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Contribution to the EU market surveillance: testing protocols and vehicle emissions performance

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Joint Research Centre 2017 light-duty vehicles emissions testing - Contribution to the EU market surveillance: testing protocols and vehicle emissions performance

This report summarises the results of the pilot study on the market surveillance of light-duty vehicles. The emission performance and the CO_2 emissions of 15 vehicles are presented. The methodology for vehicle compliance checks defined in the Guidance note published by the European Commission was applied and discussed.

Contents

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Authors

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1 Project Objectives and Boundaries

1.1 Introduction

The European Commission's Joint Research Centre (JRC) contributed and provided support to all of the actions taken by the European Commission in 2017 to streamline the EU investigations on vehicle emissions compliance, notably with the following activities:

- Testing, both in the laboratory and the road, a certain number of vehicles representative of the latest technologies appeared on the market using the latest protocols used at type approval (WLTP, RDE) to understand better the emission levels of the vehicles;
- Contributing to the work of the Commission Type Approval Authorities Expert Group (TAAEG) on market surveillance;
- Development and validation of common testing protocols and data processing to identify vehicles that present emission patterns which could be caused by potential use of defeat devices.

The work conducted in this project is introduced in the following sub-sections.

1.2 Regulatory requirements, technology trends and their impact upon real pollutant emissions

1.2.1 Pollutant emissions

The vehicles emissions test conducted in the project provide an insight on the pollutant emissions performance of the tested vehicles, relative to each other, as single vehicles or per technology classes, under comparable conditions (laboratory or same RDE routes) or relative to other data sources. The questions which are tentatively addressed are:

- Can current emissions control technology technologies of Euro 6b cars achieve already to date the Euro 6 emissions limits on the road?
- Will the new or improved technologies deliver the expected improvements, once assessed with the newest on-road test methods (RDE)?
- Under comparable conditions, which technologies appear as the cleanest and/or able to fulfil the latest environmental requirements?
- What are the essential regulatory requirements that will ensure that an improvement is achieved in terms of real world emissions performance compared to the current state (Euro 6b)?

1.2.2 CO_2 emissions

The extensive National Investigations which took place in 2016 and 2017 and the subsequent research efforts dedicated to understand the underlying causes leading to the CO_2 gap reported to date no illegal devices or practices used in order to reduce the type approval CO_2 emissions. It is not within the scope of this project to thoroughly search and identify illegal strategies, devices, control algorithms or practices that artificially and intentionally reduce CO_2 emissions measured over the certification procedure(s). However, attention is given to data generation (CO_2 emissions of vehicles both in laboratory and on-road conditions), collection of experience and know-how that will help to monitor how the new Type 1 cycle (WLTP) reports the reference CO_2 emissions of a given vehicle with respect to the NEDC.

1.3 Methodology to check the vehicles emissions compliance

1.3.1 General approach

The approach described in this paragraph is the one used by the JRC prior to the regulatory changes introduced within the 4th RDE package In-Service Conformity provisions. Until that moment and due to the large number of vehicles which can potentially be tested within a compliance verification project, several criteria are taken into account to build a sample of vehicles to test:

- The market share: Vehicles with high sales numbers should be used.
- The technical definition, i.e. the emissions standards, fuel and after-treatment can be considered as a second criterion.

Any additional information regarding the environmental performance of a given vehicle may – in the future - be considered during the selection such as Remote Sensing or results from PEMS, or from simplified emission monitoring systems (SEMS) [1,2].

1.3.2 Methodology for the detection of defeat devices

To support the EU Member States investigation activities regarding emissions of light-duty vehicles, the European Commission has published a guidance note [3] (hereinafter "the Guidance") to evaluate emissions strategies and to detect the presence of defeat devices. The JRC contributed to the development of the guidance and provided a testing protocol which the responsible authorities may use to detect illegal Auxiliary Emissions Strategies (AES). The protocol includes three main elements:

- It defines the principles to test vehicles, i.e. to modify certain elements of the standard emissions tests and to assess whether these modifications influence the behaviour of the emissions control technologies in a way that appears to be not justifiable from a technical point of view;
- In an attempt to facilitate the decision making within the National investigations which were largely focused on diesel vehicles, it recommends NOx emissions thresholds for different categories of tests, not with the objective to verify the vehicle compliance but rather to prioritise further testing on the most suspicious results;
- It proposed acceptable and non-acceptable AES for specific emissions control technologies, although the final decision lies with the Type Approval Authority who has the complete information available.

The Guidance was published in January 2017 and is subject to continuous improvements from the lessons learned during the National surveillance programs and the JRC testing. Within this project, ***the JRC kept testing vehicles with the objective to improve the test protocol, in particular its application to a variety of technologies and emissions standards.*** In case of emissions exceeding the recommended emissions thresholds, the results and the information contained herein are not conclusive and are always subject to analysis and verification by the responsible authorities. Such verification shall include additional tests of at least one similar vehicle to eliminate the potential uncertainty.

2 Methodology

2.1 Vehicle selection

2.1.1 Selection criteria and technologies

This project did not have the goal to achieve a wide coverage of the vehicles present on the European Market. Still, to be in the position to assess the environmental performance of vehicles (in combination with other databases) and to check the suitability of the test protocol for the detection of defeat devices, it was decided to build a vehicle sample as representative as possible, i.e. using high sales vehicles, several segments and the most diffused technologies in 2016-2017. The following criteria were used to build the sample:

- Sales numbers (Criterion 1);
- Vehicle manufacturer, to ensure a fair coverage of various manufacturers present on the EU market (Criterion 2);
- Vehicle segments (though not officially existing the segment definition provides an indication on the size of the vehicle);
- Vehicle emissions control and powertrain technologies.

Table 1: Vehicle size and technology selection

Vehicle segments	*Vehicle Technologies*
- A&B: Mini and Small cars - C: Medium cars - D&E: Large and executive cars - Light Commercial Vehicles	- Diesel (EGR+SCR+DPF, EGR+LNT+DPF,...) - Gasoline (non-GDI, GDI,...) - Hybrid (including mild, conventional and plug-in)

2.1.2 Sales numbers (Criterion 1)

As required by the Regulation 443/2009, Members States (MS) have to record information on each new passenger cars registered in their territory [4]. These data are recorded by the European Environment Agency (EEA) and made available through a publically available dataset [5]. This dataset was filtered and summarised, based on the type approval number and make of the vehicle before being cross-checked with consolidated data from European Automobile Manufacturers Association (ACEA) registered for the wider Europe [6]. Figure 1 presents the 2016 registration number of passenger cars in EU broken down by main group of manufacturer as defined in the ACEA data.

It has to be noted that ACEA data includes registration made in the EU28 (excluding Malta and Cyprus) and from Iceland, Norway and Switzerland. Data from EEA includes only registrations made in the EU28. This difference can explain the higher registration number displayed by ACEA. In addition, the process to clean up data on the EEA original dataset may also result in discarded data (misspelling or wrongly annotated entry) which resulted in lower registration number in the final dataset. The total number of new registration of passenger car in 2016 obtained after data processing (excluding small-volume[1] and niche manufacturers[2]) from the EEA and ACEA sources were 13.9M and 15.1M respectively.

[1] Manufacturers responsible for less than 10 000 new vehicle registrations per year.
[2] Manufacturers responsible for 10 000 to 300 000 new vehicle registrations per year.

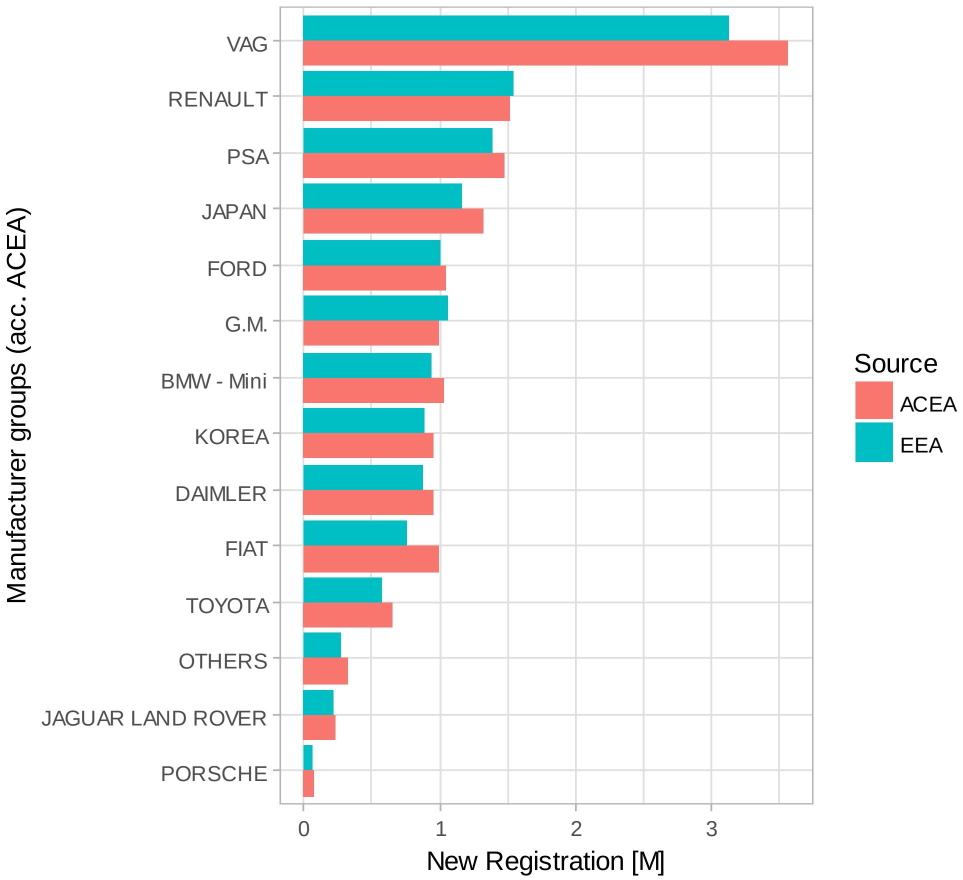

Figure 1: New passenger car registrations in EU28 (source EEA) and in enlarged Europe (source ACEA) broken down by main vehicle manufacturer groups (according ACEA classification).

2.1.3 Vehicle manufacturers sales and cluster classification (Criterion 1 and 2 combined)

As the objective was to focus on high sales vehicles and technologies, small-volume and niche manufacturers were excluded from the testing program for 2017. The bigger car manufacturers were all included and considered for the entire selection process. The choice of the clusters and the grouping for the selected manufacturers was purely arbitrary and only meant to ensure that vehicles are picked throughout the different regions. The classification of the vehicle manufactures is presented in Table 2.

Figure 2 presents the share of new registration of passenger cars in 2016 according to the consolidated data provided by ACEA for enlarged Europe, and broken down following the cluster classification defined in Table 2. According to these data and assuming a test fleet of 20 vehicles, Table 3 presents the number of vehicle by cluster to be tested together with the vehicle tested in 2017. For practical reasons, vehicles from cluster 5 will be tested in 2018.

Table 2: Cluster classification of the main car manufacturers in EU

Cluster	Country(ies) of origin	Group	Brands
Cluster 1	Germany	VAG, Daimler, B.M.W., Porsche	Volkswagen, Audi, Seat, Skoda, Mercedes, Smart, BMW, Mini, Porsche
Cluster 2	United States, Germany	Ford, G.M.	Ford, Chevrolet, Opel
Cluster 3	France	PSA, Renault	Peugeot, Citroën, DS, Renault, Dacia
Cluster 4	Italy, United Kingdom, Sweden	FIAT, Jaguar Land Rover, Saab, Volvo, Aston Martin	Fiat, Alpha Romeo, Chrysler, Dodge, Jeep, Jaguar, Land Rover, Saab, Volvo, Aston Martin
Cluster 5	Japan	Toyota, Honda, Mazda, Mitsubishi, Nissan, Subaru, Suzuki	Toyota, Honda, Mazda, Mitsubishi, Nissan, Subaru, Suzuki
Cluster 6	Korea	Hyundai, Kia	Hyundai, Kia

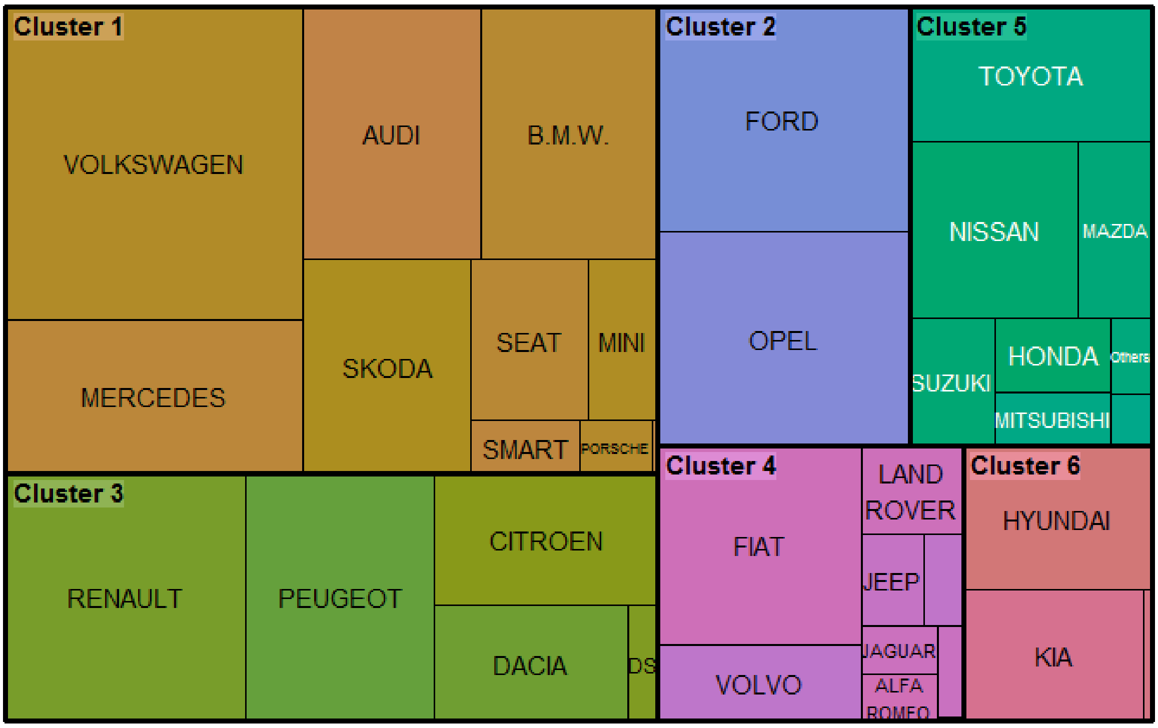

Figure 2: Share of new passenger car registrations in Enlarged Europe (source ACEA)

Table 3: Target and actual tested vehicles by main cluster

Cluster	Share	Target number of vehicle to be tested	Actual number of vehicle tested
Cluster 1	37%	7	7
Cluster 2	14%	3	2
Cluster 3	20%	4	4
Cluster 4	10%	2	1
Cluster 5	13%	3	0
Cluster 6	6%	1	1

2.1.4 Selected vehicles (All criteria combined)

Table 4 presents the vehicles included in this pilot study. In total, 15 vehicles complying with Euro 5b and Euro 6b standards were tested. Among the diesel vehicle tested, two of them were involved in a process of mandatory recall. Vehicles A and B were concerned by the recall organised by VW for vehicles equipped with the EA189 defeat device (more details on this defeat device functioning can be found in the literature [7]). These two vehicles were tested before and after the recall, thus the environmental performances of these vehicles were handled separately based on the software version. Regarding the technologies, Euro 6b gasoline vehicles were either Multipoint Fuel Injection (MPI) or Direct Injection (GDI). Euro 6b diesel vehicles were all equipped with an Exhaust Gas Recirculation (EGR) system and either Lean NOx Trap (LNT), Selective Catalytic Reduction (SCR) or both. More details on the vehicles tested can be found in Appendix 2.

Table 4: Selected vehicles (in bold, vehicles tested before and after software upgrade)

Id.	Manufacturer	Model	Seg.	Cluster	Euro	Fuel	Technologies
A	Skoda	**Yeti Outdoor 2.0l**	C	1	5b	Diesel	EGR – DPF
B	VW	**Tiguan 2.0l TDi**	D	1	5b	Diesel	EGR – DPF
C	Renault	Twingo 1.0l	A	3	6b	Gasoline	MPI
D	Fiat	Panda 1.2l	A	4	6b	Gasoline	MPI
E	Audi	A1 1.0l TSFI	A	1	6b	Gasoline	GDI
F	Ford	Fiesta 1.0l	B	2	6b	Gasoline	GDI
G	Opel	Astra 1.0 T ecoFLEX	C	2	6b	Gasoline	GDI
H	VW	Golf 1.4l TSI GTe	C	1	6b	Hybrid	GDI
I	Renault	Captur 1.5 dCi	B	3	6b	Diesel	EGR – DPF – LNT
J	Citroën	C4 Cactus 1.6l	C	3	6b	Diesel	EGR – DPF – SCR
K	VW	Golf 2.0l TDi	C	1	6b	Diesel	EGR – DPF – LNT
L	Audi	A3 2.0 TDi	C	1	6b	Diesel	EGR – DPF – LNT
M	KIA	Sportage 1.7l CRDI	D	6	6b	Diesel	EGR – DPF – LNT
N	BMW	530d 3.0l	E	1	6b	Diesel	EGR – DPF – SCR+LNT
O	Peugeot	Partner 1.6l	LC	3	6b	Diesel	EGR – DPF – SCR

2.2 Test methods

DISCLAIMER: As the declarations regarding the emissions control strategies are under the control of the vehicle Type Approval Authority, the report cannot provide any judgement on the legality of the observed systems functioning. The findings are only useful to improve the Guidance. Furthermore, the report does not include either detailed information (e.g. functioning of the emissions control technologies and/or second-by-second data) to discuss the difference(s) which may appear between the emissions from tests conducted under different conditions.

2.2.1 Introduction

As a general principle, the vehicles are tested under the standard emissions test(s). All testing starts by testing the vehicles for compliance according to the applicable regulatory methodologies (Type 1 test). This is an important step in order to make sure that the vehicle is free of malfunctioning, bad maintenance or other similar issues for which the emissions in the regulatory test could be exceeded. To detect the presence of defeat devices, the vehicles should then be tested under variations of the standard testing conditions referred to as "modified testing conditions". These general principles are illustrated in Table 5 for the various emissions standards.

Table 5: Emissions standards, regulatory emissions tests and possible modified conditions

Emissions standards	*Applicable regulatory emissions test(s)*	*Possible modified testing conditions for defat device detection*
Euro 5 Euro 6b	NEDC according to ECE R83	Modified NEDC, other cycles, on-road tests
Euro 6d-Temp Euro 6d	WLTP according to EU Reg. 2017/1151 RDE	Modified WLTP On-road tests outside the RDE "boundary conditions" (e.g. outside RDE altitude and temperature ranges)

2.2.2 Testing protocol to check for the presence of defeat devices

To detect the presence of defeat devices, the vehicles have to be tested under variations of the standard testing conditions applied for type approval referred to as "modified testing conditions".

The set of modified conditions is not fixed but instead kept open due to the need to detect specific technology behaviours in response to a complex set of parameters and the need to keep a non-predictable character. By modifying one or several of the test parameters with respect to the emissions test, one might trigger one or more of the following:

- A defeat device
- An Auxiliary Emission Strategy (AES) which becomes active and replaces the Base Emission Strategy (BES) for a specific purpose or purposes in response to a change of conditions (e.g. ambient temperature). Note that a vehicle can include several AES.
- A modified physical response of the engine and/or emissions control technologies, naturally caused by the change of conditions (e.g. ambient temperature affecting the warm-up of components) but not controlled by software in response to sensed signals/parameters.

The combination of both (the defeat device or AES and the physical effects) may result in a global change in tailpipe emissions. The JRC protocol proposed to introduce 4 categories of procedures to cover the possible situations.

• In category 1, the testing is conducted in a laboratory under a controlled environment with only limited changes when compared to the legislative cycle and the modified parameters can be controlled. The modification of the testing conditions shall not lead to a significant change in the physical response of the engine system but may lead to a limited change of the vehicle emissions. Examples of such modifications include testing vehicles with an open door or rolled-down windows.

• In category 2, the testing is conducted in a laboratory or on the road with conditions different than the legislative cycle and the value of the modified parameters can be controlled (e.g. driving a legislative cycle on a test track). The modification of the testing conditions may in some cases lead only to a limited change in the physical response of the engine system. Examples of such modifications include variations in the test temperature, the execution of hot-start tests, and the repetition of selected phases of the test cycle.

• In category 3, the testing is conducted on the road and the values of the modified parameters are - to a large extent - uncontrolled (e.g. the vehicle speed due to the traffic, the temperature, etc...). The modification of the testing conditions may lead to a significant change in the physical response of the engine system(s). The magnitude in the change of the emissions may depend on the severity of the testing conditions. Examples of such modifications include testing at various test routes characterised by a distinct altitude profile, such as the RDE compliant testing.

A category 4 is added in order to cover what we call "surprise testing" to cover testing that does not fall in any of the above categories, but may still be needed in order to detect a possible defeat device, for example in the case of evaporative emissions testing.

Under category 1, emissions exceeding the recommended thresholds are a strong indication for a possible presence defeat device, since there can be no plausible explanation for an increase in pollutant emissions by simple modifications that do not affect the engine performance. In such a case, it is certain that the vehicle sensed that it is not tested in a regulatory cycle and therefore the change in emission level.

Under categories 2 to 4, emissions exceeding the recommended thresholds might result from the possible presence of a defeat device and/or the physical effects upon the emissions control of an AES. And therefore further investigations and explanations from the manufacturers will be needed in order to identify if it is really a defeat device or an approved AES.

It should be noted that contrary to pollutant emissions the influence of certain defeat devices/modifications/optimisation strategies on CO_2 emissions have a low impact. Indeed the increases in pollutant emissions can be an order or orders of magnitude higher than the legal limit. In the case of CO_2 small differences of 5-10% may imply some optimisation approach or simply a different vehicle operation that is well within its normal operation. Hence, it is difficult to extract solid conclusions without a large number of repetitions and dedicated tests. Thus, only CO_2 emissions obtained over NEDC, WLTC and RDE are used to discuss the CO_2 deviation ratio. The selection of tests conducted in this study together with their objectives is presented in Table 6.

