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Emissions from Non-Driving Situations

Commissioned by the Federal Office for the Environment (FOEN)

Project: Research on PEMS Testing Methodology and on Real Driving Emissions (ResRDE2) *)

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*) Abbreviations see at the end of report

CONTENT

1. SUMMARY

The control of real driving emissions (RDE) by means of portable emission measuring systems (PEMS) is generally an accepted way to reduce further the air pollution of traffic.
In several research activities with different PEMS open questions resulted concerning the methodology of testing and of evaluation.
Additionally, there are questions about RDE from different types of vehicles, or on different routes with varying operating conditions, with different testing apparatus and with the use of recent evaluation method.

The project ResRDE(2) considers these objectives in 5 working packages (WP).

This 1st report presents the results of the WP1 – emissions from non-driving situations of several vehicles. These non-driving situations are: idling cold/warm, warm-up phase, stop&go operation with different portions of idling. This WP consists of: analysis of present data (part 1) and reproduction of different conditions for cold-start/warm-up and for stop&go (part 2).

The most important results are:

From part 1

- the emissions of CO, NO_x and PN are in the cold start and in the first part of the warm-up phase (c.a. 25s) considerably higher, than in the rest of the investigated urban phase, (HC-data were not available),
- the special emitting situations: “stop&go” and idling are frequently given during the warm-up phase, i.e. with engine and exhaust treatment system not warm enough,
- vehicles with smaller engine displacement have lower cumulated CO_2-emissions (lower fuel consumption), they are tendentially quicker to be warmed-up,
- in both vehicles’ groups: “gasoline” and “Diesel” there are quite considerable emissions differences between the vehicles, resulting mostly from different efficiencies of the exhaust aftertreatment systems.

From part 2

During the cold start and warm-up in the first 4 km, the emissions of older type vehicles are generally higher than for the newer technology. The majority of emissions are accumulated in the first 0.5 km of the distance driven.
The PN-level of older technology gasoline vehicle (MPI) at higher load (80 km/h) is equal to the PN-level of the newer technology (GDI) – both vehicles without GPF.

The advantages and the efficiency of the modern Diesel aftertreatment (DPF) are confirmed by a significant reduction of PN.

In the stop&go operation, there are several tendencies of increasing the specific emissions [mg/km] with the higher share of idling (except of: HC for gasoline vehicles and PN for all vehicles). One of the factors taken into consideration is the shorter distance driven with the higher portion of idling in the tested time interval. The consideration of emissions per time results in lowering most of the emissions with higher portion of idling.

2. OBJECTIVES OF ResRDE(2)

According to the project proposal from March 2019, the objectives of the working packages are:

WP1: Emission factors from non-driving situations with different vehicles.

Part 1: Analysis of present data

From the present data of RDE obtained with different vehicles, the specific situations of emissions like cold start, warm-up and stop&go, have to be found, analyzed and compared with the average cycle emissions.

Part 2: Reproduction of non-driving situations

It was proposed to investigate two gasoline and two Diesel passenger cars. The tests are performed in idling cold/warm, during the warm-up phase and in stop&go operation with a different portion of idling. The tests are performed on chassis dynamometer with measuring systems: CVS and PEMS (including HC_{FID} and PN).

After cold start, there are different options of operating profile to influence the warm-up phase. It is proposed to use two extreme variants: idling and high load (like highway). The cold start would be at 20-25°C. Other options of the cold start temperature are to be discussed.

To simulate the different portion of idling in stop&go operation, specific cycles have been created in order to repeat the same trials with all vehicles. Testing of stop&go operation will be carried out with warm engine.

WP2: RDE legislation package 4.

From January 2019, new amendments to the RDE-legislation was issued with new requirements of evaluation of results. It is necessary to deepen the new regulation, to perform the new evaluation procedure and to compare it with the previous one.

WP3: Extended RDE conditions – examples and comparisons of RDE for: winter/summer driving, mild/aggressive driving and altitude.

WP3(a): RDE – winter/summer – examples on two vehicles (passenger cars: Diesel, gasoline).

WP3(b): RDE with mild/aggressive driving behavior - examples on two vehicles (Diesel, gasoline).

WP3(c): RDE in “normal» legally valid circle compared with a high-altitude circle – examples on two vehicles (Diesel, gasoline).

WP4: Further comparisons of PN PEMS and GasPEMS: Horiba ↔ NM3 (CPC & NGK) examples on two vehicles (Diesel, gasoline), as well as the comparisons of data from HDV Euro VI (WVU).

The vehicles are tested with warm start on chassis dynamometer and on-road. Compared are: stationary CPC (PMP), PN PEMS Horiba, NM3 and NGK and gaseous components GasPEMS. The comparisons of results from the previous tests HDV Euro VI (WVU) are included.

WP5: RDE results on different RDE routes.

The same vehicle is measured on the test circuits of other associated institutes (EMPA, TCS, TFZ).

2.1. Research topics of present report

This 1st report presents the results of WP1, which consists of two parts (as mentioned in pt. 2).

In the part 1, “Analysis of present data”, the definitions and criteria of the specific non-driving situations were established. With these criteria, the RDE of seven cars were evaluated in order to show the emissions of these operating situations.
In the part 2, “Reproduction of non-driving situations”, four cars were measured on chassis dynamometer with different warm-up procedures and with different portion of idling in the stop&go operation. For the last one specific, simple driving cycles were created.

3. ANALYSIS OF PRESENT DATA (part 1)

3.1. Data origin & processing

	Gas PEMS
	
Instruments	**Horiba PEMS OBS one**
Exhaust concentrations	CO_2, CO, NO_x, NO_2
Measurement principle	heated NDIR*, CLD, heated line
Engine parameters	OBD
Vehicle speed & position	GPS
Exhaust flow	EFM
Ambient parameters	p, T, H
Electrical power	> 300 W (> 800 W with FID and PN)
Dimensions	500 x 500 x 500 mm + Pitot tube + heated line + batteries

* OBS one: H_2O is monitored to compensate the H_2O interference on CO and CO_2 sample cell heated to 60°C.

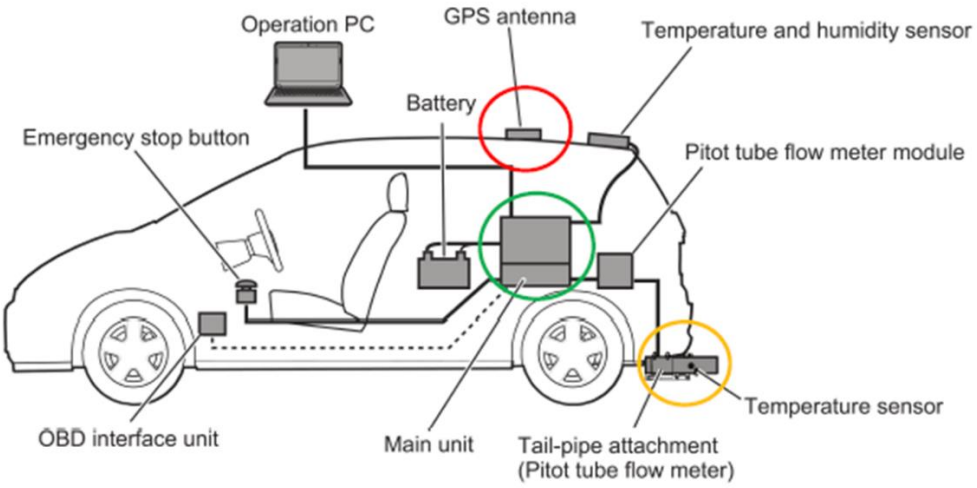
Table 1: Data of the applied GasPEMS

The emissions data originate from testing of different vehicles with PEMS (Portable Emission Measuring Systems for gaseous emissions) and with PN-PEMS (for particle number PN) at AFHB.

Table 1 represents the most important data of the GasPEMS.

The Horiba OBS-ONE-PN PEMS uses two-step dilution, a catalytic volatile particle remover (350°C) and an Isopropanol-based CPC as a main measuring unit. For further information from the manufacturer, see annex A1.

Picture 1 represents the PEMS installation on a vehicle.



Picture 1: Set-up of PEMS on a vehicle.

The results of exhaust gas measuring devices are given as volume concentrations. Nevertheless, the legal limits are expressed in [g/km] for LDV, or in [g/kWh] for HDV.
Therefore, it is necessary to install a flowmeter at the tailpipe of the vehicle and to estimate the instantaneous exhaust gas mass flow in the transient operation.

In the data processing, the vehicle positions and speeds are required. They are usually registered from the GPS (Global Positioning System), which is installed on the vehicle. If this signal is not available, e.g. in the tunnel, the speed can be obtained from the OBD-interface (on Board Diagnose) of the vehicle.

Additionally, the parameters such as the engine coolant temperature and the engine speed are registered by the OBD.

The pollutant components measured by both PEMS (Gas & PN) are carbon dioxide CO_2, carbon monoxide CO, nitric oxides NO_x (consisting of NO and NO_2) and particle number PN (considering the invisible nanoaerosol).

For the choice of data (vehicles previously measured in other projects) following criteria were taken into consideration:

- Version of the RDE route (for example see annex A2)
- The same measuring system
- Engine cold start measured
- Engine start measured
- Emission components measured (CO_2, CO, NO_x, PN, HC)
- Start-stop-system (switched off)

Seven vehicles (three gasoline and four Diesel) could be chosen for the data evaluation. Table 2 summarizes the most important data of these vehicles.

Nr.	Fuel	Displacement	Exhaust Aftertreatment System	Injection
LDV01	Gasoline	1.6	TWC	PFI
LDV02	Gasoline	4.0	TWC, GPF	DI
LDV03	Gasoline	6.2	TWC	PFI
LDV04	Diesel	2.0	DOC, DPF	DI
LDV05	Diesel	2.1	DOC, DPF, SCR	DI
LDV06	Diesel	3.0	DOC, DPF, SCR	DI
LDV07	Diesel	3.0	DOC, DPF, SCR	DI

Table 2: List of vehicles chosen for the data evaluation (LDV … light duty vehicle)

Some criteria could not be completely fulfilled:

- Start-stop-system of LDV 07 was switched on
- PN was not measured for some vehicles
- HC was not measured for all vehicles

The measured and filtered data, which are processed according to the definitions of non-driving (or special driving) situation (definitions see following section 3.2) are given in the annexes A3-1 to A3-6. These data are the basis for the diagrams of results represented in the attached figures (see chap. 6).

3.2. Definitions of non-driving situations

Distance driven and urban part

In the legal RDE-evaluation of LDV’s the parts of driving, which were performed with the speed lower than 60 km/h, are considered as “urban”, even if they were performed outside of the city.
In opposition, the urban part in this work is defined as the first 13.7 km of the distance driven. This was decided after investigating the speeds, distances and emission traces of the chosen vehicles. 13.7 km is the shortest distance before one of the vehicles reached the speed of 60 km/h.
With this definition of urban part, it is fixed that all investigated vehicles were driven below this speed limit value (60 km/h). Furthermore, it was observed that during this 13.7 km, there were the specific driving-and emissions-situations, which are the subject of this research: cold start, warm-up, stop&go, idling.

The investigation of the high-speed driving parts – rural and highway – showed no noticeable emission events.

Cold start

The cold start is defined with the engine coolant temperature (ECT) as: (ECT < t_amb +2°C), or ECT < 30°C. This means that ECT can be up to 2°C higher than the ambient temperature or it must be lower than 30°C. This definition originating from the HDV-legislation is applied in this work because it is stricter than the definition from the LDV-legislation (+7°C, 35°C).

Engine warm-up

The warm-up time is defined in two ways:

a. from the engine start (n>500 rpm) to the instant of ECT = 70°C – this is named: “ECT 70” and
b. from the engine start (n>500 rpm) to the duration of 5 minutes – this is named: “5 minutes”.

These definitions and examples of the warm-up for two vehicles (gasoline & Diesel) are represented in Fig. 0-1. It can be clearly remarked that the Diesel vehicle needs a longer time to attain the ECT 70.

Fig. 11 summarizes the time-traces of ECT for all investigated vehicles. For LDV1 and LDV5, there are some irregular increases of ECT. ECT of LDV1 reaches 70°C in approximately 4 minutes after start. However, it falls again below 70°C for approximately 1 minute. This 1 minute is accounted to the warm-up according to the definition.
For more detailed analyses it is useful to consider both warm-up definitions and the time-courses of the increasing ECT.

Stop&go

According to ASTRA, the definitions of traffic congestion which are used for the public traffic information are:
- the traffic jam on the extra-urban route is given when the speed is below 10 km/h during at least 1 minute and frequent standstill occurs,
- in the city circulation, the traffic jam is considered when the loss of summary time is over 5 minutes.

These definitions are close to the stop&go operation and they gave the basis for the definition which is easy to understand and which depicts well this driving situation.

The operation of the vehicle with the driving speeds between 1km/h and 10 km/h is considered as a “stop&go” phase. In this way, the vehicle standstill (stop) and the short acceleration by moving (go) are included in this operation mode.

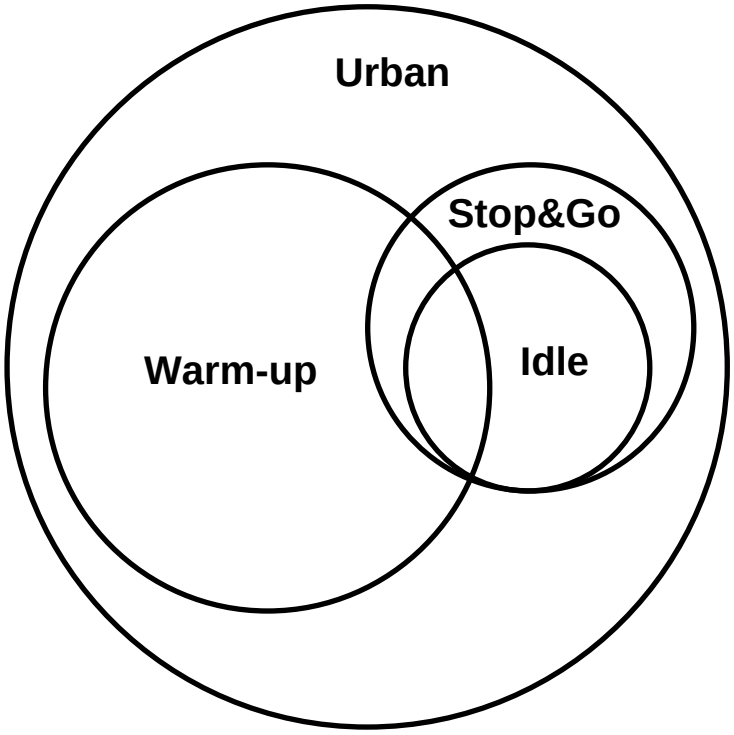
Fig. 0-2 shows the definition and example of stop&go in the urban part (13.7 km). Fig. 11 summarizes the shares of stop&go in the urban part for all investigated vehicles. These shares are in the range of 13% to 19%.

Idling

The idling phase is given, when the engine speed is between 500 rpm and 900 rpm and the vehicle speed is below 1 km/h.

Fig. 0-3 shows the definition and example of idling in the urban part and Fig. 11 summarizes the shares of idling in the urban part for all investigated vehicles. These shares are in the range of 6% to 13%.

According to these definitions, there is a certain overlapping of the data of the considered non-driving situations, see picture 2.



Picture 2: Qualitative overlapping of the analyzed data

3.3. Results

The results are represented graphically in the attached figures (chap. 6) and they are tabulated in annex A3.

The evaluated emissions data are expressed as total cumulated values in [g], [#], as emissions per time in [g/min], [#/min] or as specific emissions per distance [g/km], [#/km]. The specific emissions (per km) respond to the legal view, they are comparable with legal limit values, but they are not applicable for the non-driving situations, where the distance driven is zero (like idling or stop&go). These facts are considered in the data representation.

Figures 1 to 7 represent the cumulative emissions for the 7 investigated vehicles in all special situations:

- warm-up (including cold start) – Fig. x-1
- stop&go – Fig. x-2 and
- idling – Fig. x-3.

The emissions of the special (non-driving) situations are always shown together with the emissions of the entire urban part (13.7 km).

Warm-up

It can be remarked that for the gasoline vehicles (LDV1 - LDV3), the ECT 70-warm-up happens earlier or simultaneously with the 5 minutes-point. For the Diesel vehicles (LDV4 - LDV7) inversely, the ECT 70-warm-up takes generally a longer time and it arrives after the 5 minutes-point. These findings are also well visible in the figures 8-1 to 8-4, which represent the cumulative emissions over time (for all vehicles) during the urban phase (13.7 km). From the comparison of vehicles, it can be stated, that:

- vehicles with smaller engine displacement produce lower CO_2-emissions,
- most emissions of CO and NO_x, especially in the "gasoline" group are produced during and shortly after cold start,
- in both vehicles' groups: "gasoline" and "Diesel", there are quite considerable emissions differences between the vehicles, resulting mostly from different efficiencies of the exhaust aftertreatment systems,
- the urban phase (13.7 km) is driven by different vehicles at different time, due to different average speeds resulting from the traffic situations.

Specific emissions (per km) in the warm-up phase are compared for all vehicles in the figures 8-5 to 8-7.

The CO [g/km] in warm-up are generally higher than in the entire urban phase (13.7 km). The "warm-up increase factor" varies between 2 & 11 for gasoline and 1 & 4 for Diesel vehicles. CO-values of LDV4 are particularly high indicating most probably some problems of engine, or of inactive DOC.

The NO_x [g/km] values of two Diesel vehicles (LDV4 & LDV5) are very high, which particularly signalizes a misfunction of the SCR-system of LDV5 (LDV4 is not equipped with SCR). The specific emissions in warm-up are sometimes higher than in the urban phase with the "increase factor" ranging between 0.9 & 7.5 for gasoline and 0.9 & 5 for Diesel vehicles.

The nanoparticle emissions PN are efficiently eliminated by the DPF's – all investigated Diesel vehicles were equipped with a filter. In the "gasoline" group, the PN-data were available only for the LDV2, which was equipped with GPF. This GPF enables the urban PN-emission to be reduced below the limit value ($6 \cdot 10^{11}$ #/km). For the shorter warm-up phases, the emission peak of the cold start gets more weight and the distance driven is shorter. The filtration quality of this GPF, comparing to the DPF's is quite weak and the high specific PN-emission over the warm-up gets high above the limit value.
Similar experiences exist at AFHB from the previous research on GPF's, [1, 2]: the PN-emissions of a gasoline car (sometimes also with PFI) can reach 10^{13} #/km in $WLTC_{cold}$. The particle count filtration efficiency of the investigated GPF's could be as low as 70%-80% in WLTC, in opposition to DPF's. With this knowledge the authors suggest that the non-measured PN-values of the other two gasoline vehicles could be in average of this "urban" phase at least in the range of [10^{13} #/km].

The PN warm-up increase factors for gasoline vehicle are between 2 & 4 (regarding both definitions of warm-up) and for Diesel vehicles these increase factors are between 1.5 & 10. This means that even the DPF's with the best filtration quality allow a certain penetration of the cold start PN-emission peak, of course at an absolute very low emission level.

Stop&go

The cumulated emissions in stop&go phases are summarized for all vehicles in Fig. 9.
The comparison of emissions of the single vehicles offers a similar picture, as in the previous figures (8-5 to 8-7):

- in the "gasoline" group: CO_2-emission is higher for bigger engines (engine swept volume increases from LDV1 to LDV3); CO-value is the highest for LDV3, which shows the slowest warm-up (see Fig. 11); the PN-values are only given for LDV2 (equipped with GPF) and they confirm the mediocre filtration quality comparing to DPF's.
- in the "Diesel" group: high CO for LDV4 (insufficiency of engine, or of DOC); high NO_x for LDV4 (no SCR) and for LDV5 (inadequacy of SCR); near-to-zero PN-emissions, thanks to right-quality DPF's.

An interesting finding is given by the higher CO- and NO_x-emissions of LDV7 relatively to LDV6. Both vehicles have the same engine displacement volume and nearly identical exhaust aftertreatment systems (DOC, DPF, SCR). LDV7 was driven with its start-stop-control switched on.
This means that during the stop&go operation, the engine was stopped and started independently on the drivers wish.
By engine stop, there are no emissions produced, but by engine start, there is always an emission peak. The balance between the emission saving and emission over-producing depends on how long is the stop-time and how intense is the start-peak. The last one depends strongly on the thermal condition of the engine and of the exhaust system. In the present urban part (first 13.7 km) several start-stops must have been performed with not entirely warm exhaust aftertreatment system and the higher emission peaks at engine restart overweighed the emissions results of LDV7.

Relatively to the urban part (13.7 km) the cumulated emissions in stop&go are increased / decreased by the following factors:

for gasoline vehicles:		for Diesel vehicles:	
CO	2 - 6	CO	0.2 - 2.2
NO_x	0.7 -2.5	NO_x	0.1 - 0.4
PN	1.7 (1 vehicle)	PN	0.4 - 2.3
CO_2	0.5 - 0.7	CO_2	0.3 - 0.6

Idling

Fig. 10 represents the cumulated emissions at idling for all investigated vehicles. The relationships between the vehicles and the technical explanations are similar as in the previous section for "stop&go".

Relatively to the urban part (13.7 km) the cumulated emissions at idling are mostly decreased with the following factors:

for gasoline vehicles:		for Diesel vehicles:	
CO	0.5 - 2.5	CO	0.1 - 0.9
NO_x	0.3 - 1.1	NO_x	0.1 - 0.4
PN	0.7 (1 vehicle)	PN	0.5 - 1.8
CO_2	0.3 - 0.6	CO_2	0.3 - 0.4

4. REPRODUCTION OF NON-DRIVING SITUATIONS (PART 2)

4.1. Test vehicles, fuels and lubricants

The vehicles used for reproduction of special (non) driving situations are listed in the Table 3.

Vehicle	Instruments	Fuel	Displacement	Emission Standard	Exhaust Aftertreatment System	Injection
ga1 – “modern”	cvs	Gasoline	1.6	Euro 5	TWC	GDI
ga1 – “modern”	pems	Gasoline	1.6	Euro 5	TWC	GDI
ga2 – “dated”	cvs	Gasoline	1.6	Euro 3	TWC	MPI
di1 – “modern”	cvs	Diesel	2.1	Euro 6	DOC, DPF, SCR	DI
di1 – “modern”	pems	Diesel	2.1	Euro 6	DOC, DPF, SCR	DI
di2 –“dated”	cvs	Diesel	2.0	Euro 2	DOC	DI

Table 3: List of vehicles used for reproduction of non-driving situations on chassis dynamometer (ga … gasoline, di … Diesel)

All vehicles were operated with the Swiss market fuels and with the lubricating oils, which actually were present in each vehicle.

4.2. Test methods and instrumentation

4.2.1. Chassis dynamometer and standard test equipment

- roller dynamometer: AFHB GSA 200
- roller diameter: 502 mm
- driver conductor system: Tornado, version 3.3
- CVS dilution system: Control Sistem R03-700 with roots blower
- air conditioning in the hall automatic for intake- and dilution air
  temperature: 20 ÷ 30°C
  humidity: 5.5 – 12.2. g/kg

4.2.2. Test equipment for regulated exhaust gas emissions

This equipment fulfils the requirements of the Swiss and European exhaust gas legislation.

- regulated gaseous components:
  exhaust gas measuring system Horiba MEXA-7100
  CO, CO_2… infrared analysers (IR)
  HCFID... flame ionisation detector for total hydrocarbons
  CH_4FID... flame ionisation detector with catalyst for only CH_4
  NO/NO_X... chemoluminescence analyser (CLA)

The dilution ratio DF in the CVS-dilution tunnel is variable and can be controlled by means of the CO_2-analysis.

4.2.3. PEMS

Most important data of the used PEMS and of the stationary measuring system (CVS) are given in the Table 4.

GAS PEMS

	HORIBA MEXA 7200	**HORIBA OBS ONE**
	4x4 chassis dyno CVS	PEMS① wet
CO	NDIR	heated NDIR
CO_2	NDIR	heated NDIR
NO_x	CLD	CLD
NO	CLD	CLD
NO_2	calculated	calculated
O_2	-	-
HC	FID	-
PN	not measured	-
OBD logger	-	yes
GPS logger	-	yes
ambient (p, T, H)	yes	yes
EFM	-	pitot tube

OBS - one H_2O monitored to compensate the H_2O interference on CO and CO_2 sample cell heated to 60°C

Table 4: Overview of used measuring systems.

4.2.4. PN PEMS

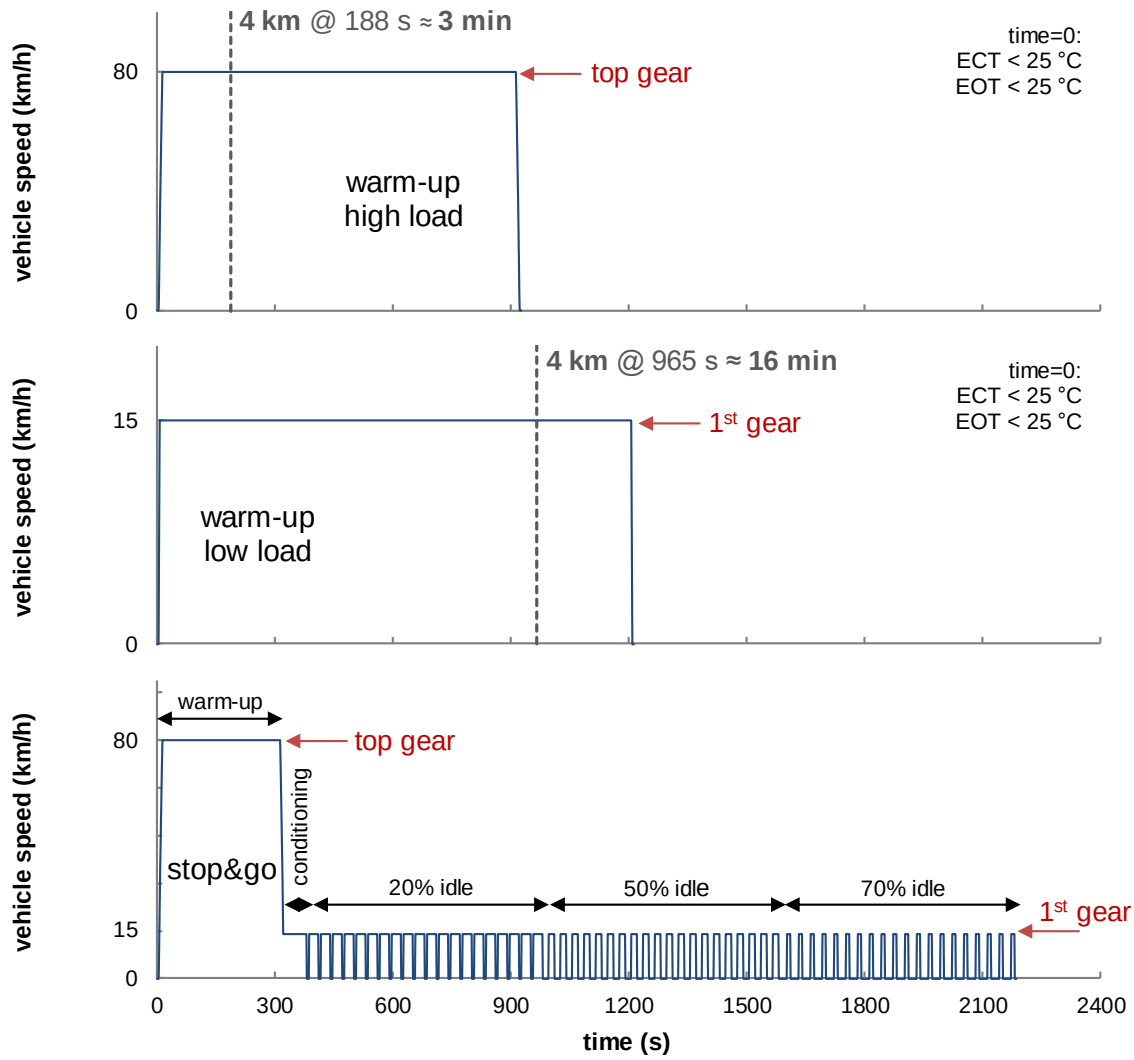
For measurements of nanoparticles (PN/CPC) the Horiba OBS-ONE-PN PEMS was used, see chap. 3.1 and annex A1.

4.3. Test procedures

The measurements of vehicles were performed on chassis dynamometer, which enable different loads during the warm-up and a performance of specific driving cycles.

4.3.1. Driving cycles on chassis dynamometer

The vehicles were tested on a chassis dynamometer in special, simplified driving cycles, which made possible to perform different warm-up procedures, and stop&go with different share of idling, picture 3. The braking resistances were set according to the legal prescriptions and responded to the horizontal road.



ECT: engine coolant temperature

EOT: engine oil temperature

Picture 3: Driving cycles for reproduction of warm-up and stop&go procedures on chassis dynamometer.

4.4. Results

The results of the experimental reproduction of some special driving situations are represented in the Figures 12-15 and in annex A4.

Fig. 12 shows the cumulated emissions in the first four minutes after the cold start (25°C) with two gasoline vehicles. The newer (modern) vehicle is equipped with the engine and exhaust aftertreatment technology Euro 5 (with GDI, TWC) and the older vehicle (dated) responds to the emission class Euro 3 (with MPI, TWC). "High load" means, that after the cold start, the vehicle was driven at 80 km/h and "low load" means the same with 15 km/h (see picture 3).

