycle 1 45km/h	77%



Thermal pre-cat model specifications

Model formula:
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:
A= 307.588
B= 3.121
C= 27.562



Measurement data is truncated at 500 degrees Celsius

Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J12**
category	**L1e-B**
category name	**high speed moped**
engine capacity class [cc]	**50**
rated power [kW]	**3**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**45**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**injection**
SAS	**Yes**
catalyst**	**2w**
reference mass class [kg]	**170**
year	**2013**
mileage [km]***	**846**

test cycles		Tested	Modelled
WMTC	Class 1 45km/h	✓	✓
AMA	Class I 45km/h	✓	✓
SRC-LeCV	Cycle 1 45km/h	✓	✓

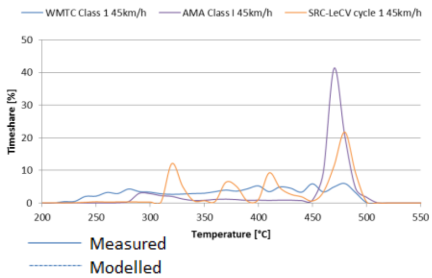
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

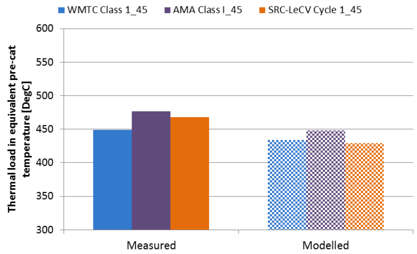
*** mileage at vehicle take-in, before any applied degreening

Thermal Load Comparison

Temperature distribution per test cycle

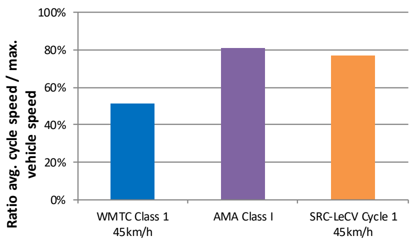


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 1 45km/h	51%
AMA Class I	81%
SRC-LeCV Cycle 1 45km/h	77%



Thermal pre-cat model specifications

Model formula:

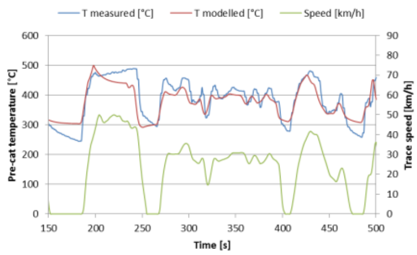
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

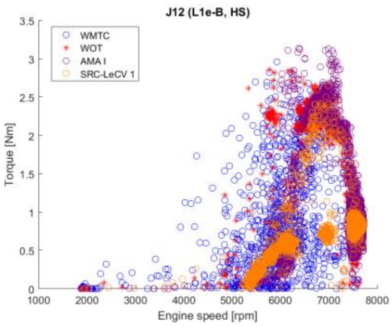
A= 303.142

B= 2.997

C= 24.997



Engine operation area per test cycle



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	J14
category	L1e-B
category name	high speed moped
engine capacity class [cc]	50
rated power [kW]	3
engine combustion type*	G-2S
# of cylinders	1
Maximum design speed [km/h]	45
Transmission	CVT
Euro class	Euro 2
Fuel delivery system	carburettor
SAS	Yes
catalyst**	2w
reference mass class [kg]	180
year	2015
mileage [km]***	500

test cycles		Tested	Modelled
WMTC	Class 1 45km/h	✓	✓
AMA	Class I 45km/h		✓
SRC-LeCV	Cycle 1 45km/h		✓

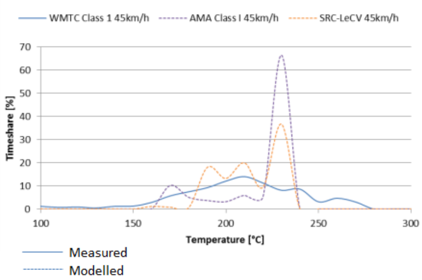
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

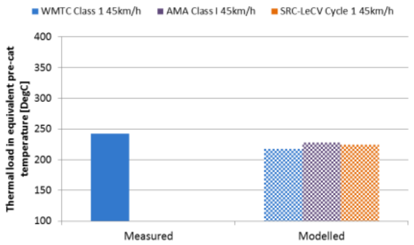
*** mileage at vehicle take-in, before any applied degreening

Thermal Load Comparison

Temperature distribution per test cycle

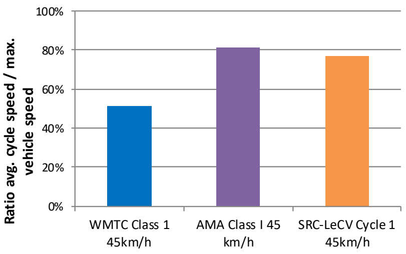


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 1 45km/h	51%
AMA Class I 45 km/h	81%
SRC-LeCV Cycle 1 45km/h	77%



Thermal pre-cat model specifications

Model formula:

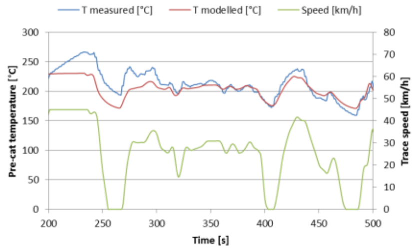
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

A= 167.214

B= 1.403

C= 5.209



Vehicle specific test results sheet | durability test cycles

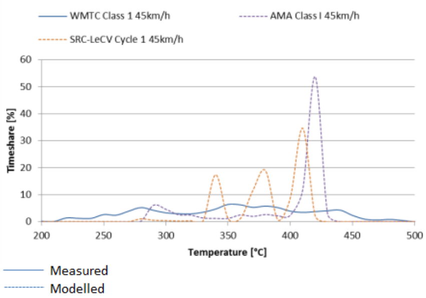
Vehicle specifications	
Vehicle ID no.	**J17**
category	**L1e-B**
category name	**high speed moped**
engine capacity class [cc]	**50**
rated power [kW]	**3**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**45**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**carburettor**
SAS	**Yes**
catalyst**	**2w**
reference mass class [kg]	**170**
year	**2013**
mileage [km]***	**4926**

test cycles		Tested	Modelled
WMTC	Class 1 45km/h	✓	✓
AMA	Class I 45km/h		✓
SRC-LeCV	Cycle 1 45km/h		✓

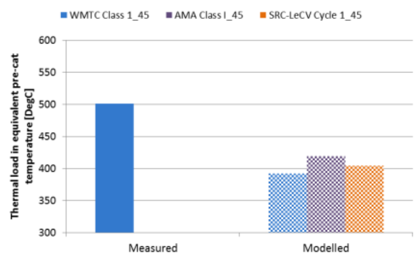
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

Thermal Load Comparison

Temperature distribution per test cycle



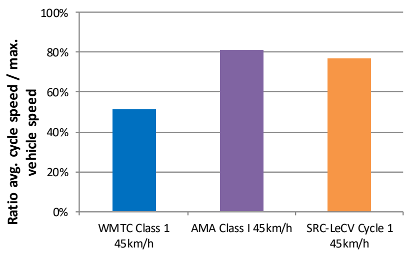
Thermal load per test cycle



The effect of the speed limiter is not well predicted by the model

Ratio: average cycle speed / maximum vehicle design speed

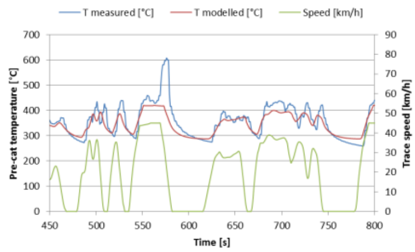
Cycle	Ratio
WMTC Class 1 45km/h	51%
AMA Class I 45km/h	81%
SRC-LeCV Cycle 1 45km/h	77%



Thermal pre-cat model specifications

Model formula:
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:
A= 286.335
B= 2.883
C= 12.236



Vehicle specific test results sheet | durability test cycles

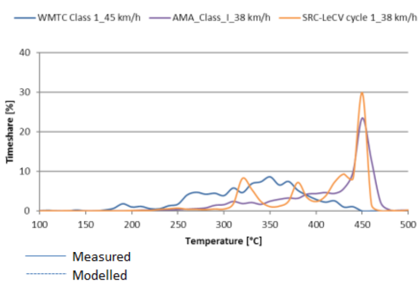
Vehicle specifications	
Vehicle ID no.	J27
category	L2e-U
category name	Three-wheel moped
engine capacity class [cc]	50
rated power [kW]	2
engine combustion type*	G-2S
# of cylinders	1
Maximum design speed [km/h]	38
Transmission	Manual
Euro class	Euro 2
Fuel delivery system	carburettor
SAS	Yes
catalyst**	2w
reference mass class [kg]	310
year	2016
mileage [km]***	100

test cycles		Tested	Modelled
WMTC	Class 1 45km/h	✓	✓
AMA	Class I 38km/h	✓	✓
SRC-LeCV	Cycle 1 38km/h	✓	✓

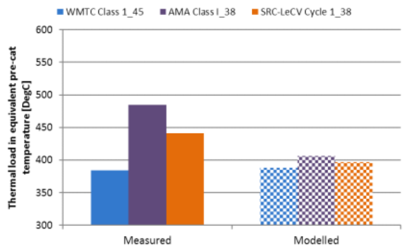
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

Thermal Load Comparison

Temperature distribution per test cycle

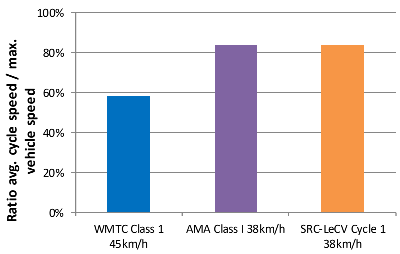


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

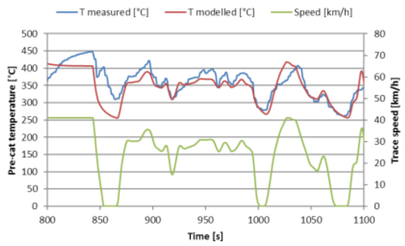
Cycle	Ratio
WMTC Class 1 45km/h	58%
AMA Class I 38km/h	84%
SRC-LeCV Cycle 1 38km/h	84%



Thermal pre-cat model specifications

Model formula:
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:
A= 247.91
B= 3.87
C= 19.29



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J19**
category	**L3e-A1**
category name	**low perf. motorcycle**
engine capacity class [cc]	**130**
rated power [kW]	**7**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**90**
Transmission	**CVT**
Euro class	**Euro 3**
Fuel delivery system	**carburettor**
SAS	**No**
catalyst**	**2w**
reference mass class [kg]	**180**
year	**2012**
mileage [km]***	**1372**

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

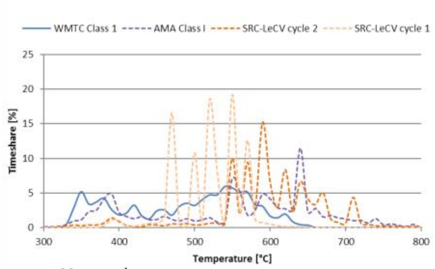
*** mileage at vehicle take-in, before any applied degreening

test cycles		**Tested**	**Modelled**
WMTC	Class 1	✓	✓
AMA	Class I		✓
SRC-LeCV	Cycle 2*		✓
SRC-LeCV	Cycle 1		✓

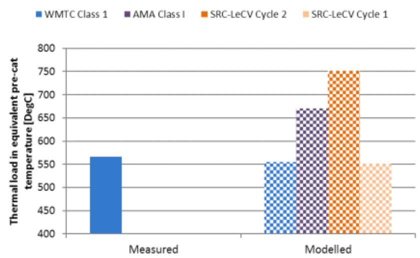
* Designated cycle according to Regulation (EU) no 134/2014

Thermal Load Comparison

Temperature distribution per test cycle

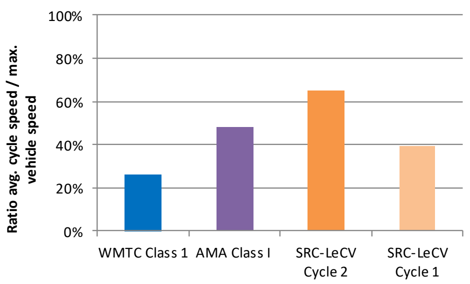


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 1	26%
AMA Class I	48%
SRC-LeCV Cycle 2	65%
SRC-LeCV Cycle 1	39%



