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Nitrogen oxides emission evaluation for Euro 6 category vehicles equipped with combustion engines of different displacement volume

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Abstract. The introduction of changes in the type approval testing procedures for vehicles is also a matter of reducing the problem of exceeding the limits specified in standards. The previous laboratory studies of vehicles' emission did not contain information on the actual engine operating conditions. Particular attention was paid to the comparative study of engines with spark and compression ignition in the context of nitrogen oxides emissions. The reason for this consideration was a significant discrepancy in the size of the engines for vehicles with a similar curb weight. The article presents the assessment of the vehicles' ecological indicators in real traffic conditions according to the latest proposals for Real Driving Emissions testing. It has been shown that despite the compliance of the vehicles with emissions approval limits in terms of nitrogen oxides performed in the study on a chassis dynamometer, they are – especially for vehicles equipped with compression ignition engines – exceeded in actual operation. It proves that special attention should be paid to compression ignition engines, which pose a threat in terms of nitrogen oxides emissions.

1. Introduction

Research comparing spark ignition and compression ignition engines is currently a major scientific focus, especially in the context of nitrogen oxide emissions [1]. The main reason behind this interest is the overwhelming number of vehicles with Diesel engines, not only personal cars, but also transport vehicles [2, 3]. Consecutive exhaust emission standards force manufacturers to reduce their emission levels, but there is still a noticeable problem with nitrogen oxide emissions [4].

Making changes to vehicle type approval testing procedures is also an attempt to drastically reduce the problem of exceeding the legal limit values. Previous vehicle laboratory tests did not provide adequate information on the actual operating conditions of the exploited engines. Adapting to the real world and responding to it was the intention behind the introduction of European regulations 715/2007/EC [5] and 692/2008 [6]. The breakthrough occurred when the decision on the mandatory use of RDE tests, i.e. in real driving conditions, was made. The regulations include incentives for vehicle manufacturers, among others, to make changes to their companies and products as soon as they are introduced.

The degree of the RDE procedures development is already so advanced that from September 2017, in addition to laboratory testing, the type approval process also includes a procedure for measuring the pollutant emissions during actual driving. The European Union regulation (715/2007 and 692/2008) on the use of RDE testing is a response to the study revealing increased NO_x emissions from cars equipped with compression ignition engines, despite the fact that such vehicles comply with the acceptable standards in laboratory conditions. According to the new rules, for all new approvals starting from 1.09.2017, and for new car model registrations from 1.09.2019, the nitrogen oxides emission measured in road conditions will not exceed 2.1 times the maximum laboratory test limit (figure 1). As a consequence, the main focus of the article is on the emission of nitrogen oxides from passenger cars powered by different types of internal combustion engine with variable displacement.

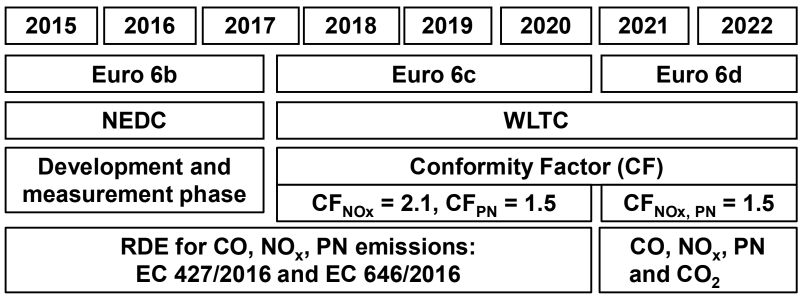

Figure 1. Requirements for type approval tests and realoperating conditions for passenger vehicles in 2015-2022.

2. Real driving emissions tests

According to Commission Regulation (EU) 2016/427 [7] and (EU) 2016/646 [8],the gradual adaptation to the introduced changes is a two-stepprocess. The first step involves the use of research procedures to analyze the results obtained in tests [9, 10]. In the second step, the manufacturers are obliged to carry out tests with specific rules for all road vehicles. Unfortunately, the research carried out by various European institutions [11, 12, 13] shows that the largest emission of nitrogen oxides comes from compression-ignition engines. There are significant differences between NO_x emissions measured in laboratory tests and in real driving conditions for both Gasoline and Diesel engines (figure 2) [14].