Several findings have to be mentioned:

- the emissions of CO, HC, NO_x and PN are generally higher for the older vehicle and, for both vehicles, these emissions are higher with higher load,
- the majority of these emissions is cumulated in the first 0.5 km of distance approximately; exception is NO_x of the dated vehicle: after 2 km NO_x starts to increase, especially with "high load" indicating some draw-back of the catalytic reduction,
- the emission traces obtained with PEMS (for the modern vehicle) are in a very good accordance with the emissions from the laboratory installation (CVS),
- the PN-emissions of the dated vehicle (MPI) at high load are identical with the emissions of the modern vehicle (GDI); this confirms the high PN-emissions potential of the MPI fleet as well,
- the nearly linear increase of cumulated CO_2-emissions is connected to the fuel consumption of vehicles, the relationships of slopes are influenced by the fact, that this representation is given over the driving distance and responds to different operating time. The distance of 4 km means for 80 km/h 3 minutes and for 15 km/h 16 minutes of driving

Fig. 13 represents the cumulated emissions for the Diesel vehicles. "Dated" means Euro 2 (DOC) and modern means Euro 6 (DOC, DPF, SCR). The remarkable findings are:

- the emissions of CO, HC, NO_x and PN are generally higher for the older vehicle,
- the emissions of CO, HC, and for the older vehicle, also NO_x, are higher with lower load (inversely to gasoline vehicles),
- the emissions of CO, HC and NO_x for the older vehicle, and particularly at low load, are cumulated not only at cold start but also in the entire represented time slot until 4 km distance driven,
- the PN-emissions of both vehicles are cumulated mainly during the cold start:
    - for the older vehicle they are significantly higher than for the newer one (up to 6 orders of magnitude) and are independent of the load,
    - for the newer vehicle (with DPF) the PN-values at low load are lower than at high load due to the lower penetration of the cold start emission peak,
- the emission traces obtained with PEMS (for the modern vehicle) are in a very good accordance with the emissions from the laboratory installation (CVS),
- the nearly linear increase of cumulated CO_2-emissions is connected to the fuel consumption of vehicles, the differences of slopes for low- and high load result from the representation of results over the distance and not over the time (see remarks to Fig. 12).

Fig. 14 summarizes the distance-specific emissions in "stop&go" warm operation with different time-portions of idling for all investigated vehicles. The representation is in linear and in logarithmic scale.

With increasing share of idling the following points can be remarked:

- CO-values increase for Diesel di2 (dated) and for gasoline ga1 (modern),
- HC-values increase for both Diesel vehicles and they do not increase for gasoline vehicles,
- NO_x-values increase for all represented vehicles (no values for ga1),
- PN-values are not influenced by the idling portion,
- CO_2-values, which represent the fuel consumption per km, increase for all vehicles, since there is lower distance driven with higher share of idling.

Fig. 15 shows the same results as Fig. 14 in a time-specific representation. The principal relationships of emissions between the vehicles are unchanged but the influence of idling portion is modified. This is best visible for the higher-emitting vehicle di2. With increasing share of idling for di2, the emissions of HC, NO_x and PN decrease and the CO_2-values stay nearly unchanged. For other vehicles there are even tendencies of lowering CO_2 (with increasing share of idling).

The answer to the question: how does the share of idling influence the emissions in the stop&go operation? – finally depends on the representation (consideration) over the distance or over the time.

5. CONCLUSIONS

Analysis of present data

For research of emissions from non-driving or special driving situations the RDE data of 7 vehicles (3 gasoline and 4 Diesel) were analyzed.
The first 13.7 km of distance after cold start were defined as "urban" part and definitions of: warm-up (including start), "stop&go" and idling, were established in order to enable the automatic evaluation.

The most important conclusions from this research are:

- the emissions of CO, NO_x and PN are in the cold start and in the first part of the warm-up phase (c.a. 25s) considerably higher, than in the rest of the investigated urban phase, (HC-data were not available),
- the special emitting situations: "stop&go" and idling are frequently given during the warm-up phase, i.e. with engine and exhaust treatment system not warm enough,
- vehicles with smaller engine displacement have lower cumulated CO_2-emissions (lower fuel consumption), they are tendentially quicker to be warmed-up,
- in both vehicles' groups: "gasoline" and "Diesel" there are quite considerable emissions differences between the vehicles, resulting mostly from different efficiencies of the exhaust aftertreatment systems,
- the specific emissions [in g/km] are in the warm-up generally significantly higher than in the investigated urban phase (13.7 km); the respective "increase factors" are in average: for CO 6; for NO_x 4; for PN 6,
- the cumulated emissions [in g] represent in average following percent shares of the urban phase emissions:

for "stop&go":

gasoline vehicles		Diesel vehicles	
CO	4.00	CO	1.40
NO_x	1.60	NO_x	0.25
PN	1.70	PN	1.35
CO_2	0.60	CO_2	0.45

for idling:

gasoline vehicles		Diesel vehicles	
CO	1.50	CO	0.50
NO_x	0.70	NO_x	0.25
PN	0.70	PN	1.15
CO_2	0.45	CO_2	0.35

- the GPF, which was applied on one of the investigated gasoline vehicles showed a weak filtration quality comparing to the DPF's which were used on the Diesel vehicles,
- the start-stop-system switched on during the warm-up is tendentially disadvantageous because the cold exhaust aftertreatment system cannot eliminate sufficiently the emissions peaks produced by restarting the engine.

Reproduction of non-driving situations

The non-driving (or special driving) situations – warm-up with different engine load and stop&go with different portions of idling – were reproduced on a chassis dynamometer with two gasoline vehicles and two Diesel vehicles. Both vehicles types were represented by a newer and an older technology.

During the cold start and warm-up in the first 4 km, the emissions of older type vehicles are generally higher than for the newer technology. The majority of emissions are accumulated in the first 0.5 km of the distance driven.
The PN-level of older technology gasoline vehicle (MPI) at higher load (80 km/h) is equal to the PN-level of the newer technology (GDI) – both vehicles without GPF.

The advantages and the efficiency of the modern Diesel aftertreatment (DPF) are confirmed by a significant reduction of PN.

In the stop&go operation, there are several tendencies of increasing the specific emissions [mg/km] with the higher share of idling (except of: HC for gasoline vehicles and PN for all vehicles). One of the factors taken into consideration is the shorter distance driven with the higher portion of idling in the tested time interval. The consideration of emissions per time results in lowering most of the emissions with higher portion of idling.

6. LIST OF FIGURES

Pictures in text

Attached figures

7. ANNEXES

8. REFERENCES

[1] Czerwinski, J.; Comte, P.; Heeb, N.; Mayer, A.; Hensel V.: Nanoparticle Emissions of DI Gasoline Cars with/without GPF. SAE Technical Paper 2017-01-1004, Detroit, April 2017.

[2] Czerwinski, J.; Comte, P.; Engelmann, D.; Heeb, N.; Muñoz, M.; Bonsack, P.; Hensel, V.; Mayer, A.: PN-Emissions of Gasoline Cars MPI and Potentials of GPF. SAE Technical Paper 2018-01-0363, Detroit, April 2018. DOI:10.4271/2018-01-0363.

9. ABBREVIATIONS

AFHB Abgasprüfstelle FH Biel, CH
AGR Abgasrückführung
ASTRA Federal Office of Roads, CH

CF	Conformity Factor
CLD	Chemoluminescence Detector
DI	Direct Injection
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particle Filter
ECT	engine coolant temperature
EFM	Exhaust Flow Meter
EMPA	Eidgenössische Material-Prüfanstalt
EMROAD	Data processing reference software
EOT	engine oil temperature
ES	engine start
EU	European Union
FID	Flame Ionization Detector
FOEN	Federal Office of Environment, CH
GPF	Gasoline particulate filter
GPS	Global Positioning System
HD	Heavy Duty (Nutzfahrzeuge)
HDV	Heavy Duty Vehicles
ISC	In-Service Conformity
LD	Light Duty (Personenfahrzeuge)
LDV	Light Duty Vehicles
NDIR	Non-Dispersive Infrared
OBD	On Board Diagnosis
OCE	Off-Cycle Emissions
PEMS	Portable Emissions measurement system
PFI	port fuel injection
PN	Particle Number / Partikelanzahl
RDE	Real Driving Emission
ResRDE	research of RDE
SCR	Selective Catalytic Reduction
TA	Type Approval
TCS	Touring Club Switzerland
TFZ	Technisches Forschungszentrum, Straubing, DE
TPA	Tailpipe Attachment / Endrohraufsatz
TWC	Three-way catalyst
V	vehicle
VIN	Vehicle Identification Number
WHTC	World Heavy-Duty Transient Cycle
WLTC	World Light-Duty Transient Cycle
WP	working package
WVU	West Virginia University

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Berner Fachhochschule
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Emissions from Non-Driving Situations

Commissioned by the Federal Office for the Environment (FOEN)

Project: Research on PEMS Testing Methodology and on Real Driving Emissions (ResRDE2) *)

BAFU contract nbr.:15.0002.PJ/S081-0349, 1st report, WP1

Figures

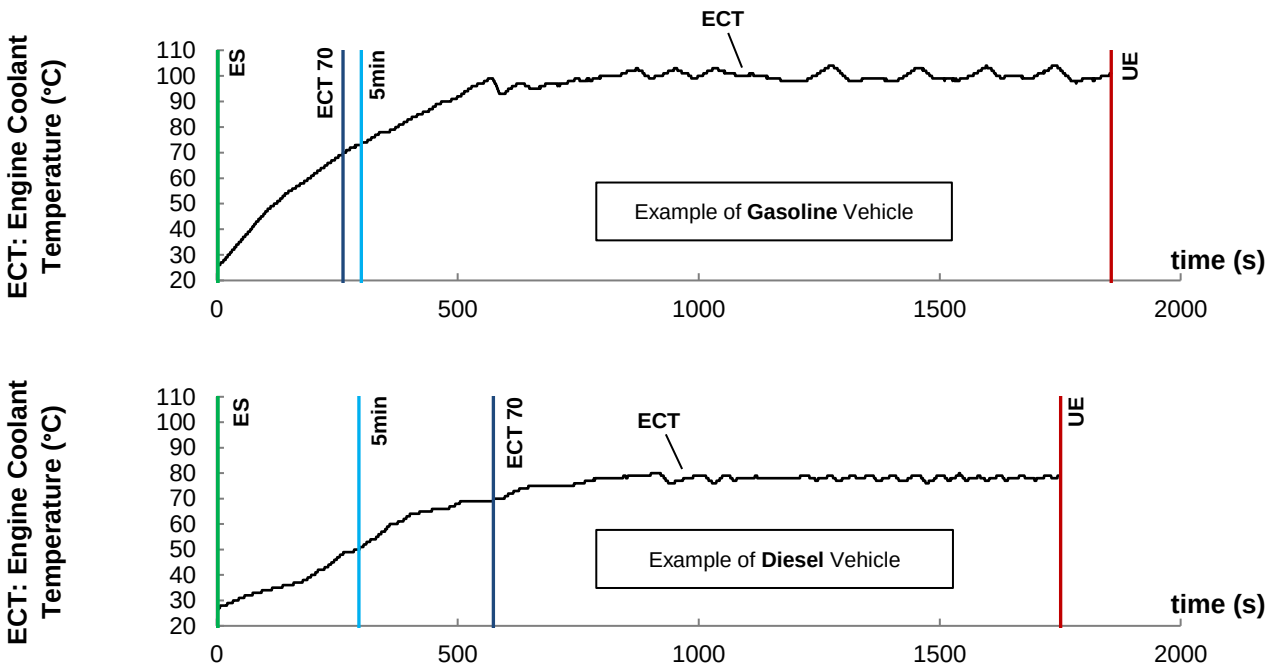
February - April 2020 R001a

*) Abbreviations see at the end of report

PEMS - RDE

Definition of Emission Situations

Warm-Up During RDE



ES: Engine Start (Start of "Engine In Operation")

UE: Urban phase End (geographically defined distance: 13.7 km)

ECT 70: Engine Coolant Temperature (ECT) reaches 70°C

5min: 5min after engine cold start

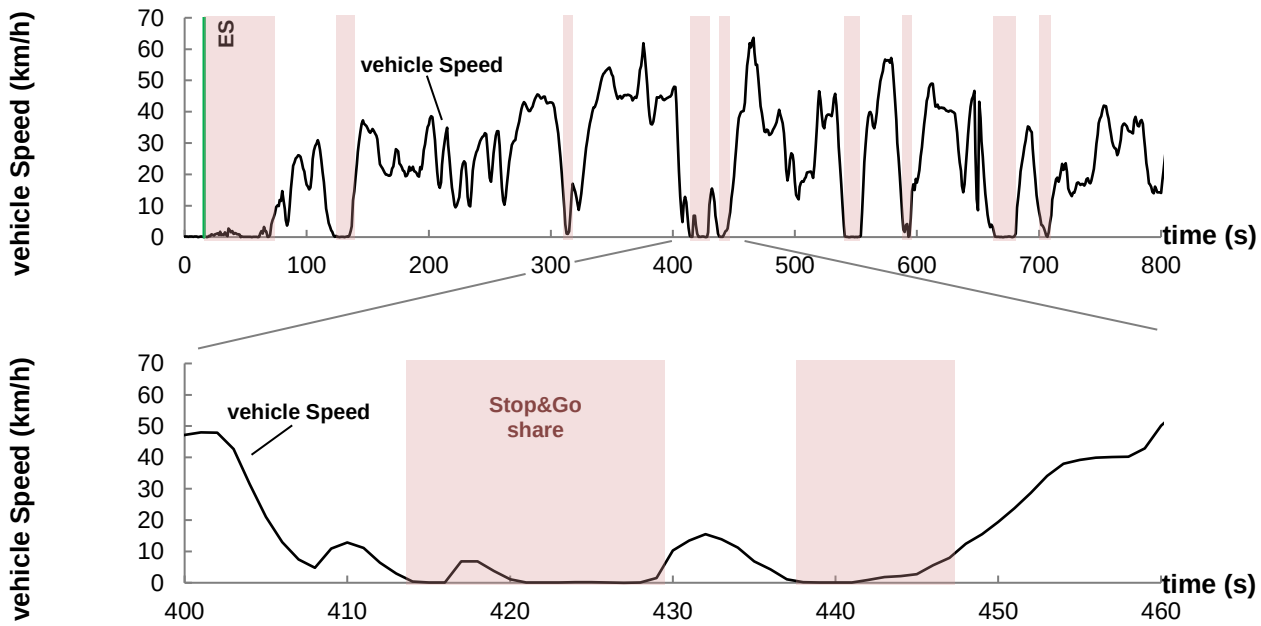
Definitions		start	end
Cold Start	state	ECT < t_amb +2°C OR ECT < 30°C	-
Engine In Operation	state	engine speed > 500 rpm	-
Warm-up ECT 70	phase	Cold Start AND Engine In Operation	ECT > 70°C
Warm-up 5min	phase	Cold Start AND Engine In Operation	phase time > 5min

PEMS - RDE

Definition of Emission Situations

Stop&Go During RDE

Example



ES: Engine Start (Start of "Engine In Operation")

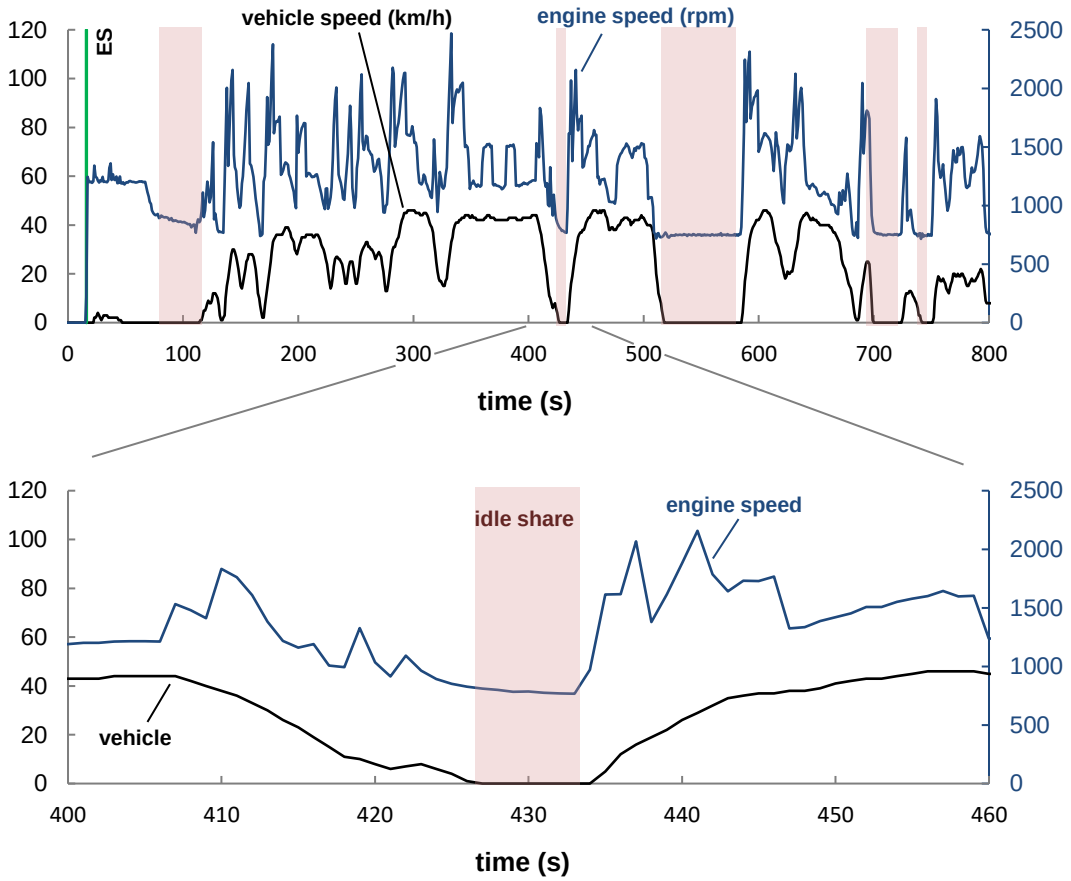
Definition		start	end
Stop&Go	phase	vehicle speed < 1km/h	vehicle speed > 10 km/h

PEMS - RDE

Definition of Emission Situations

Idle During RDE

Example



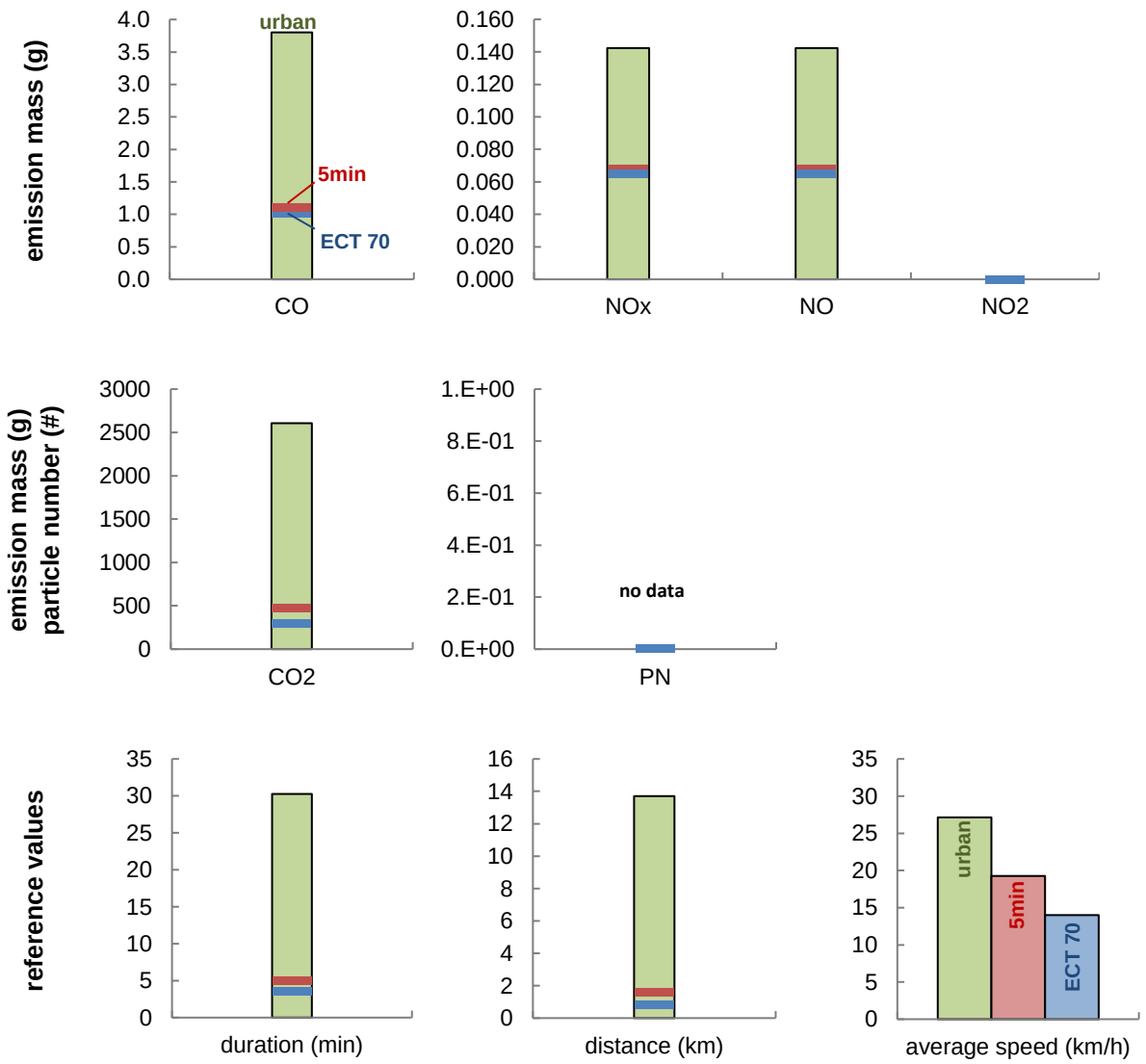
ES: Engine Start (Start of "Engine In Operation")

Definition		start	end
Idling	state	500 rpm < engine speed < 900 rpm	-
Idle	phase	vehicle speed < 1km/h AND Idling	Idle Start Condition FALSE

PEMS

Cumulated Emissions During Warm-Up Phase of RDE

LDV01, 1.6l, Gasoline, TWC, PFI, Start-Stop System:Off



ECT 70: engine coolant temperature reaches 70°C

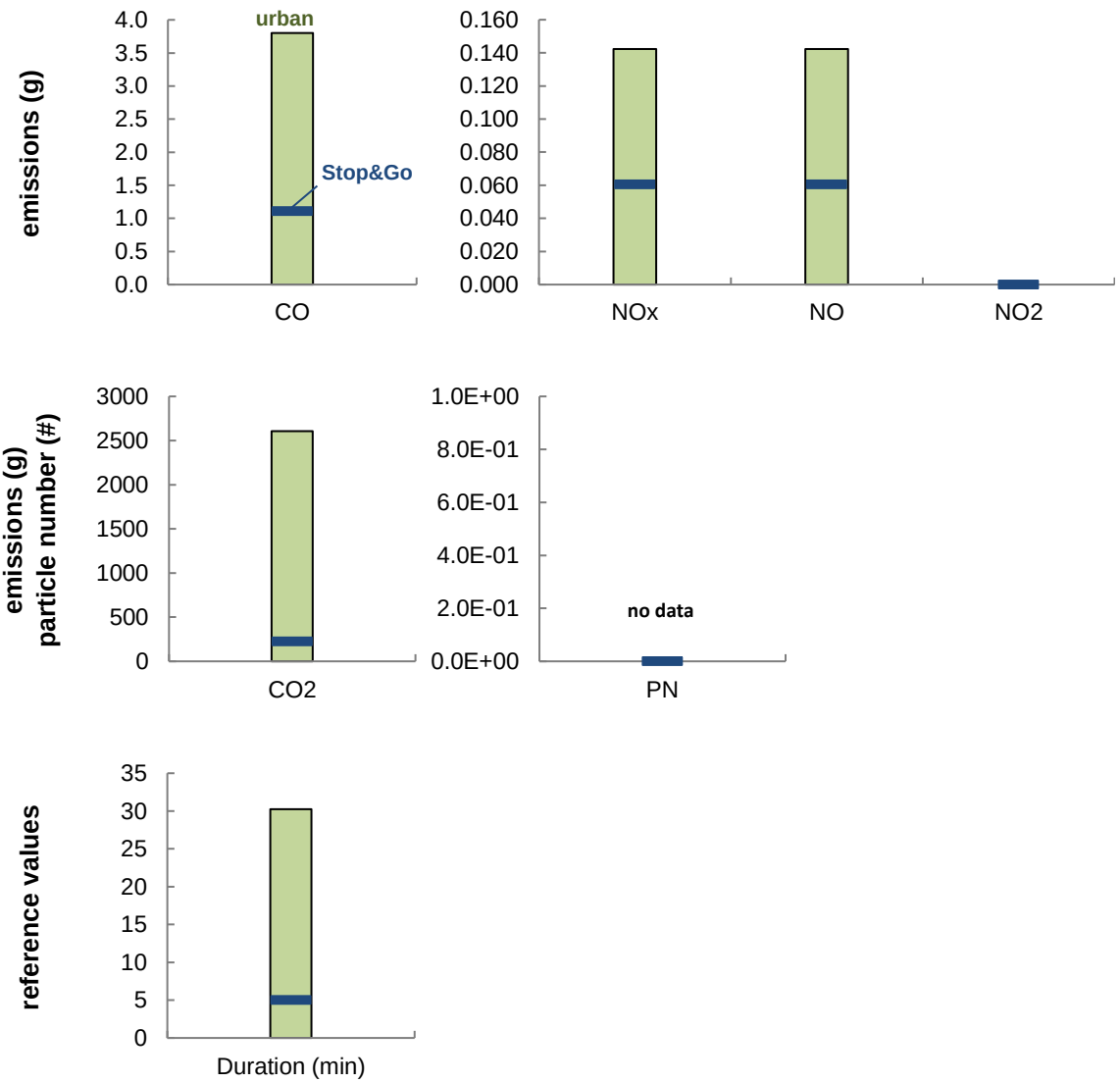
5min: 5 min after engine cold start

urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Cumulated Emissions During Stop&Go Phase of RDE

LDV01, 1.6l, Gasoline, TWC, PFI, Start-Stop System:Off

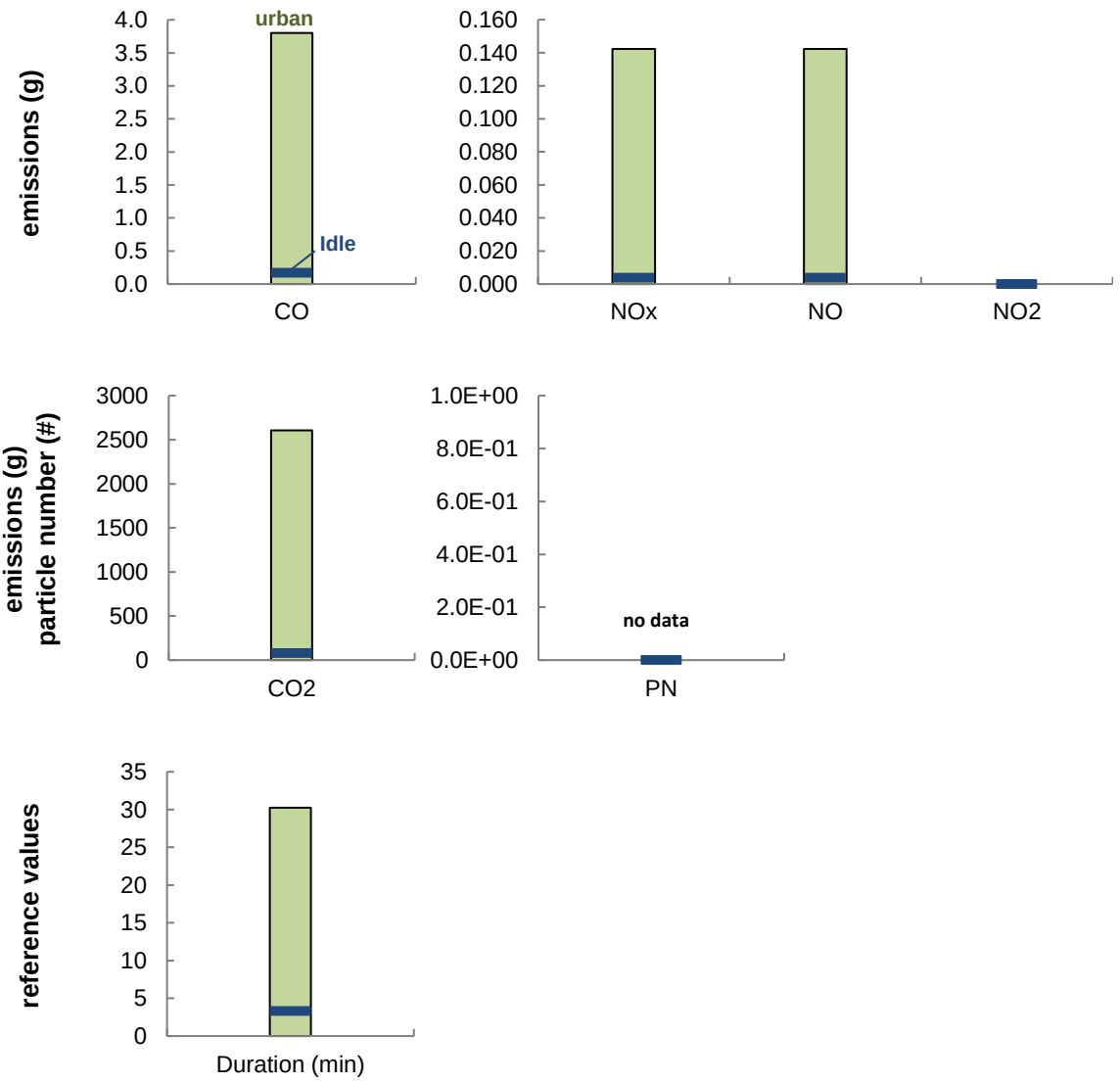


urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Cumulated Emissions During Idle Phase of RDE