Thermal pre-cat model specifications

Model formula:

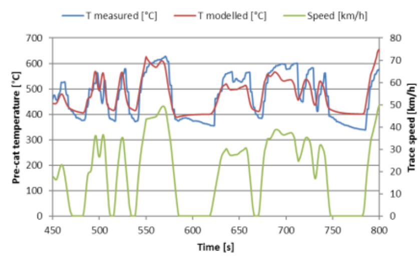
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

A= 401.00

B= 3.45

C= 27.78



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J23**
category	**L3e-A1**
category name	**low perf. motorcycle**
engine capacity class [cc]	**130**
rated power [kW]	**11**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**105**
Transmission	**CVT**
Euro class	**Euro 3**
Fuel delivery system	**injection**
SAS	**No**
catalyst**	**3w**
reference mass class [kg]	**n/a**
year	**2010**
mileage [km]***	**0**

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

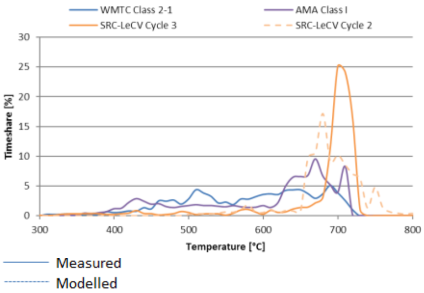
*** mileage at vehicle take-in, before any applied degreening

test cycles		Tested	Modelled
WMTC	Class 2-1	✓	✓
AMA	Class I	✓	✓
SRC-LeCV	Cycle 3*	✓	✓
	Cycle 2		✓

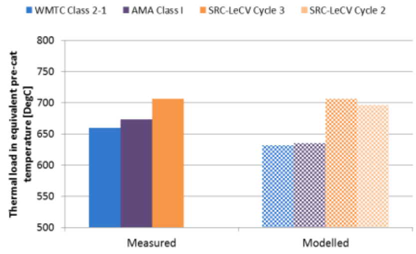
* Designated cycle according to Regulation (EU) no 134/2014

Thermal Load Comparison

Temperature distribution per test cycle

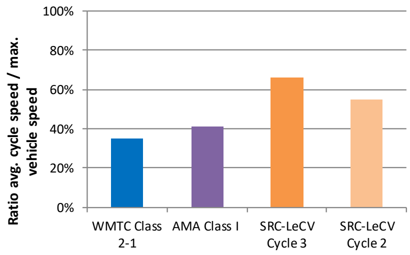


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 2-1	35%
AMA Class I	41%
SRC-LeCV Cycle 3	66%
SRC-LeCV Cycle 2	55%



Thermal pre-cat model specifications

Model formula:

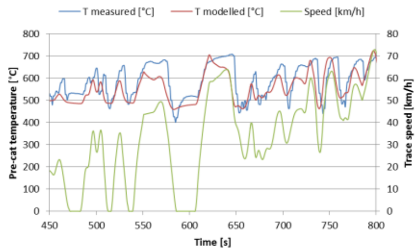
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

A= 483.541

B= 1.887

C= 19.69



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J11**
category	**L3e-A2**
category name	**low perf. motorcycle**
engine capacity class [cc]	**160**
rated power [kW]	**10**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**95**
Transmission	**CVT**
Euro class	**Euro 3**
Fuel delivery system	**injection**
SAS	**No**
catalyst**	**3w**
reference mass class [kg]	**200**
year	**2015**
mileage [km]***	**950**

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

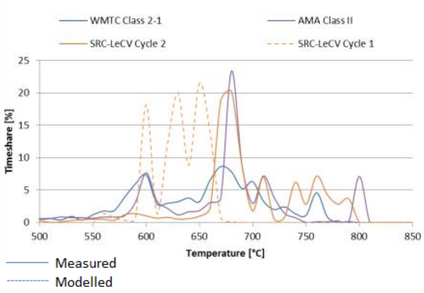
*** mileage at vehicle take-in, before any applied degreening

test cycles		Tested	Modelled
WMTC	Class 2-1	✓	✓
AMA	Class II	✓	✓
SRC-LeCV	Cycle 1		✓
	Cycle 2*	✓	✓

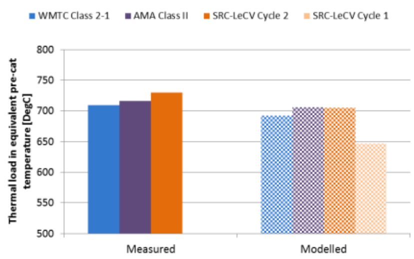
* Designated cycle according to Regulation (EU) no 134/2014

Thermal Load Comparison

Temperature distribution per test cycle

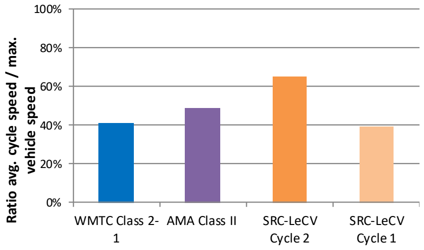


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 2-1	41%
AMA Class II	49%
SRC-LeCV Cycle 2	65%
SRC-LeCV Cycle 1	39%



Thermal pre-cat model specifications

Model formula:

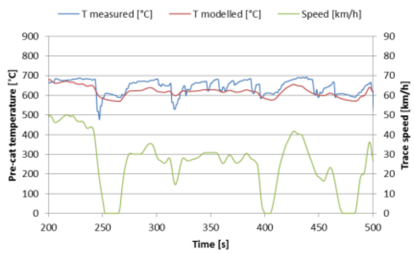
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

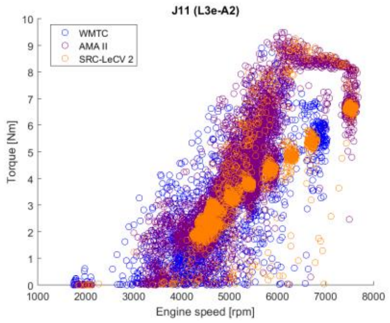
A= 565.095

B= 2.004

C= 9.898



Engine operation area per test cycle



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J13**
category	**L3e-A2**
category name	**medium perf. motorcycle**
engine capacity class [cc]	**280**
rated power [kW]	**19**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**128**
Transmission	**CVT**
Euro class	**Euro 4**
Fuel delivery system	**injection**
SAS	**Yes**
catalyst**	**3w**
reference mass class [kg]	**240**
year	**2015**
mileage [km]***	**2871**

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

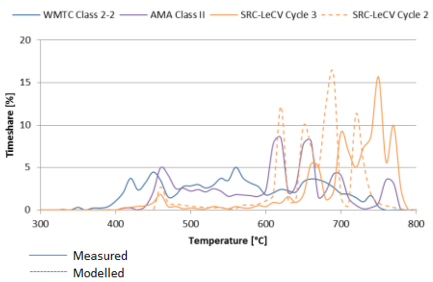
*** mileage at vehicle take-in, before any applied degreening

test cycles		Tested	Modelled
WMTC	Class 2-2	✓	✓
AMA	Class II	✓	✓
SRC-LeCV	Cycle 2		✓
	Cycle 3*	✓	✓

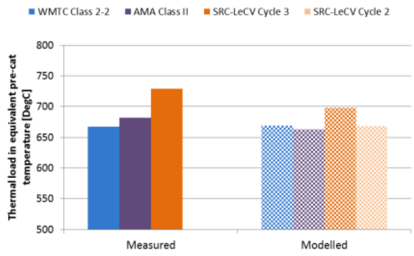
* Designated cycle according to Regulation (EU) no 134/2014

Thermal Load Comparison

Temperature distribution per test cycle

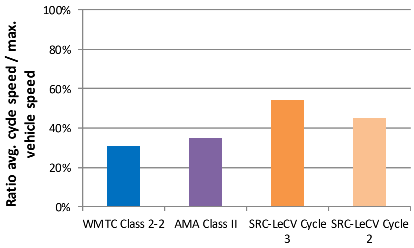


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 2-2	31%
AMA Class II	35%
SRC-LeCV Cycle 3	54%
SRC-LeCV Cycle 2	45%



Thermal pre-cat model specifications

Model formula:

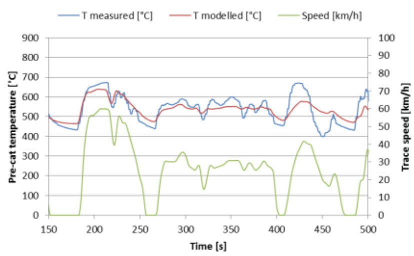
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

A= 462.52

B= 2.901

C= 9.08



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	J15
category	L3e-A2
category name	medium perf. motorcycle
engine capacity class [cc]	690
rated power [kW]	32
engine combustion type*	G-4S
# of cylinders	1
Maximum design speed [km/h]	>150
Transmission	Manual
Euro class	Euro 4
Fuel delivery system	injection
SAS	Yes
catalyst**	3w
reference mass class [kg]	230
year	2016
mileage [km]***	1000

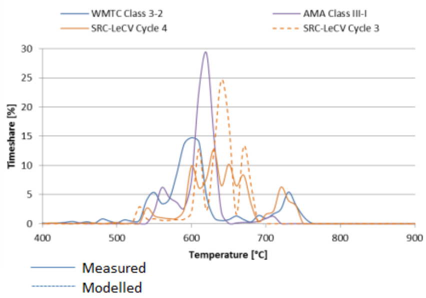
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

test cycles		Tested	Modelled
WMTC	Class 3-2	✓	✓
AMA	Class III I	✓	✓
SRC-LeCV	Cycle 4*	✓	✓
SRC-LeCV	Cycle 3		✓

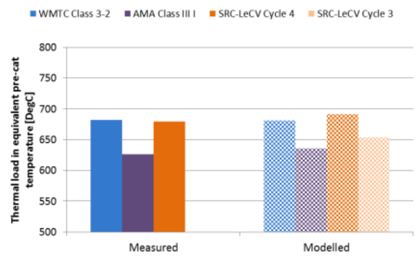
* Designated cycle according to Regulation (EU) no 134/2014

Thermal Load Comparison

Temperature distribution per test cycle



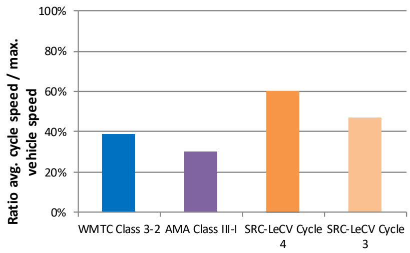
Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio*
WMTC Class 3-2	39%
AMA Class III-I	30%
SRC-LeCV Cycle 4	60%
SRC-LeCV Cycle 3	47%

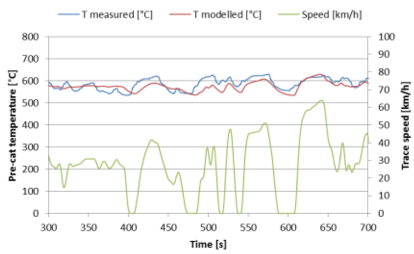
* With a maximum speed of 150 km/h



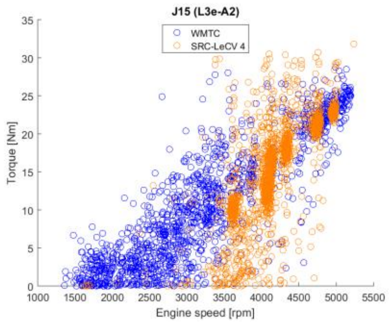
Thermal pre-cat model specifications

Model formula:
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:
A= 530.174
B= 1.591
C= 2.437



Engine operation area per test cycle



* Torque data of AMA not available

Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	J18
category	L3e-A3
category name	high perf. motorcycle
engine capacity class [cc]	1170
rated power [kW]	92
engine combustion type*	G-4S
# of cylinders	2
Maximum design speed [km/h]	>150
Transmission	Manual
Euro class	Euro 4
Fuel delivery system	injection
SAS	No
catalyst**	3w
reference mass class [kg]	300
year	2015
mileage [km]***	1156

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

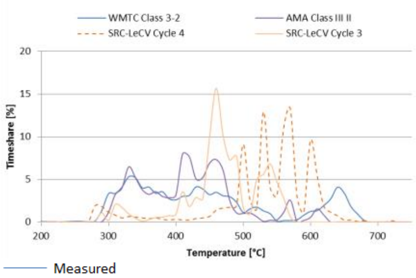
*** mileage at vehicle take-in, before any applied degreening

test cycles		Tested	Modelled
WMTC	Class 3-2	✓	✓
AMA	Class III-II	✓	✓
SRC-LeCV	Cycle 3	✓	✓
	Cycle 4*		✓