Table 6: Type of tests and objectives

Type of Test	*Category*[3]	*Objectives*
NEDC Cold	-	Vehicle emissions compliance under standard conditions
NEDC Hot	2	Emissions performance with hot engine, to check for a potential timer or vehicle conditioning triggering AES[4]
NEDC w/o preconditioning Cold	2	Emissions performance on a cold started NEDC driving cycle without pre-conditioning of the vehicle, to check for the potential vehicle conditioning triggering AES
NEDC Repeated Hot	2	Emissions performance with hot engine (without turning off the engine between the two tests), to check for a potential timer or distance windows triggering AES
Modified NEDC Cold +10% Speed	2	Vehicle emissions on a modified NEDC driving cycle, to check for a potential speed or distance windows triggering AES
Modified NEDC Cold -10% Speed	2	Vehicle emissions on a modified NEDC driving cycle, to check for a potential speed window triggering AES
NEDC hot with additional engine loads (A/C and lights)	2	Emissions performance with hot engine and additional engine loads (A/C and lights), to check for a potential use of vehicle systems triggering AES
NEDC +10°C Cold	2	Emissions performance at low ambient temperature, to check for a potential thermal window triggering AES
NEDC +30°C Cold	2	Emissions performance at high ambient temperature (higher than 30°C[5]), to check for a potential thermal window triggering AES
WLTC Cold	2	Emissions performance on cold started WLTC to check for a potential timer, vehicle conditioning, as well as speed or distance windows triggering AES.
WLTC Hot	2	Emissions performance on hot started WLTC to check for a potential timer, vehicle conditioning, as well as speed or distance windows triggering AES
RDE	3	Emissions performance on road, to check for ECS functioning under uncontrolled conditions, beyond the NEDC conditions

2.3 Tests conducted per vehicle

As a core test matrix, all the vehicles selected for this study were checked over their respective test cycle for Type 1 test: NEDC cold. In addition, all vehicles were tested over the NEDC hot, WLTC cold, WLTC hot and on the road over two different RDE compliant routes. Then, on a case-by-case basis, these vehicles were tested on chassis dynamometer over NEDC tests carried out using modified parameters (e.g. speed trace, ambient temperature, and vehicle condition) as described in Table 6. For instance, while ambient temperature was studied only in a lower range for the gasoline vehicles (+10°C), it was studied in both lower and higher range for the diesel vehicles (+10°C and +30°C). Table 7 summarises the type of tests conducted for each vehicle included in this study.

[3] The categorisation of the various types of tests is made by the responsible testing entity and should be based on the lessons learned from its own testing activities and/or the publicly available information. It is subject to adaptations and revisions depending on the emissions control technology.

[4] In the following AES will stand for AES or Defeat Device. The decision on whether something can be considered an AES or a Defeat Device is always the responsibility of the Type Approval Authority.

[5] These test were carried out at ca. 30°C due to laboratory facility limitation

Table 7: Tests conducted for each vehicle - NB: Vehicles in bold were part in a voluntary or mandatory recall. These vehicles were tested before and after software upgrade.

Id.	Model	Euro	Fuel	NEDC (Acc. to Reg.83) Cold	NEDC Hot	NEDC w/o preconditioning Cold	NEDC Repeated Hot	Mod. NEDC +10% Speed Cold	Mod. NEDC -10% Speed Cold	NEDC with engine loads Hot	NEDC at +10°C Cold	NEDC at +30°C Cold	WLTC Cold	WLTC Hot	RDE	Other test
Category				1	2	2	2	2	2	2	2	2	2	2	3	-
A	**Yeti Outdoor 2.0l TDi**	5b	Diesel	X	X						X		X	X		X
B	**Tiguan 2.0l TDi**	5b	Diesel	X	X			X							X	X
C	Twingo 1.0l	6b	Gasoline	X	X	X	X	X		X	X		X	X	X	
D	Panda 1.2l	6b	Gasoline	X	X			X	X	X	X		X	X	X	
E	A1 1.0l TSFI	6b	Gasoline	X	X			X	X	X	X		X	X	X	
F	Fiesta 1.0l	6b	Gasoline	X	X								X	X	X	
G	Astra 1.0 T ecoFLEX	6b	Gasoline	X	X	X	X	X		X	X		X	X	X	
H	Golf 1.4l TSI GTe	6b	Hybrid	X							X		X		X	X
I	Captur 1.5 dCi	6b	Diesel	X	X	X	X	X		X	X	X	X	X	X	
J	C4 Cactus 1.6l	6b	Diesel	X	X						X	X	X		X	X
K	Golf 2.0l TDi	6b	Diesel	X	X	X		X		X	X	X	X	X	X	X
L	A3 2.0 TDi	6b	Diesel	X	X						X	X	X	X	X	X
M	Sportage 1.7l CRDI	6b	Diesel	X	X	X	X	X		X	X	X	X	X	X	
N	530d 3.0l	6b	Diesel	X	X	X	X	X			X	X	X	X	X	
O	Partner 1.6l	6b	Diesel	X	X	X	X	X		X	X	X	X	X	X	

2.4 Test settings

The chassis dynamometer tests were conducted at the European Commission Joint Research Centre (EC-JRC) Ispra, Italy, using two of the Vehicle Emission Laboratories (VELA). The first facility was composed of a chassis dynamometer (two rolls with 48'' diameter, inertia range 454-4540 kg, MAHA Haldenwang, Germany), a Constant Volume Sampler (CVS, flow rate range 3 m^3 min^{-1} - 30 m^3 min^{-1}) with a critical flow venturi, and gas analyzer benches (MEXA-7100 for the raw exhaust and MEXA-7400 for the dilution tunnel and bags, HORIBA, Japan). The second facility was composed of a chassis dynamometer (two rolls with 48'' diameter, inertia range 250-4500 kg, ZÖLLNER GmbH, Bensheim, Germany), a CVS (CVS i60 LD, flow rate range 2 m^3 min^{-1} - 20 m^3 min^{-1}) with a critical flow venturi, and gas analyzer benches (AMAi60 R1(D1) for both the raw exhaust and the dilution tunnel and bags, AVL, Graz, Austria).

Vehicles were tested in the laboratory applying the resistances on the chassis dynamometer that were not the official NEDC road load values used during the type approval of these vehicles. For NEDC tests, in some cases tabulated chassis dyno coefficients (Regulation 83) have been used but for most vehicles road load coefficients were calculated based on the vehicle characteristics (inertia and dimensions). Formulas for calculation of these NEDC road load coefficients (F0, F1, and F2) were derived from a JRC database of vehicles for which road loads were known and provided by OEM's [8]. Road load coefficients for WLTP tests have been calculated from NEDC road loads taking into consideration all procedural differences between NEDC and WLTP procedures that have an impact on road load [8]. In addition, all WLTP tests have been done following the requirements of the new test procedure such as: increased and more realistic test mass, new gearshift strategy (for vehicles with manual transmission), test temperature, accuracy of the chassis dyno for the road load simulation, and vehicle preconditioning. In addition, the WLTP regulation prescribes the correction of measured CO_2 results for the vehicle's battery state of charge (SOC) at the end of the test. However, the WLTP CO_2 results included in this report have not been corrected for the SOC of the battery and this could impact the final results by additional 1-2% [22]. In addition, the ambient temperature correction test (ATCT) which is mandatory in Europe has not been applied in the JRC WLTP tests. Hence the likely WLTP-based official CO_2 emissions of the vehicles tested would be about 4% higher than what is reported here [22].

To assess emissions performance of vehicle over on-road tests, the three following models of PEMS were used:

- SEMTECH-DS (Sensors, Saline, Michigan, USA – model 2008)
- SEMTECH-ECOSTAR (Sensors, Saline, Michigan, USA – model 2013)
- MOVE (AVL, Graz, Austria – model 2016)

2.5 Quality control and validation of test results

For the laboratory tests, a minimum of two repetitions per test type were carried out per vehicle. As the purpose of the testing protocol was to detect a potential AES rather than accurately reported an emission performance of the specific vehicle over modified testing condition, this screening approach was adopted. As a first quality check, the repeatability of the pollutant measurement was assessed for each type of test described in Table 6. The quality check was considered successful when at least one of the two conditions defined in Table 8 was fulfilled. The tolerances for repetition acceptance were inspired by the permissible tolerances defined in Appendix 3 of RDE regulation of the recommended validation of PEMS equipment [9]. For on-road tests, the latest requirements defined in the RDE3 regulation 2017/1151 including the amendments of RDE3 laid down in regulation 2017/1154 were used and fulfilled for most of the tests[6] (boundary conditions,

[6] Test normality not verifiable or not always fulfilled for Vehicles B, D, K and O. Trip dynamicity not always fulfilled for Vehicles J and M.

trip dynamicity, periodic regeneration etc.) [10]. For the data evaluation, the method described in Appendix 5 of the RDE3 regulation was used (Moving Average Window method) and conducted with EMROAD (version 5.96).

Table 8: Conditions of acceptance of the laboratory test type experimental results

Pollutants	*Condition 1* *Limit of the absolute difference between max and min values of the repetitions*	*Condition 2* *Limit of the coefficient of variation of the repetitions*
THC	15 mg/km	15%
PN	$1\ 10^{11}$ #/km	50%
CO	15 mg/km	15%
CO_2	10 g/km	10%
NOx	15 mg/km	15%

3 Pollutant Emissions Results

3.1 Introduction

The primary objective of the section is to provide an insight on the emissions performance of the tested vehicles, relative to each other, as single vehicles or per technology classes, under comparable conditions (laboratory or same RDE routes) or relative to other data sources. With this analysis, the questions which are addressed are:

- Under comparable conditions, which technologies appear as the cleanest and/or able to fulfil the latest environmental requirements?
- With Euro 6b, is there a significant trend towards an improvement or a worsening of the real-world emissions performance?

In the present chapter, the difference between laboratory and on-road emissions is not discussed. This point is presented and discussed in Section 4.

This chapter seeks to answer these questions based on the laboratory and PEMS emissions data collected by the JRC in 2017. The emissions performance is presented for "reference situations", i.e. the Type 1 test (NEDC – see limits in Table 9) and RDE (complete and urban, conducted and processed according to the RDE3 rules laid down in regulation 2017/1151). The results from tests conducted specifically to detect AES/defeat devices are presented in Section 5. The vehicle sample is relatively small (15 vehicles of various technologies and emissions standards). In addition, the RDE data collected during the project does not cover the full variability of the on-road emissions for a given vehicle, within or outside the RDE boundary conditions. ***The project pollutant emissions results are therefore compared in a second step with the data from European National programs*** [11–15] ***or other databases*** [16,17]***, to determine whether the findings from the vehicle sample can be safely assumed as representative for the to-date European situation.***

Table 9: Regulated pollutant Type 1 test limits for the vehicles included in this study

Pollutants	*Diesel Euro 5b*	*Gasoline Euro 6b*		*Diesel Euro 6b*	
		MPI	*GDI*	*M1*	*N1 Cl.2*
THC [mg/km]		100	100		
NMHC [mg/km]		68	68		
NOx [mg/km]	180	60	60	80	105
HC+NOx [mg/km]	230			170	195
CO [mg/km]	500	1000	1000	500	630
PM [mg/km]	4.5	4.5	4.5	4.5	4.5
PN [#/km]	$6\ 10^{11}$		$6\ 10^{12}$	$6\ 10^{11}$	$6\ 10^{11}$

3.2 JRC 2017 emissions results

3.2.1 NOx emissions

NOx emissions obtained for the NEDC and RDE tests are presented in Figure 3, while Table 10 shows the average emissions by main vehicle technologies and emissions standards. Please note that the names used for the various vehicles in all figures and tables below should be read as making reference to Table 4. The following observations can be made for their laboratory and on-road emissions (under RDE conditions):

- The limits on the NEDC were fulfilled over the cold cycles in all cases for all the vehicles.

- The Euro 6b gasoline vehicles emitted on average 8 times less compared to the Euro 6b diesel.
- Within the Euro 6b gasoline vehicles, a significant difference was found between MPI vehicles and GDI ones for the on-road NOx emissions. While average NOx emissions over NEDC were rather low for the two technologies, vehicles equipped with GDI displayed 7-8 times more NOx over the RDE tests compared to the MPI vehicles. All Euro 6b gasoline vehicles remained however within the upcoming RDE conformity factor of 1.5 defined for Euro 6d standard.
- For the NEDC cycles, the NOx emissions are on average 18% higher for Euro 6b diesel vehicles on the hot NEDC when compared to the cold NEDC. This point/issue is analysed and discussed further in section 5.3.2.
- The NOx emissions from Euro 6b diesel vehicles tend to decrease with respect to the Euro 5b diesel. The NEDC results were 4 times less, a result that is expected as the limit decreased from 180 mg/km to 80 mg. The RDE results also decreased 2 times (but only one vehicle Euro 5b diesel was tested on the road in this study). Although this assessment is based on only two Euro 5b diesel vehicles, their average NOx emissions were in agreement with former JRC studies [18]. Indeed, as the average NOx emissions of Euro 5b diesel vehicles A and B were found to be 154 ± 75 and 743 ± 120 mg/km, former studies including 5 Euro 5b diesel vehicles exhibited 200 ± 40 and 710 ± 300 mg/km over cold NEDC and on-road test respectively [18–20]. The Euro 6b results are also in agreement with the literature [11–15,21].
- The RDE urban emissions resulted systematically lower when compared to the RDE emissions for the complete trip, both on average and for individual vehicles.

Table 10: Average NOx emissions in mg/km over NEDC and RDE tests by emissions standard and vehicle technology. Data obtained before software upgrade are excluded (Vehicles A and B).

Cycle / Vehicle Technology (#)	NEDC Cold	NEDC Hot	Urban RDE	Complete RDE
Euro 5b Diesel (2)	120	298	660	826
Euro 6b Gasoline non-GDI (2)	7	7	10	10
Euro 6b Gasoline GDI (3)	10	10	72	78
Euro 6b Diesel (excluding LCV) (8)	45	53	295	417

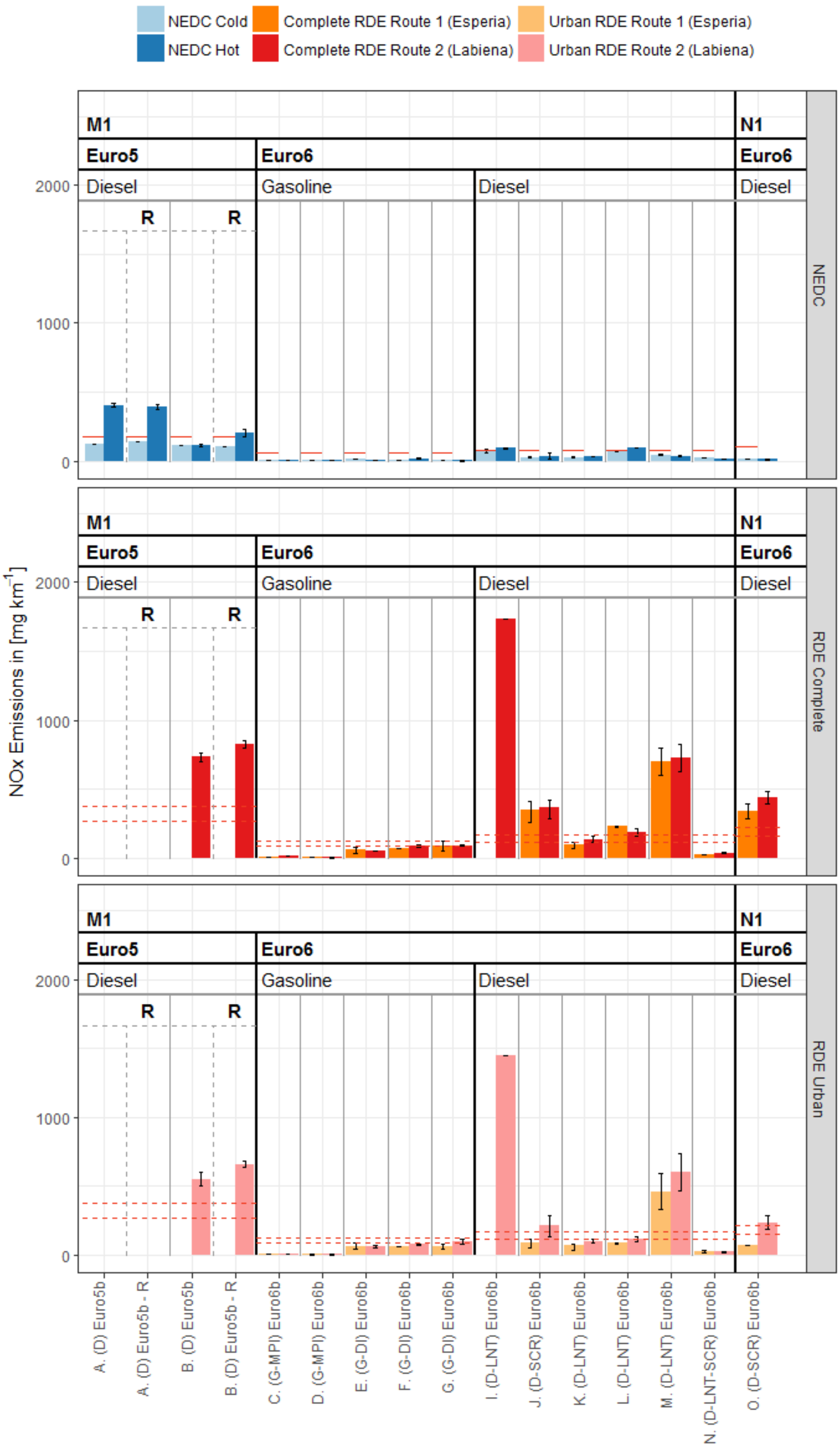

Figure 3: NOx emissions for the NEDC laboratory cold and hot tests (top panel) and on-road tests (middle and bottom panels). Error bars stand for min and max values. Vehicle A was not tested on-road. Vehicle B was tested on-road over RDE Route 2 only. On top panel, horizontal red lines stand for the NOx standards defined for Cold NEDC. On middle and bottom panels, dashed horizontal red lines stand for the NOx standard including the conformity factor of 1.5 and 2.1. "R" labels identify the reprogrammed vehicles measured after voluntary or mandatory recalls.

3.2.2 CO emissions

The CO emissions obtained for the NEDC and RDE tests are presented in Figure 4, while Table 11 shows the average emissions by main vehicle technologies and emissions standards. The following observations can be made for their laboratory and on-road emissions (under RDE conditions):

- The Euro 6b diesel vehicles emitted on average 7 times less compared to the Euro 6b gasoline.
- The CO emissions from Euro 6b diesel vehicles tend to increase with respect to the Euro 5b diesel (50% and 37% more over NEDC and on-road tests respectively). CO emissions from diesel vehicles remained however at a very low level.
- The CO emissions from Euro 6b gasoline vehicles varied a lot depending on test conditions. As expected due to the catalyst light-off, the emissions over the cold cycles were systematically higher than those over the hot NEDC. As already well documented, CO is mostly related to the cold start of the gasoline vehicles [22,23].
- For the on-road tests, the CO emissions from gasoline vehicles were found 5 times higher over the complete Route when compared to the urban part of the RDE route. This finding is consistent with the recent RDE data provided by the manufacturers during the RDE monitoring phase [24,25].
- Within the Euro 6b gasoline vehicles, a noticeable difference was found between MPI and GDI vehicles. GDI vehicles exhibited systematically lower CO emissions when compared to the MPI vehicles. Such trend was particularly reinforced over the hot NEDC and over Complete RDE routes (ca. 3 times les CO emissions from GDI equipped vehicles). In addition, over on-road CO emissions, a more pronounced difference between urban part and complete RDE routes were found for MPI vehicles (almost 7 times more respectively) compared to GDI vehicles (4 times more respectively).
- Diesel and GDI vehicles CO emissions were systematically below the corresponding CO limit defined for Type 1 test (cold NEDC), both over the NEDC and on-road (for urban and complete trips). However, the average CO emissions of MPI gasoline vehicles over the complete RDE trip exceed 1000 mg/km (Type 1 Euro 6 limit for gasoline vehicles). This discrepancy came from the behaviour of one vehicle (C) over one RDE Route (Esperia, cf. Figure 4). Over this test, Vehicle C displayed over the Motorway section an RDE CO emission of ca. 10 g/km. Such behaviour is not isolated and will be presented more in detail 5.4.2. Without this outlier value, the average of CO RDE emission over complete route from Euro 6b MPI gasoline vehicles is 311 ± 80 mg/km, thus below the CO limit.

Table 11: Average CO emissions in mg/km over NEDC and RDE tests by emissions standard and vehicle technology

Cycle / Vehicle Technology (#)	NEDC Cold	NEDC Hot	Urban RDE	Complete RDE
Euro 5b Diesel (2)	128	4	46	25
Euro 6b Gasoline non-GDI (2)	360	332	203	1399
Euro 6b Gasoline GDI (3)	299	95	111	434
Euro 6b Diesel (excluding LCV) (8)	170	23	51	46

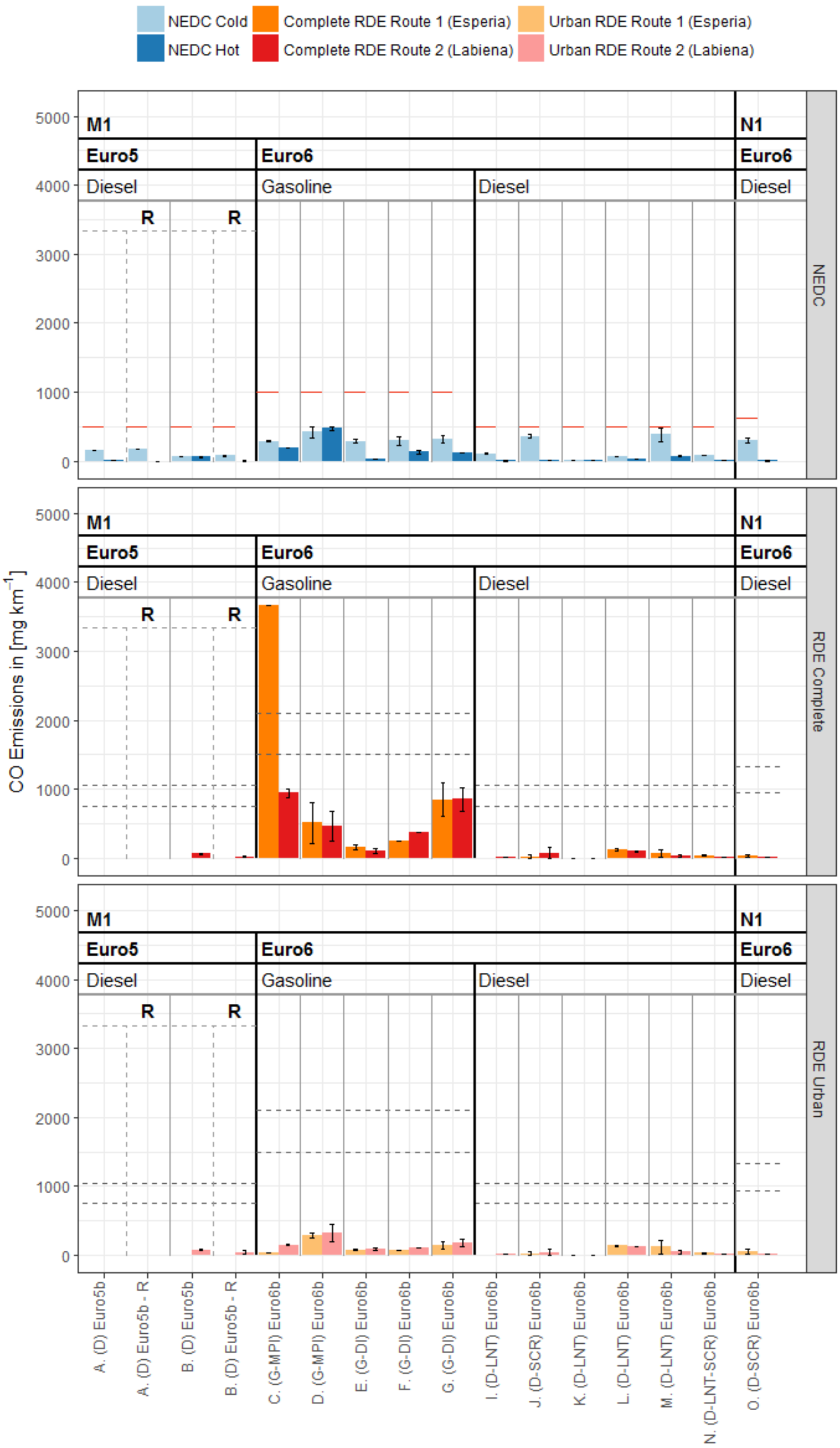

Figure 4: CO emissions for the NEDC laboratory cold and hot tests (top panel) and on-road tests (middle and bottom panels). Error bars stand for min and max values. Vehicle A was not tested on-road. Vehicle B was tested on-road over RDE Route 2 only. On top panel, horizontal red lines stand for the CO standards defined for Cold NEDC. On middle and bottom panels, dashed horizontal grey lines stand for the CO standard including a conformity factor of 1.5 and 2.1 (for illustration purposes). "R" labels identify the reprogrammed vehicles measured after voluntary or mandatory recalls.