LDV01, 1.6l, Gasoline, TWC, PFI, Start-Stop System:Off

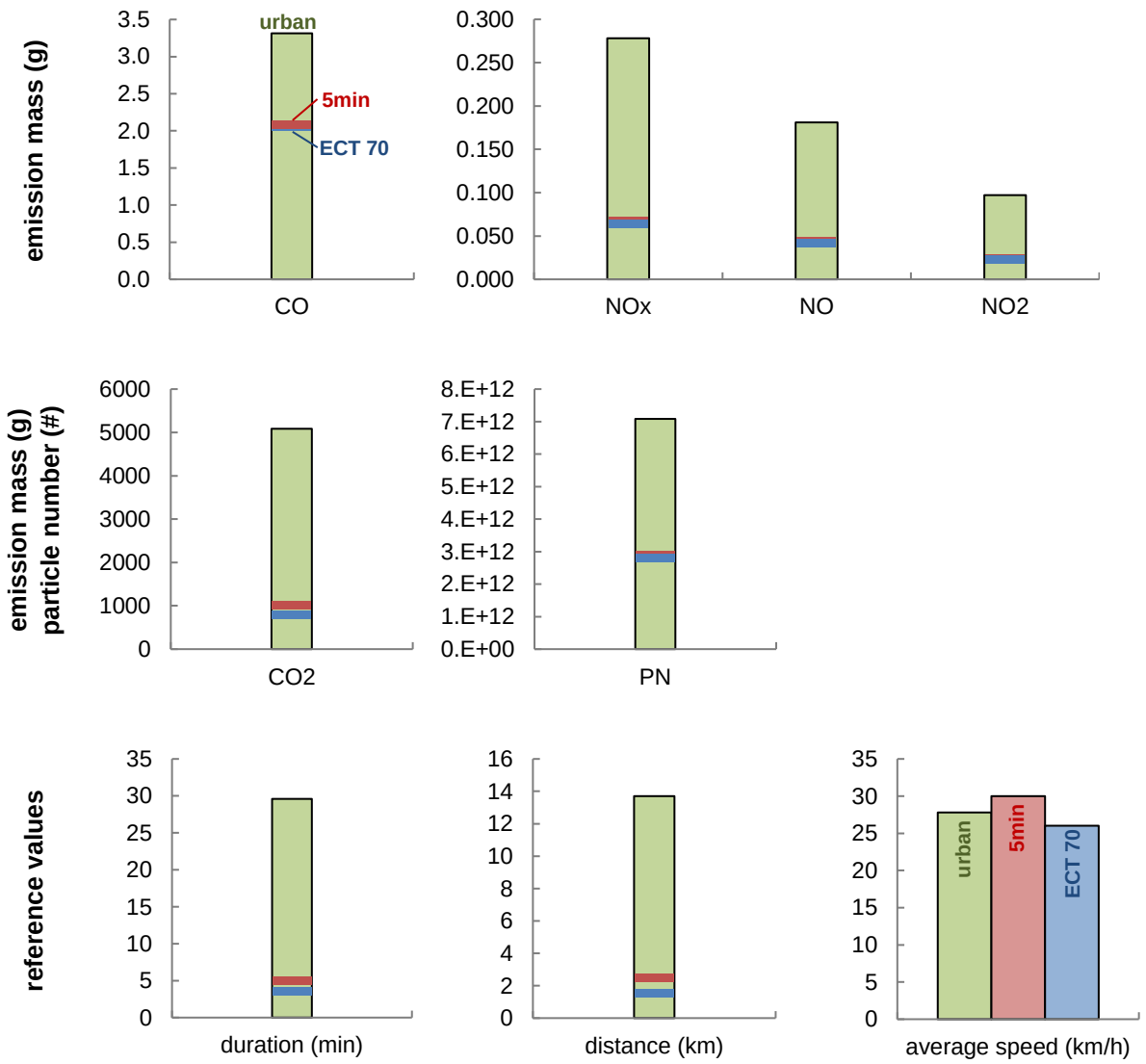


urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Cumulated Emissions During Warm-Up Phase of RDE

LDV02, 4.0l, Gasoline, TWC + GPF, DI, Start-Stop System:Off



ECT 70: engine coolant temperature reaches 70°C

5min: 5 min after engine cold start

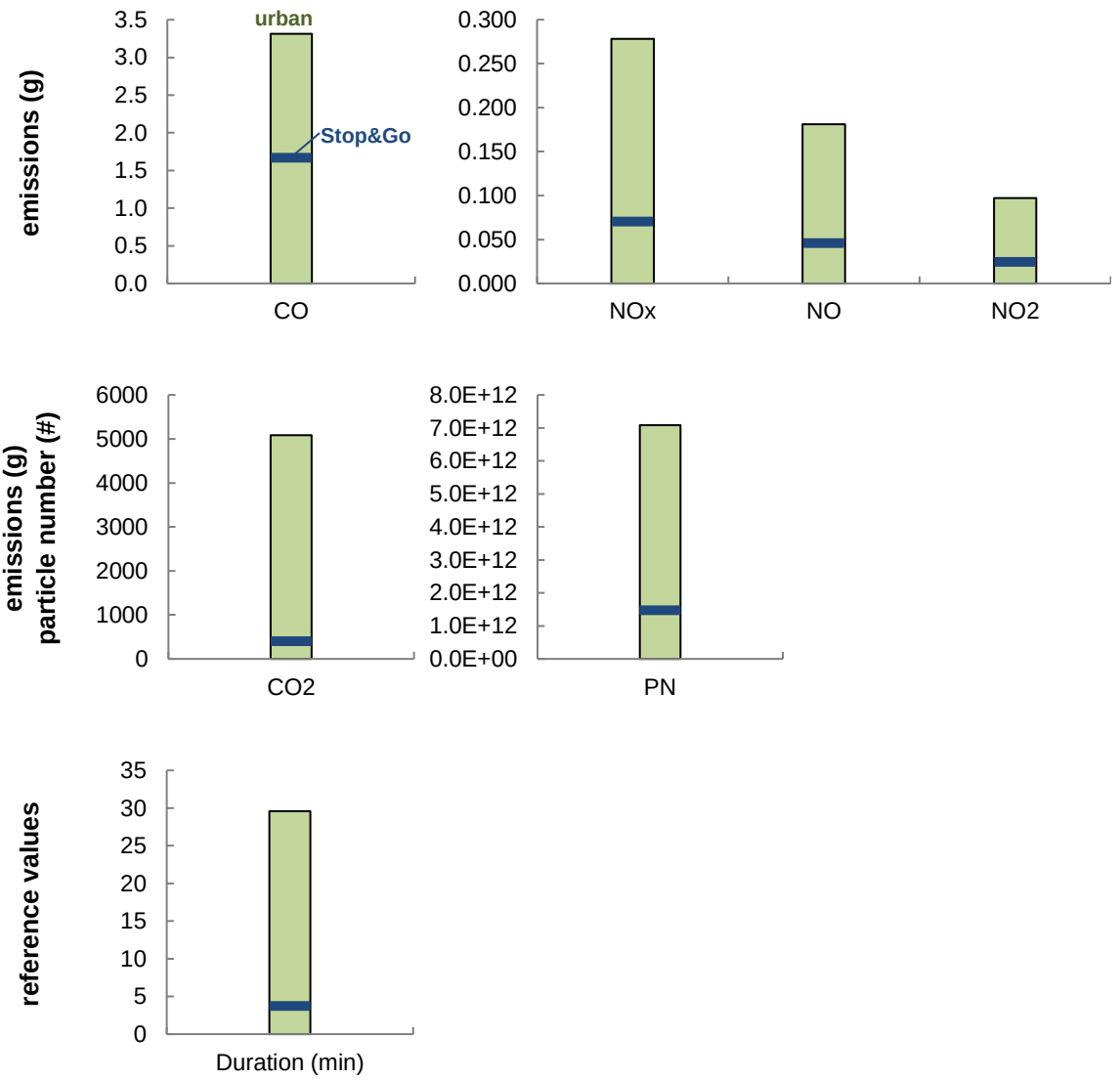
urban: part of RDE-Route (geographically defined distance: 13.7 km)

Fig. 2-2

PEMS

Cumulated Emissions During Stop&Go Phase of RDE

LDV02, 4.0l, Gasoline, TWC + GPF, DI, Start-Stop System:Off



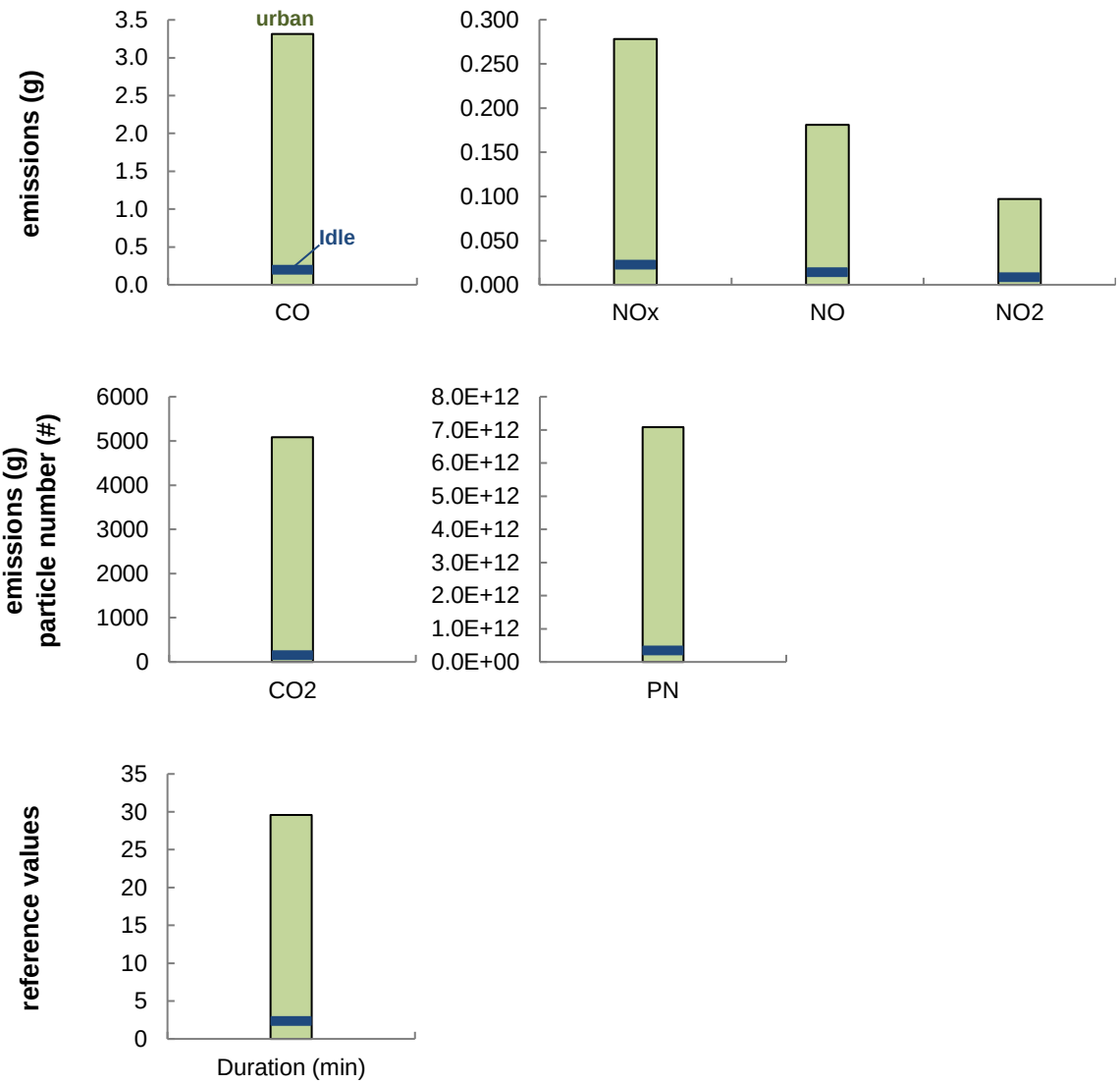
urban: part of RDE-Route (geographically defined distance: 13.7 km)

Fig. 2-3

PEMS

Cumulated Emissions During Idle Phase of RDE

LDV02, 4.0l, Gasoline, TWC + GPF, DI, Start-Stop System:Off

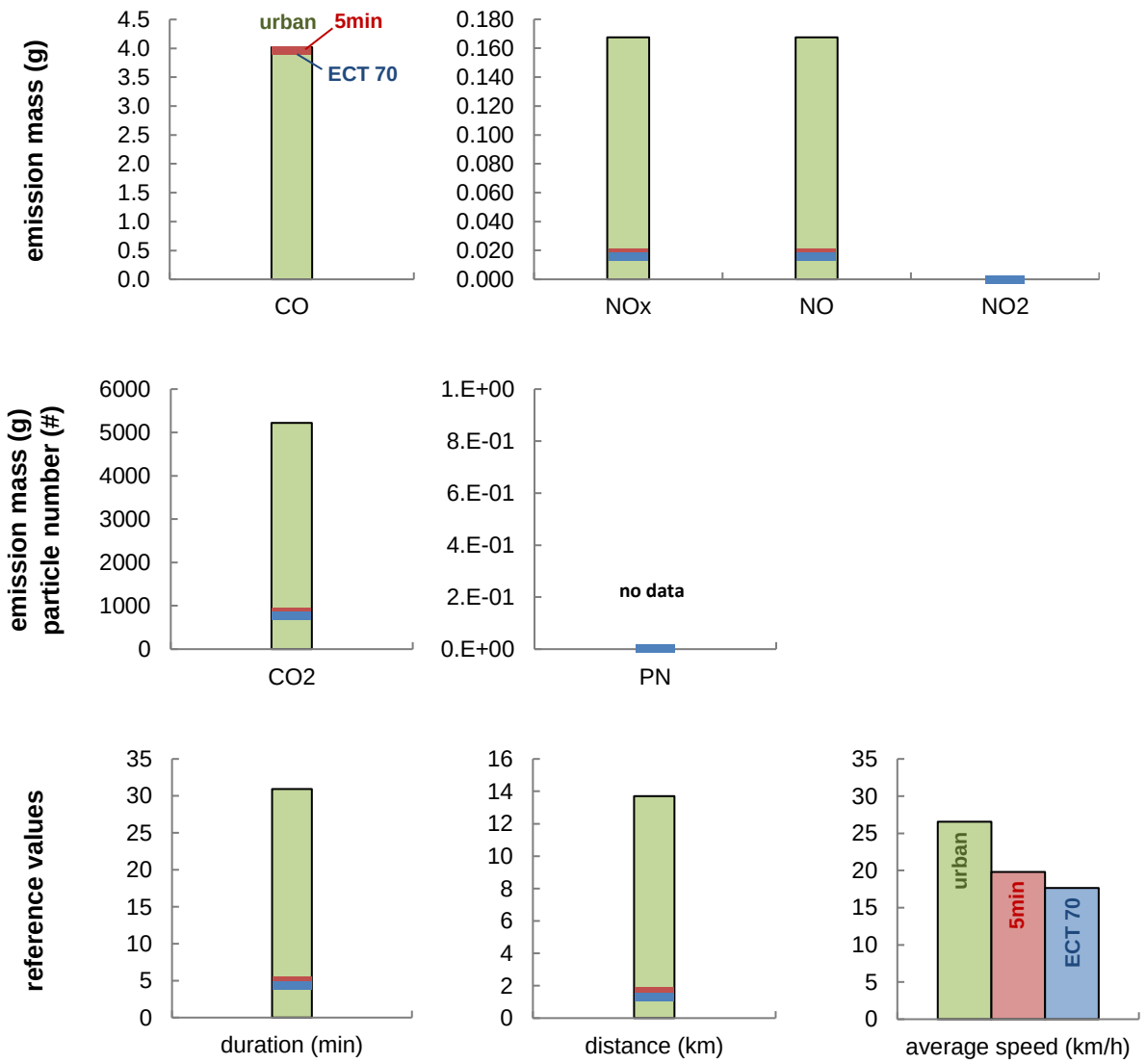


urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Cumulated Emissions During Warm-Up Phase of RDE

LDV03, 6.2l, Gasoline, TWC, PFI, Start-Stop System:Off



ECT 70: engine coolant temperature reaches 70°C

5min: 5 min after engine cold start

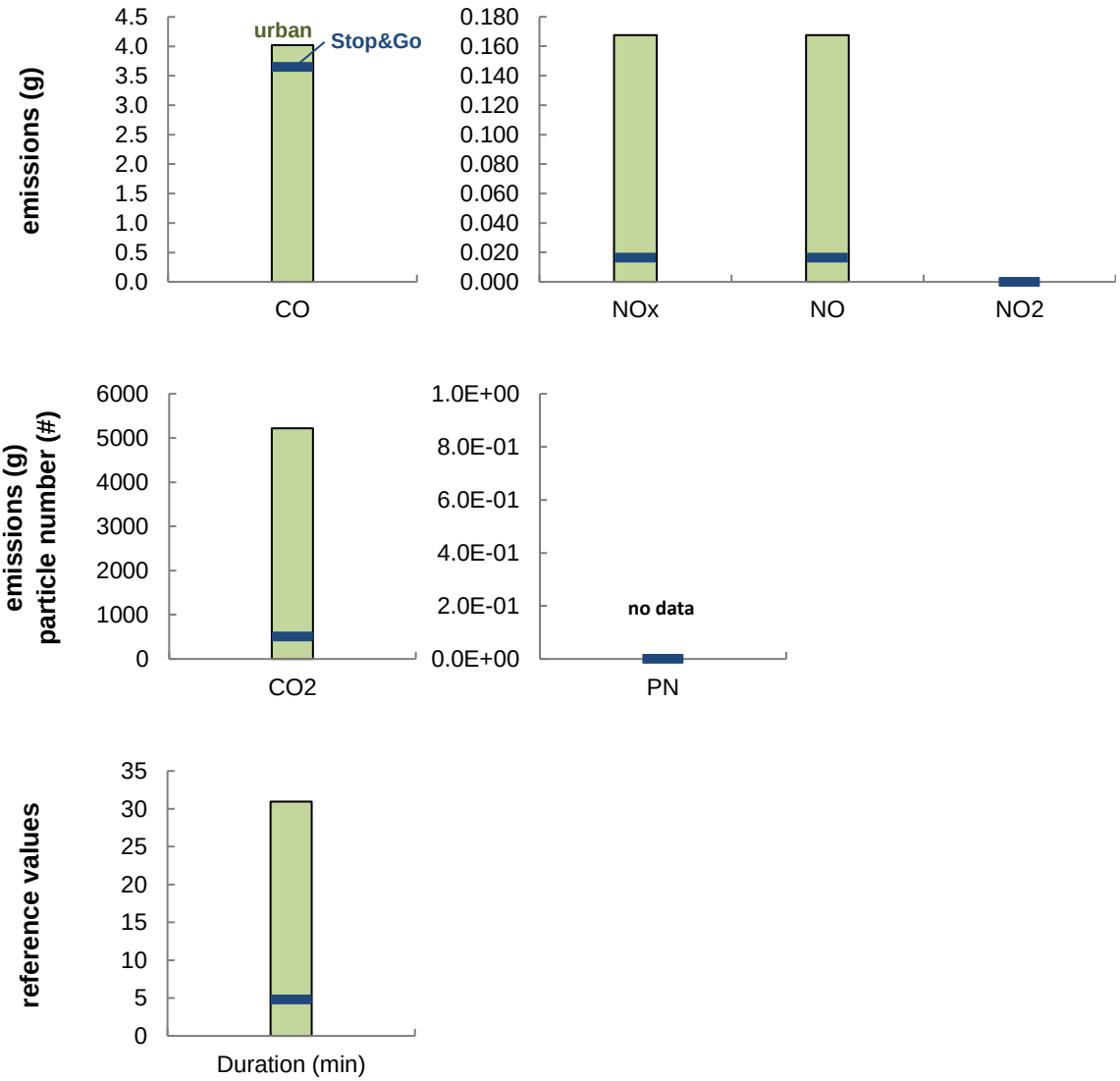
urban: part of RDE-Route (geographically defined distance: 13.7 km)

Fig. 3-2

PEMS

Cumulated Emissions During Stop&Go Phase of RDE

LDV03, 6.2l, Gasoline, TWC, PFI, Start-Stop System:Off

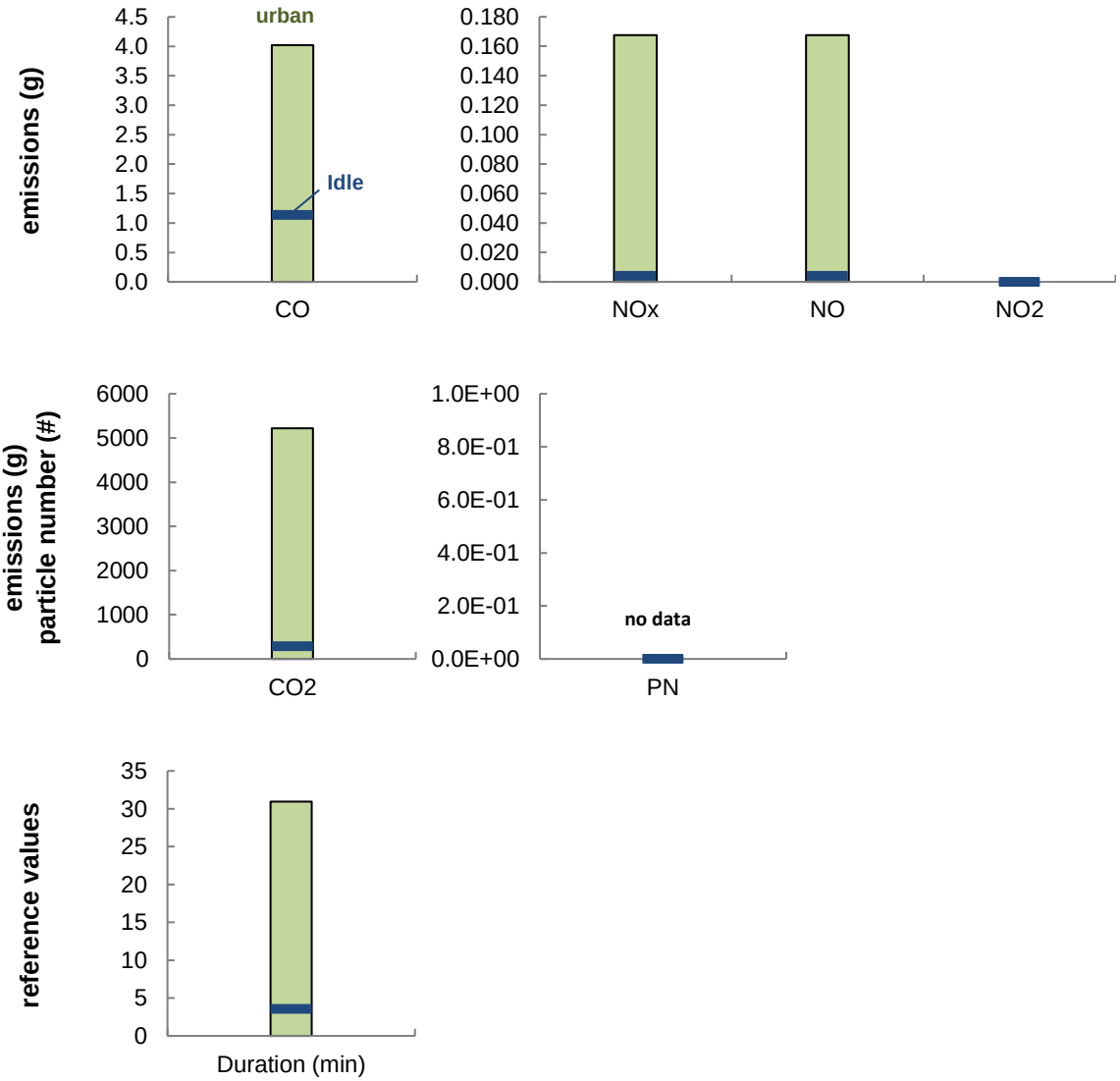


urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Cumulated Emissions During Idle Phase of RDE

LDV03, 6.2l, Gasoline, TWC, PFI, Start-Stop System:Off

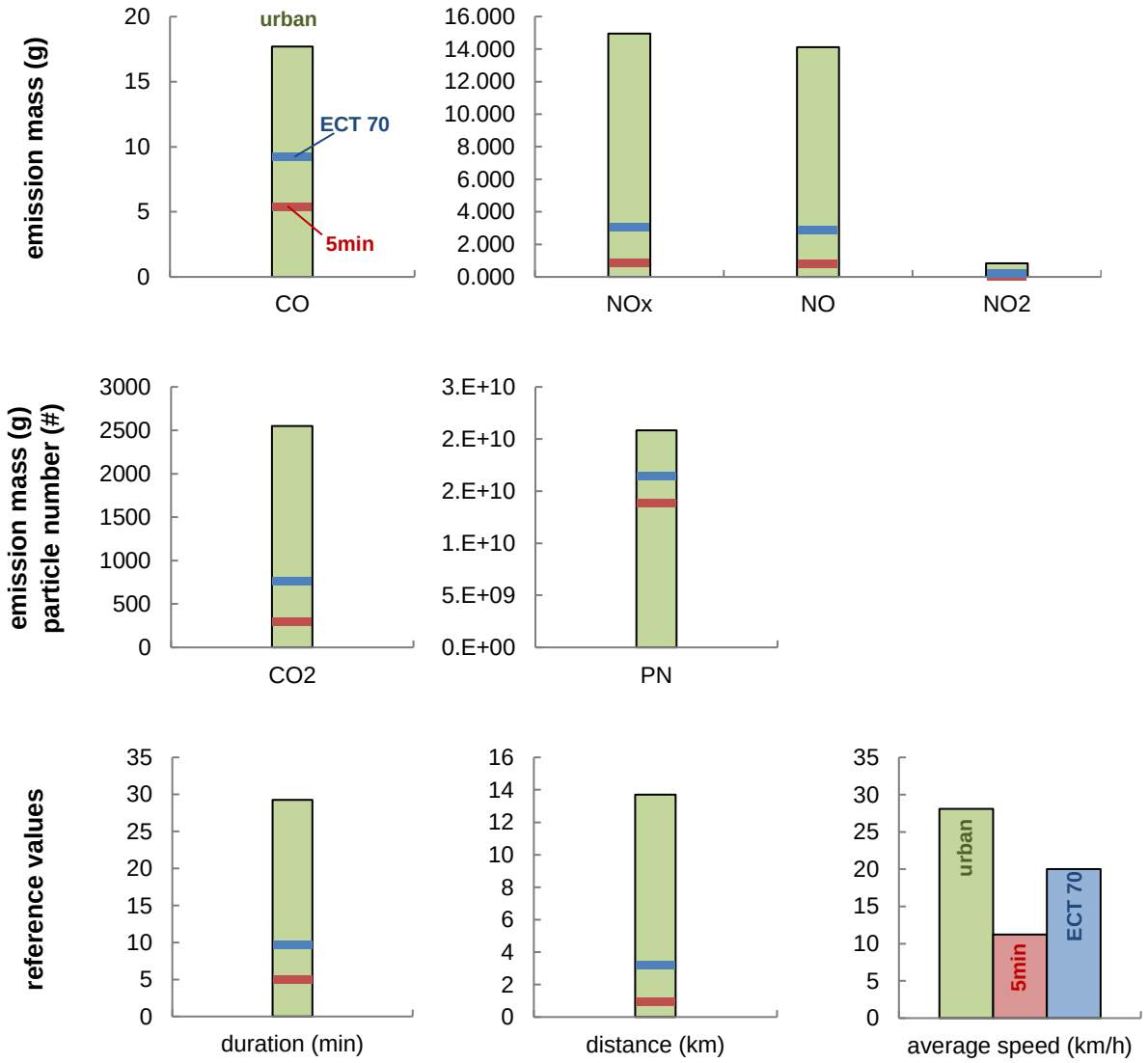


urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Cumulated Emissions During Warm-Up Phase of RDE

LDV04, 2.0l, Diesel, DOC + DPF, DI, Start-Stop System:Off



ECT 70: engine coolant temperature reaches 70°C

5min: 5 min after engine cold start

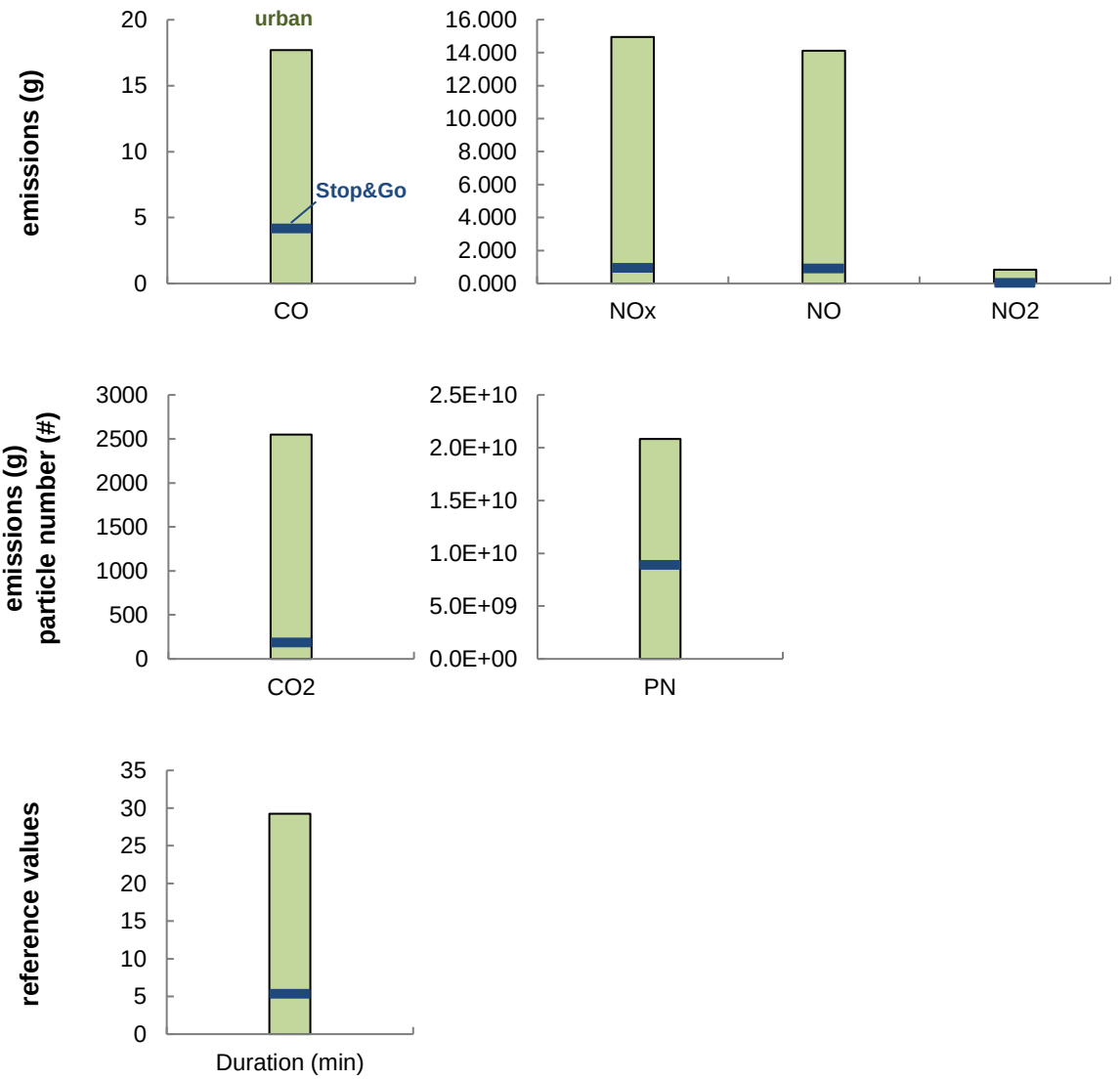
urban: part of RDE-Route (geographically defined distance: 13.7 km)

