Air Quality, Atmosphere & Health (2019) 12:251–257
https://doi.org/10.1007/s11869-018-0646-5

# Environmental study focused on the suitability of vehicle certifications using the new European driving cycle (NEDC) with regard to the affair "dieselgate" and the risks of $NO_x$ emissions in urban destinations

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Received: 21 September 2018 / Accepted: 1 November 2018 / Published online: 10 November 2018


## Abstract
At present, the standard Euro is emission standard valid within the framework of the European Union. This emission standard relates to road transport specifically, and the actual issue of the standard is Euro 6, which is established to eliminate most undesirable air pollutants. A total of 10 passenger cars equipped with diesel engines and gasoline engines were tested within the present study, whereby these engines officially fulfilled the emission standards Euro 4 ÷ 6. Considering all data obtained using the PEMS measurement system, the diesel engine emissions are several times higher than the NEDC emissions. However, the real $NO_X$ emissions of the gasoline engines exceed the NEDC emission values only in a reduced form and are well below valid emission standards. Additionally, the results obtained by the NEDC cycle are in contradiction with the findings achieved in the case of two alternative driving cycles, namely, in the case of the Common Artemis Driving Cycles (CADC) and the Worldwide harmonized Light vehicles Test Cycles (WLTC). These results demonstrate the importance of implementing new kinds of driving cycles for performing generally binding motorcar emission tests. In this way, it is also possible to solve emission problems within urban destinations to improve air quality and public health.

**Keywords** Environmental study · Dieselgate · Emissions · Urban destinations

## Introduction

The investigation of the affair "dieselgate", which concerns false manipulation with vehicle $NO_X$ emission data, opened many discussions about the effectiveness of laboratory testing (Błaszczyk et al. 2017; Chríbik et al. 2014; Dons et al. 2018). Taking into consideration the ongoing problems concerning air pollution in many European cities, it is very important to implement new and reliable methodologies or procedures to determine motorcar emissions (Han et al. 2017; Kršák et al. 2016; Puškár and Bigoš 2012). Testing of vehicles in Europe using Portable Emissions Measurement Systems starting in 2007 indicated an unfavourable fact that light diesel engine vehicles, certified according to the standard Euro 4, 5 and 6, produce several times more $NO_X$ emissions than permitted by the corresponding emission limits (Puškár et al. 2012; Puškár and Bigoš 2013). This excess was caused by several failures in the approval procedures, namely, due to low-level values of the vehicle acceleration and the narrow temperature range (from 20 to 30 °C) applied during NEDC certification (Puškár et al. 2013; Puškár et al. 2015). Currently, these problems are solved by means of the Worldwide harmonized Light vehicles Test Procedure (WLTP) and the supplementary test Real-Driving Emissions (RDE). Both procedures will be implemented into practice shortly, but they are not oriented towards a better understanding of the real reason for increased diesel engine $NO_X$ emissions under road traffic conditions. It is possible to say that insufficient driving dynamics as well as the narrow range of temperatures during NEDC testing are not the main causes of $NO_X$ problems in the case of diesel engines. A relevant amount of increased $NO_X$ emissions may be caused due to application of defeat strategies utilising defeat devices. A defeat device is any motor vehicle hardware, software or design that interferes with or disables emission controls under real-world driving conditions, even if the vehicle passes formal emissions testing (Puškár et al. 2017).

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The analysis presented in this article includes 10 passenger motorcars tested by means of the NEDC under laboratory conditions and on various routes in real transport. This research offers an alternative solution to verify vehicles and enables the identification of such vehicles that require a deeper evaluation of their capability.