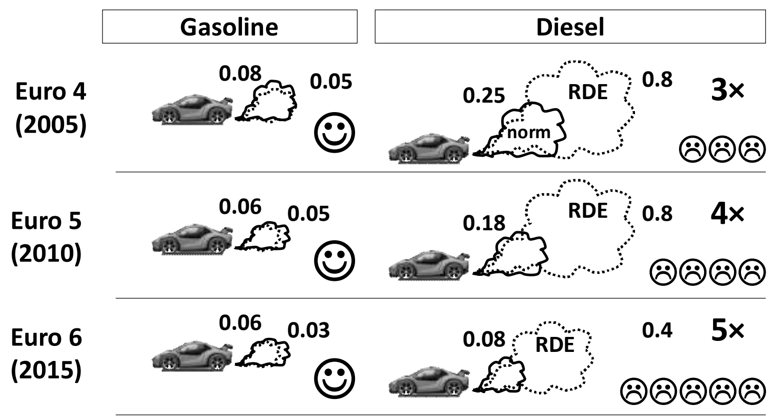

Figure 2. Differences in type approval tests and in road tests for vehicles of different emission categories with spark and compression ignition engines.

The RDE test procedure is specified and standardized also in terms of driving conditions of the tested vehicle. The drive assumes the use of urban, rural and motorway routes in a particular order, without interruption without the need for approval of the body issuing the vehicle type approval. All three test parts identified on the topographic map are strictly defined. Vehicle stops should not be performed without due justification, but only when necessary, such as those caused by traffic regulations. The regulation also specifies the altitude at which the test drive is performed as well as the ambient temperature. Conditions assume that the test is performed at an altitude of over 700 m a.s.l., and less than 1300 m a.s.l. The temperature is determined similarly and the test is performed only at 0 °C to 30 °C, extending this range to–7 °C to 35 °C, if necessary [15].

It is assumed that urban transit is to take place at a speed not exceeding 60 km/h, with an average speed in the range of 15 to 30 km/h. In rural areas the vehicle can reach speeds in the range of 60 km/h and 90 km/h. On the highway the speed limit is above 90 km/h but not exceeding 145 km/h. The only exception is when exceeding the speed limit is justified, provided the difference is no more than 15 km/h and does not last longer than 3% of the whole journey. The speed of 100 km/h should be exceeded for at least 5 minutes of the drive time.

The harmonization and standardization of the results obtained in the research tests and the type approval process is possible by dividing thewhole drive into individual parts by percentage of share. It is recommended that at least 16 km of urban, rural and motorway routes should be travelled in 90 minutes at minimumand 120 minutes at maximum. The total route is 34% urban drive, 33% rural and 33% motorway drive (figure 3).

Include:	Urban	Rural	Motorway*
Speed	0 – 60 km/h	60 – 90 km/h	> 90 km/h
Distance based	~34% (±10%)	~33% (±10%)	~33% (±10%)
Min. distance	16 km	16 km	16 km
Min. distance based	> 29%	–	–

Duration of RDE test: between 90 and 120 minutes; * max 145 km/h

Methods of RDE determining: 1 – All data
2 – EMROAD: MAW – moving average windows; based on CO_2 (JRC, Italy)
Start of next windows – every 1 s, End od windows – after ½ m_{CO2} in WLTC
Road emission – weighted average from urban, rural and motorway
3 – CLEAR: power binning (University of Graz, Austria)
Nine power categories; Road emission – weighted average from power bins

Figure 3. RDE test requirements for passenger cars split into urban, rural and motorway sections.

The test begins even before the vehicle engine starts in order to confirm that the PEMS system is working properly. The test ends when the vehicle is stopped after its route is completed and the engine is turned off.

3. Measurement methodology in real traffic conditions

3.1. Test vehicles

This article includes test results obtained from four passenger vehicles equipped with different drive systems. The main requirement for the selected test vehicles was that they comply with the Euro 6 emission standard. Two passenger cars with a spark ignition engines and two with compression ignition engines were selected for testing. The main difference between the vehicles was the engine displacement between two vehicles with the same type of internal combustion engine.

The following vehicles were selected equipped with engines (the engine characteristics are given in figure 4):

- spark ignition: with a displacement of 1.0 L (A) and 2.0 L (B),

- compression ignition: with a displacement of 1.6 L (C) and 2.0 L (D).