Fig. 4-2

PEMS

Cumulated Emissions During Stop&Go Phase of RDE

LDV04, 2.0l, Diesel, DOC + DPF, DI, Start-Stop System:Off

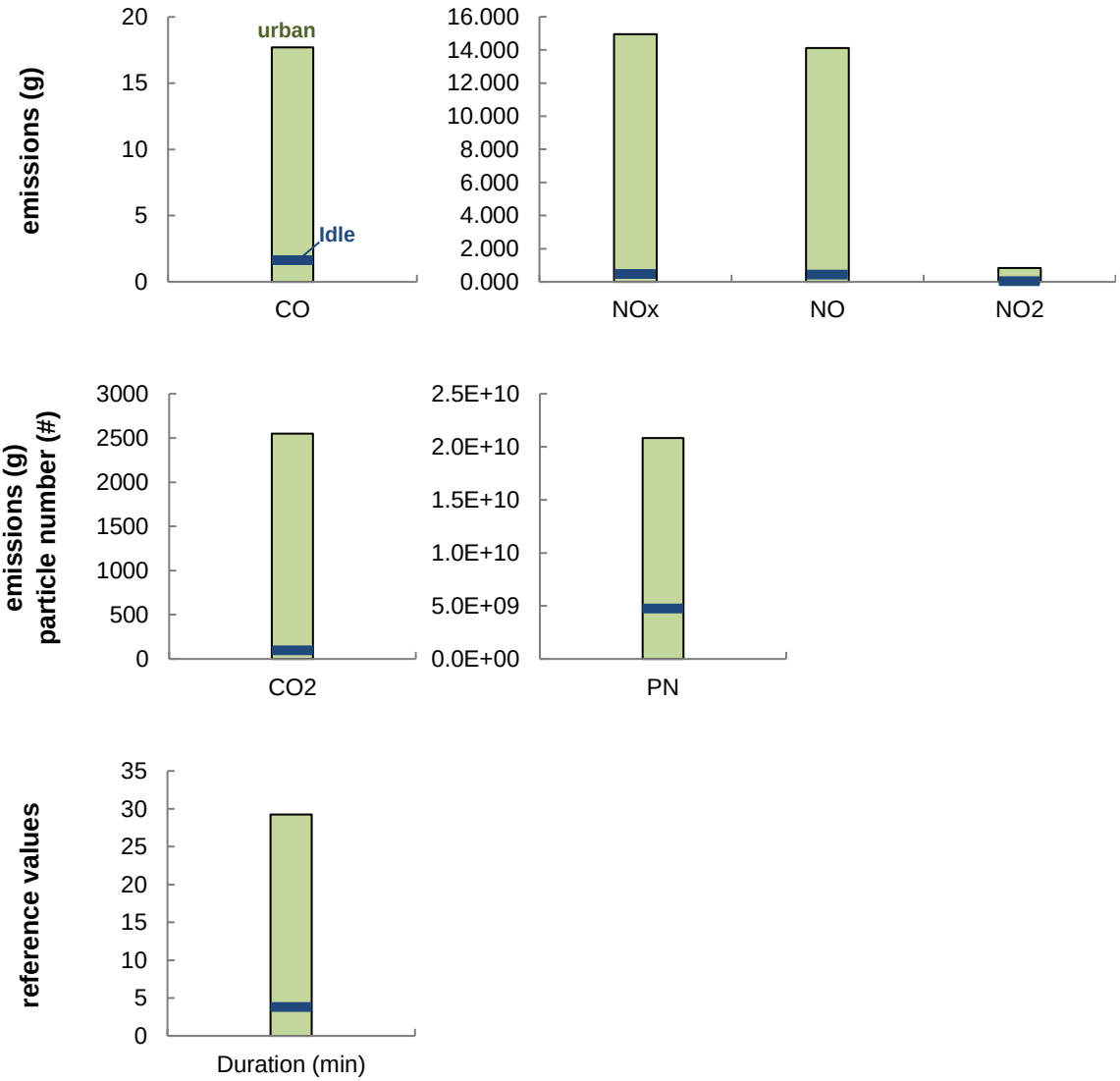


urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Cumulated Emissions During Idle Phase of RDE

LDV04, 2.0l, Diesel, DOC + DPF, DI, Start-Stop System:Off

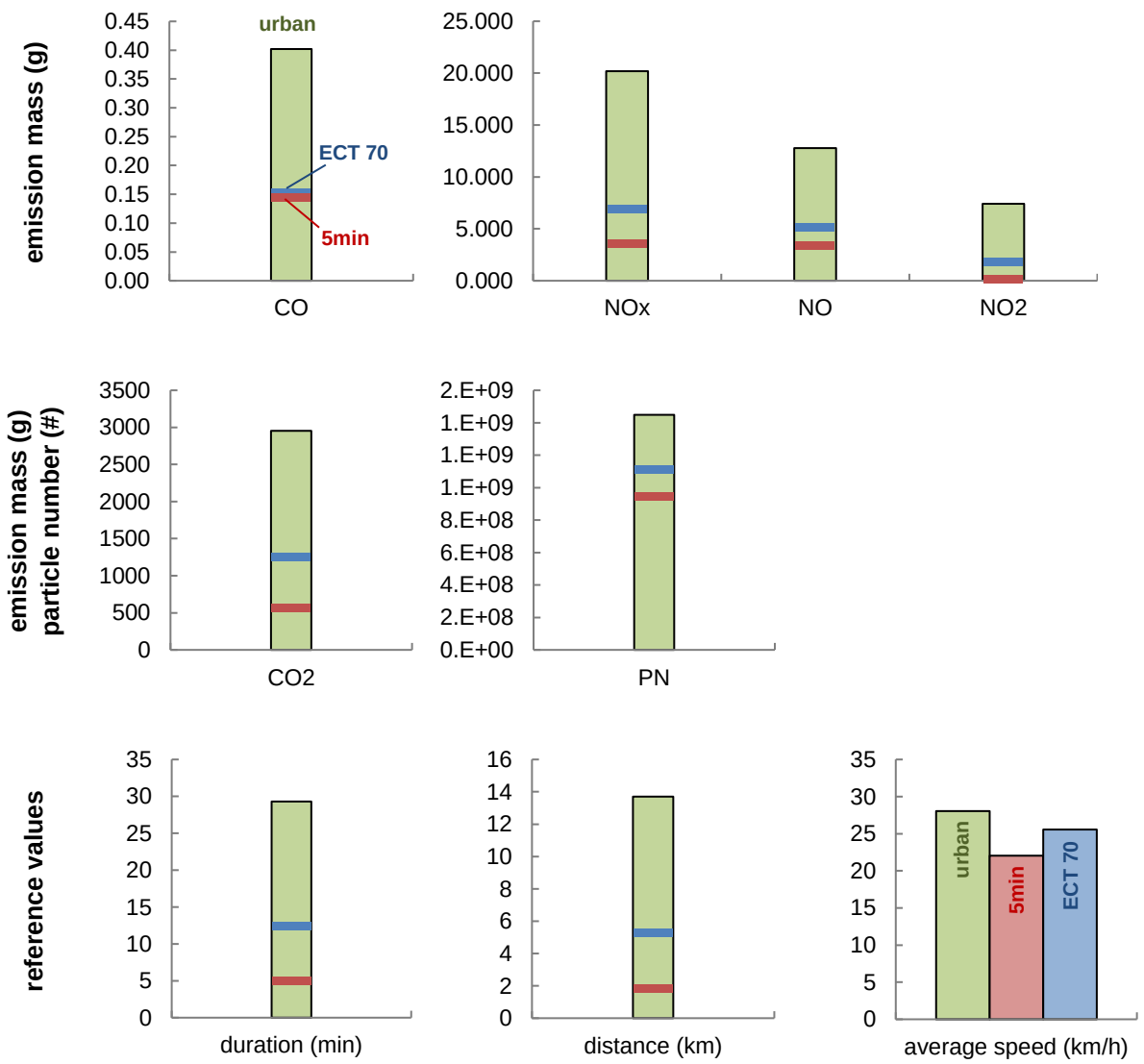


urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Cumulated Emissions During Warm-Up Phase of RDE

LDV05, 2.1l, Diesel, DOC + DPF + SCR, DI, Start-Stop System:Off



ECT 70: engine coolant temperature reaches 70°C

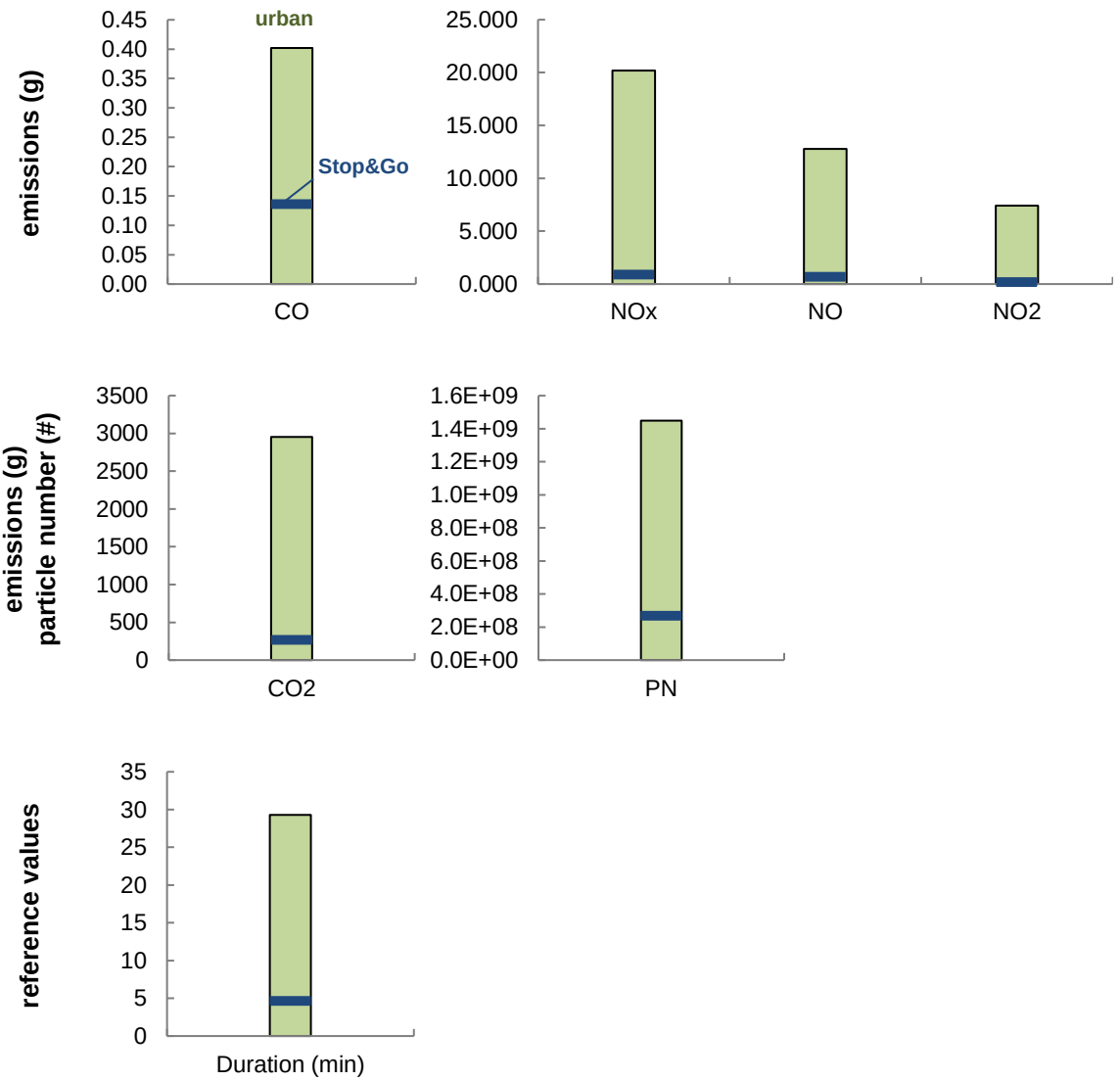
5min: 5 min after engine cold start

urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Cumulated Emissions During Stop&Go Phase of RDE

LDV05, 2.1l, Diesel, DOC + DPF + SCR, DI, Start-Stop System:Off



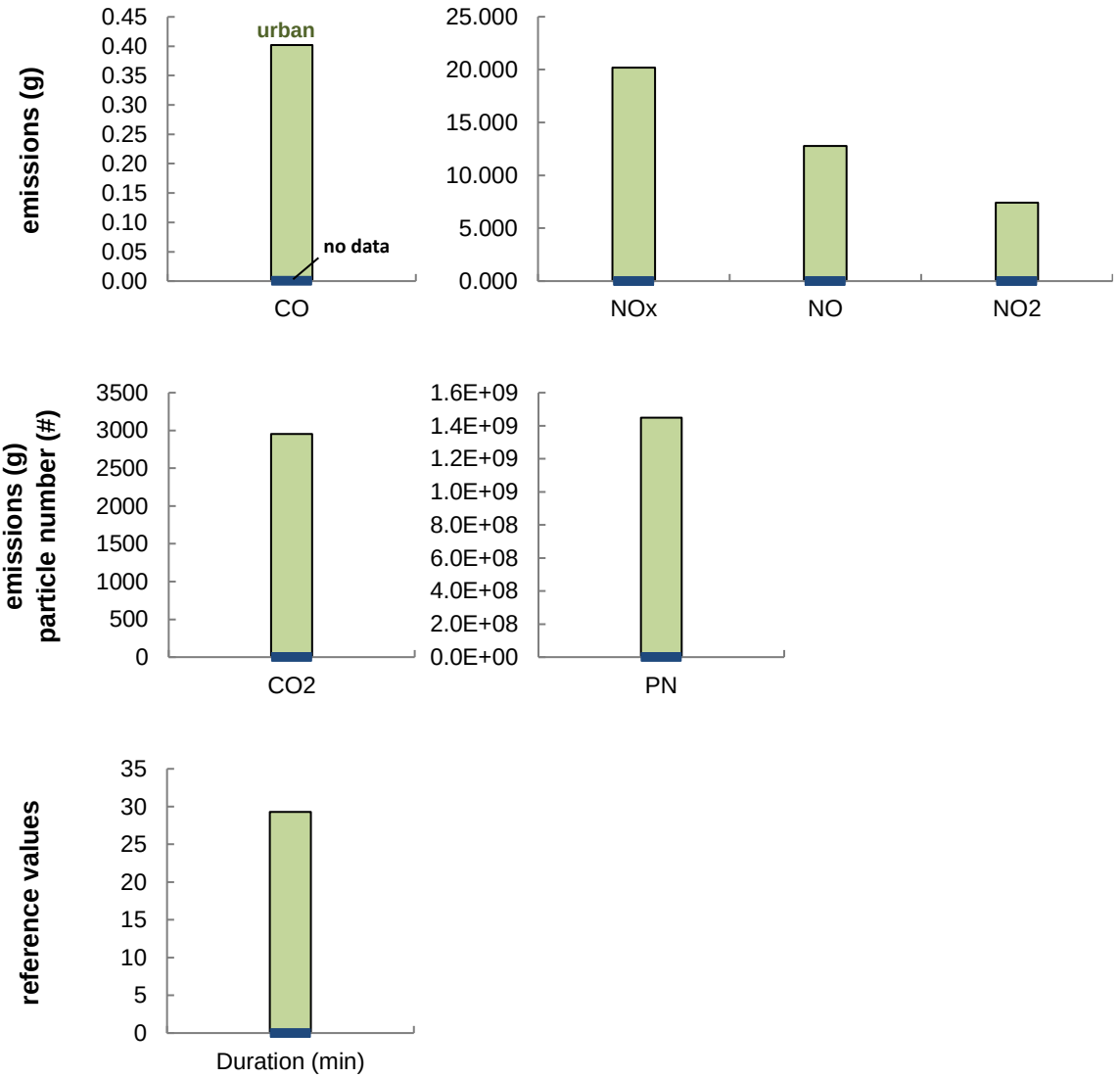
urban: part of RDE-Route (geographically defined distance: 13.7 km)

Fig. 5-3

PEMS

Cumulated Emissions During Idle Phase of RDE

LDV05, 2.1l, Diesel, DOC + DPF + SCR, DI, Start-Stop System:Off

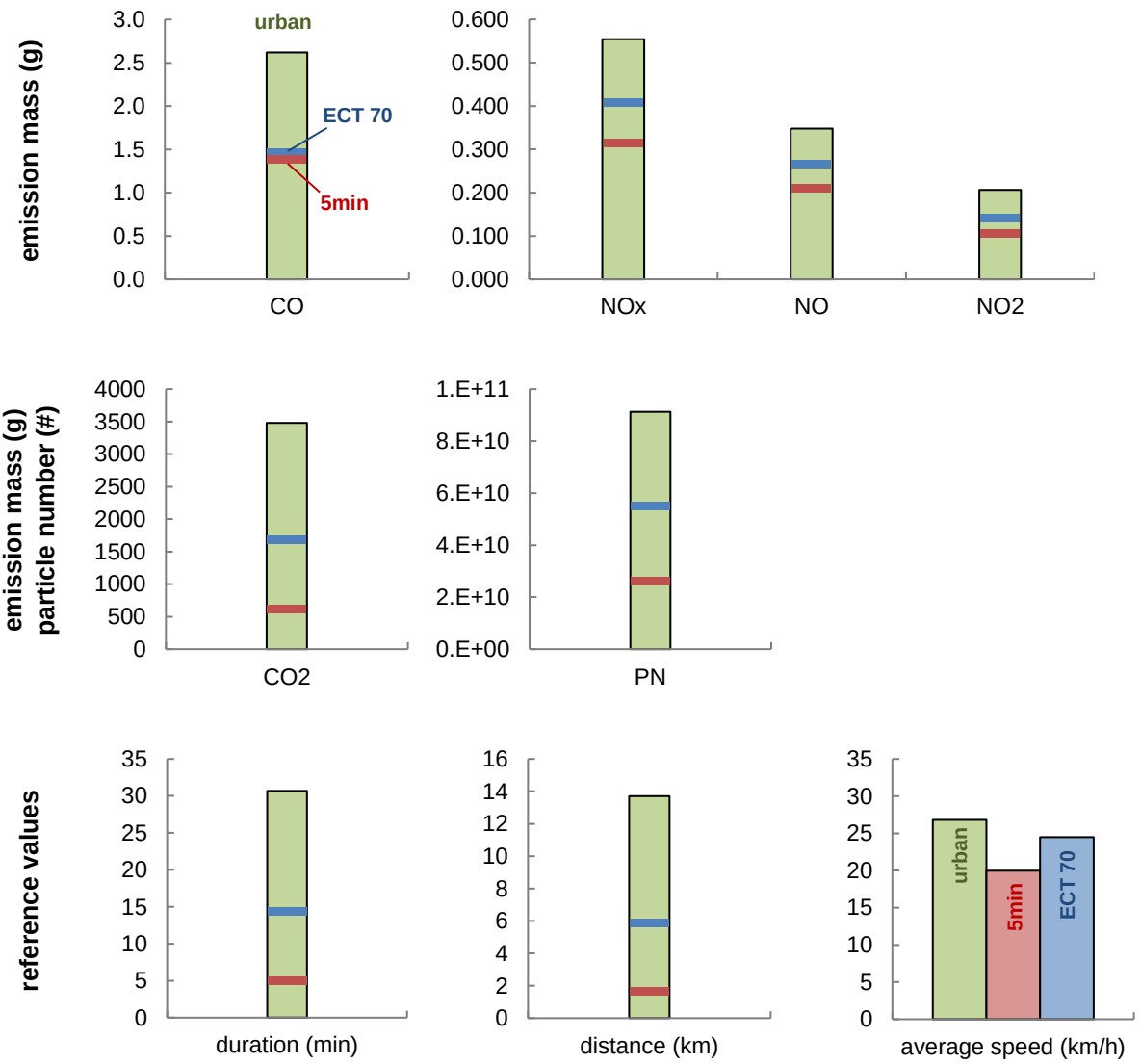


urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Cumulated Emissions During Warm-Up Phase of RDE

LDV06, 3.0l, Diesel, DOC + DPF + SCR, DI, Start-Stop System:Off



ECT 70: engine coolant temperature reaches 70°C

5min: 5 min after engine cold start

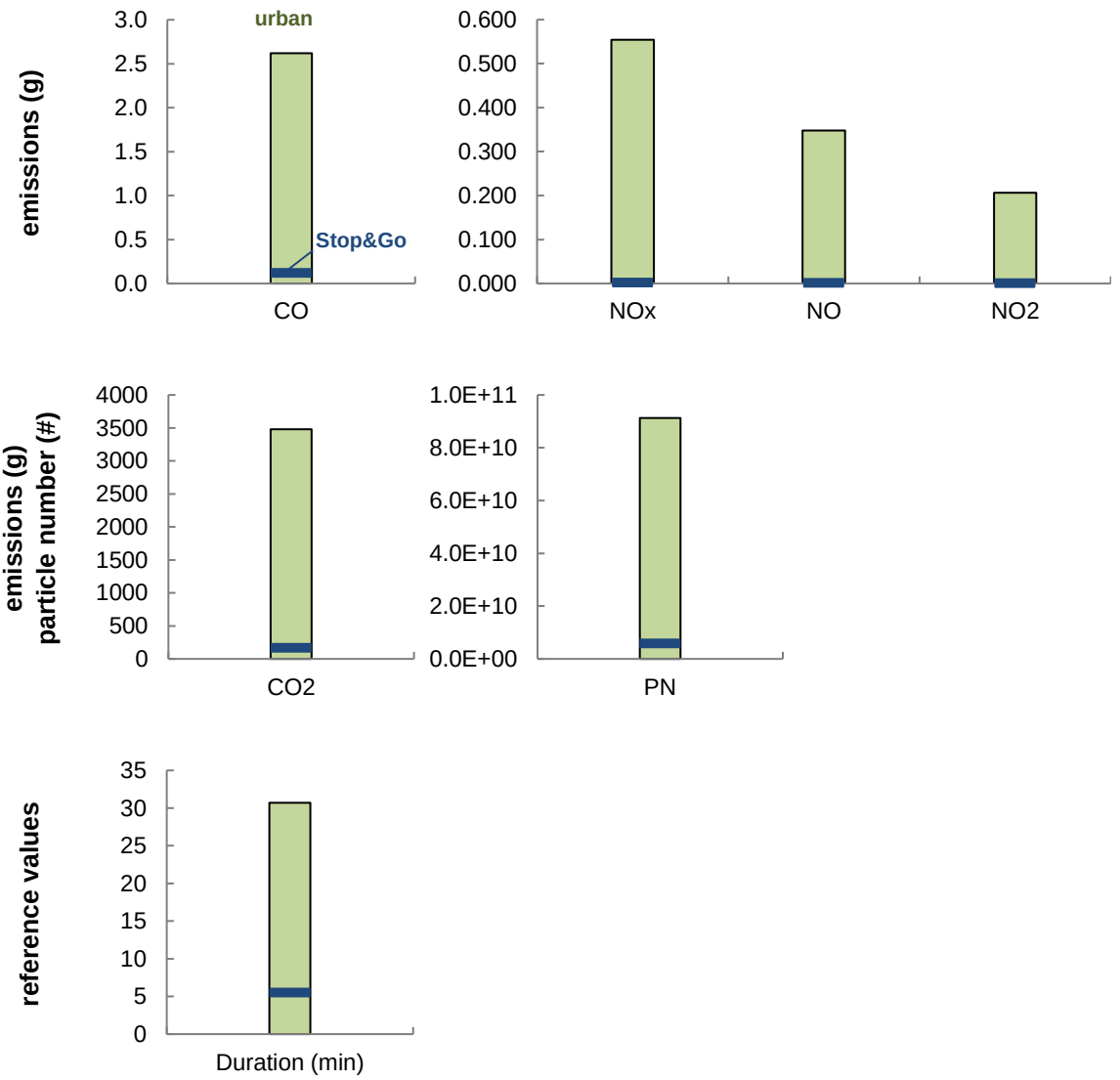
urban: part of RDE-Route (geographically defined distance: 13.7 km)

Fig. 6-2

PEMS

Cumulated Emissions During Stop&Go Phase of RDE

LDV06, 3.0l, Diesel, DOC + DPF + SCR, DI, Start-Stop System:Off



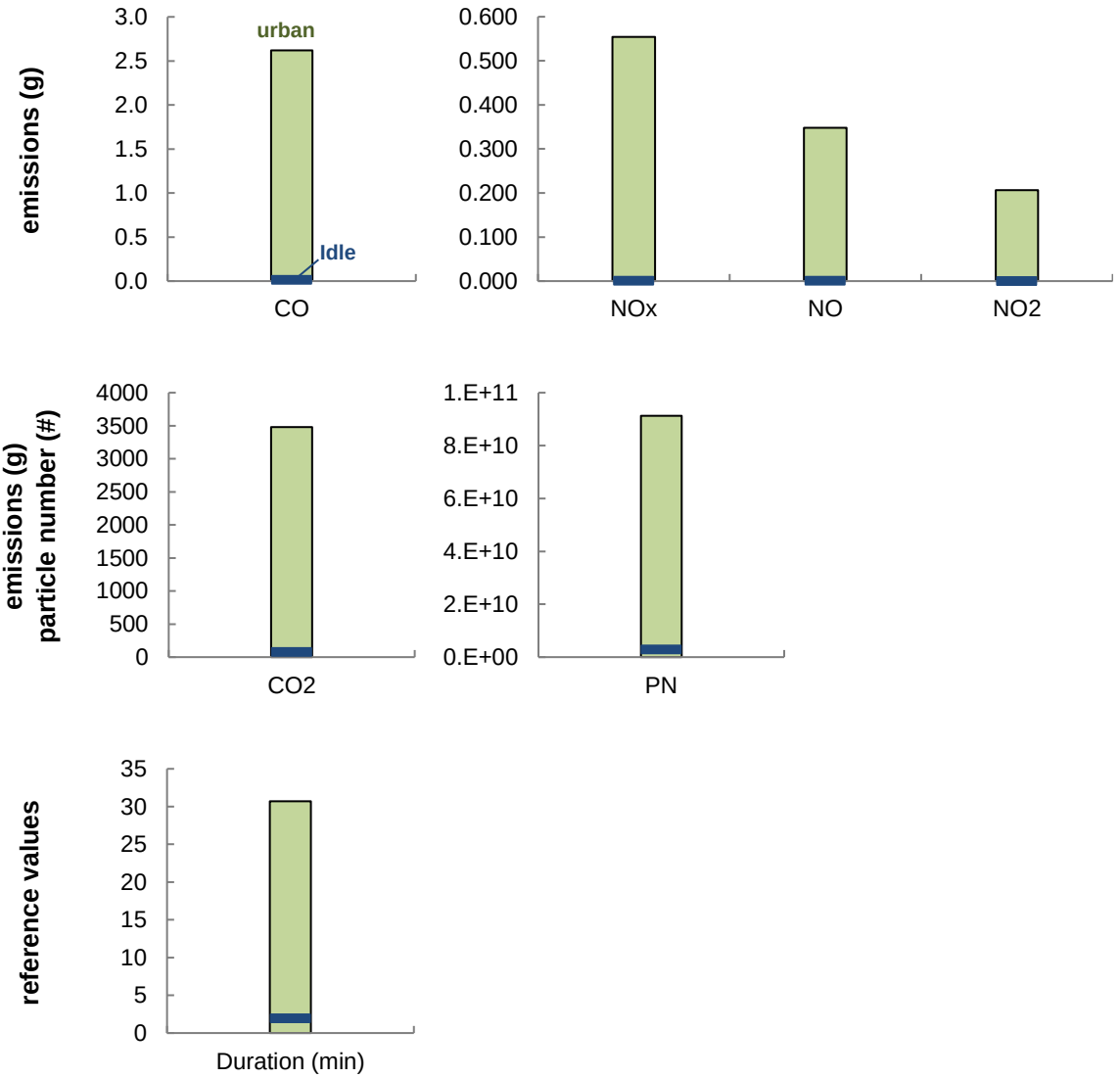
urban: part of RDE-Route (geographically defined distance: 13.7 km)

