Assessing Real-World Emission Factors of Modern Light Duty Vehicles

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Abstract

Light Duty vehicles (LDV) represent a widely used means of transportation of goods and utilities for different applications and its respective emission factors are thus relevant for emission inventory purposes. Therefore, roller test bench measurements have been carried out with 6 in-use diesel LDV of the present certification category Euro-4. Both gaseous pollutant and particle emissions have been detected in the statutory test cycle NEDC and the real-world ARTEMIS cycles CADC and IUFC15. There, a payload of 30% of the total vehicle payload has been considered to reflect more realistic vehicle usage conditions.

The measured LDV sample generally shows an acceptable pollutant emission performance but with increasing emission limit utilization, especially for NO_x emissions. Their real-world emissions are also considerably more pronounced with ratios of NO_2 of around 35% to 60%. Only vehicles equipped with original equipment manufacturer (OEM) diesel particle filters (DPF) feature clearly reduced particle mass and number emissions.

Keys-words: *Light duty vehicle, exhaust, pollutant, emission factor, real-world.*

Introduction

Light Duty vehicles (LDV) represent a common and widely used means of transportation of goods and utilities for personal and commercial applications. These vehicles typically account for a considerable mileage of the total traffic in the different road types, especially in and around city areas. Determining its respective emission factors is thus of great interest for emission inventory purposes.

Therefore, an experimental investigation on a roller test bench has been executed with 6 in-use diesel LDV of the present certification category Euro-4. The vehicles have been selected in order to represent the Swiss vehicle distribution according to sales and registration statistics. Both relevant gaseous pollutant and particle emissions have been detected in the statutory test cycle NEDC and different real-world cycles such as the ARTEMIS cycles CADC and IUFC15. There, a payload of 30% of the total vehicle payload has been considered to reflect more realistic vehicle usage conditions.

The results obtained from the present study indicate considerable improvements in pollutant emissions of LDVs with regard to sample emissions of former vehicle certification categories. But emissions of nitrogen oxides are still pronounced, especially in real-world driving conditions. Also only vehicles equipped with an original equipment manufacturer (OEM) diesel particle filter (DPF) show considerably low particle mass and number emissions.

1 - Methodology

Vehicle Sample

The main characteristics of the LDV sample employed in the test series are summarized in Table 1. The in-use vehicles have been selected from private customers in order to match the Swiss fleet distribution regarding mass, displacement and power at the time of the investigation. Both the rated power of the single vehicles and their mileage is fairly low. Three cars of the sample are equipped with an OEM DPF. Note that all the vehicles have been measured without previous maintenance.

Experimental Program

Several driving cycles were employed in the test series in order to determine the emission behavior of the individual LDVs. The statutory cold start driving cycle for Europe NEDC (Council Directive 70/220/EEC) was included as well as two real-world driving cycles: the Common Artemis Driving Cycle (CADC) and the cycle Inrets Urban Fluid Court 15 (IUFC15), both derived from car driving behavior studies within the ARTEMIS research program. The warm start cycle CADC represents European real-world driving behavior for cars in urban, rural and motorway driving (André, 2004). In order to investigate the cold start effect on pollutant emissions separately, the repetitive cold start cycle IUFC15 was executed (André et al., 1999).

Experimental Setup

The roller test bench and its settings were applied according to the provisions of Council Directive 70/220/EEC. The inertia settings were chosen according to the given flywheel class. A vehicle payload of 30% of the total vehicle payload has been considered assuming that these vehicles are almost always operated with a considerable payload. The ambient conditions of the test cell were set to 23℃ air temperature and 50% relative air humidity. The same standard fuel with low sulfur content (<10 ppm) has been employed for all vehicles to ensure real-world operating conditions.

Sampling, Analyzing and Data Processing

The exhaust was sampled with a Constant Volume Sampling (CVS) system, see Figure 1. Closed dilution of the exhaust with adequate particle filtering of the dilution air was applied. The exhaust was measured according to the statutory procedure of storing a sample of diluted exhaust in a tedlar bag and analyzing its content offline after completion of the test run. In parallel, online measuring of the raw exhaust was performed at tailpipe. All raw gas sample lines were appropriately heated to prevent water condensation.