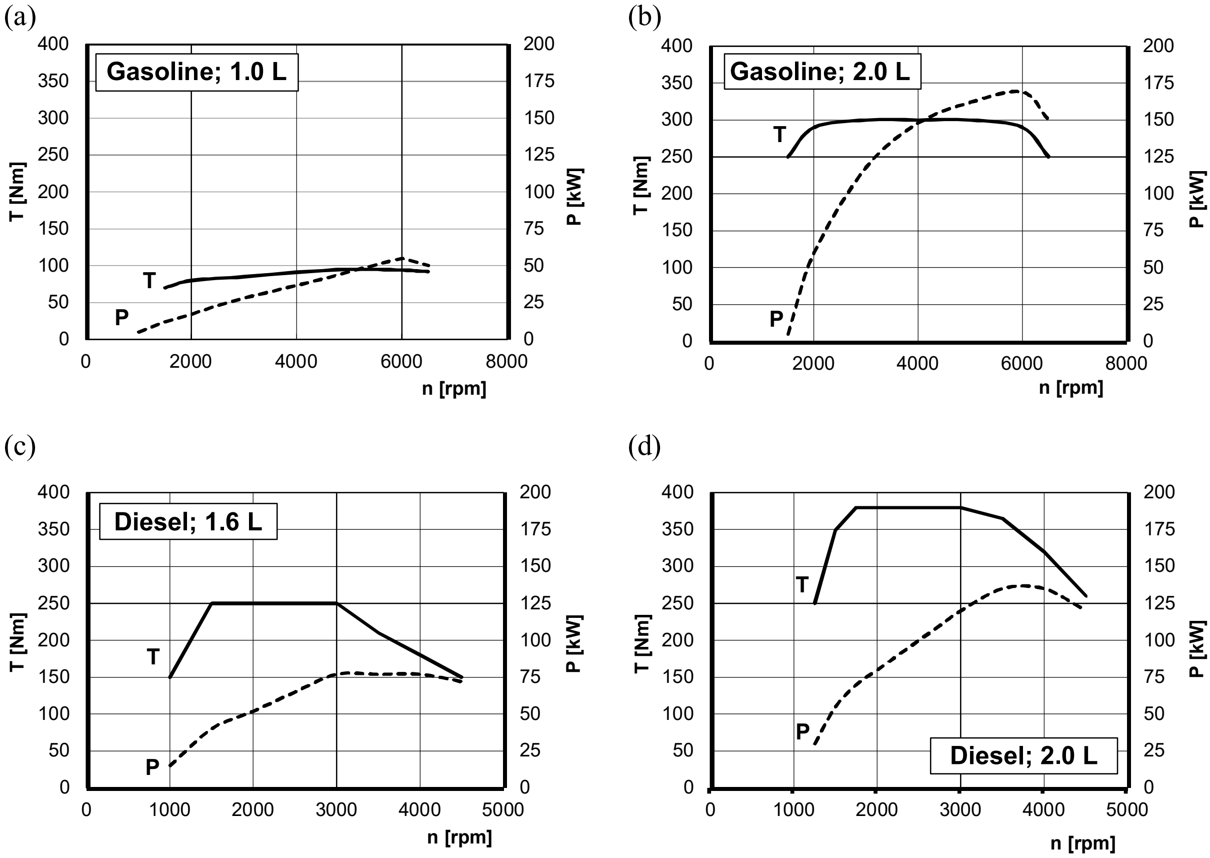

Figure 4. The engine characteristics of the Gasoline (a) and (b) and Diesel (c) and (d) engines used in the tests.

3.2. Measuring equipment

The testing apparatus is presented in figure5. A portable Semtech DS analyser was used for the measurement of exhaust emissions from vehicles. It allowed measurements of CO, CO_2, HC and NO_x. In terms of benchmarking and quality control, zero-span checks were performed before and after each measurement. Linearisations of the equipment were carried out every three months. Post-processing plausibility checks were made on all data, focusing on CO_2, to ensure that the data collected were realistic. The emissions measurement equipment had a maximum mass of 46 kg (Gas PEMS – 25 kg), together with an additional power supply (generator) – 21 kg.