3.2.3 HC emissions

As HC measurements were not conducted for the on-road tests, the on-road HC emissions were substituted by the WLTC emissions in this section. HC emissions obtained for the NEDC and WLTC tests are presented in Figure 5, while Table 12 shows the average emissions by main vehicle technologies and emissions standards. The following observations can be made:

- The Euro 6b gasoline vehicles emitted on average ca. 40% and 78% more on NEDC and WLTC respectively, when compared to the Euro 6b diesel over the cold-start tests. No difference was found over hot-start tests.
- Cold-start tests exhibited higher HC emissions when compared to hot-start tests. Similar to CO emissions, HC is primarily related to the cold-start of the gasoline vehicles [22,23], thus, the difference between HC emissions over cold and hot cycles is higher for Euro 6b gasoline when compared to Euro6b diesel vehicles (4.1 and 1.9 times more HC over cold cycles respectively). It explained also why the trend was in average more pronounced for the NEDC compared to WLTC (4 and 1.9 times more HC over cold cycles respectively). In the latter cycle, HC cold-start excess mass emission is divided by the longer distance of the WLTP (ca. 23 km versus ca. 10 km for the NEDC).
- No clear difference between HC emissions from Euro 5b and Euro 6b diesel vehicles was found, neither between Euro 6b MPI and GDI gasoline vehicles.
- HC emissions of all gasoline vehicles complied with the Type 1 emission limit (100 mg/km) both over NEDC and WLTP. Over both cycles, the maximum HC emissions were half the Type 1 limit.

Table 12: Average HC emissions in mg/km over NEDC and WLTC tests by emissions standard and vehicle technology

Cycle / Vehicle Technology (#)	NEDC Cold	NEDC Hot	WLTC Cold	WLTC Hot
Euro 5b Diesel (2)	29	12	9	9
Euro 6b Gasoline non-GDI (2)	35	14	27	13
Euro 6b Gasoline GDI (3)	43	5	37	12
Euro 6b Diesel (excluding LCV) (8)	28	12	18	13

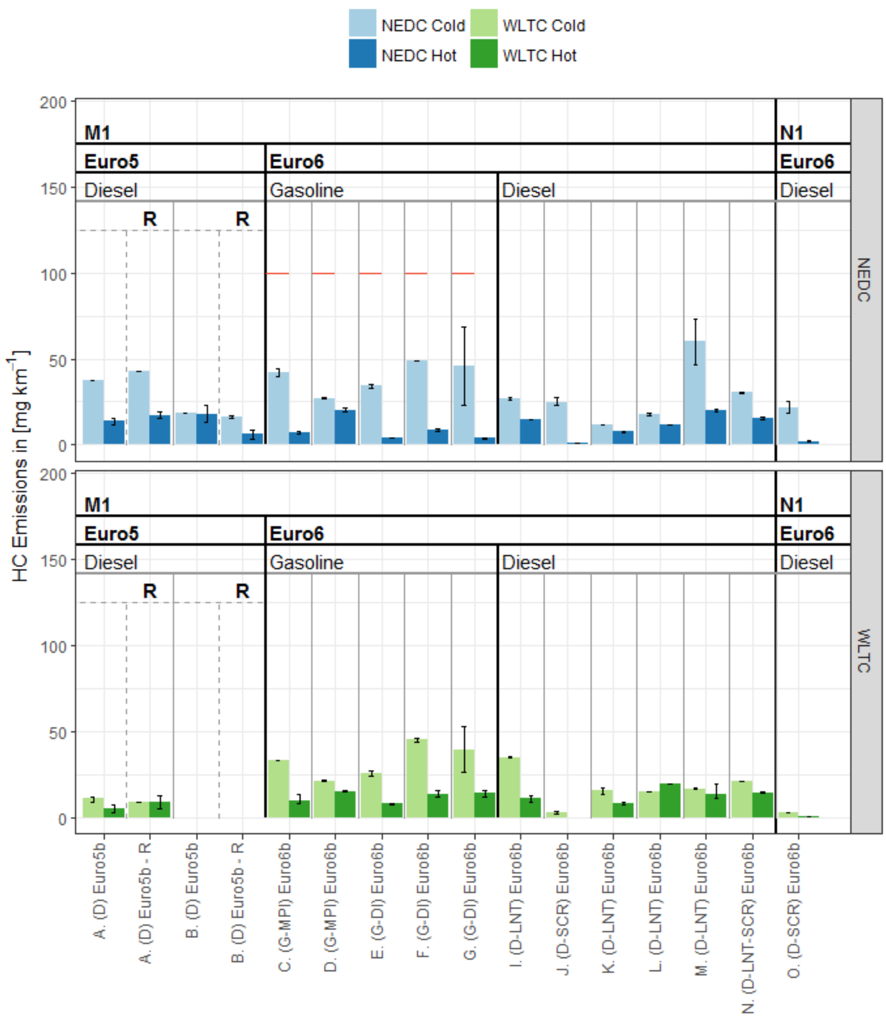

Figure 5: HC emissions for the NEDC (top panel) and WLTC (bottom panel) laboratory tests. Error bars stand for min and max values. On top panel, horizontal red lines stand for the HC standards defined for gasoline light-duty vehicles over Cold NEDC. "R" labels identify the reprogrammed vehicles measured after voluntary or mandatory recalls. Vehicle B was not tested over cold and hot WLTC, while vehicle J was not tested over hot WLTC. "R" labels identify the reprogrammed vehicles measured after voluntary or mandatory recalls.

3.2.4 PN emissions

Due to the PEMS PN equipment availability, only a limited number of vehicles were checked on-road for their particulate emissions. PN emissions obtained for the NEDC and RDE tests are presented in Figure 6, while Table 13 shows the average emissions by main vehicle technologies and emissions standards. The following observations can be made for their laboratory and on-road emissions (under RDE conditions):

- The Euro 6b diesel vehicles, all equipped with DPF, emitted on average 200 times less PN compared to the Euro 6b gasoline vehicles.
- Within the Euro 6b gasoline vehicles, a difference was found between MPI vehicles and GDI ones, the latter emitting on average 10 times more particulate. This difference between MPI and GDI technologies was even more pronounced in the laboratory than on-road, with a ratio of 15 and 6 respectively.
- No clear difference between PN emissions from Euro 5b and Euro 6b diesel vehicles was found over the NEDC tests.

- All vehicles tested over RDE tests with PN-PEMS equipment (vehicles C, D, E, F, G, M and N, including both Euro 6 diesel and gasoline engines) were systematically below the applicable limit defined for RDE including a CF of 1.5.
- Over the two Euro 6b MPI gasoline vehicles, one (vehicle D) exhibited PN emissions over a complete RDE route exceeding the PN limit of 6 10^{11} #/km defined for Euro 6b diesel vehicles.

Table 13: Average PN emissions in 10^{11} #/km over NEDC and RDE tests by emissions standard and vehicle technology. Standard limits over NEDC Cold are 6 10^{11} #/km for diesel vehicles and 6 10^{12} #/km for GDIs. "NA" stands for "not available". PN emissions were monitored over RDE tests for the five gasoline vehicles, and for only two diesel Euro 6b vehicles.

Cycle / Vehicle Technology (#)	NEDC Cold	NEDC Hot	Urban RDE	Complete RDE
Euro 5b Diesel after recall (2)	0.4	0.1	NA	NA
Euro 6b Gasoline non-GDI (2)	2.0	0.5	2.1	3.0
Euro 6b Gasoline GDI (3)	23.7	9.6	14.5	17.9
Euro 6b Diesel (excluding LCV) (8)	0.2	0.1	0.03	0.02

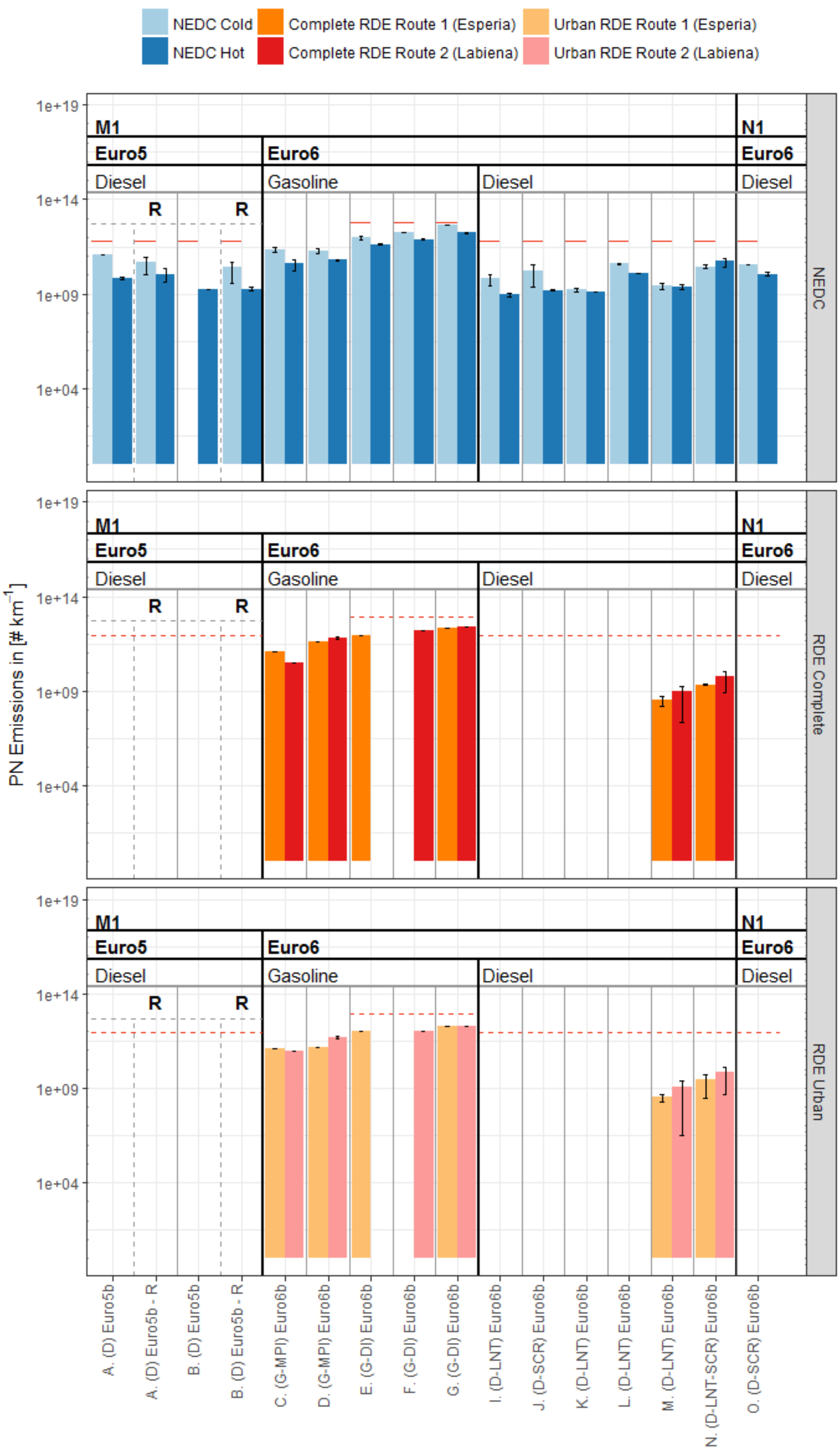

Figure 6: PN emissions for the NEDC laboratory tests (top panel) and on-road tests (middle and bottom panels). Error bars stand for min and max values. On top panel, horizontal red lines stand for the PN standards defined for diesel and gasoline with direct injection over Cold NEDC. On middle and bottom panels, dashed horizontal red lines stand for the PN standard including the conformity factor of 1.5. PN emissions from vehicles A, B, I, J, K, L and O were not measured on-road. "R" labels identify the reprogrammed vehicles measured after voluntary or mandatory recalls.

3.3 Comparison of JRC results with other data sets

3.3.1 Objectives

In this chapter, the JRC vehicle sample was compared with larger data sets obtained with similar requirements (in terms of data quality and testing conditions). This was done in order to have a better insight on the trends presented in section 3.2 for the JRC vehicle sample.

The following datasets were considered:

- The data published in the scope of European National surveillance programs [11–15];
- Databases such as the RDE monitoring exercise (as required in Regulation (EU) 2016/427 and amended by Regulation (EU) 2017/1154 [9,26]),
- The one from Emissions Analytics [16] and from Deutsche Umwelthilfe [17].

For some of the data sets, the compliance of the tests with the RDE3 regulation could only be verified for certain requirements: The main deviations of these data sets with respect to the requirements are depicted in Table 14.

Table 14: Datasets characteristics (1115 data including Euro 5 and Euro 6 gasoline and diesel vehicles)

Data Set	**Contents**	**Number of vehicles**
European National programs (2015-2016) [11–15]	Euro 5-Euro 6b Tests depending on the program On-road, NEDC, modified tests	203
Deutsche Umwelthilfe (2018) [17]	Euro 5-Euro 6b On-road data only ("RDE-like")	71
Emissions Analytics (2014-2017) [16]	Euro 5-Euro 6b On-road data only ("RDE-like" – cold start not included)	622
RDE Monitoring (2016-2017)	Euro 6b RDE data (calculated acc. to RDE3)	219

The data sets used in this section may not be fully representative for the European situation, regarding for instance the following elements: number of vehicles per technology and per segment, testing conditions used (e.g. the Emissions Analytics data is not measured on an RDE compliant route), etc. The statistical distributions obtained from the data should therefore only be considered as indicative.

3.3.2 NOx on RDE Tests

Basic statistics for the NOx RDE available data from gasoline and diesel vehicles were carried out on both full data and only RDE compliant data. Figure 7 and Figure 8 show the average NOx RDE obtained in this study over the RDE Complete route identified in the dataset above-mentioned.

On the full dataset (Figure 7 and Figure 8, top panels), for what regards the gasoline Euro 6b, the average NOx RDE of the dataset was 33 mg/km and the median value was 19 mg/km. The NOx RDE distribution had an Inter-Quartile Range (IQR) of 32 mg/km and was substantially right-skewed (skewness = 2.9). For what regards the diesel Euro 6b, the average NOx RDE was 356 mg/km and the median value was 265 mg/km. The NOx RDE distribution had an IQR of 343 mg/km and was slightly right-skewed (skewness = 1.5).

Unlike for NOx RDE from gasoline vehicles, a difference was found between Euro 5 and Euro 6b NOx RDE from diesel vehicles, with a median emission of 680 and 265 mg/km respectively. As NOx RDE distributions from Euro 6b gasoline and diesel vehicles are not normal, the variability of the two dataset can be calculated based on the Quartile based CV (IQR/median) instead of the conventional CV (standard deviation/average). Following this approach, the variability of the datasets were 1.7 for gasoline and 1.3 for diesel NOx RDE.

On the dataset composed only of RDE compliant data, gasoline Euro 6b the distribution of the NOx RDE data looks similar to those of the all datasets (Figure 7).

For the diesel Euro 6b, the NOx RDE data distribution was found substantially narrower and bimodal, with lower average and median NOx RDE (187 and 171 mg/km respectively), and lower IQR (261 mg/km) (Figure 8).

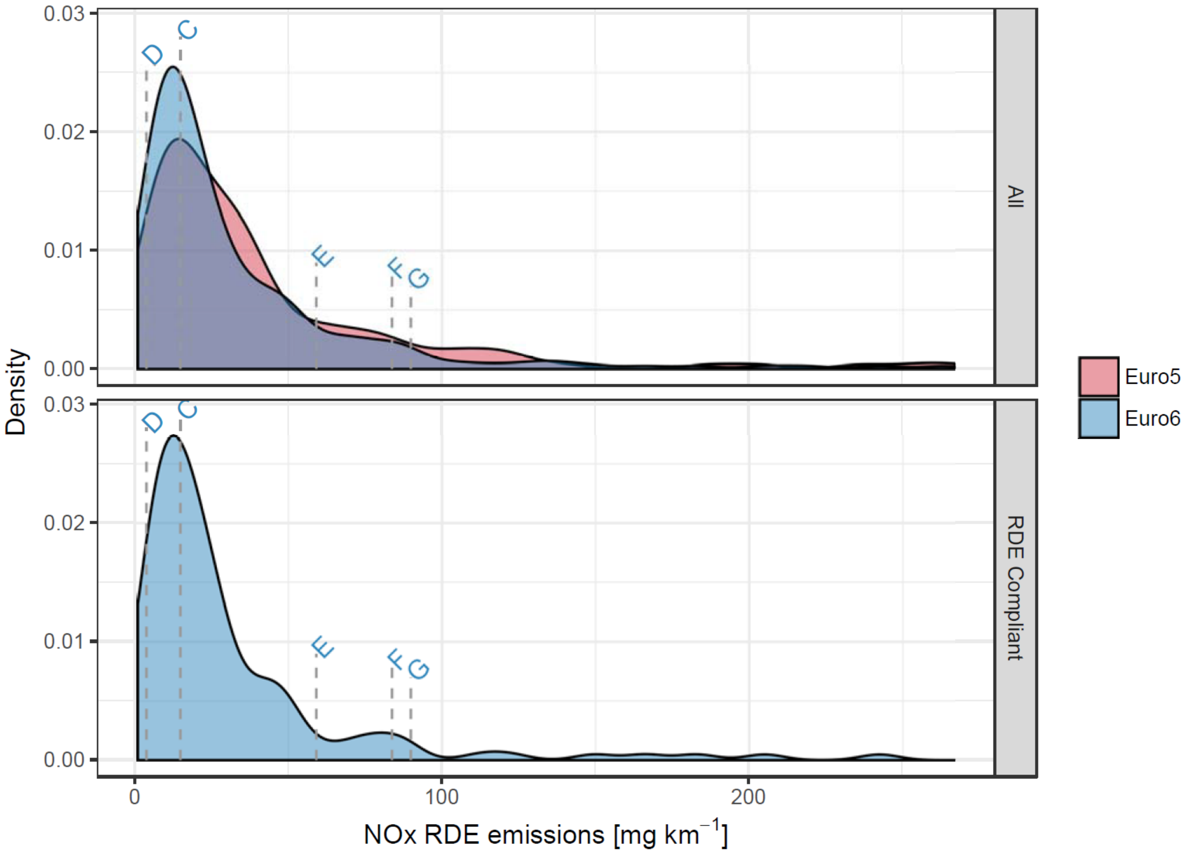

Figure 7: NOx emissions from gasoline vehicles over the on-road tests from the fleet of vehicles tested at JRC premise in 2017 together with NOx RDE from National investigations and from available database. Top panel displays all RDE emissions, while bottom panel displays only those obtained over RDE compliant testing. Letters indicate vehicles from Table 4. Top panel ("All") contains 140 and 240 Euro 5 and Euro 6 data respectively. Bottom panel ("RDE Compliant") contains 132 Euro 6 data.

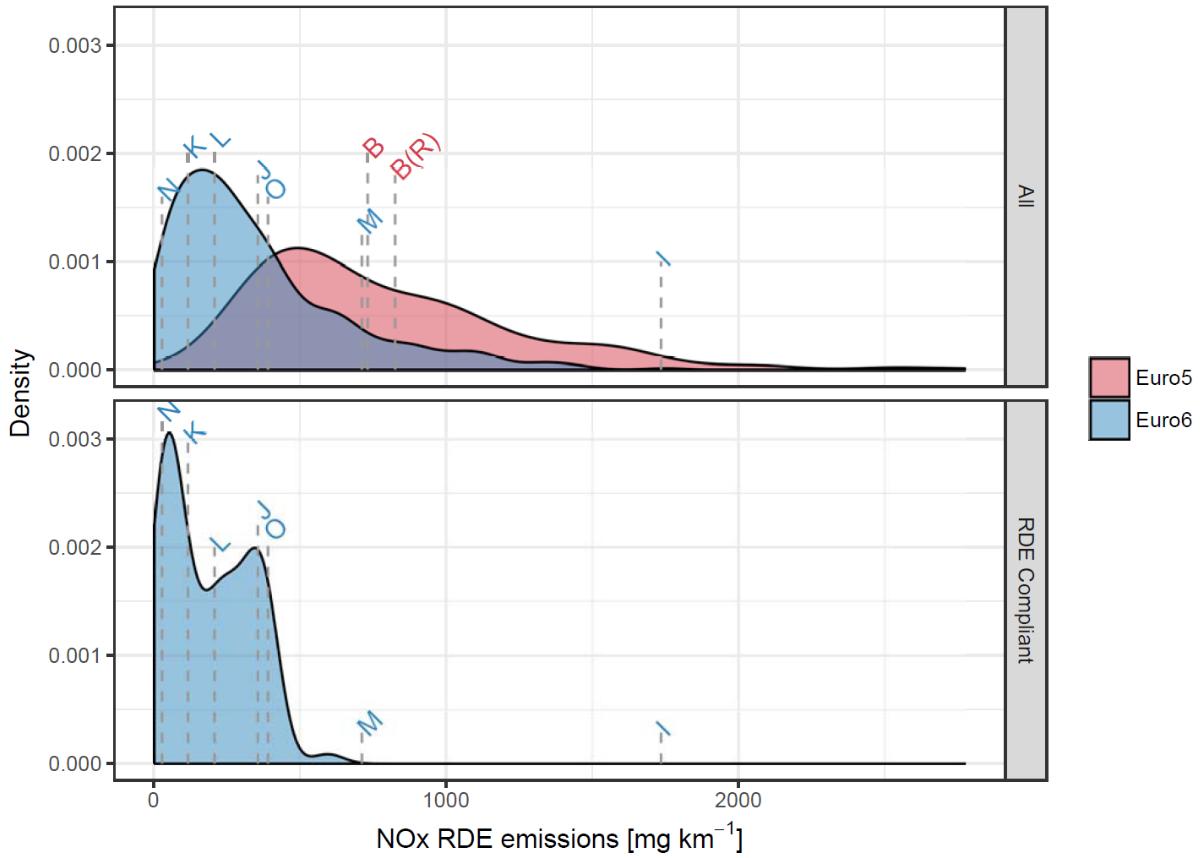

Figure 8: NOx emissions factors from diesel vehicles over the on-road tests from the fleet of vehicles tested at JRC premise in 2017 together with NOx RDE from National investigations and from available database. Top panel displays all RDE emission, while bottom panel displays only those obtained over RDE compliant testing. Letters indicate vehicles from Table 4. Top panel ("All") contains 310 and 425 Euro 5 and Euro 6 data respectively. Bottom panel ("RDE Compliant") contains 87 Euro 6 data.