Regulated pollutants were detected using standard vehicle exhaust analyzers as specified by Council Directive 70/220/EEC. A so-called Condensation Particle Counter (CPC) was also employed to gain more information on particle emission by its single counting. The configuration of this measuring device included an evaporation tube (ET) that heats the gas sample up to 400℃ to exclude the possible detection of volatile compounds.

The signal traces were corrected with respect to time and mixing delay due to the length of the sample lines and the measuring delay time of the analyzers by applying a specifically developed methodology (Ajtay and Weilenmann, 2004).

2 - Results

Statutory Emission Performance

The results obtained for single pollutant and CO_2 emissions of the diesel LDVs of certification category Euro-4 in the statutory cycle NEDC are given in Figure 2. There, the respective pollutant emission limits that depend on the empty mass of the single vehicles are also depicted in framed columns. However, note that the test results cannot be compared directly to them, as the chosen inertia mass settings for the test runs included a considerable vehicle payload that is usually not applied in the statutory test runs.

In spite of that, a rather good performance can be stated for carbon monoxide (CO) emissions: only one vehicle features a CO discharge that is considerably higher than its emission limit value. HC emission of the investigated vehicles are to be judged very low, as almost no impact on combined hydrocarbon (HC) and nitrogen oxides (NO_x) emissions is visible compared to NO_x emissions. This behavior can be explained in both cases by the higher chosen inertia weight that demands higher engine loads and thus leads to a shorter light-off time of the oxidation catalyst employed. This circumstance, however, also causes a pronounced discharge of NO_x that surpasses the respective limit value for some vehicles. Regarding particulate emissions, the effect of the use of particle filters is evident: the vehicles equipped with the latter show negligible particle mass (PM_m) and particle number (PM_N) emissions of at least two orders of magnitude below the usual values of vehicles without particle filter. Note here that the obtained particle number emissions for vehicle LD4-06 may be somehow distorted, as an unusually high dilution of the probe sample had to be chosen in order to get a signal within the detection range of the measuring device employed.

Real-World Emission Performance

Figure 3 resumes the diesel Euro-4 LDV sample emissions of single pollutants and CO_2 resulting from test runs with the real-world driving cycles CADC and IUFC15. The hot real-world emissions of CO and HC gained in the CADC are less pronounced than in the cold started statutory cycle NEDC. They even further decrease for cycle sections with more demanding speed courses because of higher engine-out exhaust and catalyst temperature. In contrast, hot emissions of NO_x, CO_2, PM_m and PM_N feature more pronounced emission levels in these cycle sections than in the statutory cycle. There, a decrease in emissions from urban to rural driving can be stated, possibly because of reduced driving dynamics. But they rise again with increasing engine load from rural to motorway driving.

With regard to real-world cold start emissions, the CO_2 discharge of the diesel Euro-4 LDV sample in the cycle IUFC15 reveals that a fully warmed-up drivetrain and exhaust after-treatment operation is only reached in the third section of the cycle. Emissions of HC and PM_N confirm this finding, whereas excess emissions of CO due to cold start only occur in the first cycle section. As expected, NO_x emissions in hot operation mode are as pronounced as in the warming-up phase.

NO/NO_2 Emission Performance

Emissions of nitrogen oxide (NO) and nitrogen dioxide (NO_2) of diesel powered vehicles are relevant, as the latter supports the decomposition of trapped particles in the DPF (Kandylas et al., 2002). Therefore, its appearance before a DPF may be useful, but tailpipe emissions are to be avoided as NO_2 is toxic and contributes to local ozone formation (Zielinska, 2005). Figure 4 shows both mean emissions of NO and NO_2 obtained in the statutory cycle NEDC, the warm start real-world cycle CADC and the cold start real-world cycle IUFC15 for the LDV subgroups with (LD4 PF) and without DPF (LD4). Shares of NO_2 to true NO_x emissions - i.e. the sum of NO and NO_2 - of 35% to 60% are detected. For vehicles with DPF it can be seen that their true NO_x emissions are slightly reduced in the statutory cycle in contrast to the real-world cycles. But interestingly, the ratio of NO_2 to NO_x is reduced for vehicles with DPF in every cycle section, reaching values of around 40%. The latter observation disagrees with the findings derived from a measurement campaign with diesel Euro 4 passenger cars (Alvarez et al., 2008a).