Fig. 6-3

PEMS

Cumulated Emissions During Idle Phase of RDE

LDV06, 3.0l, Diesel, DOC + DPF + SCR, DI, Start-Stop System:Off

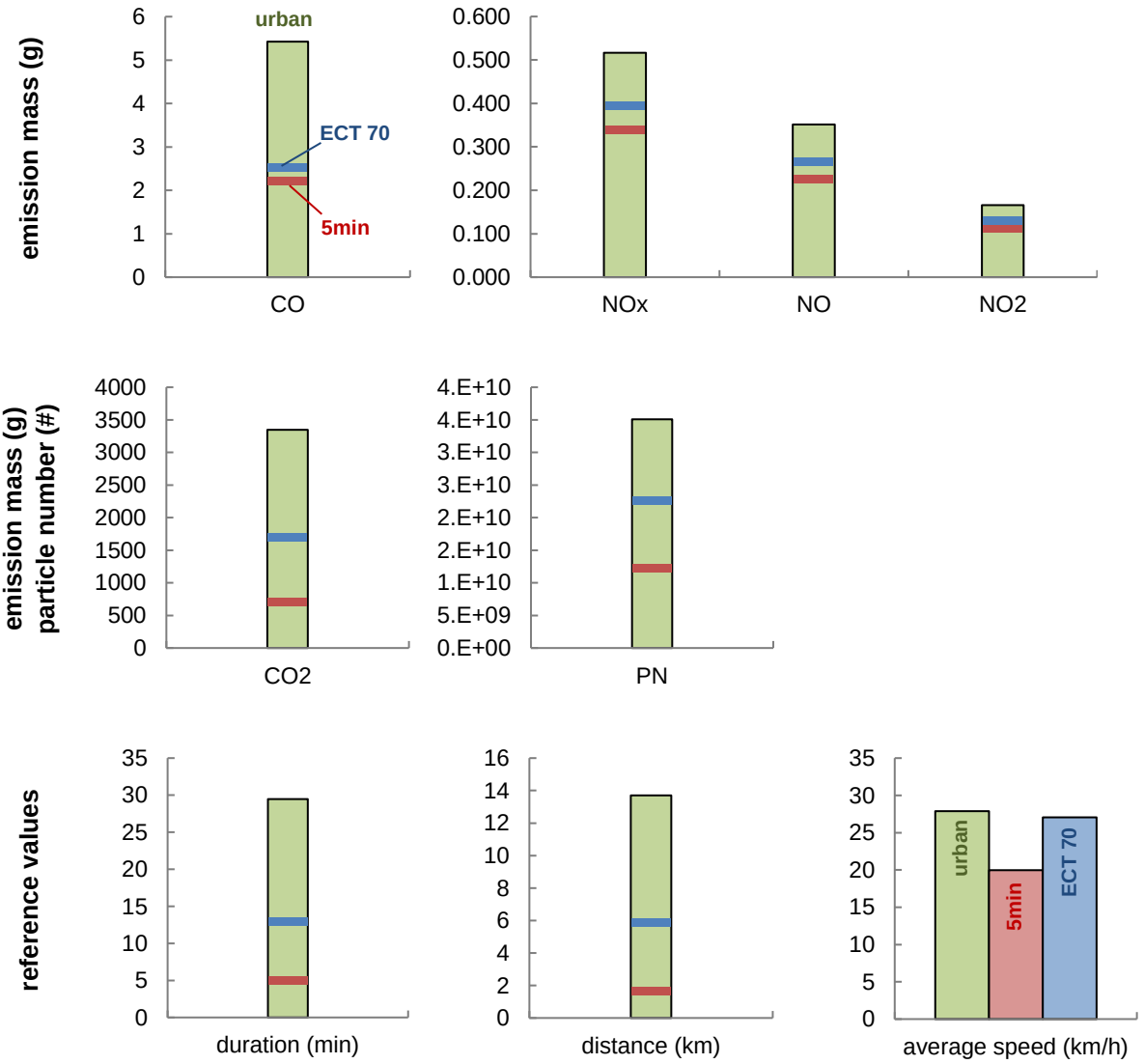


urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Cumulated Emissions During Warm-Up Phase of RDE

LDV07, 3.0l, Diesel, DOC + DPF + SCR, DI, Start-Stop System:On



ECT 70: engine coolant temperature reaches 70°C

5min: 5 min after engine cold start

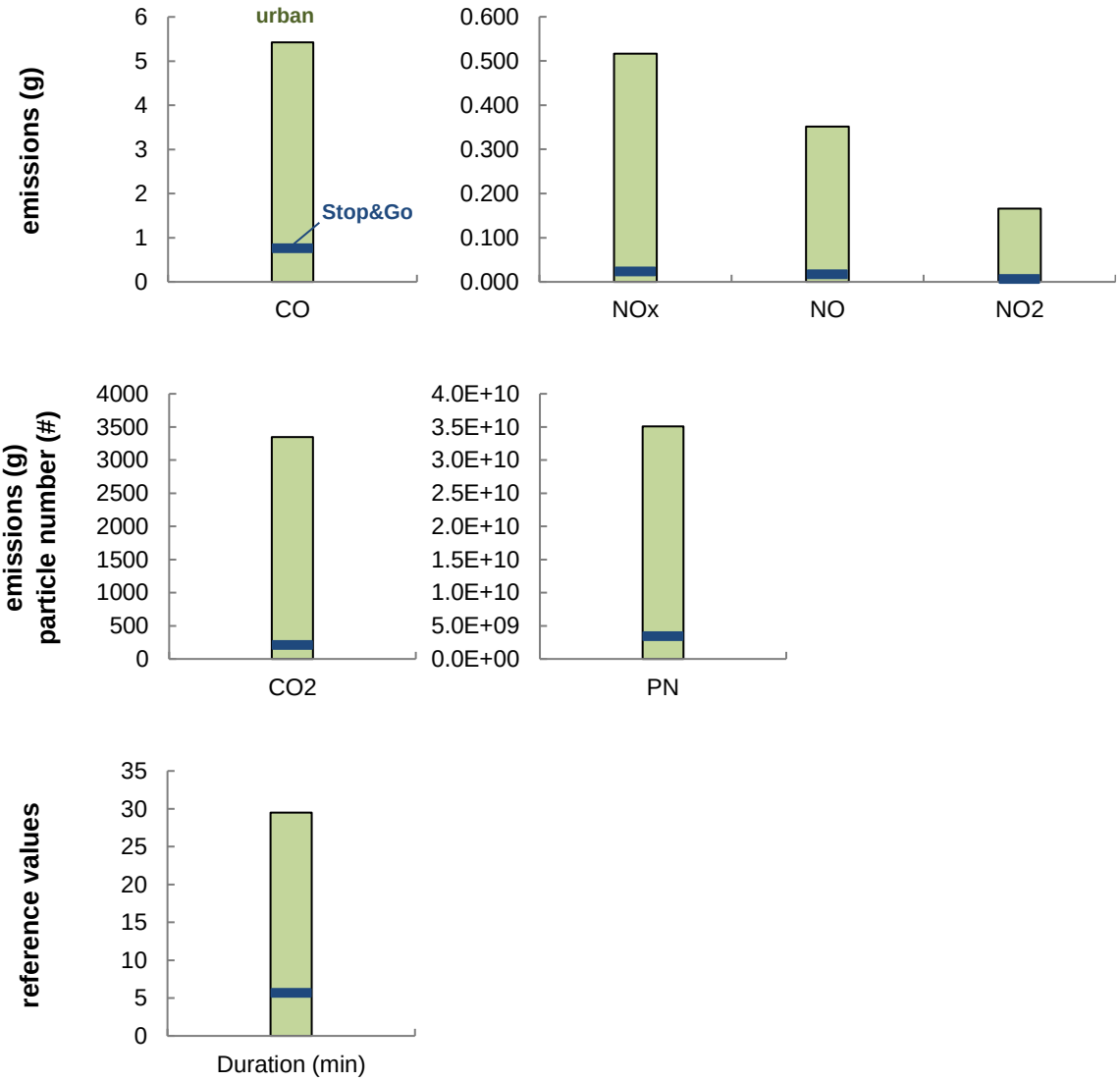
urban: part of RDE-Route (geographically defined distance: 13.7 km)

Fig. 7-2

PEMS

Cumulated Emissions During Stop&Go Phase of RDE

LDV07, 3.0l, Diesel, DOC + DPF + SCR, DI, Start-Stop System:On



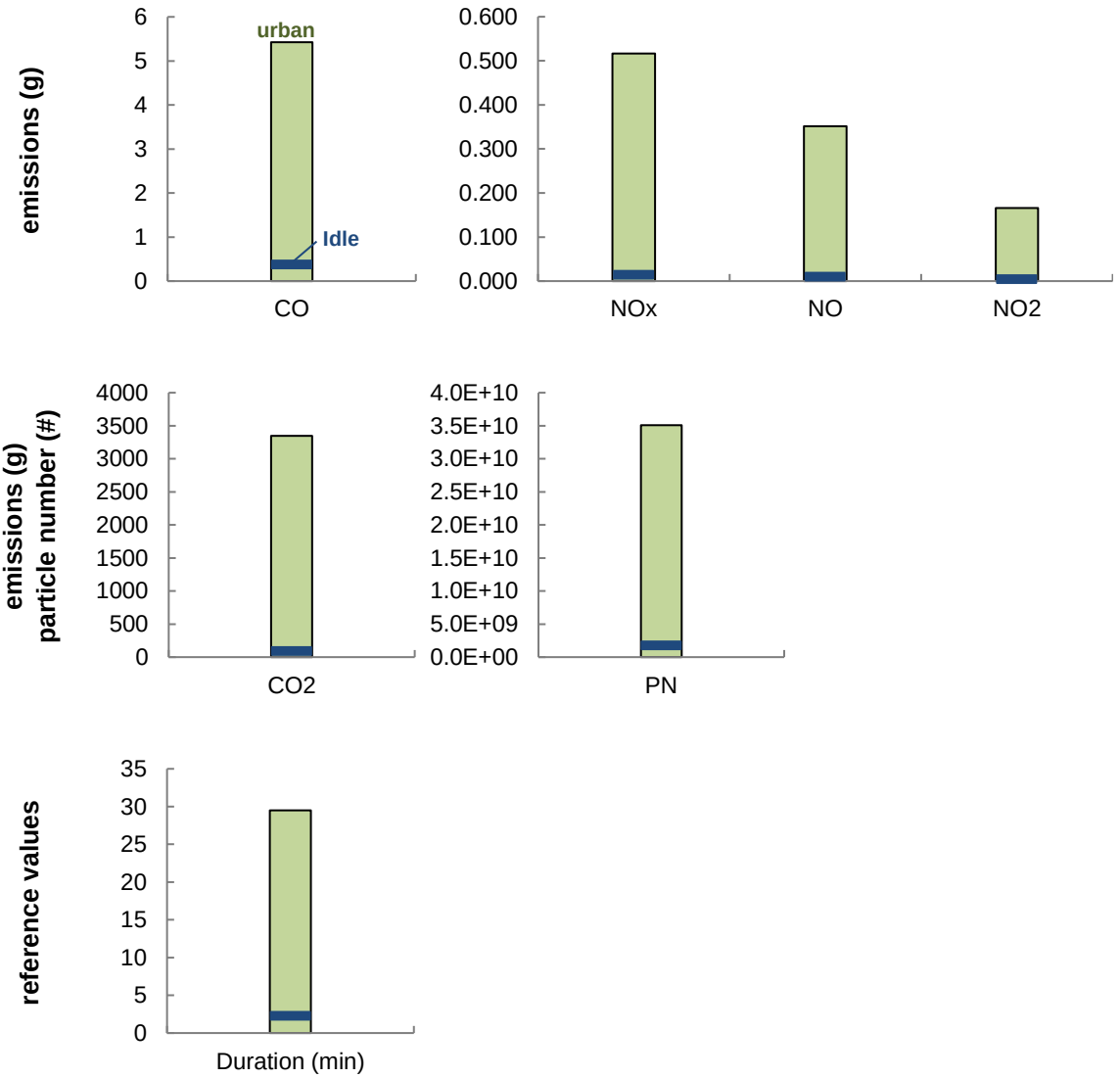
urban: part of RDE-Route (geographically defined distance: 13.7 km)

Fig. 7-3

PEMS

Cumulated Emissions During Idle Phase of RDE

LDV07, 3.0l, Diesel, DOC + DPF + SCR, DI, Start-Stop System:On



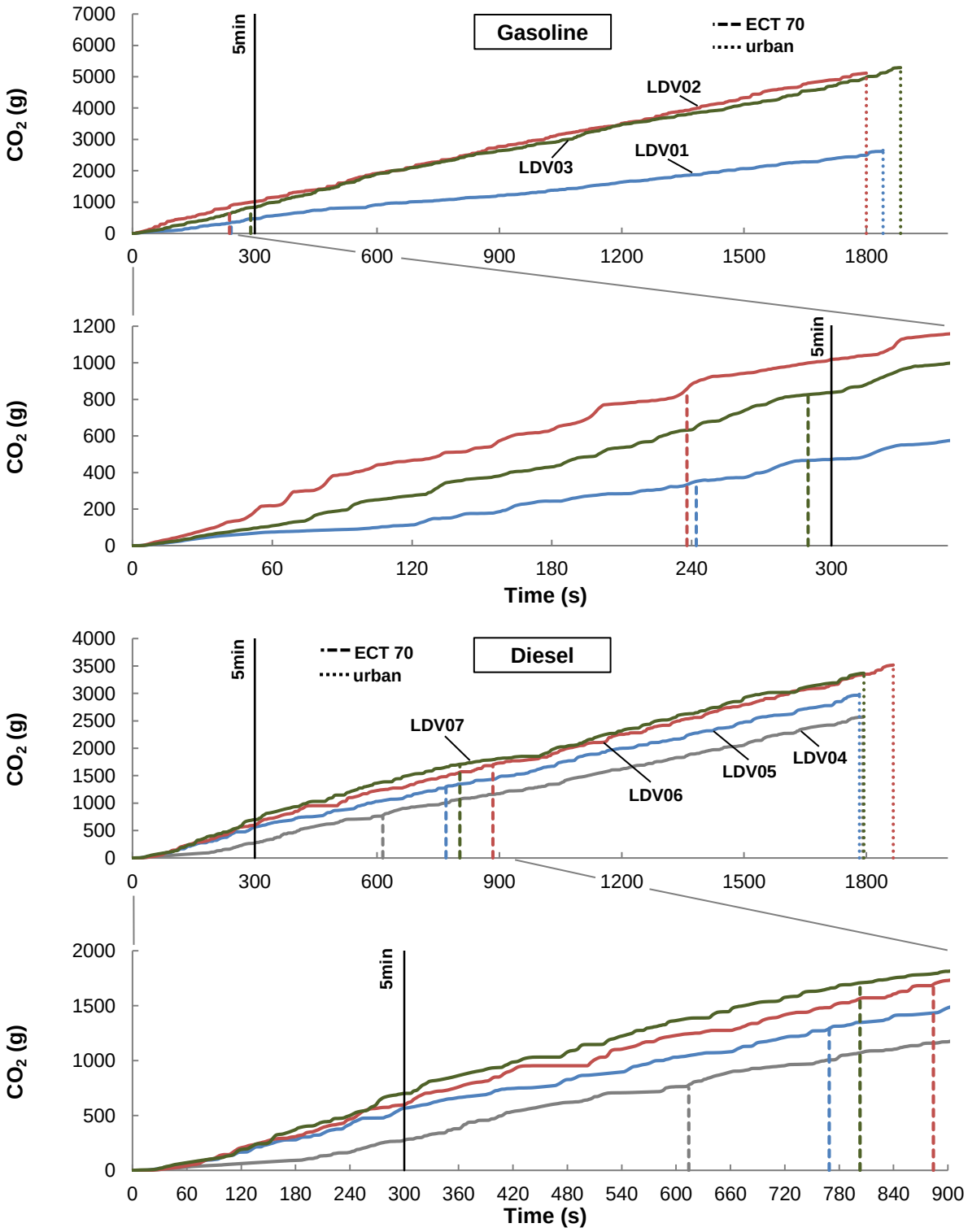
urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Emissions During Warm-Up Phase of RDE

Comparison of Cumulated CO_2, Vehicles LDV01 - LDV07

Engine Start @ Time = 0 s



ECT 70: engine coolant temperature reaches 70°C

5min: 5 min after engine cold start

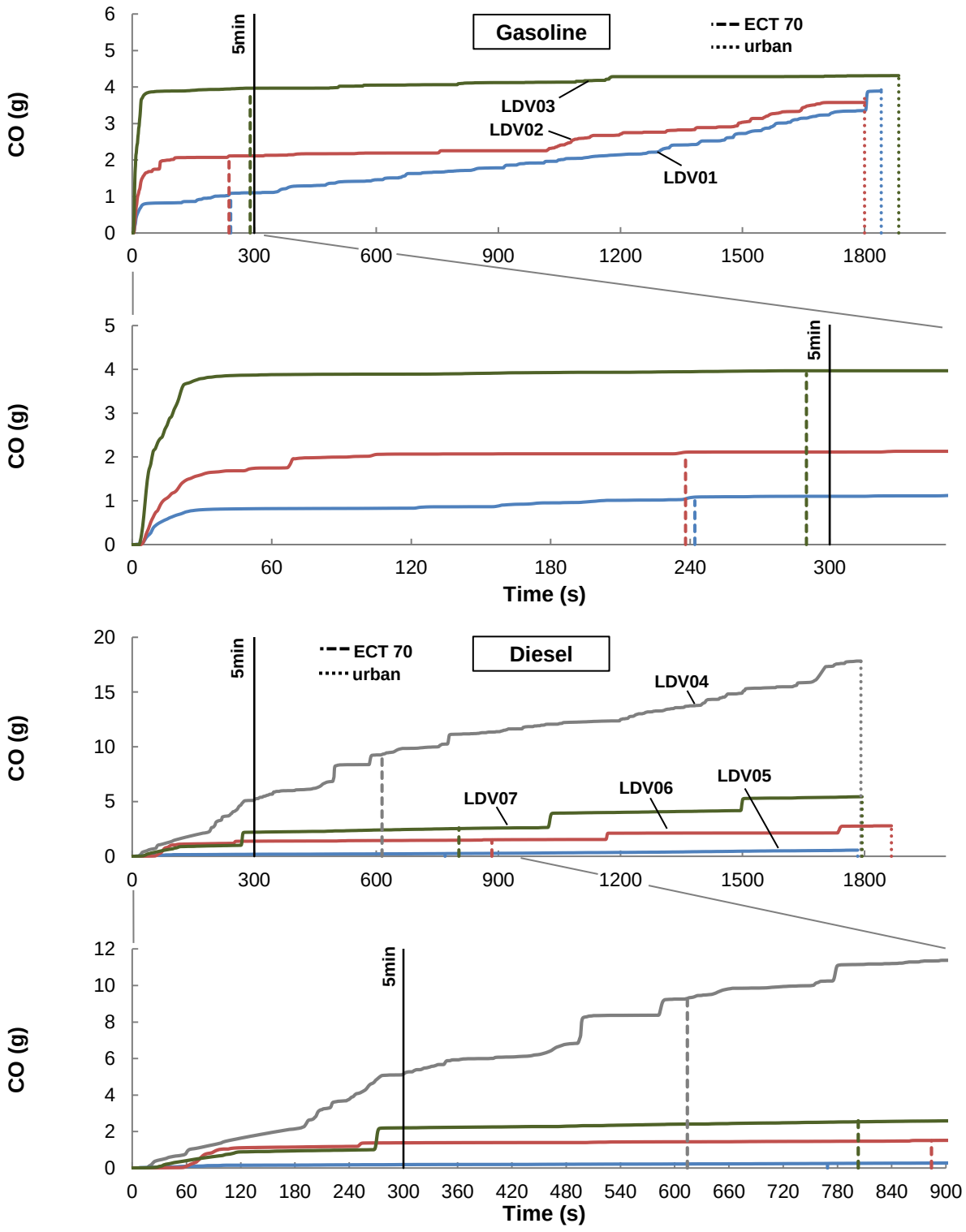
urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Emissions During Warm-Up Phase of RDE

Comparison of Cumulated CO, Vehicles LDV01 - LDV07

Engine Start @ Time = 0 s



ECT 70: engine coolant temperature reaches 70°C

5min: 5 min after engine cold start

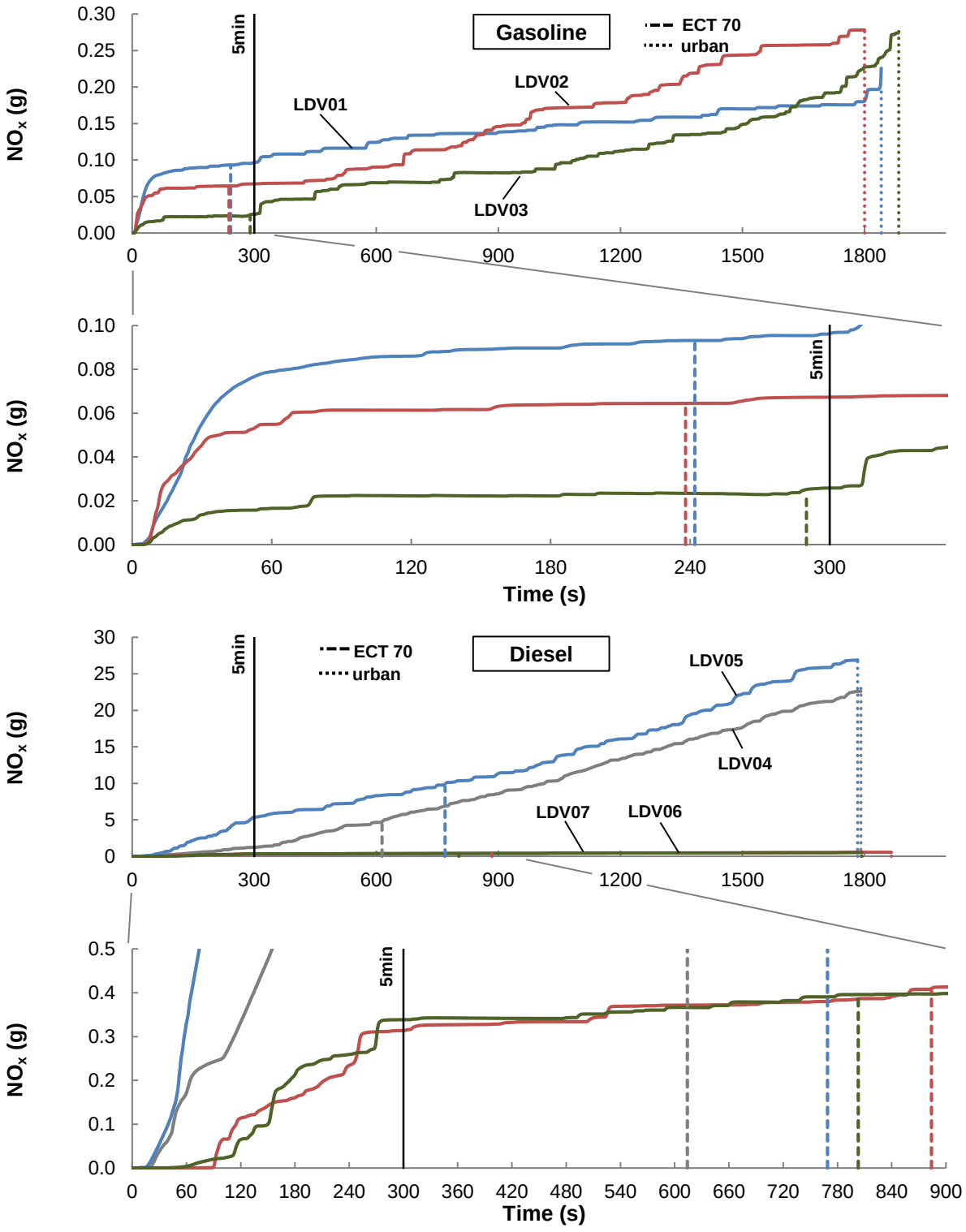
urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Emissions During Warm-Up Phase of RDE

Comparison of Cumulated NO_x, Vehicles LDV01 - LDV07

Engine Start @ Time = 0 s



ECT 70: engine coolant temperature reaches 70°C

5min: 5 min after engine cold start

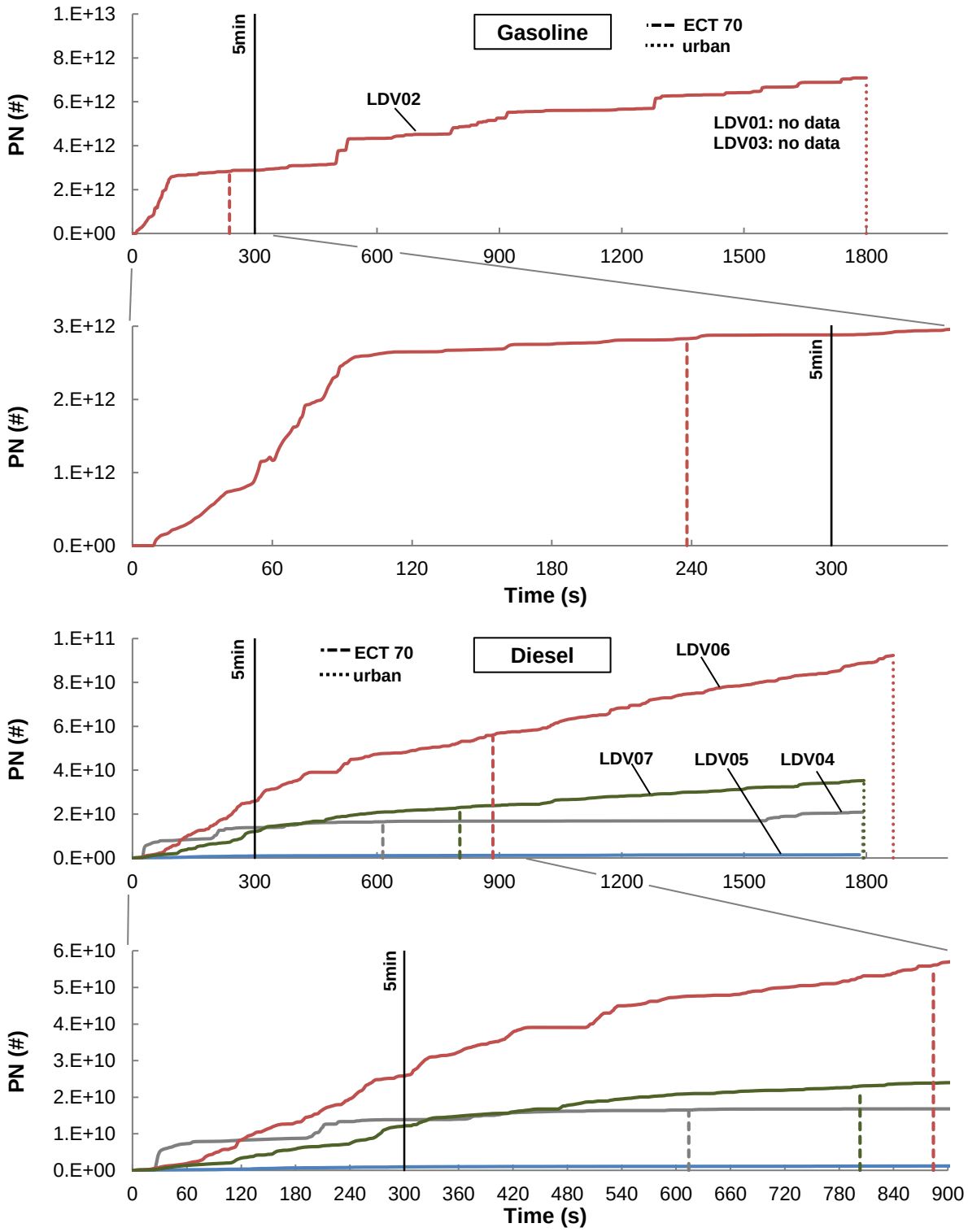
urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Emissions During Warm-Up Phase of RDE

Comparison of Cumulated PN, Vehicles LDV01 - LDV07

Engine Start @ Time = 0 s



ECT 70: engine coolant temperature reaches 70°C

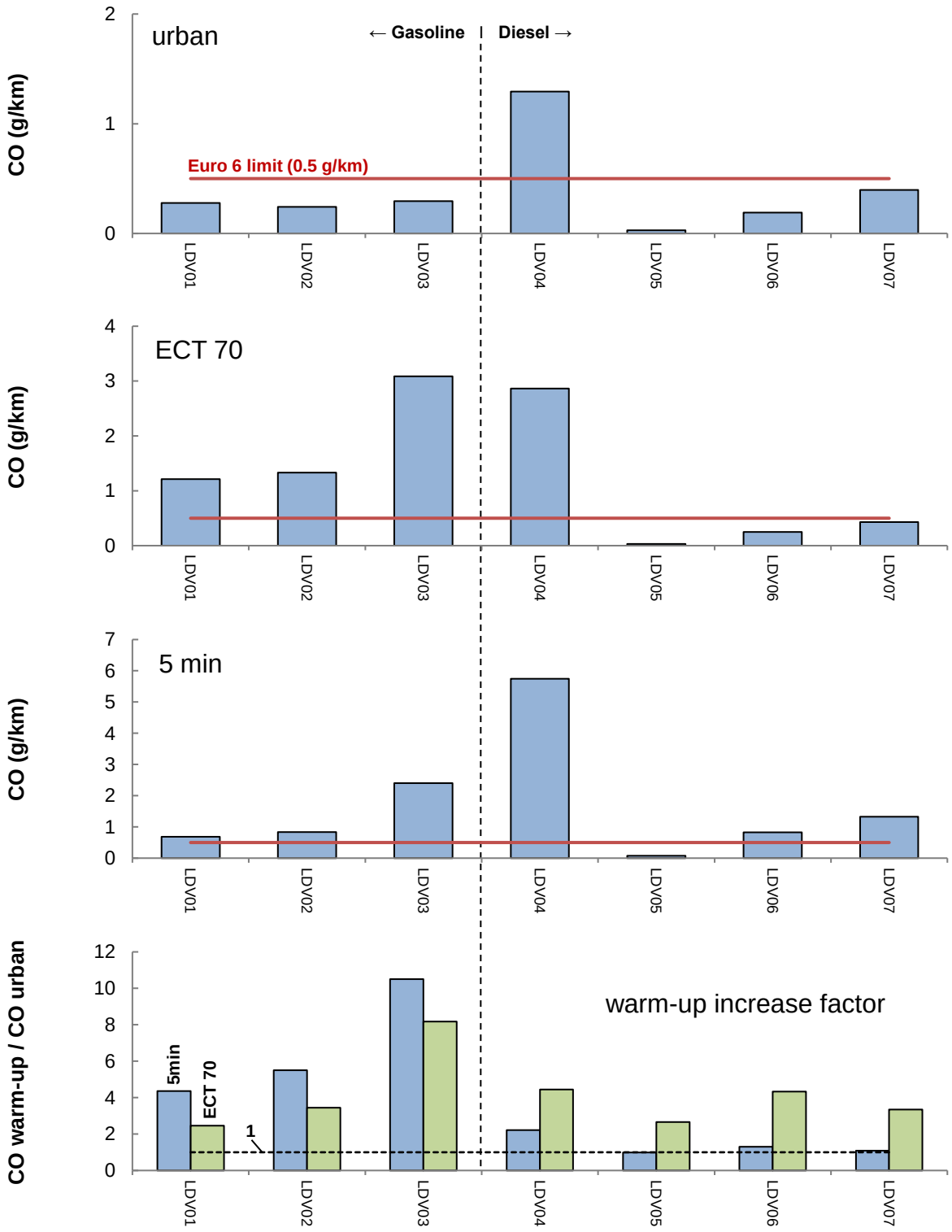
5min: 5 min after engine cold start

urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Emissions During Warm-Up Phase of RDE