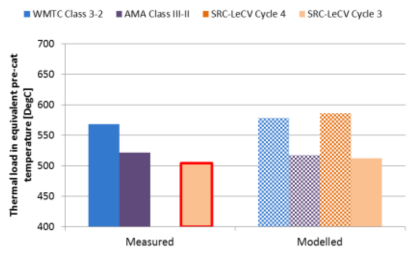
* Designated cycle according to Regulation (EU) no 134/2014

Thermal Load Comparison

Temperature distribution per test cycle



Thermal load per test cycle

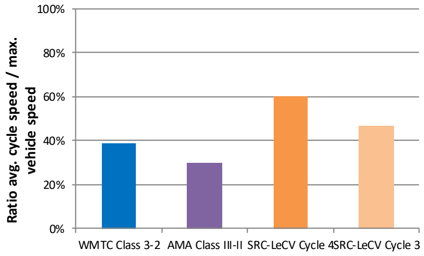


* SRC-LeCV cycle 3 is driven but cycle 4 is the correct one

Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio*
WMTC Class 3-2	39%
AMA Class III-II	30%
SRC-LeCV Cycle 4	60%
SRC-LeCV Cycle 3	47%

* With a maximum speed of 150 km/h



Thermal pre-cat model specifications

Model formula:

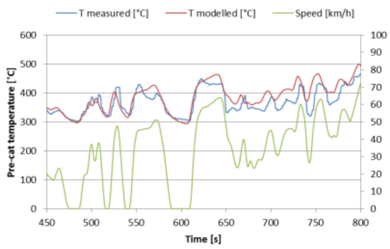
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

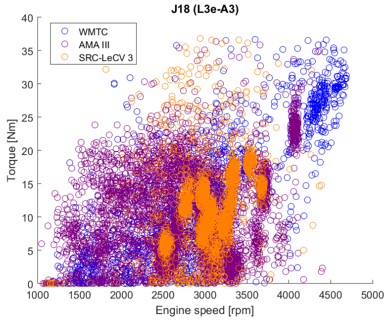
A= 288.654

B= 2.726

C= 6.801



Engine operation area per test cycle



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J21**
category	**L5e-A**
category name	**tricycle**
engine capacity class [cc]	**300**
rated power [kW]	**18**
engine combustion type*	**G-4S-H**
# of cylinders	**1**
Maximum design speed [km/h]	**125**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**injection**
SAS	**n/a**
catalyst**	**3w**
reference mass class [kg]	**340**
year	**n/a**
mileage [km]***	**773**

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

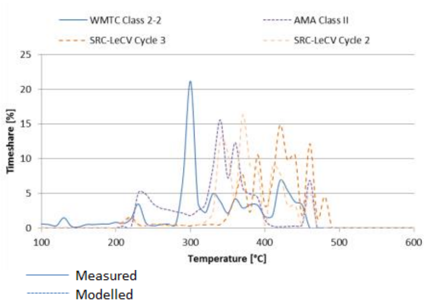
*** mileage at vehicle take-in, before any applied degreening

test cycles		Tested	Modelled
WMTC	Class 2-2	✓	✓
AMA	Class II		✓
SRC-LeCV	Cycle 2		✓
	Cycle 3*		✓

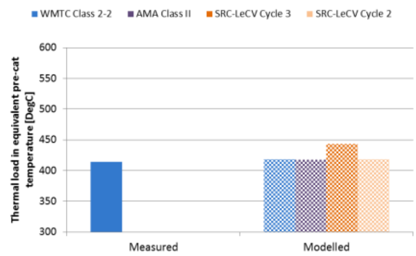
* Designated cycle according to Regulation (EU) no 134/2014

Thermal Load Comparison

Temperature distribution per test cycle

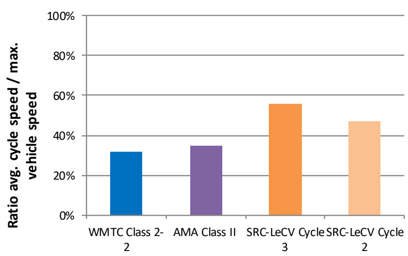


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 2-2	32%
AMA Class II	35%
SRC-LeCV Cycle 3	56%
SRC-LeCV Cycle 2	47%



Thermal pre-cat model specifications

Model formula:

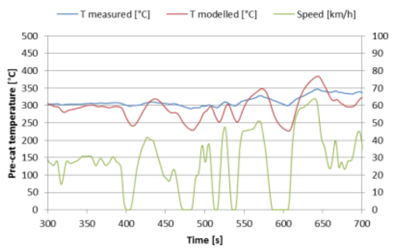
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

A= 218.263

B= 2.772

C= -0.443



Deviating exhaust temperature prediction by the model due to hybrid drivetrain.

Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J24**
category	**L5e-A**
category name	**tricycle**
engine capacity class [cc]	**200**
rated power [kW]	**8**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**55**
Transmission	**Manual**
Euro class	**Euro 2**
Fuel delivery system	**carburettor**
SAS	**No**
catalyst**	**2w**
reference mass class [kg]	**420**
year	**2016**
mileage [km]***	**100**

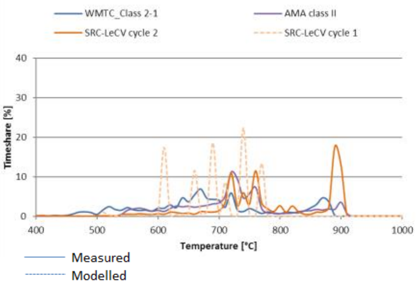
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

test cycles		Tested	Modelled
WMTC	Class 2-1	✓	✓
AMA	Class II	✓	✓
SRC-LeCV	Cycle 2*	✓	✓
SRC-LeCV	Cycle 1		✓

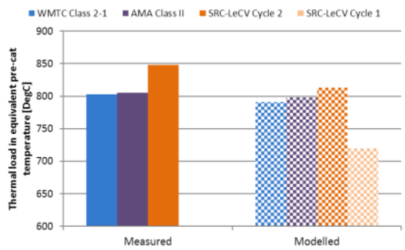
* Designated cycle according to Regulation (EU) no 134/2014

Thermal Load Comparison

Temperature distribution per test cycle

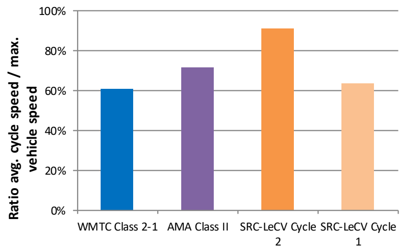


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

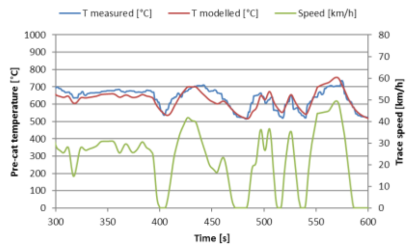
Cycle	Ratio
WMTC Class 2-1	61%
AMA Class II	72%
SRC-LeCV Cycle 2	91%
SRC-LeCV Cycle 1	64%



Thermal pre-cat model specifications

Model formula:
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:
A= 501.96
B= 5.19
C= 13.43



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J22**
category	**L6e-BU**
category name	**light quadri-mobile**
engine capacity class [cc]	**400**
rated power [kW]	**4**
engine combustion type*	**D-4S**
# of cylinders	**2**
Maximum design speed [km/h]	**45**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**injection**
SAS	**No**
catalyst**	**n.a.**
reference mass class [kg]	**0**
year	**n/a**
mileage [km]***	**988**

test cycles		Tested	Modelled
WMTC	Class 2-1	✓	✓
AMA	Class II	✓	✓
SRC-LeCV	Cycle 1 45km/h	✓	✓

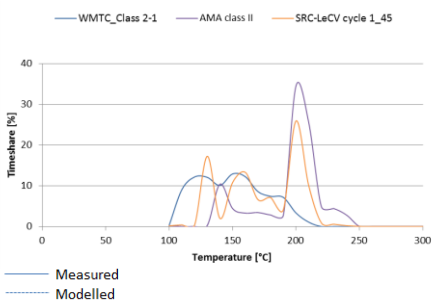
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

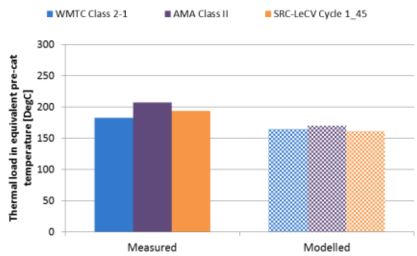
*** mileage at vehicle take-in, before any applied degreening

Thermal Load Comparison

Temperature distribution per test cycle

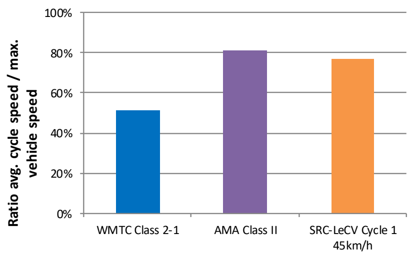


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

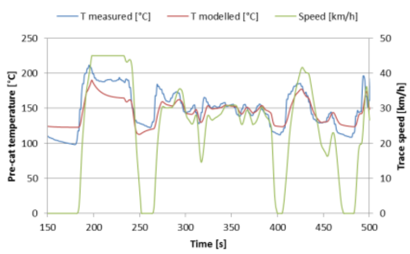
Cycle	Ratio
WMTC Class 2-1	51%
AMA Class II	81%
SRC-LeCV Cycle 1 45km/h	77%



Thermal pre-cat model specifications

Model formula:
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:
A= 122.843
B= 0.915
C= 9.242



Vehicle specific test results sheet | durability test cycles

Vehicle specifications

Vehicle ID no.	**J16**
category	**L7e-B1**
category name	**heavy all terrain quad**
engine capacity class [cc]	**980**
rated power [kW]	**15**
engine combustion type*	**G-4S**
# of cylinders	**2**
Maximum design speed [km/h]	**65**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**injection**
SAS	**No**
catalyst**	**3w**
reference mass class [kg]	**470**
year	**2016**
mileage [km]***	**538**

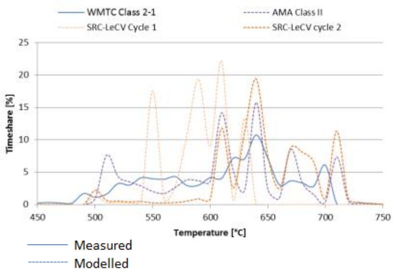
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

test cycles		Tested	Modelled
WMTC	Class 2-1	✓	✓
AMA	Class II		✓
SRC-LeCV	Cycle 1		✓
	Cycle 2*		✓

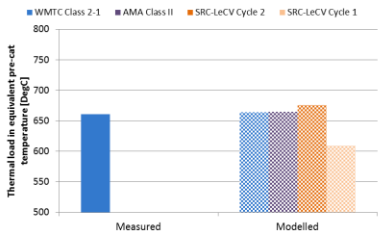
* Designated cycle according to Regulation (EU) no 134/2014

Thermal Load Comparison

Temperature distribution per test cycle

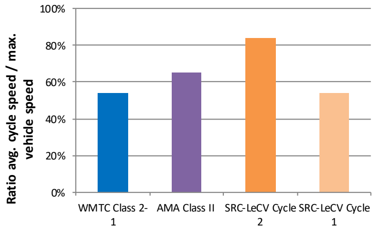


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

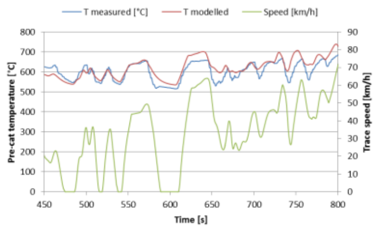
Cycle	Ratio
WMTC Class 2-1	54%
AMA Class II	65%
SRC-LeCV Cycle 2	84%
SRC-LeCV Cycle 1	54%



Thermal pre-cat model specifications

Model formula:
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:
A= 501.76
B= 2.621
C= 7.609



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J08**
category	**L7e-B1**
category name	**heavy all terrain quad**
engine capacity class [cc]	**570**
rated power [kW]	**11**
engine combustion type*	**G-4S**
# of cylinders	**1**
Maximum design speed [km/h]	**70**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**injection**
SAS	**No**
catalyst**	**2w**
reference mass class [kg]	**450**
year	**2015**
mileage [km]***	**900**

* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke

** 2w = 2-way catalyst; 3W = 3-way catalyst

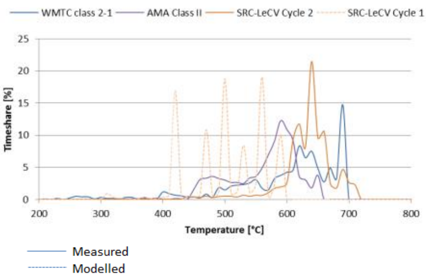
*** mileage at vehicle take-in, before any applied degreening

test cycles		Tested	Modelled
WMTC	Class 2-1	✓	✓
AMA	Class II	✓	✓
SRC-LeCV	Cycle 1		✓
	Cycle 2*	✓	✓

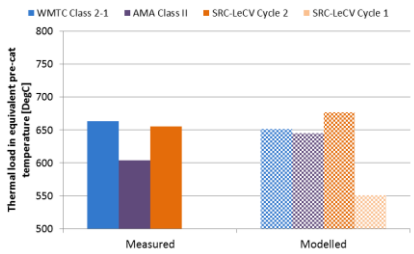
* Designated cycle according to Regulation (EU) no 134/2014

Thermal Load Comparison

Temperature distribution per test cycle

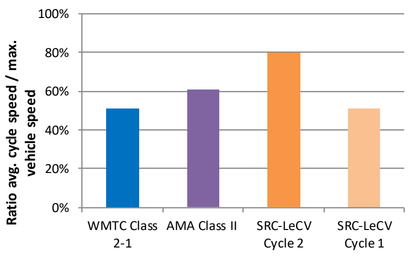


Thermal load per test cycle



Ratio: average cycle speed / maximum vehicle design speed

Cycle	Ratio
WMTC Class 2-1	51%
AMA Class II	61%
SRC-LeCV Cycle 2	80%
SRC-LeCV Cycle 1	51%



Thermal pre-cat model specifications

Model formula:

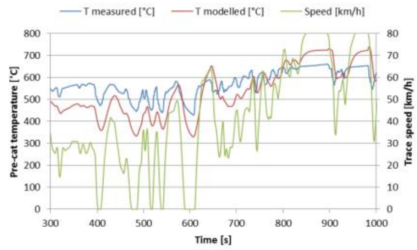
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:

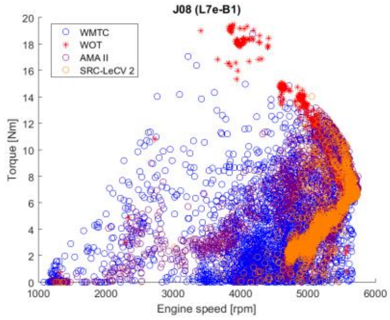
A= 311.993

B= 5.566

C= -4.671



Engine operation area per test cycle



Vehicle specific test results sheet | durability test cycles

Vehicle specifications	
Vehicle ID no.	**J09**
category	**L7e-B2**
category name	**side-by-side buggy**
engine capacity class [cc]	**700**
rated power [kW]	**15**
engine combustion type*	**G-4S**
# of cylinders	**2**
Maximum design speed [km/h]	**78**
Transmission	**CVT**
Euro class	**Euro 2**
Fuel delivery system	**injection**
SAS	**No**
catalyst**	**2w**
reference mass class [kg]	**570**
year	**2016**
mileage [km]***	**638**

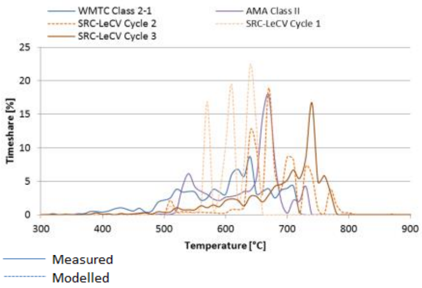
* G = gasoline; D = Diesel; 2S = 2-stroke; 4S = 4-stroke
** 2w = 2-way catalyst; 3W = 3-way catalyst
*** mileage at vehicle take-in, before any applied degreening

test cycles		Tested	Modelled
WMTC	Class 2-1	✓	✓
AMA	Class II	✓	✓
SRC-LeCV	Cycle 1		✓
	Cycle 2*		✓
	Cycle 3	✓	✓

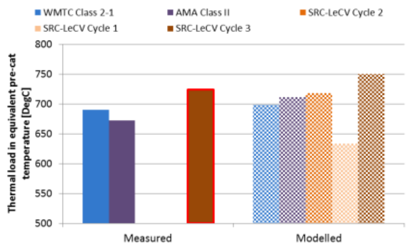
* Designated cycle according to Regulation (EU) no 134/2014

Thermal Load Comparison

Temperature distribution per test cycle



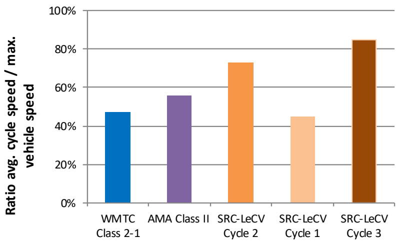
Thermal load per test cycle



* SRC-LeCV cycle 3 is driven but cycle 2 is the correct one

Ratio: average cycle speed / maximum vehicle design speed

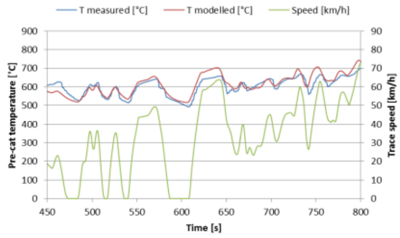
Cycle	Ratio
WMTC Class 2-1	47%
AMA Class II	56%
SRC-LeCV Cycle 2	73%
SRC-LeCV Cycle 1	45%
SRC-LeCV Cycle 3	85%



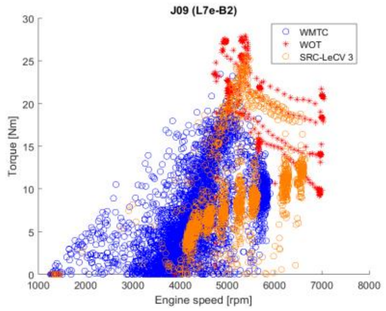
Thermal pre-cat model specifications

Model formula:
T[°C]= A + B * velocity [km/h] + C * power [m²/s³]

Where:
A= 510.783
B= 2.983
C= 7.847



Engine operation area per test cycle



* Torque data of AMA not available

N Sensitivity analysis of the Multiplicative and Additive DF calculation method

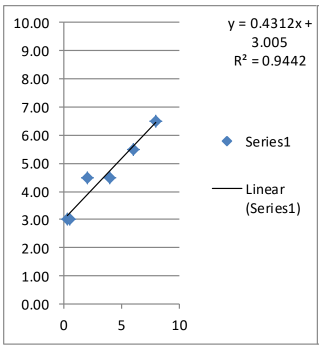
first order assessment to demonstrate the principle differences

Type I test result	3.000	2.000	0.500
g/km @3.000 km	3.215	1.375	-0.336
g/km @80.000 km	6.427	5.884	4.397
Calculated Multiplicative DF	1.999	4.280	-13.101
Value at 80.000 with Multiplicative DF	5.997	8.561	-6.550
Calculated Additive DF	3.212	4.509	4.732
Value at 80.000 with Additive DF	6.212	6.509	5.232

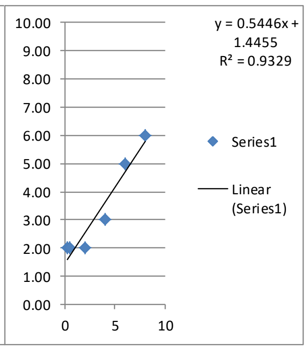
second order assessment with imaginary Type I emission values obtained during imaginary application of the procedure

Mileage [x 1000 km]	Actual example emission values		
	scenario 1	scenario 2	scenario 3
0.3	3.00	2.00	0.50
0.5	3.00	2.00	0.50
2	4.50	2.00	0.50
4	4.50	3.00	1.50
6	5.50	5.00	2.00
8	6.50	6.00	5.50

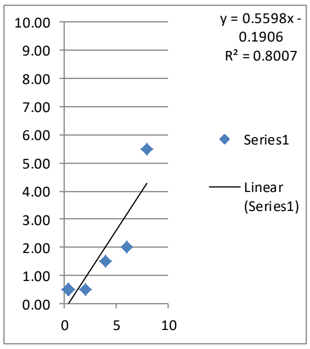
scenario 1



scenario 2



scenario 3



third order sensitivity analysis by varying the imaginary intermediate type I emission test result

type I result	60	60	60	60	60	60	60
value at 6400 km	40	60	80	100	120	140	160
value at 80000 km	100	100	100	100	100	100	100
Multiplicative DF	2.50	1.67	1.25	1.00	0.83	0.71	0.63
Additive DF	60	40	20	0	-20	-40	-60
Multiplicative DF result	150	100	75	60	50	43	38
Additive DF result	120	100	80	60	40	20	0
type I result	20	20	20	20	20	20	20
value at 6400 km	10	20	40	60	80	100	120
value at 80000 km	100	100	100	100	100	100	100
Multiplicative DF	10.00	5.00	2.50	1.67	1.25	1.00	1.00
Additive DF	90	80	60	40	20	0	-20
Multiplicative DF result	200	100	50	33	25	20	20
Additive DF result	110	100	80	60	40	20	0
type I result	600	600	600	600	600	600	600
value at 6400 km	200	400	600	800	1000	1200	1400
value at 80000 km	1200	1200	1200	1200	1200	1200	1200
Multiplicative DF	6.00	3.00	2.00	1.50	1.20	1.00	0.86
Additive DF	1000	800	600	400	200	0	-200
Multiplicative DF result	3600	1800	1200	900	720	600	514
Additive DF result	1600	1400	1200	1000	800	600	400