## Methodology and conditions

A total of 10 passengers cars were used in the experimental models, whereby three cars were equipped with gasoline engines conforming to the Euro 5 emission standard, and another seven cars were diesel engine vehicles conforming to the Euro 4 ÷ 6 standards (Figs. 2, 3, 4 and 5). The laboratory tests and road traffic tests were performed using customary fuels that are in accordance with the European Direction 2009/30/EU as well as the specifications defined by the automobile manufacturer. The laboratory emission tests were conducted on a testing stand, and the $NO_X$ and $CO_2$ emissions were determined with an analyser (Puškár and Kopas 2018; Puškár et al. 2018). Measuring of the $NO_X$ and $CO_2$ emissions in the case of real road traffic was performed by means of the Portable Emissions Measurement System (Rybár and Beer 2015; Rybár et al. 2016). The ambient temperature was measured at 1 Hz, and the atmospheric probe was an integrated part of the measuring equipment. The momentary values of the $NO_X$ and $CO_2$ emissions in terms of the real traffic were calculated according to the Direction 2016/427 with a frequency of 1 Hz, using multiplication of the polluting substance concentrations by the mass flow of exhaust gases. The emissions relating to a distance [mg/km] were calculated as the sum of the momentary emissions (generated during the measured time interval), which were divided by a passed distance corresponding to the given time interval. The whole procedure of the applied methodology is graphically illustrated in Fig. 1. The data analysis consists of two parts. The first part serves for investigation purposes (Fig. 1, the column graphs situated in the bottom left). From this reason, a column graph was created for the momentary $NO_X$ emissions [mg/s] for each vehicle during the NEDC laboratory testing, namely, the left column with the cross section lining. The middle column with the inclined section lining was created in the same way and refers to the momentary $NO_X$ emissions in the case of selected measurements performed on the road under conditions similar to NEDC. Measurements fulfilled within real road traffic on various routes and using PEMS represent the right column with the vertical section lining, whereby there were chosen conditions similar to NEDC, i.e. the combination of the vehicle speed and acceleration was determined according to NEDC, the ambient temperature was kept in the homologation range from 20 to 30 °C, and the incline of terrain was less than 0.1%. Thus, the results obtained from the performed analysis are presented in the form of column graphs. Differences among the laboratory $NO_X$ emission values and the values obtained from the real road traffic are probably caused by various driving dynamics (Sinay et al. 2018; Toman et al. 2017).

The measuring methodology, which is illustrated in Fig. 1, offers complete data from the road tests obtained by means of the system PEMS (PEMS on the road) as well as other information. The left side of Fig. 1 shows the median and the $NO_X$ emission interval corresponding to the test NEDC, as well as to the drives on the road in the NEDC regime (NEDC such as on the road) and to all the drives on roads. The column graph on the top right side in Fig. 1 describes the $NO_X$ emissions relating to the passed distance [g/km] for NEDC based on the results obtained from the testing stand (the left column), as well as from the measurement NEDC similar to on the road (the middle column) and from all other road drives (the right column).

The second part of the analysis contains a comparison of the $NO_X$ emissions, recorded by means of NEDC, with the values obtained on the roads using the similar operational conditions. This comparison requires control of the ambient temperature, together with control of the engine operation points. The temperature regulation is direct and is reached by elimination of all emission data measured on the roads in the case that the defined temperature range (i.e. from 20 to 30 °C) was exceeded. Management of the engine operation points is a more demanding task because it requires knowing the corresponding values of the following engine parameters: engine speed, angular acceleration of engine, engine torque, temperature of the engine oil and temperature of the cooling liquid. Control of these parameters is a common practice during the engine tests performed on the testing stand, but it is a less standard procedure in the case of the passenger vehicle testing on the road with regard to the fact that the required engine data are not typically known. For this reason, the engine speed is associated with vehicle speed in the case that the gear ratio and vehicle speed are the same during testing on the road and in the laboratory. At the same time, the vehicle acceleration is given by the engine angular acceleration. Finally, the engine torque is defined according to the engine $CO_2$ emissions. Namely, the engine torque is proportional to the momentary fuel consumption [g/s] and is also proportional to the $CO_2$ emissions [g/s] at the given engine speed level. The chosen approximations allow the presented method to be applied without obtaining engine data by means of interconnection with the engine control unit. Therefore, it is possible to characterise the operational testing points using vehicle speed, vehicle acceleration and momentary $CO_2$ emissions. These three parameters are easily available during testing with PEMS.