Comparison of CO Emissions per km, Vehicles LDV01 - LDV07



ECT 70: engine coolant temperature reaches 70°C

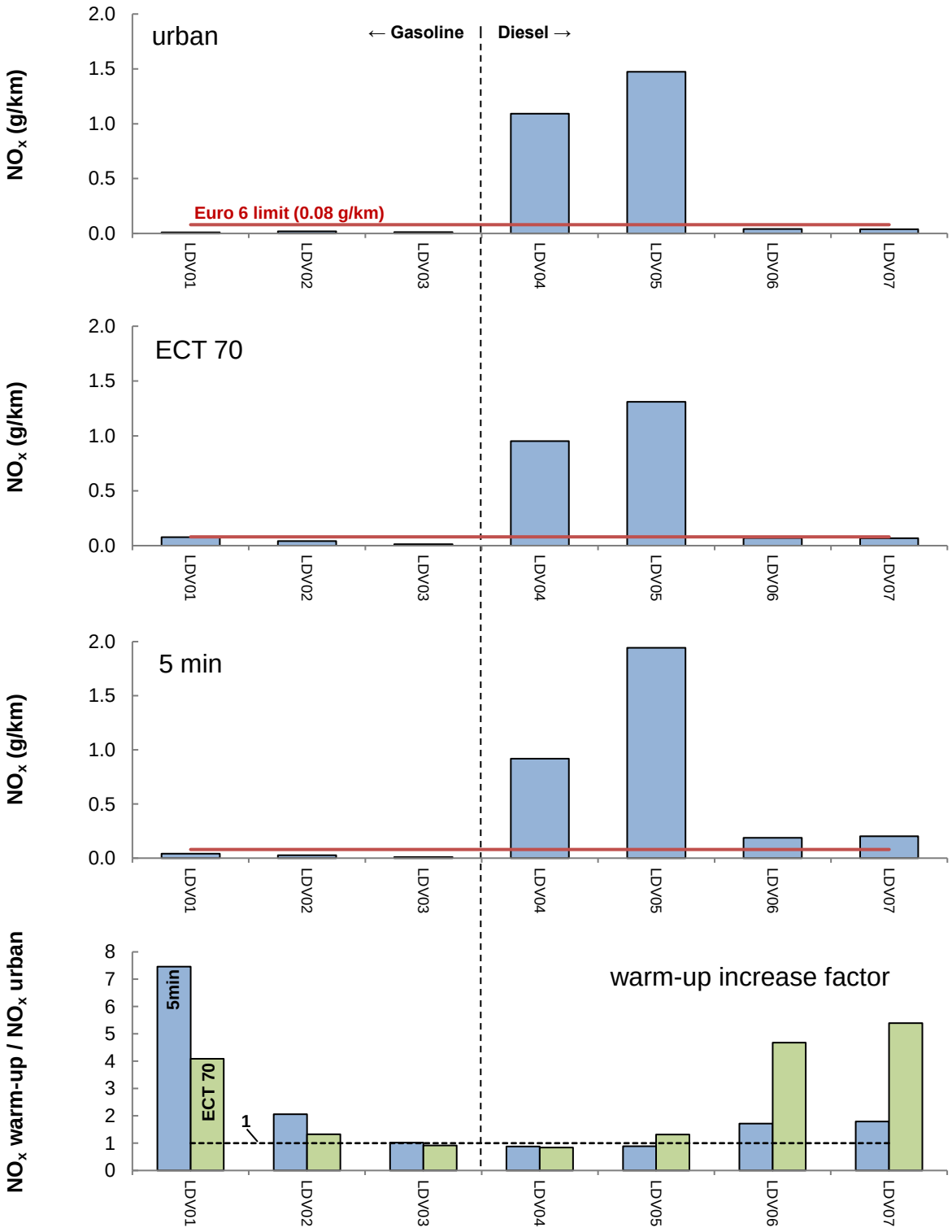
5min: 5 min after engine cold start

urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Emissions During Warm-Up Phase of RDE

Comparison of NO_x Emissions per km, Vehicles LDV01 - LDV07



ECT 70: engine coolant temperature reaches 70°C

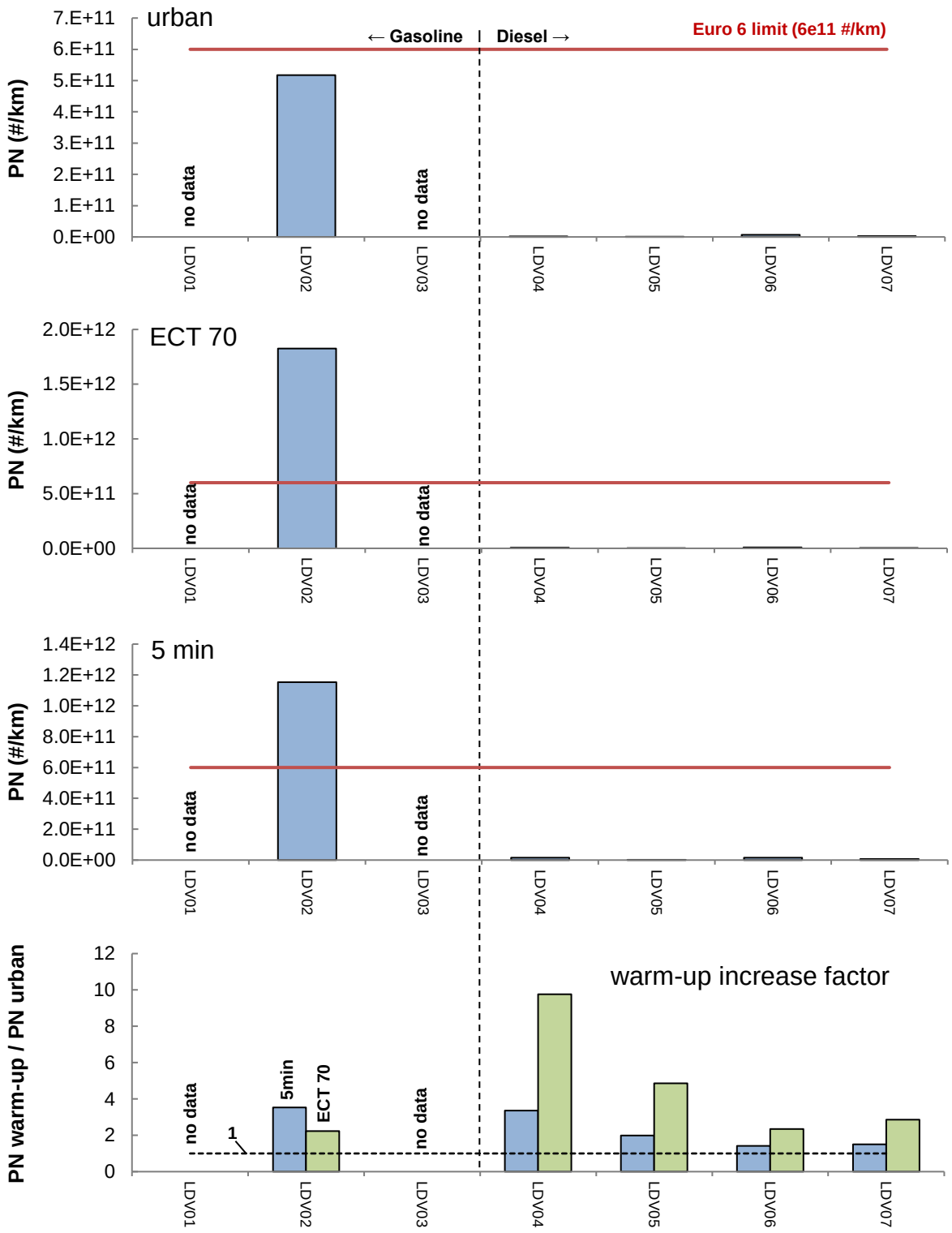
5min: 5 min after engine cold start

urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Emissions During Warm-Up Phase of RDE

Comparison of PN Emissions per km, Vehicles LDV01 - LDV07



ECT 70: engine coolant temperature reaches 70°C

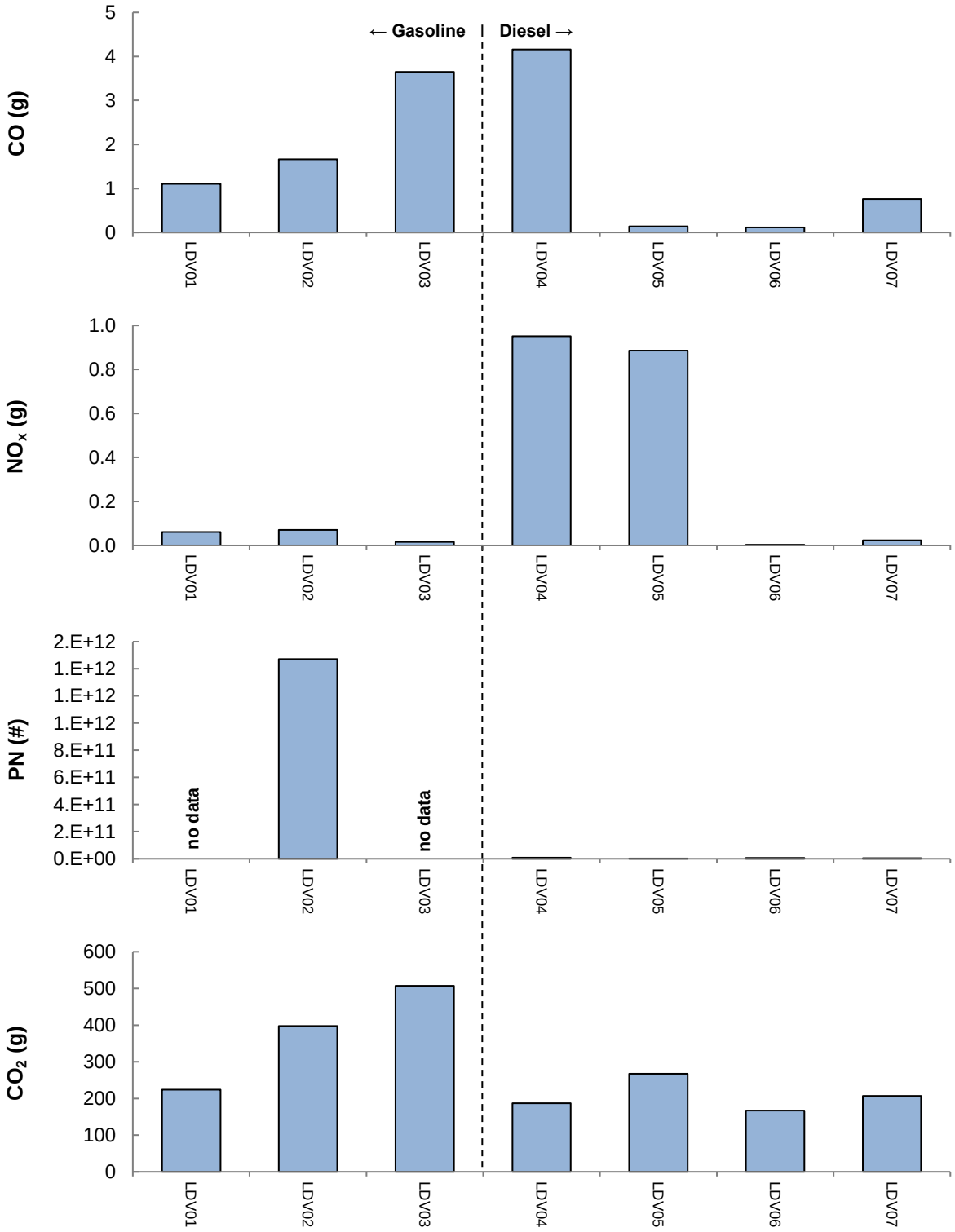
5min: 5 min after engine cold start

urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Emissions During Stop&Go Phase of RDE

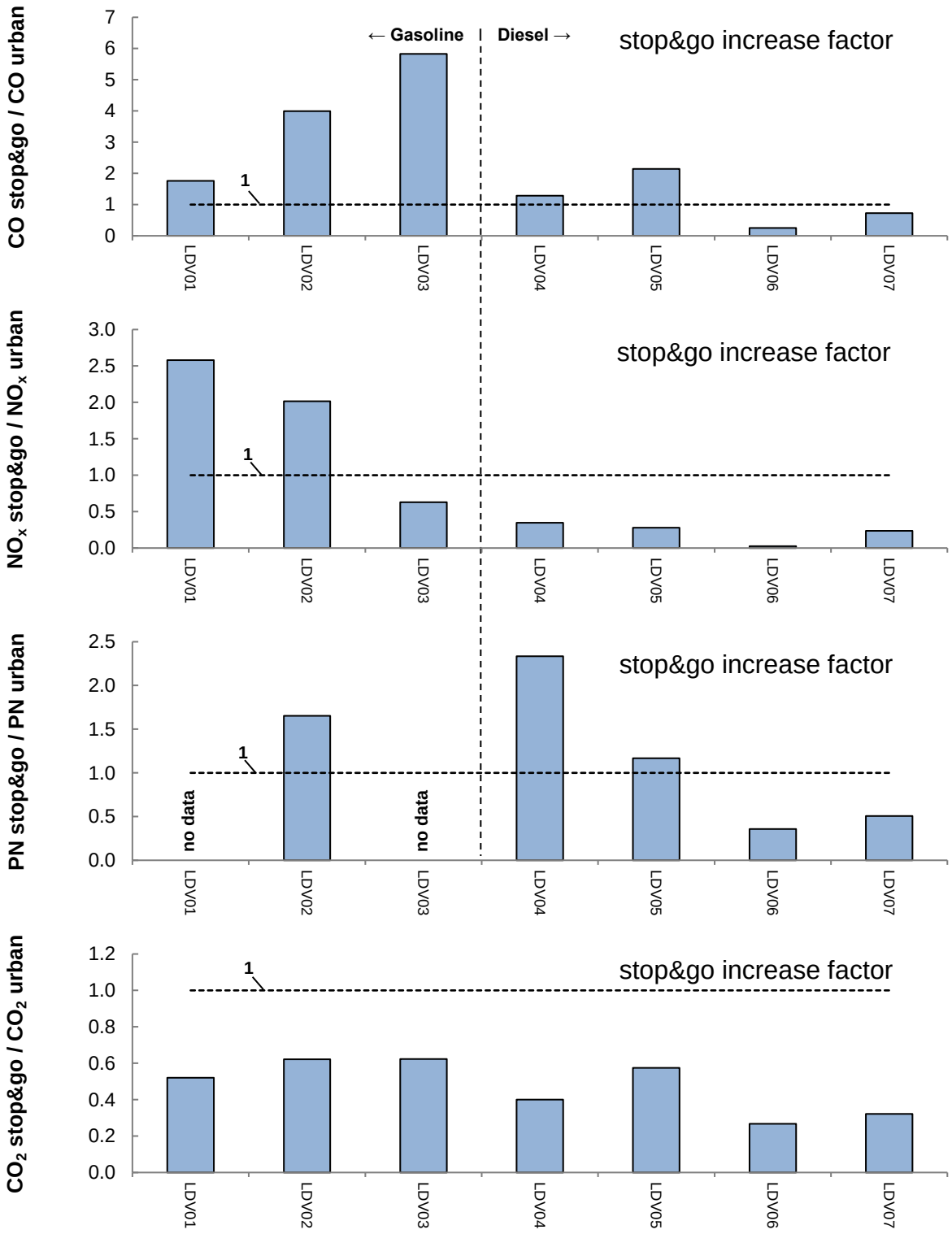
Comparison of Cumulated Emissions, Vehicles LDV01 - LDV07



PEMS

Emissions During Stop&Go Phase of RDE

Comparison of Emissions Stop&Go / Urban, Vehicles LDV01 - LDV07



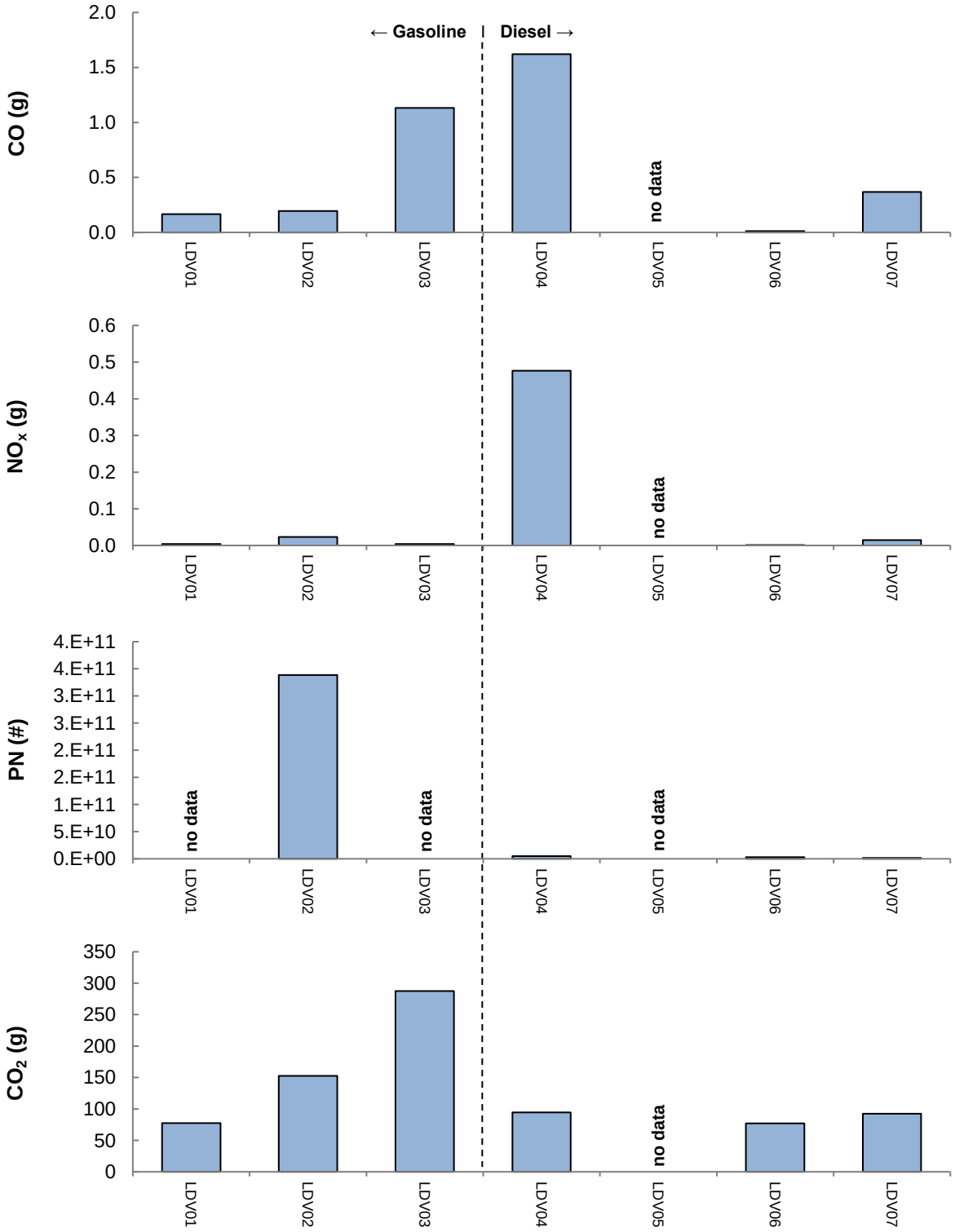
urban: part of RDE-Route (geographically defined distance: 13.7 km)

Fig. 10-1

PEMS

Emissions During Idle Phase of RDE

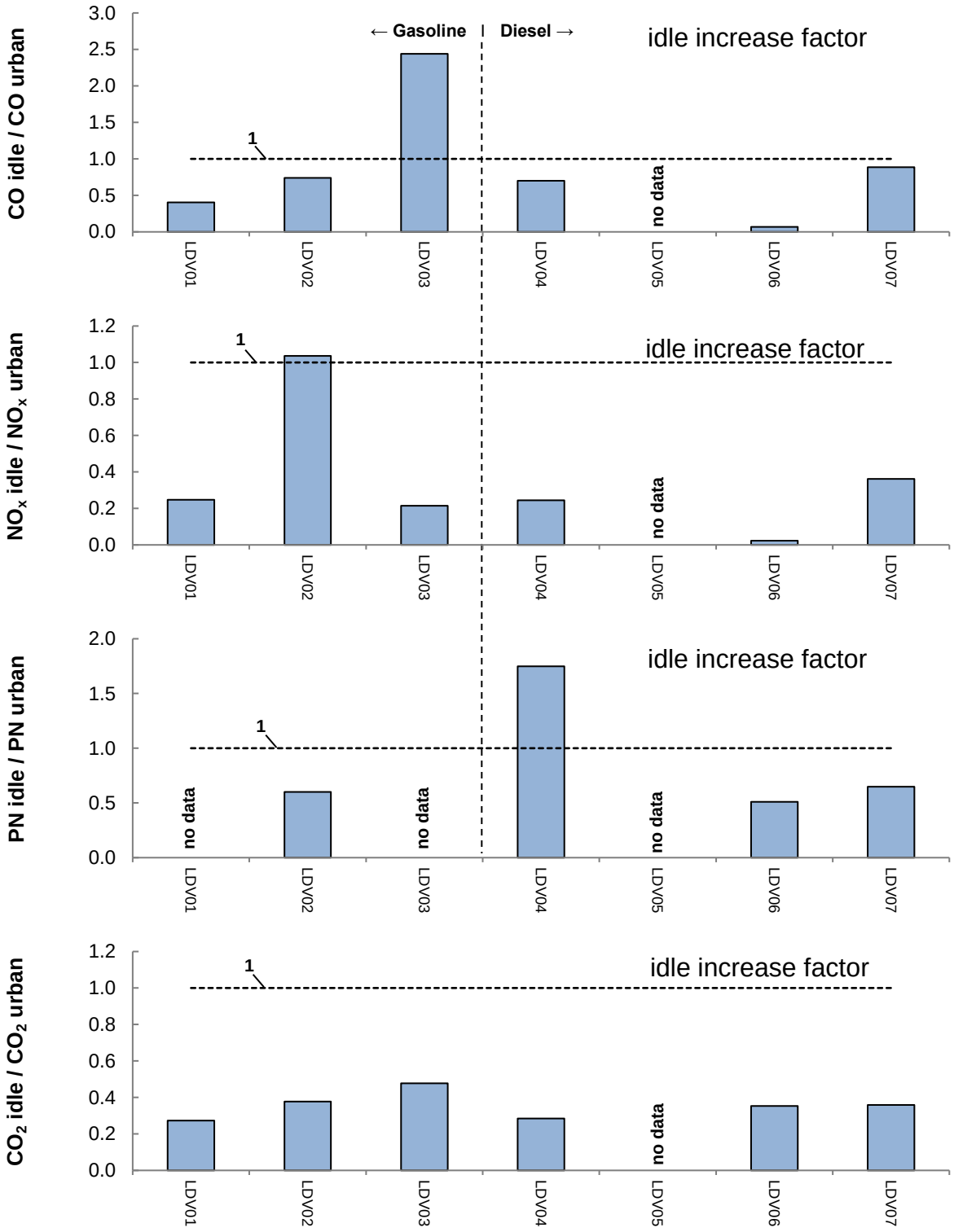
Comparison of Cumulated Emissions, Vehicles LDV01 - LDV07



PEMS

Emissions During Idle Phase of RDE

Comparison of Emissions Idle / Urban, Vehicles LDV01 - LDV07

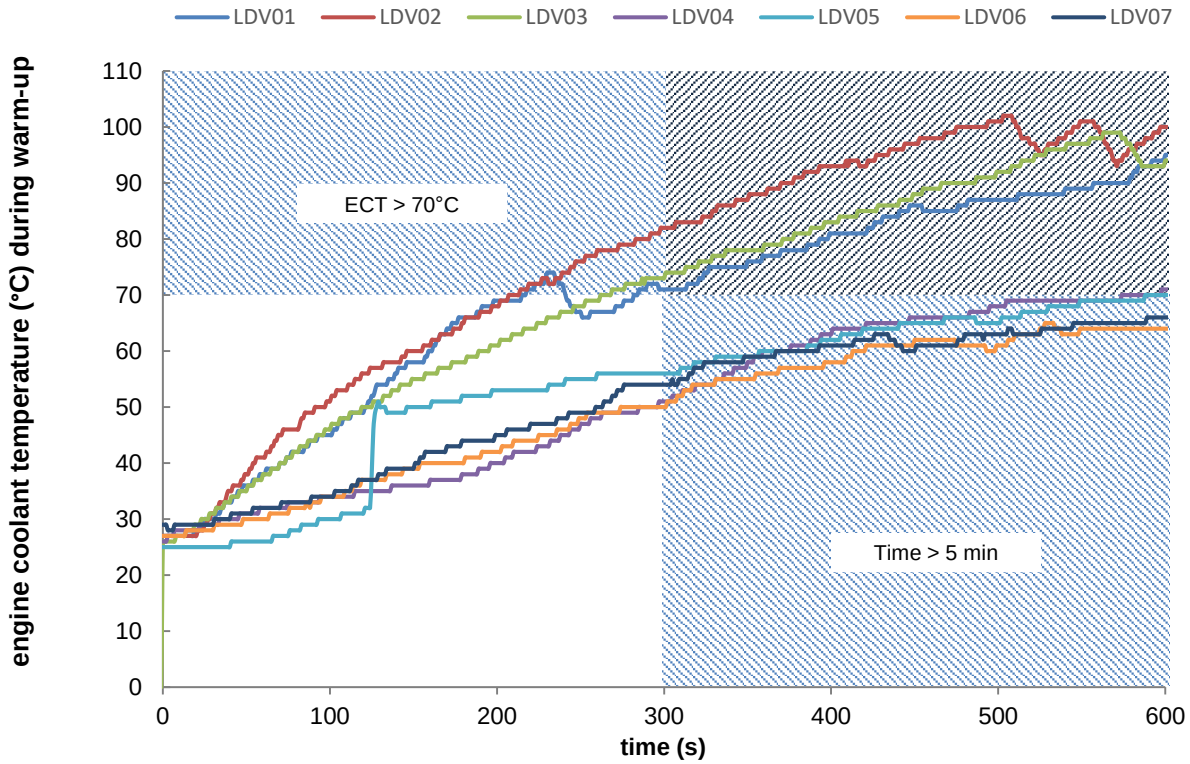


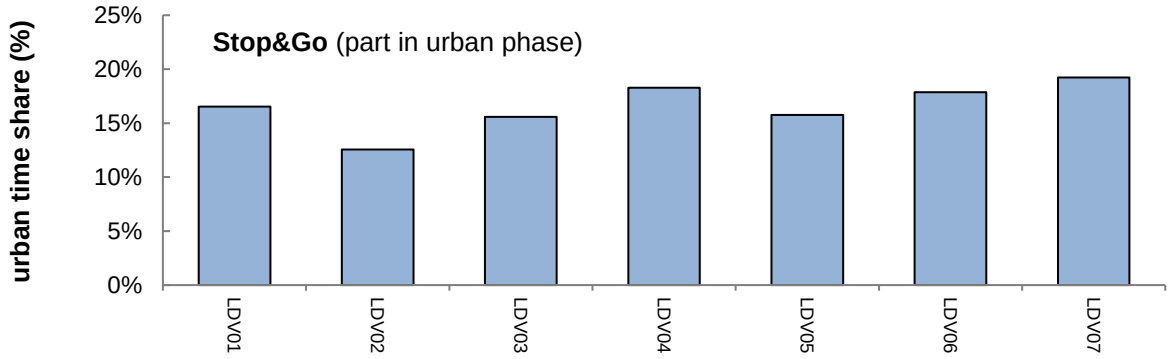
urban: part of RDE-Route (geographically defined distance: 13.7 km)

PEMS

Summary Reference Values of RDE Phases

Vehicles LDV01 - LDV07





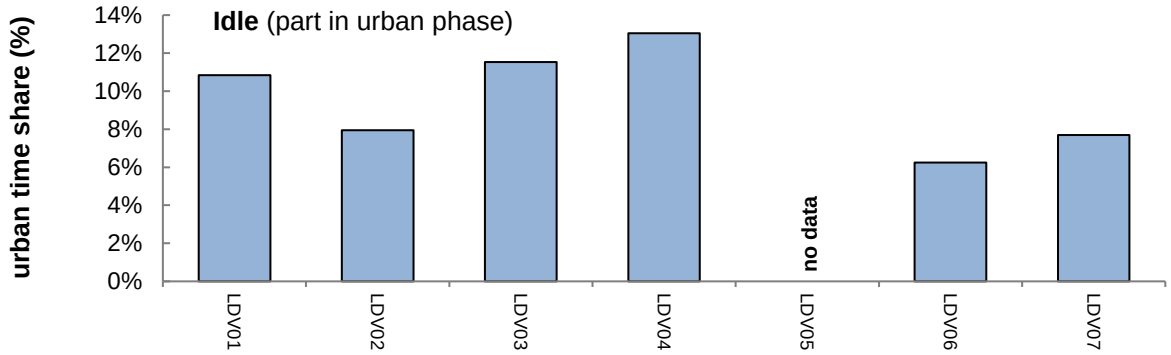


Fig. 12

Chassis Dynamometer

Emissions During Driving Cycles "Warm-Up Low/High Load"