3 - Discussion

Given the test result data, the evolution of diesel LDV emissions can be assessed with regard to the former certification categories. Figure 5 shows the mean pollutant and CO_2 emissions in the cycles NEDC and CADC of the present diesel LDV sample and a sample of diesel Euro-2 LDVs tested in another measurement campaign (Vasic et al., 2005). There, the same approach for the vehicle payload of adding 30% of the total vehicle payload has also been applied.

Generally it can be seen that broad improvements in vehicle pollutant emissions have been achieved from one certification category to the other in the respective driving cycles, especially for CO. But the relative improvements in the cycle NEDC regarding NO_x are not confirmed in the cycle CADC indicating once more the disagreement between statutory and real-world emission performance. However, some of the respective sample characteristics like empty mass, power and mileage differ substantially from each other and thus may distort the picture.

Conclusion

The present experimental investigation offers varied insight into the environmental impact of modern light duty diesel vehicles of certification category Euro-4. In general, it can be stated that the vehicles tested show an acceptable emission performance. But the results in the statutory test indicate increasing emission limit utilization, especially for NO_x. Only vehicles equipped with OEM DPF feature clearly reduced particle emissions demonstrating that DPFs are indispensable components of diesel after-treatment. However, their emission behavior during regeneration mode could not be examined within this study although assumed to be relevant according to respective investigations with passenger cars (Alvarez, 2008b). Real-world NO_x emissions of LDVs are considerably more pronounced than in the statutory cycle, especially for vehicles with DPF. There, ratios of NO_2 to NO_x of around 40% were detected, whereas LDVs without DPF featured ratios of NO_2 to NO_x up to 60%.

In parallel to diesel passenger cars, it can be concluded that a further reduction of the emissions of nitrogen oxides represents one of the main challenges for future diesel LDV developments. It seems that adequate after treatment systems are to be the most feasible solution. In fact, NO_x emissions could also be lowered by consequently designing the combustion process, but this may reduce the efficiency of the engine and thus sweep off the benefits in CO_2 emissions compared to comparable gasoline powered vehicles.

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Table 1: Main vehicle data of the diesel Euro-4 LDV sample employed in the experimental campaign.

	make	model	mass [kg]	displ. [cm^3]	power [kW]	gearbox [-]	DPF [-]	mileage [km]	class [-]
LD4-01	Fiat	Ducato	2000	2287	88	m5	no	24867	Euro-4
LD4-02	Mercedes-Benz	Vito	1960	2148	80	m6	yes	35563	Euro-4
LD4-03	Renault	Trafic T29	1930	2464	107	m6	yes	38158	Euro-4
LD4-04	Citroen	Jumper	2650	2198	88	m6	No	13482	Euro-4
LD4-05	VW	T5	2089	2461	96	m6	yes	32203	Euro-4
LD4-06	Ford	Transit	1735	2198	63	m5	No	23485	Euro-4

Figure 1: Schematic diagram of the test setup.

