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Assessment of real driving emissions via portable emission measurement system

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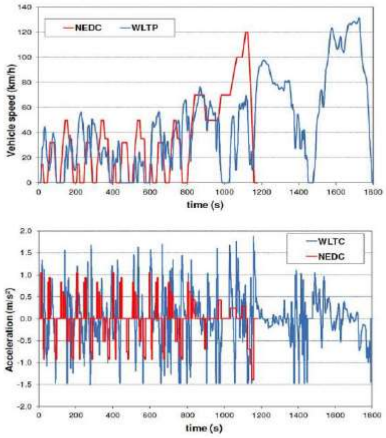
Abstract. The European Commission approved a so-called Real Driving Emission (RDE) test in response to the criticisms to the current driving cycle used at chassis dyno for homologation purpose (NEDC): it is considered outdated and misleading since air pollutants in real driving conditions are considerably higher than the certification thresholds. So, what's at stake is the air quality which degraded continuously despite the ever-increasing severity of the regulations during the last almost three decades. Thus, from September 2017, the RDE test will become part of the type approval process for all cars sold in Europe. As its name points out, it will include "real world driving" using a portable emissions measurement system (PEMS). The paper presents the RDE features (PEMS mounting, testing environment, boundary conditions, driving dynamics) and presents a case study on the influence of the driving style upon the tail-pipe emissions under the RDE testing. The results presented in the paper issued from the existing cooperation on this topic between University of Pitesti and Renault Technologie Roumanie

1. Introduction and literature review

Despite the ever-increasing severity of the European regulations regarding automotive tail-pipe pollution and CO_2 emission, real driving emissions (RDE) barely changed over the last almost three decades [1]. One reason is that till now, the European passenger car certification procedure was only about testing the vehicle in lab condition using a non-representative driving cycle. Indeed, the New European Driving Cycle (NEDC) which was long used for the homologation purpose, was finally declared outdated and misleading since it consists in a driving style rather smooth (moderate and uniform accelerations and decelerations, constant cruising speeds and many idling events), which isn't to be met in real roads. Moreover, NEDC doesn't account neither for other factors related to the real world such as: the use of air conditioning, vehicle accessories, reduced tyre pressure, [2]. Thus, these result in fuel consumption, CO_2 emissions and pollution which are non-representative of actual real-world performance. There are many studies raising the problem of certification procedure's representativeness to the real-world driving [3–8]. In fact, the automotive manufacturers are simply developing technical solutions and testing them to the letter of the law. Few of them step further because of the involved costs, which could be a commercial disadvantage on the market. Consequently, this raises questions on the real progress of EU regarding its commitment to achieve at least 20% reduction of greenhouse gas (GHG) emissions by 2020 (compared to 1990 levels) [9].

However, the problem of GHG and pollution is a complex one since, currently, there is a lack of homogeneity in worldwide type-approval procedures: each major geographic area with its own style of regulations as if the Earth atmosphere shouldn't be treated as a whole, belonging to each and every one of us. On this matter, however, progress was made as in 2009 the World Forum for the Harmonization of Vehicle Regulations of the United Nations Economic Commission for Europe (UNECE), through its working party on pollution and energy (GRPE), launched a project with the aim to develop a worldwide harmonized light duty test cycle (WLTC) and test procedure (WLTP) [10]. Two working groups were established; the first group in charge of the development of harmonized cycle (DHC) and the second group working on development of test procedures (DTP). The Joint Research Centre (JRC) of the EC has been deeply involved in both groups, participating to the design, validation and revision of the new test cycle and in developing, testing and adjusting the new test procedures [7]. Figure 1 shows a comparison with former homologation driving cycle, NEDC. A quick analysis reveals that WLTC is longer in time and distance and features a more dynamic speed profile, which means it is more representative for the real world. So, now that WLTP exists, what remains to be done is that it is undertaken at global scale.



Criteria	NEDC	WLTC
Distance [km]	11.013	23.141
Duration [s]	1180	1800
Average speed [km/h]	33.6	46.3
Max. speed [km/h]	120	131
Max. acceleration [m/s^2]	1.04	1.88
Max. deceleration [m/s^2]	-1.39	-1.52
Standstill time [s]	280	227
Standstill proportion [%]	23.7	12.6
Constant cruise driving proportion [%]	39.3	3.4
Acceleration & deceleration proportion [%]	36	84