Vehicles: Gasoline

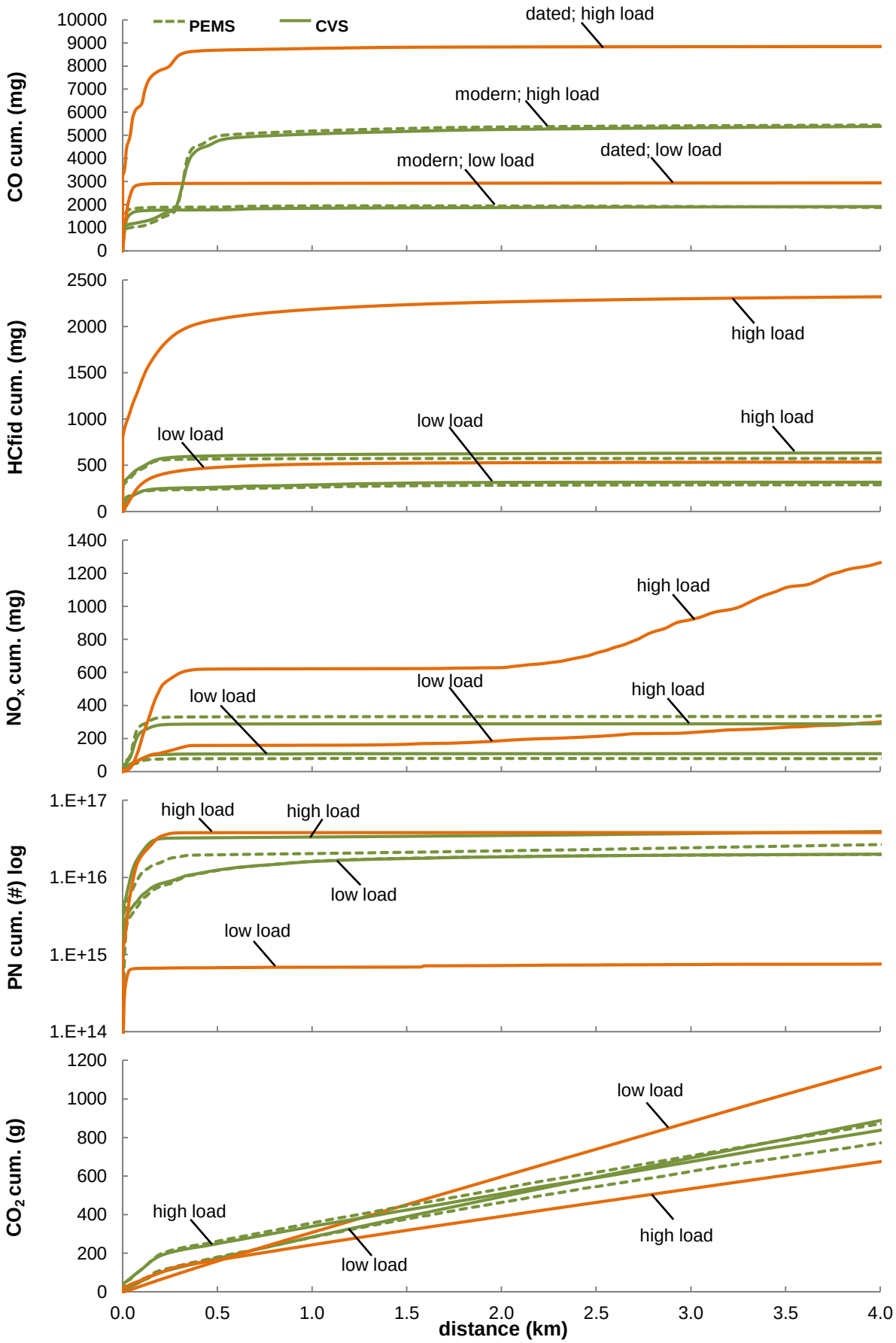


Fig. 13

Chassis Dynamometer

Emissions During Driving Cycles "Warm-Up Low&High Load"

Vehicles: Diesel

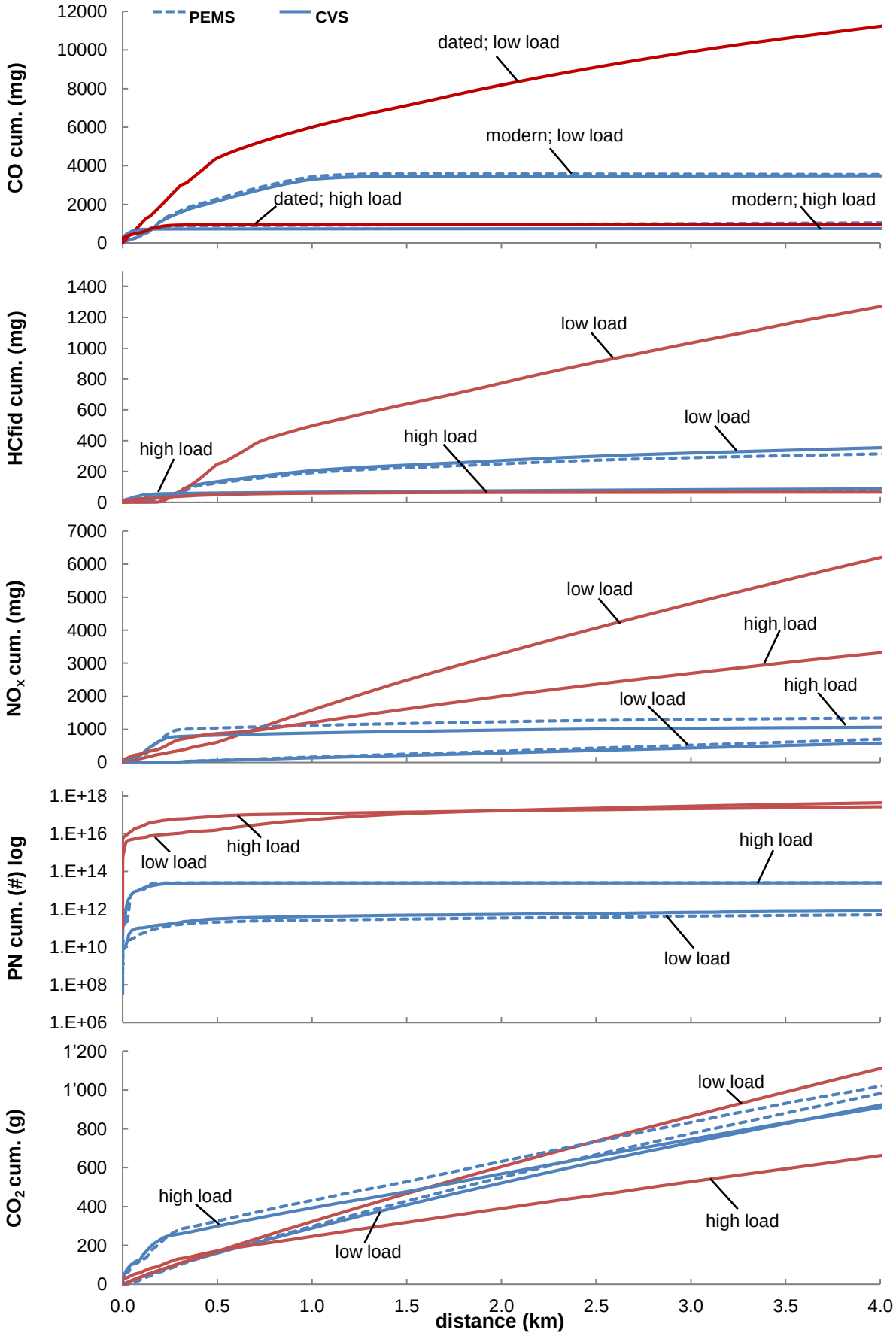


Fig. 14-1

Chassis Dynamometer

Emissions During Driving Cycle "Stop&Go"

Different Idle Portioning, all Vehicles, Distance Specific

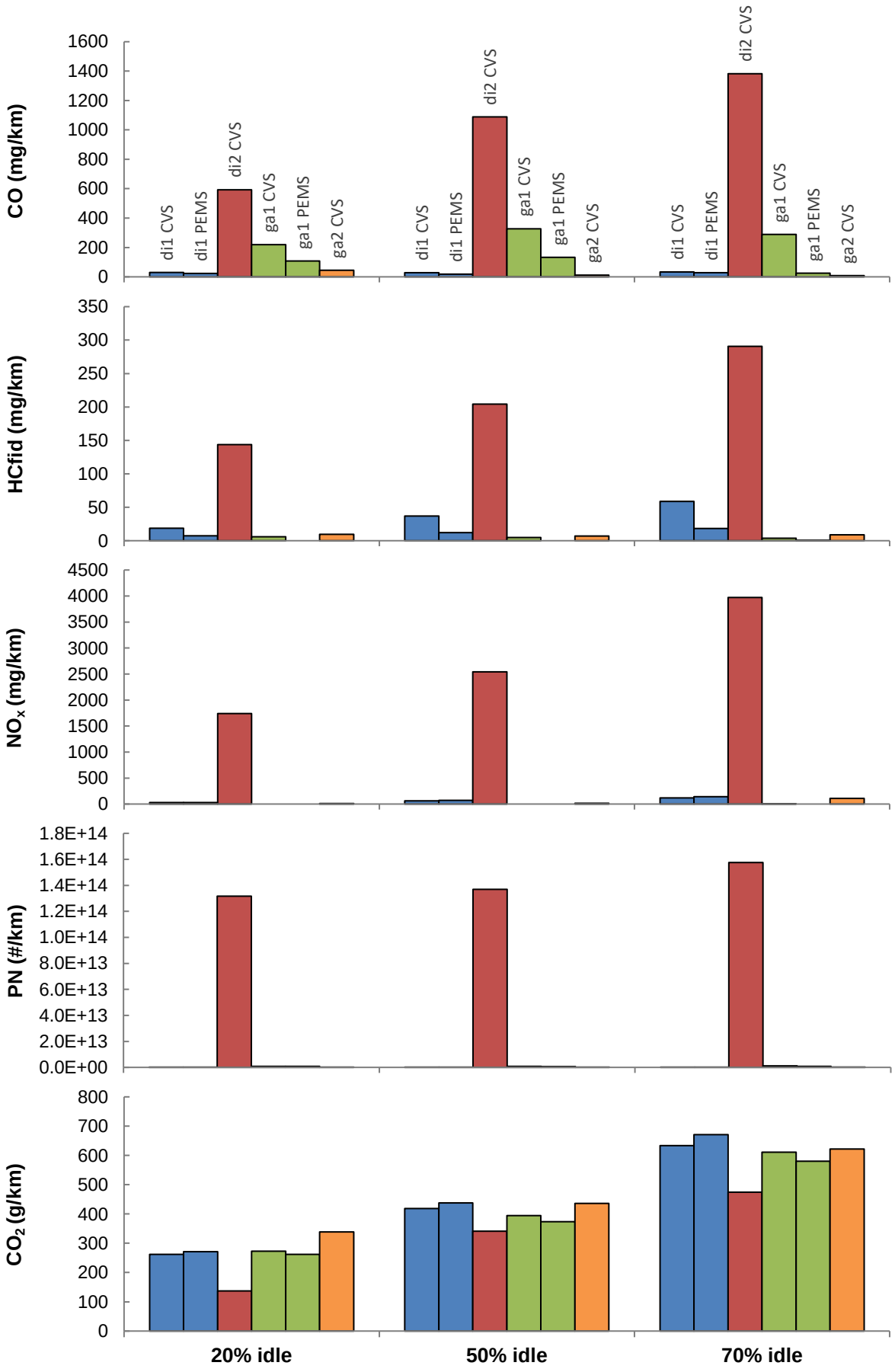
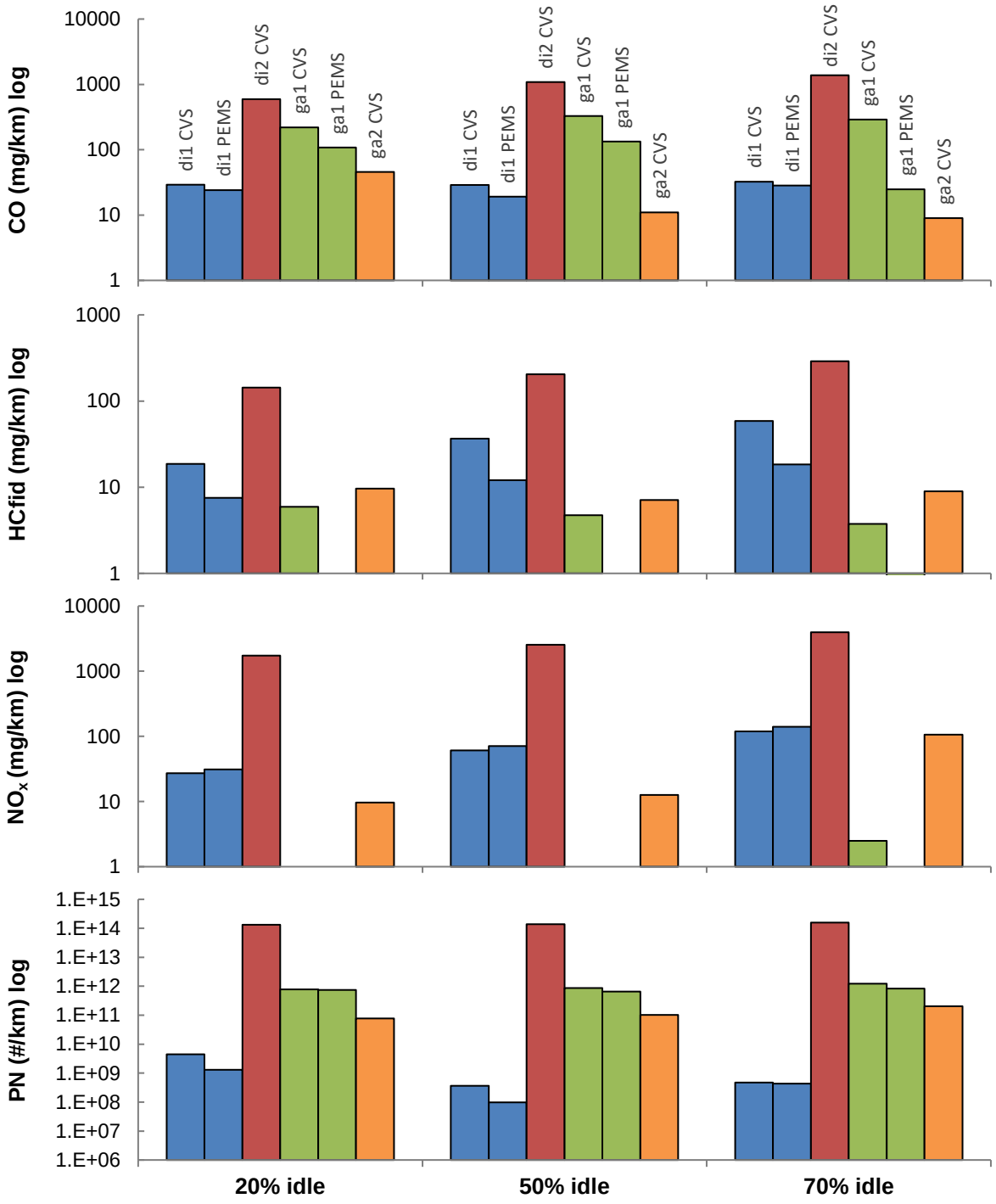


Fig. 14-2

Chassis Dynamometer

Emissions During Driving Cycle "Stop&Go" - Log Scale

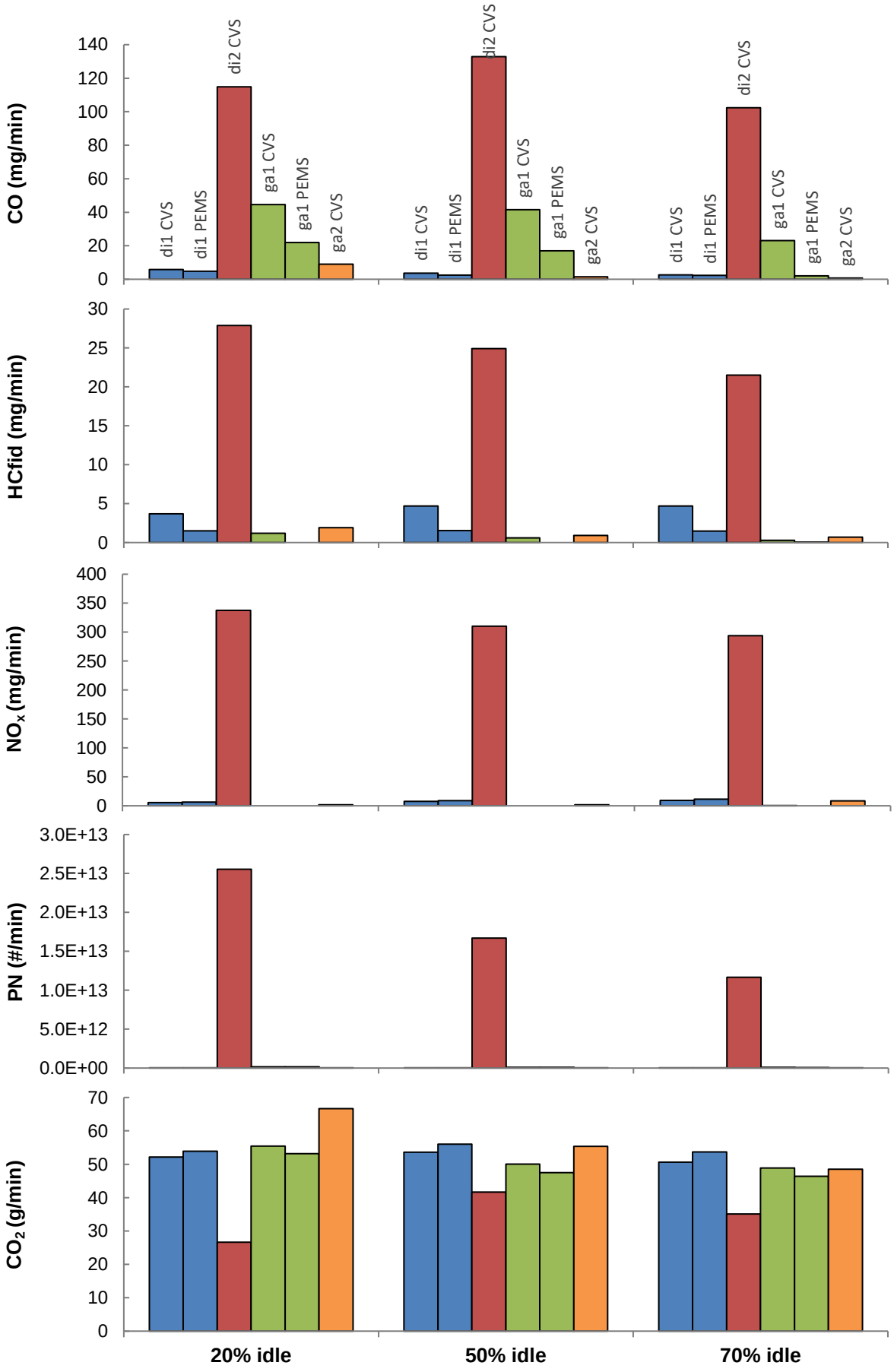
Different Idle Portioning, all Vehicles, Distance Specific



Chassis Dynamometer

Emissions During Driving Cycle "Stop&Go"

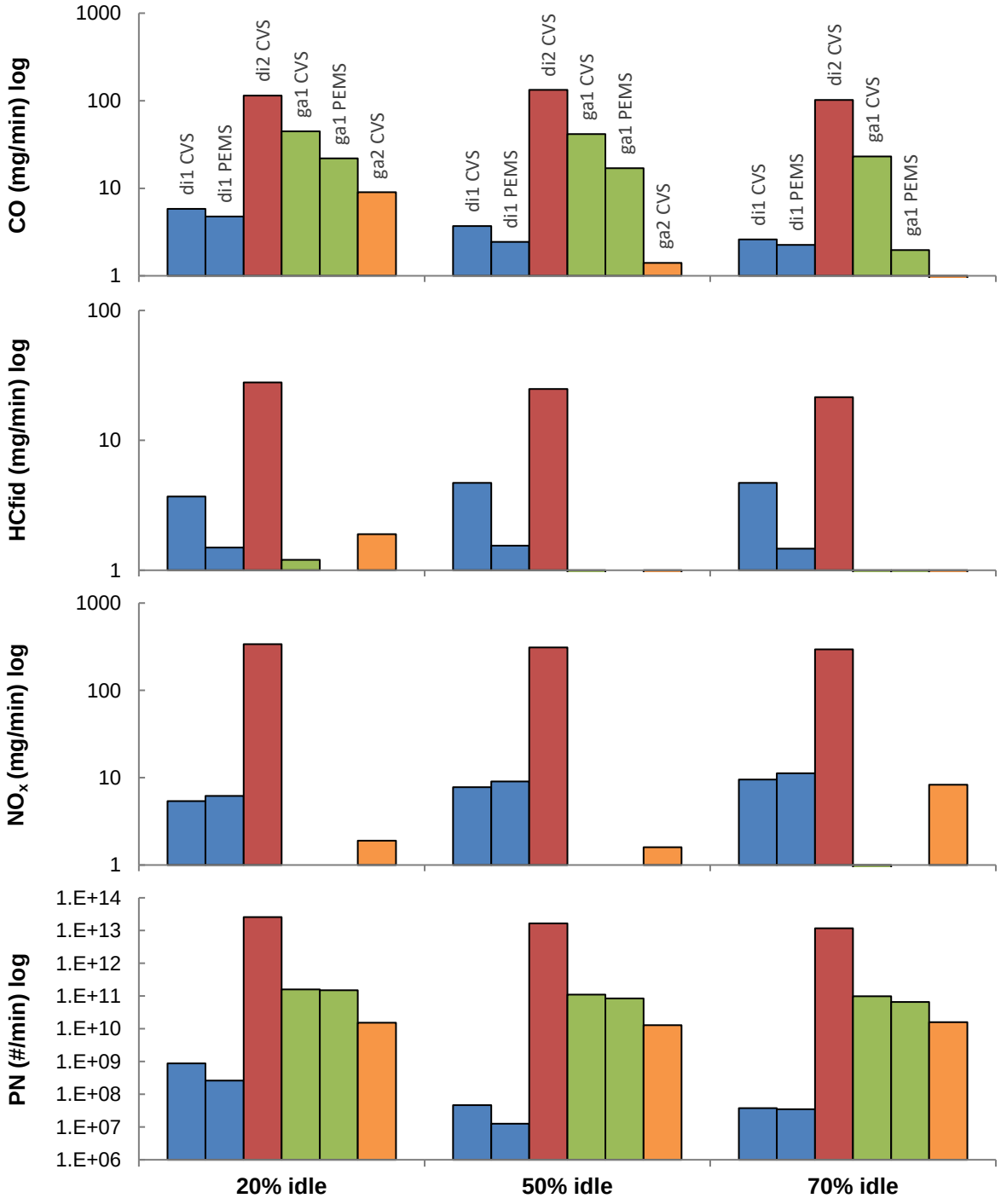
Different Idle Portioning, all Vehicles, Time Specific



Chassis Dynamometer

Emissions During Driving Cycle "Stop&Go" - Log Scale

Different Idle Portioning, all Vehicles, Time Specific



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Emissions from Non-Driving Situations

Commissioned by the Federal Office for the Environment (FOEN)

Project: Research on PEMS Testing Methodology and on Real Driving Emissions (ResRDE2) *)

BAFU contract nbr.:15.0002.PJ/S081-0349, 1st report, WP1

Annexes

February - April 2020 R001a

*) Abbreviations see at the end of report

Real Driving Measurements

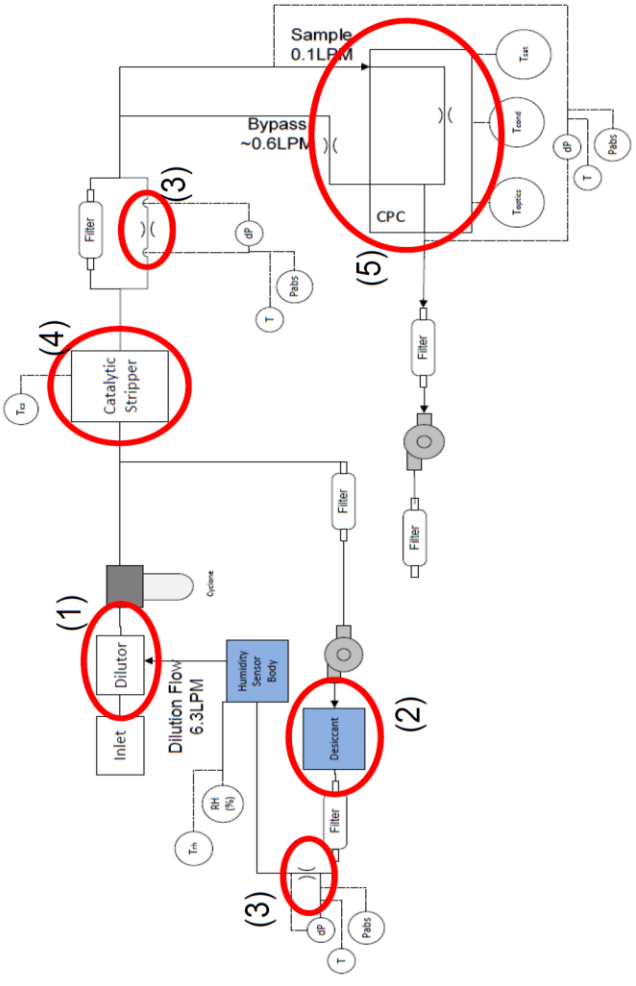
PN-PEMS Flow Schematics

HORIBA OBS ONE PN

PN counting on the road: OBS-ONE-PN

- HORIBA considered the specific requirements for measurements on the road in the development of the OBS-ONE-PN

(1) First dilution directly at the sample probe
(2) Dilution air is dried by a desiccant
(3) Flow control for both passive dilutors is realized by orifices (no MFCs)
(4) Evaporation tube is replaced by a catalytic stripper
(5) A bypassed CPC is introduced for the OBS-ONE-PN. This CPC is designed for mobile applications taking into account the specific requirements related to inclination (→ CPC design), the concentration range (→ bypass), vibration stability (→ bypass, CPC design and wick optimization), temperature control and spill issues (→ soaked CPC wick only, no reservoir)