Laboratory NEDC testing requires recording of the vehicle speed and vehicle acceleration as well as the $CO_2$ and $NO_X$ emissions for each of the tested vehicles (Fig. 1), which are

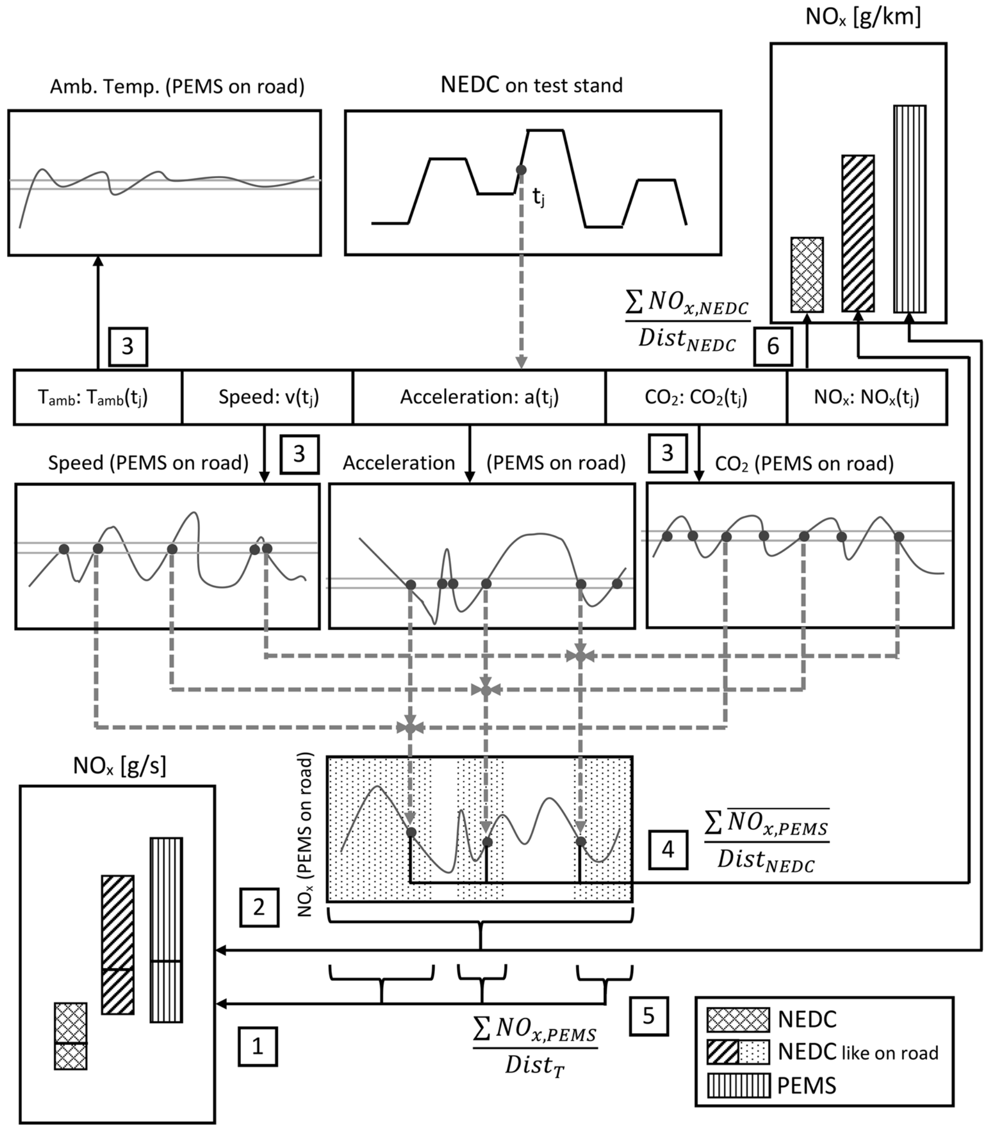


**Fig. 1** Graphical illustration of the applied measuring methodology

useful data for the PEMS analysis of the $NO_X$ emissions (Fig. 1, arrow No. 3). The average $NO_X$ emission values are calculated after harmonisation of all operational points (Fig. 1, arrow No. 4). This result is compared with the unfiltered data obtained from PEMS (Fig. 1, arrow No. 5) and the basic data (Fig. 1, arrow No. 6). Considering the accessible data collected during vehicle drives on the road within the time interval of 23 ± 16 h for each vehicle (including various roads and routes), many contact points of the vehicle speed, acceleration and $CO_2$ emissions will be found, which correspond to the points obtained during the NEDC laboratory testing. Loading of the vehicle during the NEDC laboratory test is less than loading during actual road drives. However, the cycles of the prescribed driving regimes are considerably far from the reality. For example, the time, which is determined for acceleration from 0 to 50 km/h, is a large-minded value, namely it is 26 s and the maximal testing speed is 120 km/h, but only during a few seconds. So, such dynamic of the test is evidently suggested for the vehicles that were built several decades ago and not for the present motor cars, especially for the modern powerful vehicles, which are able to complete the whole test at a minimal loading level. Additionally, such mode of driving is already never used. Another sources of deviations are the switched-out appliances, for example the air-condition system. Furthermore, the producer has a possibility to optimise moderately the vehicle before the test in order to reduce the driving resistances, for example to set-up other geometry of the wheels, to use other tyres or to use the original tyres with a higher charging pressure as well as the own mass of the car does not need to be kept according to the actual motor-car equipment. Moreover, there is also a possibility to increase the ambient temperature up to 30 °C. This fact explains some of the differences concerning values of the fuel consumption and the $CO_2$ emissions determined during the certification process.