Figure 1. NEDC vs. WLTC

Paper [7] dealt with the effect of WLTC on CO_2 and regulated pollution gases with respect to the ones issued from NEDC. The study was performed on Euro 4, 5 and 6 production vehicles. Thus, surprisingly, CO_2 emission in WLTC is comparable with the one from NEDC (a bit lower in some cases, a bit higher in other cases). The authors explained it as follows: firstly, although WLTC is more demanding, however, the cold start emissions have a smaller impact due to its longer duration (the estimated contribution of cold start emission over NEDC is between 50-60% higher than for WLTC); secondly, because of the higher dynamic of WLTC, the engine is run at higher loads, thus resulting in higher average efficiency. On the matter of regulated pollutants, the same authors drew the following conclusions: "for those pollutants whose emissions are mainly due to the cold start phase of the cycle (e.g. THC for gasoline and diesel vehicles and CO for diesel vehicles), moving from NEDC to WLTC brings an improvement due to the lower weight of the cold start emissions on the whole cycle. On the other hand, the pollutants that are emitted also during high engine load conditions (e.g. NOx on diesel vehicles and CO on gasoline vehicles), the change from NEDC to WLTC can lead to substantial emission increase". Thus, the introduction of WLTC is expected to reduce the existing gap between overall emissions obtained from NEDC and the RDE [6,7].

However, in order to deal with high on-road emissions from passenger cars, the European Commission created also the "working group for the development of a RDE test procedure for light-duty vehicles (RDE-LDV)" in 2011. The RDE-LDV is chaired by the EC and supported by the JRC of the EC and technical experts from the member states, industry and non-governmental organizations (NGO) [1]. As explained in [1], the RDE test procedure has been, for practical reasons, split into several packages. The **first RDE package** was voted positively by the Member States in the Technical Committee of Motor Vehicles (TCMV) in May 2015 and has entered into force since March 2016 (see the EU regulation 2016/427, [11]). In the RDE procedure, pollutant emissions will be measured by portable emission measuring systems (PEMS) that will be attached to the car while driving in real conditions on road. This means that the car will be driven outside and on a real road featuring random acceleration and deceleration patterns. This package deals with the technical requirements for PEMS testing. In an initial phase that started in 2016, the RDE testing will only be done for monitoring purposes, without an impact on the actual type approval, which will continue to be delivered based on the laboratory measurements. On 28th of October 2015, Member States meeting in the TCMV voted by a large majority for **the second RDE package**, which was necessary for the RDE tests to have an actual impact on type approvals issued by national authorities (see the EU regulation 2016/646, [12]). From 1st of September 2017, the new RDE tests will determine whether a new car model can be put on the market. For that, a conformity factor (CF) is set for all new vehicles at 2.1 for NO_x and at 1.5 for PN. A second stage CF is equal to 1.0, with a margin parameter that considers the additional measurement uncertainties introduced by the PEMS equipment. The margin parameter is currently set at 0.5. The latter is subject to an annual review and shall be revised as a result of the improved quality of the PEMS procedure or technical progress. **The third RDE package** will define a procedure for the measurement of the particulates and include the effect of vehicle cold starts into the RDE testing. In addition, the Commission will oblige manufacturers to publish the CFs of an individual vehicle in its certificate of conformity (CoC). In this way, the consumer will have full transparency on the real emission performance. In **the fourth RDE package,** the EC will define the rules for independent RDE testing of vehicles being in-service, including the regulatory consequences in case of non-conformity.

On the matter of in-use regulation, it has to be said that they first appeared in US. Having in mind the need to be sure that emission standards are maintained throughout the course of the vehicle's useful lifetime, the US Environmental Protection Agency (EPA) and California Air Resources Board (CARB) have implemented in 2005 a series of regulations to control NOx and PM emissions from heavy-duty diesel trucks during in-use conditions [13]. One of the most important US regulations with respect to controlling in-use emissions is Not-To-Exceed (NTE) standard, which sets limits for gaseous and PM pollutants emitted during operation in a defined portion of the engine map and specifies the protocols required to make those measurements. Emission results from this test procedure must be less than or equal to 1.25 times the pre-existing Federal Test Procedure (FTP) standards. The NTE test and associated emission limits are effective starting with 2007 model year [14].

This being the context, the paper deals with RDE features (PEMS mounting, testing environment, boundary conditions, driving dynamics) and presents a case study on the influence of the driving style upon the tail-pipe emissions under the RDE testing. The results presented in the paper issued from the existing cooperation on this topic between University of Pitesti and Renault Technologie Roumanie.

2. Real driving emissions testing. An extract from the regulations

According to Commission regulation (EU) 2016/427 [11], the RDE means "the emissions of a vehicle under its normal conditions of use". Moreover, in the same regulation it is stated that throughout its normal life, the emissions of a vehicle type-approved according to Regulation (EC) 2007/715 [15] determined and emitted at a RDE test performed in accordance to the current requirements [11], shall not be higher than the following NTE values:

$$NTE_{pollutant} = CF_{pollutant} \cdot TF(p_1, p_2, \dots) \cdot EURO6, \quad (1)$$

where EURO6 is the applicable limit from the regulation [11] and $TF(p_1, p_2, \dots)$ is a transfer function depending on different parameters (e.g. ambient temperature and humidity, etc).