11

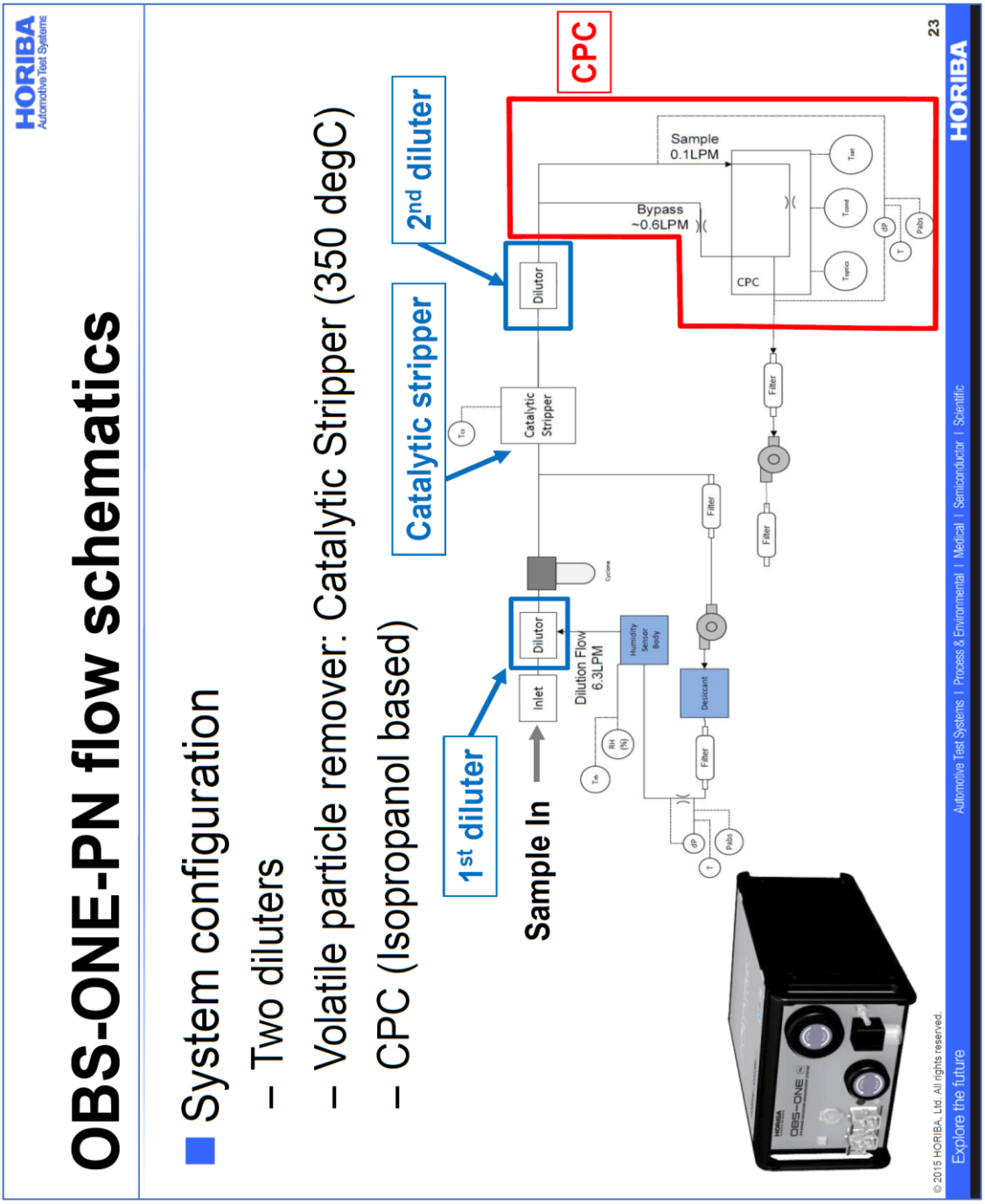
AECC Technical Seminar on RDE PN

HORIBA

Real Driving Measurements

PN-PEMS Flow Schematics

HORIBA OBS ONE PN

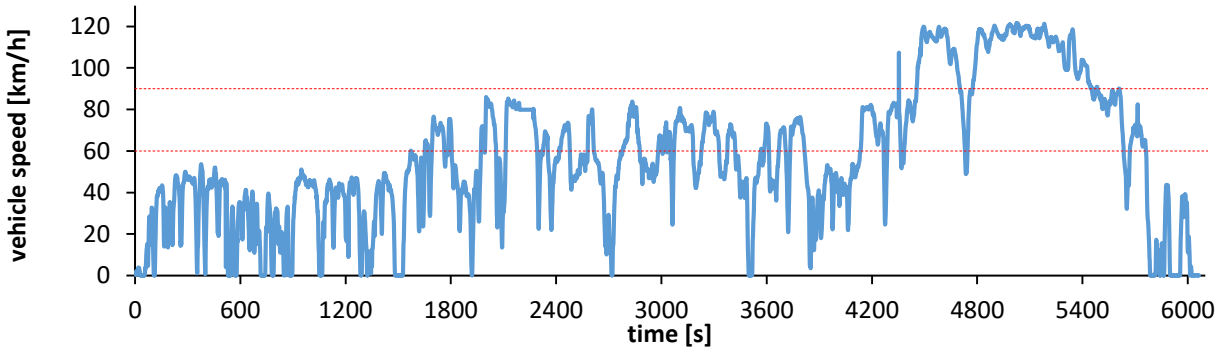


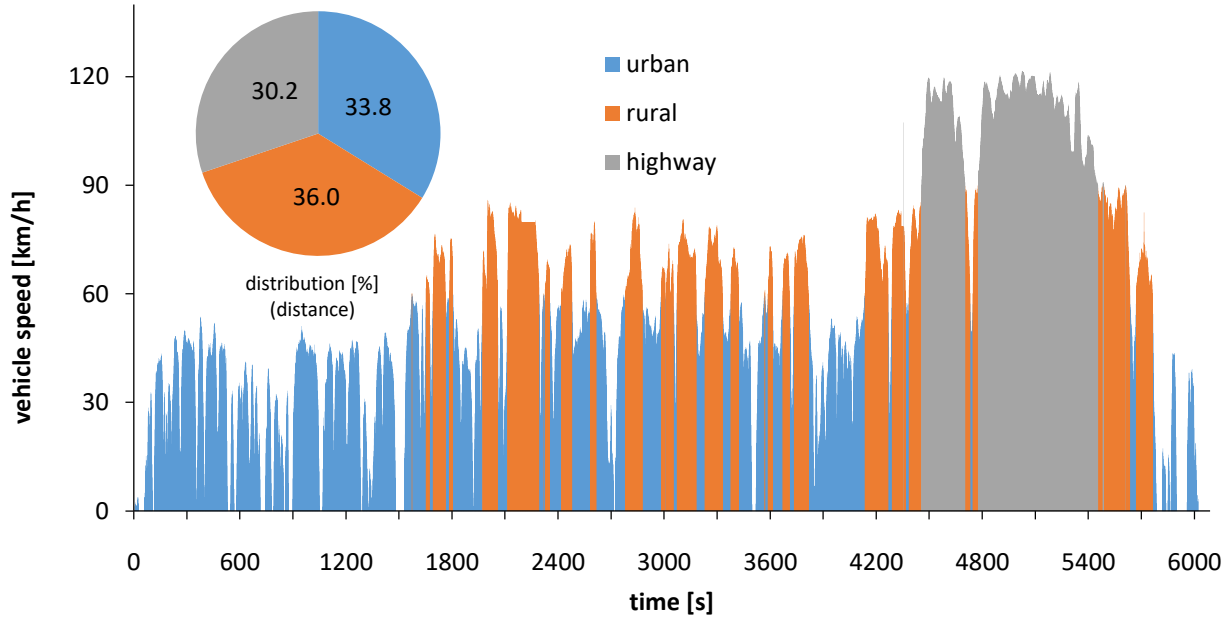
Real Driving Measurements

Road Trip for RDE

with Volvo V60 FlexFuel (LDV)

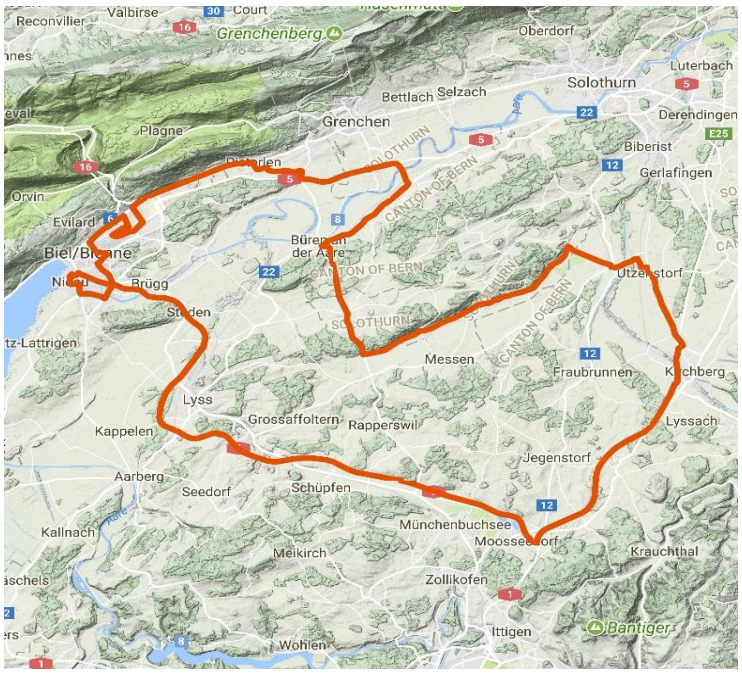
Mix of urban, rural and motorway parts





distance		
urban	32.4	km
rural	34.6	km
highway	29.0	km
total	**96.0**	**km**
time		
urban	51.1	min
rural	27.9	min
highway	15.6	min
stops	6.5	min
total	**101.1**	**min**
average speed		
urban	38.1	km/h
rural	74.2	km/h
highway	111.7	km/h
max	121.0	km/h

AFHB road-test route (AFHB06f)



PEMS

Summary of Evaluated Data

Reference Values

Present Data From RDE-Measurements

phase →		warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	Stop&Go	Stop&Go	Stop&Go	Idle	Idle	Idle	urban	urban
				urban share			urban share			urban share			urban share		
	fuel↓	**duration**	**duration**	**duration**	**duration**	**duration**	**duration**	**duration**	**duration**	**duration**	**duration**	**duration**	**duration**	**duration**	**duration**
relation →		ECT 70	ECT 70	ECT 70	5 min	5 min	5 min	Stop&Go	Stop&Go	Stop&Go	Idle	Idle	Idle	urban	urban
dependency →		traffic	traffic	traffic	-	-	-	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic
unit →		s	min	%	s	min	%	s	min	%	s	min	%	s	min
source →		data	calc.	calc.	def.	calc.	calc.	data	calc.	calc.	data	calc.	calc.	data	calc.
LDV01	gasoline	215	3.6	12%	300	5	17%	300	5	17%	197	3	11%	1816	30
LDV02	gasoline	213	3.6	12%	300	5	17%	223	4	13%	141	2	8%	1775	30
LDV03	gasoline	262	4.4	14%	300	5	16%	289	5	16%	214	4	12%	1856	31
LDV04	diesel	579	9.7	33%	300	5	17%	321	5	18%	229	4	13%	1756	29
LDV05	diesel	744	12.4	42%	300	5	17%	277	5	16%	-	-	-	1758	29
LDV06	diesel	859	14.3	47%	300	5	16%	329	5	18%	115	2	6%	1841	31
LDV07	diesel	778	13.0	44%	300	5	17%	340	6	19%	136	2	8%	1769	29
	average	**521**	**8.7**	**29%**	**300**	**5**	**17%**	**297**	**5.0**	**17%**	**172.0**	**2.9**	**10%**	**1796**	**30**
	range	**646**	**10.8**	**35%**	**0.0**	**0.0**	**1%**	**117**	**2.0**	**7%**	**114.0**	**1.9**	**7%**	**100**	**2**
	STD	**264**	**4.4**	**15%**	**0.0**	**0.0**	**0%**	**37**	**0.6**	**2%**	**43.1**	**0.7**	**2%**	**38**	**1**

phase →		warm-up	warm-up	warm-up	warm-up	warm-up	urban	warm-up	warm-up	urban
				urban share		urban share		average	average	average
	fuel↓	**ECT**	**distance**	**distance**	**distance**	**distance**	**distance**	**speed**	**speed**	**speed**
relation →		5 min	ECT 70	ECT 70	5 min	5 min	urban	ECT 70	5 min	urban
dependency →		traffic	traffic	traffic	traffic	traffic	-	traffic	traffic	traffic
unit →		deg C	km	%	km	%	km	km/h	km/h	km/h
source →		data	data	calc.	data	calc.	def.	calc.	calc.	calc
LDV01	gasoline	71	0.84	6%	1.61	12%	13.7	14.02	19.28	27.16
LDV02	gasoline	82	1.54	11%	2.50	18%	13.7	26.03	29.99	27.79
LDV03	gasoline	73	1.28	9%	1.65	12%	13.7	17.65	19.80	26.57
LDV04	diesel	50	3.22	23%	0.93	7%	13.7	20.01	11.21	28.09
LDV05	diesel	49	5.28	39%	1.84	13%	13.7	25.57	22.05	28.05
LDV06	diesel	50	5.84	43%	1.67	12%	13.7	24.50	19.98	26.79
LDV07	diesel	54	5.84	43%	1.67	12%	13.7	27.05	19.98	27.88
	average	**61.3**	**3.4**	**25%**	**1.7**	**12%**	**13.7**	**22.1**	**20.3**	**27.5**
	range	**33.0**	**5.0**	**37%**	**1.6**	**11%**	**0.0**	**13.0**	**18.8**	**1.5**
	STD	**12.6**	**2.1**	**15%**	**0.4**	**3%**	**0.0**	**4.6**	**5.1**	**0.6**

Abbreviations:

calc.	calculated
def.	defined
cum.	cumulated

PEMS

Summary of Evaluated Data

Emissions During Warm-Up Phase - Part 1

Present Data From RDE-Measurements

phase →		warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up
		cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	mass/min	mass/min	mass/min	mass/min	mass/min	mass/min	mass/min
	fuel↓	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**
relation →		ECT 70	ECT 70	ECT 70	ECT 70	ECT 70	ECT 70	ECT 70	ECT 70	ECT 70	ECT 70	ECT 70	ECT 70	ECT 70	ECT 70
dependency →		traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic
unit →		g	g	g	g	g	g	#	g/min	g/min	g/min	g/min	g/min	g/min	#/min
source →		data	data	calc.	data	data	data	data	calc.	calc.	calc.	calc.	calc.	calc.	calc.
LDV01	gasoline	298.7549	1.0138	0.0648	0.0648	0.0000	-	-	8.34E+01	0.28	0.018	0.018	0.000	-	-
LDV02	gasoline	784.3841	2.0514	0.0644	0.0418	0.0226	-	2.81E+12	2.21E+02	0.58	0.018	0.012	0.006	-	7.92E+11
LDV03	gasoline	766.5852	3.9616	0.0160	0.0160	0.0000	-	-	1.76E+02	0.91	0.004	0.004	0.000	-	-
LDV04	diesel	756.5705	9.2220	3.0693	2.8838	0.1855	-	1.65E+10	7.84E+01	0.96	0.318	0.299	0.019	-	1.70E+09
LDV05	diesel	1250.8454	0.1525	6.9229	5.1080	1.8149	-	1.11E+09	1.01E+02	0.01	0.558	0.412	0.146	-	8.94E+07
LDV06	diesel	1676.3859	1.4552	0.4067	0.2650	0.1418	-	5.49E+10	1.17E+02	0.10	0.028	0.019	0.010	-	3.84E+09
LDV07	diesel	1688.3148	2.5211	0.3951	0.2650	0.1301	-	2.26E+10	1.30E+02	0.19	0.030	0.020	0.010	-	1.74E+09
	average	**1031.7**	**2.9**	**1.6**	**1.2**	**0.3**	-	**5.81E+11**	**129.5**	**0.4**	**0.1**	**0.1**	**0.0**	-	**1.60E+11**
	range	**1389.6**	**9.1**	**6.9**	**5.1**	**1.8**	-	**2.81E+12**	**142.6**	**0.9**	**0.6**	**0.4**	**0.1**	-	**7.92E+11**
	STD	**483.9**	**2.8**	**2.4**	**1.8**	**0.6**	-	**1.12E+12**	**48.1**	**0.4**	**0.2**	**0.2**	**0.0**	-	**3.16E+11**

phase →		warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up
		mass/km	mass/km	mass/km	mass/km	mass/km	mass/km	mass/km	cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	cum. mass
	fuel↓	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**
relation →		ECT 70	ECT 70	ECT 70	ECT 70	ECT 70	ECT 70	ECT 70	5 min	5 min	5 min	5 min	5 min	5 min	5 min
dependency →		traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic
unit →		g/km	g/km	g/km	g/km	g/km	g/km	#/km	g	g	g	g	g	g	#
source →		calc.	calc.	calc.	calc.	calc.	calc.	calc.	data	data	calc.	data	data	data	data
LDV01	gasoline	356.89	1.21	0.077	0.077	0.000	-	-	474.7283	1.098	0.068	0.068	0.000	-	-
LDV02	gasoline	509.33	1.33	0.042	0.027	0.015	-	1.83E+12	1020.8205	2.086	0.067	0.044	0.024	-	2.88E+12
LDV03	gasoline	596.92	3.08	0.012	0.012	0.000	--	-	853.7489	3.963	0.019	0.019	0.000	-	-
LDV04	diesel	235.07	2.87	0.954	0.896	0.058	-	5.11E+09	295.2805	5.362	0.858	0.817	0.041	-	1.39E+10
LDV05	diesel	236.71	0.03	1.310	0.967	0.343	-	2.10E+08	569.2453	0.143	3.569	3.378	0.192	-	9.45E+08
LDV06	diesel	286.81	0.25	0.070	0.045	0.024	-	9.40E+09	610.3202	1.379	0.315	0.210	0.105	-	2.60E+10
LDV07	diesel	288.85	0.43	0.068	0.045	0.022	-	3.86E+09	701.7439	2.202	0.339	0.226	0.112	-	1.22E+10
	average	**358.7**	**1.3**	**0.4**	**0.3**	**0.1**	-	**3.69E+11**	**646.6**	**2.3**	**0.7**	**0.7**	**0.1**	-	**5.87E+11**
	range	**361.8**	**3.1**	**1.3**	**1.0**	**0.3**	-	**1.83E+12**	**725.5**	**5.2**	**3.6**	**3.4**	**0.2**	-	**2.9E+12**
	STD	**130.7**	**1.1**	**0.5**	**0.4**	**0.1**	-	**7.28E+11**	**222.4**	**1.7**	**1.2**	**1.1**	**0.1**	-	**1.15E+12**

PEMS

Summary of Evaluated Data

Emissions During Warm-Up Phase - Part 2

Present Data From RDE-Measurements

phase →		warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up	warm-up
		mass/min	mass/min	mass/min	mass/min	mass/min	mass/min	mass/min	mass/km	mass/km	mass/km	mass/km	mass/km	mass/km	mass/km
	fuel↓	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**
relation →		5 min	5 min	5 min	5 min	5 min	5 min	5 min	5 min	5 min	5 min	5 min	5 min	5 min	5 min
dependency →		traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic
unit →		g/min	g/min	g/min	g/min	g/min	g/min	#/min	g/km	g/km	g/km	g/km	g/km	g/km	#/km
source →		calc.	calc.	calc.	calc.	calc.	calc.	calc.	calc.	calc.	calc.	calc.	calc.	calc.	calc.
LDV01	gasoline	94.95	0.220	0.014	0.014	0.000	-	-	295.44	0.683	0.042	0.042	0.000	-	-
LDV02	gasoline	204.16	0.417	0.013	0.009	0.005	-	5.76E+11	408.42	0.835	0.027	0.017	0.009	-	1.15E+12
LDV03	gasoline	170.75	0.793	0.004	0.004	0.000	-	-	517.30	2.401	0.011	0.011	0.000	-	-
LDV04	diesel	59.06	1.072	0.172	0.163	0.008	-	2.77E+09	316.20	5.742	0.919	0.875	0.044	-	1.48E+10
LDV05	diesel	113.85	0.029	0.714	0.676	0.038	-	1.89E+08	309.76	0.078	1.942	1.838	0.104	-	5.14E+08
LDV06	diesel	122.06	0.276	0.063	0.042	0.021	-	5.21E+09	366.53	0.828	0.189	0.126	0.063	-	1.56E+10
LDV07	diesel	140.35	0.440	0.068	0.045	0.022	-	2.44E+09	421.44	1.323	0.203	0.136	0.067	-	7.32E+09
	average	**129.3**	**0.5**	**0.1**	**0.1**	**0.0**	-	**1.17E+11**	**376.4**	**1.7**	**0.5**	**0.4**	**0.0**	-	**2.38E+11**
	range	**145.1**	**1.0**	**0.7**	**0.7**	**0.0**	-	**5.76E+11**	**221.9**	**5.7**	**1.9**	**1.8**	**0.1**	-	**1.15E+12**
	STD	**44.5**	**0.3**	**0.2**	**0.2**	**0.0**	-	**2.29E+11**	**73.3**	**1.8**	**0.7**	**0.6**	**0.0**	-	**4.57E+11**

PEMS

Summary of Evaluated Data

Emissions During Urban Phase

Present Data From RDE-Measurements

phase →		urban	urban	urban	urban	urban	urban	urban	urban	urban	urban	urban	urban	urban	urban
		cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	mass/min	mass/min	mass/min	mass/min	mass/min	mass/min	mass/min
	fuel↓	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**
relation →		urban	urban	urban	urban	urban	urban	urban	urban	urban	urban	urban	urban	urban	urban
dependency →		traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic
unit →		g	g	g	g	g	g	#	g/min	g/min	g/min	g/min	g/min	g/min	#/min
source →		data	data	calc.	data	data	data	data	calc.	calc.	calc.	calc.	calc.	calc.	calc.
LDV01	gasoline	2607.9779	3.799	0.142	0.142	0.000	-	-	86.17	0.13	0.005	0.005	0.000	-	-
LDV02	gasoline	5084.0278	3.313	0.278	0.181	0.097	-	7.09E+12	171.85	0.11	0.009	0.006	0.003	-	2.40E+11
LDV03	gasoline	5221.8983	4.023	0.168	0.168	0.000	-	-	168.81	0.13	0.005	0.005	0.000	-	-
LDV04	diesel	2548.6274	17.713	14.947	14.110	0.837	-	2.08E+10	87.08	0.61	0.511	0.482	0.029	-	7.12E+08
LDV05	diesel	2951.9903	0.402	20.196	12.769	7.428	-	1.45E+09	100.75	0.01	0.689	0.436	0.254	-	4.95E+07
LDV06	diesel	3481.8445	2.618	0.554	0.348	0.206	-	9.13E+10	113.48	0.09	0.018	0.011	0.007	-	2.98E+09
LDV07	diesel	3345.1413	5.427	0.517	0.351	0.166	-	3.51E+10	113.46	0.18	0.018	0.012	0.006	-	1.19E+09
	average	**3605.9**	**5.3**	**5.3**	**4.0**	**1.2**	-	**1.45E+12**	**120.2**	**0.2**	**0.2**	**0.1**	**0.0**	-	**4.9E+10**
	range	**2673.3**	**17.3**	**20.1**	**14.0**	**7.4**	-	**7.09E+12**	**85.7**	**0.6**	**0.7**	**0.5**	**0.3**	-	**2.40E+11**
	STD	**1029.6**	**5.3**	**7.9**	**6.0**	**2.5**	-	**2.82E+12**	**33.3**	**0.2**	**0.3**	**0.2**	**0.1**	-	**9.53E+10**

phase →		urban	urban	urban	urban	urban	urban	urban
		mass/km	mass/km	mass/km	mass/km	mass/km	mass/km	mass/km
	fuel↓	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**
relation →		urban	urban	urban	urban	urban	urban	urban
dependency →		traffic	traffic	traffic	traffic	traffic	traffic	traffic
unit →		g/km	g/km	g/km	g/km	g/km	g/km	#/km
source →		calc.	calc.	calc.	calc.	calc.	calc.	calc.
LDV01	gasoline	190.36	0.277	0.010	0.010	0.000	-	-
LDV02	gasoline	371.10	0.242	0.020	0.013	0.007	-	5.17E+11
LDV03	gasoline	381.16	0.294	0.012	0.012	0.000	-	-
LDV04	diesel	186.03	1.293	1.091	1.030	0.061	-	1.52E+09
LDV05	diesel	215.47	0.029	1.474	0.932	0.542	-	1.06E+08
LDV06	diesel	254.15	0.191	0.040	0.025	0.015	-	6.66E+09
LDV07	diesel	244.17	0.396	0.038	0.026	0.012	-	2.56E+09
	average	**263.2**	**0.4**	**0.4**	**0.3**	**0.1**	-	**1.06E+11**
	range	**195.1**	**1.3**	**1.5**	**1.0**	**0.5**	-	**5.17E+11**
	STD	**75.2**	**0.4**	**0.6**	**0.4**	**0.2**	-	**2.06E+11**

PEMS

Summary of Evaluated Data

Emissions During Stop&Go Phase

Present Data From RDE-Measurements

phase →		stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go
		cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	mass/min	mass/min	mass/min	mass/min	mass/min	mass/min	mass/min
	fuel↓	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**
relation →		stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go	stop&go
dependency →		traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic
unit →		g	g	g	g	g	g	#	g/min	g/min	g/min	g/min	g/min	g/min	#/min
source →		data	data	calc.	data	data	data	data	calc.	calc.	calc.	calc.	calc.	calc.	calc.
LDV01	gasoline	224.0717	1.1051	0.0606	0.0606	0.0000	-	-	44.81	0.221	0.012	0.012	0.000	-	-
LDV02	gasoline	397.3273	1.6637	0.0704	0.0459	0.0245	-	1.47E+12	106.90	0.448	0.019	0.012	0.007	-	3.96E+11
LDV03	gasoline	506.9727	3.6483	0.0164	0.0164	0.0000	-	-	105.25	0.757	0.003	0.003	0.000	-	-
LDV04	diesel	186.6175	4.1606	0.9505	0.9130	0.0375	-	8.89E+09	34.88	0.778	0.178	0.171	0.007	-	1.66E+09
LDV05	diesel	267.0299	0.1359	0.8856	0.6898	0.1958	-	2.67E+08	57.84	0.029	0.192	0.149	0.042	-	5.78E+07
LDV06	diesel	166.8491	0.1164	0.0025	0.0018	0.0008	-	5.82E+09	30.43	0.021	0.000	0.000	0.000	-	1.06E+09
LDV07	diesel	206.6400	0.7582	0.0236	0.0173	0.0063	-	3.41E+09	36.47	0.134	0.004	0.003	0.001	-	6.02E+08
	average	**279.4**	**1.7**	**0.3**	**0.2**	**0.0**	-	**2.98E+11**	**59.5**	**0.3**	**0.1**	**0.1**	**0.0**	-	**7.98E+10**
	range	**340.1**	**4.0**	**0.9**	**0.9**	**0.2**	-	**1.47E+12**	**76.5**	**0.8**	**0.2**	**0.2**	**0.0**	-	**3.96E+11**
	STD	**116.8**	**1.5**	**0.4**	**0.4**	**0.1**	-	**5.87E+11**	**30.6**	**0.3**	**0.1**	**0.1**	**0.0**	-	**1.58E+11**

PEMS

Summary of Evaluated Data

Emissions During Idle Phase

Present Data From RDE-Measurements

phase →		idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle
		cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	cum. mass	mass/min	mass/min	mass/min	mass/min	mass/min	mass/min	mass/min
	fuel↓	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**	**CO2**	**CO**	**NOx**	**NO**	**NO2**	**THC**	**PN**
relation →		idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle
dependency →		traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic	traffic
unit →		g	g	g	g	g	g	#	g/min	g/min	g/min	g/min	g/min	g/min	#/min
source →		data	data	calc.	data	data	data	data	calc	calc	calc	calc	calc	calc	calc
LDV01	gasoline	77.4009	0.1668	0.0038	0.0038	0.0000	-	-	23.5739	0.0508	0.0012	0.0012	0.0000	-	-
LDV02	gasoline	152.6362	0.1946	0.0229	0.0144	0.0085	-	3.39E+11	64.9516	0.0828	0.0097	0.0061	0.0036	-	1.44E+11
LDV03	gasoline	287.6767	1.1313	0.0041	0.0041	0.0000	-	-	80.6570	0.3172	0.0012	0.0012	0.0000	-	-
LDV04	diesel	94.5365	1.6219	0.4766	0.4391	0.0375	-	4.75E+09	24.7694	0.4249	0.1249	0.1151	0.0098	-	1.24E+09
LDV05	diesel	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LDV06	diesel	76.8943	0.0113	0.0008	0.0005	0.0003	-	2.90E+09	40.1188	0.0059	0.0004	0.0003	0.0002	-	1.52E+09
LDV07	diesel	92.3543	0.3693	0.0144	0.0102	0.0042	-	1.75E+09	40.7445	0.1629	0.0063	0.0045	0.0019	-	7.71E+08
	average	**130.2**	**0.6**	**0.1**	**0.1**	**0.0**	-	**8.70E+10**	**45.8**	**0.2**	**0.0**	**0.0**	**0.0**	-	**3.7E+10**
	range	**210.8**	**1.6**	**0.5**	**0.4**	**0.0**	-	**3.37E+11**	**57.1**	**0.4**	**0.1**	**0.1**	**0.0**	-	**1.43E+11**
	STD	**74.9**	**0.6**	**0.2**	**0.2**	**0.0**	-	**1.45E+11**	**20.7**	**0.2**	**0.0**	**0.0**	**0.0**	-	**6.19E+10**

Chassis Dynamometer

Summary of Evaluated Data

Stop&Go

fuel	Nr.	meas.	idle	dist.	time	CO	HC	NOx	PN	CO2	CO	HC	NOx	PN	CO2
			%	*km*	*min*	*mg/km*	*mg/km*	*mg/km*	*#/km*	*g/km*	*mg/min*	*mg/min*	*mg/min*	*#/min*	*g/min*
diesel	1	CVS	20	1.99	10	29.1	18.6	27.1	4.44E+09	261.9	5.8	3.7	5.4	8.83E+08	52.1
diesel	1	CVS	50	1.28	10	28.9	36.7	60.9	3.65E+08	418.8	3.7	4.7	7.8	4.67E+07	53.6
diesel	1	CVS	70	0.80	10	32.5	58.8	118.8	4.72E+08	633.2	2.6	4.7	9.5	3.77E+07	50.7
diesel	1	PEMS	20	1.99	10	24.0	7.5	31.2	1.31E+09	270.8	4.8	1.5	6.2	2.61E+08	53.9
diesel	1	PEMS	50	1.28	10	19.1	12.1	71.0	9.85E+07	437.4	2.4	1.5	9.1	1.26E+07	56.0
diesel	1	PEMS	70	0.80	10	28.3	18.3	140.2	4.36E+08	671.1	2.3	1.5	11.2	3.48E+07	53.7
diesel	2	CVS	20	1.94	10	591.8	143.8	1739.2	1.32E+14	137.4	114.8	27.9	337.4	2.55E+13	26.7
diesel	2	CVS	50	1.22	10	1088.5	204.1	2541.0	1.37E+14	341.3	132.8	24.9	310.0	1.67E+13	41.6
diesel	2	CVS	70	0.74	10	1382.4	290.5	3973.0	1.58E+14	474.5	102.3	21.5	294.0	1.17E+13	35.1
gasol.	1	CVS	20	2.03	10	219.7	5.9	0.0	7.79E+11	273.1	44.6	1.2	0.0	1.58E+11	55.4
gasol.	1	CVS	50	1.27	10	327.6	4.7	0.0	8.72E+11	394.1	41.6	0.6	0.0	1.11E+11	50.0
gasol.	1	CVS	70	0.80	10	288.8	3.8	2.5	1.23E+12	611.1	23.1	0.3	0.2	9.88E+10	48.9
gasol.	1	PEMS	20	2.03	10	108.1	0.0	0.0	7.46E+11	262.1	22.0	0.0	0.0	1.51E+11	53.2
gasol.	1	PEMS	50	1.27	10	133.6	0.0	0.0	6.60E+11	373.9	17.0	0.0	0.0	8.38E+10	47.5
gasol.	1	PEMS	70	0.80	10	24.7	0.5	0.0	8.24E+11	580.1	2.0	0.0	0.0	6.59E+10	46.4
gasol.	2	CVS	20	1.97	10	45.7	9.6	9.6	7.73E+10	338.3	9.0	1.9	1.9	1.52E+10	66.6
gasol.	2	CVS	50	1.27	10	11.0	7.1	12.6	1.02E+11	436.1	1.4	0.9	1.6	1.29E+10	55.4
gasol.	2	CVS	70	0.78	10	9.0	9.0	106.4	2.02E+11	621.5	0.7	0.7	8.3	1.58E+10	48.5