## Results

Vehicles equipped with diesel engines and gasoline engines have a tendency to fulfil the requirements of the corresponding emission standards during NEDC testing. $NO_X$ emission values (mg/s) of diesel vehicles are presented in Fig. 2 using the column graphs, and $NO_X$ emission values (mg/s) of gasoline vehicles are given in Fig. 3. It is evident from the column graphs presented in Fig. 2 that most of the momentary $NO_X$ emission values of all vehicles are situated below the emission limit during NEDC testing (Fig. 2, the left columns in graphs). This fact corresponds to the abovementioned statement. However, there are recorded significant differences in the case of data obtained on the road because, in this situation, most of the momentary diesel engine emission values greatly exceed the emission limits (Fig. 2, the right columns in graphs). The on-road $NO_X$ emission values of gasoline engines are also higher than the NEDC emissions, but they are always below the emission limit. If driving conditions are selected similar to NEDC, the graphs (median values) mostly overlap the NEDC fields (Fig. 3, the middle columns in graphs). This part of the analysis indicates significantly different behaviours of the diesel vehicles during NEDC testing in comparison with the on-road drives using conditions similar to the certification procedure.

The second part of the performed analysis focuses on emission production in relation to a distance passed by a vehicle. The column graphs of the $NO_X$ emissions relating to the passed distance (g/km) for the diesel and gasoline vehicles are presented in Fig. 4. In the case that there are $NO_X$ emissions analysed by means of NEDC using the testing stand on various driving conditions, the significant differences between diesel and gasoline vehicles are also recorded. The real $NO_X$ emissions of diesel vehicles are markedly higher than the emission values measured by NEDC. Considering all the data obtained by means of PEMS, the diesel vehicles exceed the NEDC emissions markedly. However, the real $NO_X$ emissions of the gasoline engine vehicles exceed the values measured by NEDC only in a reduced form, and they are well below the valid emission standard level.