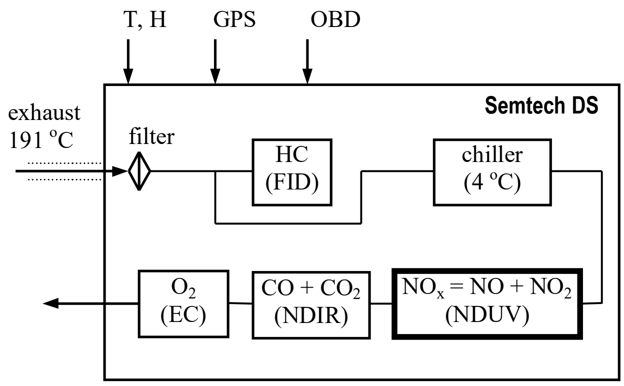

Figure 5. The measuring systems used for testing under real traffic conditions: analyser for measurement of the gaseous emissions – SEMTECH DS.

4. Results and analysis

Measurements of pollutant emissions in real driving conditions were made during urban, rural and highway driving (figure 6). The tests were performed using passenger cars equipped with Gasoline and Diesel engines, meeting Euro 6 emission standards. Despite the differences in engine displacement and their types, the common feature between them was the similar vehicle weight.

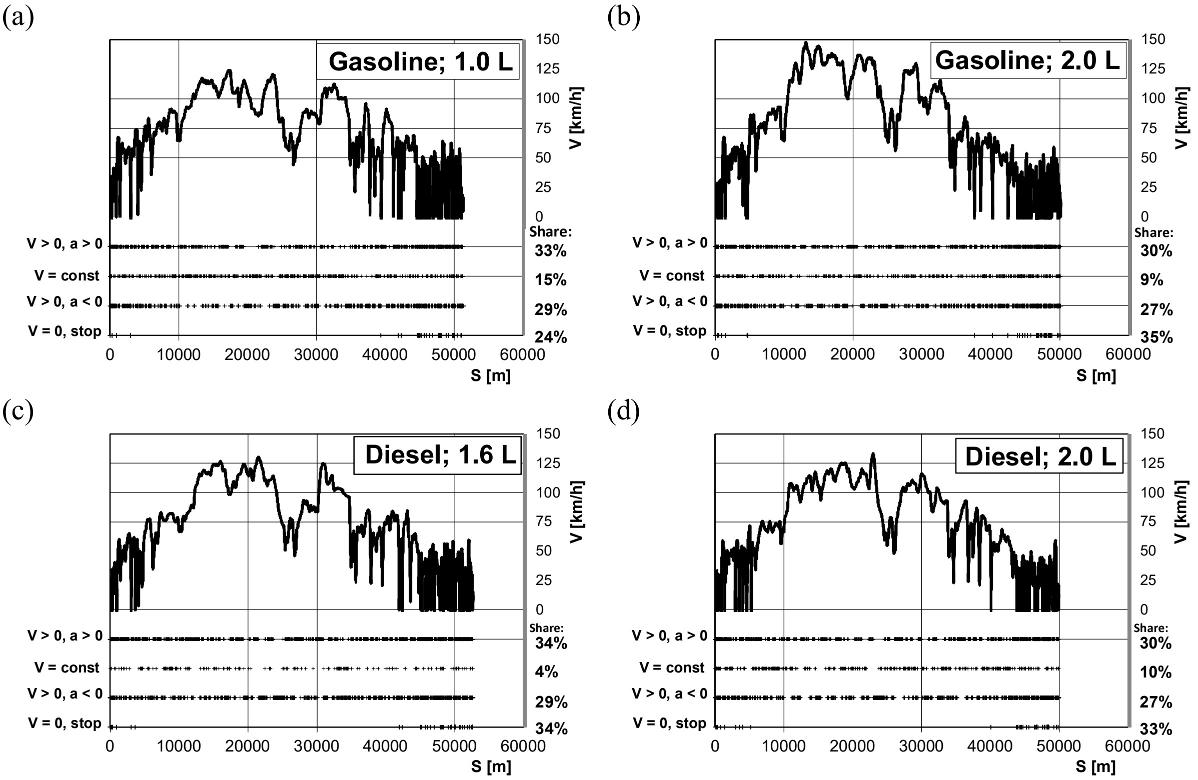

Figure 6. The vehicle speed characteristic in the RDE test together with the selected acceleration, constant speed, braking and stopping time shares for: (a) A – Gasoline engine, 1.0 L, (b) B – Gasoline engine, 2.0 L, (c) C – Diesel engine, 1.6 L, (d) D – Diesel engine, 2.0 L.