O Speed traces of driven test cycles

Type I test cycles: revised WMTC

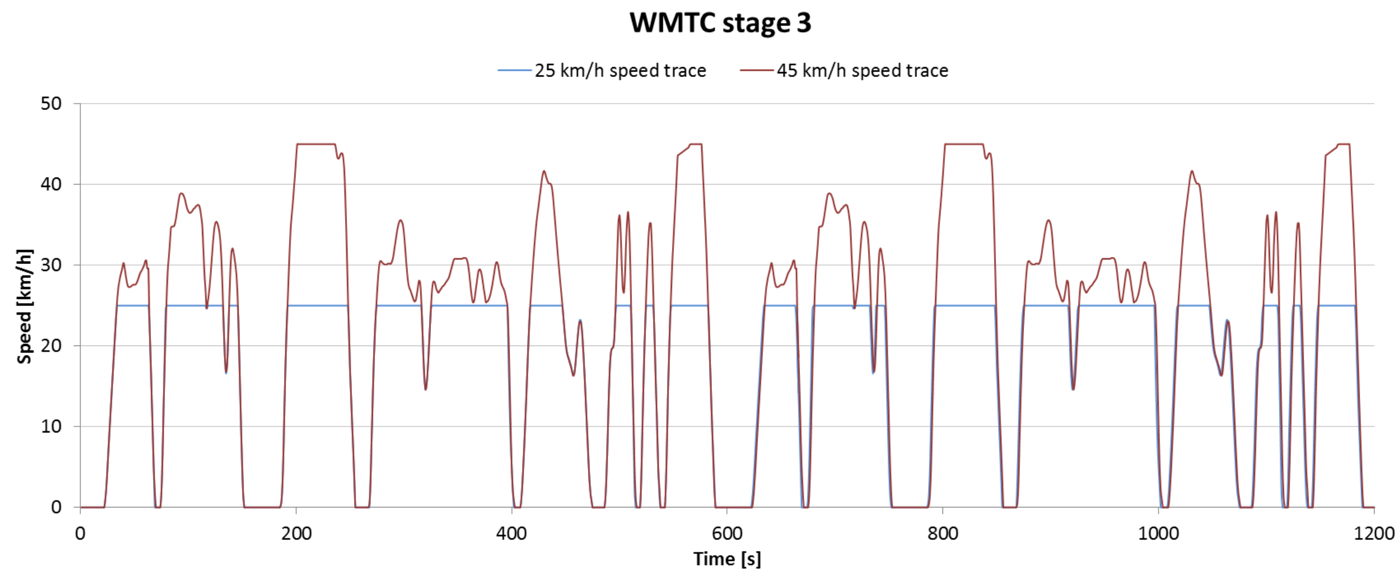


Figure 417: Revised WMTC for vehicles with a maximum speed of 25 or 45 km/h

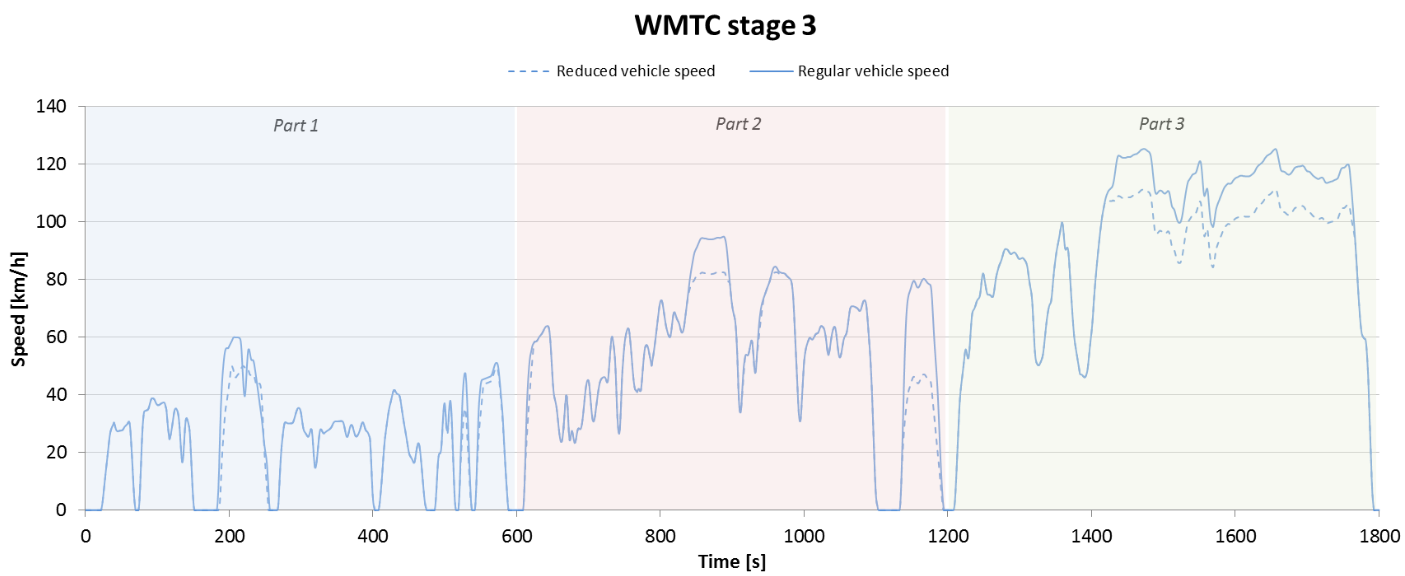


Figure 418: Revised WMTC

Type I test cycles: ECE

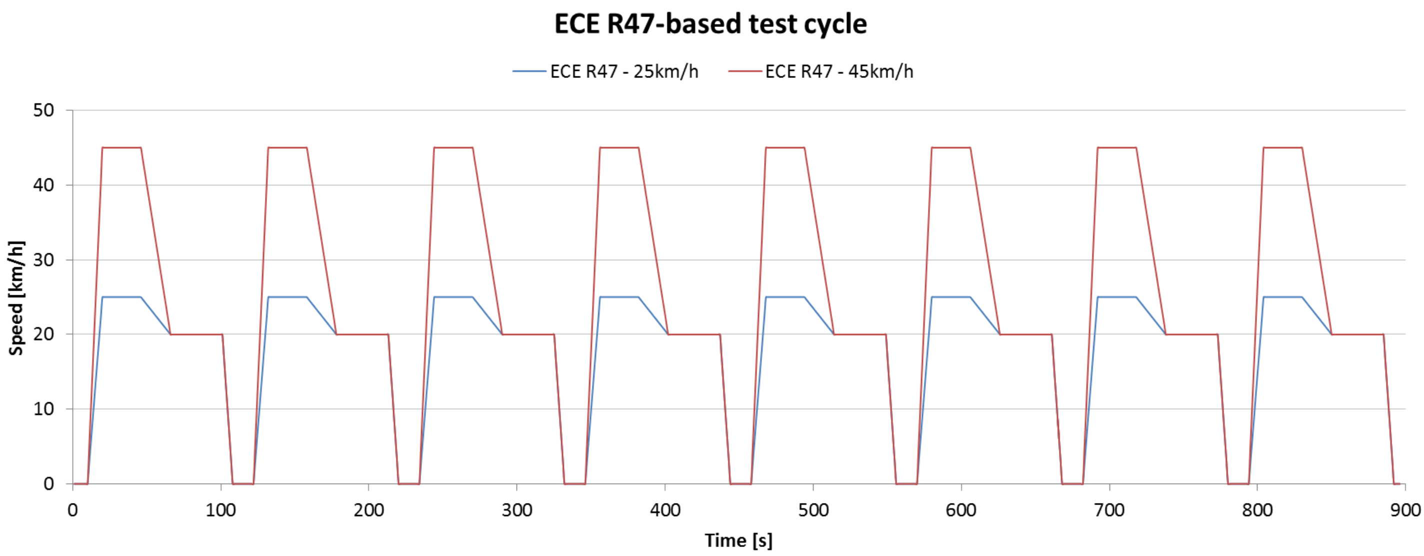


Figure 419: ECE R47-based test cycles

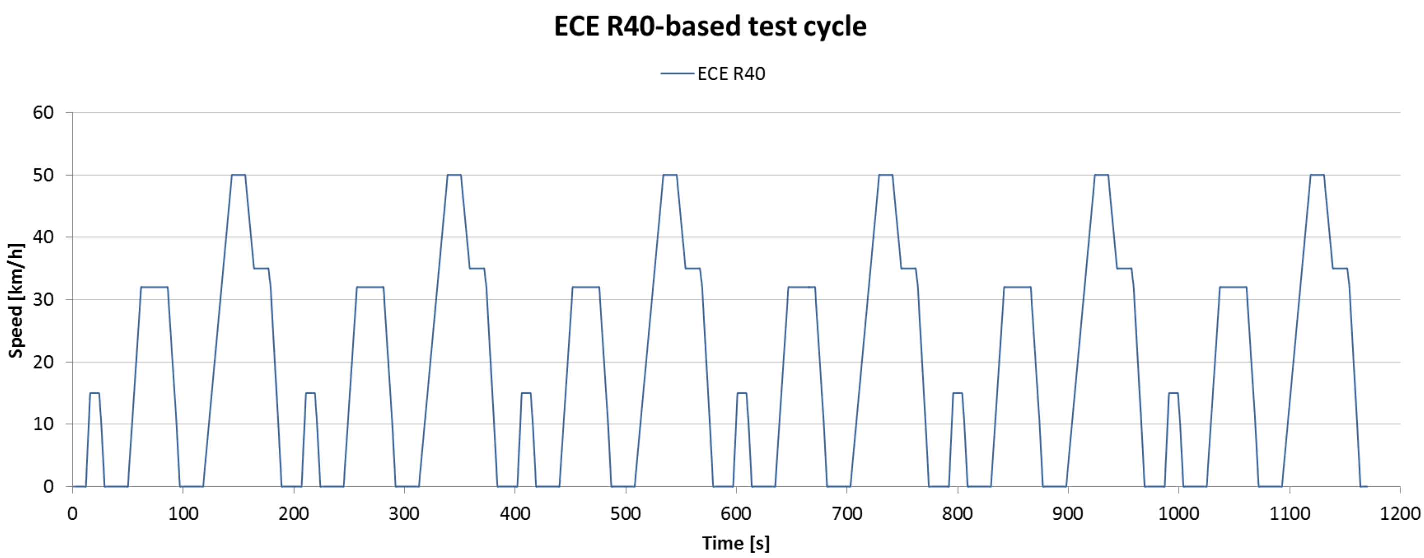


Figure 420: ECE R40-based test cycle

Type V test cycles
The displayed cycles are examples. When the target speed of the specific cycle is not met, full throttle is applied for both the SRC-LeCV and the AMA.

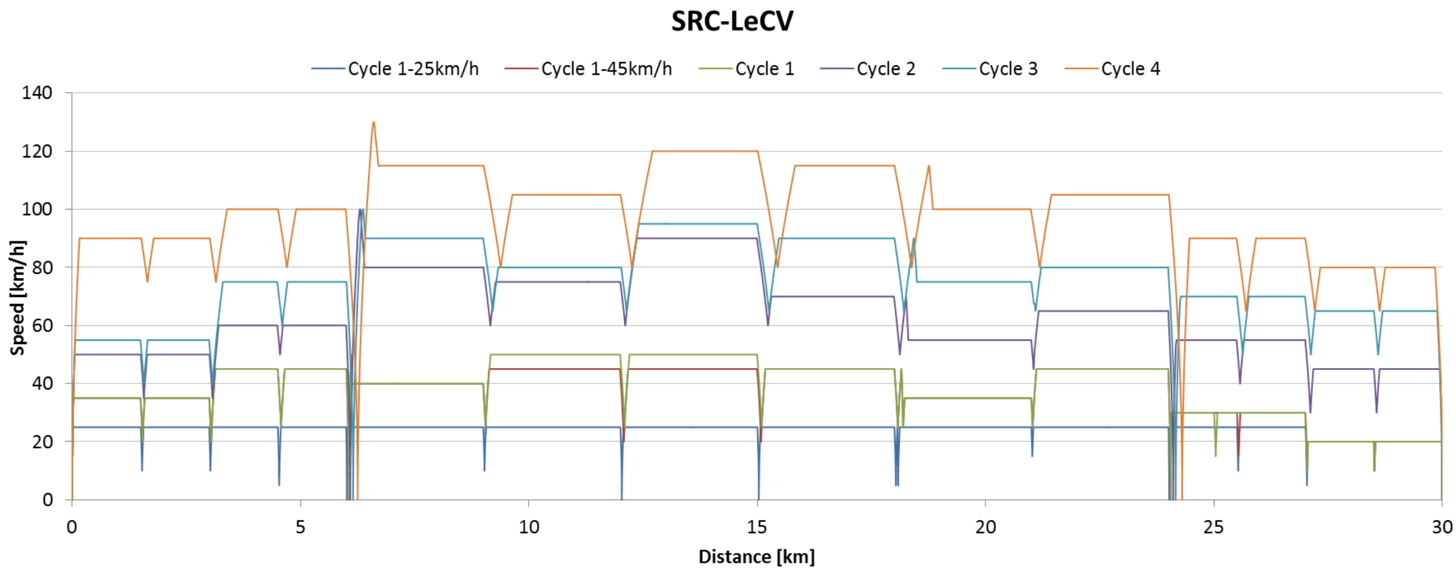


Figure 421: SRC-LeCV test cycles

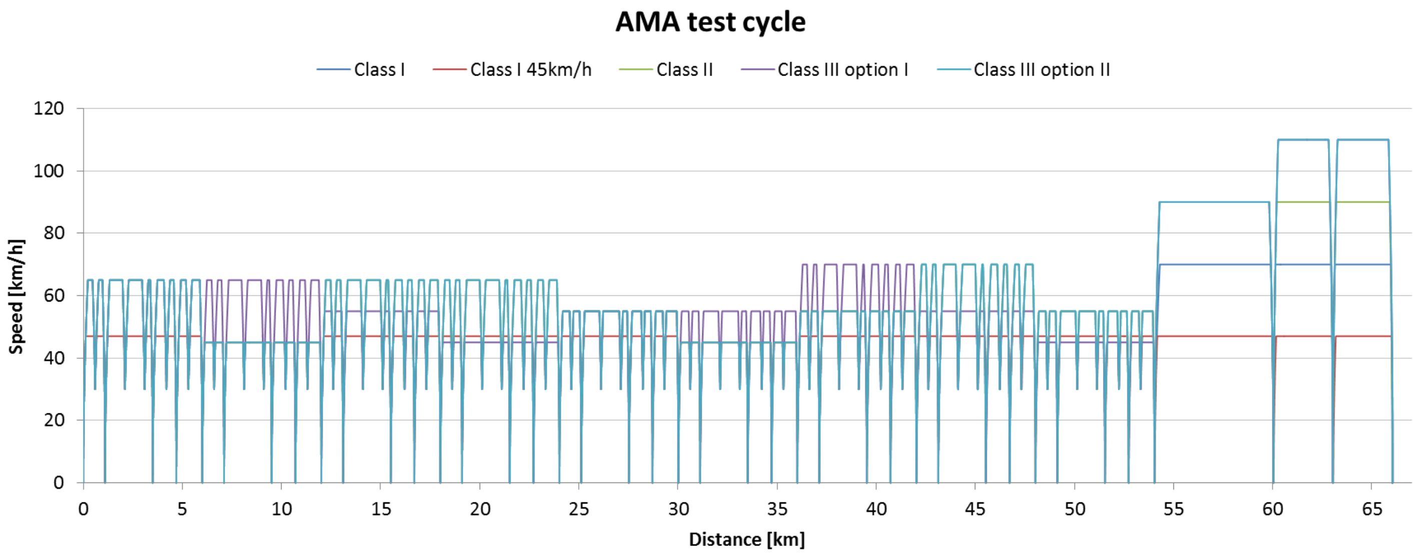


Figure 422: AMA test cycles

P Misfiring monitoring window determination

Most of the manifold absolute pressure measurements were performed using the PEMS equipment. The following pictures present schematically the connection of the sensors applied to one of the test vehicles.