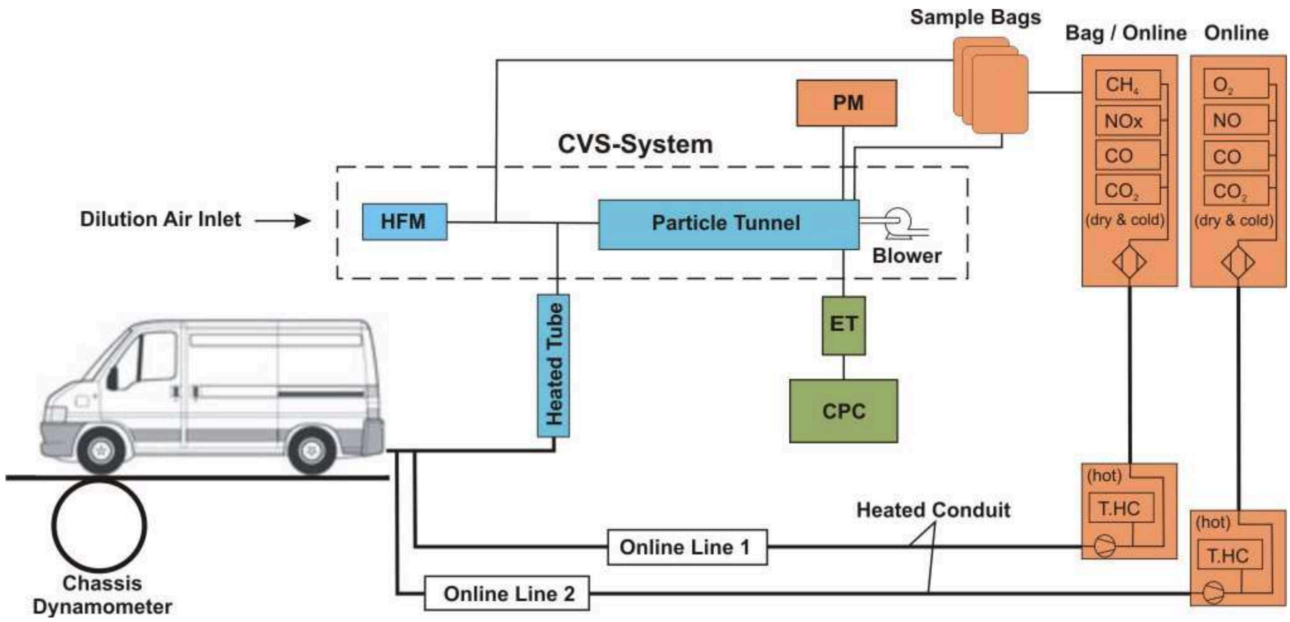

Figure 2: Pollutant and CO_2 emissions of the diesel Euro-4 LDV sample in the statutory cycle NEDC. The framed bars represent the respective emission limit values; note that a direct comparison is not possible as the chosen inertia weight is not consistent with the certification prescriptions.