Table 15 shows the descriptive statistics for the diesel and gasoline NOx RDE dataset, and the location of the results from the vehicles included in this study in the datasets distributions. It can be observed that, a posteriori, diesel Euro 6b vehicles tested in this study were evenly distributed over the range of NOx RDE of the dataset. Regarding the gasoline Euro 6b, vehicles tested were covering mostly the extreme boundaries of the dataset, with the exception of one vehicle (C) emitting nearly the median of the NOx RDE included in the dataset collected. Considering NOx RDE limit with 1.5 conformity factor, the share of vehicles complying with NOx RDE emissions complying with the limit are roughly 95% and 25% for gasoline and diesel vehicles respectively.

Table 15: Summary statistics for the NOx RDE available data from gasoline and diesel Euro 6b datasets. The average NOx RDE over the completed route measured for the vehicles including in this study are identified in the datasets deciles.

Deciles	Min.	10%	20%	30%	40%	50%	60%	70%	80%	90%	Max.
Gasoline Euro 6b – 240 vehicles											
NOx [g/km]	0.001	0.006	0.010	0.012	0.015	0.019	0.025	0.034	0.048	0.076	0.263
Vehicle		D				C				E	F,G
Diesel Euro 6b – 425 vehicles											
NOx [g/km]	0.003	0.056	0.113	0.163	0.214	0.265	0.338	0.412	0.574	0.776	1.750
Vehicle		N		K	L		J	O		M	I

3.3.3 CO on RDE Tests

Basic statistics for the CO RDE available data from gasoline Euro 6 vehicles were carried out on both data from complete route and data from the urban section of the route (both RDE compliant). Figure 9 displays the average CO RDE obtained in this study over the complete route and urban part projected in the RDE Monitoring (2016-2017) dataset (128 vehicles and 239 tests).

On the complete route, (Figure 9 top panels), gasoline Euro 6 displays an average CO RDE of 345 mg/km and the median value was 208 mg/km. The CO RDE distribution had an interquartile range (IQR) of 279 mg/km and was substantially right-skewed (skewness = 3.6). For what regards the urban part, gasoline Euro 6 had an average CO RDE of 239 mg/km and a median value of 169 mg/km. On this section, CO RDE distribution was narrower with an IQR of 201 mg/km, and was still substantially right-skewed (skewness = 5). As both distributions are not normal, the variability of the two dataset can be calculated based on the Quartile based CV (IQR/median) instead of the conventional CV (standard deviation/average). Following this approach, the variability of the datasets were 1.3 and 1.2 for the complete route and the urban section respectively.

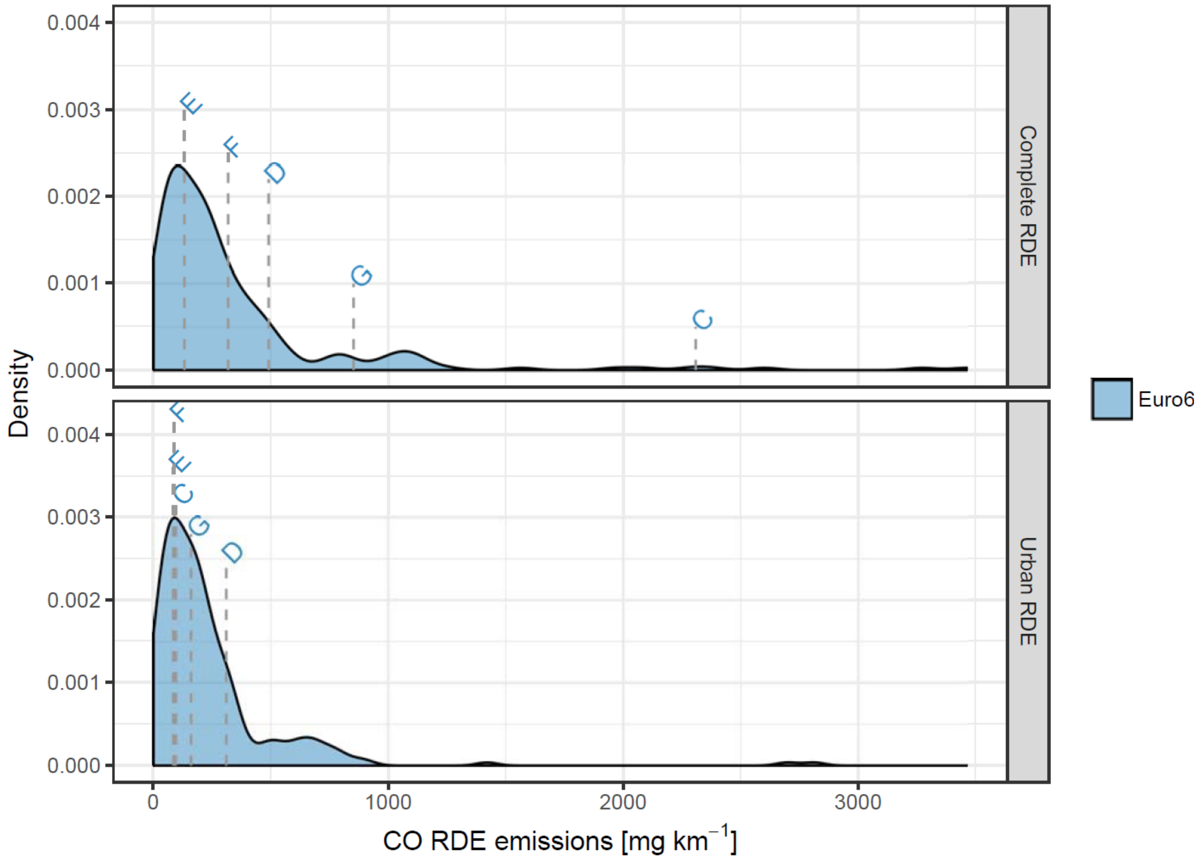

Figure 9: CO emissions factors from Euro 6 gasoline vehicles over the on-road tests from the fleet of vehicles tested at JRC premise in 2017 together with CO RDE from the RDE monitoring (2016-2017) database. Top panel displays RDE emission over the complete route, while bottom panel displays only those obtained over the urban section (239 data each). Letters indicate vehicles from Table 4.

Table 16 shows the descriptive statistics for the gasoline Euro 6 RDE dataset for the complete route and the urban section, and the location of the results from the vehicles included in this study in the dataset distributions. It can be observed that some gasoline Euro 6b vehicles tested in this study displayed rather high CO RDE over the completed route compared to the vehicles included in the RDE Monitoring (2016-2017) dataset (e.g. vehicles C, G and D). However, for what regards the urban part of the route, all of the vehicles tested in this study emitted CO RDE within the IQR of the RDE Monitoring (2016-2017) dataset (i.e. between upper and lower quartiles).

Table 16: Summary statistics for the CO RDE available data from gasoline Euro 6 RDE Monitoring (2016-2017) datasets. The average CO RDE over the completed route and the urban section measured for the vehicles including in this study are identified in the datasets deciles.

Deciles	**Min.**	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**Max.**
Complete Route											
CO [mg/km]	1.1	44.0	80.7	105.0	160.9	208.5	250.4	329.7	440.7	794.2	3462
Vehicle					E		F			D	C,G
Urban section											
CO [mg/km]	1.9	28.6	65.6	92.0	126.2	169.1	197.0	245.6	322.7	541.5	2812
Vehicle				E-F	C	G		D			

3.4 Conclusions

The emissions performance of the tested vehicles was investigated on the basis of the laboratory and on-road data collected by the JRC in 2017.

For the vehicles tested by the JRC, the limits on the Type 1 test (cold NEDC) were fulfilled for all regulated pollutants in all cases, thus strengthening the idea that the vehicles were properly functioning.

For the vehicles tested in this project, the Euro 6b gasoline vehicles emitted on average, under comparable conditions 8 times less NOx in comparison with their diesel counterparts. However, for what regards the other regulated pollutants (CO, HC and PN), Euro 6b diesel vehicles emitted on average 7, 1.5 and 200 times less emissions compared to the Euro 6b gasoline vehicles. Within this latter family, the GDI engines appeared to be cleaner for CO, and dirtier for PN and NOx emissions when compared to the MPI engines.

All the Euro 6b gasoline vehicles already meet the NOx conformity factor (1.5) proposed for the RDE3 regulation for the Euro 6d step. All vehicles tested over RDE tests with PN PEMS equipment had their PN emissions systematically below the RDE PN conformity factor (1.5). It should be noted that PN RDE from the two non-GDI gasoline vehicles were found unexpectedly large, with a level sometimes exceeding PN standard defined for Euro 6b diesel vehicles.

Based on the emissions measurements reported in this study, and those reported in previous studies, an improvement of real world NOx emission performance of Euro 6 diesel vehicles was found compared to the Euro 5 diesel vehicles. The opposite was observed for the CO but the level of emission was still very low. No clear differential trends were found between from Euro 5b and Euro 6b diesel vehicles HC and PN emissions (using WLTC as a proxy for the HC).

4 CO_2 Emissions Results

4.1 Introduction and boundaries of the exercise

The objective of this chapter is to present the CO_2 emissions emitted by the vehicles tested within the project. As introduced in Chapter 2, the vehicles were tested under various "modalities". Most of these modalities were designed to search for the presence of pollutant emissions (e.g. NOx) relevant defeat devices and were not applied to all the vehicles in the same way (see Table 7). The CO_2 emissions are reported only for conditions which were applied to all of them, i.e. the NEDC, WLTP and the RDE tests. For the RDE tests, it must be stressed that the testing conditions may vary significantly from one test to another, due to the selected route, the driver's behaviour, the traffic and the environmental conditions. The results may therefore not be representative of a European wide average value of the vehicle and shall be taken as a snapshot.

The results are all presented as "deviation ratio" (DR), i.e. the ratio of the measured CO_2 emissions to the type approved CO_2 value reported in the vehicle specifications.

As described in section 2.4, it should be noted that vehicles are tested in the laboratory applying the resistances (coast down coefficients) on the chassis dynamometer that were not the official NEDC road load values used during the type approval of these vehicles. While the road loads applied don't have significant effect on pollutant emissions results, the same is not the case for CO_2 emissions (and fuel consumption). Therefore, it is important to highlight that NEDC (cold start) CO_2 values measured and reported in this project should not be directly compared with the type-approval. Nonetheless, the resistances applied were derived using an empirical model of the JRC derived from official values for road loads communicated to the JRC in previous test campaigns, as described in [8]. Subsequent internal validation has shown that this coast down coefficient calculation model provides realistic road load values. Regarding the WLTP, all the tests have been done following the requirements of the new test procedure such as: increased and more realistic test mass, new gearshift strategy (for vehicles with manual transmission), test temperature, accuracy of the chassis dyno for the road load simulation, and vehicle preconditioning. However, as already indicated, the WLTP CO_2 results included in this report have neither been corrected for the SOC of the battery, nor for the ATCT conditions.

4.2 Results

CO_2 "deviation ratios" (DR) obtained for laboratory (NEDC and WLTP) and RDE (Complete and Urban) tests are presented in Table 17, while Figure 10 shows the average CO_2 DR broken down by main vehicle technology.

- For the NEDC cycle (cold) tests, the measured CO_2 always exceeded the declared value, the exceedance ranging from 4% to +26% (average for all vehicles 11%). Partial reason for this difference is already described in the previous section and concerns the NEDC road loads used during the JRC testing. In addition to this, deviation observed between the measured NEDC and the type approval CO_2 numbers can come from flexibilities allowed in the old procedure[7] regarding the declaration of CO_2 results and Conformity of Production (CoP). Details about these flexibilities can be found elsewhere [27]. In summary, an OEM could systematically declare CO_2 results 4% lower than the ones achieved during the tests and vehicles coming from the production line could have up to 8% higher CO_2 results compared to the corresponding type-approval value. These 2 flexibilities, when combined together, could already result in 12% DR in CO_2 results. The results of the French National Program on the control of atmospheric

[7] These flexibilities have been minimised in the WLTP.

pollutant emissions, also indicate an average discrepancy of about 12% between the official NEDC and the reproduced NEDC values [14].

- For the WLTP (cold) tests, the measured CO_2 always exceeded the declared value, the exceedance ranging from 8% to 41% (average for all vehicles 22%). The result is in line with previous studies that concluded that the WLTP is likely to increase the type-approval CO_2 emissions [8,27]. Compared to the NEDC cold start test results the WLTP cold start CO_2 emissions were higher by 2-4%. This result confirms that changing from the NEDC (20 min – ca. 10 km) to the WLTC (30 min – ca. 23 km) minimises the effect of the cold start.
- The deviation ratios corresponding to the CO_2 values measured under RDE conditions during this project are presented in Figure 10 for information only: given the intrinsic variability of the real-world fuel consumption and CO_2 emissions of a vehicle [27,28], these values shall be considered with care and cannot be considered as representative for the vehicles under real-world driving conditions. They do not constitute a robust indication of the difference between the CO_2 measured under the Type 1 test and a value which could be representative for the real operating. NEDC Cold start appears to have an effect of 7-8% compared to hot conditions, a value that has been reported in previous studies (8-11%) [28]. For the WLTP tests, these differences were within a range from 1.5% to 4% less CO_2 measured over the cold cycles. This behaviour is expected considering different impact of the cold start emissions in the two procedures (NEDC and WLTP). Longer test cycle results in the lower relative effect of a cold start on the total CO_2 emissions and smaller difference between cold and hot start CO_2 emissions.

Table 17: Average CO_2 deviation ratio over NEDC and WLTC tests broken down by main vehicle technology. Type approved CO_2 emission factor was used as baseline. Only laboratory test conducted with calculated road load values were included in this table.

Cycle Vehicle Technology (#)	NEDC Cold	NEDC Hot	WLTC Cold	WLTC Hot
Euro 6b Gasoline non-GDI (2)	1.09	1.03	1.17	1.14
Euro 6b Gasoline GDI (2)	1.21	1.12	1.31	1.29
Euro 6b Diesel (excluding LCV) (5)	1.07	1.01	1.21	1.14
All vehicles (9)	1.11	1.05	1.22	1.17

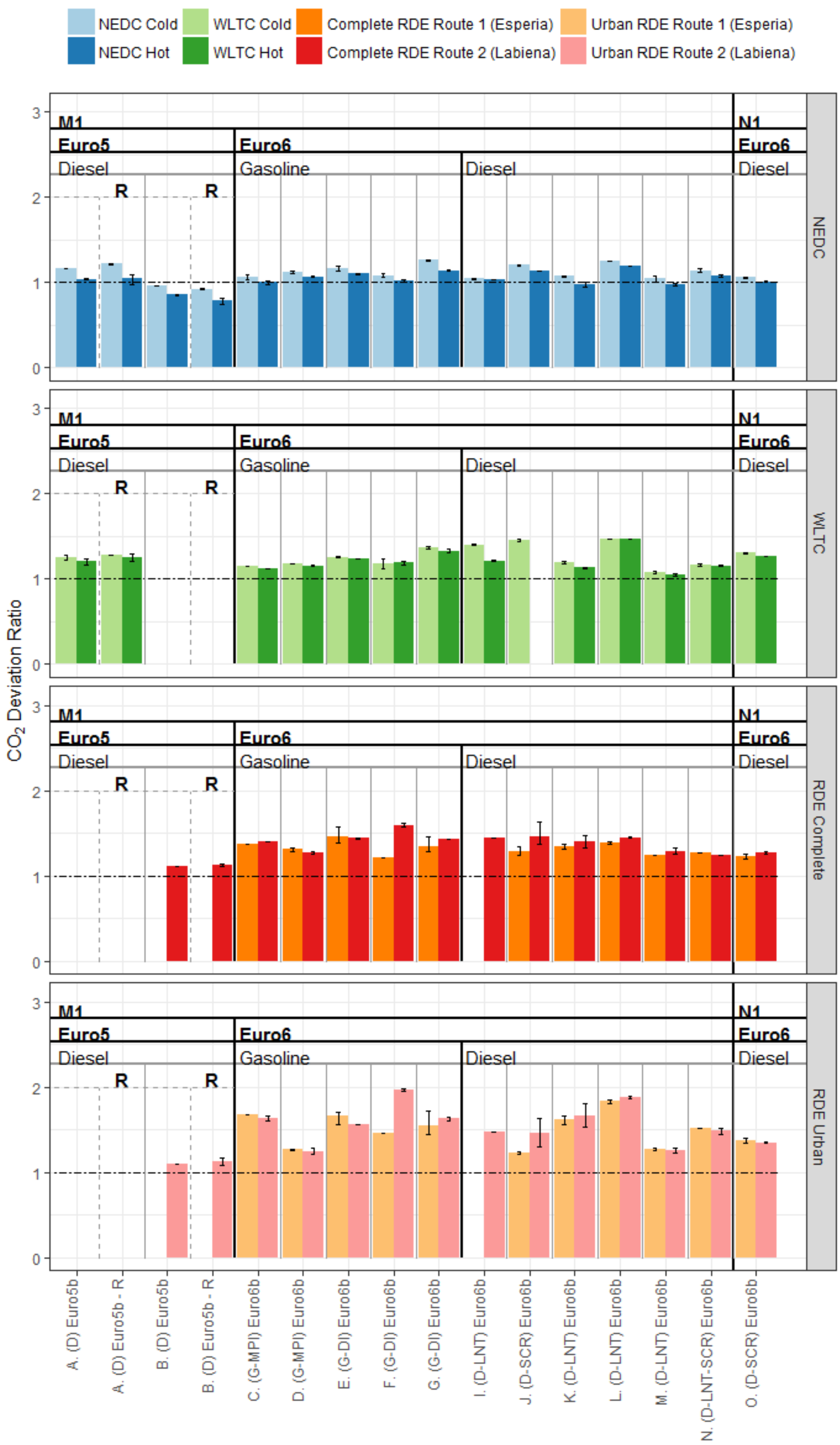

Figure 10: CO_2 deviation ratios against the declared value over the laboratory (top panels for NEDC and WLTC) and on-road tests (bottom panels for Urban and Complete RDE). Error bars stand for min and max values. Horizontal dotted lines stand for a deviation ratio of 1 (measured CO_2 equal to declared CO_2 emission). "R" labels identify the reprogrammed vehicles measured after voluntary or mandatory recalls. Note that vehicles A, B, F, J and L were tested using tabulated road load values for NEDC and WLTC cycles.

5 Assessing the methodologies for vehicle compliance checks

5.1 Boundaries of the exercise

The objective of the present section is to assess the potential of the test methods to detect *suspicious*[8] emissions control strategies using the experience and knowledge accumulated during the 2017 Pilot study. The main questions which are addressed are:

- Was the testing protocol able to detect suspicious emissions control strategies in a satisfactory manner?
- Which combinations of pollutants, test modalities and/or technologies are more prone to lead suspicious emissions control strategies (and are or will they ultimately be included in the future mandatory requirements)?

The protocol was applied to the entire vehicle sample, including the vehicles which were officially recalled, within a mandatory recall triggered by a European Type Approval Authority (e.g. the Euro 5 VW EA189 engine – vehicles A and B). For the recalled vehicles, attention was paid to the emissions control strategies prior and after the recall, as well as their emissions performance under the modified testing conditions.

DISCLAIMER: As the declarations regarding the emissions control strategies are under the control of the vehicle Type Approval Authority, the report cannot provide any judgement on the legality of the observed systems functioning. The findings are only useful to improve the Guidance. Furthermore, the report does not include either detailed information (e.g. functioning of the emissions control technologies and/or second-by-second data) to discuss the difference(s) which may appear between the emissions from tests conducted under different conditions.

5.2 Methodology

In this chapter, the vehicle tailpipe emissions are expressed as "Emissions Compliance Factors" (ECF). The ECF is defined as the vehicle emissions divided by the applicable emissions limit. The ECF is compared to the mandatory limits (for the Type 1 test) and the recommended thresholds proposed in the Guidance (for NOx and for the various categories of modified testing conditions herewith referred to as "modalities"). The modalities are defined in Table 6 together with their purpose.

For the vehicles in this study which were type approved before the RDE rules came into force, the useful comparison is how high do they emit compared with similar vehicles, since at the time there was no Not-To-Exceed limit for these vehicles. This was one of the reasons for setting the recommended thresholds in the Guidance. The other reason was in order to prioritise further testing, i.e. the vehicles that emit higher amounts should be the ones checked first.

As shown in the Table 7, the modality "Mod. NEDC -10% Speed" was applied only for two vehicles. The modality is therefore excluded from the following analysis. For the rest of the data, the average NOx, CO and PN Emissions Compliance Factors were calculated for each vehicle and each modality.

In the following figures:

- Each data point stands for the average ECF of the vehicle in the modality reported in the x axis.
- The grey boxplots display the distribution of the ECF values of the vehicles tested within the modality. The median value is displayed as horizontal black line. The

[8] In this paragraph, "suspicious" means that this project was not meant to assess the legality of the AES. In other words, the thresholds recommended in the Guidance were exceeded, the underlying cause was identified but the case is not necessarily statistically significant and should be investigated by the responsible authorities.

upper and lower parts of the grey box display the 25th and 75th percentiles values, and the upper and lower whiskers display plus or minus 1.5 times de IQR.

The Guidance also highlighted examples of situations that require particular attention:

- Strategies that lead to higher emissions when starting the engine in hot start than cold start;
- "Thermal windows" where emissions increase below or above certain ambient temperature ranges;
- Parameters such as a timer or the vehicle's speed that are used to modulate emission control systems.