Amongst the tail-pipe emissions, only CO_2, CO, NO, NO_2 and PN are mandatory to measure in RDE testing. HC measurement by FID was not considered because of safety reasons. However, currently, CFs are imposed only for NOx and PN (see table 1).

Concerning the boundary conditions (vehicle payload and test mass; ambient conditions; dynamic conditions; vehicle condition and operation), trip and operational requirements, they all are stated in [15]. Subsequently, a briefing of all these is given. First, table 1 presents a synopsis of the RDE features. In this table:

- Euro 6d-TEMP is the full Euro6 emission requirements assessed on regulatory lab test cycle and RDE testing against temporary CF, [15];
- according to the regulation, by way of derogation the lower temperature for moderate conditions shall be greater or equal to 3°C and the lower temperature for extended conditions shall be greater or equal to -2°C between the start of the application of binding NTE emission limits as defined in section

2.1 and until five years after the dates given in paragraphs 4 and 5 of Article 10 of Regulation (EC) No 715/2007, [15].

- as mentioned in [11], the cold start period covers the first 5 minutes after initial start of the combustion engine. If the coolant temperature can be reliably determined, this period ends once the coolant has reached 70 °C for the first time but no later than 5 min after initial engine start.
- if during a particular time interval during the RDE test, the ambient conditions are extended, the emissions during this period shall be divided by a value *ext* before being evaluated for compliance with the requirements [11].

Table 1. RDE features according to the regulations, [11,15]

Test	Application date	CF NO_x	CF PN	Moderate conditions		Extended Conditions		Cold start?
				Altitude [m]	Temperature [°C]	Altitude [m]	Temperature [°C]	
RDE monitoring	April 2016	w/o	w/o	0..700	0..30	700..1300	-7..0 or 30..35	No *Recorded but excluded from the emissions evaluation*
Euro 6d-TEMP	September 2017	2.1	1.5		3..30		-2..0 or 30..35	Yes
Euro 6d	January 2020	1.5	1.5		0..30		-7..0 or 30..35	Yes

The RDE test also means requirements for the trip to be used to measure the emissions of a vehicle under its normal conditions of use. Table 2 shows a synopsis of the RDE trip requirements, which consists in 3 parts that must be run continuously. Rural operation may be interrupted by short periods of urban operation when driving through urban areas. Highway operation may be also interrupted by short periods of urban or rural operation. Certainly, local speed limits remain in force at a PEMS test, though their violations per se do not invalidate the results of a PEMS test. Urban operation must contain several stop periods of min. 10 s whose share out of the urban time duration must be at account for 6-30%. The inclusion of one excessively long stop period that individually comprises >80 % of the total stop time of urban operation shall be avoided.

Table 2. RDE trip requirements, [11,12]

Detail \ Type	Urban	Rural or Extra-urban	Motorway or High-way
Trip sequence	1	2	3
Share [%] ± 10%	~ 34 *(but in any case, > 29 %)*	~ 33	~ 33
Speeds [km/h]	< 60	60..90	90..145 *(> 100 for at least 5 min)*
Average speed [km/h]	15..40	-	-
Stop periods share [%]	6..30	-	-
One stop period [s]	≥ 10	-	-
Min. distance of each trip [km]	16		
Trip duration [min]	90..120		
Difference in altitude between start and stop points [m]	≤ 100		

According to [11], the RDE test for the passenger cars or light-duty vehicles is to be carried out with a PEMS composed of the following components: gas analyzers for CO_2, CO, NO_2, NO concentration in the exhaust gas (in ppm or %); PN counter from the exhaust gas; exhaust flow mass or volume (EFM, EFV); global positioning system (GPS) to determine the position, altitude and speed of the vehicle; weather station for ambient temperature and relative humidity (RH); an engine control unit (ECU) connection for the acquisition of engine related parameters; an energy source independent of the vehicle to power the whole PEMS. Figure 2 shows the whole layout of the PEMS belonging to University of Pitesti, which was used for this study.