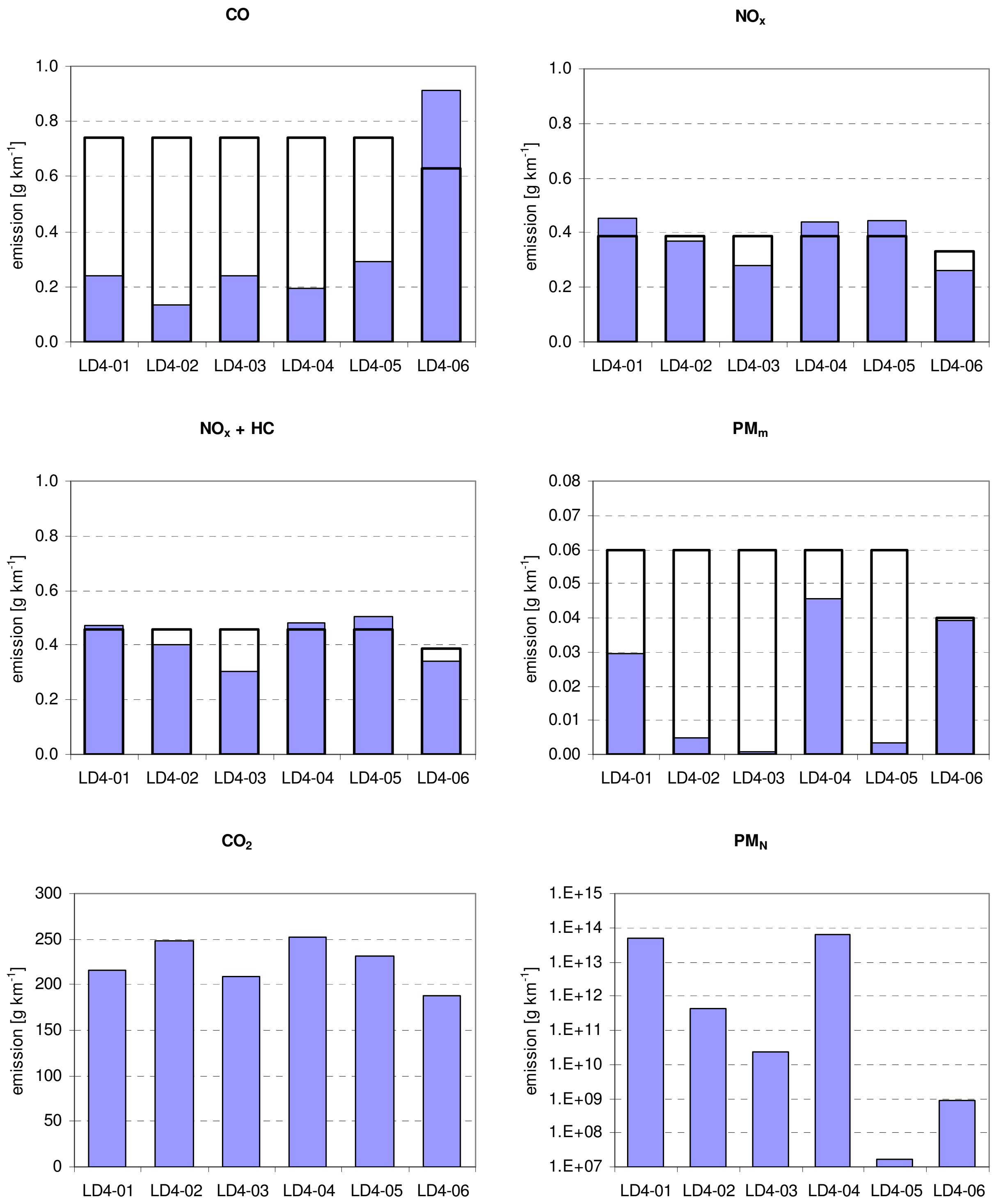

Figure 3: Pollutant and CO_2 emissions of the diesel Euro-4 LDV sample in the real-world cycles CADC and IUFC15.