The analysis conducted in the present chapter is addressing these emissions strategies, to determine whether the methodology proposed in the Guidance is able to properly detect problematic cases.

5.3 NOx emissions results

5.3.1 General findings

Figure 11 shows the average ECF values calculated for each vehicle over each test modality tested and the corresponding numbers are reported in Table 18. Colour code in the table is based on the following rules:

- Green when the ECF is lower than the applicable limit or the recommended threshold;
- Red when the ECF exceeds the applicable limit or the recommended threshold by more than 25%;
- Orange for the other cases.

The main results are as follows:

- The vehicles under investigation, including the ones which were subject to a recall, never exceed the applicable limit for the Type 1 test (NEDC). These results ensure to a large extent that the vehicles were free of malfunctioning, bad maintenance or other similar issues, at least for the pollutant considered in this section (NOx).
- The ECFs exceed the recommended thresholds for a few diesel vehicles and test modalities. Further details on the individual vehicles exceeding the thresholds are shown in Table 18.
- For the "NEDC Hot" modality, 1 out of 9 diesel vehicles exceeded the recommended threshold of 1.5. This vehicle (A) is a Euro5b which was recalled.
- For the "NEDC@+10°C" modality, 4 out of 8 diesel vehicles exceeded the recommended threshold of 1.5. The only vehicle officially recalled tested for this modality (Vehicle A) exceeded the recommended threshold.
- For the "NEDC@+30°C" modality, no Euro 6b diesel vehicle exceeded the recommended threshold of 1.5. However, two vehicles tested over a “WLTC@+30°C” modality were exceeding the recommended threshold, while it was not the case with the "NEDC@+30°C" modality (Vehicles J and L), and with the “WLTC Cold” modality (Vehicle J).
- For the "WLTC Cold" and “WLTC Hot” modalities, 4 out of 8 diesel vehicles exceeded the recommended threshold of 1.5. With an average ECF of 2.6 for “WLTC Hot” modality, these results are in line with the study published by the ICCT in 2015 [29]. In addition, in the ICCT study based on 32 Euro 6b diesel vehicles, LNT after-treatment system was associated to a poorer overall emission performance when tested over the WLTC. The same was observed here, with all the 3 Euro6b vehicles exceeding the recommended threshold of 1.5 equipped with a LNT system only (Vehicles I, L and M). The Euro5b vehicle officially recalled tested for this modality (Vehicle A) exceeded the recommended threshold. In

addition, two vehicles tested over "WLTC@+10°C" and/or "WLTC@+30°C" modalities were exceeding the recommended threshold (Vehicles J and L).

- For both RDE modalities (i.e. the two RDE routes), 2 out of 7 Euro 6b diesel vehicles exceeded at least once the recommended threshold of 5. No Euro6b gasoline vehicle exceeded the recommended threshold.

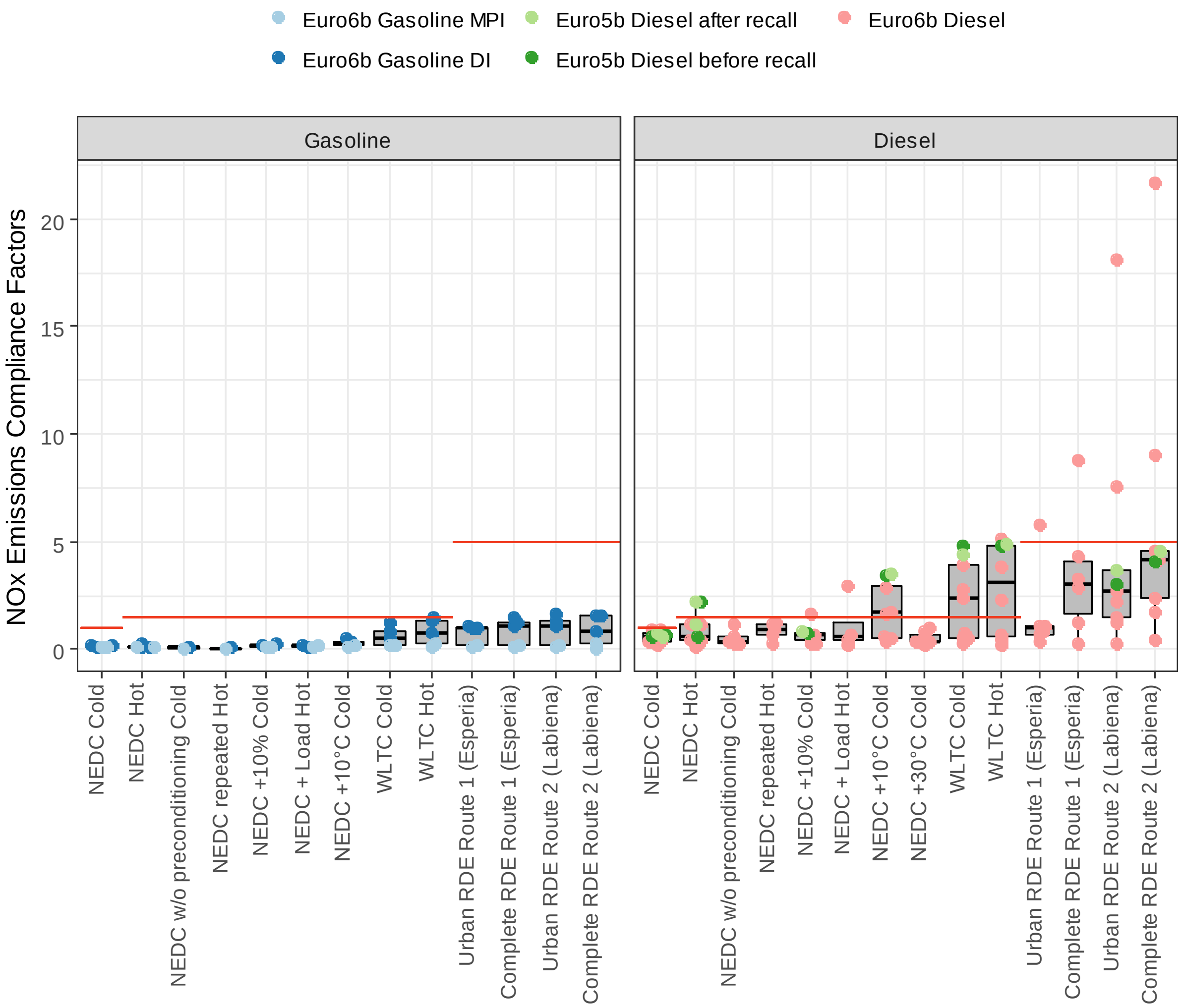

Figure 11: NOx Emissions Compliance Factors over the laboratory and on-road tests. Horizontal red lines stand for limits or recommended thresholds proposed in the Guidance.

Table 18: NOx Emissions Compliance Factors for all the vehicles tested. For vehicle H, the highest NOx emission value obtained over the charge depleting cycles was considered. "NA" stands for "not available".

Id.	Model	Euro	Fuel	NEDC (Acc. to Reg.83) Cold	NEDC Hot	NEDC w/o cond. Cold	NEDC Repeated Hot	NEDC +10% Speed Cold	NEDC -10% Speed Cold	NEDC with loads Hot	NEDC at +10°C Cold	NEDC at +30°C Cold	WLTC Cold	WLTC Hot	RDE (Min-Max)	Other test
A	Yeti Outdoor 2.0l TDi	5b	Diesel	0.7	2.3						NA		4.8	4.8		2.1[9]
A(R)	Yeti Outdoor 2.0l TDi	5b	Diesel	1.1	2.2						3.5		4.4	4.9		2.1
B	Tiguan 2.0l TDi	5b	Diesel	0.6	0.6			0.7							3.1-4.1	
B(R)	Tiguan 2.0l TDi	5b	Diesel	0.6	1.1			0.8							3.7-4.6	
C	Twingo 1.0l	6b	Gasoline	0.1	0.1	<0.1	<0.1	0.1		0.2	0.2		0.2	0.3	0.2-0.3	
D	Panda 1.2l	6b	Gasoline	0.1	0.1			0.1	0.1	0.1	0.1		0.2	0.1	0.1-0.1	
E	A1 1.0l TSFI	6b	Gasoline	0.2	0.1			0.3	0.2	0.1	0.5		1.2	1.3	0.9-1.1	
F	Fiesta 1.0l	6b	Gasoline	0.1	0.3								0.5	0.8	1-1.6	
G	Astra 1.0 T ecoFLEX	6b	Gasoline	0.2	0.1	0.1	0.1	0.2		0.2	0.4		0.8	1.5	1-1.6	
H	Golf 1.4l TSI GTe	6b	Hybrid	1.1							1.1		0.4		0.1-0.4	0.2[10]
I	Captur 1.5 dCi	6b	Diesel	0.9	1.2	1.2	1.1	1.7		2.9	1.5	0.8	4.8	5.8	18-22	
J	C4 Cactus 1.6l	6b	Diesel	0.4	0.5						1.7	0.3	0.5		1.1-4.6	3.5[11]
K	Golf 2.0l TDi	6b	Diesel	0.3	0.4	0.3	0.7	0.5		0.6	0.5	0.4	0.7	0.7	0.9-1.7	
L	A3 2.0 TDi	6b	Diesel	0.9	1.2						1.7	1.0	2.8	3.9	1.1-2.9	1.9-2.3[11,12]
M	Sportage 1.7l CRDI	6b	Diesel	0.6	0.5	0.6	1.2	0.7		0.5	2.8	0.6	2.4	2.3	5.8-9	
N	530d 3.0l	6b	Diesel	0.3	0.2	0.4	0.9	0.3			0.6	0.3	0.2	0.2	0.3-0.4	
O	Partner 1.6l	6b	Diesel	0.2	0.1	0.3	0.3	0.3		0.2	0.4	0.2	0.5	0.4	0.7-4.2	
	Category			-	2	2	2	2	2	2	2	2	2	2	3	-
	Limit or recommended threshold			1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	5	-

9 Modified NEDC with different first ECE module
10 Test: NEDC with modified cycle
11 Test: WLTC @+30°C
12 Test: WLTC @+10°C

5.3.2 Hot versus cold NEDC

For the "NEDC Hot" and "NEDC + Load Hot" modalities, the Commission stated the following in the Guidance: *"There's no valid technical justification for the reduction of the emissions performance of hot engines. This is particularly valid, when the cold and hot tests are conducted back to back on the same cycle under the exact same conditions (e.g. NEDC/WLTP). In general, at least a ten-fold decrease in emissions should be expected from a hot engine when compared to a cold one (see recent EPA data). Care should only be exercised for periodically regenerating systems to ensure that an increase of the emissions on the hot test is not caused by a regeneration (e.g. for a DPF or LNT)"*

Regarding the vehicles included in this study, one Euro 5b vehicle was exceeding the recommended threshold of 1.5 (Vehicle A). In Figure 12, NOx emissions included in the National investigations reports and recorded over cold and hot NEDC tests of diesel vehicles are shown. Most of the NOx emissions measured over the hot NEDC were greater than the ones measured over the cold NEDC (cf. points above the $NOx_{NEDC\ cold}$ = $NOx_{NEDC\ hot}$ line). Considering an arbitrary limit of 25% ($NOx_{NEDC\ hot}$ are 25% higher than $NOx_{NEDC\ cold}$ - represented by the dashed grey line in Figure 12), most of the Euro 5 and Euro 6 diesel vehicles included in the National investigation exceeded this arbitrary limit. The same occurred with the vehicles included in this study, with 4 out of 7 Euro 6b vehicles exceeding this indicative limit of 25%, confirming the general issue with hot diesel vehicles.

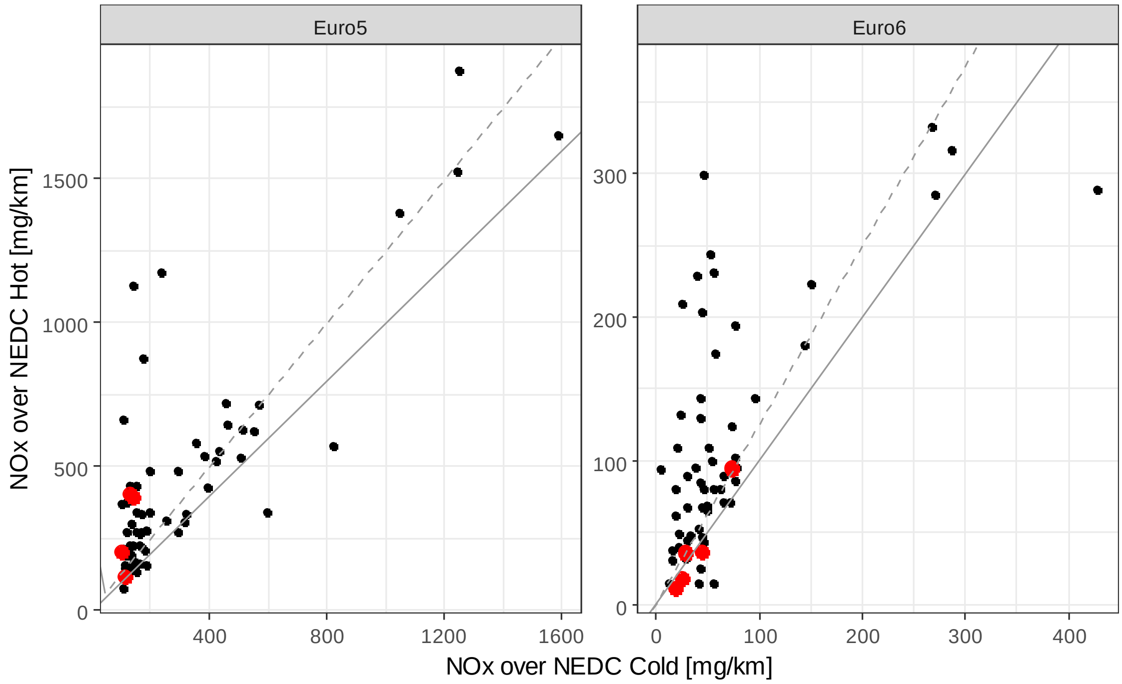

Figure 12: Cold versus hot NEDC NOx emissions from Euro 5 and Euro 6 diesel vehicles included in the National investigation programs and in this study. JRC data are highlighted in red. The grey line stands for the 1:1. Dashed grey line stands for the 1.25:1.

5.3.3 Ambient temperature effects

For the "NEDC@+10°C" modality applied to diesel engines equipped with EGR, the Commission stated in the Guidance: *"Condensation and sooting of the EGR might occur during a few seconds at engine start and at extremely low ambient temperatures (i.e. below -4C). EGR modification during these particular situations is therefore considered acceptable. EGR should be fully restored once the engine temperature reaches normal operating conditions.*

As a temporary measure the following are allowed until 1st September 2019:

1. Use of this AES in atmospheric temperatures below 10C

2. If the manufacturer employs technology that measures and calculates the conditions necessary for sooting through sensors and algorithms, i.e. "smart condensation AES", then they can reasonably employ the reduced EGR strategy when the systems shows increased sooting probability."

In addition, for and the "NEDC@+30°C" modality and the overheat protection of the EGR, the Commission stated the following in the Guidance:

"Switching EGR off in order to protect the engine from overheating at high ambient temperatures should not be allowed since valid technical measures are available to avoid such situations in European ambient temperatures."

Some vehicles from this study were found to adjust the control of the EGR system based on the ambient temperature. Such strategy, not compensated by an alternative NOx reduction system, resulted in an exceedance of the recommended threshold of 1.5. It was the case in particular for one vehicle included in this study (vehicle M).

5.4 CO emissions

5.4.1 General findings

Figure 13 shows the average ECF values calculated for each vehicle over each test modality tested and the corresponding numbers are reported in Table 19. The main results are as follows:

- The test vehicles, including the ones which were subject to a recall, never exceed the applicable limit for the Type 1 test (NEDC). These results ensure to a large extent that the vehicles were free of malfunctioning, bad maintenance or other similar issues, at least for the pollutant considered in this section (CO).
- As the focus of the first Guidance was primarily on NOx for diesel engines, there were no recommended thresholds for CO (N.B. the dashed lines in Figure 13 only indicate the thresholds used for NOx). Still, the figures clearly show two cases for which the CO emissions are way above the majority of the situations.
    - The first case is for vehicle M (Euro 6b, diesel) and for the "NEDC@+10°C Cold" modality. However, it can be seen from Table 19 that almost all Euro 6b diesel vehicles exhibited higher CO ECF over "NEDC@+10°C Cold" modality when compared to their CO ECF over "NEDC Cold" modality. This trend is consistent with the results from a study where the average CO emissions from six Euro 4 diesel vehicles were associated to higher CO emissions at low ambient temperature (including +10°C) in comparison with the standard conditions (+23°C) [22].
    - The second case is for vehicle C (Euro 6b, MPI gasoline) and for one of the RDE modalities. The elevated CO emissions occurred on the motorway at high speeds and may result from a modification of the engine stoichiometric combustion to protect the three-way catalytic converter from overheating at high engine loads. Section 5.4.2 provides further details for this situation.

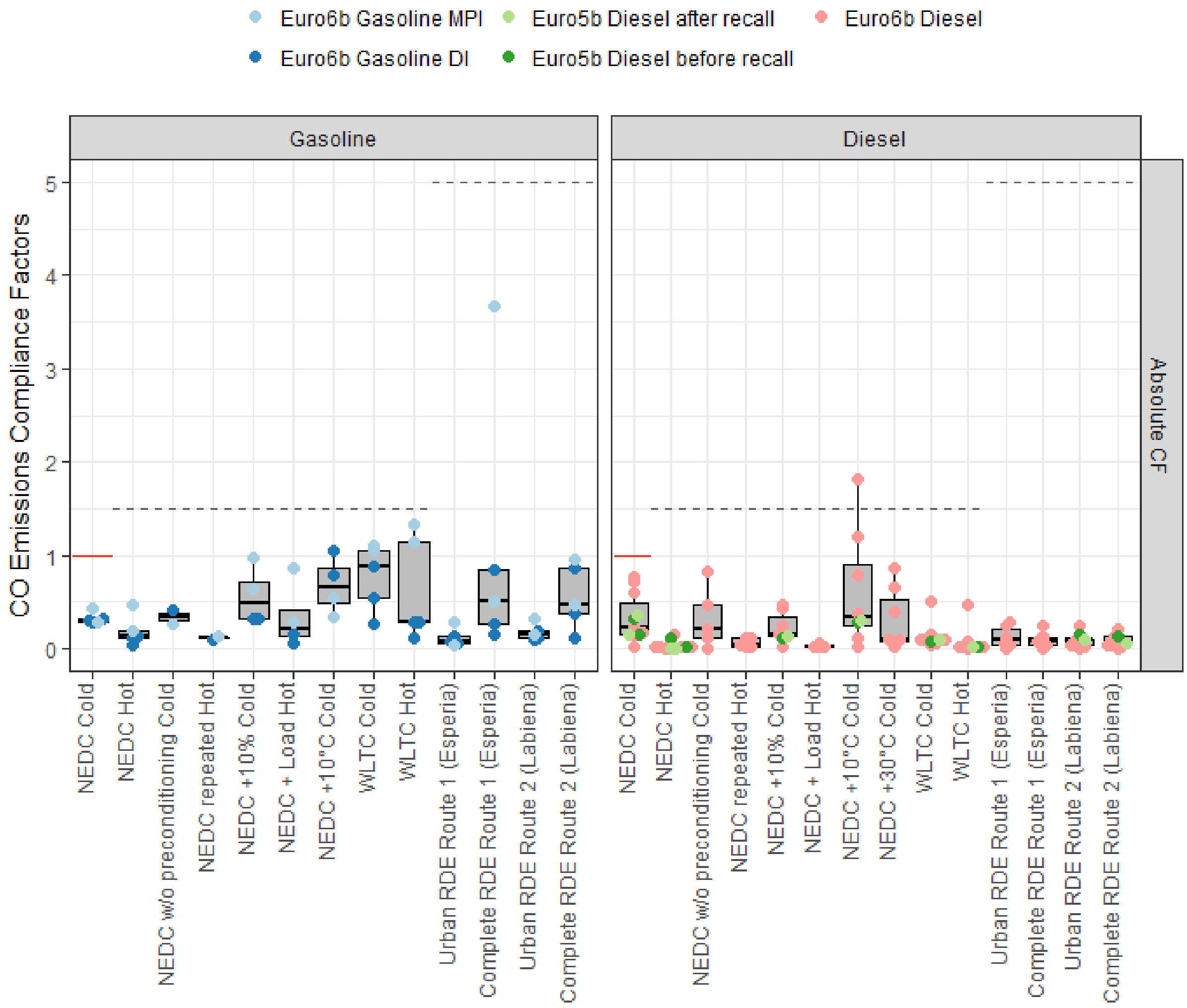

Figure 13: CO Emissions Compliance Factors over the laboratory and on-road tests. Horizontal red lines stand for the standard defined for Type 1 test. Dashed horizontal grey lines stand for tentative thresholds (not proposed in the Guidance).

Table 19: CO Emissions Compliance Factors for all the vehicles tested. For vehicle H, the highest CO emission value obtained over the charge depleting cycles was considered. "NA" stands for "not available".