The values nitrogen oxides emitted during the study were recorded and averaged. As a result, the mean emission values of nitrogen oxide during each part of the route and for the entire RDE test (figure 7) were compiled.

The nitrogen oxides emission for vehicles with Gasoline engines can be described as follows:

1. For vehicle with engine displacement of 1.0 L:
   - for urban section – 43 mg/km,
   - for rural section – 45 mg/km,
   - for highway section – 94 mg/km,
   - for the entire RDE test – 61 mg/km.
2. For vehicle with engine displacement of 2.0 L:
   - for urban section – 22 mg/km,
   - for rural section – 44 mg/km,
   - for highway section – 72 mg/km,
   - for the entire RDE test – 46 mg/km.

For vehicles equipped with Gasoline engines, the highest emission of nitrogen oxides was recorded in the motorway section of the test route, due to heavy engine loads caused by high vehicle speeds.

In comparison significantly higher nitrogen oxides emission values were obtained for vehicles with Diesel engines. These values were as follows:

1. For vehicle with engine displacement 1.6 L:
   - for urban section – 348 mg/km,
   - for rural section – 359 mg/km,
   - for highway section – 573 mg/km,
   - for the entire RDE test – 426 mg/km.
2. For vehicle with engine displacement 2.0 L:
   - for urban section – 93 mg/km,
   - for rural section – 105 mg/km,
   - for highway section – 351 mg/km,
   - for the entire RDE test – 182 mg/km.

By comparing these values, it can be stated that a vehicle with a smaller displacement Diesel engine was characterized by a significantly higher nitrogen oxides emission in all test conditions compared to a vehicle equipped with a larger displacement Diesel engine:

- for urban section the emission was 275% higher,
- for rural section the emission was 242% higher,
- for highway section the emission was 63% higher,
- for the entire RDE test the emission was 134% higher.

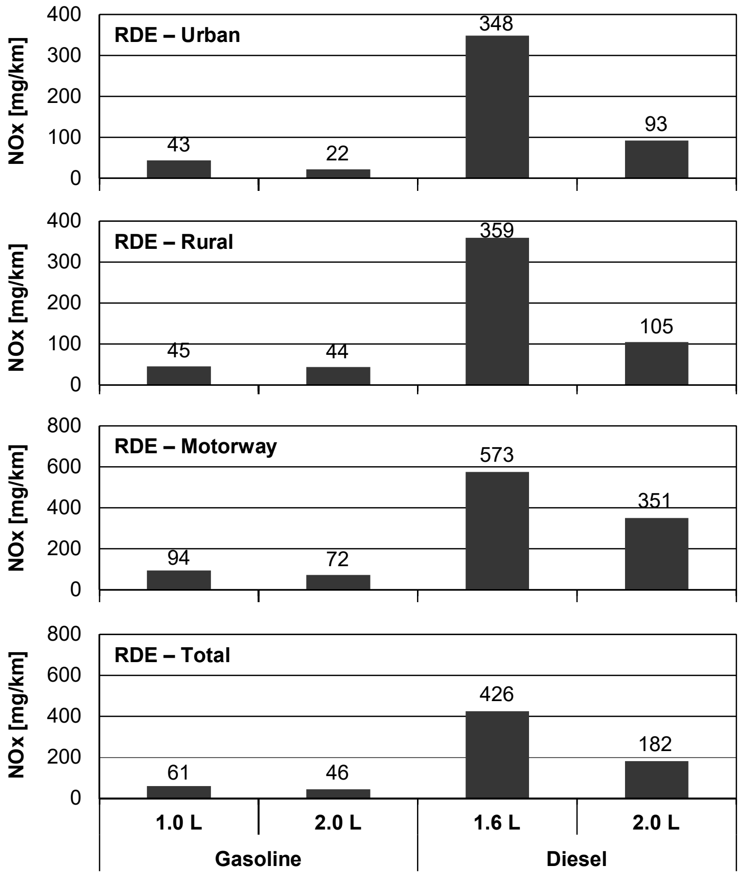

Figure 7. Combined results of the nitrogen oxides emission of the tested vehicles with Gasoline engines (1.0 L, 2.0 L) and with Diesel engines (1.6 L, 2.0 L) in individual sections of the RDE test.