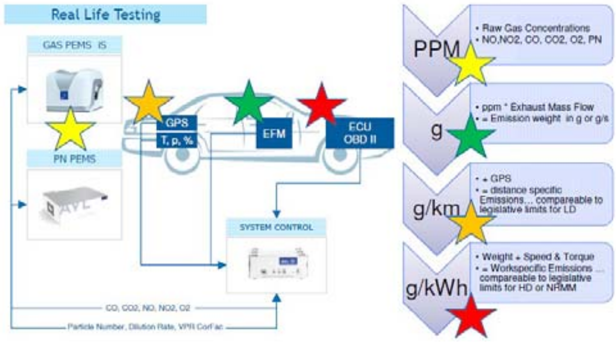


Figure 2. AVL's M.O.V.E. PEMS for RDE testing

In accordance to what figure 2 indicates, below are given the relations needed to transform the emissions from concentration (% or ppm) in distance-specific (DS) emissions, i.e., (g/km) or (#/km):

$$CO_2\left[\frac{g}{km}\right] = 10^3 \cdot \frac{CO_2[\%] \cdot 10^{-2} \cdot EFM\left[\frac{kg}{h}\right]}{v\left[\frac{km}{h}\right]} \tag{2}$$

$$CO\left[\frac{g}{km}\right] = 10^3 \cdot \frac{CO[\%] \cdot 10^{-2} \cdot EFM\left[\frac{kg}{h}\right]}{v\left[\frac{km}{h}\right]} \tag{3}$$

$$NO + NO_2 = NO_x\left[\frac{g}{km}\right] = 10^3 \cdot \frac{NO_x[ppm] \cdot 10^{-6} \cdot EFM\left[\frac{kg}{h}\right]}{v\left[\frac{km}{h}\right]} \tag{4}$$

$$PN\left[\frac{\#}{km}\right] = \frac{PN\left[\frac{\#}{m^3}\right] \cdot EFV\left[\frac{m^3}{h}\right]}{v\left[\frac{km}{h}\right]} \tag{5}$$

The techniques of measuring for each gas analyzer are usually non-dispersive ultraviolet (NDUV) for NO and NO_2 and non-dispersive infrared (NDIR) for CO and CO_2. RDE test parameters provided by the PEMS are acquired at a constant frequency of 1 Hz or higher. The installation of the PEMS shall be done in a way to influence the vehicle emissions and performance to the minimum extent possible. Usually, the PEMS may be mounted either outside the vehicle on a bike carrier attached on a usual hook at the vehicle or inside the vehicle (figure 3).

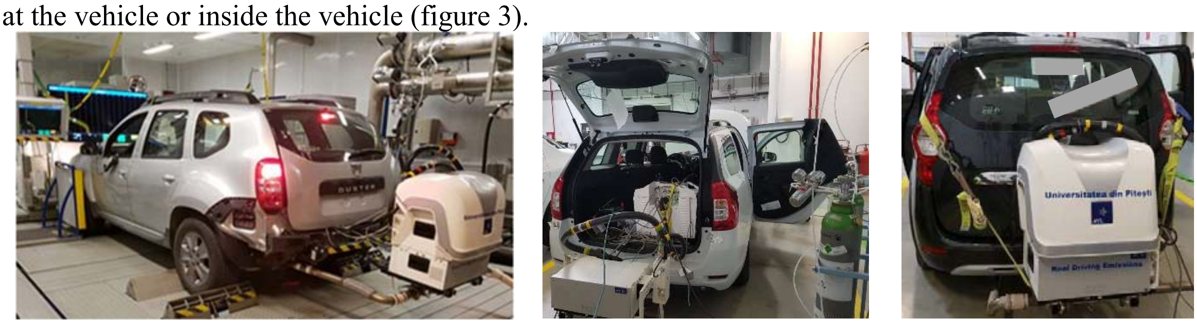


Figure 3. PEMS mounting on vehicles

Every RDE test consists of the following:

- pre-test procedure:
  - *leak-check, i.e., when the probe is disconnected from the exhaust system with the end plugged and with the analyser pump switched on, after an initial stabilisation period, all flow meters shall read nearly zero in the absence of a leak; if not, the sampling lines shall be checked and the fault corrected,*
  - *starting and stabilising the PEMS,*
  - *calibration of the gas analysers, i.e., zero and span calibration adjustments of the analysers shall be performed using calibration gases; the calibration gases shall be chosen to match the range of emissions concentrations expected during the emissions test.*

- emissions test procedure:
  - *sampling, measurement and recording of parameters shall begin prior to the start of the engine and continue throughout the on-road test of the vehicle,*
  - *the end of the test is reached when the vehicle completed the trip and the engine is switched off. The data recording shall continue until the response time of the sampling systems has elapsed.*
- post-test procedure:
  - *recalibration of gas analysers, i.e., the zero and span of the analysers of gaseous components shall be checked again by using calibration gases identical to the ones applied when performing the pre-test procedure; the purpose is to evaluate the analyser response drift compared to the pre-test calibration.*

The linearity of gas analysers, PN counter, flow-measuring instruments is to be performed at least every 3 months and shall comply with the requirements presented in [11]. Equally, it is recommended to validate the installed PEMS once for each PEMS-vehicle combination either before the test or after the completion of an on-road test. This is to be conducted on a chassis dynamometer using the WLTP and having to respect the permissible tolerances given in [11]. A validation procedure for the EFM is also provided in [11].