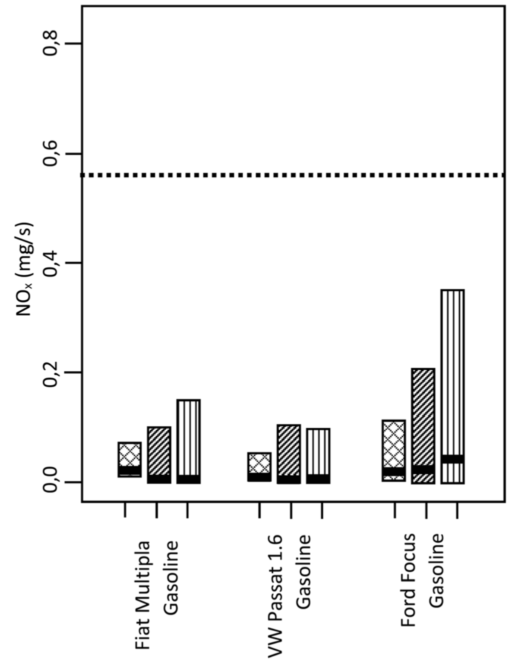


**Fig. 3** The column graphs of the $NO_X$ emissions (mg/s) for gasoline vehicles

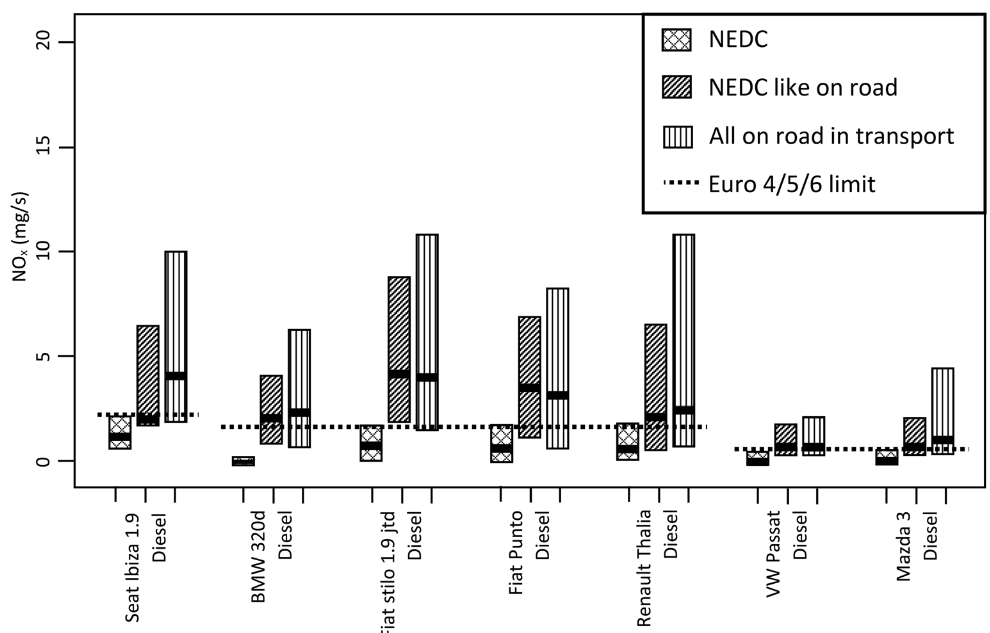


**Fig. 2** The column graphs of the $NO_X$ emissions (mg/s) for diesel vehicles

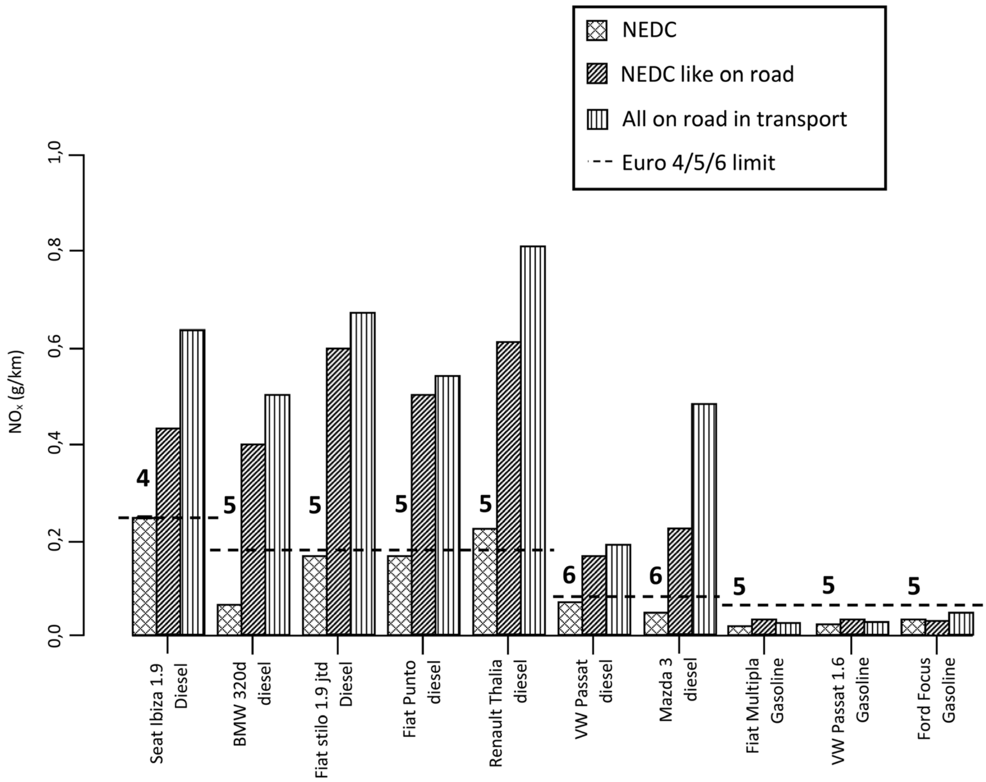


**Fig. 4** Column graphs of the $NO_X$ emissions relating to passed distance (g/km) for diesel and gasoline vehicles

The results obtained using the NEDC cycle also contradict the results measured from two alternative driving cycles, i.e. CADC and WLTC, as illustrated in Fig. 5. The average $NO_X$ emission values of diesel vehicles in real road traffic conditions exceed the average values measured in the laboratory by approximately 5%. These results confirm a necessity to introduce a new driving cycle for generally obligatory vehicle testing.

## Discussion

It is possible to confirm that the $NO_X$ emissions of diesel vehicles measured on roads using conditions similar to NEDC are higher than those using laboratory NEDC testing. The performed analysis calls in question a generally accepted opinion that the non-realistic driving dynamics and the narrow temperature interval of the NEDC tests are the main factors causing the "diesel-$NO_X$" problem in Europe. It seems that the $NO_X$ regulation is systematically decreasing during on-road drives and when diesel engine vehicle drives are performed in conditions similar to NEDC. However, this research did not analyse parameters that are relevant for regulation of the $NO_X$ emissions. There are two possibilities on principle how to reduce the $NO_X$ emissions. The first possibility is