Id.	Model	Euro	Fuel	NEDC (Acc. to Reg.83) Cold	NEDC Hot	NEDC w/o cond. Cold	NEDC Repeated Hot	NEDC +10% Speed Cold	NEDC -10% Speed Cold	NEDC with loads Hot	NEDC at +10°C Cold	NEDC at +30°C Cold	WLTC Cold	WLTC Hot	RDE (Min-Max)	Other test
A	Yeti Outdoor 2.0l TDi	5b	Diesel	0.3	<0.1						NA		0.1	<0.1		<0.1[13]
A(R)	Yeti Outdoor 2.0l TDi	5b	Diesel	0.3	<0.1						0.3		0.1	<0.1		<0.1
B	Tiguan 2.0l TDi	5b	Diesel	0.2	0.1			0.1							0.1-0.2	
B(R)	Tiguan 2.0l TDi	5b	Diesel	0.2	<0.1			0.1							<0.1-0.1	
C	Twingo 1.0l	6b	Gasoline	0.3	0.2	0.3	0.1	0.6		0.9	0.3		1.1	1.3	<0.1-**3.7**	
D	Panda 1.2l	6b	Gasoline	0.4	0.5			1.0	0.3	0.3	0.5		1.0	1.1	0.3-0.5	
E	A1 1.0l TSFI	6b	Gasoline	0.3	<0.1			0.3	0.3	0.1	1.1		0.3	0.1	0.1-0.2	
F	Fiesta 1.0l	6b	Gasoline	0.3	0.1								0.5	0.3	0.1-0.4	
G	Astra 1.0 T ecoFLEX	6b	Gasoline	0.3	0.1	0.4	0.1	0.3		0.2	0.8		0.9	0.3	0.1-0.9	
H	Golf 1.4l TSI GTe	6b	Hybrid	0.1							1.2		0.1		<0.1-0.3	<0.1[14]
I	Captur 1.5 dCi	6b	Diesel	0.2	<0.1	0.2	0.1	0.2		<0.1	0.5	0.1	0.1	<0.1	<0.1	
J	C4 Cactus 1.6l	6b	Diesel	0.7	<0.1						1.2	0.7	0.1		<0.1-0.1	0.1[15]
K	Golf 2.0l TDi	6b	Diesel	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
L	A3 2.0 TDi	6b	Diesel	0.1	0.1						0.1	0.1	0.1	0.1	0.2-0.3	<0.1-0.1[15,16]
M	Sportage 1.7l CRDI	6b	Diesel	0.8	0.1	0.8	0.1	0.4		0.1	**1.8**	0.9	0.5	0.5	0.1-0.2	
N	530d 3.0l	6b	Diesel	0.2	<0.1	0.1	<0.1	0.2			0.4	0.1	0.1	<0.1	<0.1-0.1	
O	Partner 1.6l	6b	Diesel	0.5	<0.1	0.4	<0.1	0.4		<0.1	0.6	0.3	0.1	<0.1	<0.1-0.1	
	Category			-	2	2	2	2	2	2	2	2	2	2	3	-
	Limit or recommended threshold			1	-	-	-	-	-	-	-	-	-	-	-	-

[13] Modified NEDC with different first ECE module
[14] Test: NEDC with modified cycle
[15] Test: WLTC @+30°C
[16] Test: WLTC @+10°C

5.4.2 High engine load effects

The CO emissions from vehicle C over the motorway section were found abnormally high for one of the RDE routes. The elevated CO emissions occurred on the motorway at high speeds when a modification of the engine stoichiometric combustion occurred, shifting from stoichiometric to rich (lambda <1). Such a strategy is not discussed in the Guidance but does represent an Auxiliary Emissions Strategies which shall be subject to assessment by the GTAAs. They shall in particular verify whether the risk of engine and/or after-treatment damage is real and whether the strategy is activated frequently. Though it was not the objective of the present work (focused on the protocol to detect defeat devices), the AES was activated only once out of four RDE tests, representing a mileage share of 8% of the total distance covered by RDE Route 1, and 25% of the motorway section. However, as it can be seen in Figure 14, this behaviour observed with the gasoline vehicles included in the JRC study was not an exception. Several gasoline vehicles Euro 6 included in the RDE monitoring (2016-2017) exercise exhibited higher CO emissions over the complete route than over the urban part, indicating possible management of the engine combustion stoichiometry.

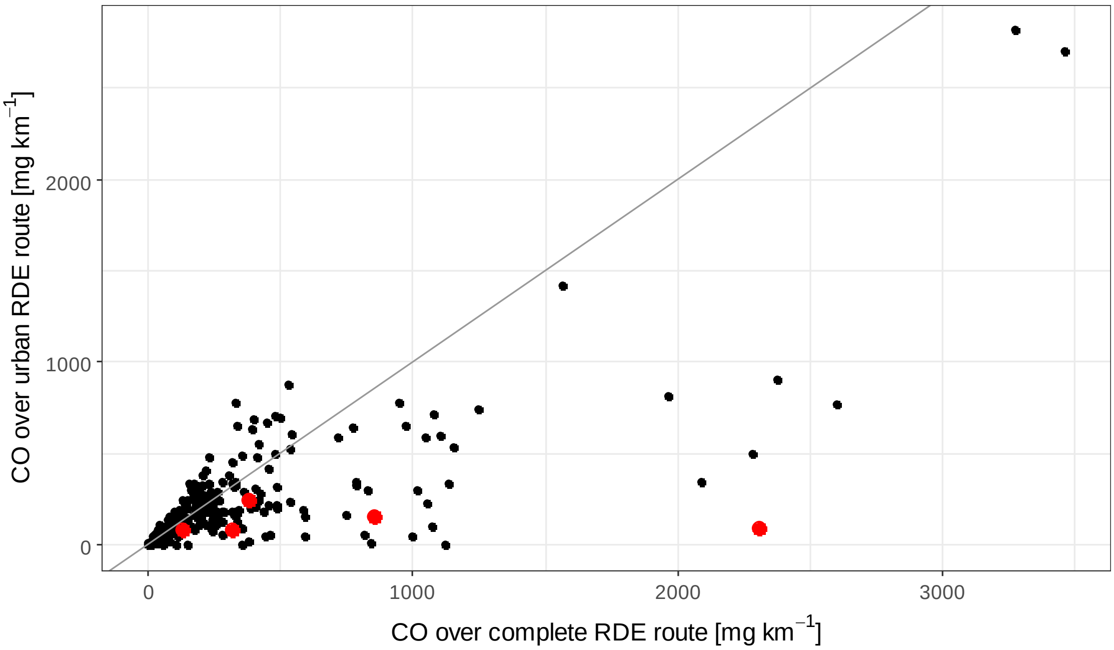

Figure 14: Complete versus urban CO RDE Euro 6 gasoline vehicles included in the RDE monitoring (2016-2017) exercise and in this study. JRC data are highlighted in red. The grey line stands for the 1:1.

5.5 PN emissions

Figure 15 shows the average ECF values calculated for each vehicle over each test modality tested and the corresponding numbers are reported in Table 20. The main results are as follows:

- PN emissions from all the vehicles never exceed the applicable limit for the Type 1 test (NEDC) and for the other modalities. This result ensures to a large extent that the vehicles were free of malfunctioning, bad maintenance or other similar issues, at least for the pollutant considered in this section (PN).
- As the focus of the first Guidance was primarily on NOx for diesel engines, there were no recommended thresholds for PN (N.B. the dotted lines in the figures only indicate the thresholds used for NOx).
- For both diesel and gasoline vehicles, there is no systematic effect of the modalities upon the level of PN emissions.

- For the gasoline vehicles, a consistent difference between the MPI and the GDI engines was shown in section 3.2.4. The difference between the two also shows in Figure 15, as the ECF of the MPI and the GDI engines was divided by their applicable temporary limit for GDI engines i.e. $6x10^{12}$, even though the limit does not apply to MPI engines.

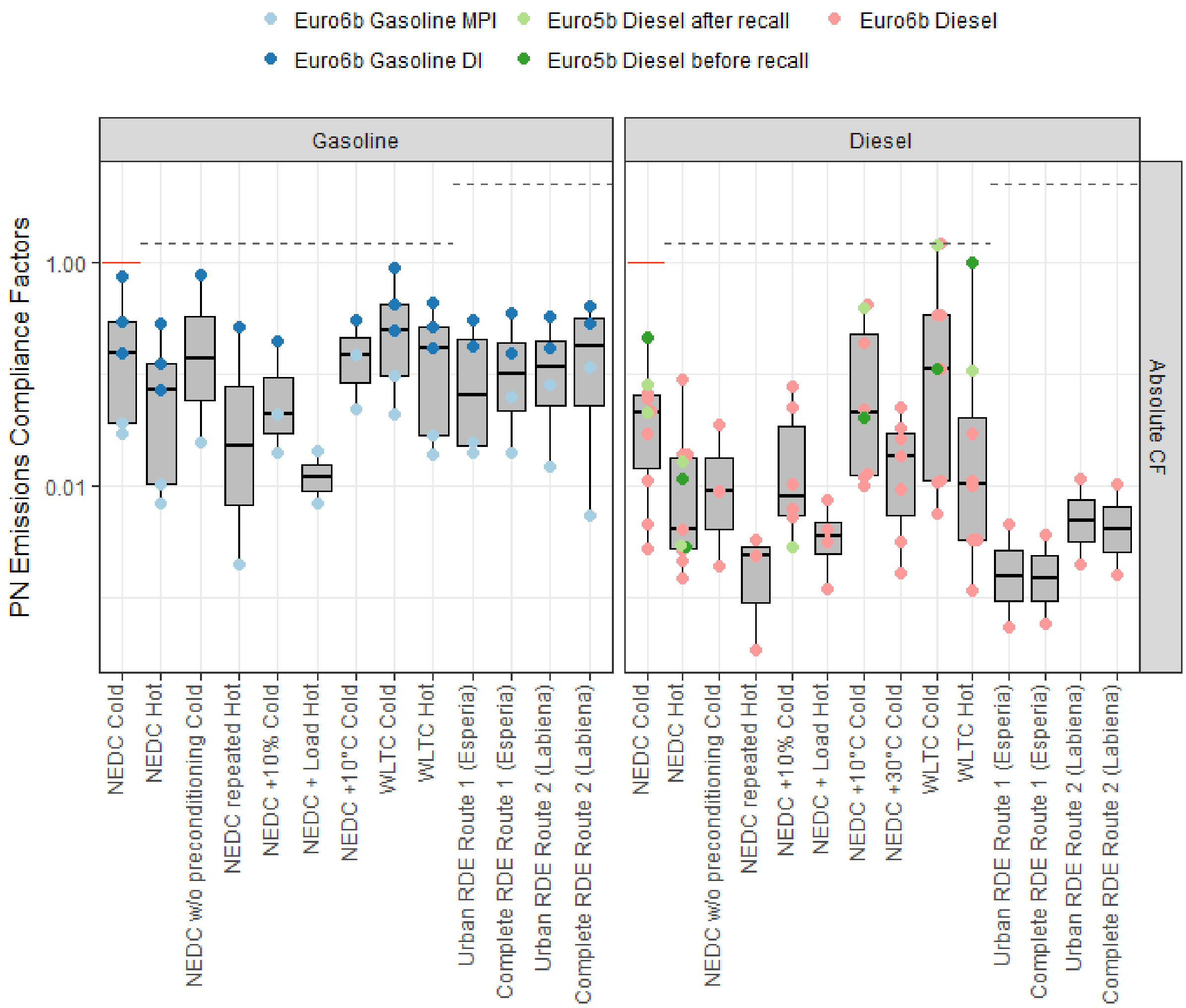

Figure 15: PN Emissions Compliance Factors over the laboratory and on-road tests. Absolute Emissions Compliance Factors (top panels) were calculated assuming PN limit of $6x10^{11}$ for the diesel vehicles and of $6x10^{12}$ for all the gasoline vehicles (NB even if the limit does not apply to non-GDI engines). Horizontal red lines stand for the standard defined for Type 1 test. Dashed horizontal grey lines stand for tentative thresholds (not proposed in the Guidance).

Table 20: PN Emissions Compliance Factors for all the vehicles tested. NB there is no PN limit applied to gasoline non-GDI engines. For vehicles C and D, PN Emissions Compliance Factors were calculated assuming a PN limit of $6x10^{12}$ #/km. “NA” stands for “not available”.

Id.	Model	Euro	Fuel	NEDC (Acc. to Reg.83) Cold	NEDC Hot	NEDC w/o cond. Cold	NEDC Repeated Hot	NEDC +10% Speed Cold	NEDC -10% Speed Cold	NEDC with loads Hot	NEDC at +10°C Cold	NEDC at +30°C Cold	WLTC Cold	WLTC Hot	RDE (Min-Max)	Other test
A	Yeti Outdoor 2.0l TDi	5b	Diesel	0.2	<0.1						NA		0.1	1		<0.1[17]
A(R)	Yeti Outdoor 2.0l TDi	5b	Diesel	0.1	<0.1						0.4		1.4	0.1		<0.1
B	Tiguan 2.0l TDi	5b	Diesel	NA	<0.1											
B(R)	Tiguan 2.0l TDi	5b	Diesel	<0.1	<0.1			<0.1								
C	Twingo 1.0l	6b	Gasoline	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	0.1		0.1	<0.1	<0.1	
D	Panda 1.2l	6b	Gasoline	<0.1	<0.1			<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1-0.1	
E	A1 1.0l TSFI	6b	Gasoline	0.2	0.1			0.2	0.2		0.3		0.2	0.2	0.2-0.2	
F	Fiesta 1.0l	6b	Gasoline	0.3	0.1								0.4	0.3	0.2-0.3	
G	Astra 1.0 T ecoFLEX	6b	Gasoline	0.7	0.3	0.8	0.3						0.9	0.4	0.3-0.4	
H	Golf 1.4l TSI GTe	6b	Hybrid	NA							0.7		0.3			0.2[18]
I	Captur 1.5 dCi	6b	Diesel	<0.1	<0.1	<0.1	<0.1	0.1		<0.1	0.1	<0.1	0.2	<0.1		
J	C4 Cactus 1.6l	6b	Diesel	<0.1	<0.1						<0.1	<0.1	<0.1			<0.1[19]
K	Golf 2.0l TDi	6b	Diesel	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1	0.3	<0.1		
L	A3 2.0 TDi	6b	Diesel	0.1	<0.1						0.4	<0.1	1.5	<0.1		<0.1-0.4[19,20]
M	Sportage 1.7l CRDI	6b	Diesel	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	
N	530d 3.0l	6b	Diesel	<0.1	0.1			0.1			0.2	<0.1	0.1	<0.1	<0.1	
O	Partner 1.6l	6b	Diesel	0.1	<0.1			<0.1		<0.1	<0.1	<0.1	<0.1	<0.1		
	Category			-	2	2	2	2	2	2	2	2	2	2	3	-
	Limit or recommended threshold			1	-	-	-	-	-	-	-	-	-	-	-	-

[17] Modified NEDC with different first ECE module
[18] Test: NEDC with modified cycle
[19] Test: WLTC @+30°C
[20] Test: WLTC @+10°C

5.6 Recalled vehicles

5.6.1 Introduction

The objective of this section is to provide an example regarding the application of the protocol to recalled vehicles, e.g. adding information about their environmental performance prior and after the recall. The vehicles chosen for this purpose were selected on the basis of:

- The publicly available information regarding their tailpipe emissions performance [14,30,31],
- The fact that the vehicles were corrected[21], either as a result of a mandatory recall launched by the Type Approval Authority (Vehicles A and B) or as a voluntary action from the car manufacturer.

DISCLAIMER: There is no intention in this project to point at faults of specific car manufacturers or models. The issues presented in this section were known by the responsible authorities in the frame of their own investigations.

5.6.2 VW EA189 Engine (Vehicles A and B)

5.6.2.1 Introduction

The vehicle details are available in Appendix 2. The NOx after-treatment technology of that vehicle is only composed of Exhaust Gas Recirculation (EGR) which is typical for Euro 5 diesel vehicles. The EGR principle and functioning is extensively depicted in the literature [32] and its physical implementation may vary depending on the manufacturer's specifications. Therefore the reader should keep in mind that the performance of the EGR system discussed in this paragraph does not necessarily reflect the one used for other vehicles and/or by other car manufacturers.

The tests modalities used for these vehicles are listed in Table 7 and were conducted both for the original vehicle and the reprogrammed vehicle. The detailed objectives and the contents of each test series are presented in Table 6 and their Emissions Compliance Factors are reported in Table 18 and Table 21.

Table 21: NOx Emissions Compliance Factors for Vehicles A and B before and after recall (R).

Id.	Model	NEDC (Acc. to Reg.83) Cold	NEDC Hot	NEDC +10% Speed Cold	NEDC at +10°C Cold	WLTC Cold	WLTC Hot	RDE (Min-Max)	Other test
A	Yeti Outdoor 2.0l TDi	0.7	2.3		3.4	4.8	4.8		2.1[22]
A(R)	Yeti Outdoor 2.0l TDi	1.1	2.2		3.5	4.4	4.9		2.1
B	Tiguan 2.0l TDi	0.6	0.6	0.7				3.1-4.1	
B(R)	Tiguan 2.0l TDi	0.6	1.1	0.8				3.7-4.6	
	Category	-	2	2	2	2	2	3	-
	Limit or recommended threshold	1	1.5	1.5	1.5	1.5	1.5	5	-

[21] Hardware and/or software, the details of the operations were not communicated to the vehicle owners but were communicated to the responsible type approval authority

[22] Modified NEDC with different first ECE module

5.6.2.2 Issues with the original vehicles

The modalities used for vehicles A and B differed mainly with the conditions used to assess their real-world emissions performance, i.e. the WLTP cycle and an RDE test respectively for vehicles A and B. The modalities *"Mod. NEDC +10% Speed - Cold"* and *"Mod. NEDC with different first ECE module"* were designed to check for the presence of a defeat device triggered by the driven distance after a certain time [7].

The strict application of the protocol succeeded in identifying the defeat device for vehicle A, i.e. the ECFs for the modalities *"Mod. NEDC with different first ECE module" was* exceeding the recommended threshold (1.5). However, the modality *"Mod. NEDC +10% Speed - Cold"* applied on vehicle B did not lead to an exceedance of the recommended threshold.

In addition, very different results were found for some modalities on both vehicles A and B, though the vehicles were equipped with the same engine and after treatment: Vehicle A exhibited higher NOx emissions for the Hot NEDC cycle (like many vehicles, see paragraph 5.3.2) and not Vehicle B. Explanations are likely to be found in the different physical characteristics of the vehicles (e.g. power-to-mass ratio) and the general condition (e.g. maintenance). For the latter element, it was not within the specifications of the project to trace the vehicles maintenance records. Still, assuming that the vehicles were properly maintained (which was confirmed by the interview of the vehicle owners), the differences measured between the two highlight the scatter which can be expected in terms of environmental performance for non-tampered and well maintained in-service vehicles.

5.6.2.3 Original versus reprogrammed vehicle

A summary of the ECF values reported for vehicles A and B before and after the recall are shown in Table 21 above.

With regards to vehicle A, it has to be noted that the reprogrammed vehicle was tested a year later after the first series of tests on the original vehicle. The vehicle condition between series of tests might have varied and played a role in the findings.

For NOx emissions (Figure 16), the reprogrammed vehicle exhibits higher emissions on all the cold NEDC cycles (approximately +8%) and lower emissions on the cold WLTC cycle (-7.7%). In any case, the NOx emissions remain above the recommended threshold (1.5) for the NEDC-like tests in Category 2 and way above the 1.5 threshold for the WLTC tests. It was no difference observed upon NOx emissions between the original and the reprogrammed vehicle. Such findings should therefore be verified with other vehicles to eliminate the potential bias due to that specific vehicle.

For CO_2 emissions (Figure 17), the differences between the original vehicle and the reprogrammed one are consistent and almost independent of the testing conditions, with an increase of CO_2 emissions around 5% for the reprogrammed vehicle.

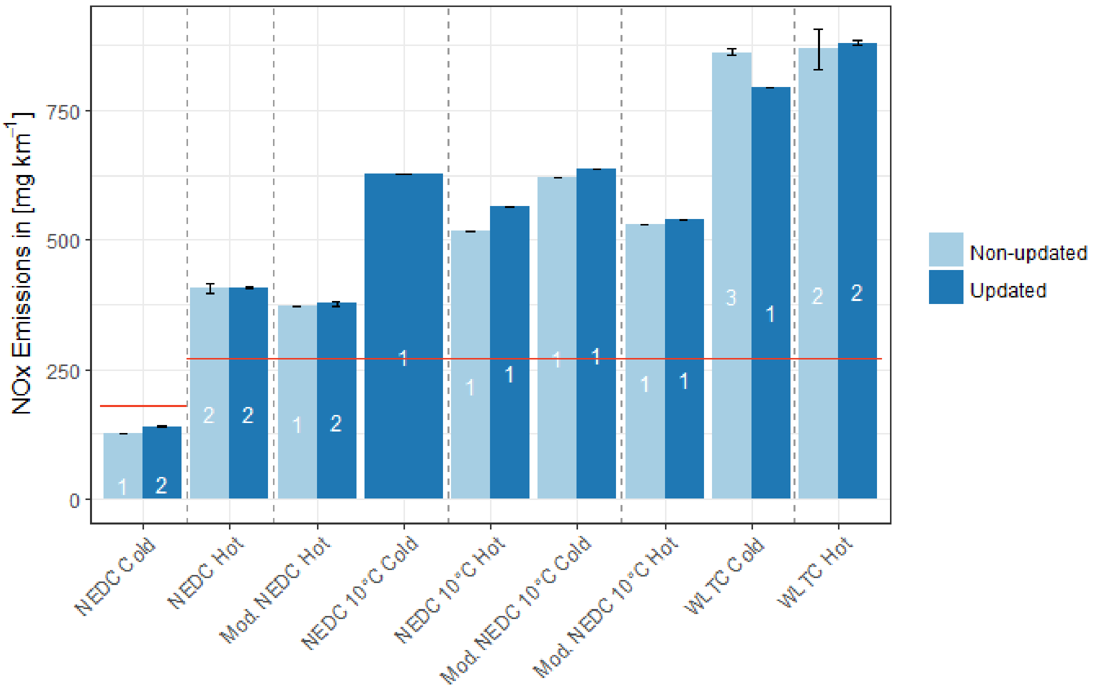

Figure 16: NOx Emissions measured during laboratory tests on the vehicle A before recall (non-updated) and after recall (updated). "Mod." stands for "Modified NEDC with different first ECE module". Error bars stand for min and max values. Numbers in the bars stand for the number of test. The horizontal red lines stand for the applicable Euro 5b limit and the indicative thresholds proposed in the Commission Guidance.

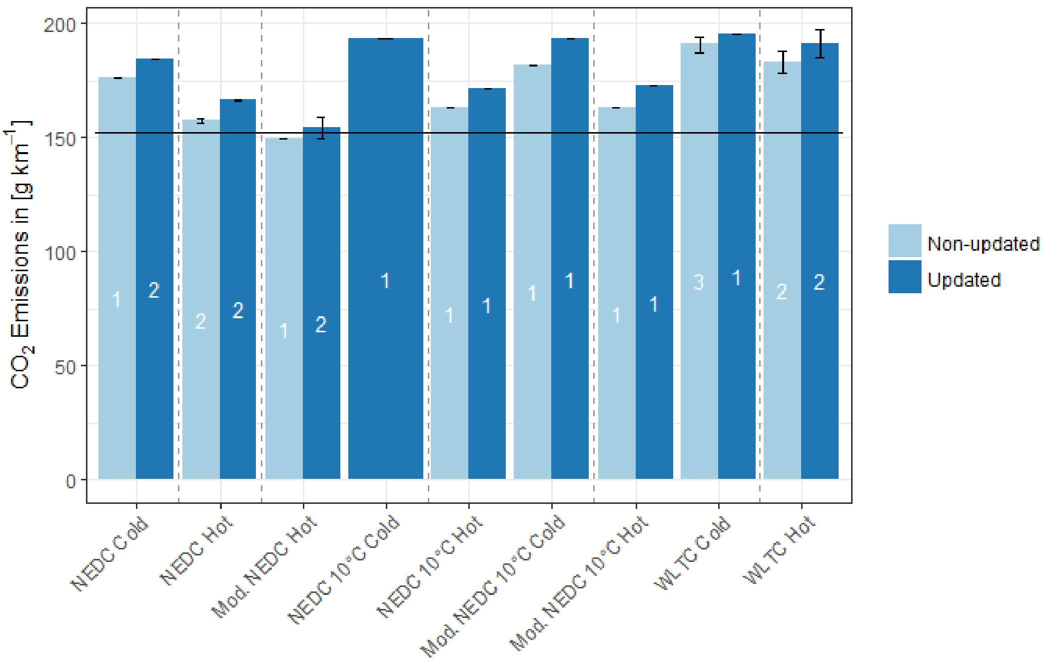

Figure 17: CO_2 Emissions measured during laboratory tests on the vehicle A before recall (non-updated) and after recall (updated). "Mod." stands for "Modified NEDC with different first ECE module". Error bars stand for min and max values. Numbers in the bars stand for the number of test. The horizontal black line stands for the declared CO_2 emission factor displayed in the type approval certificate of the vehicle (152 g/km).