After establishing the validation of an RDE test according to criteria presented above (measuring and trip criteria), there are still two other conditions to be fulfilled in order to obtain a final validation of the RDE test: driving dynamics via data pre- and post-processing. The latter is either EMROAD moving average windows (MAW) or CLEAR power binning, [11,12]. On the first way to check the driving dynamics, some helpful references may be found in [16], which are also explained in [12]:

- relative positive acceleration per speed bin used to distinguish the soft driving:

$$RPA_k\left[\frac{m}{s^2},\frac{kW\cdot s}{kg\cdot km}\right]=\frac{\sum_j\left[\Delta t\cdot(v\cdot a_{pos})_{j,k}\right]}{\sum_i d_{i,k}}, j=1\ to\ M_k, i=1\ to\ N_k, k=u,r,m, \tag{6}$$

where:
RPA_k is the relative positive acceleration for urban (u), rural (r) and motorway (m),
Δt, time difference equal to 1 second,
M_k the sample number for u, r and m,
N_k the total sample number for u, r and m.

- product between actual vehicle speed and positive acceleration greater than 0.1 m/s^2 in time step j, considering the u, r and m shares

$$(v\cdot a_{pos})_{j,k}\left[\frac{m^2}{s^3},\frac{W}{kg}\right] \tag{7}$$

- 95th percentile of the product between actual vehicle speed and positive acceleration greater than 0.1 m/s^2 in time step j, considering the u, r and m shares

$$(v\cdot a_{pos})_{k\_[95]}\left[\frac{m^2}{s^3},\frac{W}{kg}\right]. \tag{8}$$

The severity of the driving is judged by using $(v\cdot a_{pos})_{k_[95]}$parameter, while the soft driving is distinguished through RPA_k:

$$\text{If}\quad \bar{v}_k\le 74.6\frac{km}{h}\ and\ (v\cdot a_{pos})_{k\_[95]}>(0.136\cdot\bar{v}_k+14.44)\ \text{or}\quad \bar{v}_k>74.6\frac{km}{h}\ and\ (v\cdot a_{pos})_{k\_[95]}>(0.0742\cdot\bar{v}_k+18.966) \tag{9}$$

are fulfilled then the trip is invalid.

$$\text{If}\quad \bar{v}_k\le 94.05\frac{km}{h}\ and\ RPA_k<(-0.0016\cdot\bar{v}_k+0.1755)\quad \bar{v}_k>94.05\frac{km}{h}\ and\ RPA_k<0.025 \tag{10}$$

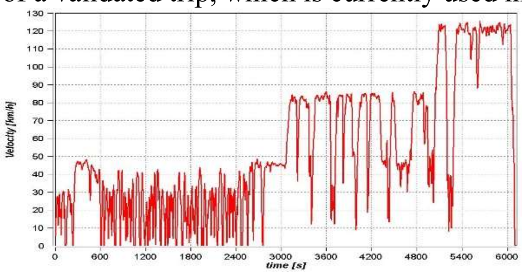
are fulfilled then the trip is invalid.

According to [3,4,11], the EMROAD validation based on the MAW method provides an insight on the RDE occurring during the test at a given scale. The test developed by JRC is divided in sub-sections (windows) and the subsequent statistical treatment aims at identifying which windows are suitable to assess the vehicle RDE performance. The mass emissions are not calculated for the complete data set, but for sub-sections of the complete data set whose length is being determined to match the CO_2 mass emitted by the vehicle over the reference laboratory cycle. The moving average calculations are conducted with a time increment corresponding to the data sampling frequency. Based on this method, the RDE test is validated if it is complete (i.e., it comprises at least 15 % of urban, rural and motorway windows, out of the total number of windows) and normal (i.e., at least 50 % of the urban, rural and motorway windows are within the primary tolerance defined for a characteristic curve).

The other method, which could be used for the validation is the so-called CLEAR or power binning developed by TU Graz. It is based on a normalization to a standardized wheel power frequency (SPF) distribution [3,4,12]. Based on this method, the RDE test is validated if the power distribution for the urban and total trip in each class falls within the tolerances given by [12].

3. Real driving emissions testing. Case study

For a better understanding of the RDE requirements and of the consequences which come with its implementation, our endeavour started with the challenge of finding the right trip. Figure 4 shows the features of a validated trip, which is currently used in our study.