application of the so-called traping catalyser, i.e. the Lean-$NO_X$-Trap (LNT), and the second possibility is reduction of the gas amount by means of the Selective Catalytic Reduction (SCR) using the reductive reagent AdBlue. The producers aimed to reduce the $NO_X$ production already before implementation of Euro 6, namely by lowering of the compression ratio, by improvement of the injection system (higher pressures mean better atomization and better burning of the fuel) or by a more efficient recirculation of the exhaust gases back into the engine pistons. Better regeneration means primarily an application of the low-pressure Exhaust Gas Recirculation (EGR), which is equipped with the exhaust gas cooler in order to reduce temperature of the fuel mixture burning and in this way to reduce the $NO_X$ production. Emission reduction has to be considered in a wider context concerning air quality and public health; the European Union engaged to improve air quality. Therefore, the first limit of $NO_X$ emissions was defined in 1992 for the light utility vehicles, with all the following stricter limits; however, $NO_X$ emissions were not reduced in practice, and the air quality was not improved in most European cities. Reduction of $NO_X$ emissions can potentially improve urban air quality, but it is also necessary to eliminate other associated problems, including, for example, inadequate reaction of ammonia in catalysers. For this reason, new solutions are applied in cities that are most often restrictions concerning the entrance of diesel engine vehicles into city centres or the promotion of public and active kinds of transport.