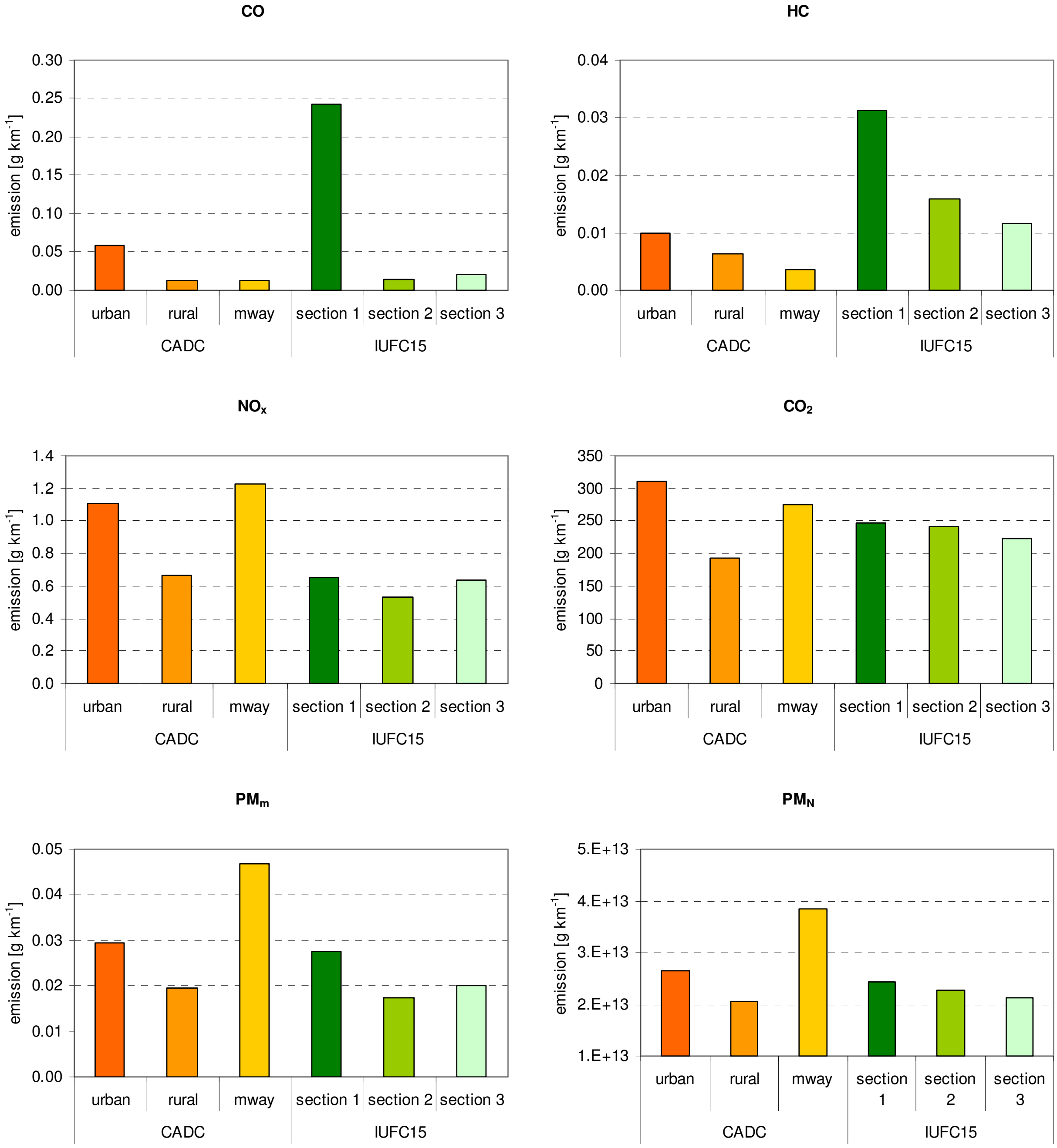

Figure 4: Emissions of NO and NO_2 of the diesel Euro-4 LDV subgroups with (LD4 PF) and without DPF (LD4) obtained in the statutory cycle NEDC and the real-world cycles CADC and IUFC15.

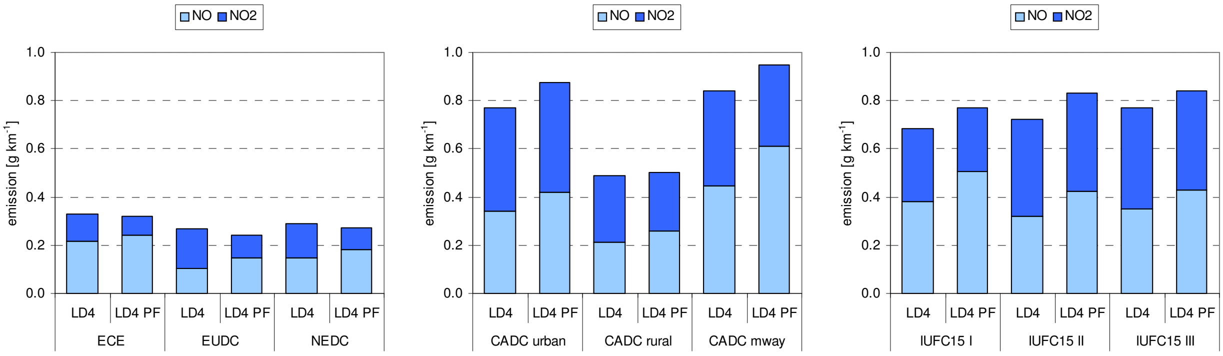

Figure 5: Pollutant and CO_2 emissions of the diesel LDV samples Euro-2 (LD2) and Euro-4 (LD4) in the statutory cycle NEDC and the real-world cycle CADC.