In order to obtain the CF value, which represents the benchmark for the obtained results, the recorded values were divided by the Euro 6 nitrogen oxides emission limit value (Gasoline – 60 mg/km, Diesel – 80 mg/km). For vehicles with Gasoline engines, these emissions were not exceeded in any part of the RDE test (figure 8). For the vehicles equipped with Diesel engines,however, the emission of nitrogen oxides was exceeded:

- For the vehicle with a 1.6 L displacement engine, the emission exceeded the permitted value in each part of the test and throughout the whole RDE test; the recorded emission exceeded the nitrogen oxide emission limit 5×(with a permitted excess of 2.1 times);
- For the vehicle with a 2.0 L displacement engine, the emission limit value was not exceeded for the urban and ruralsections of the test drive, but it was exceeded in the test highway section, which also resulted in the emission limit value for the entire RDE test being exceeded.

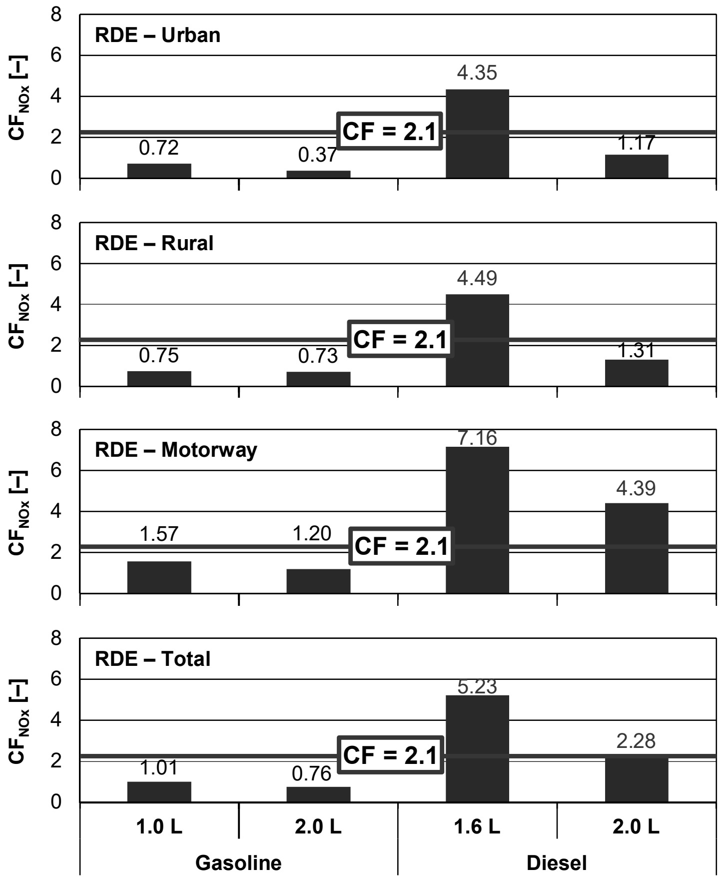

Figure 8. Combined *conformity factor* (CF) results of nitrogen oxides road emissions for the tested vehicles with Gasoline (1.0 L, 2.0 L) and Diesel engines (1.6 L, 2.0 L) in each of the sections in the RDE test.

5. Summary

Nitrogen oxides are some of the most troublesome exhaust substances associated with air pollution. The prolonged lack of control measures for nitrogen oxides emitted from internal combustion engines has led to a severe negative impact on both human health and the natural environment. Strong emphasis on the reduction of NO_x emissions and increased interest in recent years is mostly due to the ability to evaluate these compounds in type approval tests and their direct comparison to the results obtained in real driving conditions. The article evaluates their road emissions from vehicles equipped with Gasoline and Diesel engines for different displacement values (stroke volumes). Due to their different construction and operating principle, the results of the research differed significantly. After analyzing the results it can be concluded that:

- The emission of nitrogen oxides inreal driving conditions is approximately 3 times higher for vehicles equipped with Diesel engines compared to those equipped with Gasoline engines with the same displacement;
- the road emission values of nitrogen oxides are higher for vehicles with similar overall weight but fitted with smaller internal combustion engines (lower engine power and displacement) regardless of whether the considered engines are Gasoline or Diesel type.

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