Total Trip Requirements	pass/fail
Trip Shares	
Urban 34% +10% and >=29%	pass
Rural 33% +-10%	pass
Motorway 33% +-10%	pass
Minimum Distance	
Urban 16 km	pass
Rural 16 km	pass
Motorway 16 km	pass
Total Trip Duration 90 -120 min	pass

Figure 4. RDE trip

Figure 5 pictures the operating points of a gasoline production engine during running in NEDC (in green), WLTC (in blue) and RDE (in red) conditions, as well as the speed profiles for each of the 3 tests.

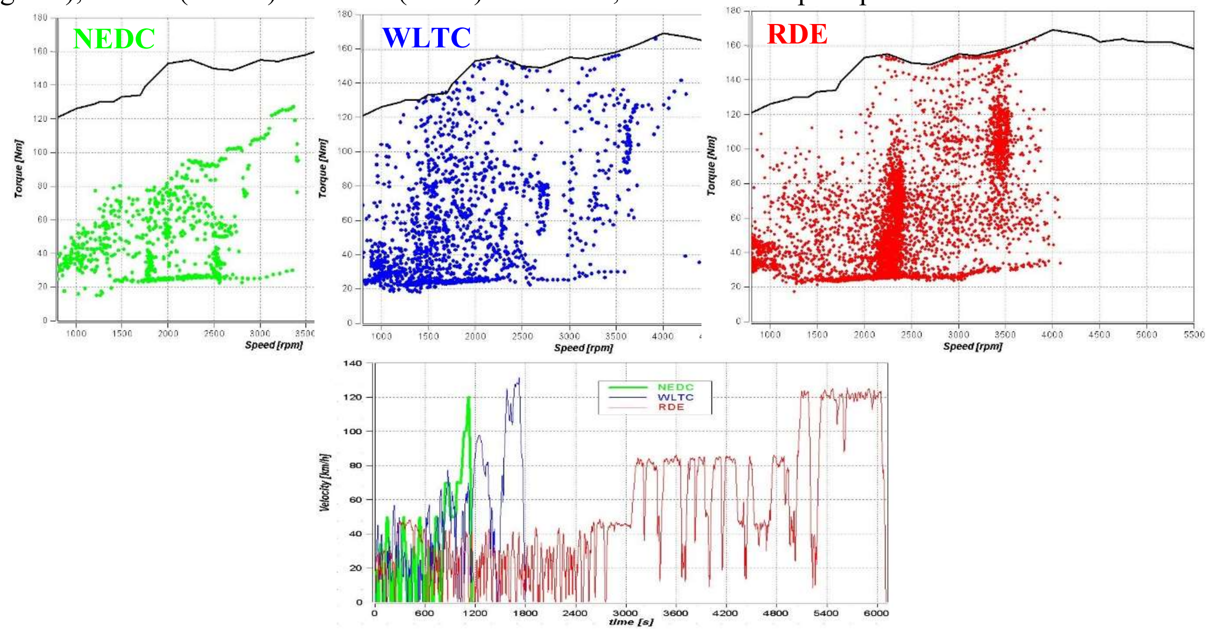


Figure 5. Engine’s operating points and speed profiles for NEDC, WLTC and RDE

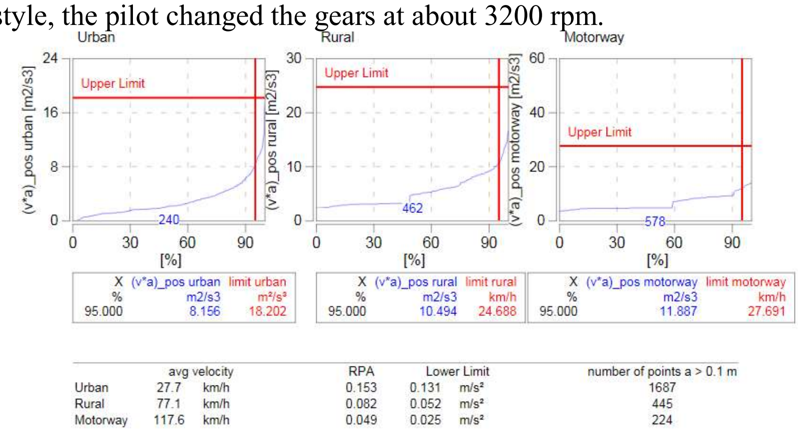
Comparing the 3 pictures, it becomes obvious that the type approval process by using WLTC and RDE is about addressing in a detailed way far more operating points of the engine. This requires the development of engines able to operate cleanly under all driving conditions. Thus, the engines which will comply with this far more severe type approval process must be adapted due to the extension of their operating range. Therefore, as indicated in [17], mixture enrichment usually performed in high loads and speeds in order to protect the exhaust valves, exhaust manifold, turbocharger (if any) and catalyst against temperature overload will be at issue. Equally, it is questionable to which extent the scavenging through valve overlap for the increase of low-end torque and transient response will still be feasible. Therefore, this must be considered early in the development phase in order to choose the right technical definition for the future engines (e.g. the integration of the exhaust manifold into the cylinder head for being possible the cooling of the exhaust gas).