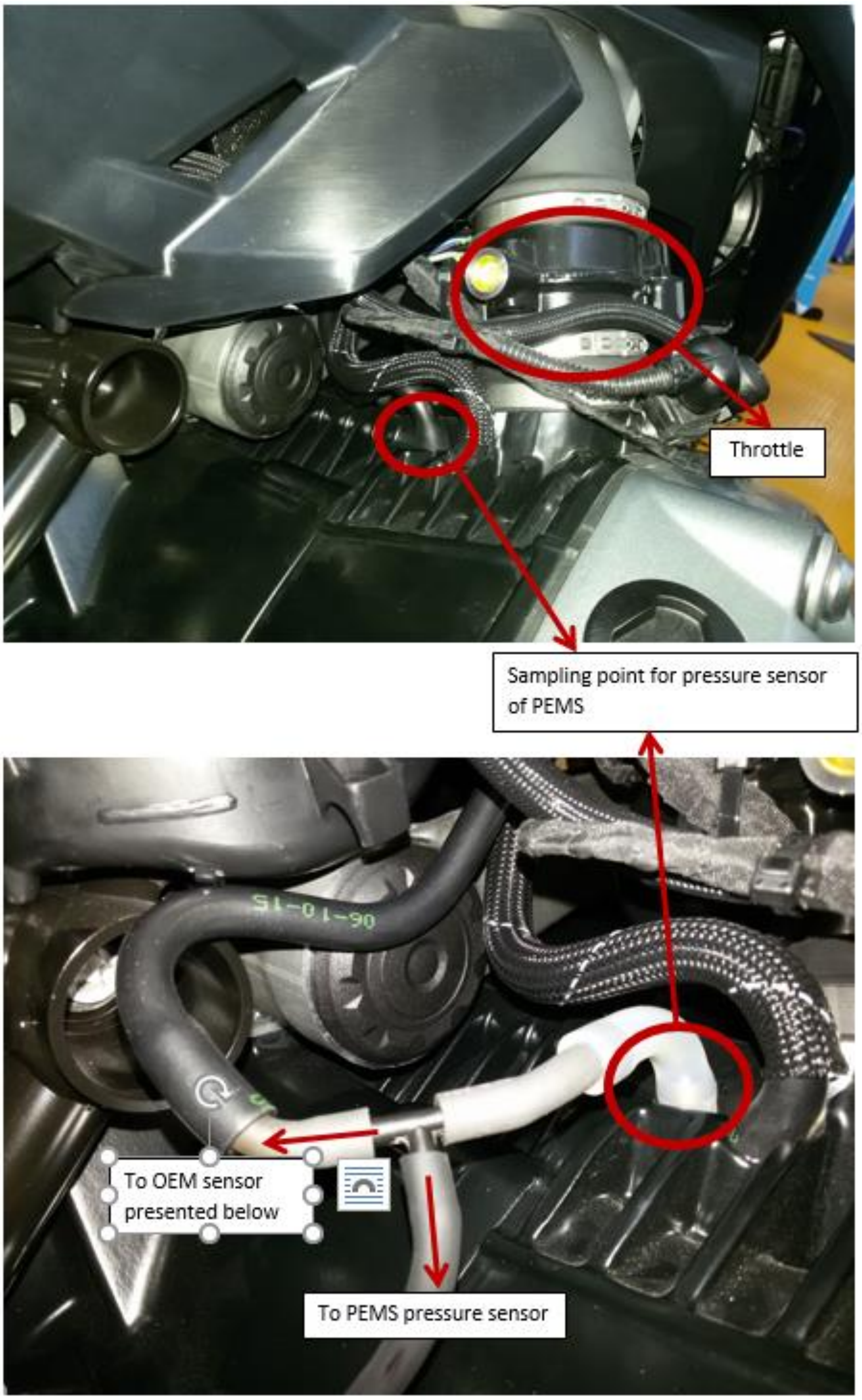


Figure 423. Sensor connections to a test vehicle measuring manifold pressure

The sensor used for the measurements is shown in the following picture, and it presents the following specifications.

Figure 424. Pressure sensor

Pressure sensor specifications:
Omega – PX303050A5V
5V Output (10V Output)
Excitation: 9 to 30 Vdc (14 to 30 Vdc) unregulated

Output: 0.5-5.5 (1-11) Vdc
Accuracy: 0.25% FS (linearity, hysteresis, repeatability)
Zero Balance: ± 2% FS
Span Tolerance: ±1% FS
Long Term Stability: ±0.5% FS
Typical Life: 100 million cycles
Operating Temperature: 0 to 160°F (-18 to 71°C)
Compensated Temperature: 30 to 130 °F (-1 to 54°C)
Total Thermal Effects: 1% FS max
Proof Pressure: 200%, 13,000 PSI max
Quiescent Exc.: 15 mA maximum
Min Load Resistance: 2000
Response Time: 1 msec
Gage Type: Stainless steel diaphragm, silicone oil filled semiconductor sensor
Shock: 50 g @ 11msec
Vibration: 15 g 10-2000 Hz
Wetted Parts: 17-4 PH and 300 Series Stainless Steel
Pressure Port: 1/4 NPT male
Press. Cavity: 0.075 cubic inches
Electrical Conn. PX303: 3 cond, 22 AWG, PVC unshielded, 3 ft (1 m) cable
Electrical Conn. PX313: Subminiature DIN Connector, Mating Connector Included
Weight: 7.8 oz (221 g) to 1000 psi; 9.9 oz (281 g) from 1000 psi

The examination of the effectiveness of the misfiring window considers the following approaches:

- The Euro 5 approach as defined in Regulation (EU) No 44/2014, where the misfiring window is bounded by the following lines:
    a. maximum design engine speed minus 500 rpm
    b. the positive torque line (i.e. engine load with the transmission in neutral)
    c. linear lines joining the following engine operating points: the positive torque line at 3000 rpm and a point on the maximum speed line defined in (a) above with the engine's manifold vacuum at 13.3 kPa lower than that at the positive torque line.
- The proposal of ACEM, which is differentiated for CVT and for manual transmission vehicles as follows:
    a. for CVT's: CVT engagement engine speed plus 500 rpm
       for manual transmission vehicles: idle engine speed plus 1000 rpm
    b. the lower of (i) the maximum nominal engine speed multiplied by 0.7 and (ii) maximum WMTC engine speed plus 1000 rpm
    c. a line joining a point on the line defined in (a) above and a point on the line defined in (b), both points with the engine's manifold vacuum at 13.3 kPa lower than that at the positive torque line.
- An alternative approach proposed with the following boundaries:
    a. Low speed limit: A speed of 2500 min^{-1} or nominal idle speed+1000 min^{-1}, whichever is lower;
    b. High speed limit: A maximum speed of 8000 min^{-1} or 1000 min^{-1} greater than the highest engine speed occurring during a Type I Test

cycle or maximum design engine speed minus 500 min^{-1}, whichever is lower;

c. A line joining the following engine operating points:
   - a point on the low speed limit defined in (a) with the engine intake vacuum at 3.3 kPa lower than the positive torque line, and
   - a point on the high speed limit defined in (b) with the engine intake vacuum at 13.3 kPa lower than the positive torque.

The manifold absolute pressure (MAP) is measured when running WMTC on the chassis dyno of JRC and of LAT, while the deceleration and steady speed phases are filtered from the analysis. The MAP measurements are projected to the bounded areas, and the summarised results of the percentage of MAP points inside the areas, are presented in Section 9.2.2. The results are also schematically presented below with charts for each test vehicle.

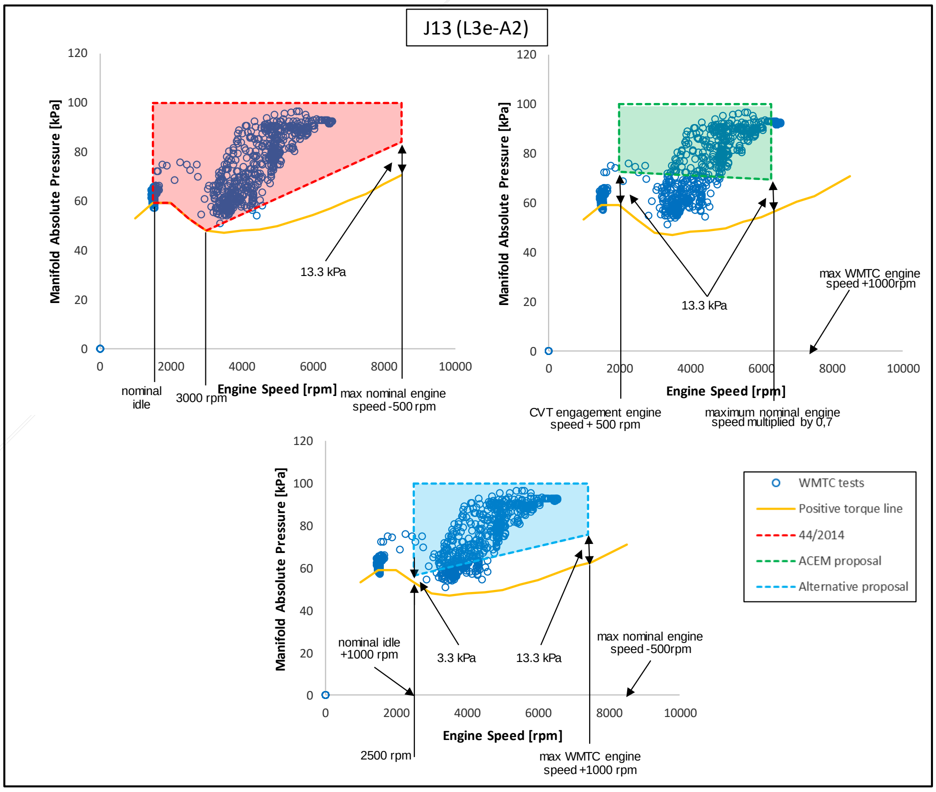


Figure 425. Misfiring window monitoring for J13 (L3e-A2)

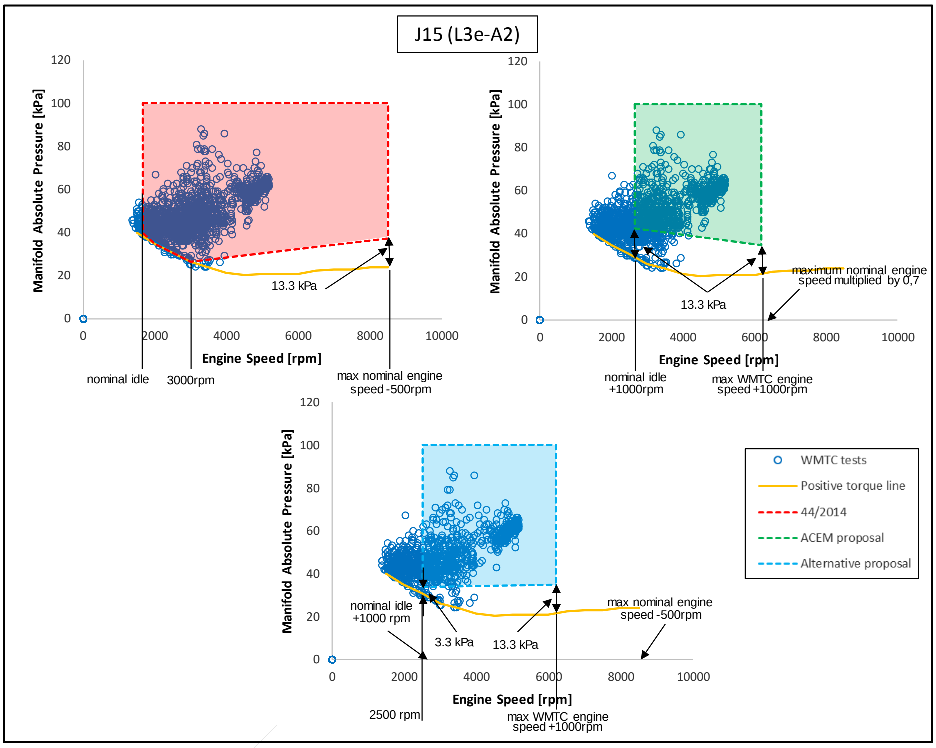


Figure 426. Misfiring window monitoring for J15 (L3e-A2)