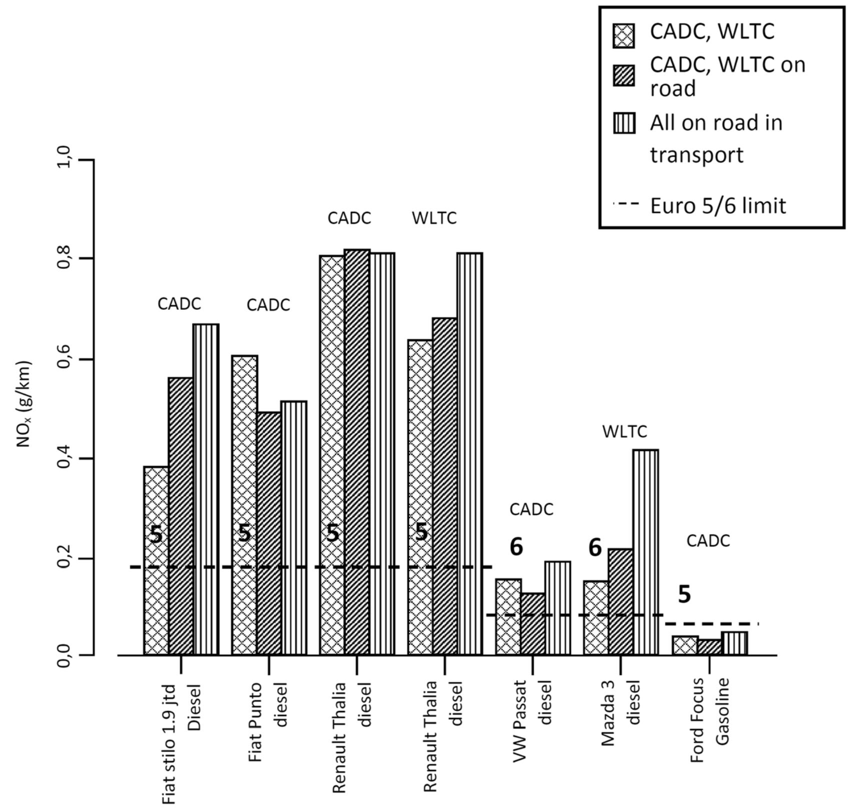


**Fig. 5** Column graphs of the $NO_X$ emissions relating to the passed distance (g/km) for diesel and gasoline vehicles in the case of the CADC and WLTC cycles

## Possibilities to solve emission problems within urban destinations

Today, $NO_X$ emissions represent a serious problem concerning human health and global air quality in urban areas. Increased traffic density is a typical problem occurring in these areas, and it is additionally more complicated due to the implementation of so-called low-emission zones (LEZ). Such zones are problematic above all for city visitors, and complications for transfer of people within intra-city destinations have become challenging.

The low-emission zones are city localities with restricted vehicular access due to high levels of air pollution. Restriction is valid for such vehicles, which exceed the defined emission limits or entry to this zone is paid. At present, there are more than 270 low-emission zones established within Europe, mainly in Germany and Italy. Other designations of the LEZ include the following: Umweltzonen, Milieuzones, Lavutslippssone, Miljozone and Miljözon. The main task of an LEZ is elimination of vehicles that are not able to fulfil emission standards according to vehicle classification or cash access to the zone. Collecting of duties is typical for Scandinavian countries, for example, in Sweden. Requirements concerning LEZs were changed in January 2012, and LEZ vehicle access was restricted and penalised very strictly.

To avoid such an unfavourable situation, an application suitable for cell phones was implemented, which can determine optimal routes while taking into consideration the arrangement of LEZs in the given city as well as vehicle type, emission standards and actual traffic situations.

## Conclusions

Considering the abovementioned facts and the results obtained from this research, the following conclusions are presented:

- Tested vehicles equipped with diesel engines officially meet emission Euro 4 ÷ 6 standards; however, they markedly exceed $NO_X$ emission limits during real traffic drives (i.e. the so-called on-road $NO_X$ emissions). A different situation is monitored in the case of gasoline vehicles because their on-road $NO_X$ emissions remain under the valid limit.
- A large portion of the increased amount of on-road $NO_X$ emissions occurring in the case of diesel engines cannot be explained by the insufficient dynamics of NEDC or the narrow temperature interval during the testing process. The presented results call into question an official opinion that insufficient NEDC testing is the main reason for the diesel-$NO_X$ problem.

- The official authorities responsible for performing the standardised approval processes recently tested on-road $NO_X$ emissions using NEDC, and the final result of the entire testing process is that the average exceeding level of the $NO_X$ emission standards reached 4.5-multiply of the limit values under the normal European temperature conditions.
- The results received from the present research offer an alternative solution to verify vehicles as well as identify such vehicles that require a deeper capability evaluation.
- The results show that NEDC certification could be accepted based on the assumption that the defined appointments will be fulfilled exactly, taking into consideration the measuring process itself and the elimination of possible false tendencies focused on reduction of the measured values, for example, to avoid application of special tires with lowered rolling resistance and disallowing the use of specific software.

**Acknowledgements** This article was written in the framework of Grant Projects: APVV-16-0259 "Research and development of combustion technology based on controlled homogenous charge compression ignition in order to reduce nitrogen oxide emissions of motor vehicles", VEGA 1/0473/17 and KEGA 041TUKE-4/2017.

**Funding information** This work was supported by the Slovak Research and Development Agency under contract no. APVV-16-0259.

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