Furthermore, to have a better understanding of different influences upon the RDE, the following plan was undertaken:

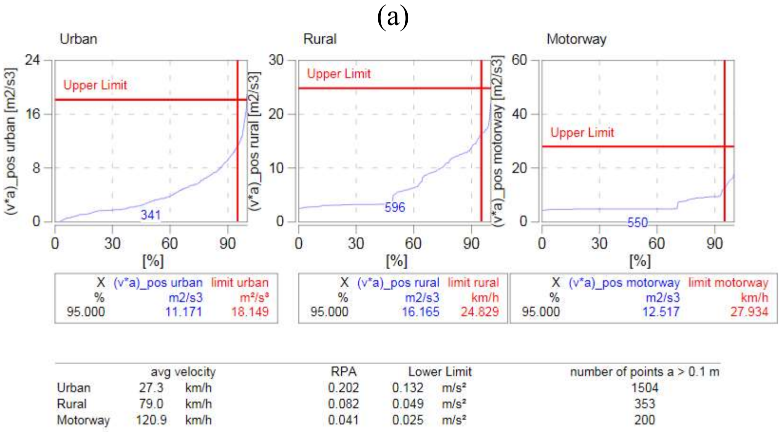
1. influence of the driving style, (“sport-driving vs. “eco-driving”) in “quasi-iso-conditions”, i.e., with the same driver, the same vehicle, during the same season and by using the same trip;
2. influence of the trip in “quasi-iso-conditions”, i.e., when using the same driver with the “same” driving style, the same vehicle and during the same season.
3. influence of the ambient conditions or of the season (winter vs. summer) in “quasi-iso-conditions”, i.e., when using the same driver with the “same” driving style, the same vehicle and the same trip.

Out of these three, only the first will be presented subsequently. Regarding the third objective, currently, a testing campaign carried out in the chassis dyno test cell is in progress. The objective is to see the effect of the ambient temperature upon the PEMS performance. Consequently, we plan a follow-up article to present the results obtained with the above methodology.

Coming back to the effect of the driving style, the vehicle which was used featured a manual transmission, so, for the “eco-driving” style, the pilot respected the recommendations of the gear-shift indicator (GSI). In short, it’s about changing the gears not higher than 2500 rpm. Conversely, for the “sport-driving” style, the pilot changed the gears at about 3200 rpm.



(a)



(b)

Figure 6. Parameters used to judge the driver’s “aggressiveness”
(a) “eco-driving, (b) “sport-driving”

Figure 6 presents the main features of these two driving styles, judged via the parameters defined in relations (6), (7) and (8). The "aggressiveness" of the driver in the second case is obvious: in each of the three parts of the RDE trip (urban, rural and motorway), the $(v \cdot a_{pos})$ is higher and still, below the regulated limit. The same observation stands for the *RPA,* as well.

Two RDE trips per driving style were performed and then, the tail-pipe emissions results were averaged and analyzed comparatively. The ambient conditions while performing these four tests were close: ~ 22°C & ~ 23% RH for "eco-driving" and ~ 24°C & 22% RH for "sport-driving". Thus, it can be said the tests were performed in "quasi-iso-conditions", i.e., with the same driver, the same vehicle, very close ambient conditions and by using the same trip. The impact of the driving style while fulfilling all the RDE trip criteria upon the tail-pipe emissions is presented in figure 7.