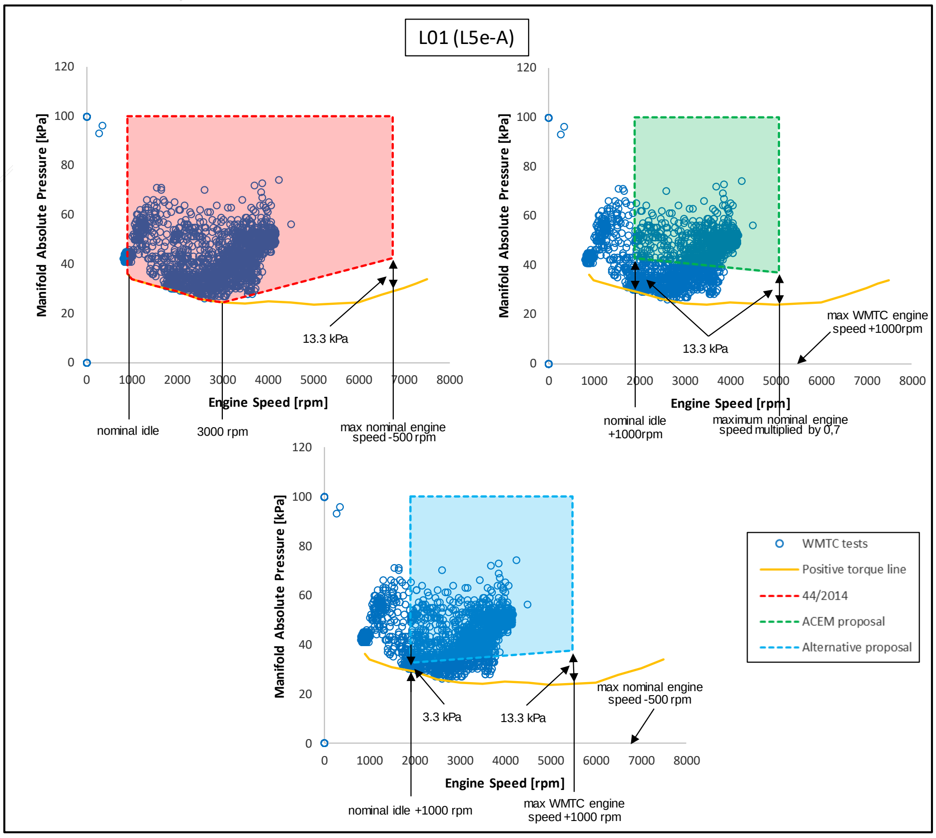


Figure 427. Misfiring window monitoring for L01 (L5e-A)

The following notes on the figures' input data should be made:

- J13 (L3e-A2): The recorded WMTC manifold pressure coming from measurements presented some artifacts due to purge valve operation. Therefore, manufacturer's provided data were used after being validated with the correct part of the measurements. As shown in Figure 428 and in Figure 429, the measured lower MAP values are in good correlation with the values provided by the manufacturer.
- J15 (L3e-A2): The positive torque line provided by the manufacturer presented some problems, therefore it has been shifted by 13.3 kPa, as it seems more realistic.
- J15 (L3e-A2): The plots of the specific Le3-A2 vehicle can only be seen as representative for very similar vehicle/engine configurations, but not for all L3e-A2 vehicle/engine configurations.

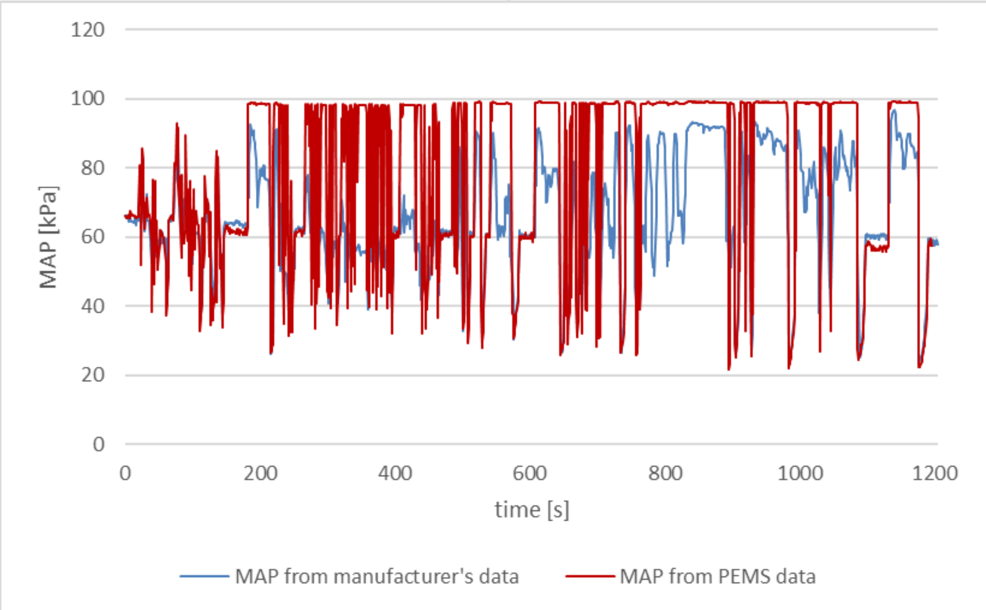


Figure 428. Second-by-second MAP data of J13 (L3e-A2)

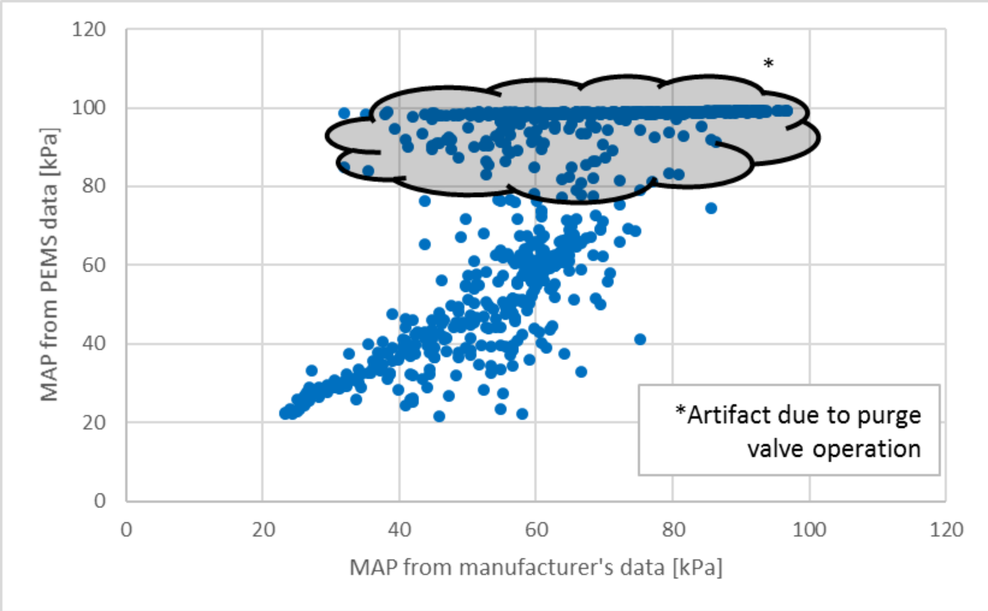
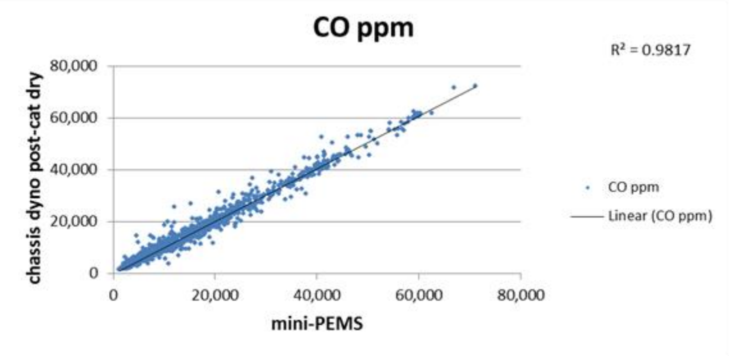
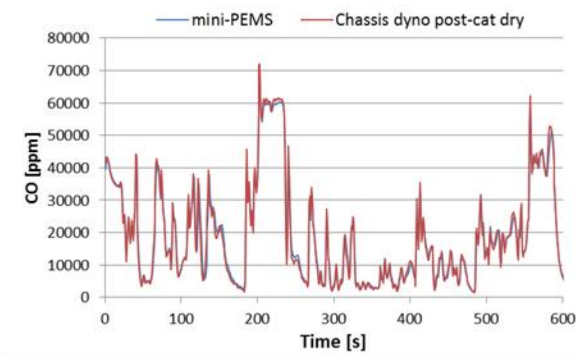


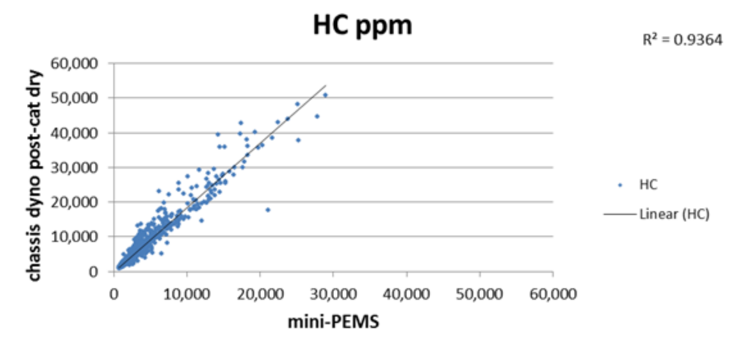
Figure 429. Correlation of MAP data coming from PEMS measurements against MAP data coming from manufacturer's database for the J13 (L3e-A2)

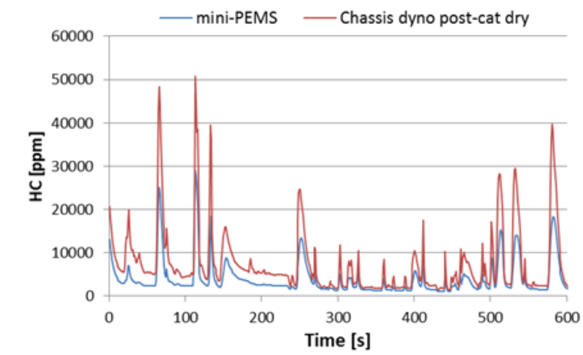
Q A comparison between emissions as measured with PEMS and the laboratory equipment

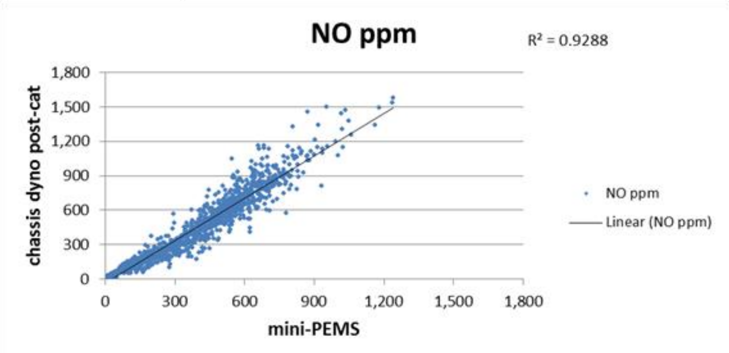
A comparison between instantaneous undiluted volume emission concentrations in the WMTC as measured with PEMS and the laboratory equipment. These figures are based on a WMTC with cold start driven with vehicle J17.