With regards to vehicle B, The reprogramming of the vehicle was made right after the first series of tests on the original vehicle. The vehicle condition for both series may be considered as similar. For NOx emissions (Figure 18), the differences between the original vehicle and the reprogrammed one are not consistent, i.e. increase or decrease depending on the test cycle. In all cases, the NOx emissions remain below the recommended thresholds (1.5 for the tests in Category 2 and 5 for the RDE tests). It was no difference observed upon NOx emissions between the original and the reprogrammed vehicle. Such findings should therefore be verified with other vehicles to eliminate the potential bias due to that specific vehicle. For CO_2 emissions (Figure 19), the reprogrammed vehicle exhibits lower emissions on the laboratory test cycles (-4% to -5%). However, over on-road tests, the difference between original and reprogrammed vehicle for CO_2 emissions (+1%) was within the measurement uncertainty.

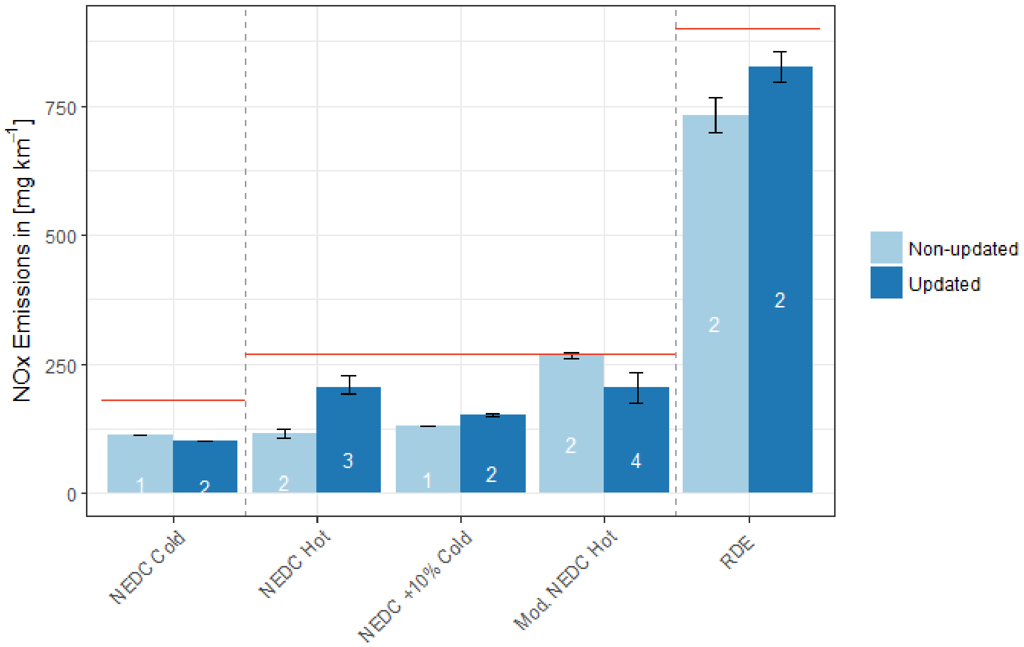

Figure 18: NOx Emissions measured during laboratory and RDE tests on the vehicle B before recall (non-updated) and after recall (updated). "Mod." stands for "Modified NEDC with different first ECE module". Error bars stand for min and max values. Numbers in the bars stand for the number of test. The horizontal red lines stand for the applicable Euro 5b limit and the indicative thresholds proposed in the Commission Guidance.

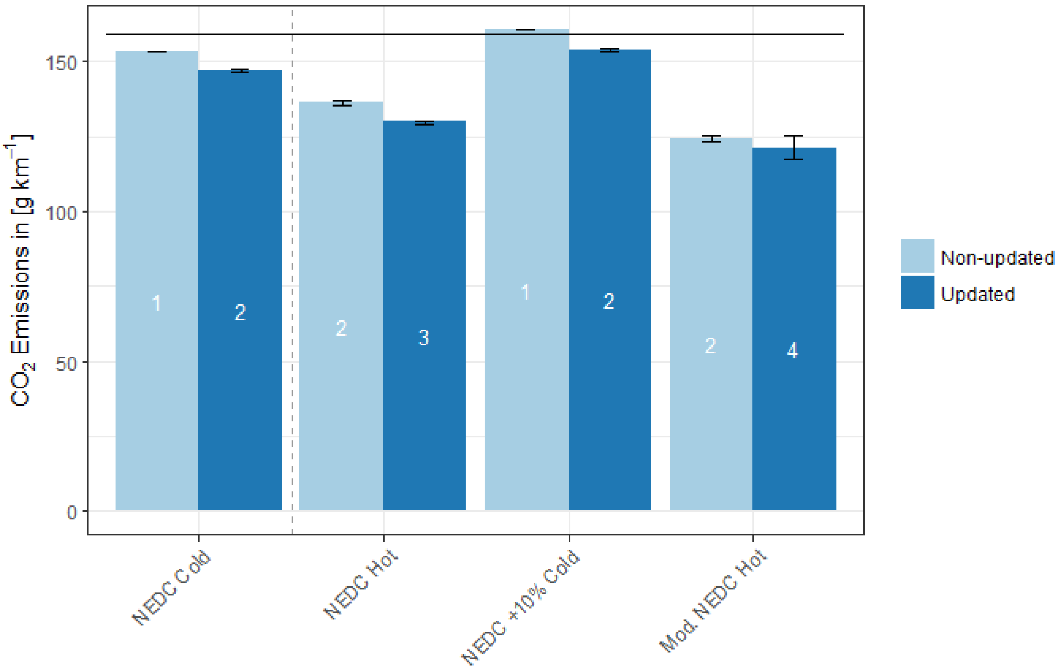

Figure 19: CO_2 Emissions measured during laboratory and RDE tests on the vehicle B before recall (non-updated) and after recall (updated). "Mod." stands for "Modified NEDC with different first ECE module". Error bars stand for min and max values. Numbers in the bars stand for the number of test. The horizontal black line stands for the declared CO_2 emission factor displayed in the type approval certificate of the vehicle (159 g/km).

6 Conclusions

6.1 Regulatory requirements, technology trends and their impact on real pollutant emission

The vehicles tested by the JRC in 2017 (primarily Euro 6b diesel and gasoline light-duty vehicles) were fulfilling the limits on the Type 1 test (cold NEDC) for all regulated pollutants, confirming the idea that the vehicles were correctly functioning. Not surprisingly, Euro 6b gasoline vehicles emitted significantly less NOx in comparison with the Euro 6b diesel vehicles (ca. 8 times less in average). However, it was the contrary for the other regulated pollutants (CO, HC and PN), with Euro 6b diesel vehicles emitting substantially less emissions (ca. 7, 1.5 and 200 times less respectively) compared to the gasoline counterparts. Within the gasoline vehicles, it appeared that GDI engines had beneficial impact on CO, but this technology had an unfavourable impact on both PN and NOx emissions when compared to the non-GDI engines.

Regarding the latest environmental requirements, it appeared that all gasoline Euro 6b vehicles tested were already below the future NOx conformity thresholds proposed for the RDE under the Euro 6d requirements. Based on the emissions measurements reported in this study, and those found previously, an improvement of real world emission performance of diesel vehicles was found for the NOx. However, regarding diesel Euro 6b vehicles, two vehicles (out of seven in the sample) were found already compliant with the RDE Euro 6d NOx requirements.

In overall, vehicles tested exhibited ranges of emissions in line with those known from various sources (independent testers, national investigations from 2016-2017, official RDE monitoring until 2017).

The entry into force of the RDE regulation since September 2017 should significantly improve the situation for both NOx and PN, as evidenced by the first RDE NOx declared values when compared to the Euro 5 and Euro 6b distribution of NOx emissions under real-driving (Figure 8).

Further to the general view on emissions performance and vehicle technologies associated with different emissions standards, the study provided the state-of-play regarding some weak points of the past implementation of the regulations by manufacturers: hot start and poor on-road NOx emissions performance for diesel vehicles. With the recent entry into force of the stringent requirements (e.g. the new WLTP, RDE...), an overall improvement is expected but shall be monitored continuously throughout the coming years. This study has shown that even a limited vehicle sample (with proper selection criteria and extensive testing) could be sufficient to follow on the effectiveness of the regulations, provided that the vehicles are recent and free of durability or tampering issues.

6.2 Methods to support the EU authorities conducting investigations

The robustness of the testing procedures to ensure that the environmental performance of the vehicles is meeting the expectations within a wide range of operating conditions is only a first step, verified at type approval. The market surveillance acts as a second pillar to ensure compliance with the emissions legislation. A major question arises for the authorities to conduct efficient market surveillance: How to detect problems in a cost-efficient way, keeping in mind that they can be various issues:

- For individual vehicles, under the responsibility of the vehicle user: poor maintenance, or tampering;
- For vehicle families during their normal life and under the responsibility of the vehicle manufacturer: compliance issues due to poor durability or defeat strategies.

Prior to checking any compliance, the authorities are therefore faced with two major difficulties: to obtain information on the worst-cases and to determine whether some high vehicles emissions can be attributed to illegal strategies.

For the first difficulty and from this study, it appears that on road-emissions testing to detect high-emitters is an obvious choice. Being tested under normal conditions of use (e.g. RDE-like), some vehicles emit much more than the vast majority within the same emissions standard and technology. Still, testing a single vehicle is not statistically meaningful and insufficient to draw conclusions or even raise suspicion regarding the compliance of an entire vehicle family. A vehicle tested on road and exhibiting high emissions may be an outlier. To draw robust conclusions from on-road emissions tests, the anomalous results of a single vehicle must be accompanied with a number of investigations such as the verification of the maintenance records, the absence of tampering and ultimately the testing of at least one similar vehicle.

Though on-road tests appear as a robust way to detect high emitters, they might not be the most cost-efficient way to screen the relative real emissions performance of a large number of in-service vehicles. Efficient data sharing of on-road emissions tests might help but the highest priority should be given to developing and using alternative and efficient techniques able to detect problematic vehicles in statistically significant manner. Once available, such techniques would provide an additional criterion for conducting market surveillance and the design of a test fleet could include:

- A share of vehicles identified as high emitters and to be checked in depth;
- A sample representative for the market sales/manufacturers/technologies.

For the second difficulty (i.e. the identification of defeat devices), the protocol proposed in the Commission Guidance has proven its robustness and its recommended thresholds were able to identify obvious cases/problems (cold versus hot NEDC, very poor on-road performance caused by illegal strategies), though they fail to catch the most sophisticated ones (See case studies in section 5.6.2).

For pre-RDE type approved vehicles (e.g. Euro 5, 6b), the assessment of emissions strategies and the search for defeat devices remains complex, time and resources consuming, as evidenced by the tests conducted in this program. For pre-RDE vehicles and on the basis of the results from this project, the JRC recommends maintaining a detailed protocol to search for defeat devices. Its basic principles should remain:

- The reference tests are the Type 1 and potentially the Type 6 (NEDC based);
- The tailpipe emissions under modified conditions shall be checked in comparison to the NEDC,
- An increase of the tailpipe emissions under the modified tests is an indication that the emissions control strategy might have changed. Depending on the parameters which have been modified with respect to the reference, it could also be the result of a "natural" physical change of the system (e.g. increased engine load on another cycle).

For RDE type approved vehicles (i.e. from Euro 6d-Temp), the protocol shall be adapted and this adaptation shall start upon availability of the first Euro 6d (or Euro 6d-Temp) vehicles. A vehicle fulfilling the RDE emissions requirements has a high probability to be free of defeat devices, at least within the RDE boundaries. Still:

- High emissions may occur during an RDE test and be caused by an emissions strategy which was not permitted and/or declared at type approval;
- It is more probably though that any defeat devices in these RDE-approved vehicles will only be active outside the RDE boundaries;
- As such the search for defeat devices in the future RDE-approved vehicles should focus in the area outside the accepted RDE boundaries.

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List of abbreviations and definitions

AES:	Auxiliary Emission Strategy
BES:	Base Emission Strategy
CoP:	Conformity of Production
CVS:	Constant Volume Sampler
DOC:	Diesel Oxidation Catalyst
DPF:	Diesel Particulate Filter
DR :	Deviation Ratio
ECE:	Economic Commission for Europe
ECF:	Emission Compliance Factor
ECS:	Emissions Control Systems
ECU:	Engine Control Unit
EGR:	Exhaust Gas Recirculation
EUDC:	Extra-Urban Driving Cycle
GDI:	Gasoline Direct Injection
GTAA:	Granting type Approval Authority
IQR:	Inter-Quartile Range
JRC:	Joint Research Centre
LNT:	Lean NOx Trap
MAW:	Moving Average Window
MPI:	Multipoint Fuel Injection
NEDC:	New European Driving Cycle
OEM:	Original Equipment Manufacturer
PEMS:	Portable Emissions Measurement Systems
RDE:	Real Driving Emissions
RL:	Road Load
RT:	Recommended Threshold
SCR:	Selective Catalytic Reduction
SOC:	State of Charge
TAA:	Type Approval Authority
TAAEG:	Type Approval Authorities Expert Group
WLTC:	Worldwide harmonised Light vehicles Test Cycle
WLTP:	Worldwide harmonised Light vehicles Test Procedures

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Appendices

Appendix 1. Testing conditions for AES[23] detection on in-service vehicles

Application of the European testing protocol: JRC test settings

Document version:10/08/2016

A. Vehicle preparation

- Recording mileage;
- Recording vehicle data;
- Recording inspection and maintenance information (if any);
- Visual inspection for rebuilds, modifications and leaks of the exhaust and after-treatment system;
- Checking for OBD faults (Scan tool);
- Checking for tyres damage;
- Checking for any anomaly which might affect the emissions performance;
- Fuel replacement (when applicable);
- PEMS installation (for on road tests).

B. Laboratory Tests Settings

Variations of the test settings were also applied changing the driving cycle (WLTP instead of NEDC) and/or the road load settings.

<u>Standard NEDC According to ECE R83</u>

Type	▪ Chassis dynamometer 2WD mode
Fuel	▪ Reference
Road Load	▪ calculated values
Vehicle pre-conditioning	▪ EUDC ▪ Soak of min. 6 hours between 20 and 30°C
Driving cycle	▪ NEDC
Test temperature	▪ 22 to 24°C
Emissions measurement	▪ Gaseous emissions, PN ▪ CVS (bags) and modal

<u>NEDC Hot Vehicle</u>

Type	▪ Chassis dynamometer 2WD mode
Fuel	▪ Reference
Road Load	▪ calculated values
Vehicle pre-conditioning	▪ None, check coolant and oil temperatures
Driving cycle	▪ NEDC
Test temperature	▪ 22 to 24°C
Emissions	▪ Gaseous emissions, PN

[23] AuxiliaryEmissions Strategies

measurement	▪ CVS (bags) and modal

<u>NEDC @ 10°C - Cold Vehicle</u>

Type	▪ Chassis dynamometer 2WD mode
Fuel	▪ Reference
Road Load	▪ calculated values
Vehicle pre-conditioning	▪ EUDC ▪ Soak of min. 6 hours between 20 and 30°C
Driving cycle	▪ NEDC
Test temperature	▪ 10°C
Emissions measurement	▪ Gaseous emissions, PN ▪ CVS (bags) and modal

<u>NEDC @ 30°C - Cold Vehicle</u>

Type	▪ Chassis dynamometer 2WD mode
Fuel	▪ Reference
Road Load	▪ calculated values
Vehicle pre-conditioning	▪ EUDC ▪ Soak of min. 6 hours between 20 and 30°C
Driving cycle	▪ NEDC
Test temperature	▪ 30°C
Emissions measurement	▪ Gaseous emissions, PN ▪ CVS (bags) and modal

<u>NEDC with speeds +10% - Cold Vehicle</u>

Type	▪ Chassis dynamometer 2WD mode
Fuel	▪ Reference
Road Load	▪ calculated values
Vehicle pre-conditioning	▪ EUDC ▪ Soak of min. 6 hours between 20 and 30°C
Driving cycle	▪ Modified NEDC, speeds +10%
Test temperature	▪ 22 to 24°C
Emissions measurement	▪ Gaseous emissions, PN ▪ CVS (bags) and modal

NEDC with speeds -10% - Cold Vehicle

Type	▪ Chassis dynamometer 2WD mode
Fuel	▪ Reference
Road Load	▪ calculated values
Vehicle pre-conditioning	▪ EUDC ▪ Soak of min. 6 hours between 20 and 30°C
Driving cycle	▪ Modified NEDC, speeds -10%
Test temperature	▪ 22 to 24°C
Emissions measurement	▪ Gaseous emissions, PN ▪ CVS (bags) and modal

NEDC, 4WD chassis dynamometer - Cold Vehicle

Type	▪ Chassis dynamometer 4WD mode
Fuel	▪ Reference
Road Load	▪ calculated values
Vehicle pre-conditioning	▪ EUDC ▪ Soak of min. 6 hours between 20 and 30°C
Driving cycle	▪ NEDC
Test temperature	▪ 22 to 24°C
Emissions measurement	▪ Gaseous emissions, PN ▪ CVS (bags) and modal

NEDC, 4WD chassis dynamometer - Hot Vehicle

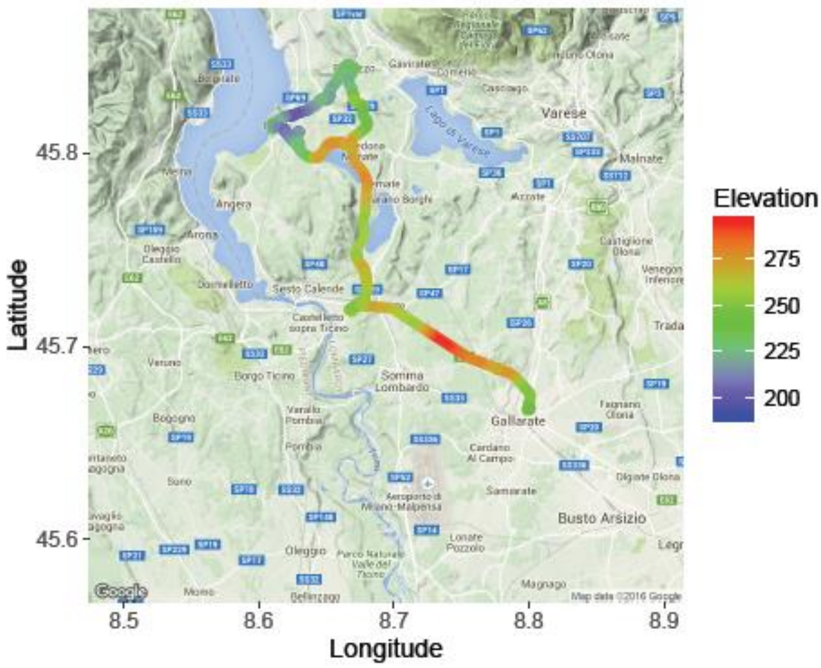
Type	▪ Chassis dynamometer 4WD mode
Fuel	▪ Reference
Road Load	▪ calculated values
Vehicle pre-conditioning	▪ None, check coolant and oil temperatures
Driving cycle	▪ NEDC
Test temperature	▪ 22 to 24°C
Emissions measurement	▪ Gaseous emissions, PN ▪ CVS (bags) and modal

C. On-Road Tests

RDE Route # 1 - Esperia

Type	▪ On-road
Fuel	▪ Market
Vehicle pre-conditioning	▪ None, only recording oil and coolant temperatures
Driving cycle	▪ JRC RDE route #1 - Esperia
Test temperature	▪ Depending on day/time, measured
Emissions measurement	▪ Gaseous emissions ▪ PEMS
Data evaluation	▪ None ▪ RDE Type - Trip composition, Appendix 5 (Moving Window) and Appendix 7 (Excess of driving dynamics)

Total Distance [km]	▪ Ca. 79
Urban Rural Motorway Distance Shares [%]	▪ 38.5 – 27.5 – 34.0
Average speed [km/h]	▪ 48.8
Average urban speed [km/h]	▪ 27.5
Cumulative altitude gain [m/100km]	▪ 813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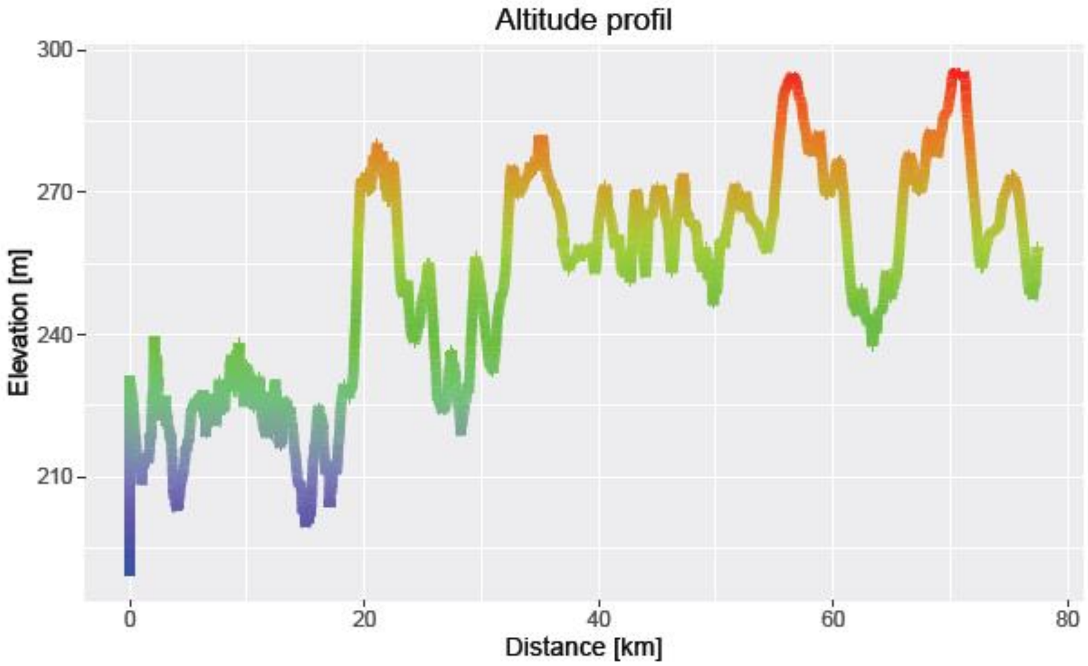
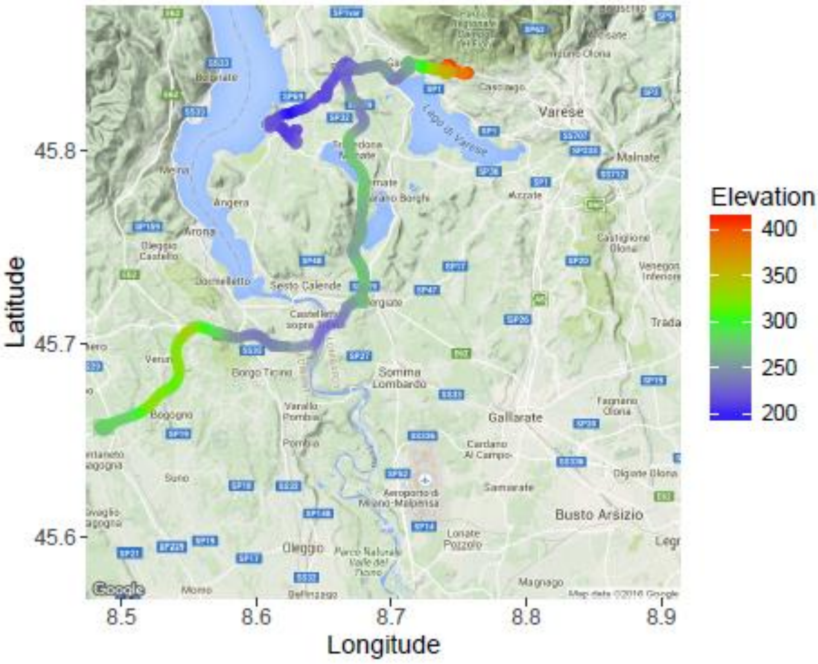
250
225
200
45.8
45.7
45.6
Latitude
8.5
8.6
8.7
8.8
8.9
Longitude