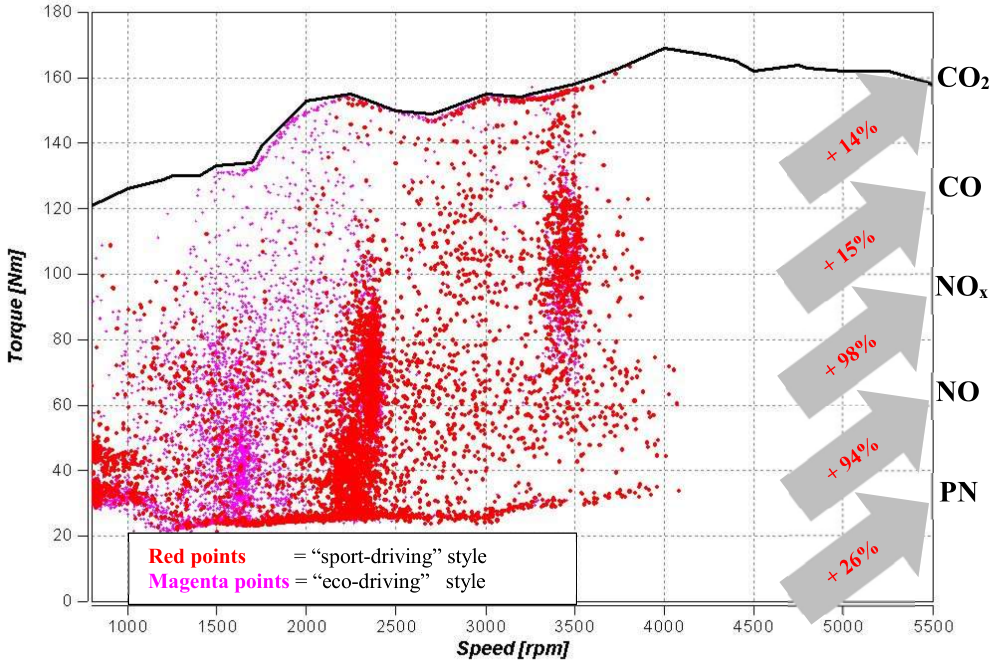


Figure 7. Driver's aggressiveness effect on tailpipe emissions

The increase in tail-pipe emissions while using the "sport-driving" are within expectations and of course are related with the engine's operation in higher loads and speeds. Thus, one may see that especially, NO_x and PN are strongly affected when driving more aggressive. Consequently, driving behavior can be the object of an additional measure to be taken to reduce air pollution from road vehicles.

4. Conclusions

Road mobility is the engine of economic development and is one of the fundamental aspects of social cohesion because it allows everyone the freedom of movement, along with the advantages inherent to it: easy access to various jobs, to public services, vacations/leisure etc. Even though it still represents the most spread energy source in the field of road mobility, the combustion engine faces environmental issues. Furthermore, despite the ever-increasing severity of the European regulations regarding automotive tail-pipe emissions, the population is exposed to air pollutants concentrations above the accepted limited. Consequently, the RDE testing was added to the type approval procedure for reasons of achieving a better representativeness to the real-world driving. Lab testing for type approval is and will be wanted because of the standardization and repeatability. Thus, both parts of the type approval process (lab testing + RDE) aim at achieving a real reduction in tail-pipe emissions. Nevertheless, it needs to be underlined, that even if vehicle emissions standards are a very powerful tool to reduce air pollution from road vehicles, they are not the only tool available for meeting air quality objectives. Additional measures which address traffic volumes, fuels and driving behavior are also necessary.

On the one hand, our study showed that RDE means new technical challenges for engine and after-treatment technology developers. Nonetheless, despite the inherent efforts of the manufacturers needed to cope with, it will also contribute to giving the combustion engines a more positive environmental image. On the other hand, it also presented a case study on the assessment of the driving style effect upon the emissions while performing RDE tests. As expected, results showed a significant increase in tail-pipe emissions while adopting a more aggressive driving style, which support the above statement regarding the addition measures which could be taken to meet the air quality objectives.

5. References

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Nomenclature. Abbreviations and notations

CARB	California Air Resources Board
CF	Conformity factor
CO	Carbon monoxide
CO_2	Carbon dioxide
CoC	Certificate of conformity
DS	Distance-specific
EC	European Committee
ECU	Engine control unit
EFM/V	Exhaust Flow Mass/Volume
EPA	US Environmental Protection Agency
EU	European Union
FID	Flame ionization detection
FTP	Federal Test Procedure
GHG	Greenhouse gas
GPS	Global positioning system
GSI	Gear shift indicator
HC	Unburnt hydrocarbons
JRC	Joint Research Centre
LDV	Light-duty vehicles
MAW	Moving average windows
NDIR	Non-dispersive infrared
NDUV	Non-dispersive ultraviolet
NEDC	New European Driving Cycle
NGO	Non-governmental organisations
NOx	Nitric oxides
NTE	Not-To-Exceed
PEMS	Portable emission measuring systems
RDE	Real driving emissions
RH	Relative humidity
RPA	Relative positive acceleration
SPF	Standardised power frequency
TCMV	Technical Committee of Motor Vehicles
THC	Total unburnt hydrocarbon
UNECE	United Nations Economic Commission for Europe
WLTC	Worldwide harmonized light duty test cycle

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