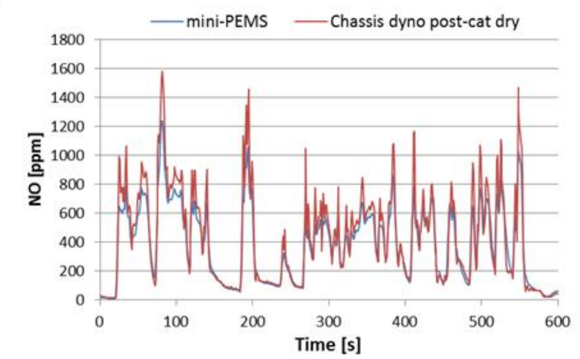


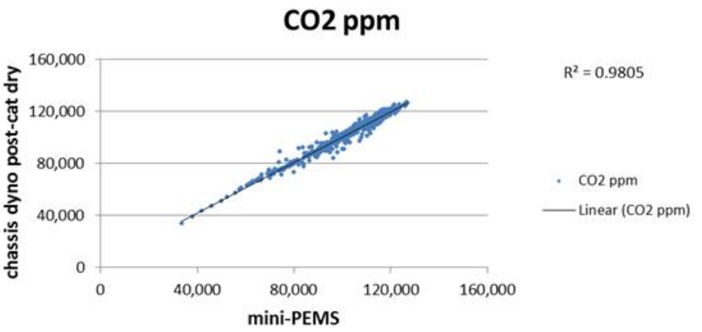


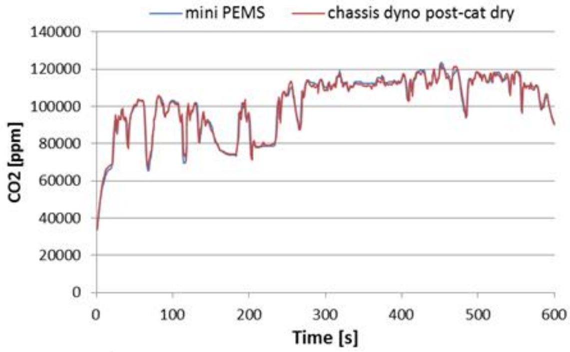




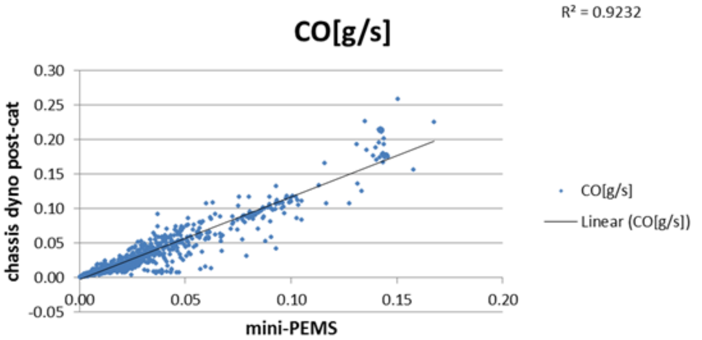


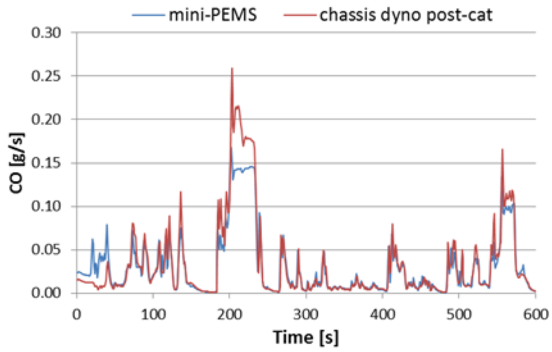


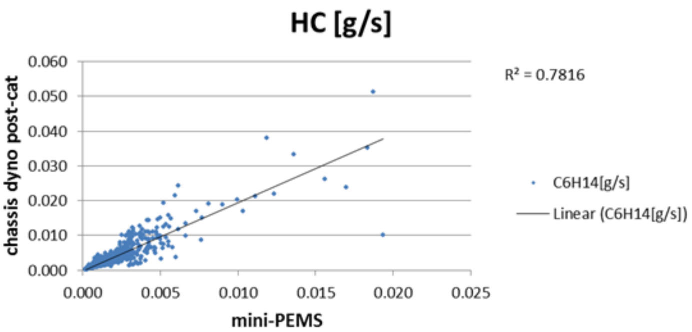


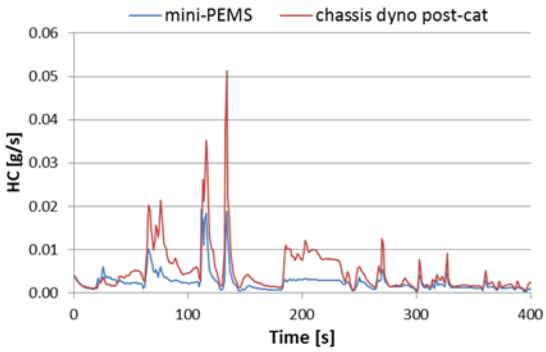


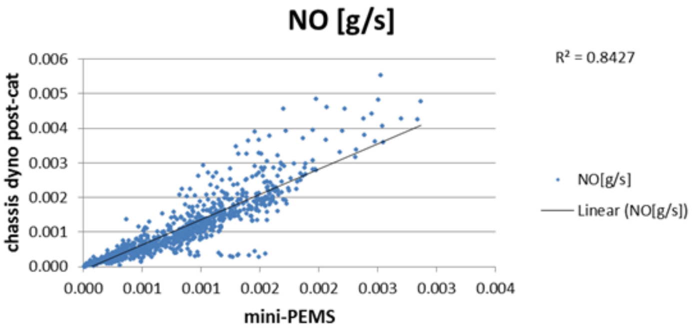
A comparison between instantaneous undiluted mass emissions in the WMTC as measured with PEMS and the laboratory equipment. These figures are based on a WMTC with cold start driven with vehicle J17.

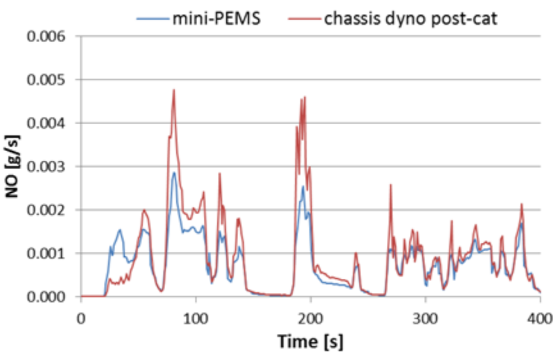


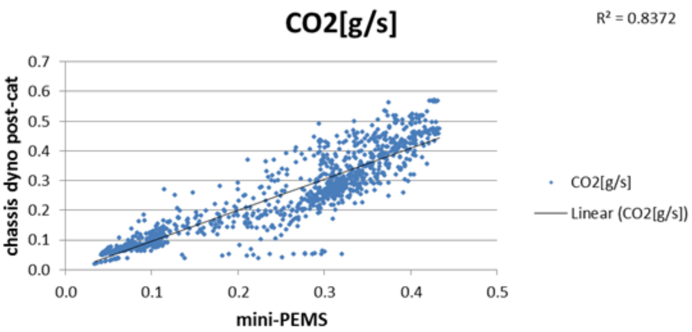


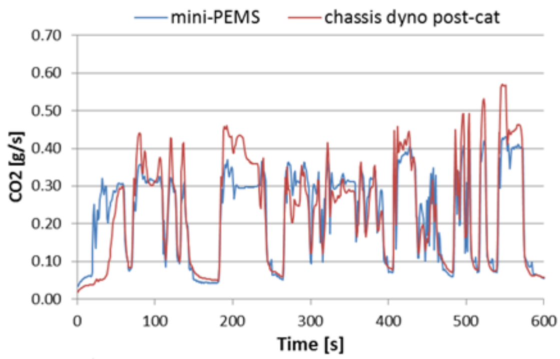









CO2[g/s]
R² = 0.8372
chassis dyno post-cat
mini-PEMS
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
CO2[g/s]
Linear (CO2[g/s])


mini-PEMS
chassis dyno post-cat
CO2 [g/s]
Time [s]
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0
100
200
300
400
500
600

R List of abbreviations

ACEM	The Motorcycle Industry in Europe
A/F	Air-Fuel
AMA	The USA EPA Approved Mileage Accumulation durability cycle as defined in Regulation (EU) No 134/2014
ATV	All-Terrain Vehicle
ATVEA	All-Terrain Vehicle industry European Association
AUTH	Aristotle University of Thessaloniki
BAT	Bench Ageing Time
CBA	Cost-Benefit Analysis
CDF	Cumulative Distribution Function
CH_4	Methane
CI	Compression Ignition
CNG	Compressed Natural Gas
CO	Carbon monoxide gas
CO_2	Carbon dioxide gas
COPERT	COmputer Programme to calculate Emissions from Road Transport
CV	Coefficient of Variation
CVF	Crankshaft Velocity Fluctuation
CVS	Constant Volume Sampler
CVT	Continuously Variable Transmission
DF	Deterioration Factor
DI	Direct Injection
DG JRC	Directorate General Joint Research Center of the European Commission
DG GROW	Directorate General Growth of the European Commission
DPF	Diesel Particulate Filter
EC	European Commission
ECU	Engine Control Unit
EEA	European Environment Agency
EF	Emission Factor
Effect Study	Euro 5 L-category Environmental Effects Study
EFI	Electronic Fuel Injection
EGR	Exhaust Gas Recirculation
EMEP	European Monitoring and Evaluation Programme
EPA	Environmental Protection Agency (US)
EQUAL	European association of manufacturers of quadricycles
ETC	Electronic Throttle Control
EU	European Union
FC	Fuel Consumption
FID	Flame Ionisation Detector
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GPS	Global Positioning System
GWP	Global Warming Potential
H/W	Hardware

ICE	Internal Combustion Engine
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
kt	kiloton
L-cat	Light category vehicles (L-category)
LAT	Laboratory of Applied Thermodynamics of the Aristotle University of Thessaloniki
LNT	Lean NO_x Trap
LowCVP	Low Carbon Vehicle Partnership
LPG	Liquid Petroleum Gas
MAF	Mass Air Flowmeter
MAP	Manifold Absolute Pressure
MCWG	Motorcycle Working Group
MI	Malfunction Indicator
MIL	Malfunction Indicator Light
NDIR	Non-Dispersive Infrared analyser
NG	Natural Gas
NMHC	Non-Methane Hydro-Carbons
NO	Nitric oxide gas
NO_2	Nitric dioxide gas
NO_x	Nitric oxides gases
NPV	Net-Present Value
O_2	Oxygen gas
OBD	On-Board Diagnostics
OSC	Oxygen Storage Capacity
OTL	OBD Threshold
PCV	Positive Crankcase Ventilation
PEMS	Portable Emission Measurement System
PI	Positive Ignition
PM	Particulate Mass
PN	Particle Number
ppm	parts per million
Pre-Study	Input to the Euro 5 L-category Effect Study (present study)
R101	UNECE-Regulation No. 101
R40	UNECE-R40 driving cycle as detailed in UN Regulation No. 40
R47	UNECE-R47 driving cycle as detailed in UN Regulation No. 47
RDE	Real Driving Emissions
RES	Remote Emission Sensing
RPM	Revolutions Per Minute (engine speed)
SAPS	Sulphated Ash, Phosphorus and Sulphur
SBC	Standard Bench Cycle
SHED	Sealed Housing for Evaporative emission Determination
SI	Spark Ignition
SIBYL	Vehicle stock, air pollutants, and GHG projection and policy evaluation tool (developed by EMISIA)
SRC	Standard Road Cycle
SRC-LeCV	The Standard Road Cycle for L-Category Vehicles as defined in Regulation (EU) No 134/2014
TA	Type Approval
TAA	Type Approval Authority

THC	Total Hydrocarbons
ToR	Terms of Reference
TS	Technical Service
ULV	Useful Life Value
UN L-EPPR	Working Group on international environmental and propulsion performance requirements for L-category vehicles
UNECE	United Nations Economic Commission for Europe
US	United States
Vkm	Vehicle-kilometer
VOC	Volatile Organic Compound
WMTC	Worldwide harmonized Motorcycle driving Cycle as defined in Regulation (EU) No 134/2014
w/o	without
WOT	Wide Open Throttle

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