Altitude profil
300
270
240
210
Elevation [m]
0
20
40
60
80
Distance [km]

RDE Route # 2 - Labiena

Type	▪ On-road
Fuel	▪ Market
Vehicle pre-conditioning	▪ None, only recording oil and coolant temperatures
Driving cycle	▪ JRC RDE route #2 - Labiena
Test temperature	▪ Depending on day/time, measured
Emissions measurement	▪ Gaseous emissions ▪ PEMS
Data evaluation	▪ None ▪ RDE Type - Trip composition, Appendix 5 (Moving Window) and Appendix 7 (Excess of driving dynamics)

Total Distance [km]	▪ Ca. 94
Urban Rural Motorway Distance Shares [%]	▪ 36.7 – 25.7 – 37.6
Average speed [km/h]	▪ 51.0
Average urban speed [km/h]	▪ 27.5
Cumulative altitude gain [m/100km]	▪ 860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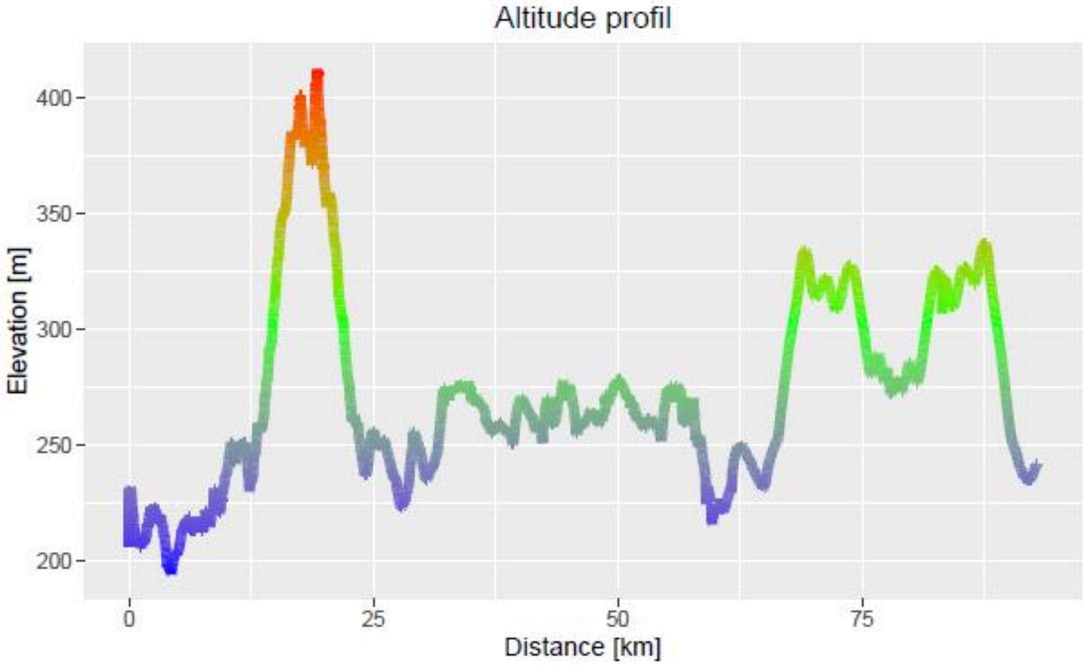
45.8
45.7
45.6
Longitude
8.5
8.6
8.7
8.8
8.9
Elevation
400
350
300
250
200
Varese
Gallarate
Busto Arsizio
Google


Altitude profil
Elevation [m]
400
350
300
250
200
Distance [km]
0
25
50
75

Appendix 2. Vehicles characteristics

A. Vehicle A

Table 22: Vehicle A specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and N/(km/h)^2 respectively.

Vehicle OEM	Skoda
Vehicle Model	Yeti
Vehicle Class	M1
Vehicle Code	VW034
Fuel Type	Diesel
Emissions Control Technologies	EGR+DPF
Model Year	2014
Vehicle Identification Number	TMBLD75L0F6045247
Homologation Number	e11*2007/46*0010*21
Emissions Standard	Euro 5b
Odometer Reading	38275
Transmission Type	Manual
Number of Gears	6
Engine Capacity in cm^3	1968
Rated Power in kW	103
Tyre Dimensions	225/50/R17
RL coefficients NEDC	Inertia: 1590, F0: 76, F1: 0, F2: 0.05
RL coefficients WLTC	Inertia: 1775, F0: 247.1, F1: 0, F2: 0.056
Declared CO_2 value in g/km	152
Software upgrading date	18/11/2016

Figure 20: Vehicle A tested

B. Vehicle B

Table 23: Vehicle B specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and N/(km/h)^2 respectively.

Vehicle OEM	VW
Vehicle Model	Tiguan
Vehicle Class	M1
Vehicle Code	VW038
Fuel Type	Diesel
Emissions Control Technologies	EGR+DPF
Model Year	2013
Vehicle Identification Number	WVGZZZ5NZEW009832
Homologation Number	e1*2001/116*0450*17
Emissions Standard	Euro 5b
Odometer Reading	29173
Transmission Type	Automatic
Number of Gears	7
Engine Capacity in cm^3	1968
Rated Power in kW	130
Tyre Dimensions	235/55/R17
RL coefficients NEDC	Inertia: 1590, F0: 104.6, F1: -0.19, F2: 0.041
Declared CO_2 value in g/km	159
Software upgrading date	12/06/2017

Figure 21: Vehicle B tested

C. Vehicle C

Table 24: Vehicle C specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and N/(km/h)^2 respectively.

Vehicle OEM	Renault
Vehicle Model	Twingo
Vehicle Class	M1
Vehicle Code	RT010
Fuel Type	Gasoline
Injection	MPI
Emissions Control Technologies	TWC
Model Year	2017
Vehicle Identification Number	VF1AHB40D58701104
Homologation Number	e1*2007/46*0457*09
Emissions Standard	Euro 6b
Odometer Reading	654
Transmission Type	Manual
Number of Gears	5
Engine Capacity in cm^3	999
Rated Power in kW	51
Tyre Dimensions	185/60/R15
RL coefficients NEDC	Inertia: 910, F0: 60.8, F1: 0.32, F2: 0.03
RL coefficients WLTC	Inertia: 1032, F0: 92.6, F1: 0.33, F2: 0.032
Declared CO_2 value in g/km	112

Figure 22: Vehicle C tested

D. Vehicle D

Table 25: Vehicle D specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and N/(km/h)^2 respectively.

Vehicle OEM	Fiat
Vehicle Model	Panda
Vehicle Class	M1
Vehicle Code	FT059
Fuel Type	Gasoline
Injection	MPI
Emissions Control Technologies	TWC
Model Year	2016
Vehicle Identification Number	ZFA31200003748634
Homologation Number	e3*2007/46*0064*30
Emissions Standard	Euro 6b
Odometer Reading	2336
Transmission Type	Manual
Number of Gears	5
Engine Capacity in cm^3	1242
Rated Power in kW	51
Tyre Dimensions	175/65/R14
RL coefficients NEDC	Inertia: 1020, F0: 66.3, F1: 0.63, F2: 0.03
RL coefficients WLTC	Inertia: 1118, F0: 98.1, F1: 0.65, F2: 0.032
Declared CO_2 value in g/km	119

Figure 23: Vehicle D tested

E. Vehicle E

Table 26: Vehicle E specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and $N/(km/h)^2$ respectively.

Vehicle OEM	Audi
Vehicle Model	A1
Vehicle Class	M1
Vehicle Code	VW036
Fuel Type	Gasoline
Injection	GDI
Emissions Control Technologies	TWC
Model Year	2016
Vehicle Identification Number	WAUZZZ8X2HB047238
Homologation Number	e1*2007/46*0414*21
Emissions Standard	Euro 6b
Odometer Reading	2539
Transmission Type	Manual
Number of Gears	5
Engine Capacity in cm^3	999
Rated Power in kW	70
Tyre Dimensions	215/40/R17
RL coefficients NEDC	Inertia: 1130, F0: 74, F1: 0.68, F2: 0.029
RL coefficients WLTC	Inertia: 1236, F0: 108.8, F1: 0.7, F2: 0.031
Declared CO_2 value in g/km	98

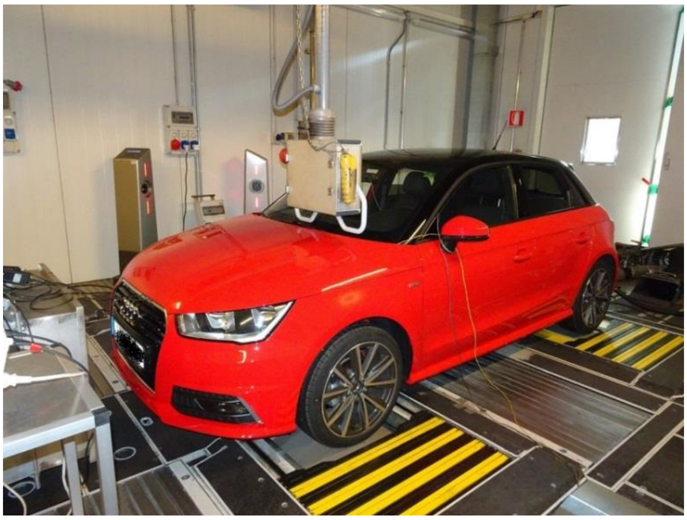


Figure 24: Vehicle E tested

F. Vehicle F

Table 27: Vehicle F specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and $N/(km/h)^2$ respectively.

Vehicle OEM	Ford
Vehicle Model	Fiesta
Vehicle Class	M1
Vehicle Code	FD007
Fuel Type	Gasoline
Injection	GDI
Emissions Control Technologies	TWC
Model Year	2015
Vehicle Identification Number	WF0DXXGAKDFY03062
Homologation Number	e9*2001/116*0069*20
Emissions Standard	Euro 6b
Odometer Reading	88
Transmission Type	Manual
Number of Gears	5
Engine Capacity in cm^3	998
Rated Power in kW	59
Tyre Dimensions	215/70/R16
RL coefficients NEDC	Inertia: 1020, F0: 95, F1: 0, F2: 0.028
RL coefficients WLTC	Inertia: 1215, F0: 165, F1: 0, F2: 0.032
Declared CO_2 value in g/km	105

Figure 25: Vehicle F tested

G. Vehicle G

Table 28: Vehicle G specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and N/(km/h)^2 respectively.

Vehicle OEM	Ford
Vehicle Model	Fiesta
Vehicle Class	M1
Vehicle Code	OL001
Fuel Type	Gasoline
Injection	GDI
Emissions Control Technologies	TWC
Model Year	2017
Vehicle Identification Number	W0LBD8EA5G8088874
Homologation Number	e4*2007/46*0996*04
Emissions Standard	Euro 6b
Odometer Reading	2074
Transmission Type	Manual
Number of Gears	5
Engine Capacity in cm^3	999
Rated Power in kW	77
Tyre Dimensions	205/55/R16
RL coefficients NEDC	Inertia: 1360, F0: 86.7, F1: 0.23, F2: 0.032
RL coefficients WLTC	Inertia: 1451, F0: 125.2, F1: 0.23, F2: 0.035
Declared CO_2 value in g/km	103

Figure 26: Vehicle F tested

H. Vehicle H

Table 29: Vehicle H specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and $N/(km/h)^2$ respectively.

Vehicle OEM	VW
Vehicle Model	Golf GTE
Vehicle Class	M1
Vehicle Code	VW032
Fuel Type	Hybrid Gasoline
Injection	GDI
Emissions Control Technologies	TWC
Model Year	2015
Vehicle Identification Number	WVWZZZAUZFW806364
Homologation Number	e11*2007/46*0623*13
Emissions Standard	Euro 6b
Odometer Reading	8395
Transmission Type	Automatic
Number of Gears	6
Engine Capacity in cm^3	1395
Rated Power in kW	110
Tyre Dimensions	225/40/R18
RL coefficients NEDC	Inertia: 1590, F0: 7.60, F1: 0, F2: 0.0515
Declared CO_2 value in g/km	39

Figure 27: Vehicle H tested

I. Vehicle I

Table 30: Vehicle I specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and N/(km/h)^2 respectively.

Vehicle OEM	Renault
Vehicle Model	Captur
Vehicle Class	M1
Vehicle Code	RT011
Fuel Type	Diesel
Emissions Control Technologies	EGR+LNT+DPF
Model Year	2017
Vehicle Identification Number	VF12RAJ1D57771151
Homologation Number	e2*2001/116*0327*80
Emissions Standard	Euro 6b
Odometer Reading	21590
Transmission Type	Automatic
Number of Gears	6
Engine Capacity in cm^3	1461
Rated Power in kW	66
Tyre Dimensions	205/60/R16
RL coefficients NEDC	Inertia: 1250, F0: 83.1, F1: 0.03, F2: 0.038
RL coefficients WLTC	Inertia: 1390, F0: 124.2, F1: 0.03, F2: 0.04
Declared CO_2 value in g/km	99

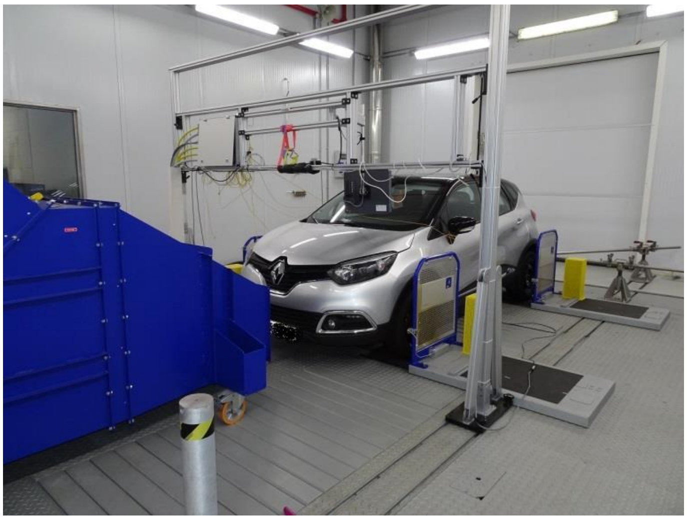


Figure 28: Vehicle I tested

J. Vehicle J

Table 31: Vehicle J specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and N/(km/h)^2 respectively.

Vehicle OEM	Citroën
Vehicle Model	C4 Cactus
Vehicle Class	M1
Vehicle Code	CN002
Fuel Type	Diesel
Emissions Control Technologies	EGR+SCR+DPF
Model Year	2016
Vehicle Identification Number	VF70BBHYBGE510809
Homologation Number	e2*2007/46*0440*05
Emissions Standard	Euro 6b
Odometer Reading	4792
Transmission Type	Manual
Number of Gears	5
Engine Capacity in cm^3	1560
Rated Power in kW	73
Tyre Dimensions	205/55/R16
RL coefficients NEDC	Inertia: 1250, F0: 6.8, F1: 0, F2: 0.046
RL coefficients WLTC	Inertia: 1345, F0: 185.5, F1: 0, F2: 0.048
Declared CO_2 value in g/km	95

Figure 29: Vehicle J tested

K. Vehicle K

Table 32: Vehicle K specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and N/(km/h)^2 respectively.

Vehicle OEM	VW
Vehicle Model	Golf
Vehicle Class	M1
Vehicle Code	VW037
Fuel Type	Diesel
Emissions Control Technologies	EGR+LNT+DPF
Model Year	2015
Vehicle Identification Number	WVWZZZAUZFW307263
Homologation Number	e1*2007/46*0623*13
Emissions Standard	Euro 6b
Odometer Reading	25602
Transmission Type	Automatic
Number of Gears	6
Engine Capacity in cm^3	1968
Rated Power in kW	110
Tyre Dimensions	225/40/R18
RL coefficients NEDC	Inertia: 1360, F0: 90.5, F1: 0.62, F2: 0.03
RL coefficients WLTC	Inertia: 1531, F0: 134.9, F1: 0.64, F2: 0.032
Declared CO_2 value in g/km	117

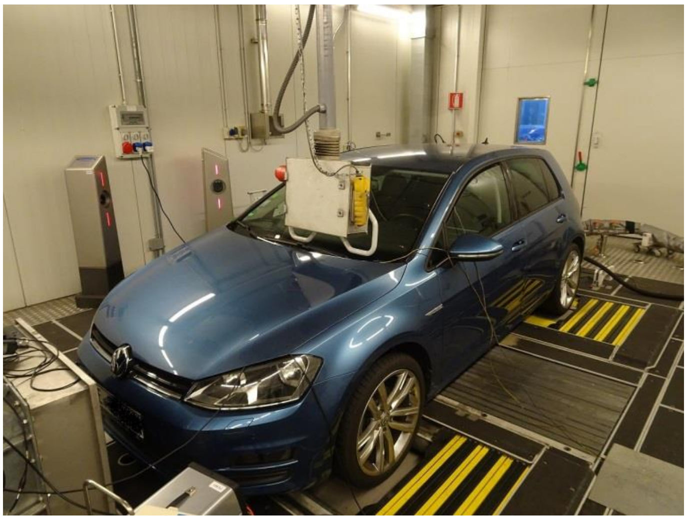


Figure 30: Vehicle K tested

L. Vehicle L

Table 33: Vehicle L specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and N/(km/h)^2 respectively.

Vehicle OEM	Audi
Vehicle Model	A3
Vehicle Class	M1
Vehicle Code	VW035
Fuel Type	Diesel
Emissions Control Technologies	EGR+LNT+DPF
Model Year	2015
Vehicle Identification Number	WAUZZZ8V2F1121968
Homologation Number	e1*2007/46*0607*16
Emissions Standard	Euro 6b
Odometer Reading	24473
Transmission Type	Automatic
Number of Gears	6
Engine Capacity in cm^3	1968
Rated Power in kW	110
Tyre Dimensions	225/45/R17
RL coefficients NEDC	Inertia: 1590, F0: 7.6, F1: 0, F2: 0.052
RL coefficients WLTC	Inertia: 1763, F0: 246.9, F1: 0, F2: 0.048
Declared CO_2 value in g/km	120

Figure 31: Vehicle L tested

M. Vehicle M

Table 34: Vehicle M specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and N/(km/h)^2 respectively.

Vehicle OEM	Kia
Vehicle Model	Sportage
Vehicle Class	M1
Vehicle Code	KA001
Fuel Type	Diesel
Emissions Control Technologies	EGR+LNT+DPF
Model Year	2017
Vehicle Identification Number	USYPG815AHL272827
Homologation Number	e11*2007/46*3144*03
Emissions Standard	Euro 6b
Odometer Reading	14771
Transmission Type	Manual
Number of Gears	6
Engine Capacity in cm^3	1685
Rated Power in kW	85
Tyre Dimensions	215/70/R16
RL coefficients NEDC	Inertia: 1470, F0: 97.2, F1: -0.09, F2: 0.041
RL coefficients WLTC	Inertia: 1614, F0: 143.5, F1: -0.09, F2: 0.044
Declared CO_2 value in g/km	124

Figure 32: Vehicle M tested

N. Vehicle N

Table 35: Vehicle N specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and $N/(km/h)^2$ respectively.

Vehicle OEM	BMW
Vehicle Model	530d
Vehicle Class	M1
Vehicle Code	BW014
Fuel Type	Diesel
Emissions Control Technologies	EGR+LNT+SCR+DPF
Model Year	2017
Vehicle Identification Number	WBAJC91000G470998
Homologation Number	e1*2007/46*1688*00
Emissions Standard	Euro 6b
Odometer Reading	4810
Transmission Type	Automatic
Number of Gears	8
Engine Capacity in cm^3	2993
Rated Power in kW	195
Tyre Dimensions	245/40/R19
RL coefficients NEDC	Inertia: 1700, F0: 111, F1: 0.34, F2: 0.029
RL coefficients WLTC	Inertia: 1863, F0: 163.8, F1: 0.35, F2: 0.031
Declared CO_2 value in g/km	124

Figure 33: Vehicle N tested

O. Vehicle O

Table 36: Vehicle O specifications. RL stands for road load, with Inertia, F0, F1 and F2 in kg, N, N/(km/h) and N/(km/h)^2 respectively.

Vehicle OEM	Peugeot
Vehicle Model	Partner
Vehicle Class	N1, Class 2
Vehicle Code	PT009
Fuel Type	Diesel
Emissions Control Technologies	EGR+SCR+DPF
Model Year	2017
Vehicle Identification Number	VF37BBHY6HJ582834
Homologation Number	e2*2007/46*0001*25
Emissions Standard	Euro 6b
Odometer Reading	79
Transmission Type	Manual
Number of Gears	5
Engine Capacity in cm^3	1560
Rated Power in kW	73
Tyre Dimensions	195/65/R15
RL coefficients NEDC	Inertia: 1360, F0: 86.4, F1: 0.14, F2: 0.046
RL coefficients WLTC	Inertia: 1574, F0: 135.2, F1: 0.15, F2: 0.049
Declared CO_2 value in g/km	112

Figure 34: Vehicle O tested

KJ-NA-29302-EN-N

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